



UNION OF ENGINEERS AND TEXTILE
TECHNICIANS OF SERBIA

VII INTERNATIONAL SCIENTIFIC CONFERENCE
**CONTEMPORARY TRENDS
AND INNOVATIONS IN THE
TEXTILE INDUSTRY**

VII MEĐUNARODNA NAUČNA KONFERENCIJA
**SAVREMENI TRENDovi I
INOVACIJE U TEKSTILNOJ
INDUSTRIJI**

PROCEEDINGS

EDITOR:
Prof. dr SNEŽANA UROŠEVIĆ

Belgrade, 19-20th September, 2024
Union of Engineers and Technicians of Serbia
Dom inženjera „Nikola Tesla“



UNION OF ENGINEERS AND TEXTILE TECHNICIANS OF SERBIA

AND

**UNION OF ENGINEERS AND TECHNICIANS OF SERBIA
FACULTY OF TECHNOLOGY AND METALLURGY IN BELGRADE
FACULTY OF TECHNOLOGY, SHTIP, NORTH OF MACEDONIA
FACULTY OF MECHAICAL ENGINEERING, ALBANIA
SOCIETY FOR ROBOTICS OF BOSNIA I HERZEGOVINA
BASTE - BALKAN SOCIETY OF TEXTILE ENGINEERING, GREECE**

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**Conference is financially supported by The Ministry of Science,
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UNION OF ENGINEERS AND TEXTILE TECHNICIANS OF SERBIA



“CONTEMPORARY TRENDS AND INNOVATIONS IN THE TEXTILE INDUSTRY” CT&ITI 2024 PROCEEDINGS

Editor: Prof. dr Snežana Urošević,
University of Belgrade, Technical Faculty in Bor

Technical Editor: Doc. dr Violeta Stefanović

Cover design: MSc Igor Urošević

Photographs: Assoc. prof. dr Mirjana Devetaković

From the Ethnographic Collection of Hristifor Crnilović,
Ethnographic Museum - Manak's House, Belgrade

**Publisher: Union of Engineers and Textile Technicians of Serbia, Belgrade, Serbia,
September, 2024.**

For the publisher: Prof. dr Snežana Urošević

**Conference is financially supported by The Ministry of Science, Technological
Development and Innovation of the Republic of Serbia**

Printed: SatCip, Vrnjačka banja, Serbia

Printing: 100 copies

ISBN-978-86-900426-7-8

CIP - Каталогизacija у публикацији
Народна библиотека Србије, Београд

677(082)
687.1(082)

**МЕЂУНАРОДНА научна конференција Савремени трендови и иновације у
текстилној индустрији (7 ; 2024 ; Београд)**

Zbornik radova = Proceedings / VII međunarodna naučna konferencija Savremeni trendovi i inovacije u tekstilnoj industriji = VII International Scientific Conference Contemporary Trends and Innovations in the Textile Industry, CT&ITI, Belgrade, 19-20 th September, 2024 ; [organized by] Union of Engineers and Textile Technicians of Serbia ... [et al.] ; editor Snežana Urošević. - Belgrade : Union of Engineers and Textile Technicians of Serbia, 2024 (Vrnjačka Banja : SatCip). - [15], 609 str. : ilustr. ; 25 cm

Radovi na srp. i engl. jeziku. - Tiraž 100. - Str. [7]: Preface / Snežana Urošević. - Napomene i bibliografske reference uz radove. - Bibliografija uz svaki rad. - Registar.

ISBN 978-86-900426-7-8

a) Текстилна индустрија -- Зборници б) Индустрија одеће -- Зборници

COBISS.SR-ID 150904585



PREFACE

The 7th International conference "Contemporary Trends and Innovations in the Textile Industry" CT&ITI 2024, is co-organized by:

- Union of Engineers and Textile Technicians of Serbia,
- Union of Engineers and Technicians of Serbia,
- Faculty of Technology and Metallurgy in Belgrade, University of Belgrade, Serbia,
- Faculty of Technology, "Goce Delchev" University, Shtip, North Macedonia,
- Faculty of Mechanical Engineering, Polytechnic University of Tirana, Albania,
- Society for Robotics of Bosnia and Herzegovina and
- Balkan Society of Textile Engineering-BASTE of Greece.

The Ministry of Science, Technological Development and Innovation of the Republic of Serbia recognized the importance of this Conference, and thus, supported it.

The aim of this Conference is to consider current technical, technological, economic, ecological, R&D, legal and other issues related to the textile industry, then the application of contemporary achievements and the introduction of technical and technological innovations in the production process of fiber, textile, clothing and technical textile by applying scientific solutions in order to improve the business and increase the competitive advantages of the textile industry on the domestic and global market.

Leading scientists and experts from the Balkans and other countries, working at faculties, textile colleges and institutes, but also individuals who professionally deal with the issues at hand are taking part in this Conference.

The Conference program involves papers dedicated to the scientific and practical aspects of the following topics: Textile and Textile Technology, Textile Design, Management and Marketing in the Textile Industry and Ecology and Sustainable Development in the Textile Industry. The Conference program includes 66 papers, and a total of 158 participants from 17 countries: Albania, Australia, Bosnia and Herzegovina, Bulgaria, Croatia, Germany, Greece, India, North of Macedonia, Montenegro, Portugal, Romania, Serbia, Slovenia, Spain, Turkey and Ukraine.

Therefore, this Conference is an opportunity for establishing scientific, educational and economic cooperation of our country with other countries. Certain number of papers by domestic authors present the project results dealing with fundamental research and technological development, financed by the Ministry of Ministry of Science, Technological Development and Innovation of the Republic of Serbia.

I would like to thank all those who have made it possible to organize the conference Contemporary Trends and Innovations in the Textile Industry and make it a success. First, I would like to thank the Scientific and Organizing Committee for working hard, spending countless hours and finding the best solutions for numerous organizational aspects of our Conference. I also thank all the other institutions that supported the Conference in various ways, because without their support, the Conference could not have been organized. Last but not least, I would like to thank plenary lecturers, all authors and co-authors and guests for their participation in the Conference.

On behalf of the Organizing Committee

Prof. dr Snežana Urošević, president



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PLENARY LECTURES



VII International Scientific Conference
„Contemporary trends and innovations in the textile industry“
19-20th September, 2024, Belgrade, Serbia



BIOACTIVE TEXTILE MATERIALS BASED ON CELLULOSE AND CHITOSAN

Original scientific paper
DOI: 10.5937/CT_ITI24001K

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ABSTRACT: Here, we present a detailed review of recent research and achievements in the field of bioactive textile materials based on cellulose and chitosan. The most important properties of cellulose and chitosan are outlined, giving rise to the interest in their combining. Their combination is particularly attractive because both cellulose and chitosan are not harmful to human beings and the environment. Rising living standards and increased environmental awareness are driving forces for the development of bioactive textile materials based on cellulose and chitosan. We present various types of bioactive textile materials based on cellulose and chitosan that we have developed recently. In this review, we have shown that the field of bioactive textile materials based on cellulose and chitosan is an inexhaustible source of ideas and opportunities for further development.

Keywords: cellulose, chitosan, textile materials, bioactivity.

BIOAKTIVNI TEKSTILNI MATERIJALI NA BAZI CELULOZE I HITOZANA

APSTRAKT: Ovde predstavljamo detaljan pregled novijih istraživanja i dostignuća u oblasti bioaktivnih tekstilnih materijala na bazi celuloze i hitozana. Navedena su najvažnija svojstva celuloze i hitozana, koja izazivaju interesovanje za njihovo kombinovanje. Njihovo kombinovanje je posebno atraktivno jer i celuloza i hitozan nisu štetni za ljude i životnu sredinu. Rastući životni standard i povećana ekološka svest su pokretačke snage za razvoj bioaktivnih tekstilnih materijala na bazi celuloze i hitozana. Predstavljamo različite vrste bioaktivnih tekstilnih materijala na bazi celuloze i hitozana koji su razvijeni u našim laboratorijama. U ovom pregledu smo pokazali da je oblast bioaktivnih tekstilnih materijala na bazi celuloze i hitozana nepresušan izvor ideja i mogućnosti za njen dalji razvoj.

Ključne reči: celuloza, hitozan, tekstilni materijali, bioaktivnost.



1. INTRODUCTION

Increased environmental awareness, the predicted reduction of fossil resources as well as the increased costs of their extraction, have fueled a surge of interest in renewable and sustainable resources. The greatest interest was attracted by polysaccharides due to their renewability, recyclability and biodegradability, as well as the fact that they represent the most abundant fraction of biomass. Cellulose and chitosan are the most widespread natural polysaccharides and have been used for a long time in various applications [1].

However, the number of reports on the successful combination of these two polysaccharides has only become significant since the 1990s. The consideration of combining these two polysaccharides was based on the fact that both have a similar molecular structure, but different properties that can be advantageously combined. Cellulose primarily offers good structural, mechanical, and hydrophilic properties, while chitosan offers a wide range of bioactive properties [2].

Knowledge of interactions at the molecular level between cellulose and chitosan was crucial for the development of bioactive textile materials based on cellulose and chitosan. The research groups of *Holmberg* [3] and *Laine* [4] provided some essential information about such interactions. Based on these theoretical studies, various bioactive textile materials based on cellulose and chitosan have been developed to date.

In this review, we aim to present the scope and complexity of the combination of these two exceptional polysaccharides, cellulose and chitosan, and their importance for the development of bioactive textile materials based on them. Special attention is given to viscose fabric and various approaches to combining it with chitosan.

2. CELLULOSE

Cellulose is the most abundant natural polymer on Earth with $\sim 1.5 \times 10^{12}$ tons of cellulose produced each year. The molecular structure of cellulose, isolated from plant cell walls, was first discovered and determined by the French scientist *Anselme Payen* in 1838. In addition to plants, cellulose is also produced by some types of algae, fungi, and bacteria [5].

Cellulose is an organic compound consisting of a linear chain of β (1 $\rightarrow$ 4) linked D glucose units (Figure 1.). A single D glucose unit is a hexose that takes on one of α or β forms, depending on the position of the hydroxyl groups. As a result of the glucose structure, cellulose contains a large amount of free hydroxyl groups located at the C2, C3, and C6 atoms. The main hydroxyl groups along polysaccharide chains can be easily modified by oxidation, esterification, acylation, grafting, and etherification resulting in a wide range of cellulose derivatives [6]. Native cellulose or cellulose I is the most crystalline type of cellulose which exists in two forms: $I\alpha$ and $I\beta$. Cellulose $I\alpha$ crystal has a triclinic unit cell, and cellulose $I\beta$ crystal has a monoclinic unit cell. Both, cellulose $I\alpha$ and $I\beta$ are present in native cellulose structures but in different ratios depending on the source of cellulose. Other allomorphs of cellulose are possible, the most common of which are cellulose II, III, and IV. Cellulose II can be prepared by mercerisation or regeneration of cellulose I. Cellulose

III can be prepared from cellulose I or cellulose II by treatment with liquid ammonia, resulting in cellulose III1 or cellulose III2. Cellulose IV1 and IV2 can be prepared by heating cellulose III1 or cellulose III2 in glycerol [7].

Single cellulose macromolecules interconnect via hydrogen bonds to form cellulose microfibrils that exhibit highly-ordered crystalline and low-ordered amorphous regions. The intermolecular hydrogen bonds in the crystalline regions are strong, which ensures the good structural and mechanical properties of cellulose, as well as its insolubility in most solvents. They also provide prevention of cellulose melting. The cellulose macromolecules are usually longer than the crystalline regions. As a consequence, one cellulose macromolecule can run from one crystalline region to another, passing through amorphous regions, and thereby holding the crystalline and amorphous regions together. Due to the large distance between cellulose macromolecules in amorphous regions, fewer intermolecular hydrogen bonds are established between cellulose macromolecules, which allows cellulose macromolecules to form hydrogen bonds with other molecules, such as water. This gives macromolecular cellulose its hygroscopic and hydrophilic characteristics [8].

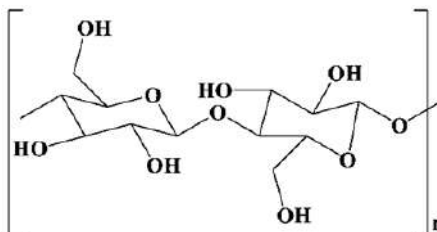


Figure 1: Molecular structure of cellulose [6]

3. CHITOSAN

Chitosan is a polysaccharide obtained by alkaline deacetylation of chitin and is the second most commonly used natural polymer. Chitin was discovered in 1811. when the French chemist and pharmacist *Henri Braconnot* studied fungi. It is the main structural component of the exoskeleton of crustaceans (such as spiders, butterflies, ladybirds, lobsters, prawns, and crabs) as well as the cell walls of certain fungi. According to its molecular structure, chitin is poly-N-acetyl-D-glucosamine, which is formed during biosynthesis. The molecular structure of chitin is similar to the molecular structure of cellulose, with the difference that the hydroxyl group on the C2 atom of each glucosidic unit of chitin is replaced by an acetylated amino group. Given that the mutual packing of chitin macromolecules in the crystal lattice takes place in a manner analogous to cellulose, the supramolecular structure of chitin is extremely similar to the supramolecular structure of cellulose. But, unlike cellulose, which exists in nature in only one form, chitin appears in nature in three different forms: α , β , and γ [9].

Complete alkaline deacetylation of chitin is impossible by conventional procedures, so commercial chitosan typically contains 15-25% acetylated amino groups. Therefore,

chitosan is a heteropolysaccharide consisting of β (1 $\rightarrow$ 4) linked units of 2-acetamido-2-deoxy- β -D-glucopyranose and 2-amino-2-deoxy- β -D-glucopyranose units (Figure 2.) [9].

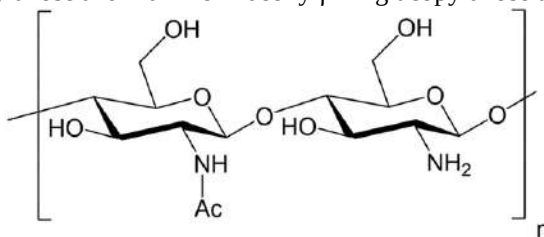


Figure 2: Molecular structure of chitosan [10]

Unlike most polysaccharides that are neutral or negatively charged, chitosan is positively charged due to the presence of a large number of free amino groups in its structure. Consequently, chitosan can only be dissolved in dilute acid solutions, which limits its application in various fields. To overcome this limitation, many scientists have focused their research on the chemical modification of chitosan to obtain water-soluble chitosan derivatives [10].

Regardless of solubility limitations, chitosan stands out among numerous bioactive compounds due to its biocompatibility, biodegradability, non-toxicity, and wide range of bioactive properties. Its antibacterial, antifungal, antiviral, antioxidant, anti-inflammatory, analgesic, hemostatic, anticoagulant, and anticancer properties have made it very suitable for obtaining products used in health care and medicine [11, 12]. In recent years, the most attention has been devoted to studying its antimicrobial and antioxidant properties. Chitosan has been found to possess a broad spectrum of antimicrobial activity against fungi, and Gram-positive and Gram-negative bacteria. However, the exact mechanisms of chitosan's antimicrobial activity have not yet been fully elucidated. The most accepted hypothesis is based on the disruption of the cell membrane/cell wall of the microorganism due to the interactions between the positively charged chitosan and the negatively charged membrane of the microorganism [13].

Generally accepted mechanisms of antimicrobial action of chitosan are based on:

- disruption of the cell membrane/cell wall,
- interactions with the DNA of microorganisms,
- chelation of nutrients necessary for the survival of microorganisms, and
- the formation of a dense polymer film on the surface of microorganisms [13].

Protonated amino groups of chitosan play a key role in disrupting the cell membrane/cell wall of microorganisms. When the pH value of chitosan's environment is lower than its pKa value, amino groups are protonated giving chitosan a positive charge. The cell wall of Gram-positive bacteria is negatively charged due to the presence of teichoic acid located in the thin peptidoglycan layer, while the cell wall of Gram-negative bacteria is extremely negatively charged due to the presence of lipopolysaccharides located in the outer layer of the membrane. Also, in the case of fungi, the cell wall contains components that make it negatively charged. Electrostatic interactions between positively charged chitosan



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molecules and negatively charged components of the microorganism's cell wall can lead to blocking intra/extracellular exchange or even rupture of the cell wall and, ultimately, leakage of cytoplasmic contents [13]. Fu et al. [14] showed that teichoic acids found in the cell wall of *S.aureus* interact with chitosan derivatives and thus inhibit bacterial growth, in some cases up to almost 100%. Using electron microscopy, Li et al. [15] recorded damage to the cell membrane and leakage of the cytoplasmic content of *E.coli* in the presence of chitosan. Interactions of chitosan with the DNA of microorganisms are particularly related to low molecular weight chitosans. Hydrolysis products of low molecular weight chitosan can establish interactions with the DNA of microorganisms, which affects protein synthesis and inhibition of mRNA of microorganisms [13]. This mechanism of antimicrobial action of chitosan was confirmed by Liu et al. [16] against *E.coli*, and by Sebt et al. [17] against *A. niger*. Chelation of nutrients necessary for the survival of microorganisms is based on the ability of chitosan to complex with metal ions. Cell wall components of both Gram-positive and Gram-negative bacteria attract divalent metal ions that are essential for their survival. Phosphate groups of teichoic acid found in the peptidoglycan layer of Gram-positive bacteria particularly attract Mg^{2+} and Ca^{2+} ions, which participate in maintaining enzyme functions and membrane integrity. Lipopolysaccharides, components of the outer membrane layer of Gram-negative bacteria, also have a strong affinity for divalent metal ions due to their negative charge. In this regard, chitosan negatively affects the survival of microorganisms by chelating metal ions and nutrients that are necessary for the growth of microorganisms. The formation of a dense polymer film on the surface of microorganisms is characteristic of chitosans of high molecular weight, which can be deposited on the surface of microorganisms and thus prevent the intake of nutrients and oxygen into them, which has a particularly negative effect on the survival of aerobic bacteria [13]. The deposition of chitosan on the outer membrane of *E.coli* was recorded by Helander et al. [18] using electron microscopy.

Chitosan has the ability to activate antioxidant mechanisms in human cells that prevent oxidative stress responsible for the creation of reactive oxygen species (ROS) at diseased sites in the body. Chitosan as a ROS scavenger has distinctive antioxidant activity that can prevent peroxidation and degradation of cell membranes, lipids, proteins, and genomes. This unique feature results from the reaction of ROS with the free amino and hydroxyl groups of chitosan leading to an increase in the stability of ROS [13]. Sun et al. [19] reported that chitosan and its derivatives act as hydrogen donors for ROS neutralization. The latest research has shown that chitosan nanoparticles have superior permeability and immune modulation, without toxicity to human cells, and enhanced antibacterial activity compared with bulk chitosan. Withal, much research effort has been devoted to the chitosan nanoparticles/metals hybrids development, to connect the chelating properties of chitosan with the antibacterial properties of metals. Metal chelation with chitosan increases the positive charge density of chitosan nanoparticles, which leads to their enhanced adsorption onto the negatively charged bacterial cell wall, and thus to the inhibition of bacterial cell growth. Zinc is one of these metals, which show great antibacterial properties. An additional advantage of using chitosan nanoparticles/metals hybrids is the US-FDA



approval of chitosan and zinc as safe for many dietetic and wound dressing applications [20].

3. TEXTILE MATERIALS BASED ON CELLULOSE AND CHITOSAN

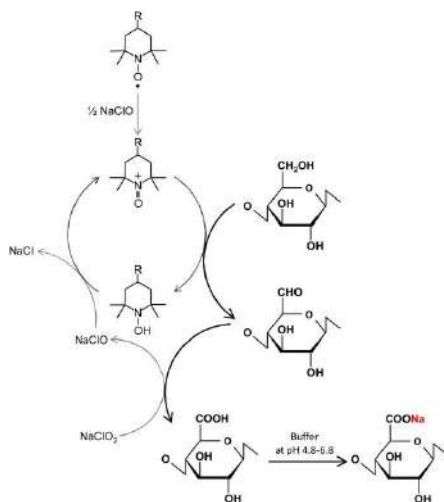
Similarities between the chemical and molecular structures of textile materials based on cellulose and chitosan/chitosan-based nanoparticles enable high affinity between them. The most likely intermolecular interactions between textile materials based on cellulose and chitosan/chitosan-based nanoparticles are based on H-bonds and *Van der Waals* forces. However, for more intense and irreversible binding between textile materials based on cellulose and chitosan/chitosan-based nanoparticles, it is necessary to introduce carboxyl and/or aldehyde groups into/onto the textile materials based on cellulose, which are then potential anchoring sites for chitosan/chitosan-based nanoparticles. Carboxyl groups of textile materials based on cellulose as host material can provide electrostatic attraction between them and chitosan/chitosan-based nanoparticles as adsorbate, while aldehyde groups are an excellent choice because they can allow covalent binding of chitosan/chitosan-based nanoparticles by forming a *Schiff's* base. These bounds, when present at the same time, may serve as a starting point for irreversible binding of chitosan/chitosan-based nanoparticles onto textile materials based on cellulose [20, 21].

2,2,6,6-tetrametilpiperidin-1-oksil (TEMPO) oxidation and coating with TEMPO-oxidized cellulose nanofibrils (TOCN) proved to be very effective in introducing a large number of functional groups (carboxyl and aldehyde) in/on the textile materials based on cellulose. In this way, subsequent improved binding of chitosan/chitosan-based nanoparticles in/on the textile materials based on cellulose is enabled. It is important to point out that the coating of textile materials based on cellulose with TOCN has an advantage over the TEMPO oxidation of textile materials based on cellulose in terms of preserving mechanical properties. It is known that the structure of cellulose changes during TEMPO oxidation, which generally leads to a significant deterioration of the mechanical properties of TEMPO-oxidized textile materials based on cellulose. In contrast, it was found that coating textile materials based on cellulose with TOCN improves their mechanical properties [21]. The section below provides a brief overview of the TEMPO oxidation of the textile materials based on cellulose as well as the obtaining of TOCN and the coating of textile materials based on cellulose with TOCN.

TEMPO oxidation of textile materials based on cellulose in TEMPO/NaClO/NaClO₂ system under weakly acidic conditions is a complex reaction. The mechanism of TEMPO oxidation of textile materials based on cellulose in the TEMPO/NaClO/NaClO₂ system is shown in Figure 3. (a). As can be seen from Figure 3. (a), the reaction starts by oxidation of TEMPO to the oxoammonium ion (TEMPO⁺) with NaClO. TEMPO⁺ oxidizes the hydroxyl groups at the C6 atoms of textile materials based on cellulose to aldehyde groups and is reduced to the N-hydroxy-TEMPO. The aldehyde groups are directly oxidized to the sodium carboxylate groups with NaClO₂, and then NaClO generated *in situ* from NaClO₂ oxidizes the N-hydroxy-TEMPO, again to the TEMPO⁺. In addition to aldehyde groups formed as intermediates at the C6 atoms cellulose, a low amount of aldehyde groups can

also be formed as reducing ends of cellulose due to the cleavage of the 1,4-glycosidic bond by β -elimination of cellulose during TEMPO oxidation of textile materials based on cellulose in TEMPO/NaClO/NaClO₂ [22].

a)



b)

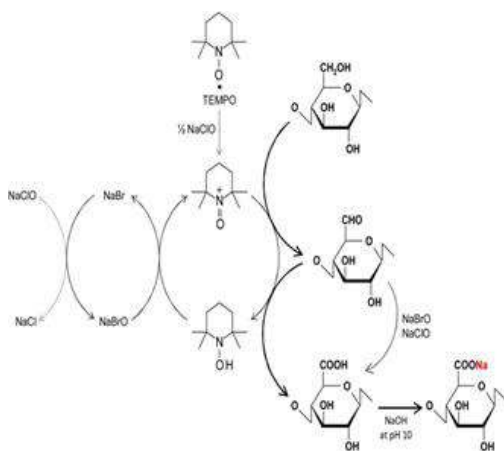


Figure 3: TEMPO oxidation of textile materials based on cellulose in TEMPO/NaClO/NaClO₂ system under weakly acidic conditions (a), TEMPO oxidation of cotton in TEMPO/NaBr/NaClO system under alkaline conditions (b) [22]

The most promising way to obtain TOCN is a combination of TEMPO oxidation of cotton in a TEMPO/NaBr/NaClO system under alkaline conditions, and subsequent mechanical



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disintegration of TEMPO-oxidized cotton to nanofibrils using an ultrasonic homogenizer [13]. The mechanism of TEMPO oxidation of cotton in the TEMPO/NaBr/NaClO system under alkaline conditions is shown in Figure 3. (b). The reaction starts with the oxidation of TEMPO to the oxoammonium ion (TEMPO^+) with NaClO. TEMPO^+ oxidizes the hydroxyl groups at the C6 atoms of cotton to aldehyde groups. The reduced TEMPO or N-hydroxy-TEMPO is then oxidized by NaBrO, formed from NaBr by oxidation with NaClO. The aldehyde groups are directly oxidized to the sodium carboxylate groups with NaClO and/or NaBrO. Compared to TEMPO oxidation of cellulose in TEMPO/NaClO/NaClO₂ system under weakly acidic conditions, during TEMPO oxidation of cellulose in TEMPO/NaBr/NaClO system under alkaline conditions a larger amount aldehyde groups are formed as reducing ends of cellulose due to more pronounced cleavage of the 1,4-glycosidic bond by β -elimination of cellulose. In other words, during TEMPO oxidation of cellulose in TEMPO/NaBr/NaClO system under alkaline conditions leads to more pronounced depolymerization of cellulose, which is desirable for facilitated mechanical disintegration of TEMPO-oxidized cotton to nanofibrils [13, 22].

After TEMPO oxidation in TEMPO/NaBr/NaClO system under alkaline conditions oxidation, the nanofibrils inside the cotton are more easily separated from each other. Namely, the repulsive forces between the ionized carboxyl groups overcome the attractive forces between the hydroxyl groups that hold the nanofibrils inside the cotton together. It was established that after TEMPO oxidation in the TEMPO/NaBr/NaClO system under alkaline conditions oxidation, mechanical defibrillation of the same raw material is achieved with drastically lower energy consumption. Until now, after TEMPO oxidation in the TEMPO/NaBr/NaClO system under alkaline conditions oxidation, mechanical treatments were most often used with the use of a kitchen blender and the ULTRA-TURRAX® systems. However, it was found that mechanical treatment with the use of an ultrasonic homogenizer is the fastest and requires the least energy consumption. The operating principle of the ultrasonic homogenizer is based on the generation of hydromechanical forces that lead to the defibrillation of TOCN from the starting material with a yield of over 95% [13].

Coating of textile materials based on cellulose with TOCN is based on immersing textile materials based on cellulose in a water dispersion of TOCN. Then excess water is removed by squeezing it onto a laboratory padder. Korica et al. [13] investigated the stability of the adsorbed TOCN on the textile materials based on cellulose by monitoring the zeta potential changes with the time of exposure of textile materials based on cellulose coated with TOCN to the aqueous solution. The obtained results showed that the exposure of textile materials based on cellulose coated with TOCN to an aqueous solution does not lead to changes in the zeta potential that could indicate the release of TOCN. In other words, the obtained results indicated that during the coating of textile materials based on cellulose with TOCN, an extremely strong connection between textile materials based on cellulose and TOCN was achieved, based on the system of hydrogen and Van der Waals bonds.

In previous research in this area, Korica et al. [13, 20, 21, 23] obtained TEMPO-oxidized and TOCN-coated viscose fabrics with increased content of carboxyl and aldehyde groups. TEMPO-oxidized viscose fabric has 438 mmol/kg cellulose carboxyl groups and 440



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mmol/kg cellulose aldehyde groups, while TOCN-coated viscose fabric has 86 mmol/kg cellulose carboxyl groups and 27 mmol/kg cellulose aldehyde groups. Compared to raw viscose fabric, TEMPO-oxidized and TOCN-coated viscose fabrics achieved improved binding of chitosan/chitosan-based nanoparticles. In addition, TEMPO-oxidized and TOCN-coated viscose fabrics also showed improved persistence of bound chitosan/chitosan-based nanoparticles during multiple washing cycles.

Korica et al.[13] conducted experiments on a model of ultra-thin films to determine which pH values are most suitable for improved binding of chitosan/chitosan-based nanoparticles on textile materials based on cellulose. It has been proven that pH 5.5 is the most suitable in terms of simultaneously establishing electrostatic and covalent interactions between textile materials based on cellulose and chitosan/chitosan-based nanoparticles. In their further research [13, 20, 21 23], raw, TEMPO-oxidized, and TOCN-coated viscose fabrics were functionalized with chitosan (CH), and chitosan nanoparticles without and with embedded zinc (NCH and NCH+Zn, respectively) at pH 5.5. Compared with raw viscose fabric, TEMPO-oxidized, and TOCN-coated viscose fabrics bound a higher amount of CH, NCH, and NCH+Zn. Accordingly, TEMPO-oxidized and TOCN-coated viscose fabrics functionalized with CH, NCH, and NCH+Zn achieved higher antibacterial and antioxidant activity than raw viscose fabric functionalized with CH, NCH, and NCH+Zn.

The washing durability of raw, TEMPO-oxidized, and TOCN-coated viscose fabrics functionalized with CH, NCH, and NCH+Zn was monitored after one, three, and five washing cycles. As a consequence of a higher amount of irreversibly bound CH, NCH, and NCH+Zn, TEMPO-oxidized and TOCN-coated viscose fabrics contributed more efficient and durable antibacterial and antioxidant activity than raw viscose fabric. TEMPO-oxidized viscose fabric functionalized with CH achieved the most efficient and durable antibacterial activity: up to five washing cycles in the case of *S.aureus*, and up to three washing cycles in the case of *E.coli*. The antioxidant activity of all viscose fabrics functionalized with CH, NCH, and NCH+Zn was not significantly deteriorated after multiple washing cycles.

3. CONCLUSION

The development of bioactive textile materials based on cellulose and chitosan represents a particularly interesting and promising strategy in the context of new sustainable and environmentally friendly products obtained from renewable resources. As shown in this brief review, chemical modification and intelligent combination of these polysaccharides can be exploited to develop of new bioactive textile materials based on cellulose and chitosan with improved and tailored properties and therefore with potential applications as medical textiles.

Acknowledgments: The authors thank the Ministry of Science, Technological Development and Innovation of the Republic of Serbia for funding (Contract No. 451-03-66/2024-03/200287 and Contract No.451-03-65/2024-03/200135).



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REVITALISATION OF NATURAL DYES – RED SHADES OF TEXTILES DYED WITH *RUBIA TINCTORUM* UNDER DIFFERENT PROCESS PARAMETERS

Original scientific paper
DOI: 10.5937/CT_ITI24002S

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ABSTRACT: The demands of modern life and industry tend toward environmentally sound and sustainable processes in all areas of human activity, including the textile industry. In response to this demand, natural dyes, which had fallen into oblivion at the end of the 19th century, gained popularity as an acceptable alternative to synthetic dyes. The natural dye obtained from the plant *Rubia tinctorum* belongs to the group of acid-mordant dyes. The chemical structure of the main pigment, alizarin, and the method of binding it to fiber are described in the paper. Basic botanical and agronomic data are presented, as well as the history of *Rubia tinctorum* dyeing and the possibilities of its modern application. Dyeing of wool and silk fabrics was carried out at different pH values and with different mordants (without mordant and with aluminum, copper, and iron). After dyeing, spectrophotometric analysis of the aqueous solutions of *Rubia tinctorum* was performed, and the color parameters of the dyed samples were determined spectrophotometrically. A test of washing and sunlight fastness was performed and the color difference determined spectrophotometrically was revealed. Considering the obtained results, an optimal dyeing procedure with the *Rubia tinctorum* plant is recommended. By dyeing wool and silk material with different process parameters, a wide range of red tones with h values from 30° (red part of the spectrum) to 70° (yellow part of the spectrum) was obtained. In combination with different brightness and chromaticity, wool and silk textiles with orange, pink, red and burgundy tones of satisfactory fastness were obtained, ready for the challenges of the market.

Keywords: alizarin, mordant dyes, natural dyes, *Rubia tinctorum*.



REVITALIZACIJA PRIRODNIH BOJA – CRVENE NIJANSE TEKSTILA BOJANOG SA RUBIA TINCTORUM U OVISNOSTI O PROCESNIM PARAMETRIMA

APSTRAKT: *Zahtevi savremenog života i industrije teže ekološki prihvatljivim i održivim procesima u svim oblastima ljudske delatnosti, uključujući i tekstilnu industriju. Kao odgovor na ovaj zahtev, prirodne boje, koje su pale u zaborav krajem 19. veka, stekle su popularnost kao prihvatljiva alternativa sintetičkim bojama. Prirodna boja dobijena iz biljke Rubia tinctorum pripada grupi kiselo-mordantnih boja. U radu je opisana hemijska struktura glavnog pigmenta alizarina i način njegovog vezivanja za vlakna. Prikazani su osnovni botanički i agronomski podaci, istorijat bojenja Rubia tinctorum i mogućnosti njegove savremene primene. Bojenje vunenih i svilenih tkanina vršeno je pri različitim pH vrednostima i različitim moćilima (bez moćila i sa aluminijumom, bakrom i gvožđem). Nakon bojenja, urađena je spektrofotometrijska analiza vodenih rastvora Rubia tinctorum, a parametri boje obojenih uzoraka su određeni spektrofotometrijski. Izvršen je test otpornosti na pranje i sunčevu svetlost i otkrivena je spektrofotometrijski određena razlika u boji. S obzirom na dobijene rezultate preporučuje se optimalan postupak bojenja biljkom Rubia tinctorum. Bojenjem vunenog i svilenog materijala sa različitim procesnim parametrima dobija se širok spektar crvenih tonova sa h vrednostima od 30° (crveni deo spektra) do 70° (žuti deo spektra). U kombinaciji različitog sjaja i hromatike, dobija se vuneni i svileni tekstili narandžastih, roze, crvenih i bordo tonova zadovoljavajuće postojanosti, spremni za izazove tržišta.*

Ključne reči: *alizarin, mordantne boje, prirodne boje, Rubia tinctorum.*

1. INTRODUCTION

In view of the fact that the synthetic dyes used for dyeing textiles generally pollute the environment and can cause health problems for people, there is an increasing revival in the use of natural dyes, in line with the global trend towards an "eco" lifestyle [1,2]. Many synthetic dyes are classified as hazardous on skin contact and customers are demanding safer products, especially for babies and children. Compared to synthetic dyes, natural dyes causes much less pollution in the dyeing process itself and in the subsequent disposal of textile waste due to its biodegradability and cleaner dyeing process. The applicability of natural dyes for dyeing cellulose materials is increasingly being researched, particularly because of current fashion trends [2,3]. Furthermore, scientific research in the field of natural dyes is extremely important for archaeology and the conservation and restoration of textiles [4].

Rubia tinctorum produces anthraquinone pigments in its root, the most important and common of which is alizarin, which has been used for dyeing textiles since 2000 BC. These pigments provide useful colours that have a pronounced light and heat fastness [5,6]. There are about 80 species of *Rubia tinctorum*, the most famous of which are the dyer's *Rubia*

tinctorum, the foreign or Mediterranean *Rubia peregrina* and the Indian *Rubia cordifolia*. *Rubia tinctorum* is a herbaceous, low-growing plant with lanceolate leaves and a stem [7-9]. *Rubia tinctorum* is native to southern Europe, western Asia and northern Africa, but is also cultivated elsewhere. Mature plants produce star-shaped, pale yellow flowers that bloom in June and round black seeds that look like pepper [6,8,10]. Only the root of the plant is used for dyeing. The root of *Rubia tinctorum* is used for dyeing cotton, silk and wool with premordanting it in aluminium salts (red tones), chromium salts (red-brown tones) or iron salts (purple tones). It is also used for the production of paints and inks and histological preparations [5,10-12]. In order for alizarin to be bound to the fibre, the material must be complexed with metal salts. One example of this is the formation of a complex with chromium. The chromium ion is bound to the alizarin by a covalent and coordinative bond via the hydroxyl groups of the alizarin. One chromium ion, which is trivalent, binds to three molecules of alizarin (Fig. 1) [6-8,11-13]. Protein fibres bind to alizarin by forming hydrogen bonds between the polypeptide chains and the dyes and simultaneously complexing alizarin with metal ions (e.g. chromium) (Fig. 2) [2,14].

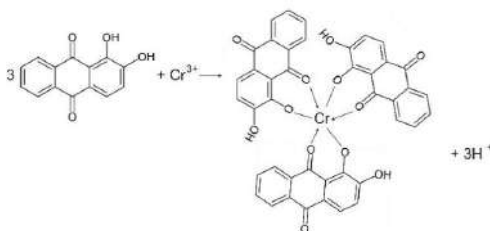


Figure 1: Formation of complex between alizarin and chromium [14]

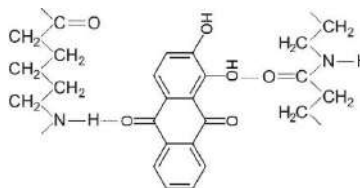


Figure 2: Binding of alizarin to protein textile material by hydrogen bonds [14]

Rubia tinctorum is not only used as a textile dye, but also has medicinal value. *Rubia tinctorum* has antioxidant, antimicrobial and antifungal properties as well as a blood pressure lowering effect and can be worn directly on the skin without any concerns. Root extracts are used to treat kidney and urinary stones. It is also used as a laxative mixture and mild sedative, as well as for menstrual and urinary problems [1,9,15]. Modern methods of dyeing textiles with *Rubia tinctorum* include research into replacing mordants with textile pre-treatments such as cationisation and plasma treatment, which achieve similar effects to pre-treatment with aluminium or tin salts, i.e. a brilliant shade and good fastens properties are achieved [16,17].

2. EXPERIMENTAL PART

2.1. Dye extraction

The dry root of *Rubia tinctorum* was used for dye extraction (Fig. 3). The plant was collected in the village of Petrovići in Montenegro at an altitude of about 700 metres above sea level, where it grows as a wild species.



(a) Dry root of *Rubia tinctorum*



(b) Chopped dry plant

Figure 3: Preparation of dry *Rubia tinctorum* root for dye extraction

Dye extraction was performed in soft water containing 20 g/L *Rubia tinctorum* root. The extraction was performed in a 1:40 bath ratio (considering the mass of mass of the plant) at 100 °C for 60 min. The bath was then allowed to cool for 12 h and the extract was decanted.

2.2. Mordanting of the textile material with metal salts

Mordanting was performed as simultaneous process with textile dyeing. For that reason were treated with 5% mordants (based on the mass of the material): potassium aluminium sulphate dodecahydrate $KAl(SO_4)_2 \cdot 12H_2O$, copper (II) sulphate pentahydrate $CuSO_4 \cdot 5H_2O$ and ferrous(II) sulphate heptahydrate $FeSO_4 \cdot 7H_2O$; (Kemika, Zagreb, Croatia).

2.3. Dyeing with *rubia tinctorum* root

Dyeing with *Rubia tinctorum* root was performed at 60 °C for 60 min with a bath ratio of 1:30 using the apparatus Polycolor (Mathis, Switzerland). Dyeing process was performed in acidic, neutral and alkaline conditions. pH of 4 was adjusted with 20% acetic acid (Kemika, Zagreb, Croatia) and pH of 8 was adjusted with Na_2CO_3 (Kemika, Zagreb, Croatia). After dyeing, the were rinsed with cold water.

2.4. Colour analysis

Colour characteristics were measured using a remission spectrophotometer, Datacolor 850, measuring geometry d/8°, D65, measuring aperture of 9 mm. The coordinates used to determine colour values are L^* for lightness, a^* for redness (positive value) and greenness (negative value), b^* for yellowness (positive value) and blueness (negative value), C^* for chroma and h° for hue angle in the range of 0° to 360° of undyed and dyed were determined according to ISO 105-J01:1997 Textiles—Tests for colour fastness—Part J01: General principles for measurement of surface colour.

2.5. Wash fastness analysis

Wash fastness of dyed materials were tested in a laboratory apparatus for wet processes Polycolor (Mathis, Switzerland). The test was performed according to standard ISO 105-



VII International Scientific Conference
„Contemporary trends and innovations in the textile industry“
19-20th September, 2024, Belgrade, Serbia

C06:2010 (A2S) Textiles—Tests for colour fastness—Part C06: Colour fastness to domestic and commercial laundering, using 2 g/L of standard detergent (James Heal ECE A, without optical brighteners and without phosphates), with a bath ratio of 1:20, temperature of 40 °C, time of 30 min. The results of wash fastness are given as numerical values of total colour difference (DE) calculated according to CIE76 equation (1), as well as in grey scale grades, obtained by comparing unwashed samples with samples that were washed after the 5th washing cycle.

$$DE = [(DL^*)^2 + (Da^*)^2 + (Db^*)^2]^{1/2} \quad (1)$$

Where are: $DL^* = (L^* \text{ washed}) - (L^* \text{ unwashed})$; $Da^* = (a^* \text{ washed}) - (a^* \text{ unwashed})$; $Db^* = (b^* \text{ washed}) - (b^* \text{ unwashed})$.

2.6. Light fastness analysis

Lightfastness testing of the samples were performed on Xenotest 440 ((SDL Atlas, Rock Hill, SC, USA). Xenotest 440 is used for laboratory simulation of external weather influences on the stability and durability of textile and other materials. Analysis was evaluated according to the modified ISO 105-B02 and 13 B04 test methods using Xenotest 440. Test conditions simulated in this research were: Total light time: 41:10 h, Radiant exposure: 6226 kJ/m², Irradiance control: 300–400 nm, Filter system: B04, E: 42 W/m² (± 2 W/m²), CHT: 32 °C (± 3 °C), BST: 47 °C (± 8 °C), RH: 40% (± 8 %), no spray, fan speed: 2000 rpm. Using the same equation as for the wash fastness, the lightfastness properties was also evaluated by calculating total colour difference values (DE).

3. RESULTS AND DISCUSSION

3.1. Visual assessment of dyed textile samples

The visual assessment of the wool samples is shown in Tab. 1, while the silk samples are shown in Tab. 2. The visual assessment of the sample is extremely important when dyeing with natural dyes, as it often deviates considerably from objective spectrophotometric measurements, and it is extremely important in the real field of application of natural dyes, e.g. in the fashion industry or in textile restoration.

It can be observed that a wide range of red shades is achieved by changing both parameters, the pH conditions and the use of mordant. Without mordant and with aluminium, more brilliant shades are obtained and with copper and iron, duller shades.

Table 1: Visual assessment of dyed wool samples

Mordant	pH 4	pH 7	pH 8
Without			
Al			
Cu			
Fe			

Table 2: Visual assessment of dyed silk samples

Mordant	pH 4	pH 7	pH 8
Without			
Al			
Cu			
Fe			

3.2. Spectrophotometric analysis of dyed textile samples

An objective spectrophotometric analysis monitored the influence of the pH solution for dyeing and the choice of mordant on the colour parameters lightness (L^*), chromaticity (C^*) and tone (h°). In this way, it is possible to determine the range of red shades that can be achieved with just one *Rubia tinctorum* plant, but with different parameters of the dyeing process. The results obtained for the wool samples are shown in Tab. 3 and Fig. 4 and for the silk samples in Tab. 4 and Fig. 5.

It can be seen, all coloured samples belong to the yellow-red part of the spectrum between coordinates $+a^*$ ($0^\circ = \text{red}$) and $+b^*$ ($90^\circ = \text{yellow}$). Wool and silk samples dyed under acidic conditions show a higher chromaticity value than samples dyed under neutral and alkaline conditions. Generally, silk samples showing a lower chromaticity than wool samples. For all samples, the highest chromaticity is achieved by mordanting with aluminium. In contrast to the neutral and acid-dyed wool samples, where the copper-treated samples have the lowest chromaticity, in acid, the iron-treated sample is the least saturated. Silk samples mordanted with iron have the lowest chromaticity, regardless of the pH value. The tone value of acidic wool samples dyed without mordant and mordanted with aluminium they have a pronounced shift towards small values, i.e. A pure red hue. The sample mordanted with copper has an angle closer to the yellow part of the spectrum. Under neutral conditions, the sample dyed without mordanting has the lowest tone value, tending towards the red part of the spectrum, in contrast to the samples mordanted with metals, whose angle is greater than 45° and which tend towards the yellow-orange colouration. Alkaline coloured wool samples have a tone value between yellow-orange and red-orange. In the case of silk samples, the colour tone value of acidic samples belongs to the red-orange part of the spectrum, with the exception of the sample mordanted with copper, which is approximately pure orange. The neutral silk samples dyed with iron has the yellowest tone, while the other three neutral samples tend towards red. The alkaline sample dyed with iron is most strongly attracted to the yellow-orange tone, but is difficult to detect due to its low chromaticity. The other alkaline samples are all below 45° and belong to the red-orange colour tone. The darkest samples are acidic, while the lightest wool samples are neutral. The copper-mordanted samples has the lowest brightness under alkaline

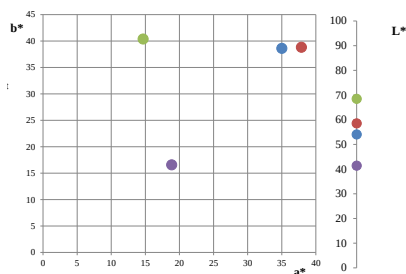
conditions. In both neutral and alkaline, the lightest wool sample is treated with aluminium. The lightest silk sample in the alkaline conditions is dyed without mordanting, in the neutral, coming up the sample treated with aluminium and in the acidic conditions sample mordanted with copper. In all neutral and acidic samples, the darkest samples were treated with iron. As can be seen from the measurement results, all colour parameters obtained are largely dependent on the process parameters of the metal salt treatment (mordanting) and the pH value. The same metal salt used at different pH conditions does not produce the same colour. Even in the same pH range, the colour tone changes depending on the metal used. Apart from the dependence on the mordanting and the pH value, the colour shade also differs with regard to the chemical structure of the textile material used for dyeing. This results from the theoretical assumptions made in the introductory part of the article with regard to the formation of the dye-metal-fibre complex (Fig. 1 and 2).

Table 3: Spectrophotometric parameters of wool samples

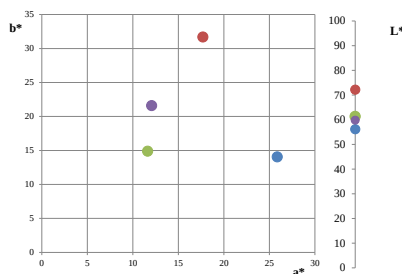
Sample	L*	C*	h°
wool_pH4_without	54.12	52.13	47.79
wool_pH4_Al	58.57	54.24	45.68
wool_pH4_Cu	68.52	42.95	70.00
wool_pH4_Fe	41.44	25.12	41.26
wool_pH7_without	56.16	29.43	28.52
wool_pH7_Al	72.18	36.29	60.83
wool_pH7_Cu	61.31	18.88	51.99
wool_pH7_Fe	59.80	24.74	60.79
wool_pH8_without	60.62	29.13	39.16
wool_pH8_Al	62.89	39.54	44.34
wool_pH8_Cu	53.85	14.43	42.61
wool_pH8_Fe	59.23	24.87	48.21

Table 4: Spectrophotometric parameters of silk samples

Sample	L*	C*	h°
silk_pH4_without	60.36	37.08	37.98
silk_pH4_Al	61.64	38.60	34.76
silk_pH4_Cu	65.43	26.42	47.48
silk_pH4_Fe	46.80	10.95	29.08
silk_pH7_without	66.24	29.23	30.87
silk_pH7_Al	68.54	35.75	43.78
silk_pH7_Cu	62.38	31.33	38.83
silk_pH7_Fe	57.69	23.83	54.19
silk_pH8_without	68.08	25.61	42.66
silk_pH8_Al	67.30	33.20	43.66
silk_pH8_Cu	61.59	25.76	33.20
silk_pH8_Fe	66.64	20.97	56.45



(a) pH 4



(b) pH 7

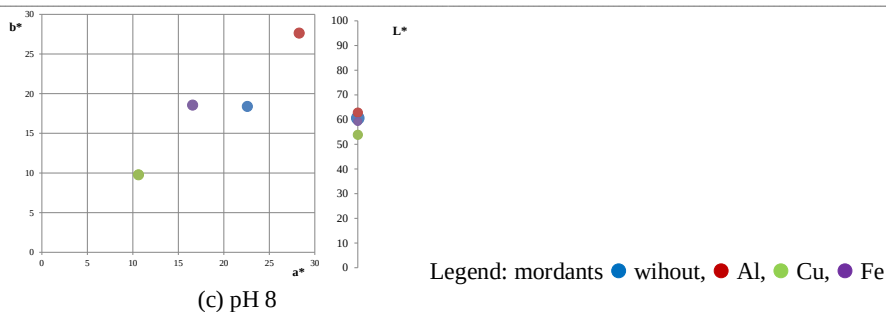


Figure 4: Colour analysis of wool samples in the a*/b* colour space

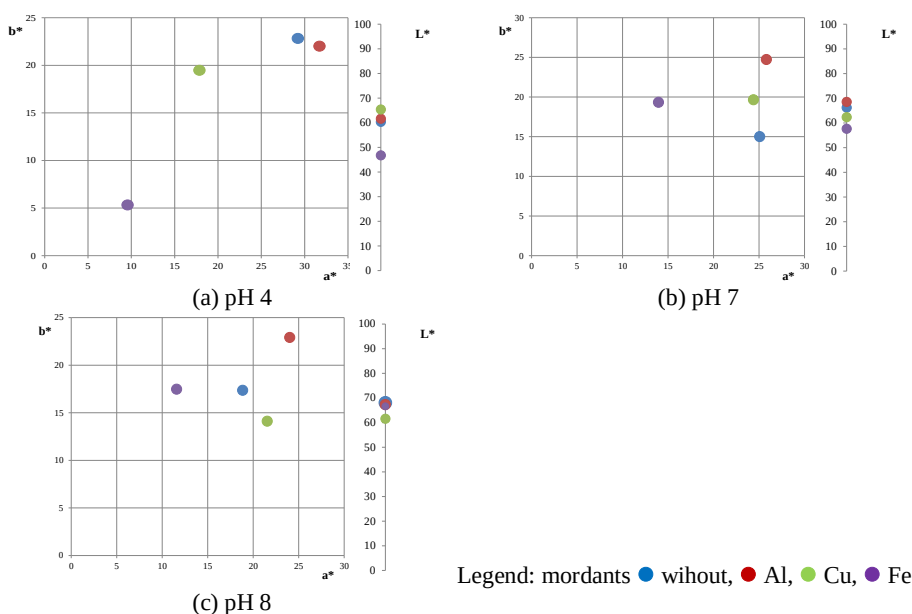


Figure 5: Colour analysis of silk samples in the a*/b* colour space

3.3. Fastnes Properties

Achieving good colour fastness is one of the most important properties of coloured textiles. This is especially true for textiles dyed with natural dyes, as poor colour fastness is often cited as one of their disadvantages. For this reason, research has carried out a test of colour fastness to washing (Fig. 6) and light fastness (Fig. 7). The diagrams show that the wool and silk samples have relatively poor fastness properties, especially after dyeing in a neutral medium. In terms of fastness to washing, the total colour difference (dE) is up to 16 for wool and 14 for silk, but these values are lower for light fastness, up to 7 for wool and 11 for silk. However, it is strongly noted that fastness is significantly increased by dyeing in an acidic medium and by using metal saalts as mordants, and dE decreases



significantly for all samples. This is logical and to be expected considering that the main component of *Rubia tinctorum* root is alizarin. As shown in Fig. 2 and 3 in the introductory section, alizarin readily forms complexes with metal ions via a coordination bond and binds to textile protein materials via hydrogen bonds.

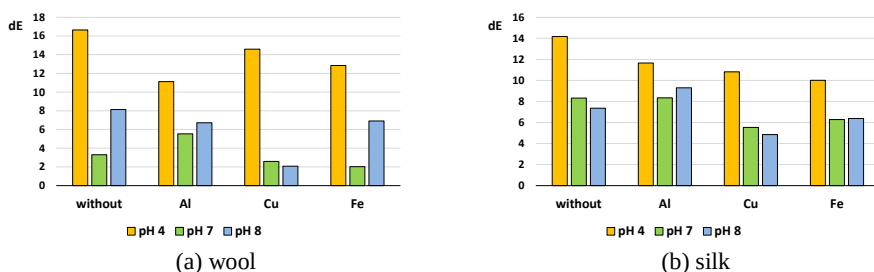


Figure 6: Wash fastness

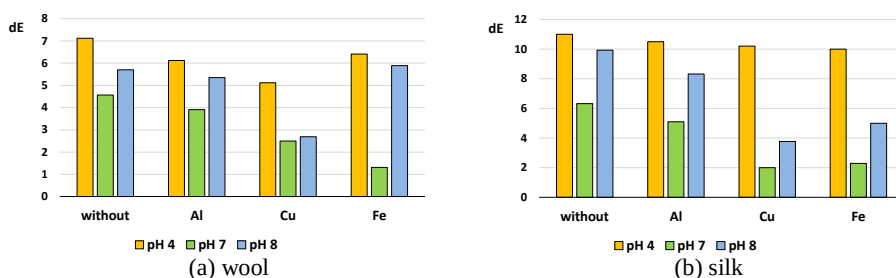


Figure 7: Light Fastness

4. CONCLUSION

A root of *Rubia tinctorum* plant is rich in the chemical compound alizarine and can be used to successfully dye wool and silk in an extremely wide range of red shades. It has been confirmed that the red shades achieved are influenced by the pH value of the dye bath and the choice of mordants, the metal salts that form coloured red complexes with alizarin. When aluminium is used, brighter and more brilliant red shades are obtained, whereas with copper and iron the brightness and chromaticity decreases and red shades are obtained that belong to the darker, achromatic tones. As alizarin is an acidic mordant yes, the colour fastness of the textiles can be significantly improved by dyeing in an acidic medium and using mordants. This research can make an important contribution to revitalising the use of the *Rubia tinctorum* plant for dyeing modern textiles, whether for fashion purposes or for the restoration and preservation of traditional heritage textiles.



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CUSTOMIZING THE GARMENT DESIGN USING COMPUTATIONAL DESIGN AND 3D PRINTING TECHNOLOGIES: A CASE STUDY

Original scientific paper
DOI: 10.5937/CT_ITI24003M

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ABSTRACT: Incorporating CAD programming into the design process of a garment can provide multiple benefits. The use of computational design can automate the wearable design and increase the potentials of customization. 3D printing finds application in many sectors due to its capacity to fabricate unusual geometries with reduced cost, especially when limited number of products are involved. The current paper contributes towards automating the design and manufacturing of customized garments. The proposed algorithm uses a number of dimensions of the human body as input data, and parameterizes a predefined clothing pattern. Then a set of fabrication commands (G-code) is generated in order to lead towards the manufacturing of garments with the use of a 3D printer. A case study is presented, using flexible 3D printing material and including special connectors created.

Keywords: Garment design, Design automation, 3D printing, Computational design, Flexible materials.

PRILAGOĐAVANJE DIZAJNA ODEĆE KORIŠĆENJEM RAČUNARSKOG DIZAJNA I TEHNOLOGIJA 3D ŠTAMPANJA: STUDIJA SLUČAJA

APSTRAKT: Uključivanje CAD programiranja u proces dizajna odeće može pružiti višestruke prednosti. Korišćenje računarskog dizajna može automatizovati dizajn odeće i povećati potencijal prilagođavanja. 3D štampa nalazi primenu u mnogim sektorima zbog svoje sposobnosti da proizvede neobične geometrije sa smanjenim troškovima, posebno kada se radi o ograničenom broju proizvoda. Ovaj rad doprinosi automatizaciji dizajna i



VII Međunarodna naučna konferencija
„Savremeni trendovi i inovacije u tekstilnoj industriji“
19-20. septembar 2024. Beograd, Srbija

proizvodnje odevnih predmeta po meri. Predloženi algoritam koristi neke početne dimenzije ljudskog tela kao ulazne podatke i parametariše unapred definisani obrazac odeće. Zatim se generiše skup komandi za proizvodnju (G-kod) kako bi se vodila ka proizvodnji odevnih predmeta uz upotrebu 3D štampača. Studija slučaja je predstavljena na kraju, koristeći fleksibilni materijal za 3D štampanje i uključujući kreirane specijalne konektore.

Ključne reči: Dizajn odeće, Automatizacija dizajna, 3D štampa, Računarski dizajn, Fleksibilni materijali.

1. INTRODUCTION

Computational design is an additional tool that helps designers create innovative geometric forms. The term computational design refers to Computer Aided Design (CAD) based programming in which the designer can implement an algorithm. The algorithm consists of nodes, which represent specific functions that perform various procedures. With the use of nodes, the designer can define various parameters, in order to parameterize the final result obtained [1]. It is crucial to mention that the creation of the algorithm can be done using text and/or visual programming languages. Computational design due to its flexibility and simplicity is used in many fields, such as for the study of the identity of a brand or its description in the development of commercially available products [2]. Another field directly linked to computational design is the wearables industry. In wearable products, the use of algorithmic design is necessary, as in most cases, with an aim to focus on each individual user special characteristics. Some of the areas in which computational design plays an important role in the field of wearable products are the health-based applications [3]. In recent years, industry has adopted the use of computational design in combination with new technologies, such as 3D printing and 3D scanning [4].

In the textile industry, this new and completely different way of designing and manufacturing includes the integration of 3D printing into the entire fabrication process. This significant change in the textile industry, radically update the entire production model. Several studies have addressed the multiple benefits that can arise from the use of 3D printing in cloth manufacturing. Some of the advantages of 3D printing are, the complex structures, the unlimited shapes that can be produced and the optimization of the design itself. At the same time, with the aforementioned fabrication process, the textile waste of traditional processes can be significantly reduced [5, 6]. Materials that can be used in such a process are flexible materials that can be printed using a 3D printer. The most common type of 3D printers that support these flexible materials is the FDM (Fused Deposition Method) technology. In this method, the formable filament is extruded from a heated nozzle. Nozzle movements, extrusion speed and other printer settings determine the final printed result [7]. In many studies, tests of 3D printed garments have been carried out aiming in their future commercial use. More specifically, the cost and time required to create a garment is investigated. Furthermore, in some cases, the garment is made entirely



by a 3D printer, while in others the garment uses a combination of the traditional method and 3D printed parts. Through experimentation and testing, technical problems and design changes are underlined in order to be shorted out. The outcomes of these processes can be a series of components for mass production in the fashion industry [8].

The primary feature of 3D-printed garments is their ability to curve and fold due to their structure. This characteristic is so crucial that garments can be printed from rigid materials. The various structures greatly impact the overall properties of the garment. In several studies, a comparison is made between various structures with an aim to documenting and organizing their characteristics. In the context of creating various prototypes, tensile and bending strength tests have been carried out [9]. Furthermore, through specific questionnaires it emerged that potential users have the appropriate knowledge of 3D printing and at the same time are positive about wearing a 3D printed garment in the future [10]. Another area where 3D printing technology is combined with the textile industry is the design of jewelry products. Cultural fashion elements can be incorporated into existing clothing using 3D printing in certain instances [11]. These items can be worn as standalone accessories or integrated into the main garment. Nevertheless, 3D printing is a manufacturing method with unlimited potential in the clothing industry [12].

The present paper aims in creating an algorithm that automates the process of designing and manufacturing a custom garment via 3D printing technology. More specifically, the algorithm consists of two specific units. It automates the design of the sew pattern in the first unit, using dimensional data from the user, and then in the second part it generates automatically the G-code used in the fabrication of the garment with a 3D printer. The input of the second unit is based on the results acquired from the first one.

2. PROPOSED METHODOLOGY

The proposed research study aims to design and manufacture a custom elastic garment through 3D printing methodology. This particular garment will be able to be manufactured entirely using a 3D printer. The design process is divided into four stages: a) the body dimension measuring, b) the algorithm implementation using a visual programming language, c) the automatic design of geometries based on parameters and d) the garment production using additive manufacturing process. The process starts by taking measurements in key areas of a human body (i.e. bust, waist and waist). In the second stage, an algorithm is developed through visual programming with an aim to automate the initial design steps, using the aforementioned human body's dimensions as input parameters. The third stage involves finalizing the algorithm to generate the sew pattern, which serves as the foundation for the garment design. Any adjustments to the input data will directly impact the shape of the sew pattern. Finally, a new algorithm is implemented in the last stage in order to generate the G-code for prototyping using additive manufacturing. G-code is a text file that describes with coordinates a specific path to be followed by a 3D printer head. According to these stages, an application is completed, which automates the process of designing and manufacturing a custom garment (Figure 1).

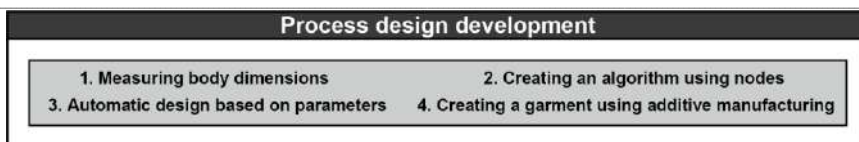


Figure 1: The four steps of the proposed process

2.1. Input, output and processing data

The study aims to create a straightforward garment design process by developing an algorithm that minimizes the amount of information required from the user/customer without compromising the quality of the final result. The measurements from the human body of the user includes the waist circumference, the bust circumference, the shoulder length, and the height between shoulder and waist. The previous data are essentials in order to create a garment design that perfectly complements the user's body. The result of the algorithm is a cloth prototype, which consists of half of the garment. The cloth pattern is developed by vector lines on a two-dimensional plane. The other half of the cloth prototype is symmetrical based on the original one and therefore does not need to be generated by the algorithm. Figure 2 depicts how the application works.

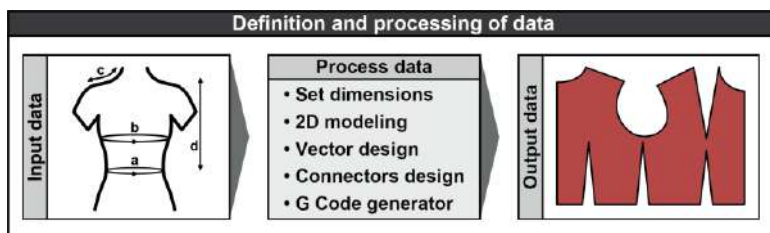


Figure 2: Input, output and processing data

2.2. Algorithm definition and parametrization

The algorithm was developed in Grasshopper3D™, a visual programming language. With the Grasshopper3D™ programming language, various algorithmic nodes are inserted and connected with an aim to produce an appropriate framework. The final result of this process, creates a digital representation of cloth prototype based on CAD data. In figure 3, the image on the left displays the complete code, while on the right are examples of clothing patterns that can be produced by the algorithm.

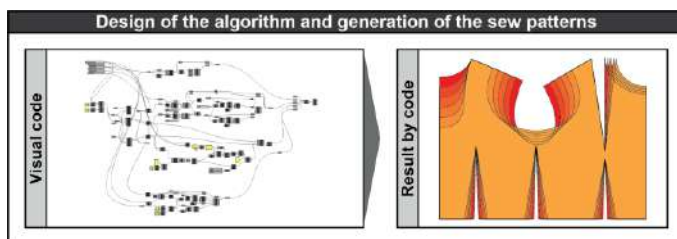


Figure 3: The visual code and the cloth digital prototype

In addition to basic body measurements, the algorithm also requires two neck opening sizes (one in front of the sternum and one behind the back). The specific data directly concern the aesthetic part of the garment as they mainly affect the appearance. Some of the alternative sizes that the garment could support are shown in figure 4. The shape used in the front versus the shape used in the back differs in both size and shape.

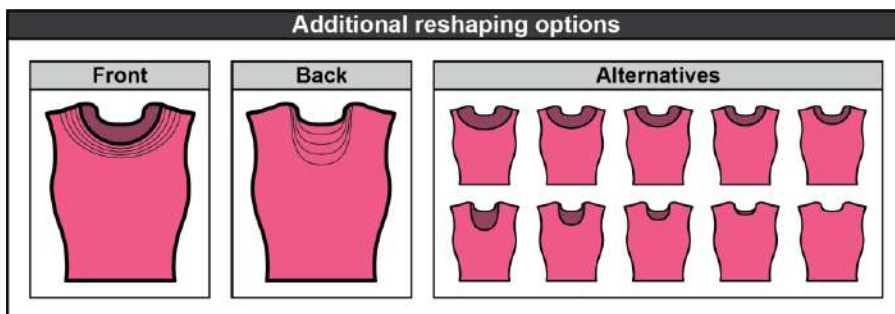


Figure 4: Front and back neck opening area.

Every variable in the algorithm's input is subjected to validation rules, with each dimension bound by a particular value range. The purpose of these constraints is to prevent any potential deadlocks in the code. If the waist circumference number is extremely small, large, or negative, it can cause problematic issues with the algorithm's ability to solve the geometrical constraints.

In figure 5, all input data and their corresponding special numbers are displayed on the cloth prototype (i.e. 1. bust size = 45cm, 2. waist size = 36cm, 3. garment height = 35 cm, 4. front neck size = 14°, 5. back neck size = 7°, 6. shoulders length = 10cm).

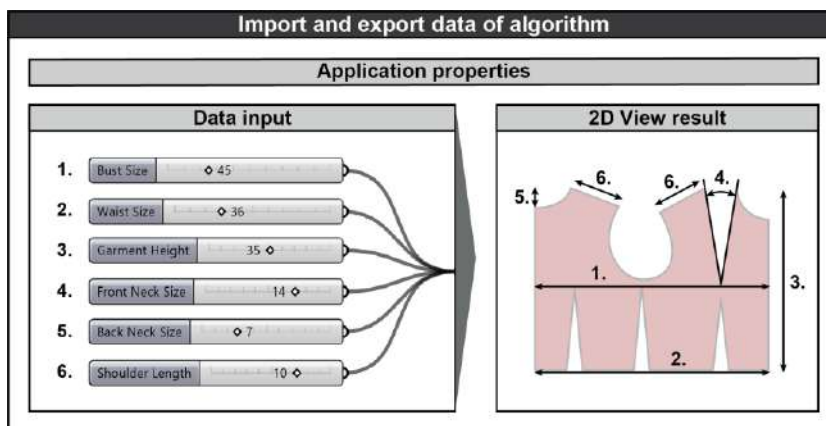


Figure 5: Input data and design parameters

2.3. The assembly process

Prior to manufacture, the garment should be cut into smaller sections. These small sections offer two main benefits compared to a one-piece garment (according to 3D printing part fabrication). One benefit is the option to use smaller printers, like desktop ones, to print garments without needing a large and expensive piece of equipment. Another advantage is the reduced printing time by dividing the garment into sections and printing them simultaneously on multiple printers, thus reducing the overall production time (based on the number of sections). The disadvantage of the segmentation is the need for part assembly at the end.

In this research project, the garment was divided into 8 sections in order to reduce the printing time and minimize the assembly time. These sections were joined using multiple printed links and secured with special holes. Figure 6 depicts the different parts of the garment and how they are connected.

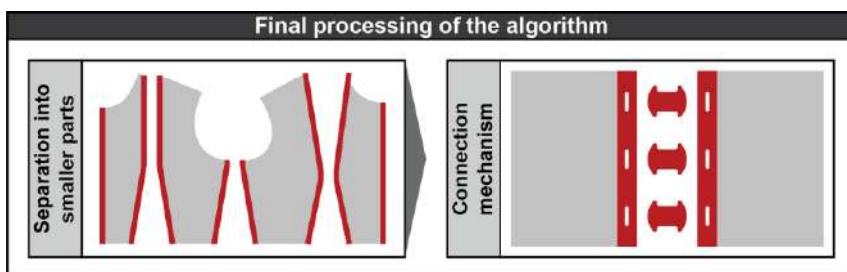


Figure 6: Garment's assembly description

2.4. The G-code generation

The method of additive manufacturing (FDM) was selected for the garment fabrication. 3D printing involves manufacturing objects according to coordinate instructions using a G-code. In the proposed study, an algorithm was used to automate the creation of the G-code in order to manufacture the set of garment's parts. The fabrication code produced was based on the computational design techniques programmed via Grasshopper 3D™. Figure 7 illustrates the algorithm and the result of this procedure.

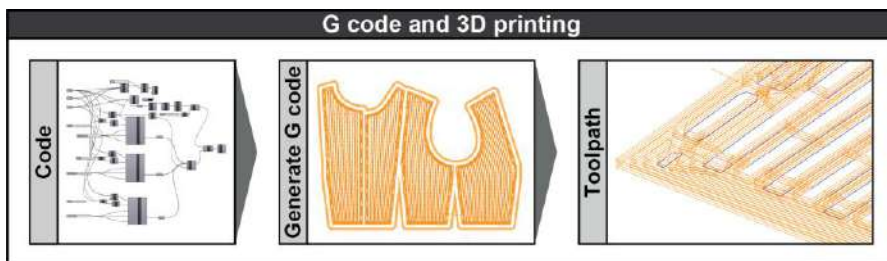


Figure 7: Generating G-code for 3D printing

2.5. Results

This study concluded with the printing of a garment tailored to fit a body's dimensions (burst size = 45cm, waist size = 36cm, garment height = 35 cm, front neck size = 14°, back neck size = 7°, shoulders length = 10cm). The process involved recording the necessary measurements from a human manikin, input the data into the CAD based application to create the sewing pattern, and finally automatically generating the G-code for 3D printing. The garment was printed using the Creatbot™ D600 Pro 3D printer. The material chosen belongs to the category of flexible filaments is and named CREALITY CR-TPU (Thermoplastic Polyurethane). The fit of the 3D printed garment was applied evenly on the body used. Figure 8 presents the process of 3D printing and the final result of the garment on the human manikin.

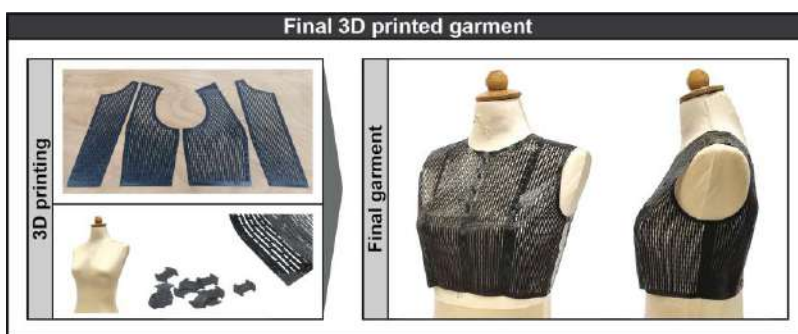


Figure 8: The physical garment prototype

3. CONCLUSION

The study presented an integrated approach to designing and fabricating custom garments using 3D printing technology. An algorithm was developed through computational design to streamline the entire design and fabrication process. The main goal of the study is to create a custom wearable garment that will be fully adapted to the dimensions of its user. More specifically, the user should measure four basic dimensions on his/her body and enter them into the CAD-based application. The application uses an algorithm and automates the design of the cloth pattern. By utilizing a new algorithm designed around a specific pattern, the G-code based fabrication process was automated, ultimately enabling the application to automatically design and fabricate garments based on users' data. The application was then tested with measurements taken from a human manikin before creating a custom garment using the generated G-Code. The algorithm successfully handled the input of various data. The final garment fit well on the human manikin in terms of size and shape. For future development, it is expected to incorporate more data related to the garment's aesthetic aspects and thus offering more options for different knitting types. This could enhance the user experience. Additionally, real-time 3D photorealistic rendering of the garment could be implemented for users to preview.



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EVALUATION OF SOME PHYSICAL PROPERTIES OF NEW DEVELOPED “SAXCELL” BLENDED WOVEN FABRICS

Original scientific paper
DOI:10.5937/CT_ITI24004C

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ABSTRACT: As consumer demands increase, environmental concerns also inevitably arise. Within the textile production chain, each processing step has its own environmentally harmful impact on nature. Every fiber, yarn bobbin, meter of fabric, chemical used, consumer lifecycle of each textile item, and recycling or waste stage of every T-shirt leaves its own footprint. Conventional natural fiber types such as cotton, wool, silk, and linen have their own environmental footprint related to their cultivation, processing steps, and consumer use. Similarly, traditional synthetic-based man-made fiber types have their own footprint in terms of raw material sourcing and degradation time in nature. Recycling in the textile industry holds paramount importance in the global pursuit of sustainability. Cellulose based recycled fibers have been preferred by the consumers lately as they provide sustainable products with high comfort and satisfying mechanical properties. There are different recycling methods currently discussed in various forums namely as “mechanical, thermo-mechanical and chemical recycling. SaXcell is a new cellulose based recycled fiber made from used cotton textiles. In the eco-friendly SaXcell process, the used cotton textiles are dissolved in a closed loop system where the water and chemicals used are chemically recycled during the process. The pulp obtained from SaXcell process is converted into fibers by lyocell wet spinning. Utilizing SaXcell based products are believed to be contributing to textile industry with a sustainable and circular production manner. This study has been performed in order to perform a comparative study for woven fabrics produced from new developed “SaXcell” yarns varying in different blend ratios in terms of some mechanical properties such as tensile strength, tear strength, seam slippage. As the results are satisfying, this study may encourage the producers and the consumers for utilizing of new developed ‘SaXcell’ fibre with different fibre blends which may create alternative sustainable textile products.



Keywords: SaXcell, sustainability, chemically recycling process, woven fabric.

PROCENA NEKIH FIZIČKIH SVOJSTVA NOVIH RAZVIJENIH „SAKSCCELL“ MEŠANIH TKANINA

APSTRAKT: Kako potražnja potrošača raste, neizbežno se javlja i zabrinutost za životnu sredinu. U okviru lanca proizvodnje tekstila, svaki korak obrade ima svoj ekološki štetan uticaj na prirodu. Svako vlakno, kalem od prediva, metar tkanine, upotrebljena hemikalija, životni vek potrošača svakog tekstilnog predmeta i faza recikliranja ili otpada svake majice ostavljaju svoj trag. Konvencionalni tipovi prirodnih vlakana kao što su pamuk, vuna, svila i lan imaju svoj ekološki otisak koji se odnosi na njihovu kultivaciju, korake obrade i upotrebu potrošača. Slično tome, tradicionalni tipovi veštačkih vlakana na bazi sintetike imaju svoj otisak u pogledu izvora sirovina i vremena degradacije u prirodi. Reciklaža u tekstilnoj industriji ima izuzetan značaj u globalnoj potrazi za održivošću. Reciklirana vlakna na bazi celuloze su u poslednje vreme preferirana od strane potrošača jer obezbeđuju održive proizvode sa visokim komforom i zadovoljavajućim mehaničkim svojstvima. Postoje različite metode reciklaže o kojima se trenutno raspravlja na različitim forumima, naime „mehanička, termo-mehanička i hemijska reciklaža. SaKscell je novo reciklirano vlakno na bazi celuloze napravljeno od korišćenog pamučnog tekstila. U ekološki prihvatljivom SaKscell procesu, korišćeni pamučni tekstili se rastvaraju u sistemu zatvorene petlje gde se voda i hemikalije koje se koriste hemijski recikliraju tokom procesa. Pulpa dobijena SaKscell procesom se pretvara u vlakna mokrim pređenjem liocela. Veruje se da korišćenje proizvoda zasnovanih na SaKscell-u doprinosi tekstilnoj industriji na način održive i kružne proizvodnje. Ova studija je sprovedena da bi se izvršila uporedna studija za tkane tkanine proizvedene od novorazvijenih „SaKscell“ prediva koje variraju u različitim odnosima mešanja u pogledu nekih mehaničkih svojstava kao što su zatezna čvrstoća, čvrstoća na kidanje, klizanje šava. Kako su rezultati zadovoljavajući, ova studija može podstaći proizvođače i potrošače da koriste novo razvijena 'SaKscell' vlakna sa različitim mešavinama vlakana koja mogu stvoriti alternativne održive tekstilne proizvode.

Ključne reči: SaKscell, održivost, proces hemijske reciklaže, tkana tkanina.

1. INTRODUCTION

The need for textile recycling is driven by a convergence of challenges: climate change, biodiversity decline, population growth, and a surge in waste volumes (partly due to improved living standards in various countries). Heightened awareness of these issues, coupled with concerns over raw material production and the consumption of textile products, is fostering a new wave of consumers prioritizing sustainable goods. Numerous textile brands, retailers, and manufacturers have begun incorporating sustainability



VII International Scientific Conference
„**Contemporary trends and innovations in the textile industry**“
19-20th September, 2024, Belgrade, Serbia

principles into their products and supply chains over recent years. The textile sector stands as one of the largest industries globally, impacting both people and the environment at various stages, spanning from production to disposal. Cotton has been used for many years in many different regions of the world. It is a strategic fibre owing to its wide usage leading to high employment opportunities in textile sector. Fabric production and usage are significant contributors to negative environmental impacts. They have a substantial effect on the environment, leading to a reduction in cotton cultivation and the use of water, farmland, fertilizers, and pesticides on a large scale. Extending the lifespan of cotton products helps promote a cleaner, healthier world. Regarding raw material usage, the textile industry consumed approximately 118 million tons in 2021, with 24 million tons being cotton and 80 million tons being plastic-based. Projections suggest this figure will rise to 144 million tons by 2030, propelled by population expansion, improving living standards in developing nations, and the ongoing surge of fast fashion and ultra-fast fashion. The escalating utilization of synthetic materials in textiles directly correlates with an estimated 9% annual influx of microplastics into oceans [1-4].

Textile manufacturers need to find a way to transform their business models towards a more sustainable future by reducing the requirement for virgin raw material. This can be succeeded by considering recycled textile materials with the closed loop system. There are many different recycling methods being applied to re-process the different types of waste materials such as mechanical, thermo-mechanical, chemical recycling. Upstream in textile processing today, the spinner is tasked to produce yarns with recycled materials and is expected to deliver comparable quality. However, the use of mechanically recycled fibers in spinning has specific quality considerations. Such fibers have a higher short-fiber and nep content and may often be colored, particularly if post-consumer material is used. Generally, plastics are broken down into their intermediate products in chemical recycling. This can be carried out down to the polymer or monomer level. Whether the process is based on polymers or monomers, these substances need to be purified for further processing. This is accomplished by filtration or separation processes. The pure polymers or monomers can be further processed in subsequent processes into new raw material, in which the monomers must first be brought back to polymer level. Fibers can then be spun from this raw material. Since the basis is purified polymer or monomer, the newly spun fibers achieve a quality almost comparable to virgin fibers. This is a major advantage of chemical recycling. If selecting chemical recycling, the type of waste is most important. At present, processes that go back to the polymer level are primarily used if the original material is cotton-based or MMCF (man-made cellulose fibers). The cellulose is extracted and a pulping process, as already used in conventional cellulose processes, is applied. Typically, in chemical recycling, plastics are broken down into their intermediate components, which can extend to the polymer or monomer level. Regardless of whether the process focuses on polymers or monomers, these substances require purification for further utilization. This purification is achieved through filtration or separation techniques. The purified polymers or monomers can then undergo subsequent processes to transform into new raw materials, with monomers needing to be reverted to polymer level initially. From this refined raw material, fibers can be spun. Given that the foundation is purified

polymer or monomer, the resulting fibers exhibit a quality nearly akin to virgin fibers, presenting a significant advantage of chemical recycling. When opting for chemical recycling, the nature of the waste material holds paramount importance. Presently, processes reverting to the polymer level are predominantly utilized when the original material is cotton-based or MMCF (man-made cellulose fibers). In such cases, cellulose is extracted, and a pulping process, akin to conventional cellulosic processes, is implemented [4-8].

Today, there are some new considerable efforts for reducing the ecological hazard and waste generated during textile processing or developing sustainable and green materials. One of these promising approaches is to promote the usage of SaXcell fibre in textile products as virgin (100%) or with other blends. SaXcell, an abbreviation of Saxion cellulose, is a regenerated virgin textile fibre made from chemically recycled domestic cotton waste. The process to transfer domestic cotton waste into SaXcell fibre is a crucial step in the circular textile chain. SaXcell production (figure 1, figure 2) starts with sorting domestic cotton textile waste into an as pure as possible, well-defined waste stream. Next, the pure waste stream is grinded and non-textile components like zippers, nails and buttons are removed. The result is a dry mixture of textile fibres with different fibre lengths. All fibre lengths, long and short, are suitable as raw material for SaXcell. The dry mixture exists of different colours and is chemically decoloured and made suitable for the wet spinning process. Wet spinning can be done according Viscose or Lyocell processes. This means that the new fibre can be produced with few adjustments in the settings of machines on existing installations in Europe and Worldwide. The end product of this step is SaXcell, a regenerated virgin cellulose fibre. The fibre can be cut to specified lengths, spun into yarns and woven or knitted into fabrics. Colouring can take place at the fibre, yarn or fabric [9].



Figure 1: Cotton waste utilized for SaXcell fibre



Figure 2: Ecofriendly SaXcell Process [9]

2. MATERIAL

SaXcell blended yarns (50% combed cotton 50% SaxCell) of Ne 10/1 linear yarn density and 100% SaXCell yarns of Ne 30/1 and Ne 40/1 linear yarn density were produced by using the compact yarn production line. New developed compact drum spinning machine was utilized for the yarn production. Yarn quality parameters including coefficient of variation of mass ($CV_m\%$), IPI (total number of thin, thick places and neps amount), hairiness, tensile and elongation values (%) were obtained from Uster Tester 5, Uster Tensorapid 4 by feeding cops of each system in the same order to the testers (Table 1). The tests were carried out under standard atmospheric conditions, and the samples were conditioned a minimum of 24 hours before the tests.

Table 1: Yarn properties of SaXcell fabrics

Yarn code	Yarn linear density	Yarn composition (%)	T/PM	$CV_m\%$	IPI	H	Elongation(%)	RKM (cN/tex)
SL30	Ne 30/1	100% Saxcell	860	11.3	40	4.29	9.2	29.3
SL40	Ne 40/1	100% Saxcell	1045	11.25	62	3.68	8.46	27.36
SL10	Ne 10/1	100% Saxcell	500	7.42	3.5	7.4	8.34	21.39
SLC10	NE 10/1	50% Saxcell 50% cotton	500	7	3	7.5	8.20	21.20

In order to analyse some mechanical properties of fabrics produced from SaXcell and SaXcell blended yarns, six different fabrics from different warp and weft yarn types were woven on ITEMA R9500 model weaving machine. Fabric constructional properties including the fabric weight, number of weft and warp yarns in 1 cm, fabric construction, weaving type were displayed in Table 2.

Table 2: Structural properties of woven fabrics

Fabric codes	Warp and Weft Yarn Composition	Woven type	Fabric weight (g/m ²)	Warp yarn count	Weft yarn count	Warp density (thread/cm)	Weft density (thread/cm)
F1	100% SaXcell	poplin	313	Ne 10/1	Ne 10/1	30	17
F2	100% SaXcell	Twill	167	Ne 30/1	Ne 30/1	30	17
F3	50% SaXcell 50% Cotton	Dobby woven	319	Ne 30/1	Ne 30/1	36	34
F4	50% SaXcell 50% Cotton	poplin	145	Ne 10/1	Ne 10/1	28	17
F5	50% SaXcell 50% Cotton	Twill	131	Ne 40/1	Ne 40/1	40	35
F6	100% SaXcell	poplin	145	Ne 30/1	Ne 30/1	28	17

3. METHOD

After the production of the woven samples, all fabrics were conditioned for 24 h in standard atmospheric conditions (at the temperature of $20\pm 2^{\circ}\text{C}$ and relative humidity of $65\pm 2\%$). they were subjected to pilling, abrasion, fabric tenacity in warp and weft direction,

Tensile Strength

The tensile properties of 6 different fabric samples were measured with the Instron testing device according to ISO 13934-2 standard [10].

Tear Strength

Resistance to tearing of textiles is also an important characteristic for the fabrics. When a static load is applied to pre-cracked samples, a tearing area called “del zone” generates which arises from stretching and sequential breakage of yarn groups along the fabric. Tearing continues as the del zone moves forward in the tearing direction with further sliding of longitudinal yarns and stretching of transverse yarns. In order to get the tearing results of samples, Determination of tear force of trouser-shaped test specimens (Single tear method) was applied in warp and weft wise according to ISO 13937-2:2000 [11]

Seam Slippage Strength

Failure of the seams of the garment by breaking of the sewing thread or by seam slippage affects serviceability of the shirting fabrics. Seam strength relates to the force required to



break the stitching thread at the line of stitching. Seam slippage strength of SaXcell blended fabrics were determined according to ISO 13936-1 standard by using Shimadzu tensile tester. For seam strength tests; rectangular specimens of 400 mm length and 100mm width were prepared. 5 specimens (350*100) with their long sides parallel to the weft of the fabric for determining warp seam strength and with their long sides parallel to the warp of the fabric for determining the weft seam strength according to ISO 13936-1: 2004 test standard by using Shimadzu tensile tester. The values of seam strength were recorded as the required load for failure of sewing zone. Test speed was set as 50 mm/min while the jaws' width was adjusted as 100 mm.

4. RESULTS AND DISCUSSION

Tensile strength

Tensile strength results of SaXcell blended fabrics in warp and weft wise are revealed in figure 3. According to figure 3, maximum tensile strength in warp wise was obtained from F3 coded dobby fabrics produced from 50% SaXcell 50% cotton blended yarns of Ne 30/1 linear density while minimum tensile strength was obtained from F5 coded twill fabrics produced from 50% SaXcell 50% cotton blended yarns of Ne 40/1 linear density. When it comes to tensile strength in weft wise, maximum tensile strength was provided from F3 coded fabrics produced from 50%SaXcell 50% cotton blended yarns of Ne 30/1 linear density whereas minimum value was found among F5 coded 2/2 twill fabrics produced from 50% SaXcell 50% cotton blended yarns of Ne 40/1 linear density.

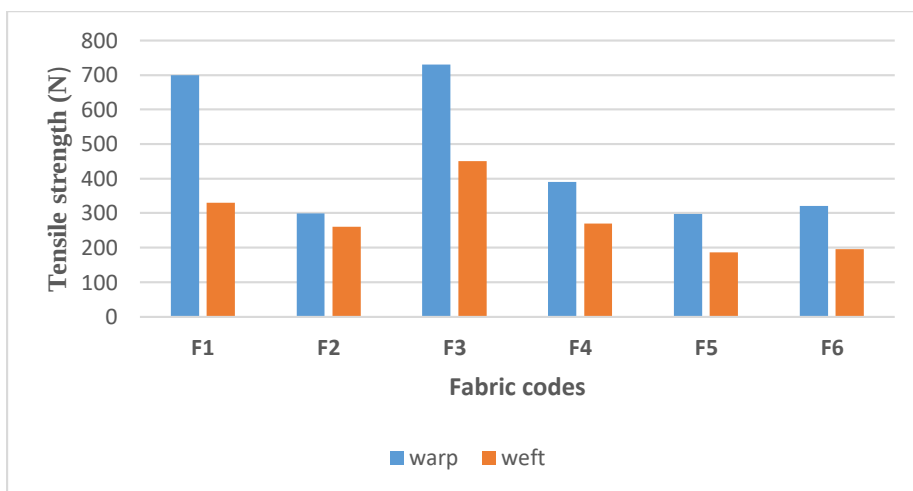


Figure 3: Tensile strength results

Tear Strength Results

Tear strength results of SaXcell blended fabrics are indicated below in Figure 4. According to Figure 4, maximum tear strength in warp wise was obtained from F3 coded dobby woven fabrics produced from 50 % SaXcell 50 % cotton blended yarns of Ne 30/1 linear density while minimum tear strength was found among F6 coded poplin fabrics produced from 100% SaXcell yarns of Ne 30/1 linear density. When it comes to tear strength in weft wise, maximum tear strength was obtained from F3 coded dobby wovens while minimum value was observed among F6 coded poplin fabrics produced from 100% SaXcell yarns of Ne 30/1 linear density. As a general evaluation, maximum tear strength results in warp and weft wise were retrieved from 50% SaXcell -50 % cotton dobby woven fabrics.

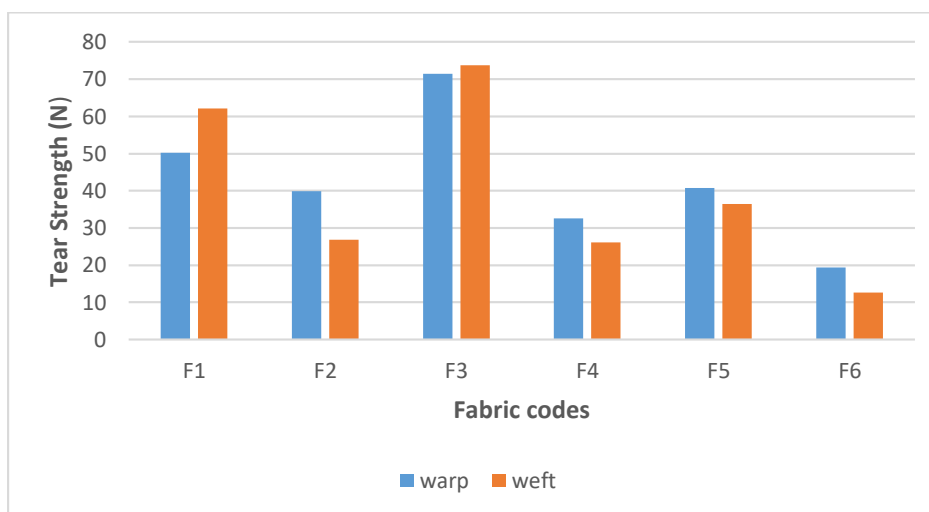


Figure 4: Tear strength results

Seam Slippage Strength

Figure 5 indicates seam slippage results of SaXcell blended fabrics. According to figure 5, maximum seam slippage strength in weft wise was obtained from F1 coded 100 % SaXcell poplin fabrics produced from Ne 10/1 SaXcell yarns while minimum value was observed among F2 coded 100 % SaXcell twill fabrics produced from Ne 30/1 SaXcell yarns. When it comes to seam slippage strength in warp wise, F2 coded 100 % SaXcell twill fabrics produced from Ne 30/1 SaXcell yarns provided highest seam slippage strength value while minimum value was obtained from F5 coded 2/2 twill fabrics produced from 50% SaXcell 50% cotton yarn of Ne 40/1 linear density. As a general evaluation the seam slippage strength results of SaXcell fabrics were found above the required value although there were some variations depending on the woven type and yarn linear density of the fabrics.



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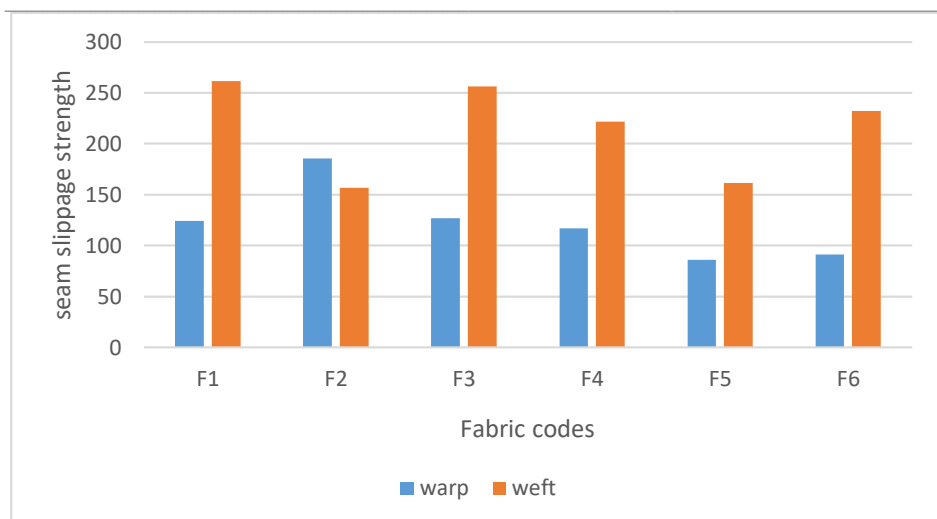


Figure 5: Seam slippage strength results of Saxcell fabrics

5. CONCLUSION

Rising consumer demands and growing environmental awareness have led to increased calls for sustainable textile materials. The intricate life cycle of textile products presents numerous potential environmental impacts within the framework of sustainability. While cotton fiber remains the favored primary material for textiles worldwide, it is imperative to minimize chemical residues throughout the entire production process, from cotton cultivation to the end products, in a sustainable manner.

SaXcell has been a new attempt for textile recycle process in a closed loop system with the sustainable manner. As the tensile, tear and seam slippage strength of woven fabrics produced from SaXcell have been satisfying this study may encourage the textile yarn producers for utilizing SaXcell in their yarn blends for a more sustainable textile production.

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IMPLEMENTATION OF SDGS IN THE TEXTILE SECTOR IN ALBANIA FOR A SUSTAINABLE, GREEN AND COMPETITIVE SECTOR IN THE REGION

Original scientific paper
DOI: 10.5937/CT_ITI24005S

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ABSTRACT: Textile and apparel sector of Albania has a long tradition as one of the most important industries contributing to Albania's GDP and it has made good results in exports, investments, and employment. 72 per cent of enterprises in the sector are owned by Albanians, while only 8 per cent have joint ownership of Albanian and foreign investors. The jointly owned enterprises are the only ones that increased in number, by 13.7 per cent from 2020 to 2021, despite the declining trend in the total number of enterprises within the past two years. Most manufacturing enterprises in garment and footwear manufacturing sector cannot purchase raw materials from suppliers or design the products. Some of the enterprises make efforts in upgrading their business model but this is still very limited. Some survey findings indicate that this sector has many unexploited opportunities that would add more value to the production chain. As the sector is heavily reliant on orders from the Italian market, contract providers have almost full control of pricing, margins, timing, and sales. The CMT business model leaves little room for sourcing locally produced inputs that might further stimulate the local economy. The changes made to the Corporate Fiber & Materials Benchmark survey this year means Textile Exchange can now more closely monitor and report SDG progress. With 169 targets to be met by 2030, and over 232 indicators for measuring progress at country-level, the Global Goals were designed to stimulate positive outcomes for people, planet, prosperity, peace and partnerships.

Keywords: Manufacturing business model, Sustainable Development Goals, Value added, digitalization, green solutions.

IMPLEMENTACIJA SDGS-a U TEKSTILNOM SEKTORU U ALBANIJI ZA ODRŽIVI, ZELENI I KONKURENTNI SEKTOR U REGIONU

APSTRAKT: Sektor tekstila i odeće u Albaniji ima dugu tradiciju kao jedna od najvažnijih industrija koja doprinosi albanskom BDP-u i postigao je dobre rezultate u izvozu,

Union of engineers and textile technicians of Serbia



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investicijama i zapošljavanju. 72 odsto preduzeća u sektoru su u vlasništvu Albanaca, dok samo 8 odsto ima zajedničko vlasništvo albanskih i stranih investitora. Zajednička preduzeća su jedina koja su se povećala u broju, za 13,7 odsto od 2020. do 2021. godine, uprkos trendu smanjenja ukupnog broja preduzeća u poslednje dve godine. Većina proizvodnih preduzeća u sektoru proizvodnje odeće i obuće ne može da kupuje sirovine od dobavljača niti da dizajnira proizvode. Neka od preduzeća ulažu napore da unaprede svoj poslovni model, ali je to još uvek veoma ograničeno. Neki nalazi istraživanja pokazuju da ovaj sektor ima mnogo neiskorišćenih mogućnosti koje bi dodale više vrednosti proizvodnom lancu. Pošto se sektor u velikoj meri oslanja na narudžbine sa italijanskog tržišta, dobavljači ugovora imaju skoro potpunu kontrolu nad cenama, maržama, vremenom i prodajom. CMT poslovni model ostavlja malo prostora za nabavku lokalno proizvedenih inputa koji bi mogli dodatno stimulisati lokalnu ekonomiju. Promene napravljene u anketi o korporativnim vlaknima i materijalima ove godine znače da Tekstile Ekchange sada može pažljivije da prati i izveštava o napretku SDG-a. Sa 169 ciljeva koje treba ispuniti do 2030. godine i preko 232 indikatora za merenje napretka na nivou zemlje, Globalni ciljevi su dizajnirani da stimulišu pozitivne rezultate za ljude, planetu, prosperitet, mir i partnerstva.

Ključne reči: Poslovni model proizvodnje, ciljevi održivog razvoja, dodata vrednost, digitalizacija, zelena rešenja.

1. OVERVIEW OF THE CURRENT SITUATION OF TEXTILE SECTOR IN ALBANIA

Textile and apparel sector of the country has a long tradition and is one of the most important industries contributing to Albania's GDP. It has made good results in exports, investments, and employment; attracting investments. Albania belongs to the most price competitive countries among the European textile industries. Production is mainly based on cut-make-trim (CMT) basis. Materials are imported, and only the labor work is done and finished garments are re-exported. Coupled with its geographic advantages, Albania's low cost and skilled labor force is being put to optimum utilization for processing business. Albania is dedicated to foreign markets especially the EU [1].

In July 2022, the value of total exports was EUR 334,049,839, increasing by 23.0% compared with the same period of the previous year, and decreasing by 14.3% compared with June 2022. Within that annual increase of 23.0%, a positive contribution was made by the group, "Textile and footwear," adding 6.6 percentage points. Total exports during the first seven months of 2022 increased by 40.1% as compared with the same period of the previous year, where the group "textiles and footwear" held the 3rd place with 6.9%. The TCLF sector in Albania is characterized as labor-intensive. These type of enterprises are located all over the country and apply a diverse array of business models. The export of textiles and footwear, which constitute important shares of Albania's foreign trade, respectively, continued to recover during the first five months of 2022, accounting for 27% of the volume of exports [2].



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What is unsustainable in the textile, clothing, and leather and footwear industry in Albania? - In recent years, Albania's economic performance benefited from reform progress and some large investments in infrastructure and renewable energy. However, despite a robust average Gross Domestic Product (GDP) growth of 3.4 % between 2015 and 2018 [2], the economy remains highly vulnerable to foreign demand shocks and natural hazards. Albania suffered two shocks with devastating consequences: The earthquake in November 2019 and the COVID-19 pandemic in spring 2020, which affected the economy. Currently, the Albanian economy is trying to mitigate the high inflationary trends resulting from the War in Ukraine [1].

Strengths of the industry

Textile industry of the country has stabilized with its simplified corporate tax codes, and VAT. Market environment of Albania has become positive over a period of time. The country remains as the last continental European market for high skills and low cost; labor intensive production. Key focus of Albanian textile industry is high quality, low costs, rapid response, and full package services of contract manufacturing.

Textile and apparel sector in Albania is ideally placed for short lead time, small production runs responding quickly to changing fashion trends. Albania is located in close proximity to the most important European fashion centers that enhances its manufacturing options.

Main reasons of doing business in Albania are as follows [3]:

- Optimistic investment climate
- Competitive sector with sustainability
- Medium to high end productivity
- Competitive taxation and incentives policy
- Proximity to EU countries – geographic location
- Free economic zones
- Macroeconomic stability
- A very active and representing industry association
- Qualitative academic and professional education covering the sector.

Sustainable Development Goals in Textile Sector in Albania

The SDGs are a global call to action to end poverty, protect the earth's environment and climate, and ensure that people everywhere can enjoy peace and prosperity. Through a Sustainable Development Cooperation Framework with the Government of Albania, the UN fully supports and works towards the complementary agendas of Albania's Goal of accession to the European Union (EU), national priorities, as well as harmonization and aid effectiveness. This includes Albania's commitment to achieving the SDGs. [4]

Albania's baseline report underscores that the national strategic policy framework is most harmonized with the SDG targets in SDG 3 (good health and well-being); SDG 7 (affordable and Clean Energy); SDG 8 (good jobs and economic growth); and SDG 9 (industry, innovation and infrastructure), while the least harmonization is with SDG 14 (life below water).

Albania as part of the Western Balkans – Investments opportunities

For Albania foreign direct investment (FDI) is a top priority. Albania has special state



agency (AIDA – Albanian Investment and Development Agency) focused on attracting FDI [5].

Looking at the trends for each of the WB economies, one can note that in Albania inward FDI has been stable during the period 2010-2019.

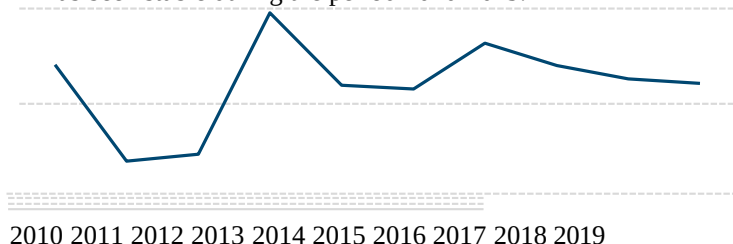


Figure 1: Inward FDI trend, 2010 - 2019

Looking at the four European countries where most FDI in the Western Balkans originates (the Netherlands, Switzerland, Austria and Germany), one can note that the Western Balkan economies take up a minor share of their total outward FDI (Table 1). For the Netherlands, Switzerland and Germany, the share of outward FDI that goes to the WB is less than 1%. Only for Austria is the share of WB FDI more significant at 4.8%. Since the WB economies are relatively smaller than other CESEE countries, their share in FDI originated in other countries is relatively smaller [5].

Table 1: Outward FDI to WB countries from four European countries

	Total outward FDI (EUR million)	FDI in the WB (EUR million)	FDI in the WB (% of total)
Netherlands	572,066	3,991	0.7%
Switzerland	479,529	3,858	0.8%
Austria	72,827	3,483	4.8%
Germany	705,169	2,499	0.4%

2. METHODOLOGY

To obtain a clearer view of the actual situation of the sector, production capacity, technology condition, financing needs of the sector to remain competitive and for a future growth and sustainability a survey of manufacturing enterprises was designed and released to 180 manufacturing enterprises, all members of ProExport Albania. The survey focused in particular on the economic growth, Sector, innovation, and infrastructure, Responsible production and consumption, and the ESG criteria in order to identify gaps with regard to productivity, human resources, equipment, technology, digitalization, and lean manufacturing, with the ultimate objective of working together towards ensuring financing



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opportunities, higher performance of enterprise managerial staff, higher skilled labour force, technology upgrade according to the real needs of the sector for a more decent working conditions, better workplace cooperation, increased productivity, increased employment, and energy efficiency.

A total of 151 enterprises responded.

The size of enterprises and their placement in the supply chain are expected to correlate positively with working conditions, innovation, application of international production standards, together with updating lean manufacturing, resource efficiency and cleaner production, intention towards the circular economy or their will and readiness to start working towards such goals. This purposeful sample size represents about 22% per cent of the textile, clothing, leather and footwear enterprises employing 10 or more workers, and approximately 84% per cent of the ProExport Albania members, the only association of the textile and garment enterprises in Albania. Enterprises that participated in the survey are 70 per cent in production of textile and garment and 30 per cent in production of leather, footwear or other category.

The sampling is random and purposefully, so it can represent in a good scale the situation and needs of the sector.

Survey results and findings

According to collected data on the number and distribution of the companies in country, from a total of 700 enterprises, 65% of the companies are in the textile and garment sector with about 36,400 employees. The companies in the textile sector are partly certified with ISO 9001 - OHSAS 18001 with a percentage of about 35% of the active enterprises in the sector.

35% of the companies are in the footwear sector with about 19,600 employees. The companies in footwear sector are partly certified with ISO 9001 - OHSAS 18001 with a percentage of about 15% of the 245 enterprises active in the sector.

The clothing and footwear manufacturing sector has over 740 active factories and enterprises, large, medium and small in the country and over 75,000 employees. For 2022, this industry provided about 40 percent of the country's exports with a value of over 950 million Euros.

These enterprises operate under one of the following business models or production modality:

- make only: sewing only.
- cut only: cutting process only.
- cut, make and trim: manufacturers cut the fabric, make the clothes according to the design, and trim while the designs and raw materials are provided by the customer.
- full cycle: design is included.
- own collection: own brand and private label.

Enterprise Information - The distribution of enterprises participating in the survey correlates with the geographic distribution of enterprises in the country, as shown by the national official data. The production destinations of the invited Textile, Clothing, Leather and Footwear (TCLF) enterprises to answer the survey are the following:

- Italy 61%
- Germany 21%
- Greece, Austria, Hungary, Belgium, Netherlands etc. 18%.

The majority of enterprises operate in premises hired; 38% in owned premises and only 1% use contracts for exploiting the property.

Around 56% of the enterprises are well established in the market with an activity in the sector of longer than 10 years. Only 6% are new in the market with 1-2 years of activity, the majority are old.

27 enterprises are owned by females and 70 enterprises owned by males; 79% of the enterprises have Albanian ownership; 15% foreign ownership and only 6% are in a joint ownership. 90% of the employed working force in the sector according to the survey are females.

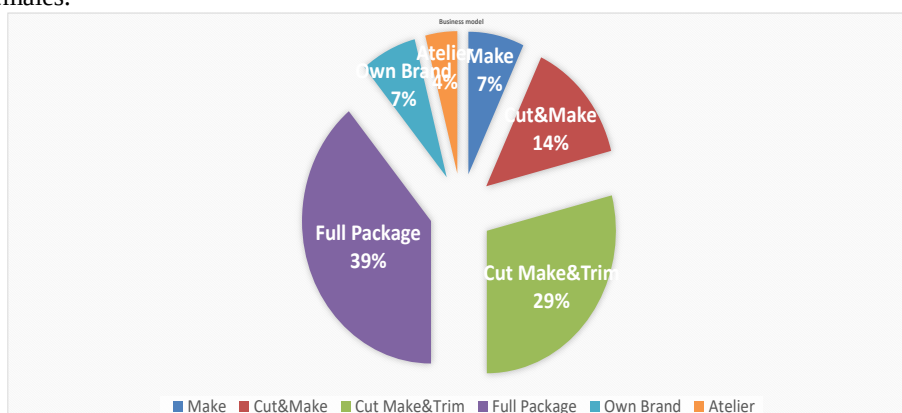


Figure 2: Business model applied by TCLF companies in country

Machinery, equipment - The most purchased or invested machinery and equipment in the sector with 97% is owned by the enterprises and only 3% is owned by the subcontractor; 71% of the equipment and machinery is purchased by the owner with its own capital; 13% purchased by the owner through bank loans and is all paid; 16% of Albanian owners have purchased machinery with loans which have not been paid yet. About the age of machinery 4% have very new or recently purchased machinery; 81% new or normal; 11% old and 4% have not invested in machinery and equipment operating with very old one. The transformation of the production processes by supporting the purchase of innovative industrial machinery by increasing the depreciation index from the current rate of 20% to 40%. In this way the tax burden will be smoother for the enterprises and they will have more liquidity. 52% of enterprises own their own.



The lack of employees is often referred by the enterprises as one of the main actual issues of the sector. Some of the enterprises have started considering hiring of foreign workers. Ten enterprises have responded they have hired foreign workers.

Products and production - About the typology of production 70% of the enterprises operate in garment manufacturing subsector, 22% in the footwear subsector, and 8% respond in other typology of products such as textiles, home textiles, technical textiles etc. 30% of the enterprises, according to the survey, have 2 years active contracts with their clients, 17% of them 3 years contracts, 2% and 36% respectively 6 months and 1 year contracts. 15% of the enterprises do not specify the length of agreements they have with the clients.

About the production destination, 78 enterprise work only for export; 1 for home market only, 8 enterprise work for they own brand; 15 only as subcontractors; 19 export and subcontracting; 3 enterprises work for export and home market. We can see here that many enterprises want to remain in the subcontracting working model to save the security of their contracts which in the sector are middle and long term.

72% of the enterprises produce outwear (fashion); 24% of them produce footwear, 1% protective clothing, bags for packaging; 2% underwear, 1% paper bags and garments (outwear).

The main products or services for the home market are: medical clothes, work wear, sportswear, footwear, finishing and dying for jeans products, stamping.

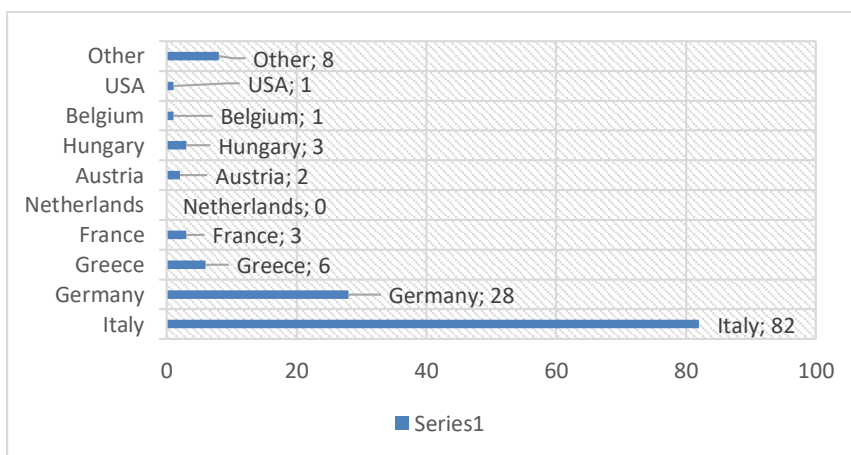


Figure 3: Export destination



Raw materials import - For the purchase/import of the raw materials, About 70% of the market is Italy and Germany. 50% purchase it in Italy; 9% in Germany, 3% in Greece, 3% in China, 2% in Hungary, 1% in Pakistan, 3% in Albania and 3% do not specify the import country for the raw material.

Export and destination diversification - About 50% of the companies are planning to expand their export markets. These markets are preferably in the Western Europe. Meanwhile 42% enterprises are planning to diversify their products portfolio.

Skills needed from enterprises - The most preferred time for the required training is after the official working hours for 53% of them; 33% answer during the lunch break; 11% before the official work start and only 3% do not specify. Lack of the labor force is the major and most common problem that enterprises face.

95% of the companies answer that the lack of labor force is a big problem for them; the high raw material prices is the main issue for 30% enterprises; high price of the electricity is the main problem for 60 % of the enterprises, 30% of the enterprises see impossible the access to the financing tools; lack of government support is the main problem for 65% of the enterprises, excessive customs procedure is the problem for 10 of the enterprises participating in the survey.

Businesses operating in the TCLF sector through ProExport association have request from the Albanian government a fast line for the incoming foreign employees (from Nepali, India). Currently the work permit last 90 days as Labor Office procedure, in many cases even longer forcing enterprises reapplying with increased cost and loss of time.

The needed skills and training plans mostly needed are: technical skills for 66% of the enterprises; 44% of enterprises need more technical, practical and technological skills; 45% of them need skills and training plans for some specific operations and processes; 25% of the enterprises need more practical skills for graphical and design, CAD/CAM.

The owner or administrators of the enterprises need trainings in some specific issues such as: 63% enterprises on how to be more competitive in the international markets; 54% of the enterprises on how to find and increase the financial support of the sector; 35% on how to increase the visibility of the sector; 39% of enterprises administrators need more trainings on how to increase and consolidate the role of the business association; 36% on how to diversify the production; 50% enterprise administrators on how to increase the efficiency of production; 34% enterprise need more training on the importance of the financial data management and access.



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Table 1: Survey findings for TCLF manufacturing enterprises and recommendations [6]

Categories of survey questions	Main findings of survey in telegram style:	Recommendations
General information	Majority of enterprises in the TCLF sector in the country are 10 - 30 years old	
	64% of enterprises work for 1-5 foreign suppliers: 12% for more than 10 foreign suppliers	Production diversification
	46% of enterprises have full package operations and own their brand business model	Add value to the production chain
SDG8 – Sustainable economic growth; decent work for all	93% of enterprises have made significant investments in technology; and 86% still have plans for further investment	High value-added services
	46% of enterprises have an interest in finding new suppliers and new sources of raw materials	Production and export diversification
	The enterprises report labor shortages within the following occupations: sewing operators, textile engineers, pattern making specialists, machine maintenance technicians, production managers, quality control specialists, and graphic designers.	Better human resource management Better working conditions and higher wages Updated training curricula (VET Centers)
SDG9 – Resilient infrastructure; sustainable industrialization; foster innovation	70% of enterprises completely rely on suppliers for pattern design, technical specifications, production cards	Increase competition with more technological investment; offer higher value-added services; increase competitiveness through innovation
	32% of enterprises source raw materials; 42% have acclimatization standards for the	Foster a more resilient infrastructure through value added



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	storage of raw materials; only 30% of them need or perform testing of raw materials; 59.3% have the capacity to make technical specifications and production cards themselves	processes towards material sourcing
	The main destination of the products of the enterprises is Italy with (40%); followed by the EU single market (unspecified 28%), Germany (16%), Greece (4%), the UK (4%), China (4%), and domestic distribution (4%)	Decrease reliance on the suppliers alone and diversify client base
	25% of enterprises have no training plans for employees and 7% prefer to hire trained employees	Enhance advanced training programs relevant to the TCLF sector
	11% of responding enterprises complete quality control only at the end-of-line; 37% both end-of-line and middle-of-the-line – Around 50% do not complete any form of quality control	Provide ad hoc advanced training to the enterprises on “Quality Improvement”; “Lean Manufacturing”; and “Resource Efficiency” Introduce and improve KPIs
	46% of enterprises have no information on the lifespan of their products	Provide ad hoc advanced training to the enterprises on Resource Efficiency
SDG12 – Sustainable production and consumption patterns	35.7% of enterprises separately collect or recycle waste: Of those, 69% apply textile collection for recycling; 42% paper; 35% plastic; 15% leather; 23% electronics and batteries; and 8% oil	Waste management plans; separation and recycling
	Only 2 enterprises use organic materials; 18% use recycled materials; 53% unsure (it depends on the supplier); only 50% carry out material consumption analysis	
	71% of enterprises do not monitor their water, material, or carbon footprints	Increase cooperation between enterprises and foreign clients



3. CONCLUSIONS

Albanian manufacturers need to switch their competitive advantage from low-value added services that generate only low income for employees in the sector towards full cycle, guaranteeing quality jobs, better working conditions, including occupational safety and health workplaces. Albania's competitive advantage could be quality and design. Albania could stand out on quality performance, elaborating with design, offering customized or on-demand ready-to-wear goods for customers in the middle and high-segment of the value chain [7].

The common challenges for scaling-up an efficient use of resources that have the highest potential to act against the desired developments are a lack of awareness and a lack of finance.

Unsustainable production and consumption is the common thread between the triple-faceted planetary crisis of climate change, nature loss, and pollution. Therefore, all efforts must be made to transform the textile value chain towards sustainability and circularity, where it should act as a crucial lever for an overall transformation to a circular economy.

Tools for the Implementation and Monitoring of the action plan for the SDGs in the sector are:

- **Zero Draft Roadmap for the TCLF Sector** with the cooperation of all stakeholders in country Best practices in the developed countries going from linear to circular production, where materials are not discarded after use, but instead recycled or used in other ways so that the waste is kept to a minimum. New business models are currently being explored, often based on a radical redefinition of what the term 'fashion' constitutes.
- **Key EU actions** for circular and sustainable product design to reduce products' environmental impact [8].
- By making sustainability the core of a business strategy, **the concept of eco-innovation** can support small and medium-sized enterprises to become more resilient. Thinking from a life cycle perspective means considering all phases of the product life cycle, from extraction of raw materials through material processing, manufacturing, distribution, use, repair and maintenance to disposal or re-use [9].
- **Actions for reaching sustainable products**



Figure 4: Added value from eco-innovation - an overview of the business drivers

- **Sustaining Competitive and Responsible Enterprises (SCORE)** - The ILO is assisting government agencies, training providers, business associations and trade unions in about 20 countries to offer SCORE Training to SMEs.
- **Resource Efficiency and Cleaner Production (RECP)** - The methodology assumes the following core interventions:
 - Training and coaching of experts and enterprises staff on efficient use of resources.

The skills obtained by national experts allow them to conduct RECP assessments in clothing and footwear enterprises, with a deep understanding of the RECP principles, practices, and method, to improve resource efficiency, reduce environmental impacts, and save costs to the enterprises.

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ANALYSIS OF SAFETY CLIMATE FACTORS IN TEXTILE INDUSTRY

Original scientific paper
DOI:10.5937/CT_ITI24006M

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ABSTRACT: This paper presents the results of the analysis of the impact of the main safety climate elements on the overall occupational safety in textile companies in the Republic of Serbia. SEM (Structural Equation Modeling) methodology was applied to validate and test the proposed conceptual model of safety climate. A statistical analysis was performed using the software package SPSS 18.0 and Smart PLS 4. The previously developed model with seven hypotheses was tested on a sample of 267 respondents employed in 8 companies. The results of the empirical research confirm some of the hypotheses and point to the existence of a positive correlation between them. Within the conclusions of the research, special emphasis is placed on those safety climate factors where certain possibilities for improvement have been established and which represent the specificity of textile industry. Finally, the obtained results point to the significant fact that the formation of an adequate safety climate in textile companies can have a positive effect on the improvement of overall occupational safety in this sector.

Keywords: Safety climate, occupational safety, textile industry, employees, analysis.

ANALIZA FAKTORA KLIME BEZBEDNOSTI U TEKSTILNOJ INDUSTRIJI

APSTRACT: U ovom radu su prikazani rezultati analize uticaja glavnih elemenata klime bezbednosti na sveukupnu bezbednost na radu u tekstilnim kompanijama u Republici Srbiji. Za validaciju i testiranje predloženog konceptualnog modela klime bezbednosti primenjena je SEM (Structural Equation Modeling) metodologija. Statistička obrada podataka je izvršena korišćenjem softverskih paketa SPSS 18.0 i Smart PLS 4. Prethodno razvijeni model sa sedam hipoteza je testiran na uzorku od 267 ispitanika angažovanih u 8 kompanija. Rezultati empirijskog istraživanja potvrđuju neke od postavljenih hipoteza i ukazuju na postojanje pozitivne korelacije među njima. U okviru zaključaka istraživanja, poseban akcenat je na onim faktorima klime bezbednosti kod kojih su ustanovljene



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određene mogućnosti poboljšanja i koji predstavljaju specifičnost tekstilne industrije. Konačno, dobijeni rezultati ukazuju na značajnu činjenicu da formiranje adekvatne klime bezbednosti u tekstilnim kompanijama može pozitivno uticati na unapređenje sveukupne bezbednosti na radu u ovom sektoru.

Ključne reči: Bezbednosna klima, zaštita na radu, tekstilna industrija, zaposleni, analiza.

1. INTRODUCTION

The measurement, analysis, and assessment of occupational safety in many manufacturing companies rely on classic indicators, such as the occurrence of occupational injuries, providing significant feedback on the occupational safety system, its shortcomings, and the incidents themselves. This way of occupational safety assessment in companies represents a reactive approach to managing it considering events and results that have already occurred [1]. On the other hand, a proactive approach to occupational safety management is increasingly being used in practice, which involves assessing, describing, and improving the safety climate. Safety climate can be defined as the perception of employees, their attitudes and beliefs about the organization, rules, procedures, and practices of occupational safety [2,3]. Using a proactive approach to occupational safety management enables the identification of all potential deficiencies in the organization's safety system. The purpose of identifying these deficiencies is to analyze them and provide guidelines for positive changes, thus reducing the probability of the occurrence of workplace injuries [4]. Additionally, safety climate reflects the safety policy implemented by a company and thus has a direct impact on the safety behavior of employees and the improvement of the safety performance of the entire company [5]. Therefore, it can be said that the company's management has a significant role in creating and maintaining a positive safety climate, which represents the key to improving safety performance within the organization [6,7]. In this direction, in the first step, it is necessary to identify the key factors of the safety climate with shortcomings. In the second step, it is indispensable to identify individuals or groups in the organization that influence these factors in order to improve the safety climate and occupational safety performance [8]. Consequently, it is possible to create adequate strategies and undertake actual activities with the aim of improving occupational safety performance.

At the global level, along with agriculture, the textile industry is one of the largest industrial fields. An extremely large number of the world's population is employed in the textile industry because it is a labor-intensive activity. The labor-intensive nature of the textile industry causes the existence of a large number of workplaces with a relatively high risk of employee injury [9,10]. Research has shown that in the textile industry, the most complex sector of industrial production, the factors of the working environment: ergonomics, microclimate, lighting, noise, vibrations, radiation, factors arising from the operation of machines, and the effect of electric current, chemical, and biologically active reagents, directly affect the health and safety of employees [11]. Moreover, there are some



additional causes that negatively affect the safety of employees in the textile industry, the relatively low average salary of employees in the industry being one of them. Low salaries cause inadequate job satisfaction and create inadequate enthusiasm, which unfortunately reflects on non-compliance with the rules and procedures for safe performance of work activities [12]. In addition, the awareness of the importance of occupational safety is at a very low level, and the cause of this is the low level of education of workers. Finally, there are regions in the world, primarily in the Asian continent, where managers in companies in the textile industry do not show the necessary dedication to the safety of employees at the workplace. All this in synergy causes the textile industry globally to be among the industries with the highest rates of accidents and injuries at workplaces [13]. This branch of industry is often considered „female” [14], taking into account the fact that in some areas of production as much as 70% of the employees are women, leading to the appearance of numerous occupational diseases and injuries of women as a sensitive group of the population due to inadequate working conditions [11].

Having the aforementioned reasons in mind, a large number of researchers have studied safety and health in the textile industry, the costs of investments in safety and health, as well as risk analysis in companies and workplaces [9-13,15]. However, a very small or almost negligible number of researchers have studied safety climate in the textile industry. That was the main incentive for the research conducted and presented in the present paper. Therefore, the aim of the conducted research on textile companies on the territory of the Republic of Serbia was to analyze the factors of safety climate at work. The results of the research represent a model of safety climate at work, which enables the identification of weaknesses and deficiencies of certain factors of safety climate in the textile industry. In this way, the proposed and tested model becomes a useful tool in the direction of improving the safety climate, and consequently improving the occupational safety performance.

2. RESEARCH HYPOTHESES AND CONCEPTUAL MODEL

The results presented in this paper represent a continuation of previous research by the authors of this paper. Namely, the research hypotheses and conceptual model were defined in and borrowed from the paper by Milijić et al. [1]. In the previous research, the modeling of safety climate in manufacturing companies was conducted, and as the model is universal, in the continuation of the research it was used in the process of analyzing safety climate factors in the textile industry.

The conducted research is based on the following seven hypotheses:

Hypothesis H1: *Safety awareness and competencies positively affect occupational safety.*

Hypothesis H2: *Communication about safety has a positive impact on occupational safety.*

Hypothesis H3: *The organizational environment has a positive effect on occupational safety.*

Hypothesis H4: *Management support has a positive effect on occupational safety.*

Hypothesis H5: *Risk judgment has a positive effect on occupational safety.*

Hypothesis H6: Safety precautions have a positive impact on occupational safety.

Hypothesis H7: Safety training has a positive impact on occupational safety.

Each research hypothesis refers to one factor of safety climate, and based on them, a conceptual model of positive influences in the field of safety climate was formed (Fig. 1).

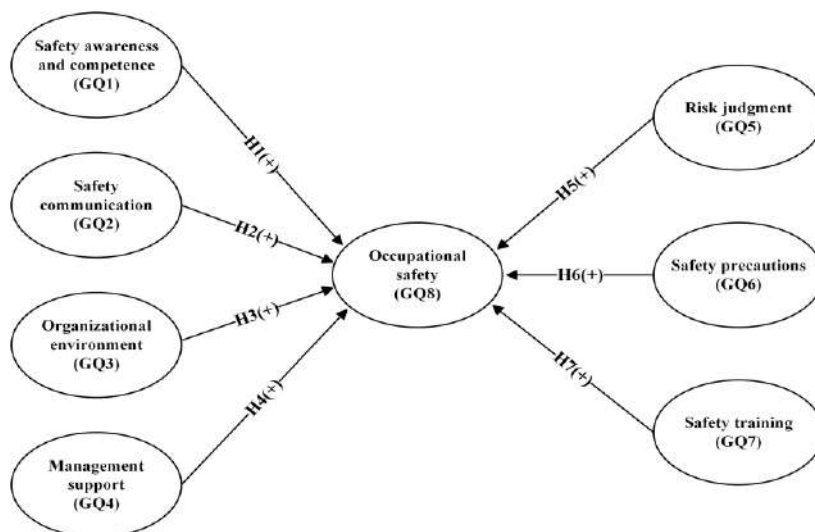


Figure 1: Conceptual model of safety climate

3. RESEARCH METHODOLOGY

The questionnaire methodology for data collection was applied in the conducted research. The questionnaire was developed by some of the authors of this paper during previous research on the issue of safety climate in manufacturing companies [1]. Its application is universal, regardless of the field of production engaged in by the companies in which the employee survey is conducted. The questionnaire consists of two parts. The first part contains 6 questions of a demographic character, as well as 2 questions related to describing the company. In this research, the question related to the company's activity was omitted, because all the companies in which the research was conducted belong to the textile industry. The second part of the questionnaire consists of 23 questions divided into 8 groups, which are related to the area of safety climate.

3.1. Sampling and Data Collection

An anonymous survey was conducted among employees of 8 textile companies operating in the territory of the Republic of Serbia. A total of 316 employees were surveyed, of which 267 correctly filled the collected questionnaires, representing 84.49%. A five-point Likert



scale was used to grade respondents' answers, with values from 1 to 5, where 1 represents the least importance (absolutely disagree with the given statement) and 5 represents the greatest importance (absolutely agree with the given statement), and with intermediate evaluation levels rated 2, 3 and 4. The ratio of the sample size (267 respondents) to the number of questions (23 questions from the questionnaire) is 11.61, which is significantly higher than the recommended minimum level of 5, according to Hair et al. [16]. Hence, an adequate sample size was provided for quality statistical data processing.

The demographic characteristics of the participants in the conducted survey are shown in Table 1.

Table 1: Demographic characteristics of the studied sample

Variables	Category	N	Percentage %
Size of company	Less than 50 employees	24	9.0
	51 – 100 employees	44	16.5
	101 – 300 employees	199	74.5
	Above 301 employees	0	0
Position in the company	Production workers	225	84.3
	Workers indirectly related to production	17	6.4
	Administrative workers	15	5.6
	Managers	10	3.7
Educational level	Elementary school	43	16.1
	High school	206	77.2
	Higher education	10	3.7
	University	8	3.0
Years of work experience	Less than 5 years	104	39.0
	6 – 15 years	79	29.6
	16 – 25 years	69	25.8
	Above 26 years	15	5.6
Gender	Male	42	15.7
	Female	225	84.3
Age	Less than 29 years	35	13.1
	30 – 44 years	131	49.1
	45 – 54 years	85	31.8
	Above 55 years	16	6.0
Accident involvements	Yes	32	12.0
	No accident	235	88.0



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All respondents are employed in small and medium-sized companies. The largest number of respondents are production workers, 225 of them, or 84.3%. On the other hand, only 10 managers were surveyed, i.e. 3.7% of the total number of respondents. In observing the level of education of the respondents, it is completely in line with the workplaces in which they are employed. Namely, the largest number of respondents have graduated from high school, 206 of them, or 77.2%. On the other hand, only 8 respondents have a university degree, which is 3.0% of the total number of respondents. Observing the work experience of the respondents, it can be concluded that the employees do not have too much work experience, because 104 of them, or 39%, have work experience of less than 5 years. Considering the gender structure of the respondents, the specificity of the textile industry is observed, i.e. that the female workforce dominates. In the studied sample, 225 respondents are female, i.e. 84.3% of the total number. This is a far higher percentage of the female workforce compared to other industries, where the share of the female workforce is less, or far less than 50% [1,17,18]. As for the age structure of the respondents, the largest number of them are in the age group of 30-44 years, 131 of them, or 49.1%. There are 35, or 13.1%, under the age of 29, while there are 16 of the most experienced workers, workers over 55, or only 6.0% of the total number. These indicators suggest a relatively young workforce in the textile industry in the Republic of Serbia. Finally, observing the number of employees who experienced some kind of workplace injury, 32 of them, that is, only 12.0%, are in this category.

This result can be characterized as satisfactory in comparison with other industries in the territory of the Republic of Serbia [1,17,18].

4. RESEARCH RESULTS

The set of collected data was analyzed with statistical tools using the SPSS 18.0 software package. Structural modeling was performed using Smart PLS 4 software.

4.1. Descriptive Statistics

As the first step in data processing, descriptive statistics of the examined sample were performed (Table 2). Descriptive statistics summarize the sample and describe the collected data. Table 2 shows standard statistical parameters: sample size, range, mean, standard deviation and variance [19].

Table 2: Descriptive statistics of the studied sample

Mark (Variable)	N	Range	Mean		Std. Deviation	Variance
			Statistic	Std. Error		
Q 1.1.	267	3	4.52	.045	.727	.529
Q 1.2.	267	4	4.45	.051	.827	.684
Q 1.3.	267	4	4.33	.050	.821	.674
Q 1.4.	267	3	4.36	.051	.826	.682



Q 1.5.	267	3	4.34	.050	.809	.655
Q 2.1.	267	4	3.64	.067	1.092	1.192
Q 2.2.	267	4	3.88	.065	1.061	1.126
Q 2.3.	267	4	3.66	.061	1.004	1.007
Q 2.4.	267	4	3.98	.066	1.078	1.161
Q 3.1.	267	4	2.99	.092	1.502	2.256
Q 3.2.	267	4	3.12	.096	1.571	2.467
Q 3.3.	267	4	3.09	.101	1.644	2.702
Q 4.1.	267	4	4.34	.066	1.080	1.167
Q 4.2.	267	4	3.54	.098	1.604	2.573
Q 5.1.	267	4	2.58	.100	1.630	2.658
Q 5.2.	267	4	2.25	.085	1.391	1.935
Q 5.3.	267	4	2.61	.090	1.476	2.178
Q 6.1.	267	4	3.94	.068	1.104	1.219
Q 6.2.	267	4	4.05	.060	.987	.975
Q 7.1.	267	4	3.79	.090	1.469	2.159
Q 7.2.	267	4	3.82	.084	1.366	1.865
Q 8.1.	267	4	2.06	.066	1.083	1.174
Q 8.2.	267	4	1.87	.061	.998	.997

4.2. The Reliability Analysis of the Safety Indicators

The quality of the statistical data processing, that is, the obtained results, is guaranteed by determining the reliability and validity of the measurement scales. Reliability and validity of the measurement scales on the studied sample were performed by evaluating the internal consistency of the data collection instrument using the Cronbach alpha test [20]. Cronbach's formula is used to calculate the average values of the correlations between the items of the measuring instrument (alpha coefficient) when the answers to the questions are rated based on the levels of the given scales (e.g. a five-point Likert scale).

Based on the Cronbach alpha coefficients of the internal consistency of the question groups within the safety climate questionnaire used (GQ1 - GQ8), its validity and reliability were confirmed. The values of Cronbach alpha coefficients for all 8 groups of questions in the questionnaire are greater than 0.70 (Table 3) and suggest a good possibility of data modeling, as indicated by the reference literature [21].

In other words, the groups of questions are properly formed and the questionnaire reliably measures what it was designed and created for, so reliable results can be expected in the continuation of the analysis.



Table 3: Interconsistency coefficients of the safety climate questionnaire

Groups of questions	Number of Items	Cronbach alpha coefficient
GQ1 (Safety awareness and competence)	5	0.781
GQ2 (Safety communication)	4	0.724
GQ3 (Organizational environment)	3	0.920
GQ4 (Management support)	2	0.737
GQ5 (Risk judgment)	3	0.851
GQ6 (Safety precautions)	2	0.763
GQ7 (Safety training)	2	0.881
GQ8 (Occupational safety)	2	0.858

4.3. Structural Model

Partial least squares structural equation modeling (PLS-SEM) was utilized to statistically validate the final model of safety climate in the textile industry. Using the Smart PLS 4 software package, structural equations were created, i.e. the connections between safety climate factors and the achievement of satisfactory occupational safety performance were analyzed.

PLS-SEM analysis is very reliable in cases where smaller samples are used in data analysis, which is also the case in the conducted research where the sample size is 267 [22]. Additionally, PLS-SEM is widely used because of its ability to simultaneously show the relationships between all latent variables while dealing with measurement errors in the structural model. Also, it is characterized by exceptional prediction accuracy, especially in very complex situations and complex models. Furthermore, PLS-SEM is very flexible because it is based on fewer assumptions about the data distribution [23,24]. Finally, the PLS method focuses on maximizing the variance of the dependent variable explained by the independent variable instead of constructing a covariance matrix as in the case of standard SEM analysis [25]. For the aforementioned reasons, PLS-SEM was used to test the model and proposed hypotheses.

Figure 2 shows the results of the analysis of the structural model of safety climate in the textile industry. The values of the regression coefficients are shown on the arrows that represent the relationships between the latent variables. These coefficients explain the strength of the connections between dependent and independent variables and refer to the influence of Safety awareness and competence (GQ1), Safety communication (GQ2), Organizational environment (GQ3), Management support (GQ4), Risk judgment (GQ5), Safety precautions (GQ6), and Safety training (GQ7) on the dependent variable Occupational safety (GQ8).

The coefficient of determination (R^2) is shown on the graphic symbol of the dependent variable. It indicates the participation of the explained variability in total, i.e. how much variation of the dependent variable is explained by the predictor variable. In addition to the regression coefficients, the t-test values are shown in brackets.

The Structural model of safety climate is shown at the Figure 2.

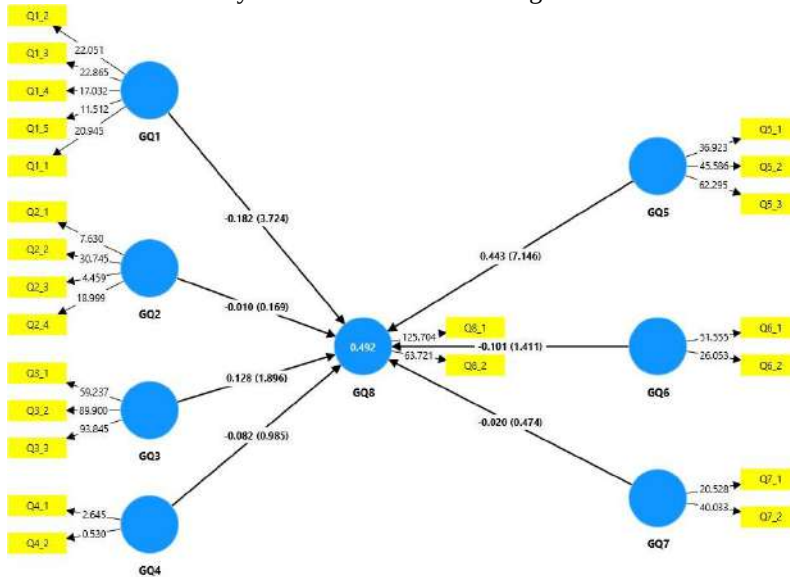


Figure 2: Structural model of safety climate: Path coefficients and T statistics

Table 4 shows the results of structural modeling of the safety climate in companies operating in the textile industry on the territory of the Republic of Serbia.

Table 4: Results of structural model of safety climate

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (O/STDEV)	P Values
Safety awareness and competence -> Occup. safety	-0.182	-0.189	0.049	3.724	0.000
Safety communication -> Occupational safety	-0.010	-0.018	0.061	0.169	0.866
Organizational environment -> Occupational safety	0.128	0.132	0.068	1.896	0.058
Management support -> Occupational safety	-0.082	-0.075	0.083	0.985	0.325
Risk judgment -> Occupational safety	0.443	0.438	0.062	7.146	0.000
Safety precautions -> Occupational safety	-0.101	-0.103	0.071	1.411	0.158
Safety training -> Occupational safety	-0.020	-0.010	0.043	0.474	0.636



5. DISCUSSION OF RESULTS

Based on the results shown in Table 1 and described in Chapter 3, it can be seen that the largest number of production workers participated in the research, 225 of them, i.e. 84.3%. As for education, they mostly have adequate schooling (high school). Moreover, it is a relatively young population because the largest number of them are in the age group of 30-44, 131 of them, or 49.1% of the total number of respondents. The participants of this research do not have too much work experience, as 104 of them, or 39%, have less than 5 years of work experience. This may be a consequence of the large fluctuation of the labor force, as a reflection of the economic transition. Finally, the main specificity of the studied sample, i.e. the entire textile industry, is that it is dominated by the female labor force (225 respondents are female, i.e. 84.3% of the total number). In our previous research on the safety climate on the territory of the Republic of Serbia, the respondents were employed in other industrial sectors (construction industry, metallurgical industry, machine industry, furniture production, etc.), where the percentage share of the female workforce was far less than 50%. in some cases even less than 20% [1,17,18]. Since safety climate represents a set of employees' perceptions related to occupational safety, the gender structure of respondents in the textile industry is very significant in terms of the final results obtained. Hence, the specifics of the results obtained during the study of the safety climate in the textile industry can be interpreted, in relation to the results obtained during previous research in other industrial sectors.

Observing the results of the descriptive statistics of the studied sample (Table 2), it is evident that the mean value of the worst-rated question by the respondents is 1.87, while the mean value of the best-rated question is 4.52. This result suggests a rather different perception and attitude of the respondents in relation to the performance of certain claims. It is also observed that employees have a pronounced negative attitude towards a certain number of questions from particular groups: Risk judgment - GQ5 and Occupational safety - GQ8. On the other hand, employees in the textile industry positively evaluated questions from the following groups: Safety awareness and competence - GQ1, Management support - GQ4 and Safety precautions - GQ6. Such a result is encouraging, since employees have a developed awareness of the importance of occupational safety, as well as trust in management in terms of its support for occupational safety. With this attitude of the employees, the improvement of the safety climate can be expected, as well as the subsequent improvement of occupational safety performance. When observing the high values of the standard deviation in the respondents' answers (values range from 0.727 to 1.644), they indicate a different perception of occupational safety among production and non-production workers, i.e. managers, which is expected.

Based on the results shown in Table 3 (values of Cronbach alpha coefficients for all 8 groups of questions are above the recommended value of 0.7), it can be concluded that there is an internal consistency of the variables within all 8 groups of the control model. Thus it was confirmed that the measuring instrument was valid and reliable, i.e. that it adequately measured what it was created for (safety climate).



The structural model of the safety climate in the textile industry in the Republic of Serbia, with the results of hypothesis testing, is shown in Figure 2. The obtained results show that two of the seven hypotheses were confirmed (H3: *The organizational environment has a positive effect on occupational safety*, and H5: *Risk judgment has a positive effect on occupational safety*). The regression coefficients (path coefficients) have positive values, which means that the independent variables Organizational environment and Risk judgment have a positive influence on the dependent variable Occupational safety. Judging by the results of the t-test, only the H5 hypothesis (*Risk judgment has a positive effect on occupational safety*) is confirmed and acceptable with statistical significance because the value of the t-test is above the recommended value of 1.96 ($t=7.146$; $p<0.000$).

This result points to the conclusion that Risk judgment has a strong influence on Occupational safety (the regression coefficient is 0.443). This indicates that employees in the textile industry properly observe potential risks at their workplaces and treat them adequately (respecting work and safety procedures, using protective equipment, etc.). Such perceptions and attitudes, and consequently also behavior at the workplace, certainly have a great impact on the safety of employees. In other words, a positive impact is thus made on occupational safety performances. Moreover, an adequate Organizational environment has a positive influence on Occupational safety, albeit with a slightly lower statistical significance. This impact is expected because adherence to safety procedures during work operations, as well as an adequate work operations tact, greatly reduce the probability of risk occurrence, i.e., the occurrence of harmful events. This result is in contrast with our previous research (in other industrial sectors), where employees, regardless of the inadequate organizational environment, consciously performed their work activities in a very risky environment [1]. This points to the conclusion that employees in the textile industry, that is, the female workforce, are far more aware of the risks in the workplace, as well as the importance of an adequate working environment compared to the male workforce.

On the other hand, the remaining 5 hypotheses were not confirmed (H1, H2, H4, H6, and H7). This result can also be said to represent the specificity of the textile industry. Namely, based on the responses of employees in the textile industry, Safety awareness and competence, Safety communication, Management support, Safety precautions and Safety training do not have a positive impact on Occupational safety, but even so, the injury rate of employees in this industry is only 12%. which is less compared to other industrial sectors in the Republic of Serbia [1]. This result of the conducted research suggests the conclusion that the state of occupational safety in the textile industry is relatively satisfactory since the respondents actually express their opinion about the elements that could be improved and do not evaluate them as definitely unsatisfactory. Therefore, these elements actually represent a guideline for potential improvements in occupational safety performance.

6. CONCLUSION

The analysis of safety climate factors in the textile industry in the Republic of Serbia underlines revealing conclusions. Occupational safety in the textile industry, as well as in



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other industrial sectors, can be reliably described by 23 questions (variables), classified into 8 groups (latent variables), which represent the proposed conceptual model.

By analyzing the structural model, i.e., by testing the proposed hypotheses, and based on the conceptual model, the final conclusion was made. Organizational environment and Risk judgment have a positive effect on the performance of Occupational safety. On the other hand, Safety awareness and competence, Safety communication, Management support, Safety precautions, and Safety training do not have a positive effect on Occupational safety. Therefore, these factors of safety climate represent the fundamental point of its improvement, i.e. enhancing the performance of the overall occupational safety in textile organizations.

Finally, it can be concluded that the scope of work, as the primary specificity of the textile industry and the accelerated growth and development of modern business conditions, have also placed new demands on the textile industry to take special care of strengthening safety climate through the organization of work, which could raise the awareness of employees to an even higher level, reduce the number of injuries at workplaces, and achieve a higher level of occupational safety performance.

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VII Međunarodna naučna konferencija
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19-20. septembar 2024. Beograd, Srbija



SESSION I
TEXTILES AND TEXTILE TECHNOLOGIES



VII International scientific conference



„Contemporary trends and innovations in the textile industry“

19-20th September, 2024, Belgrade, Serbia



OPTIMISATION OF PROCESSING CONDITIONS OF PECTIN/RED CLOVER EXTRACT NANOEMULSIONS FOR MEDICAL TEXTILE APPLICATIONS¹

Original scientific paper
DOI: 10.5937/CT_ITI240070

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ABSTRACT: Herein we report the generation of pectin(P)/red clover extract (RCE) nanoemulsions (NEs). To that end, P/RCE NEs were prepared employing ultrasonication process (0, 1, 5, and 10 min) both in the absence and presence of a surfactant mixture consisting of 1/3 Span® 80/Tween® 80. Droplet size and Zeta potential data were statistically evaluated. The most significant factor for RCE NEs was determined to be the presence of surfactant mixture. Minimum droplet size (prediction: 51±1 nm) could be achieved by determining ultrasonication time as 5 min by using 1/3 Span® 80/Tween® 80 for aqueous RCE NEs. Addition of the RCE NEs to pectin solutions increased the droplet sizes to a large extent (372-728 nm). The prepared P/RCE NEs could be used to coat any kind of fibrous structure to produce medical textiles for hormonal regulation.

Keywords: Red clover extract, pectin, surfactant, ultrasonication, nano emulsion.

OPTIMIZACIJA USLOVA PRERADE NANOEMULZIJA PEKTIN/CRVENE DETELINE ZA PRIMENE U MEDICINSKOM TEKSTILU

APSTRAKT: Ovdje izveštavamo o stvaranju nanoemulzija (NE) pektin(P)/ekstrakt crvene deteline (RCE). U tom cilju, P/RCE NE su pripremljeni korišćenjem procesa ultrazvučne obrade (0, 1, 5 i 10 min) iu odsustvu iu prisustvu smeše surfaktanta koja se sastoji od 1/3

¹The extended version of this paper has been accepted for publication in *The Journal of The Textile Institute*.



Span® 80/Tween® 80. Veličina kapljice i Podaci o potencijalu Zete su statistički procenjeni. Najznačajniji faktor za RCE NE je utvrđeno da je prisustvo smeše surfaktanata. Minimalna veličina kapljica (predviđanje: 51 ± 1 nm) se može postići određivanjem vremena ultrazvučne obrade kao 5 min korišćenjem 1/3 Span® 80/Tween® 80 za vodene RCE NE. Dodavanje RCE NE u rastvore pektina povećalo je veličinu kapljica u velikoj meri (372-728 nm). Pripremljeni P/RCE NE mogu se koristiti za oblaganje bilo koje vrste vlaknaste strukture za proizvodnju medicinskog tekstila za hormonsku regulaciju.

Ključne reči: ekstrakt crvene deteline, pektin, surfaktant, ultrazvučna obrada, nano emulzija.

1. INTRODUCTION

Emulsion is defined as the dispersion of two immiscible liquids. Here, spherical droplets form the dispersed phase, while the liquid surrounding it forms the continuous phase [15,16]. Water and oil are the commonly used liquids to form emulsions. The oil droplets dispersed in an aqueous phase are called oil-in-water (O/W) emulsions. A third component called emulsifier/surfactant is added to emulsions for both decreasing the droplet size and achieving a long-term stability. Emulsifiers have hydrophilic and hydrophobic parts, which position in the aqueous and oil phase, respectively [1,2], thereby reducing the interfacial tension and hindering/delaying the aggregation of droplets [3].

Based on their droplet size and stability, there are 3 types of emulsions, i.e., coarse emulsions, micro emulsions, and nano emulsions [4] (Table 1). Nowadays, NEs have attracted great attention due to the following advantages: They require less amount of emulsifier for their preparation. They are not affected by physical and chemical variations including temperature and pH [5]. They can encapsulate active ingredients such as herbal extracts/essential oils, endowing them with increased solubility and controlled release properties [6,7].

Herbal extracts/essential oils play a significant and increasingly important role in the food- and health-related fields [8]. However, they require emulsifiers to improve their water insoluble, unstable, and volatile natures. Pectin can act as an emulsifier in nanoemulsions (NEs) due to containing hydrophobic methoxyl and hydrophilic carboxyl groups in its structure [9,10]. Therefore, it can be very interesting to prepare pectin nanoemulsions together with herbal extracts for women's health. Many herbs traditionally used for women's health conditions have been found to contain phyto-estrogens. During the past few decades, red clover (*Trifolium pratense* L.), being a leguminous plant with phyto-estrogenic components, has gained considerable attention.

Red clover contains some important isoflavones such as genistein, daidzein, formononetin, and Biochanin A, which have beneficial effects on prevention of osteoporosis, improved cardiovascular health and lowered risk of diabetes, obesity, neurological disorders and a wide variety of cancers including breast and endometrial cancer [11-16]. It would be interesting and beneficial to generate pectin nanoemulsions together with red clover extract

for medical textile applications. This is the first study, in which pectin/red clover extract nanoemulsions were generated and characterized.

Table 1: Emulsion types: physicochemical properties [17].

	Emulsion/coarse emulsion	Micro emulsion	Nano emulsion
Size	1-100 μm	10-100 nm	<200 nm
Optical property	Turbid	Clear	Clear/slightly opaque
Preparation method	High and low energy	Low energy	High and low energy
Effect of T and pH	Stable	Affected	Stable

2. EXPERIMENTAL PART

2.1. Materials

Pectin, dimethyl sulfoxide (DMSO) (ACS Reagent, > 99.90), Tween® 80, Span® 80, ethyl oleate, and all other chemicals and solvents were purchased from Sigma Aldrich Pty. Ltd, Australia. Red clover extract (RCE) was kindly provided by Linnea SA, Switzerland. Ultrapure (UP) water (conductivity: 0.055 $\mu\text{S}/\text{cm}$) was used in all experiments.

2.2. Preparation of RCE Containing Aqueous and Pectin Nanoemulsions

A total amount of 10 ml coarse emulsions containing RCE was ultrasonicated at 20 kHz, 50% power (400 Watts), 70% pulse for 0, 1, 5, 10, and 20 min. For this purpose, a stepped micro processing tip model of OR-T-156 (diameter: 3.8 mm, length: 25.6 cm) was used. Experiments were designed considering the related literature [18,19]. 50 mg RCE was used in a total volume of 10 ml emulsion. For this purpose, RCE was first dissolved in DMSO and then mixed with ethyl oleate. Afterwards, oily phase containing RCE was added to aqueous phase. In the presence of the surfactant mixture, it was mixed with the aqueous phase previously. Experimental design and related notations were given in Table 2. Stock aqueous RCE NEs were generated and stored in the fridge in aluminium foil wrapped tubes to due RCE's light sensitivity.

Table 2: The notation used for stock aqueous RCE NEs.

Explanation	Notation for Ultrasonication			
	0 min	1 min	5 min	10 min
- surfactant mixture	SR.0	SR.1	SR.5	SR.10
+ surfactant mixture	SRT.0	SRT.1	SRT.5	SRT.10

To generate pectin RCE NEs, pectin solution was prepared first. Pectin (6 wt.%) was added to pre-heated ultrapure water and stirred overnight at 75°C, 1000 rpm. Pectin solutions



were just vortexed after adding stock RCE NEs prepared according to the optimised processing conditions. Notation used for aqueous and pectin RCE NEs is shown in Table 3.

Table 3: The notation used for aqueous and pectin RCE NEs.

Explanation	NE Type	Notation
- surfactant mixture	Aqueous	R.0
		R.5
+ surfactant mixture		RT.0
		RT.5
- surfactant mixture	Pectin	PR.0
		PR.5
+ surfactant mixture		PRT.0
		PRT.5

2.3. pH and Electrical Conductivity of Nanoemulsions

The pH and electrical conductivity of solutions and nanoemulsions were measured using a pH meter (Mettler Toledo SevenEasy pH-Meter) and conductivity meter (TPS, WP-Plus), respectively.

2.4. Dynamic Light Scattering Analysis of Nanoemulsions

Dynamic light scattering (DLS) measurements were performed with the Zetasizer Nano ZS (Malvern Panalytical Ltd, UK).

2.5. Statistical Analysis of DLS Results of Nanoemulsions

The results derived from the Zetasizer Nano ZS measurements were statistically evaluated in Design Expert®6.06 software by using general factorial design. To judge the statistical importance of the variations, ANOVA was applied. Statistical significance was calculated with statistical significance level set at $p \leq 0.05$.

3. CONCLUSION

3.1. pH and Electrical Conductivity of Stock Aqueous RCE NEs

Ultrapure (UP) water has a pH value of 5.53 ± 0.02 . Stock aqueous red clover extract nanoemulsions with and without surfactant mixture showed slightly increased pH values (between 5.71 ± 0.02 and 5.82 ± 0.03). All stock aqueous red clover extract nanoemulsion samples had low electrical conductivity values (13.13 ± 0.21 and 21.00 ± 0.23 $\mu\text{S}/\text{cm}$).

3.2. Statistical Analysis for Zeta Potential of Stock Aqueous RCE NEs

Droplet size and Zeta potential values were statistically analysed for determining the optimum processing conditions. After entering the Zeta potential data to the Design Expert®6.06 software, LINEAR model was selected (Table 4 and Table 5).

Table 4. Sequential model sum of squares for Zeta potential of stock aqueous red clover extract nanoemulsions.

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Mean	11056,52	1	11056,52			
Linear	340,6093	3	113,5364	5,022844	0.0175	Suggested
2FI	71,70234	3	23,90078	1,077983	0.4064	
Quadratic	37,24889	1	37,24889	1,836086	0.2124	Aliased
Cubic	126,3406	4	31,58516	3,513726	0.1255	Aliased
Residual	35,95631	4	8,989079			
Total	11668,38	16	729,2738			

Table 5. Model summary statistics for Zeta potential of stock aqueous red clover extract nanoemulsions.

Source	Std. Dev.	R-Squared	Adjusted	Predicted		
			R-Squared	R-Squared	PRESS	
Linear	4,754368	0,556681	0,445851	0,184144	499,1875	Suggested
2FI	4,70869	0,673869	0,456448	-0,09975	672,8899	
Quadratic	4,504122	0,734747	0,502651	-0,20668	738,3177	Aliased
Cubic	2,998179	0,941234	0,779628	0,36301	389,7474	Aliased

To judge the statistical importance of the variations, Analysis of Variance (ANOVA) was applied (**Table 6**). The model developed explains 55,66% of Zeta potential with these data.

Table 6. ANOVA table for Zeta potential of aqueous red clover extract nanoemulsions.

Source	Sum of Squares	Contribution-%	DF	Mean Square	F Value	Prob > F	
Model	340,6093	55,66808	3	113,5364	5,022844	0.0175	significant
A	165,1225	26,98708	1	165,1225	7,305007	0.0192	significant
B	90,84681	14,84771	1	90,84681	4,019056	0.0681	
C	84,64	13,83329	1	84,64	3,744467	0.0769	
Residual	271,2482	44,33192	12	22,60402			
Cor Total	611,8575	100	15				



The regression contour plots obtained from regression equations are demonstrated in **Figure 1**. Here x-axis represents days and y-axis shows ultrasonication time.

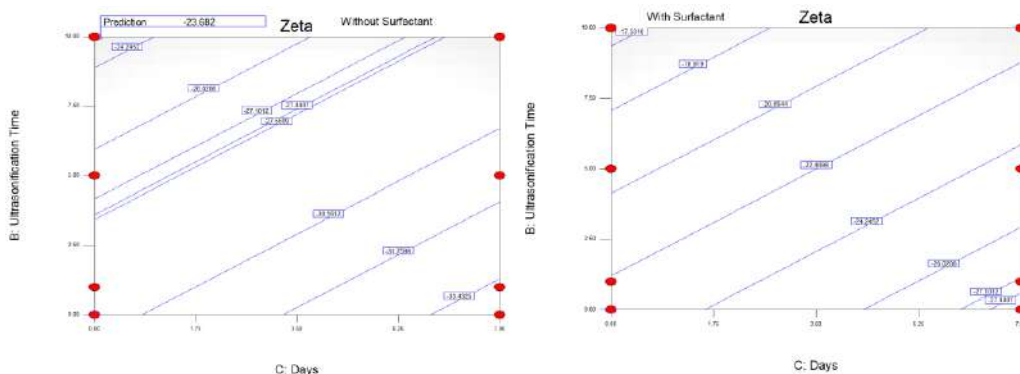


Figure 1. Regression contour plots for Zeta potential of stock aqueous red clover extract nanoemulsions without (left) and with (right) surfactant mixture.

3.3. pH and Electrical Conductivity of Aqueous and Pectin RCE NEs

Aqueous RCE NEs delivered nearly the same pH and electrical conductivity values as the stock aqueous RCE NEs. Usage of pectin solutions decreased the pH values considerably (changing between 3.70 and 3.90), which could be attributed to acidic nature of pectin. Electrical conductivity (EC) values of the pectin RCE NEs were also very high (between 2480 ± 31 - 2589 ± 14 mS cm^{-1}).

3.4. Droplet Size Distribution Aqueous and Pectin RCE NEs

Independent of ultrasonication, red clover extract nanoemulsions (RCE NEs) without containing the surfactant mixture presented the same droplet size of around 250 nm. Addition of surfactant mixture further decreased the droplet sizes to 166 nm in the case of only vortexing. Application of an ultrasonication time of 5 min provided very small sizes of 56 nm.

Addition of the stock RCE NE to pectin solutions increased the droplet sizes to a large extent. Especially the addition of ultrasonicated samples led to bigger droplet sizes in pectin red clover extract nanoemulsions.

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MODIFIED FIBROUS TEXTILE WASTE AS ADSORBENTS FOR REMOVAL OF PHARMACEUTICALS FROM WATER

Original scientific paper
DOI:10.5937/CT_ITI24008V

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ABSTRACT: Textile industry is a significant environmental polluter, generating vast amounts of waste during production, processing, dyeing, and distribution. Disposing of chemical and solid textile waste poses serious risks to soil, water, and air quality. In order to mitigate this inconvenience, solid textile waste can be reused through redesign or recycling methods. One such method involves repurposing textile waste as adsorbent or as a raw material for carbon adsorbent preparation. In this study, fibrous textile waste, waste cotton yarns and flax fibers were utilized as cost-effective resources for carbon material production. Carbon materials were derived from waste fibers and yarns through carbonization and subsequent activation using KOH as an activating agent. The adsorption characteristics of newly prepared materials were examined through the adsorption of various drugs from water. Factors such as contact time, initial concentration, and pH of the drug mixture in an aqueous solution were studied to understand their impact on the adsorption capacity of carbon adsorbents. The obtained results were analyzed using pseudo-first and pseudo-second order kinetics models, Freundlich and Langmuir isotherms. It has been shown that carbon materials obtained by the activation of cotton yarn and flax fibers can be used as highly efficient adsorbents for the rapid removal of drugs from water.

Keywords: cotton yarn, flax fibers, textile waste, adsorption, pharmaceuticals.



ADSORPCIJA LEKOVA IZ VODE PRIMENOM MODIFIKOVANOG VLAKNASTOG TEKSTILNOG OTPADA

APSTRAKT: Tekstilna industrija je jedan od najvećih zagađivača životne sredine zbog ogromnih količina otpada koji se generišu tokom proizvodnje, obrade, bojenja i distribucije. Odlaganje hemijskog i čvrstog tekstilnog otpada nosi ozbiljne rizike po kvalitet zemljišta, vode i vazduha. Da bi se ublažio negativni uticaj tekstilne industrije na životnu sredinu, čvrsti tekstilni otpad se može ponovo upotrebiti korišćenjem metoda redizajniranja ili recikliranja. Jedan od vidova ponovne upotrebe tekstilnog otpada je njegovo korišćenje kao adsorbenta ili sirovine za proizvodnju ugljeničnih adsorbenata. U cilju smanjenja količine vlaknastog tekstilnog otpada, u ovom radu je ispitana mogućnost njegovog korišćenja za dobijanje ugljeničnih adsorbenata. Primenom metoda karbonizacije i naknadne aktivacije u prisustvu KOH kao aktivirajućeg agensa, polazeći od pamučnog prediva i vlakana lana dobijeni su ugljenični materijali. Adsorpcione karakteristike dobijenih materijala ispitivane su adsorpcijom ostataka kardiovaskularnih lekova iz vode. Ispitan je uticaj vremena kontakta, početne koncentracije i početne pH vrednosti smeše lekova na adsorpcioni kapacitet pripremljenih adsorbenata. Dobijeni rezultati su analizirani korišćenjem kinetičkih modela pseudo-prvog i pseudo-drugog reda, kao i Frojndlihove i Lengmirove adsorpcione izoterme. Pokazano je da se karbonizacijom i naknadnom aktivacijom pamučnog prediva i vlakana lana mogu dobiti visoko efikasni adsorbenti za brzo uklanjanje lekova iz vode.

Ključne reči: pamučno predivo, vlakna lana, tekstilni otpad, adsorpcija, lekovi.

1. INTRODUCTION

The textile industry generates vast quantities of waste, much of which ends up in landfills or incinerators, contributing to soil, water, and air pollution. However, recent research has explored innovative approaches to repurpose textile waste, offering potential solutions to both environmental and economic concerns. One promising avenue is the thermal modification of textile waste, particularly through processes like carbonization and chemical activation [1,2]. Carbonization involves subjecting organic materials to high temperatures in an inert atmosphere, resulting in the conversion of these materials into carbonaceous residues. On the other hand, chemical activation involves treating carbonized materials with activating agents to create a porous structure, enhancing their adsorption properties. Cotton yarn and flax fibers, which are part of solid textile waste, are rich in cellulose and lignocellulosic components and exhibit considerable potential for transformation into effective adsorbents through thermal modification processes [3,4]. The resulting carbon-based adsorbents retain the fibrous structure of the original textile waste while offering enhanced surface area and porosity, ideal for adsorption applications [5]. In this work, we focus on the application of cotton and flax fibers-based carbon adsorbents for the purification of water contaminated with pharmaceuticals from the class of cardiovascular (enalapril, cilazapril, metoprolol, clopidogrel). Pharmaceuticals, emerging

as significant contaminants in water sources due to their widespread use and incomplete removal by conventional wastewater treatment processes, pose risks to human health and ecosystems [6]. The utilization of modified fibrous textile waste as adsorbents for pharmaceutical removal offers several advantages. Firstly, it provides a sustainable solution to both the textile waste problem and water contamination, aligning with principles of circular economy and environmental management. Additionally, the fibrous nature of the adsorbents facilitates the filtration of water, allowing efficient removal of different pollutants. Through systematic experimentation, we explore the adsorption capacity, kinetics, and mechanisms of cotton and flax fibers-based carbon adsorbents towards various pharmaceutical compounds commonly found in water sources.

Overall, this paper contributes to the growing body of research on sustainable materials and technologies for water purification, demonstrating the potential of thermally modified fibrous textile waste as an effective adsorbent for the removal of pharmaceuticals from water.

2. MATERIALS AND METHODS

Waste cotton yarn and flax fibers were used as a starting material for obtaining carbon adsorbents in the process of carbonization, followed by chemical activation. Carbonization was performed in an electrical furnace in an inert nitrogen atmosphere at 900 °C, with a heating rate of 5 °C/min. After carbonization, the obtained materials were activated in the presence of KOH, as an activating agent, where the mass ratio of KOH and carbonized material was 1:2. Activation was also performed in an inert nitrogen atmosphere at a temperature of 900 °C, with a heating rate of 5 °C/min. Activated carbon material obtained from cotton yarn was labeled as AcC, while the activated sample obtained from flax fibers was labeled as AcF.

Adsorption experiments were performed in a batch system, with constant mixing (150 rpm). For adsorption efficiency examination, 0.02 g of carbon sample was immersed in 25 cm³ of a mixture of selected pharmaceuticals with an initial concentration of 1 mg/dm³ of each analyte. The influence of the initial pH of the solution on the adsorption efficiency of activated carbon samples was examined by adjusting the initial pH to values of 2, 4, 6, 8, and 10. The influence of contact time was examined by the adsorption of pharmaceuticals from 50 cm³ of solution (2.5 mg/dm³) onto 0.1 g AcC and AcF. At certain time intervals (10, 15, 30, 60, 120, and 180 minutes) samples were taken, and the pharmaceutical concentration was determined by liquid chromatography-tandem mass spectrometry. The experimental data were analyzed using the pseudo-first (Eq. 1) and the pseudo-second order model (Eq. 2):

$$q_t = q_e(1 - e^{-k_1 t}) \quad (1)$$

$$q_t = q_e - \left(\frac{1}{q_e} + k_2 t \right)^{-1} \quad (2)$$

where q_e (mg/g) is the equilibrium adsorbed amount of adsorbate per unit mass of adsorbent, q_t (mg/g) is the amount of adsorbate per unit mass of adsorbent in time t (min), k_1 (1/min), and k_2 (g/(mg min)) are the pseudo-first, and the pseudo-second order rate constants.

The influence of initial adsorbate concentration on adsorption was examined through the adsorption of cardiovascular pharmaceutical (25 cm³, initial concentration of 1.5; 2.5; 3.5, and 5 mg/dm³) onto 0.02 g AcC and AcF. Collected data were fitted with Langmuir (Eq. 3) and Freundlich (Eq. 4) adsorption isotherm:

$$q_e = \frac{Q_0 b C_e}{1 + C_e} \quad (3)$$

$$q_e = K_f C_e^{1/n} \quad (4)$$

where C_e (mg/dm³) is the equilibrium concentration of adsorbate in the solution, Q_0 (mg/g) is the maximum adsorption capacity, b (dm³/mg) is the Langmuir constant, and K_f (mg^{1-1/n}dm^{3/n}g⁻¹) and $1/n$ are empirical Freundlich constants.

3. RESULTS AND DISCUSSION

The pH value of a pharmaceutical solution is a significant factor, which can affect the adsorption efficiency of examined adsorbents. The influence of the initial pH value on the adsorption efficiency of AcF and AcC is given in Figure 1.

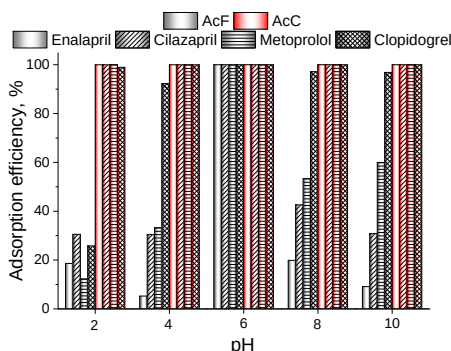


Figure 1: The influence of initial pH value on the adsorption efficiency of AcF and AcC toward cardiovascular drugs

The adsorption efficiency of AcC does not depend on the initial pH value, since this sample completely removed all examined cardiovascular drugs from the water solution. On the other hand, adsorption onto AcF is influenced by initial pH and depends on the polarity of the pharmaceutical; generally the highest adsorption efficiency is obtained for less polar compounds. The highest adsorption efficiency for both samples is observed for an initial pH value of 6, and therefore this value is taken as an optimal pH for the following adsorption experiments.

The influence of contact time on the adsorption capacities of AcC and AcF is shown in Figure 2, along with the fitting of experimental data with pseudo-first and pseudo-second kinetic models. Kinetic parameters obtained by fitting of experimental data with kinetic models are presented in Table 1.

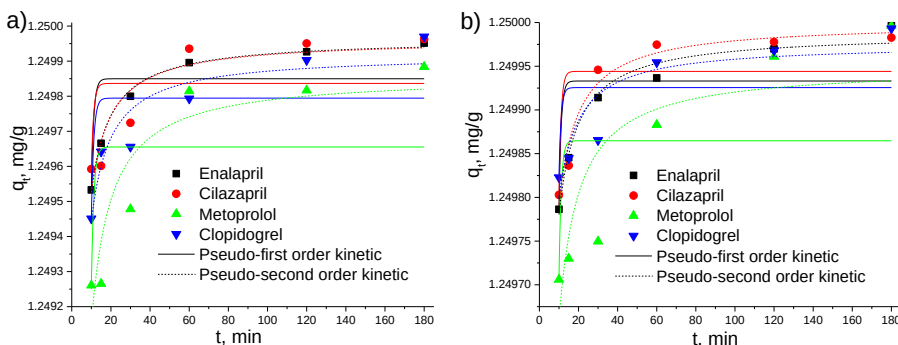


Figure 2: The influence of contact time on adsorption capacities of a) AcF and b) AcC

Table 1: Kinetic parameters for adsorption of cardiovascular drugs onto AcF and AcC

Sample	Analyte	Pseudo-first order			Pseudo-second order			$q_{e,exp}$, mg/g
		$q_{e,cal}$, mg/g	k_1 , 1/min	R^2	$q_{e,cal}$, mg/g	k_2 , g/(mg min)	R^2	
AcF	Enalapril	1.2499	0.8267	0.51888	1.2500	227.3	0.99477	1.2500
	Cilazapril	1.2498	0.8521	0.15617	1.2500	229.3	0.82950	1.2500
	Metoprolol	1.2497	0.8035	0.15089	1.2499	140.7	0.82649	1.2499
	Clopidogrel	1.2498	0.8189	0.42879	1.2499	209.6	0.85390	1.2500
AcC	Enalapril	1.2499	0.9040	0.47312	1.2500	481.6	0.96942	1.2500
	Cilazapril	1.2499	0.9076	0.41363	1.2500	481.1	0.95587	1.2500
	Metoprolol	1.2499	0.8957	0.08645	1.2500	343.2	0.69924	1.2500
	Clopidogrel	1.2499	0.9396	0.17587	1.2500	569.2	0.79681	1.2500

The adsorption capacities of both samples increase with time, with very fast initial adsorption. Already after 10 minutes, the adsorption process reaches equilibrium, and both samples almost completely remove the drugs from the solution. According to the correlation coefficients (R^2) and the equilibrium adsorption capacities calculated by the models used (Table 1), the adsorption of cardiovascular drugs onto AcF and AcC can be described by pseudo-second order kinetic model.

Although adsorption capacity increases with the initial concentration, there is no characteristic plot on the q_e - C_e dependence (Figure 3), which indicates the lack of surface saturation in an examined concentration range, especially in the case of clopidogrel adsorption on both adsorbents.

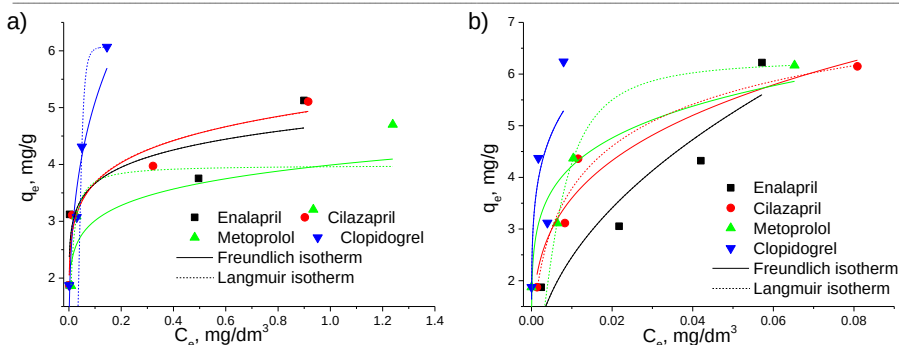


Figure 3: Influence of initial concentration on a) AcF and b) AcC adsorption capacities and fitting of equilibrium data with Langmuir and Freundlich isotherm model

Adsorption equilibrium data were fitted with Langmuir and Freundlich isotherm models and the obtained parameters are summarized in Table 2.

Table 2: Isotherm parameters for adsorption of cardiovascular drugs onto AcF and AcC

Sample	Analyte	Freundlich isotherm			Langmuir isotherm		
		K_f , $\text{mg}^{1-1/n}\text{dm}^3/n\text{g}^{-1}$	$1/n$	R^2	Q_0 , mg/g	b , dm^3/mg	R^2
AcF	Enalapril	4.70	0.108	0.66354	316.75	0.015	0.32670
	Cilazapril	4.99	0.133	0.92789	73.81	0.072	0.85560
	Metoprolol	3.99	0.122	0.51341	3.99	146.8	0.17959
	Clopidogrel	10.06	0.295	0.80297	2340.67	0.004	0.79029
AcC	Enalapril	21.66	0.473	0.81483	3312.12	0.01	0.62929
	Cilazapril	12.23	0.266	0.91694	8.88	8.79	0.88768
	Metoprolol	9.46	0.175	0.84750	6.29	5720.48	0.04571
	Clopidogrel	13.07	0.187	0.50483	1719.64	0.01	0.00933

According to the correlation coefficients (R^2) Freundlich adsorption isotherm better describes the adsorption of cardiovascular drugs onto both adsorbents. The highest maximal adsorption capacities (Q_0) are obtained for the adsorption of clopidogrel on AcF and enalapril on AcC. For both adsorbents, obtained heterogeneity factor ($1/n$) values are close to 0, implying that the surfaces of examined materials are relatively heterogeneous and that the adsorption of selected pharmaceuticals is most likely a chemical process.

3. CONCLUSION

The current study underscores the utilization of fibrous textile waste as a primary material for the production of effective carbon adsorbents. By employing waste flax fibers and cotton yarn and subjecting them to carbonization followed by the activation processes, we successfully developed two highly efficient adsorbents capable of removing cardiovascular

drugs from water. Our findings demonstrate that the adsorption of selected pharmaceuticals onto activated flax fibers is dependent on the initial pH value. Moreover, less polar compounds exhibit a greater affinity towards this adsorbent. Conversely, activated cotton yarn demonstrates consistent and nearly complete removal of selected drugs regardless of the initial pH value of the solution. Furthermore, the adsorption of cardiovascular drugs was observed to be a rapid process, conforming to the pseudo-second order kinetic model, while equilibrium adsorption, can be aptly described by the Freundlich isotherm model. These results conclusively indicate that the waste flax fibers and cotton yarn can be effectively reused for the production of highly efficient carbon adsorbents, facilitating the rapid removal of cardiovascular drugs from water.

ACKNOWLEDGMENTS

This work was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract No. 451-03-65/2024-03/200135, 451-03-66/2024-03/200287 and 451-03-66/2024-03/200017).

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OPTIMIZATION OF COP DIAMETER AT BOTTON RING RAIL STAGE IN RING SPINNING PROCESS USING TAGUCHI METHOD

Original scientific paper
DOI:10.5937/CT_ITI24009T

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ABSTRACT: The ring-spinning process is an important manufacturing process for the mass customization of clothing goods, especially for large-run yarns. Cop quality is one of the most important characteristics concerning ring-spun yarns. It is mainly evaluated and compared via the diameter of a cop. This study aimed to optimize the ring spinning parameters influencing the cop diameter. The optimization of the spinning process was investigated using the Taguchi method. Using the S/N ratio, the best combination of factor levels that yield the highest value of cop diameter was detected efficiently.

Keywords: Taguchi method, optimization, ring spinning, yarn, cop diameter.

OPTIMIZACIJE PREČNIKA NAMOTAJA U DONJEM POLOŽAJU PRSTENA U PROCESU PRESTENESTOJ PREDENJE PO TAGUCHI METODE

APSTRAKT: Prtoces predenja prstena je važan proizvodni process za masovno prilagođavanje odevnih premeta, posebno za prediva velikih serija. Kvalitet namotka je jedna od najvažnijih karakteristika prstenestih prediva. Uglavnom se procenjuje i poredi preko prečnika namotka. Ova studija je imala za cilj optimizaciju parametara u process prstenestoj predenje koji utiču na prečnik namotka. Optimizacija procesa predenja je ispitavana primenom Tagučić metode. Koristeći odnos S/N, efikasno je otkrivena najbolja kombinacija nivoa faktora koja daje najveću vrednost prečnika namotka.

Ključne reči: Tagučić metoda, optimizacija, predivo, dijametar namotka.

1. INTRODUCTION

The commonly used, ring spinning process is one of the oldest process-oriented spinning used for staple spinning. The ring spinning process is quite simple. The roving is the input for the process and passes through a basic, and usually 3 roll, drafting system. After drafting, the fiber is twisted into a yarn structure by a whirling spindle, which has a removable bobbin on it. The staple fiber such as cotton and wool or mixed with synthetic staple fiber has to go through a series of processes until reaching the finished product or the yarn package [1]. Ring spun yarn is made by twisting and thinning the cotton strands to make a very fine, strong, soft rope of fiber. The twist that provides the final entanglement is built up from the outside to the inside. The structure of ring-spun yarn gives final products visual, tactile, aesthetic, and elastic fabric properties suitable for a wide range of end uses [2-4]. Ring-spun yarn are also suitable for functionalization with biopolymer [5,6].

The winding of yarn in ring spinning is complex. The yarn is wound in layers along the length of the trapped plastic bobbin, mounted on the spindle, the action of which is termed „cop building“ [7]. This layering of yarn enables it to be easily unwound without slough-off and with undue tension variations during high-speed yarn rewinding. The point of the lay of yarn on the bobbin is periodically moved up and down by the motion of the ring rail, and after each cycle (one chase), the bottom-most point of yarn lay is shifted upwards a little by means of a step in height of the start position of the ring rail's periodic motion. The wound bobbin or „cop“ has three distinct parts: a lower curved base, a cylinder in the middle, and a conical tip [1]. While forming the base of the cop, the upward shift of the ring rail at the bottom of the chase is kept low, giving a shorter traverse. Since the length of yarn delivered during each traverse stroke is the same, the volume per layer is increased, thereby generating curvature. The average speed of the traverse of the ring rail is slower during its upward stroke than during its downward stroke. The slow traverse of the rail during its upward stroke helps in laying more coils of yarn, i.e. with a short pitch. These coils are called „winding coils“. Since the bobbin is trapped with its diameter reducing from the bottom to the top, the winding rpm must increase from the bottom to the top. This leads to a progressive decrease in the pitch of the coils or an increasing package density from the bottom to the top. To maintain a constant package density, the ring rail is accelerated during its upward motion. For the same reason, the ring rail decelerates during its downward stroke. The yarn coils laid during the downward stroke are „binding coils“ with a long pitch.

The cop size in ring spinning is very much limited both by the size of the ring and by the permissible height. The ring diameter varies from 35 to 52 mm and the lift (length of the bobbin over which yarn is wound or ring rail traverse) from 175 to 205 mm [8]. The ratio of the lift to ring diameter is around 4 to 7.5. Since the yarn tension is inversely proportional to $\sin\alpha$, i.e. R_b/R , reducing the bobbin diameter below the ring radius leads to excessive tension on the yarn and end breaks. The maximum yarn content in the cop is around 60 to 110 g, which necessitates frequent stops on the machine for doffing the package. An increase in package height and diameter above the values indicated would result in



uncontrollable yarn tension and excessive power consumption, as the power to rotate the package is proportional to the ring diameter to the power of 2.75.

Many research works have been conducted on the prediction and evaluation properties of yarns [9,10], while minor ones operated on the optimization of spinning parameters. The purpose of this study is to optimize cop diameter in the ring-spinning process using Taguchi method.

2. EXPERIMENTAL PART

2.1. Materials

Yarns were obtained from a mixture of cotton and polyester fiber. The fiber properties are given in Table 1.

Table 1: Properties of fibers used for yarn producing

Cotton Type	Cotton part in the blend (%)	Linear density (dtex)
Russian I Class	51	1.68
Maklen	49	1.67

2.2. Spinning process

The cotton carded yarn with 15 tex linear density was produced on a ring spinning frame.

2.1. Methods

A cop diameter, d_c , was determined by the direct method by measuring the diameter of each individual coli with a precision ruler.

There are various factors affecting the cop diameter. However, factors that could be controlled easily were chosen in this study. Taguchi analysis was conducted using Minitab software.

Cop diameter was larger-the-best characteristic value and the S/N ratio of each experiment was calculated using Equation 1.

$$S / N = -10 \log \left(\frac{1}{n} \sum_{i=1}^n \frac{1}{y_{ij}^2} \right) \quad (1)$$

where: y_{ij} is j-th characteristic value of i-th experiment and n is the repeat count of y in an experiment

In this study, the cop diameter was chosen for response value y and 9 S/N ratios were calculated using three values of cop diameter.

3. RESULT AND DISCUSSION

Nine groups of combination of coded parameters were performed and the result of the cop diameter is shown in Table 2. The experiments were conducted by following the settings spinning process parameters. Taguchi used the single-to-noise (S/N) ratio to measure the

value of the quality characteristics of choice [11]. S/N is characterized into three categories: normal is the better, smaller is the better, and larger is the better [12].

In this paper, the larger the better characteristic was applied due to the intention to achieve a higher cop diameter. The S/N ratio of the determined cop diameter is shown in Table 2.

Table 2: Parameter code, determined cop diameter, the mean value, and S/N ratio

Exp. No.	Parameter code			Experiment (cop diameter, mm)			y_{exp}	S/N ratio
	Traveler mass (mg) K	Spindle speed (min ⁻¹) L	Doff stage (mm) M	y_1	y_2	y_3		
1	1	1	1	y_{11}	y_{12}	y_{13}	37.8	31.55
2	1	2	2	·	·	·	42.0	32.47
3	1	3	3	·	·	·	37.9	31.57
4	2	1	2	·	·	·	42.3	32.53
5	2	2	3	·	·	·	37.7	31.53
6	2	3	1	·	·	·	36.1	31.15
7	3	1	3	·	·	·	37.2	31.41
8	3	2	1	·	·	·	36.4	31.22
9	3	3	2	y_{91}	y_{92}	y_{93}	40.1	32.07

The optimum conditions for this approach were obtained by sorting the delta in an order of significantly affecting the process (Table 3). The higher the delta value signifies the more effects its parameter contributes.

Table 3: Optimum conditions by utilizing the S/N ratios

	Factors and levels		
	K	L	M
Level 1	31.86	31.83	31.31
Level 2	31.73	31.74	32.35
Level 3	31.57	31.60	31.50
Delta	0.30	0.23	1.04
Rank	2	3	1
Optimum	K1	L1	M2

The highest plots of each parameter were chosen as could be seen in Figure 1, with the reason that the ratio set was the largest the better [13]. The same optimum conditions could be seen in Table 3 by the delta values therefore, the optimum conditions by this approach were as follows: K1L1M2.

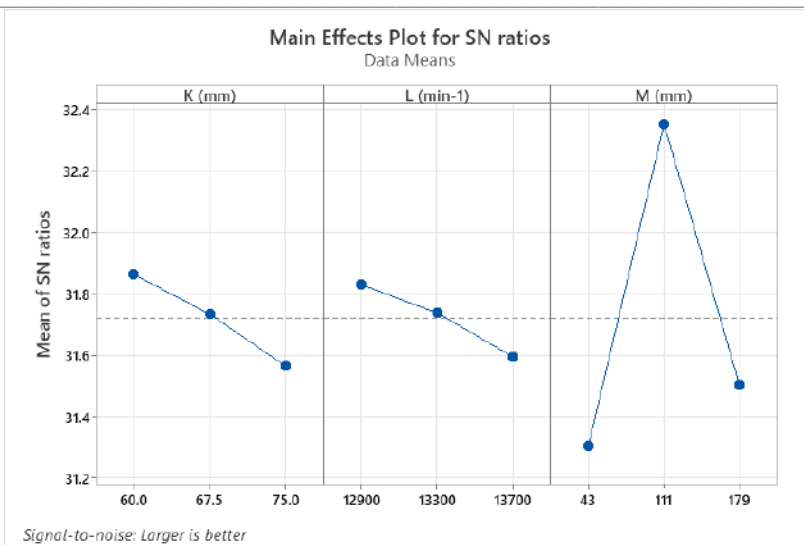


Figure 1: Main effect plot for S/N ratios

ANOVA is a statistical decision-making tool to detect differences in the average performance and helps test the significance of all main factors. The ANOVA method was utilized to understand the percentage of contribution of each parameter [14]. Table 4 showed that factor M had a significant influence on the cop diameter, while factors K and L had no influence on the cop diameter. Factor M had the highest value of 88.86% in contribution, which significantly affected the cop diameter in the ring spinning process.

Table 4: ANOVA results

Factor	Degree of freedom (Df)	Sum of squares (SS)	Mean square (MS)	F-value	p-value	Contribution (%)
K	2	0.13342	0.066709	9.00	0.100	6.42
L	2	0.08338	0.041692	5.62	0.151	4.01
M	2	1.84810	0.924952	124.64	0.008	88.86
Residual error	2	0.01483	0.007413			
Total	8	2.07973				

The purpose of the verification test was to confirm the validity of the predicted value. Minitab was utilized to predict the result of a cop diameter in the ring-spinning process with the optimum settings obtained by using the S/N ratio. The predicted result for crop diameter in Minitab was 42.5778 (Figure 2).

Prediction

Mean
42.5778

Settings

K	L	M
60	12900	111

Figure 2: Prediction by Minitab

To compare the experiment executed under the optimal conditions with the prediction that was generated by Minitab percentage of error was calculated. The percentage of error was 0.52% so the optimal conditions obtained by using different approaches were verified.

4. CONCLUSION

The diameter of the cop in the ring-spinning process was characterized and evaluated at the variation in spindle speed, traveler mass, and cop height. It was concluded that changing the doff stage over the cop had a severe effect on the diameter of the cop which gave a recommendation for engineering design too but the cop optimum diameter for the manufacturers and researchers. Traveler mass and spinning spindle had no effect. The optimization method of Taguchi gave a reasonable result to the maximum cop diameter corresponding to the specimen and test condition. According to the proposed levels of the control factors it was concluded that the maximum cop diameter at the bottom ring rail position could be achieved at the factor level K1L1M2.

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A STUDY ABOUT SAFFLOWER OIL LOADED EMULSION ELECTROSPUN NANOFIBERS

Original scientific paper
DOI: 10.5937/CT_ITI24010G

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ABSTRACT: In this study, it was aimed to achieve production and characterization of safflower oil-loaded core sheath nanofibers via emulsion electrospinning. For this aim, firstly, polyvinyl(alcohol) (PVA) based emulsion polymer solutions were prepared with different safflower oil concentrations. Then, polymer solution properties were determined in terms of the understanding effect of safflower oil concentrations on emulsion electrospun nanofiber morphology. Nanofiber production was carried out under the optimum process parameters for all samples. Lastly, safflower-loaded nanofibrous surfaces were characterized morphologically and chemically. Gas chromatography-mass spectrometry (GC-MS) was performed for determination of oil acids and phenolic compounds in safflower oil. It is thought that the nanofibrous surfaces designed and produced have a high potential for use as face masks for skin care.

Keywords: Safflower oil, nanofibers, emulsion electrospinning, skin care, face mask.

STUDIJA O ELEKTROSPINSKIM NANOVLAKNIMA U EMULZIJI PUNJENIM ULJEM ŠAFRANA

APSTRAKT: Cilj ovog istraživanja bio je da se postigne proizvodnja i karakterizacija nanovlakna omotača jezgra napunjenih šafranovim uljem putem emulzionog elektropredenja. Za ovaj cilj, prvo, pripremljeni su rastvori emulzionih polimera na bazi polivinila(alkohola) (PVA) sa različitim koncentracijama ulja šafranke. Zatim su određena svojstva rastvora polimera u smislu razumevanja uticaja koncentracija ulja šafranke na morfologiju emulzionih elektrospunovih nanovlakna. Proizvodnja nanovlakna je obavljena po optimalnim procesnim parametrima za sve uzorke. Na kraju, morfološki i hemijski su okarakterisane nanofibrozne površine napunjene šafranom. Za određivanje uljnih kiselina i fenolnih jedinjenja u ulju šafranke urađena je gasna hromatografija-masena spektrometrija (GC-MS). Smatra se da nanofibrozne površine dizajnirane i proizvedene imaju veliki potencijal za upotrebu kao maske za lice za negu kože.



Ključne reči: ulje šafranike, nanovlakna, elektrospinoвање emulzije, nega kože, maska za lice.

1. INTRODUCTION

Safflower oil is widely used in the food, cosmetics, pharmaceutical, and food industries. Safflower oil offers the additional benefit of being more cost-effective to produce, making it a viable alternative for individuals who are unable to purchase more expensive options such as olive oil and other valuable oils [1]. The high content of linoleic acid and α -tocopherol in safflower oil enhances the quality and appearance of skin. The hair and skin benefits of safflower oil are attributed to its vitamin E content and its lightweight structure, which promotes easy absorption into the scalp [2].

Emulsion electrospinning is an alternative to coaxial for producing core sheath nanofibers. There is no need to modify the classical electrospinning setup to produce nanofibers in the core-shell structure by emulsion electrospinning. One of the most important points is to create stable emulsions. If water-in-oil or oil-in-water emulsions are not formed correctly, the core shell structure cannot be achieved. To make stable emulsions with multiphase systems, the HLB value of the surfactant and the ratio of the inner phase to the outer phase are very important [3]. The advantage of core-shell nanofibers over nanofibers produced by other methods such as blend and suspension is the long-term release of the additives in the form of controlled release [4].

Upon further examination of the literature, it is observed that the studies in which safflower oil and nanofibers are combined are quite limited. When the superior properties of safflower oil and nanofibers are combined, it is thought that this material will have potential for use in different application areas.

2. MATERIALS AND METHODS

2.1. Materials

In this study, polyvinyl alcohol ($M_n = 88,000$, 88% hydrolyzed) was used as the polymer, distilled water was used as a solvent, safflower oil (*Carthamus tinctorius* L.) was used as a natural agent, and surfactant (Cremophor RH40) was used as an emulsifier.

2.1. Methods

The first step in the study was the preparation of stable emulsions. For this purpose, all PVA polymer solutions were prepared at an equal concentration of 10 wt %. Safflower oil was added to the PVA polymer solutions at different concentrations, such as 2 wt %, 4 wt %, 6 wt %, and 8 wt %. Finally, equal amounts (2 wt %) of surfactant were added to each solution to form an emulsion and stirred at room temperature. Then, solution properties such as viscosity, conductivity (SelectaCD2005), and surface tension with the Wilhemly Plate method (Biolin Scientific Sigma 702) were measured.

Emulsion electrospinning was carried out under optimum process parameters such as voltage (22.4 Kv), feed rate (0.4 mL/h), and distance between electrodes (22 cm). Then, safflower loaded PVA nanofibers were characterized via SEM images as morphological

and structural. FT-IR analysis was performed to verify the safflower oil in nanofibrous structure. GC-MS was used to determine the presence of oil acids and phenolic compounds in safflower oil.

3. RESULTS AND DISCUSSIONS

3.1. Solution Properties Results

Table 1: GC-MS analyze result of safflower oil

Component Name	Area (%)
Tetradecanoic acid (Myristic acid)	0.05
9-Hexadecenoic acid (Palmitoleic acid)	0.03
Hexadecanoic acid (Palmitic acid)	5.67
9,10-Methylene hexadecanoic acid	0.02
Heptadecanoic acid (Margaric acid)	0.01
9,12-Octadecadienoic acid (Linoleic acid)	46.67
9-Octadecenoic acid (Oleic acid)	44.72
Octadecanoic acid (Stearic acid)	2.17
11-Eicosenoic acid	0.09
Eicosenoic acid (Arachidic acid)	0.14
13-Docosenoic acid (Erucic acid)	0.01
Docosanoic acid (Behenic acid)	0.05
Other components	0.36

In all,13 components were identified as fatty acids in the safflower oil structure. Main constituents were determined linoleic acid (46.67%), oleic acid (44.72%), palmitic acid (5.67%) and stearic acid (2.17%), respectively. Polymer solution properties were measured to investigate the effect of safflower oil concentration on solution properties such as viscosity, conductivity and surface tension (Figure 1).

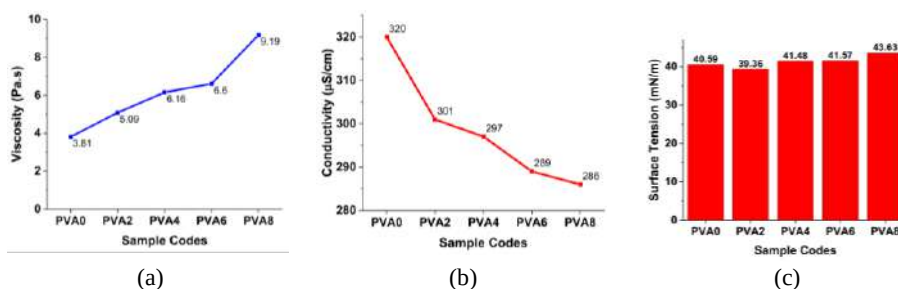
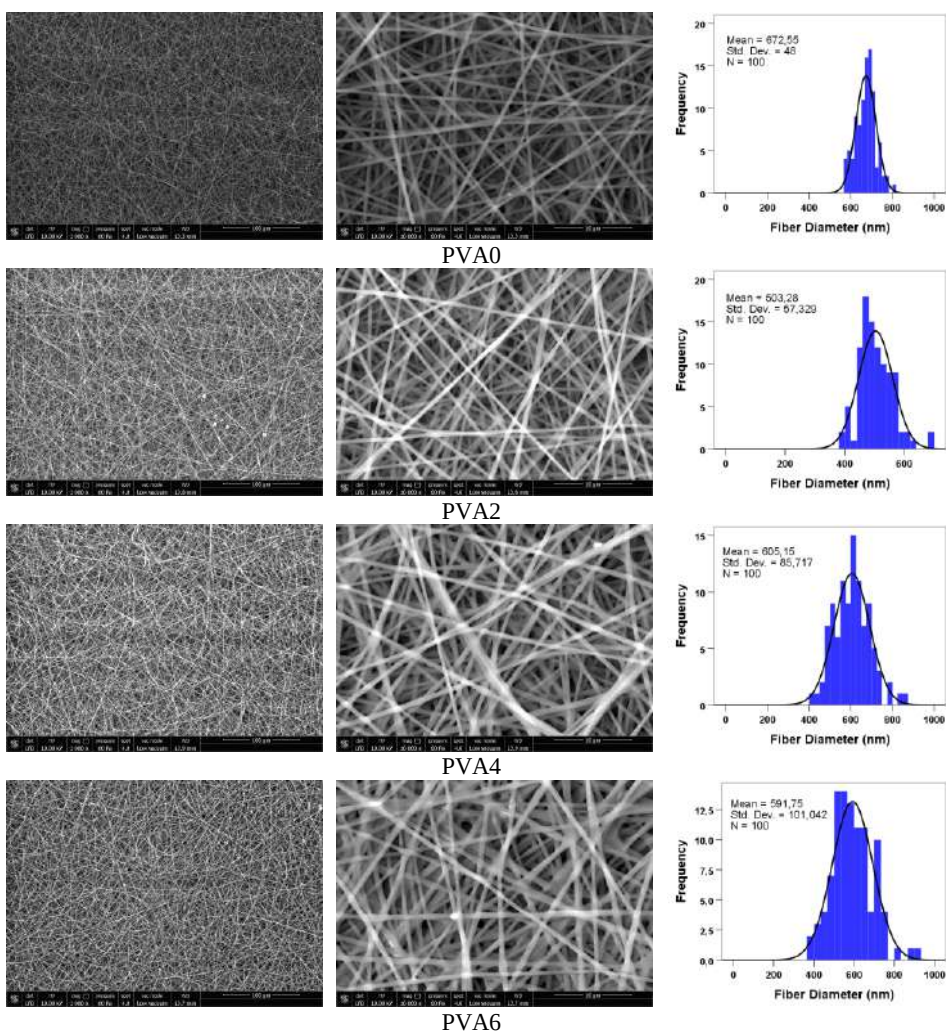


Figure 1: Solutions properties of PVA based polymer solutions with different concentrations of safflower oil a) Viscosity b) Conductivity c) Surface tension

When the graphs are analyzed, it is seen that as safflower oil concentration increases, viscosity increases, conductivity decreases and surface tension does not change.

3.2. Fiber Morphology Results

SEM images were taken to analyze the fiber morphology, fiber diameters and nanoweb quality. These SEM images are given in Figure 2 with fiber diameter histograms.



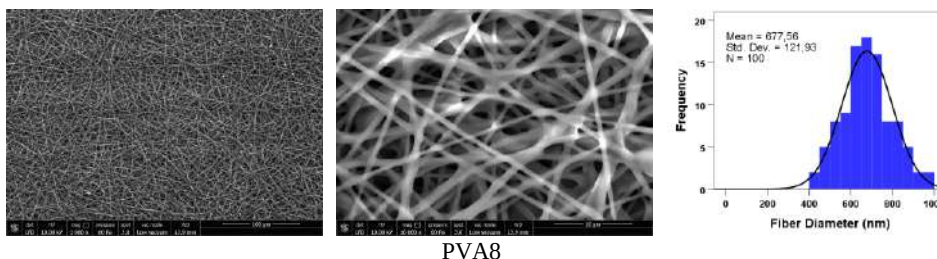


Figure 2: SEM images (1.000x-10.000x) and histograms of PVA nanofibers produced with various concentrations of safflower oil

As seen from SEM images and histograms, the nanofibers are fine, uniform, very smooth, bead-free, homogeneous, and high nanoweb quality. However, as the safflower oil concentration increased, reticulated structures were observed in the nanoweb structure. The normal distribution curve of all histograms has a single peak. This indicates that the nanofibers have a highly homogeneous fiber diameter distribution. Fiber diameter and fiber diameter uniformity coefficient with safflower oil concentration graph are given in Figure 3.

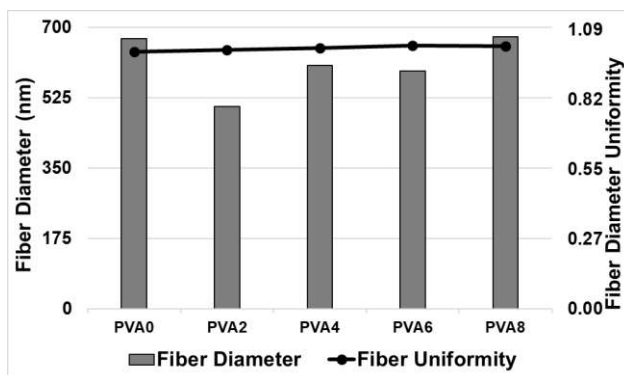


Figure 3: Average fiber diameter and diameter uniformity results of PVA nanofibers with various concentrations of safflower oil

According to Figure 3, average fiber diameter varies between 503 and 677 nm. Fiber diameter uniformity coefficients were close to 1 and were not affected by safflower oil concentration.

Chemical characterization was performed using Fourier transform infrared spectroscopy (FT-IR). FT-IR spectra of PVA, SA, and PCL10-1 nanofibers are given in Figure 3.

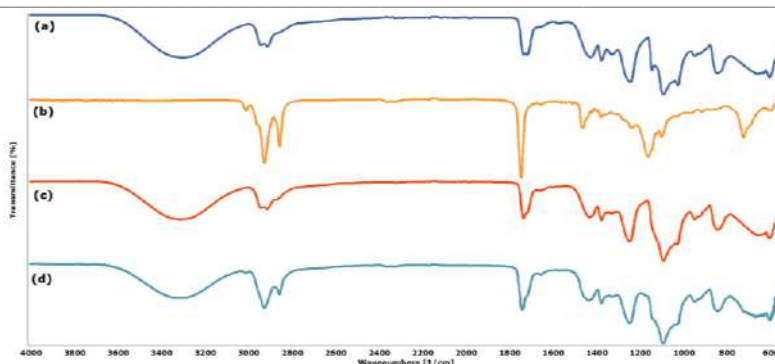


Figure 3: FT-IR spectra of: a) PVA; b) Safflower oil; c) PVA0; d) PVA8

In PVA spectra, the strong hydrogen bonded band occurred at approximately $3400\text{--}3200\text{ cm}^{-1}$ wavelength in the spectra of PVA polymer. Because of the high hydrophilic forces, intramolecular and intermolecular hydrogen bonding is expected to occur among PVA chains. Another important absorption peak was confirmed at 1141 cm^{-1} . The crystallinity of PVA is primarily responsible for this vibrational band, which is related to the carboxyl stretching band (C–O) [5]. These peaks appeared in the spectra of the PVA0 and PVA8 coded nanofibers. There are absorption bands in the general safflower oil spectrum at $1815\text{--}659$, $3146\text{--}2816$, $3391\text{--}3382$, $3631\text{--}3530\text{ cm}^{-1}$. Peaks around the $3600\text{--}3500\text{ cm}^{-1}$ region could be attributed to –OH stretching while the $3300\text{--}2800\text{ cm}^{-1}$ region is associated with –CH stretching. The C–O stretch takes place at $1800\text{--}1700\text{ cm}^{-1}$ and $1200\text{--}650\text{ cm}^{-1}$ is the finger-print region [6]. These characteristic peaks were not observed in the spectrum of the sample coded PVA0 without safflower oil, while the peaks appeared in the sample coded PVA8 containing 8 wt % safflower oil. This result chemically verified the presence of safflower oil in the structure of safflower oil loaded nanofibers.

4. CONCLUSION

In conclusion, the production and characterization of PVA-based nanofibers containing safflower oil were carried out by the emulsion electrospinning method. The findings of the study revealed the importance of the phases forming the emulsion in the emulsion electrospinning method. In other words, there was a strong relationship between oil concentration, solution properties, fiber spinning performance and fiber morphology.

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FABRICATION OF PCL/SEPIOLITE COMPOSITE NANOFIBERS

Original scientific paper
DOI: 10.5937/CT_ITI24011G

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ABSTRACT: In this study, it was aimed to produce and characterize PCL-based composite nanofibrous material containing various concentrations of sepiolite (SEP). The PCL polymer concentration was kept constant at 10 wt% in consideration. Sepiolite was added to the PCL solution at concentrations of 0, 0.5, 1.0, 1.5, 2.0, and 2.5 wt % respectively. Firstly, the properties of the prepared solutions such as viscosity, surface tension and conductivity were determined. The results of the solution properties indicated that the addition of SEP resulted in an increase in the viscosity, conductivity, and surface tension values of the solutions. Then, the nanofiber production was carried out via electrospinning method. Subsequently, the nanofibers were characterized morphologically by the SEM-EDS analysis. The results of the analysis demonstrated that all nanofibers exhibited smooth, bead-free, and uniform structures. Additionally, the fiber diameter was observed to decrease as the SEP concentration increased. The EDS analysis revealed the presence of magnesium (Mg) and silicon (Si) in nanofibers containing SEP. Considering the excellent features of sepiolite such as being biocompatible and non-toxic along with those of nanofibers, it is thought that the nanofibrous material produced can be used in medical applications such as wound dressing, medicine, bone regeneration.

Keywords: Sepiolite, Polycaprolactone, Nanofibers, Electrospinning.

IZRADA PCL/SEPIOLIT KOMPOZITNIH NANOVLAKNA

SAŽETAK: Cilj ovog rada bio je da se proizvede i karakteriše kompozitni nanovlaknasti materijal na bazi PCL-a koji sadrži različite koncentracije sepiolita (SEP). Koncentracija PCL polimera je održavana konstantnom na 10 tež%. Sepiolit je dodat u PCL rastvor u koncentracijama od 0, 0,5, 1,0, 1,5, 2,0 i 2,5 tež. % respektivno. Prvo su određena svojstva pripremljenih rastvora kao što su viskozitet, površinski napon i provodljivost. Rezultati svojstva rastvora su pokazali da je dodavanje SEP-a dovelo do povećanja vrednosti viskoziteta, provodljivosti i površinskog napona rastvora. Zatim je proizvodnja nanovlakna sprovedena metodom elektropredjenja. Nakon toga, nanovlakna su morfološki okarakterisana SEM-EDS analizom. Rezultati analize su pokazali da su sva nanovlakna pokazala glatke strukture bez perli i ujednačene strukture. Pored toga, primećeno je da se

prečnik vlakana smanjuje kako se koncentracija SEP povećava. EDS analiza je otkrila prisustvo magnezijuma (Mg) i silicijuma (Si) u nanovlaknima koja sadrže SEP. Uzimajući u obzir odlične karakteristike sepiolita kao što je biokompatibilnost i netoksičnost zajedno sa onima nanovlakna, smatra se da se proizvedeni nanovlakni materijal može koristiti u medicinskim aplikacijama kao što su zavoji rana, medicina, regeneracija kostiju.

Ključne reči: sepiolit, polikaprolakton, nanovlakna, elektropredenje.

1. INTRODUCTION

Sepiolite is a naturally occurring hydrated magnesium silicate clay mineral ($\text{Mg}_4\text{Si}_6\text{O}_{15}(\text{OH})_2 \cdot 6\text{H}_2\text{O}$) with a fibrous structure and unique physicochemical characteristics. It is used in many industrial applications, including adsorbents, catalysts, plastics and polymeric materials, animal feed additives, pharmaceuticals and cosmetics, soil amendments, ceramics and refractories, environmental remediation, and medical applications [1-2]. Sepiolite is generally considered to be biocompatible and non-toxic [3], which makes it a promising material for a wide variety of medical applications. Its unique properties make it stand out among other materials in the medical field [4]. Current studies indicate possible uses in wound dressings [5], drug delivery systems [6], tissue engineering [4], bone grafting, dental materials and diagnostic imaging. The use of sepiolite in medicine is relatively new compared to other industries.

Electrospinning is a versatile and scalable technique for the fabrication of nanofibers with diameters in the range of a few nanometers to several micrometers. Nanofibers have unique properties, such as high surface area-to-volume ratio, flexibility, low density, porosity, and tunable mechanical, electrical, and optical properties, making them suitable for various applications, including tissue engineering, filtration, drug delivery, and sensors. Electrospun nanofibers can be produced from a variety of materials, including synthetic polymers, natural polymers, biopolymers, ceramics, composites, minerals, and hybrid materials. Each material offers unique characteristics suitable for specific applications [7-9].

Polycaprolactone (PCL) is a biodegradable polyester, whose unique combination of properties and versatility have made it popular in a wide variety of industries. PCL is a valuable material with broad applications across multiple industries, including biomedical, packaging, and textiles. Its biodegradability, biocompatibility, mechanical properties, thermal stability, processability, and environmentally friendly characteristics make it highly sought after. PCL finds applications in various biomedical fields such as drug delivery systems, tissue engineering scaffolds, wound dressings, dental materials, and implantable biomaterials [10-11].

The objective of this study is to produce nanofibrous composite nanofibrous material through the electrospinning method using PCL polymer and sepiolite in different ratios (0, 0.5, 1.0, 1.5, 2.0, and 2.5 wt %). In literature, there is limited study with sepiolite and therefore this pre-experimental study will be useful for biomedical applications of nanofibers especially bone regeneration etc.



2. MATERIALS AND METHODS

2.1 Materials

In the study, PCL ($M_n=80,000$) was used as a polymer, chloroform and dimethylformamide (DMF) were used as solvents and sepiolite was used as a mineral additive to fabricate the nanofibrous materials. PCL, chloroform and DMF were purchased from Sigma-Aldrich Corporation (St. Louis, MO, USA). The sepiolite mineral was supplied from Eskişehir, Turkey.

2.2 Methods

In all solutions, the PCL polymer concentration was set at 10 wt%. Table 1 displays contents of the solutions along with their corresponding sample codes.

Table 1: The concentration of PCL and SEP with sample codes

Sample Codes	PCL Concentration (wt%)	SEP Concentration (wt%)
SEP-0	10	0
SEP-0.5	10	0.5
SEP-1	10	1.0
SEP-1.5	10	1.5
SEP-2	10	2.0
SEP-2.5	10	2.5

The first step in the production of nanofibers was the preparation of the PCL polymer solution. Various concentration of SEP was added into the PCL polymer solution. All of the solutions were prepared at room temperature for a period of 24 hours with constant stirring.

After preparing the polymer solutions, their properties including conductivity (measured using Selecta CD 2500), viscosity, and surface tension (measured using the Wilhelmy Plate technique with Biolin Scientific Sigma 702) were determined. The production of nanofibrous materials was subsequently carried out by electrospinning system under the optimized process parameters.

The electrospinning process was used to fabricate the nanofibers at laboratory scale. The process parameters identified Table 2, such as applied voltage, needle-to-collector distance, and solution flow rate, were optimized and maintained during spinning. The nanofibers were collected on an aluminum sheet for 15 min. The electrospinning process was performed under the same environmental conditions for all samples.

Table 2: Process parameters of electrospinning

Voltage (kV)	Distance Between Electrodes (cm)	Feed Rate (mL/h)	Humidity (%)	Temperature (°C)
23.5 (± 0.5)	22	0.450	47 (± 3)	23.5 (± 0.5)

The morphology of the produced nanofibers was characterized by Scanning Electron Microscope (SEM). Additionally, quantitative chemical analysis of the inorganic matter in the nanofibers was performed by Energy Dispersive Spectrometry (EDS). SEM-EDS analyses were conducted on an FEI Quanta 250 FEG instrument. The average fiber diameter was determined by measuring the diameter of 100 randomly selected fibers on SEM images. Moreover, the uniformity of the fiber diameter, and the surface structure of the nanoweb was assessed via SEM images. ImageJ program was used to measure fiber diameters and then statistical analysis of morphological parameters such as fiber diameter histogram was performed using SPSS analysis program. The average fiber diameter uniformity coefficient values were calculated using the following formula.

$$A_n = \frac{\sum n_i d_i}{\sum n_i} \quad (\text{Number average}) \quad (1)$$

$$A_w = \frac{\sum n_i d_i^2}{\sum n_i d_i} \quad (\text{Weight average}) \quad (2)$$

n_i =fiber number

d_i =fiber diameter

The fiber diameter uniformity coefficient was calculated by the ratio of A_w to A_n . An ideal optimum value for uniform fibers should be close to 1 [12].

3. RESULTS AND DISCUSSION

The results about solution properties of PCL/SEP are given in Table 3.

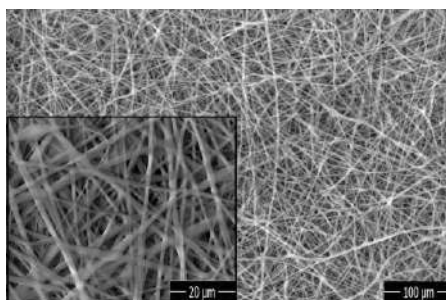
Table 3: Solution properties of PCL/SEP polymer solutions

Sample Codes	Conductivity (μS/cm)	Viscosity (Pa·s)	Surface Tension (mN/m)
SEP-0	0.43	0.709	27.07
SEP-0.5	0.99	0.734	30.20
SEP-1	1.32	0.991	30.05
SEP-1.5	1.49	1.044	30.07
SEP-2	1.73	1.818	30.46
SEP-2.5	1.85	2.461	35.23

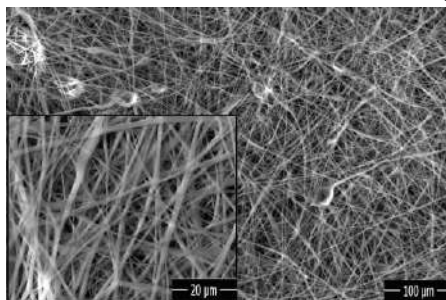
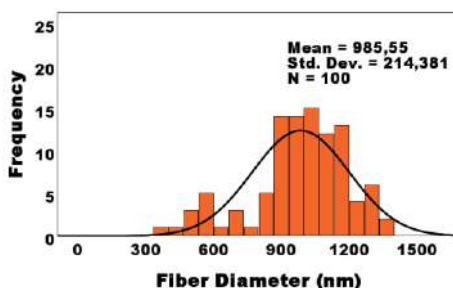
The results indicated that the conductivity and viscosity increased in direct relation to the SEP concentration in the solutions. While the viscosity of the first three samples (*SEP-0.5*, *SEP-1*, *SEP-1.5*) increased by minimal amounts, the viscosity values of the *SEP-2* and *SEP-2.5* samples exhibited a notable increase. The SEP mineral is known to be sensitive to pH [13]. It is postulated that the increase in viscosity is dependent on the pH value of the solution. The electrical conductivity exhibited a logarithmic increase with the concentration of SEP in the solutions. The conductivity of polymer solutions is related to the number of ions present [14]. The observed increase in conductivity indicated that SEP undergoes ionization in the polymer solution.

Upon analysis of surface tension values, it can be concluded that the addition of SEP results in a slight increase in surface tension within the solutions. This increase was particularly pronounced in the *SEP-2.5* sample. While the surface tension of the sample without SEP (*SEP-0*) was 27.07 mN/m, the surface tension of the sample containing 2.5 wt% SEP (*SEP-2.5*) was 35.23 mN/m. This increase in surface tension resulted in a decline in electrospinning performance.

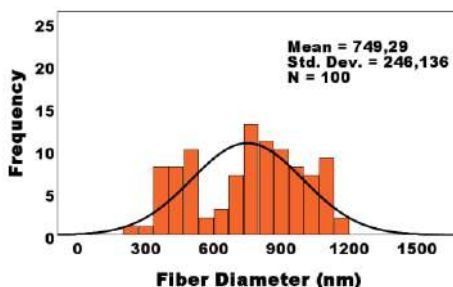
Figure 1 presents SEM images (1.000x and 10.000x) and fiber diameter histograms of PCL-based nanofiber samples produced with various concentrations of SEP

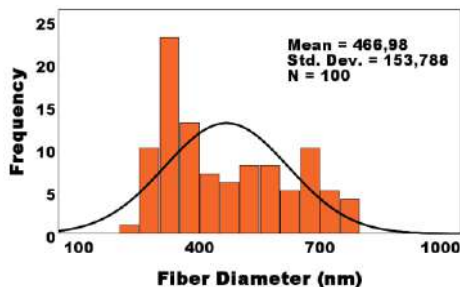
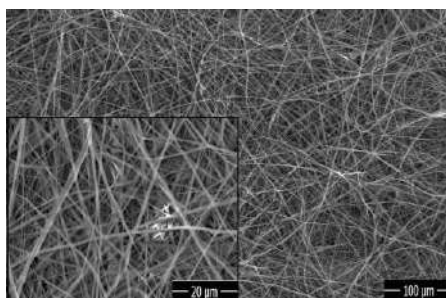


SEP-0

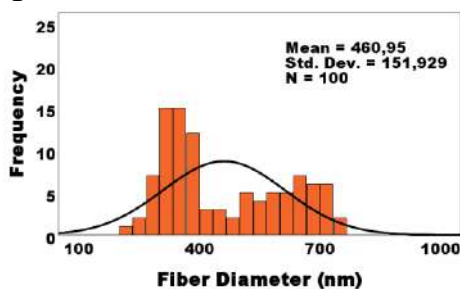
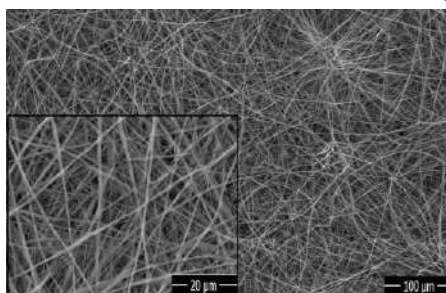


SEP-0.5

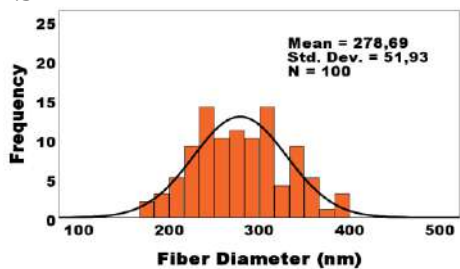
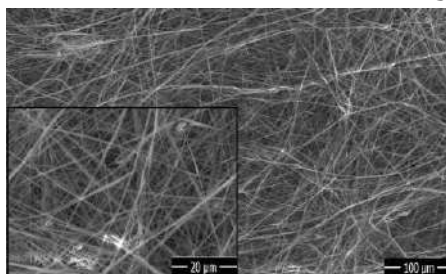




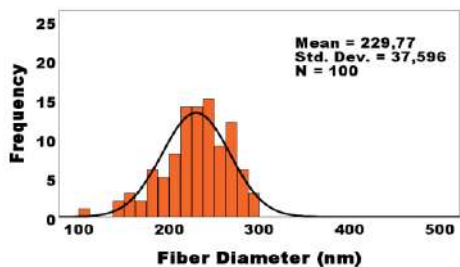
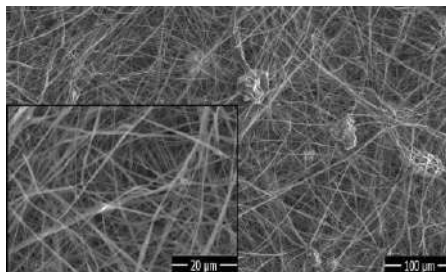
SEP-1



SEP-1.5



SEP-2



SEP-2.5

Figure 1: SEM images (1.000x, 10.000x) and fiber diameter histograms of PCL-based nanofiber samples produced with various SEP concentrations

Upon examination of the SEM images of the nanofibers produced, it was determined that only those produced with PCL polymer resulted in the formation of very thick fibers. Despite this, the fibers were found to be smooth, beadless, and uniform. When the SEM images of the nanofibers obtained by adding SEP to the PCL solution were examined, it was understood that the fibers gradually became thinner. All nanofibers obtained from solutions with different SEP concentrations were found to be smooth, beadless, and uniform. When the histograms obtained by measuring the diameters of 100 randomly selected fibers from SEM images are examined, it is evident that all histograms are single-peaked and have a flattened frequency distribution curve.

In Figure 2, the impact of varying concentrations of the SEP on the average fiber diameter and the fiber diameter uniformity coefficient is presented.

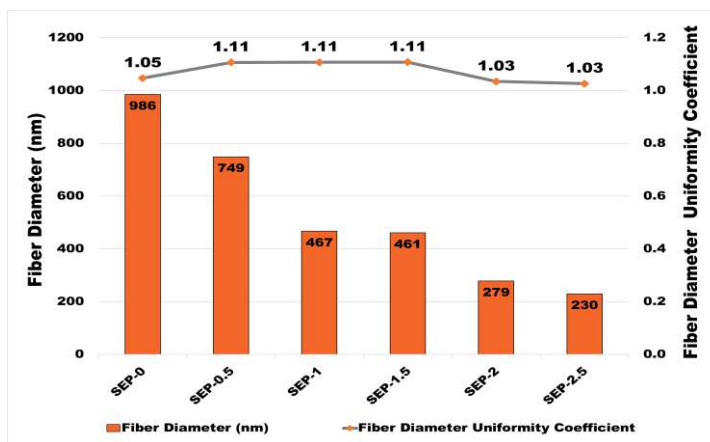


Figure 2: The effect of SEP concentration on the average fiber diameter and fiber diameter uniformity coefficient of PCL-based nanofibers

Figure 2 clearly demonstrated that the incorporation of SEP resulted in a reduction in the average fiber diameter. The most uniform fibers were observed in the SEP-2.5 sample. The average fiber diameter of this solution was determined to be 230 nm. The fiber diameter uniformity coefficient value for the SEP-0 sample without SEP was found to be 1.05. Upon the addition of SEP, the fiber diameter uniformity coefficient initially increased to 1.11 and subsequently decreased to 1.03 for the SEP-2 and SEP-2.5 samples. A value approaching 1 indicates a uniform fiber structure. This suggests that the SEP-2 and SEP-2.5 samples possess a more uniform fiber diameter than the others.

The results of the EDS analysis of nanofibers containing various concentrations of SEP particles are presented in Table 4.

Table 4: EDS results of the PCL nanofibers with various concentrations of SEP

Sample Codes	C (%)	O (%)	Mg (%)	Si (%)
SEP-0	70.76	29.24	-	-
SEP-0.5	71.00	28.90	0.09	-
SEP-1	69.85	29.52	0.38	0.25
SEP-1.5	70.41	29.10	0.21	0.27
SEP-2	69.34	29.59	0.43	0.63
SEP-2.5	72.67	25.86	0.51	0.96

The presence of SEP minerals on PLC-based nanofiber surfaces was confirmed by EDS analysis. The EDS results of all nanofibers exhibited Carbon (C) and Oxygen (O) values. No different elements were detected in the SEP-0 sample, which without SEP, as anticipated. However, the presence of Magnesium (Mg) and Silicon (Si) was revealed by the addition of SEP to the solutions. As the concentration of SEP in the solutions increased, the amounts of Mg and Si detected in the nanofibers also increased, in general.

4. CONCLUSION

In the study, PCL-based nanofibrous materials containing various concentrations of sepiolite were successfully electrospun and characterized via SEM-EDS. The concentration of PCL polymer was maintained at 10 wt %. Sepiolite was added to the PCL solution at concentrations ranging from 0 to 2.5 wt%. The effect of SEP concentration on the conductivity, viscosity, and surface tension of PCL solutions was determined. The results indicated that the addition of SEP to the solutions resulted in an increase in conductivity, viscosity, and surface tension. The findings of the SEM analysis indicated that all nanofibers exhibited smooth, bead-free, and uniform structures. Furthermore, the fiber diameter was observed to decrease as the concentration of SEP increased. The EDS analysis demonstrated the presence of Mg and Si elements in nanofibers containing SEP. In addition; the relations between SEP concentration, spinning performance, fiber morphology, average fiber diameter and fiber diameter uniformity were analyzed. The high surface tension and viscosity of the SEP-2.5 sample led to a reduction in electrospinning performance. The exceptional properties of sepiolite, such as biocompatibility and non-toxicity, and the superior properties of nanofibers suggest that the resulting nanofiber material can be used in various medical applications, such as bone regeneration.

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TOWARDS IMPROVING MEASUREMENT METHOD FOR MECHANICAL PROPERTIES OF TEXTURED FILAMENT/ELASTANE HYBRID YARNS

Original scientific paper
DOI: 10.5937/CT_ITI24012K

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ABSTRACT: The mechanical properties of hybrid yarns containing elastomeric component are rather difficult to measure. A standard approach to measuring tenacity and elongation cannot be applied to this type of yarn. The main reason is the high elasticity of both elastane and textured filaments. An attempt was made in this study to solve the problem by measuring the mechanical properties of textured filament/elastane hybrid yarns under pretension force which is higher than standard ones. Several pretension forces were applied: 1.5 cN, 4.5 cN, 7.5 cN, 10.5 cN and 13.5 cN. Textured polyamide 6.6 was used as a spirally covering filament, while the core yarn was LYCRA® elastomeric yarn with various linear densities. The results indicated that with an increase in the pretension force, the elongation of the polyamide/ LYCRA® hybrid yarns decreased whereas, the pretension forces had little effect on the tenacity values for investigated samples. These preliminary results are promising, however, the method must be further developed to be ultimately applicable to all complex yarns containing elastomer filament.

Keywords: tenacity, elongation, textured filament, polyamide, Lycra, hybrid yarn.

POBOLJŠANJE METODE MERENJA MEHANIČKIH SVOJSTAVA TEKSTURIRANI FILAMENT/ELASTAN HIBRIDNIH PREĐA

APSTRAKT: Merenje mehaničkih svojstava hibridnih pređa koje sadrže elastansku komponentu vrlo je komplikovano. Standardni pristup merenju prekidne jačine i istegljivosti ne može se primeniti na ovaj tip pređa. Glavni razlog je velika elastičnost kako elastanskih, tako i teksturiranih filamenata. U okviru ovog istraživanja, rešavanju navedenog problema se pristupilo merenjem mehaničkih svojstava teksturirani filament/elastan hibridnih pređa uz prednaprezanje veće od standardnih vrednosti. U ovom radu je primenjeno nekoliko različitih sila predzatezanja: 1,5 cN, 4,5 cN, 7,5 cN, 10,5 cN, i 13,5 cN. Kao spiralno omotavajući filament korišćen je tekstirirani poliamid 6.6, a za jezgro hibridne pređe upotrebljene su Lycra® elastomerne pređe različitih finoća. Rezultati su pokazali da se sa povećanjem sile predzatezanja, izduženje poliamid/Lycra®



hibridnih pređa smanjuje, uz slabo izražen uticaj sile predzatezanja na vrednosti prekidne jačine ispitivanih hibridnih pređa. Ovakvi rezultati su obećavajući, međutim, metoda se mora dalje razvijati da bi bila generalno primenjiva na sve složene pređe koje sadrže elastanski filament.

Ključne reči: prekidna sila, izduženje, teksturirani filament, poliamid, Lycra, hibridna pređa.

1. INTRODUCTION

Spirally covered yarns are hybrid yarns where one or more yarns (cover) are winded around another yarn (core). The main reasons for producing this type of yarn are protection and improvement of the mechanical properties of the core, control of core elasticity and improving structural and comfort properties of the core [1]. In this research, hybrid yarns comprise a core of bare and twistless elastic yarn spirally single-covered by polyamide 6.6 [2]. The linear density ratio of elastomer and polyamide yarn can be adjusted by changing the fineness of the elastomer or polyamide yarn or changing the draft ratio of the elastomer during the covering process. In this study, the elastomer draft ratio was the same for all the samples, and the same polyamide filament was always used, to exclude the effect of that yarn properties [3], [4].

There is no data in the literature about the measurement method for the mechanical properties of the covered yarn. This is mainly because standard pretension forces for elastomer or polyamide yarn measurements result in poorly distributed results, so it is impossible to connect between production properties and yarn type [5].

2. MATERIALS AND METHODS

In this research, testing was done in three phases. Firstly, the polyamide filament's linear density and mechanical properties were measured before making covered yarn. Breaking force and elongation of polyamide 6.6 textured yarn were measured at 6 different pretension forces (PF): 1.5 cN, 4.5 cN, 7.5 cN, 10.5 cN, 13.5 cN and 16.5 cN. The second step was the preparation of covered hybrid yarn samples. In the third phase, linear density, elongation, and breaking force of covered hybrid yarn were measured.

Five types of spirally covered polyamide/elastomer hybrid yarns were produced for this research. Textured polyamide 6.6 yarn with a linear density of 22 dtex containing 7 monofilaments produced by Fulgar SpA, Italy, covered bare elastomeric yarns with 1550 turns per meter. Core was LYCRA® elastomeric yarn with linear density: 17 dtex, 22 dtex, 33 dtex, 44 dtex and 78 dtex. Produced hybrid yarns are given in Table 1, where PA/EL shows the ratio of real linear density of polyamide 6.6 and linear density of stretched elastomer. From each type of hybrid yarn, eight bobbins were produced at the same positions on the covering machine RPR type GSP22, four were twisted in the S direction, while for the other four, Z torsion was applied. Temperature and humidity were controlled during the production process in the 25 – 30°C temperature range and relative humidity

range of 55 - 60%. All samples were conditioned for 7 days in the same conditions as they had been produced.

Table 1: Polyamide/Lycra® hybrid yarns used in the study

Sample	Elastomer core			PA/EL
	Type	Linear density [dtex]	Filament count	
17 LYCRA 22/7 T 1550 SC	LYCRA® 16AL	17	1	4.4
22 LYCRA 22/7 T 1550 SC	LYCRA® 16AL	22	1	3.4
33 LYCRA 22/7 T 1550 SC	LYCRA® 926L	33	2	2.3
44 LYCRA 22/7 T 1550 SC	LYCRA® 162C	44	4	1.7
78 LYCRA 22/7 T 1550 SC	LYCRA® 162C	78	5	1.0

The linear density of the samples was measured by Mesdan lab electronic wrap reel for yarns, according to the UNI EN ISO 2060 test method. The same method was used for measuring the linear density of polyamide 6.6 yarn, used in this research. The measurement was conducted on the polyamide filament from two bobbins, which were used for producing all 40 sample bobbins [6].

Breaking force and elongation were measured using the Tomsic Tenso Tester, at 300 m/min speed. The sample's initial length was 0,200 m. A testing procedure was performed for each bobbin at one pretension force twenty times. Measurements were done at the following pretension forces: 1.5 cN, 4.5 cN, 7.5 cN, 10.5 cN and 13.5 cN. Some of the pretensions were impossible to apply for all yarn samples. Table 2 gives maximal pretensions on the sample yarns and their average factual (measured) linear density.

Yarn tenacity is calculated according to the following formula:

$$T = \frac{F_b}{T_{dr}} \cdot 0.1 \quad (1)$$

Where T is tenacity in cN/tex, F_b is breaking force in cN, and T_d is measured average linear density of the yarn sample in dtex.

Table 1: Factual linear density and maximal possible pretension forces for tested samples

Yarn	Average factual linear density [dtex]	Max. used PF [cN]
17 LYCRA 22/7 T 1550 SC	21.60	13.5
22 LYCRA 22/7 T 1550 SC	28.41	13.5
33 LYCRA 22/7 T 1550 SC	30.04	13.5
44 LYCRA 22/7 T 1550 SC	33.10	10.5
78 LYCRA 22/7 T 1550 SC	39.55	7.5

3. RESULTS AND DISCUSSION



The average tenacity of the yarns with different pretension forces is given in Figure 1. According to the results, it can be concluded that an increase in pretension forces does not cause a significant difference in the tenacity of the hybrid yarns.

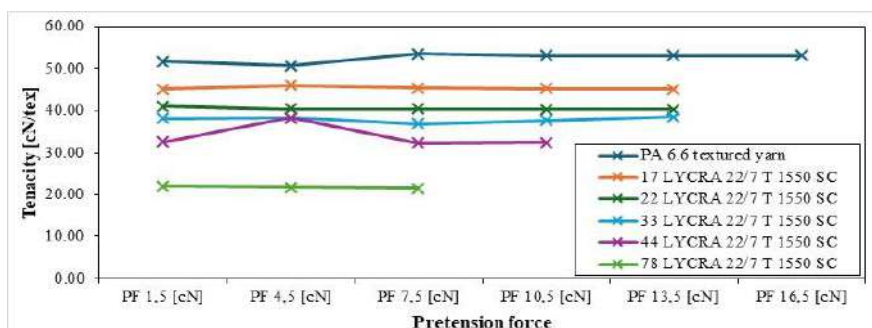


Figure 1: Yarn tenacity under different pretension forces

With an increase in pretension force, yarn elongation decreases, according to Figure 2. This effect can be related to the behavior of the spirally covered hybrid yarns under increased tension forces. With an increase in the pretension force of the elastomer yarn, the distribution of turns of polyamide filament changes on the same length of the sample. As a result, the number of turns per meter of the hybrid yarn decreases. In addition, the diameter of the elastomer core decreases with an increase in pretension force, and the diameter of the polyamide spiral is inversely proportional to the tension force. For an ideal model of the hybrid yarn, elastomer and polyamide filament are parallel under maximal possible pretension. According to this elaboration, it can be concluded that the elongation of because the total elongation of the system (hybrid yarn) appears to be much more dependent on the elongation of polyamide filament. It seems that the effect of the elastomeric core on the yarn elongation is of much less significance despite the elastomer's intrinsically extremely high extensibility. the spirally covered elastomer/polyamide hybrid yarn is lower under higher pretension forces

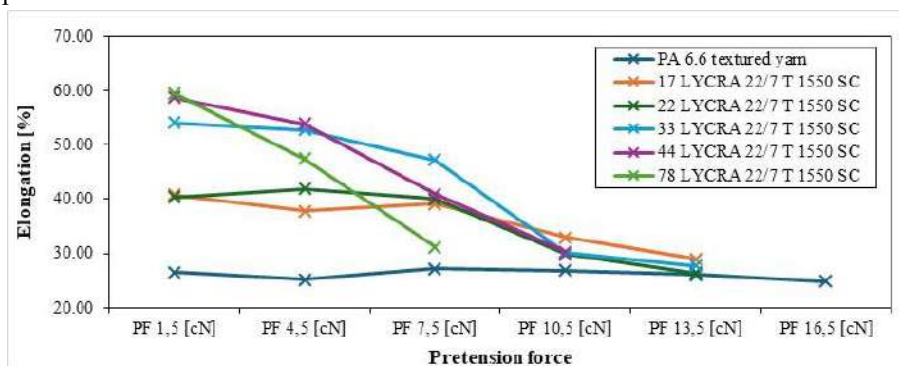


Figure 2: Yarn elongation under different pretension forces

Figures 3 – 7 show the normal distribution of the tenacity and elongation of spirally covered elastomer/polyamide hybrid yarns. As mentioned earlier, the tenacity at different pretension forces is similar for all samples. In addition, the normal distribution of tenacity is quite similar for all pretension forces for all samples. In contrast, the normal distribution for elongation results had different density values for different pretension forces. The density of the normal distribution of elongation results grows as the pretension force grows. The highest pretension forces have the highest density of normal distribution of the elongation results. These results justify the idea of this research to increase the pretension force while measuring the mechanical properties of spirally covered elastomer/polyamide hybrid yarns.

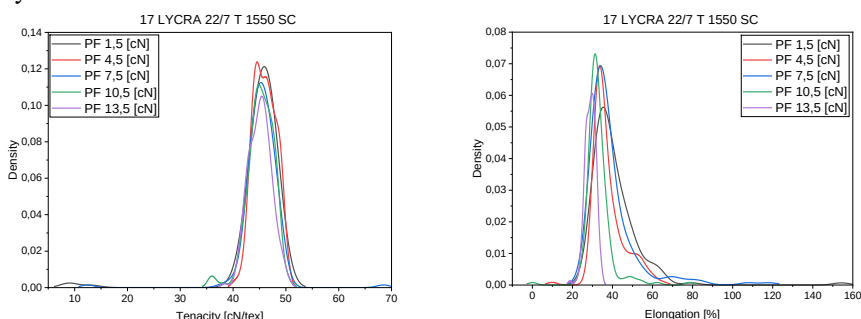


Figure 3: Normal distribution of tenacity and elongation under different pretension forces for sample 17 LYCRA 22/7 1550 SC

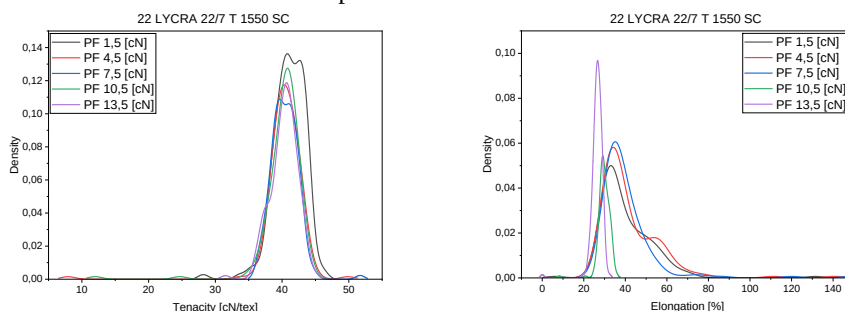


Figure 4: Normal distribution of tenacity and elongation under different pretension forces for sample 22 LYCRA 22/7 1550 SC

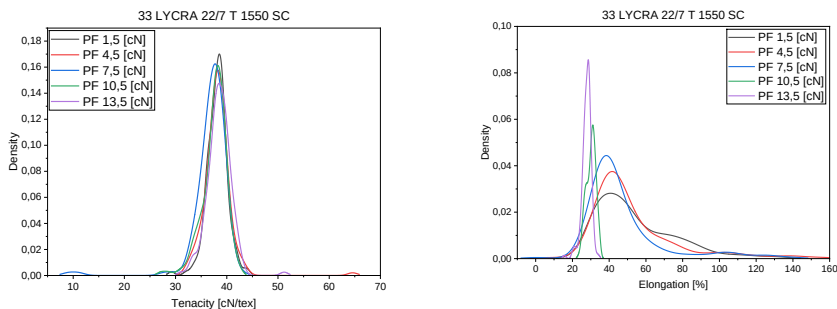


Figure 5: Normal distribution of tenacity and elongation under different pretension forces for sample 33 LYCRA 22/7 1550 SC

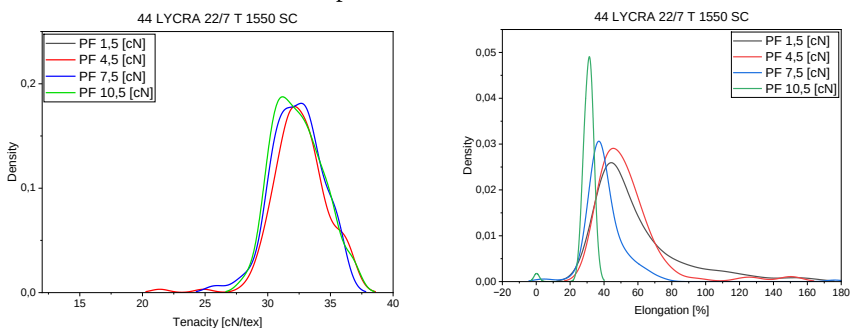


Figure 6: Normal distribution of tenacity and elongation under different pretension forces for sample 44 LYCRA 22/7 1550 SC

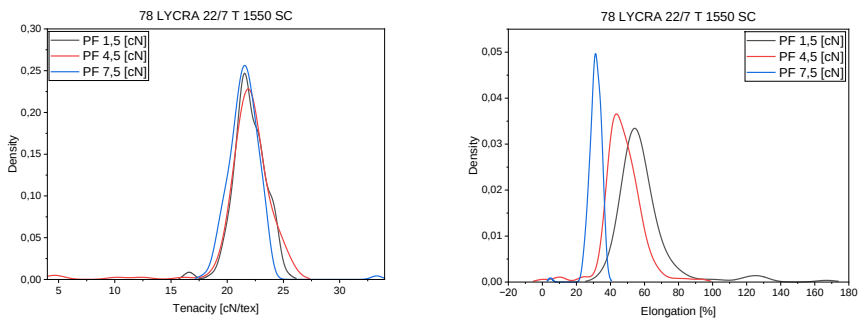


Figure 7: Normal distribution of tenacity and elongation under different pretension forces for sample 78 LYCRA 22/7 1550 SC

3. CONCLUSION



The present research investigated the effect of pretension forces while measuring the mechanical properties of spirally covered Lycra/polyamide hybrid yarns. The results show that:

- Pretension force influences the elongation values of spirally covered elastomeric/polyamide hybrid yarns.
- Pretension forces have little effect on the tenacity of investigated samples.
- Higher pretension forces have a higher density of normal distribution of elongation of measured samples.
- To get a clearer correlation between the pretension force and linear density of the polyamide/elastomer hybrid yarn, the proposed measurement method must be further developed.

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EMULSION ELECTROSPINNING OF PVA/ROSEMARY NANOFIBERS

Original scientific paper
DOI: 10.5937/CT_ITI24013G

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ABSTRACT: The purpose of this study was to develop a nanofibrous wound dressing material through the emulsion electrospinning method utilizing polyvinyl alcohol (PVA) polymer and rosemary essential oil (REO). The study involved the preparation of PVA/REO emulsions at varying REO ratios (0, 2, 4, 6, 8 wt%). First, the emulsion properties, such as viscosity, conductivity, and surface tension, were determined. The incorporation of REO resulted in a discernible enhancement in viscosity, accompanied by a minor reduction in conductivity. There was no appreciable alteration in surface tension. The emulsion electrospinning approach was used to produce the nanofiber composite material from these emulsions. Subsequently, the surface morphology of these nanofiber composites was investigated via the scanning electron microscope (SEM). Although REO increased the diameters of the nanofibers produced, it was observed that the nanofibers were smooth, beadless, and exhibited uniform structural properties. Besides, gas chromatography-mass spectrometry (GC-MS) was used to identify chemical compounds in rosemary essential oil. According to GC-MS analysis, 25 components were identified in REO, and 1.8-cineole (eucalyptol) was identified as the major component (58.7%). The study found that the addition of REO had a significant effect on the emulsion properties and morphology of the nanofibers. The emulsion electrospinning approach was got through to be a promising method for producing composite nanofibers from two immiscible liquids, such as an essential oil and an aqueous polymer solution.

Keywords: Polyvinyl alcohol, Rosemary, Essential oil, Nanofibers, Wound dressing, Emulsion electrospinning.

EMULZIJA ELEKTROSPINING NANOVLAKNA PVA/RUZMARINA

APSTRAKT: Svrha ovog istraživanja je bila da se razvije nanofibrozni materijal za zavoje rana metodom emulzije elektrospinozanja korišćenjem polimera polivinil alkohola (PVA) i eteričnog ulja ruzmarina (REO). Studija je uključivala pripremu PVA/REO emulzija u

različitim REO odnosima (0, 2, 4, 6, 8 tež.%). Prvo su određena svojstva emulzije, kao što su viskoznost, provodljivost i površinski napon. Ugradnja REO je rezultirala uočljivim povećanjem viskoziteta, praćeno manjim smanjenjem provodljivosti. Nije bilo značajnih promena u površinskom naponu. Za proizvodnju kompozitnog materijala od nanovlakna od ovih emulzija korišćen je pristup emulzionog elektropredenja. Nakon toga, morfologija površine ovih kompozita od nanovlakna je ispitana pomoću skenirajućeg elektronskog mikroskopa (SEM). Iako je REO povećao prečnike proizvedenih nanovlakna, primećeno je da su nanovlakna bila glatka, bez perli i da su pokazala ujednačena strukturna svojstva. Pored toga, gasna hromatografija-masena spektrometrija (GC-MS) je korišćena za identifikaciju hemijskih jedinjenja u eteričnom ulju ruzmarina. Prema GC-MS analizi, 25 komponenti je identifikovano u REO, a 1,8-cineol (eukaliptol) je identifikovan kao glavna komponenta (58,7%). Studija je otkrila da dodatak REO ima značajan uticaj na svojstva emulzije i morfologiju nanovlakna. Pristup emulzionog elektropredenja postao je obećavajući metod za proizvodnju kompozitnih nanovlakna iz dve tečnosti koje se ne mešaju, kao što su eterično ulje i vodeni rastvor polimera.

Ključne reči: polivinil alkohol, ruzmarin, eterično ulje, nanovlakna, zavoj za ranu, elektrospinoвање emulzije.

1. INTRODUCTION

Essential oils are natural aromatic volatile oils extracted from plants. They have been used for centuries in various cultures around the world. Today, essential oils are utilized in traditional and complementary medicine, aromatherapy, massage therapy, cosmetics, perfumes, and the food industry. They exhibit a range of activities including antiparasitic, antifungal, antibacterial, antiviral, antioxidant, anti-inflammatory, anti-carcinogenic, anti-aging, and neuroprotective properties [1-2].

Rosemary (*Rosmarinus officinalis L.*) is a medicinal and aromatic plant species that grows on the northern and southern coasts of the Mediterranean, as well as in the lower regions of the Himalayas. It has been found to possess antioxidant, antimicrobial, antibacterial, anti-cancer, anti-inflammatory, and pesticide removal properties. Due to these characteristics, rosemary is utilized for medicinal purposes, as well as in perfumes, cosmetics, and aromatherapy [3].

Nanofibers are being increasingly explored and utilized in the field of wound dressings due to their unique features and advantages over traditional materials. Nanofiber-based wound dressing represents a promising advancement in wound care technology, offering a range of benefits that can contribute to faster healing, reduced infection risk, and improved patient outcomes [4-5].

Electrospinning is a technique used to produce microscale to nanoscale materials from polymeric solutions [6]. Emulsion electrospinning is a novel and efficient method for the easy production of functional nanofiber structures from two immiscible liquids, such as an essential oil and an aqueous polymer solution. This approach allows for the preparation of homogeneous and stable emulsion solutions, making the production of nanofibers much



easier compared to conventional electrospinning systems. Additionally, emulsion electrospinning does not require any extra apparatus [7].

The objective of this study was to fabricate a nanofiber material for wound dressing via emulsion electrospinning method using polyvinyl alcohol (PVA) polymer and rosemary essential oil (REO). The present study demonstrates an innovative approach to the production of PVA/REO nanofibers by emulsion electrospinning method, which has the potential as a wound dressing.

2. MATERIALS AND METHODS

2.1 Materials

PVA (Mw 89,000-98,000, 99+ % hydrolyzed) was used as a polymer, and distilled water was used as a solvent. To prepare emulsion; a surfactant (PEG-40 hydrogenated castor oil) was used as an emulsifier and rosemary (*Rosmarinus officinalis L.*) essential oil was used as an additive. PVA polymer was purchased from Sigma-Aldrich Corporation (St. Louis, MO, USA); surfactant was supplied by Ersu Chemistry, Izmir, Turkey; and the rosemary essential oil was acquired from Botalife, Isparta, Turkey. All chemicals were analytical grade and used without further purification.

2.2 Methods

The study began with emulsion preparation for nanofiber production via emulsion electrospinning. Emulsion preparation occurred in two stages. Initially, the polymer solution was created by mixing PVA polymer in distilled water. Afterwards, various ratios of rosemary oil and surfactant were added to the PVA solution to obtain the emulsions. The emulsion was stirred for approximately 24 hours at room temperature. Subsequently, the emulsion properties were determined, including conductivity (SelectaCD2005), viscosity, and surface tension (measured by the Wilhelmy Plate technique with Biolin Scientific Sigma 702). The surfactant was used to create an oil-in-water emulsion due to the immiscibility of the polymer solutions and REO. Table 1 presents the concentration of polymer, surfactant, and REO used in the study.

Table 1: The concentration of PVA, surfactant, and REO

Sample Codes	PVA (wt%)	Surfactant (wt%)	REO (wt%)
PVA	10	0	0
PVA/REO-0	10	3	0
PVA/REO-2	10	3	2
PVA/REO-4	10	3	4
PVA/REO-6	10	3	6
PVA/REO-8	10	3	8

The nanofibers were fabricated through the emulsion electrospinning process. The electrospinning process parameters (Table 2), including applied voltage, distance between

the needle and collector, and solution flow rate, were optimized and kept constant during the spinning process. The emulsion electrospinning process was conducted under the same ambient conditions for all samples, and the nanofibers were collected on an aluminum sheet for 15 minutes.

Table 2: Process parameters of emulsion electrospinning

Voltage (kV)	Distance Between Electrodes (cm)	Feed Rate (mL/h)	Humidity (%)	Temperature (°C)
21.5	18	0.250	38 (± 2)	20 (± 2)

In the last part of the study, the morphology of the nanofibers, including the fiber diameter, the uniformity of the diameter, and the surface structure of the web, was analyzed using the SEM. Fiber diameters were calculated using Image J analysis software. Statistical analysis of the morphological parameters, such as the fiber diameter histogram, was performed using the SPSS statistical program. The formula below was used to calculate the average fiber diameter uniformity coefficient values:

$$A_n = \frac{\sum n_i d_i}{\sum n_i} \quad (\text{Number average}) \quad (1)$$

$$A_w = \frac{\sum n_i d_i^2}{\sum n_i d_i} \quad (\text{Weight average}) \quad (2)$$

n_i =fiber number

d_i =fiber diameter

The fiber diameter uniformity coefficient was calculated by the ratio of A_w to A_n . The closer the average fiber diameter uniformity coefficient is to 1, the more uniform the fibers [8]. Additionally, the identification of chemical compounds in rosemary essential oil was accomplished using gas chromatography coupled with mass spectrometry (GC-MS).

3. RESULTS AND DISCUSSION

Table 3 presents the conductivity, viscosity, and surface tension values of polymer solutions containing REO.

Table 3: Properties of polymer solutions of PVA with various concentrations of REO

Sample Codes	Conductivity (μS/cm)	Viscosity (Pa·s)	Surface Tension (mN/m)
PVA	309	2.43	41.73
PVA/REO-0	323	4.28	40.13
PVA/REO-2	314	6.46	40.19
PVA/REO-4	300	8.43	37.87
PVA/REO-6	296	9.41	37.03
PVA/REO-8	292	12.61	37.69



The conductivity value of the solution prepared with only a PVA polymer was measured as 309 $\mu\text{S}/\text{cm}$. The addition of a surfactant to the solution resulted in a slight increase in conductivity. However, the subsequent addition of REO to the solutions caused a decrease in conductivity. As the REO content in the solutions increased, the trend of decreasing conductivity persisted. Furthermore, various studies have demonstrated that certain essential oils can reduce conductivity [7, 9].

As anticipated, the viscosity values of the emulsions exhibited an increase in accordance with the REO ratio in the solutions. It is essential to acknowledge that the surfactant also contributed to an elevation in the viscosity of the emulsions to a certain extent. The viscosity of the PVA polymer solution without REO was measured as 2.43 Pa·s. Upon the addition of only surfactant to this solution, the viscosity of the PVA/REO-0 solution was determined to be 4.28 Pa·s. It was also determined that the viscosity continued to increase with the addition of REO to the solutions.

The surface tension values was analyzed to determine the impact of REO addition to polymer solutions. The results indicated that the addition of REO did not significantly alter the surface tension values.

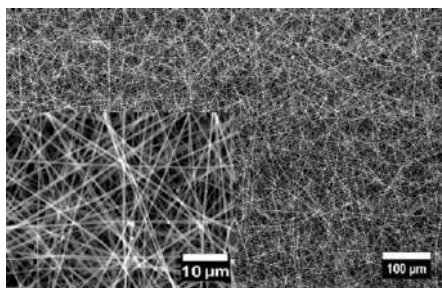
The essential oil of rosemary was subjected to analysis by gas chromatography-mass spectroscopy (GC–MS). A total of 25 components, representing 99.06% of the total oil, were identified in Table 4. The major components were identified as 1.8-cineole (eucalyptol) (58.7%), camphor (9.66%), α -pinene (8.69%), 2- α -pinene (4.08%), borneol (3.55%), camphene (2.96%), α -terpineol (2.49%), respectively. The findings of other studies yielded comparable results [10].

Table 4: Components of REO by GC-MS analysis

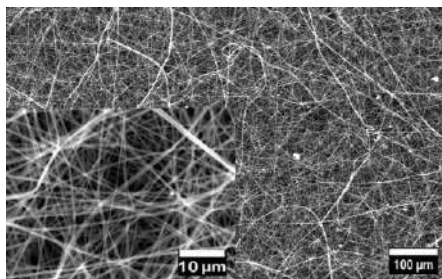
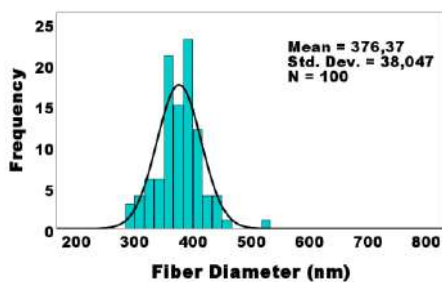
Component Name	% Area
<i>Tricyclene</i>	0.03
<i>α-Thujene</i>	0.01
<i>α-Pinene</i>	8.69
<i>Camphene</i>	2.96
<i>2-α-Pinene</i>	4.08
<i>α-Myrcene</i>	0.89
<i>1-Phellandrene</i>	0.33
<i>α-Terpinene</i>	0.21
<i>o-Cymene</i>	1.98
<i>1.8-Cineole (Eucalyptol)</i>	58.7
<i>cis-ocimene</i>	0.02
<i>ζ-Terpinene</i>	1.70
<i>α-Terpineolene</i>	0.10
<i>α-Linalool</i>	0.41

Camphor	9.66
Borneol	3.55
4-Terpineol	0.61
α-Terpineol	2.49
Exobornyl acetate	1.11
α -Gurjunene	0.02
trans-Caryophyllene	0.77
Aromadendrene	0.52
Alloaromadendrene	0.11
Ledene	0.07
Caryophyllene oxide	0.04

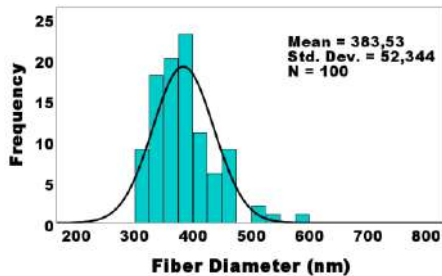
The SEM images and fiber diameter histograms of the PVA/REO nanofiber samples, produced with varying REO concentrations, are presented in Figure 1. These images and histograms are provided at two magnifications: 1.000x and 10.000x.



PVA



PVA/REO-0



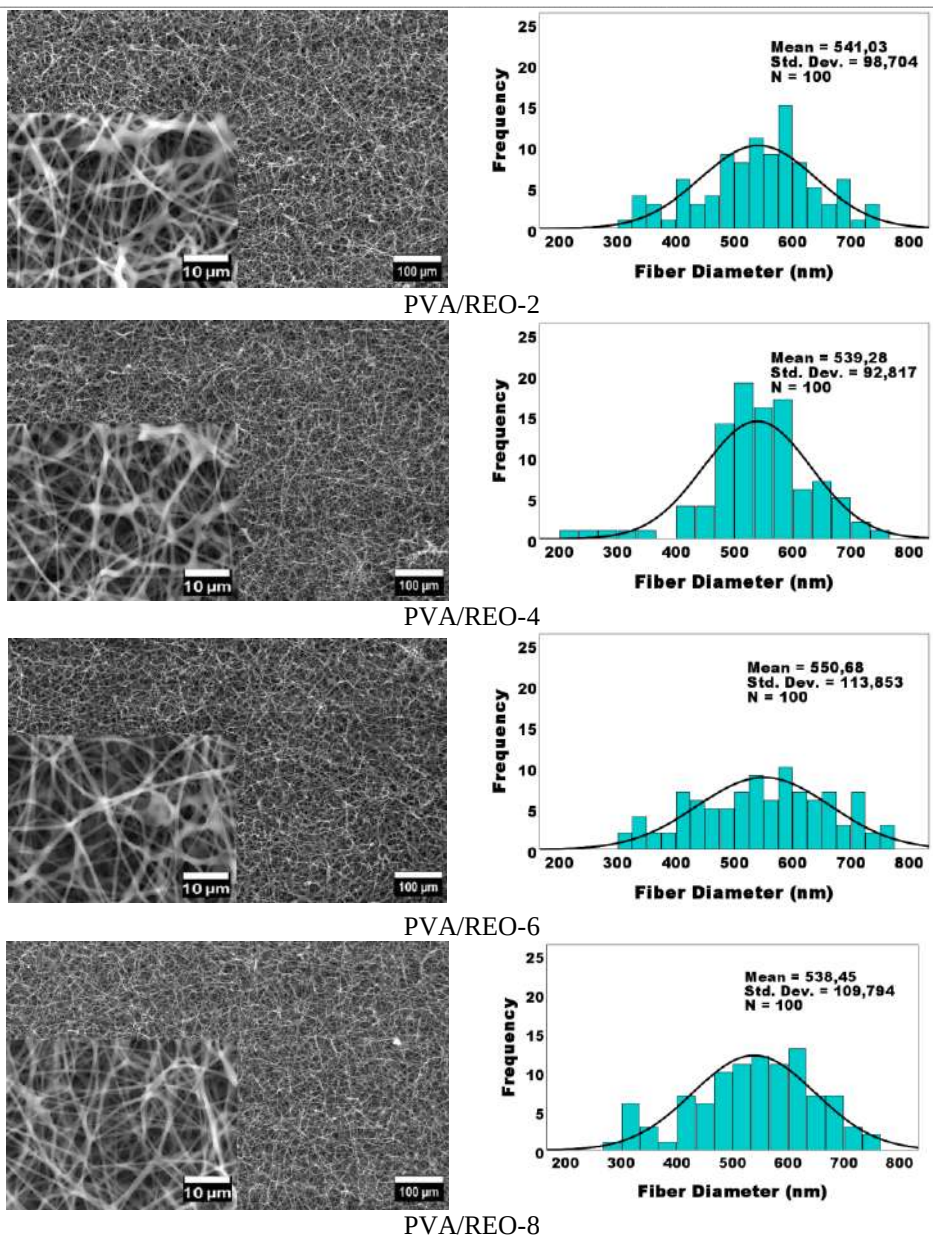


Figure 1: SEM images and fiber diameter histograms of PVA/REO nanofiber samples produced with various REO concentrations (1.000x, 10.000x).

Upon examination of the SEM images of the nanofibers produced at the same process parameters, it was observed that the nanofibers produced exclusively with PVA polymer exhibited thin, smooth, bead-free, and uniform structural characteristics. It was determined that the nanofibers produced by the addition of surfactant to the PVA solution exhibited a uniform structure and that the fineness of the nanofibers was comparable to that of the PVA polymer. The histogram curves of both nanofibers exhibited a single peak, indicating a normal distribution of fiber fineness. Upon examination of the SEM images of the nanofibers obtained by adding REO to the solutions, it became evident that the fibers exhibited a more adhesive appearance. The histograms derived from the SEM images revealed that the standard deviation of the nanofibers containing REO was higher, indicating the formation of nanofibers with disparate fiber diameters (ranging from 200 to 800 nm).

The influence of REO concentration on the average fiber diameter and fiber diameter uniformity coefficient is illustrated in Figure 2.

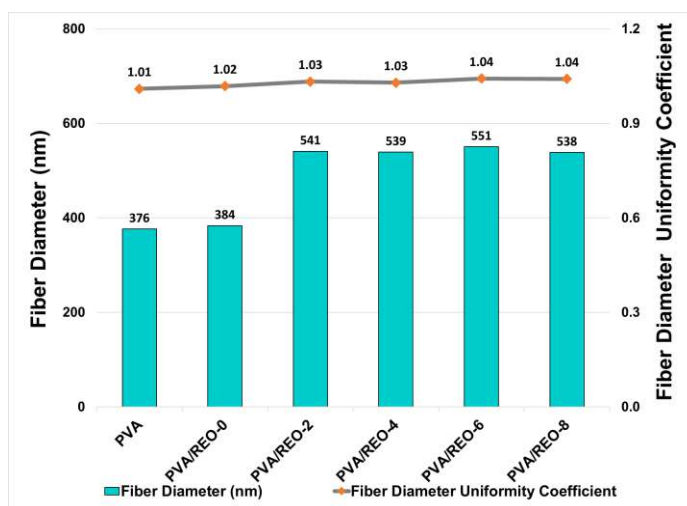


Figure 2: The effect of REO concentration on the average fiber diameter and fiber diameter uniformity coefficient of PVA nanofibers

Figure 3 illustrates that the nanofibers produced with PVA polymer have an average fiber diameter of 376 nm. The average fiber diameter of the nanofibers obtained with the addition of surfactant has an average fiber diameter of 384 nm. Upon examination of the average fiber diameters of the nanofibers obtained by adding REO to the solutions, it was observed that the fiber diameters increased. The average fiber diameter of the nanofibers obtained by adding REO was found to be between 538 and 551 nm. It was determined that the increase of the concentration of REO did not cause a significant change in the average fiber diameter.

Upon examination of the graph of fiber diameter uniformity coefficients, it was found that the addition of REO increased fiber non-uniformity. The fiber diameter uniformity



coefficient of nanofibers without REO was 1.01, while this value increased to 1.04 when REO was added. These results also support the SEM images.

3. CONCLUSION

In this study, REO-loaded PVA-based nanofibrous material (PVA/REO) was fabricated by emulsion electrospinning process. The GC-MS analysis identified 25 components in rosemary oil, with 1.8-cineole (eucalyptol) representing the most abundant (58.7%). According to the obtained results; it was observed that viscosity, spinning performance, fiber morphology, and average fiber diameter were affected by the REO concentration in emulsions. The addition of REO resulted in a noticeable increase in viscosity, while a slight decline in conductivity was observed. There was no significant change in surface tension. The study revealed that it is possible to produce nanofibers from two immiscible liquids, namely rosemary essential oil and an aqueous polymer solution (PVA), using the emulsion electrospinning method. It was noticed that, although REO increased the diameters of the nanofibers produced, the nanofibers exhibited smooth, beadless, and uniform structural properties. Considering the superior properties of rosemary such as being antibacterial and antimicrobial along with those of nanofibers, the composite material produced can be used as a wound dressing.

ACKNOWLEDGMENT

The authors would like to thank Osman BODUR, and Taner ERKAYMAZ, and Süleyman Demirel University Natural Products Application and Research Center (SUDUM) for their contributions during GC-MS analysis.

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SOIL DEGRADATION OF DENIM FABRICS PRODUCED BY DIFFERENT FINISHING TREATMENTS

Original scientific paper
DOI: 10.5937/CT_ITI24014S

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ABSTRACT: This study investigates the effects of some washings and special treatment processes on the biodegradation of denim fabrics. Finishing treatments and special processes were applied systematically on a raw denim fabric to evaluate the effect of individual applications on biodegradation. According to the results, all the finishing processes applied to obtain a worn appearance influence denim fabrics' mechanical and biodegradation properties. Stone washing and its combination with bleaching were determined as the most aggressive applications for denim fabrics. Although a significant decrease was observed, three months of biodegradation is enough to obtain nearly fully damaged fabrics.

Keywords: Biodegradation, denim fabric, finishing, soil, weight loss.

DEGRADACIJA TKANINA OD TEKSASA PROIZVODENA RAZLIČITIM ZAVRŠNIM TRETMANIMA

APSTRAKT: Ova studija istražuje uticaj nekih pranja i procesa specijalnog tretmana na biorazgradnju teksas tkanina. Završni tretmani i specijalni procesi su sistematski primenjeni na sirovu teksas tkaninu da bi se procenio efekat pojedinačnih aplikacija na biorazgradnju. Prema rezultatima, svi procesi završne obrade koji se primenjuju da bi se dobio pohabani izgled utiču na mehanička i biodegradirajuća svojstva teksasa. Pranje kamena i njegova kombinacija sa beljenjem utvrđeni su kao najagresivnije primene za teksas tkanine. Iako je primećeno značajno smanjenje, tri meseca biorazgradnje su dovoljna da se dobiju skoro potpuno oštećene tkanine.

Ključne reči: biorazgradnja, teksas tkanina, završna obrada, zemlja, gubitak težine.

1. INTRODUCTION

Jeanswear is becoming more and more popular all over the world. However, many non-biodegradable and environmentally harmful wastewater is produced during jeanswear production. Although durability is not one of the main concerns of denim product

consumers, wear on fabric because of previously mentioned chemical and mechanical applications may decrease the necessary performance properties of denim products. There are many studies conducted on the effects of different mechanical and chemical finishing processes on the physical and mechanical properties of denim fabric. To the increasing trend in sustainability, studies using recycled fiber, fewer chemicals, and less water in denim production is the new concept in research [1-6].

Sandin and Peters (2018) This paper comprehensively reviews studies of the environmental impact of textile reuse and recycling, to provide a summary of the current knowledge and point out areas for further research [7].

When previous studies were evaluated, it was obvious that there were limited studies about the degradation behavior of denim fabrics. For this purpose, this current research investigates the effect of common treatments on the degradation behavior of denim fabrics.

2. MATERIALS and METHODS

2.1. Materials

There is a systematic experimental plan for the research. The same raw fabric was used and application of different washing/finishing procedures were, eight denim fabrics having different looks and different properties were handled.

One type of denim fabric made of 100% cotton having 3/1 twill weave was used in the research as a raw fabric. Linear density values of the warp and weft yarns were Ne 6 (10,2 tex) and Ne 12 (20,3 tex), fabric setting was 24 and 20 cm-1 for warp and weft directions, and mass per unit area of the raw fabric was 13,1 ons/yd². Seven different washing and fading procedures were applied and eight fabric types were evaluated in terms of degradation behavior for three soil burial periods. Table 1 summarizes the applied finishing processes and shows fabric codes.

Table 1: Washing and special treatment applied on denim fabrics

Fabric code	Explanation of denim fabrics
H	Raw fabric
R	Rinse washed
E	Enzyme treated
T	Stone-washed
TE	Stone-washed, Enzyme treated
TH	Stone-washed, Bleached
TK	Stone-washed, Ice-bleached
OZ	Ozone treated



2.2. Methods

The degradation behavior of fabrics was investigated by soil burial method for different periods. After the last burial period, the soil samples were also examined besides the fabric samples to evaluate the harmful effect in the soil during degradation. Thus, the method part contains two main sections such as the fabric tests before and after the burial period and the soil tests.

Before the soil burial process, fabric thickness, and weight per unit area values (Figure 1) were determined. Photographic and microscopic views of the test samples were taken. Three burial periods were followed such as 1 month, 2 months, and 3 months. After every soil burial period, the visual examination was recorded, and microscopic view and weight loss were determined.

3. CONCLUSIONS

Fabric-breaking strength properties were determined to have a better understanding of the effects of applied treatments and to evaluate biodegradation better. Table 2 shows the results of basic structural properties and breaking strength values. As seen in Table 2, especially stone washing and the processes combined with stone washing destroyed the fabric in a high amount both in warp and weft directions. Besides the most dramatic decrease is obtained for the weft direction of ozone-treated denim fabric. These results were utilized to comment clearly on the biodegradation results. Figure 2 and 3 show the results of soil degraded fabrics..

Table 2: Basic structural and mechanical results of denim fabrics

Denim fabric code	Mass per unit area		Thickness (mm)	Breaking strength (N)	
	g/m ²	(oz/yd ²)		Warp	Weft
H	442,8	(13,1)	0,89	843,5	319,5
R	433,1	(12,8)	1,00	834,6	270,1
E	414,3	(12,2)	1,06	729,6	259,6
T	408,2	(12,0)	1,06	613,2	255,8
TH	423,8	(12,5)	1,00	645,4	233,8
TK	396,8	(11,7)	0,99	639,7	189,7
TE	408,1	(12,0)	0,97	544,4	182,0
OZ	396,2	(11,7)	0,98	657,4	141,3

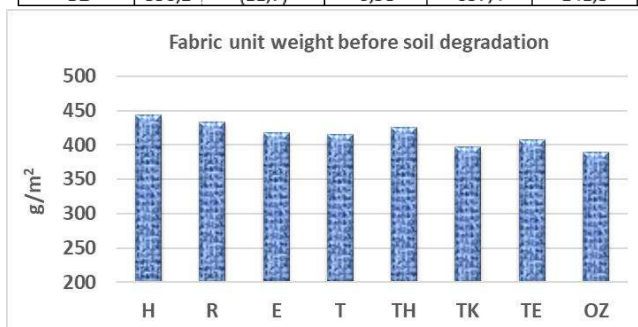


Figure 1: Fabric unit weight before the soil degradation period

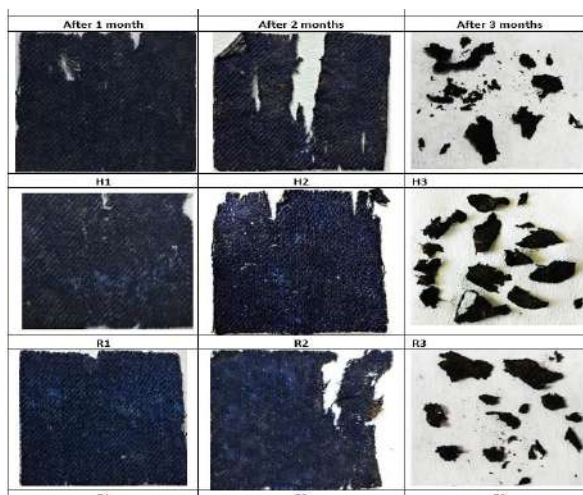


Figure 2: Figure. Photographic views of the H, R, E coded denim fabrics after different soil burial periods (1, 2, 3 months)

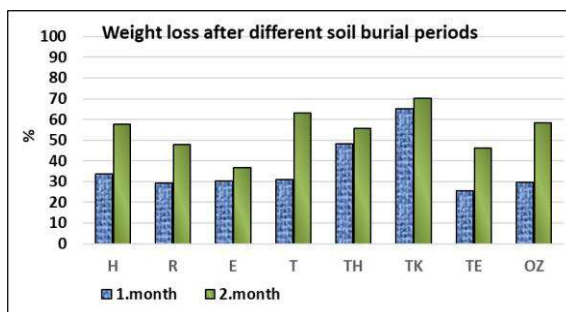


Figure 3: Figure. Weight loss of the denim fabrics after different soil burial periods (1, and 2 months)

The weight loss values of all the test samples were summarized first and illustrated in Figure 3. As seen in Figure 3, the highest degradation was obtained in TK samples for 1 month of buried denim fabrics. Acceleration in degradation was seen for all denim samples. For a two-month burial period, only stone-washed and stone-washed-ice bleached denim fabrics lost their weight by more than 60%. After a three-month degradation period, except for two test fabrics (R, E coded fabrics), all denim fabrics used in the research have lost their weights higher than 80%. The results indicate that the denim fabrics used in the research present good soil biodegradation. Besides this does not mean denim fabrics are not harmful to the environment, As it is well known, the most harmful processes during textile production are dyeing, drying, and finishing processes, and also denim production has a very big negative effect on soil and marine pollution. With the



help of this study, denim garment producers may find a new solution to garment industry tails.

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THE INFLUENCE OF AMBIENT TEMPERATURE ON THE RATE OF COLOR CHANGE OF THERMOCHROMIC INKS

Original scientific paper
DOI: 10.5937/CT_ITI24015M

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ABSTRACT: The aim of this paper is to examine the influence of ambient temperature on the rate of color change of thermochromic inks, which belong to the group of smart materials. Magenta reversible thermochromic ink was used, which was printed by manual screen-printing technique on different types of textile materials. The activation temperature of the used ink is 31°C. The experiment results indicate a relationship between the ambient temperature and the speed of color change, such that higher ambient temperatures cause slower color change and vice versa. Understanding the effect of ambient temperature on the color change of a thermochromic print is important for its more effective use.

Keywords: thermochromic inks, screen printing, color change, smart textiles.

UTICAJ TEMPERATURE OKRUŽENJA NA BRZINU PROMENE OBOJENJA TERMOKROMNIH BOJA

APSTRAKT: Cilj ovog rada je ispitivanje uticaja temperature okruženja na brzinu promene obojenja termohromnih boja, koje spadaju u grupu pametnih materijala. Korišćena je magenta reverzibilna termohromna boja, koja je štampana manuelnom sito tehnikom štampe na različitim vrstama tekstilnih materijala. Temperatura aktivacije korišćene boje je 31°C. Rezultati eksperimenta ukazuju da postoji veza između temperature okruženja i brzine promene boje, tako da veća temperature okruženja uzrokuje sporiju promenu boje i obrnuto. Razumevanje uticaja temperature okruženja na promenu boje termohromnog otiska važna je za njegovu efikasnu upotrebu.

Ključne reči: termohromne boje, sito štampa, promena boje, pametni tekstilni materijali.

1. INTRODUCTION

Thermochromic inks belong to the group of chromic materials, and their main characteristic is their reaction to thermal external stimulus, on the basis of which they can change or lose their coloration [1-2]. Figure 1 shows the color change scheme of thermochromic inks due to temperature changes. The color change of thermochromic inks can be irreversible or reversible. Irreversible inks have the ability to change coloration only once, the first time they react to a thermal stimulus, while reversible inks change coloration with each temperature change [3]. Thermochromic inks contain microencapsulated active material that is dispersed in a suitable binder. The active material determines the color property.

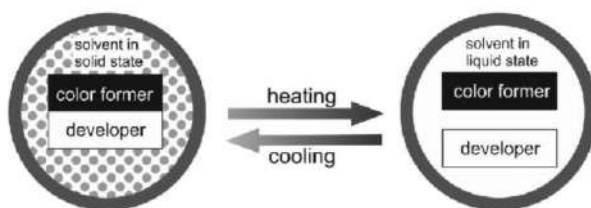


Figure 1: Schematic representation of the color change of thermochromic inks

Thermochromic inks are divided into two groups: leuco dyes and liquid crystals. The main difference between leuco dyes and liquid crystals is that leuco dyes show a single color change with molecular rearrangement. In contrast, liquid crystals have a whole spectrum of color changes from one color to another. They are colorless but change color below the activation temperature of liquid crystals as the temperature increases. For example, when tracking the color change from colorless to red, as the temperature increases, a whole range of colors appear (through orange, yellow, green, blue, and violet). As the orientational structure of the liquid crystal changes with temperature and due to different interactions of light with the liquid crystal to produce color reflection, colors are created by interference. Leuco dyes are easier to handle and are often used in screen printing. They are suitable for use on textiles and have the ability to react to temperatures from -15°C to 60°C . However, most current applications are limited to three standard temperature ranges: cold ($\sim 10^{\circ}\text{C}$), body heat activated ($\sim 31^{\circ}\text{C}$), and warm ($\sim 43^{\circ}\text{C}$). The cold region is used to check the freshness of drinks, i.e. whether they are properly chilled. A body-activated region can be used to cover a piece of information with a layer that can become transparent from body heat. A hot region is usually applied to food packaging to inform the consumer that the food is too hot to eat [4-6].

The application of thermochromic inks is diverse. They can be used as part of packaging, in medicine and security printing, fashion design, sports, etc. There is a growing interest in the use of thermochromic inks in architecture for interior or exterior house coatings, as well as for tiles or wallpaper [7-8].

Given that thermochromic inks can be printed on textile materials, an important factor in the quality of the printed sample is its longevity (colorfastness) and the possibility of continuous manifestation of the thermochromic effect. Thermochromic inks printed on textile materials should be resistant to mechanical damage, such as rubbing and wear, in order to maintain their functionality and aesthetics during a long period of use. Also, it is important that they are resistant to washing in order to preserve their color and the effect of color change over time. In addition, they should be stable when temperature changes to ensure that they only respond to the desired temperature and do not change unpredictably. It is also important that thermochromic inks are resistant to sunlight to ensure that the color will not fade during exposure to the sun.

2. MATERIALS AND METHODS

2.1. Test samples

In this work, two different white textile materials were used as a printing surface. Samples of dimensions 35 x 50 mm were created from both materials, on which one field of dimensions 20 x 20mm was printed. The total number of samples was 6, and for each of them, the weight, thickness, the number of threads per unit length, and the composition of the material were determined. The material characteristics are shown in Table 1.

Table 1: Characteristics of printing substrates

Textile material	Fabric weight g/m ²	Fabric thickness mm	Number of threads per unit length threads/cm		Material composition	
			Wrap	Weft	Type	%
Sample 1	0.405	168.4	26	20	Polyester	100
Sample 2	1.070	238	25	17	Polyester, Elastane	97, 3

The samples were printed manually using the screen-printing technique, using a screen with a mesh count of 120 threads/inch. A rubber squeegee with a thickness of 9 mm and a hardness of 75 A was used for printing. A water-based magenta reversible thermochromic leuco dye with an activation temperature of 31 °C, manufactured by SFXC, was used. According to the manufacturer's instructions, the paint should be prepared by mixing the binder (25 ml) and the pigment (25 ml) in a 1:1 ratio before printing. The samples were dried at a temperature of 160 °C for 2 minutes in a multifunctional device COLO DRY53A.

2.2. Measurements

For the purposes of the research, color, and temperature measurements were made during the time interval during which the thermochromic ink cooled. To determine the temperature of the samples, a thermal imaging camera, Fluke TiS45, was used at a distance of 1 meter from the samples, at an angle of 45 °. The obtained temperature values were used to analyze the cooling rate of thermochromic prints.

In order to determine the color of the print, a colorimetric measurement was performed using a Techkon SpectroDens spectrophotometer (Germany). Measuring geometry 0/45, 2 ° standard observer, and D50 illumination were used. Colorimetric testing yielded CIE Lab coordinates that were used to calculate the color difference. To calculate the absolute color difference, the following formula is used, where ΔE^* is the absolute color difference, ΔL^* is the difference in brightness, Δa^* is the difference on the red/green axis, and Δb^* is the difference on the yellow/blue axis.

$$\Delta E^* = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \quad (1)$$

Color difference values are divided into the following groups: $\Delta E < 1$ (the difference is not noticeable), ΔE between 1 and 3 (visible difference only to the trained eye), ΔE between 3 and 6 (the color difference can be seen by the untrained eye) and ΔE over 6 (obvious color deviations) [9].

2.3. Procedure

As it is necessary to reach the activation temperature of the ink in order for it to change its coloration, which in this work was a temperature of 31 °C, the samples were heated on a stone slab for 2 minutes at a temperature of 50 °C (Figure 2). After 2 minutes, the samples were removed from the heated stone slab to gradually cool down so that the thermovision and colorimetric characteristics could be monitored and the relationship between them could be established through analysis. This procedure was repeated for both samples under conditions of different external temperatures. Since two different textile materials of different thicknesses were used in the experiment, the cooling time was different. The time interval for cooling the first sample was 1 minute, while for the second sample, the cooling time and measurement period were twice as long, 2 minutes. The ambient conditions that were present during the experiment were measured using an Extech RH520A device. The temperature during the first measurement was 22 °C ± 2 °C, while during the second measurement, the temperature was 26 °C ± 2 °C.

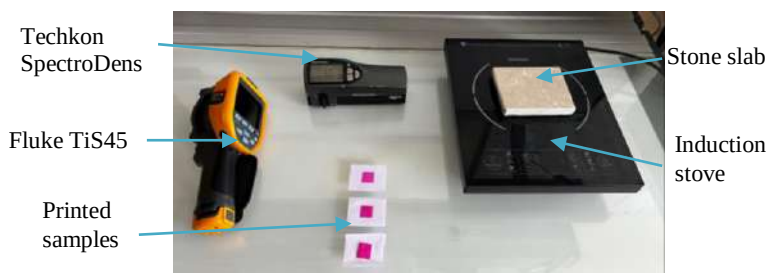


Figure 2: Experimental setup

3. RESULTS

3.1. Thermovision measurements

Figures 3 and 4 show the rate of temperature change during the print cooling time for both samples in different ambient temperature conditions. By analyzing the graphs obtained, it can be seen that the values of the rate of temperature change are different for both samples, which was expected. Also, it can be noticed that the ambient temperature has an effect on the rate of temperature change on the print.

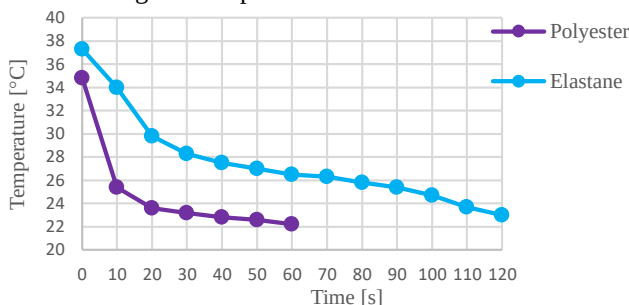


Figure 3: Comparative display of temperature changes over time at a temperature of 22°C

At the beginning of the measurement, sample 1 had a temperature of 34.5 °C, and at the last measurement, 22.3 °C, which is a total temperature change of 12.2 °C. Sample 2 at the beginning of the measurement had 37.3 °C, and at the end, 23.4 °C, so it changed the temperature by 15 °C. A greater degree of temperature change between measurement intervals before reaching the activation temperature was shown by sample 1, where the difference was 9.1 °C, compared to sample 2, where the change between measurement intervals was 3.3 °C and 5 °C. By comparing both samples at an ambient temperature of 22 °C, it can be concluded that sample 1 cooled faster.

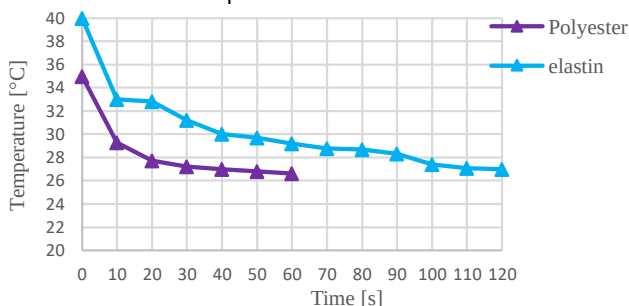


Figure 4: Comparative display of temperature changes over time at a temperature of 26°C

Sample 1 had a temperature of 35 °C at the beginning of the measurement, while 26.8 °C was measured at the last measurement, which is a total temperature change of 8.2 °C. Sample 2, at the beginning of the measurement, had a temperature of 40 °C and, at the end, 2 °C, so it changed the temperature by 13 °C. A greater degree of temperature change

between measurement intervals before reaching the activation temperature was shown in sample 2, where the difference was 7.2 °C, compared to sample 1, where the change between measurement intervals was 5.8 °C, but in sample 1, the color is activated faster, in less time. By comparing both samples at an ambient temperature of 26 °C, it can be concluded that sample 2 cooled more, but that sample 1 cooled faster, i.e. it reached the print activation temperature first.

By analyzing the measurement results for both different ambient conditions, it can be concluded that the temperature of the ambient influences the temperature change rate of thermochromic inks. A higher ambient temperature results in a smaller temperature change and a higher value for the minimum temperature during the print cooling time intervals for both samples.

3.2. Colorimetric measurements

The measured CIE Lab values were used to calculate the absolute color difference. The aim of this analysis was to determine the effect of ambient temperature on the color change of the print during its cooling time. Figures 5 and 6 present comparative views of the color difference for both samples with time intervals of 10 seconds each for ambient temperatures of 22 °C and 26 °C. It can be noticed that both samples have a different color change in each measurement time interval and that the color change values increase as the print cools, which is expected.

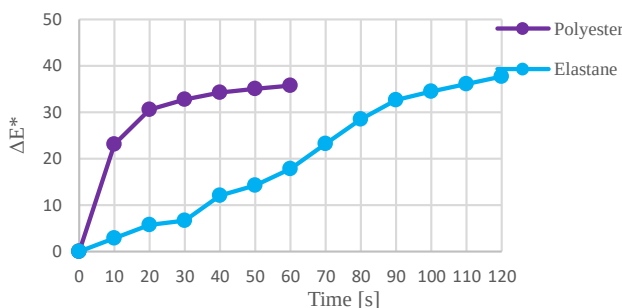


Figure 5: Comparative display of changes in absolute color difference over time at a temperature of 22 °C

In Figure 5, it can be seen that the color difference values are significantly higher in sample 1, which is consistent with the thermovision measurements. As a color difference over 5 is considered a massive difference, it can be seen that with sample 1 at every value interval, the color differences are clearly noticeable. With sample 2, the color differences have smaller values, but those after the second measurement interval are also in the group of differences that are considered massive.

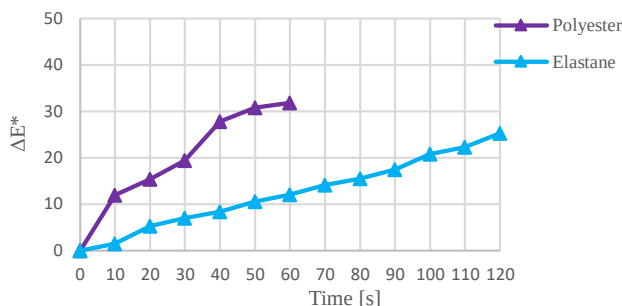


Figure 6: Comparative display of changes in absolute color difference over time at a temperature of 26 °C

In Figure 6, it can be seen that at an ambient temperature of 26 °C, sample 1 also has higher color change values. For sample 1, a color change was recorded at all time intervals, which is considered a massive difference. The color difference values of sample 2 and at a higher temperature have smaller values, and from the second measurement time interval, they also have a massive color difference.

A greater color difference in the time interval between reaching the activation temperature was observed in samples tested at an ambient temperature of 22 °C, which is another proof that the ambient temperature also affects the color change of the prints due to their gradual cooling.

3. CONCLUSION

This research has shown that the ambient temperature significantly affects the rate of change of coloration of thermochromic inks. The analysis of the measurement results in different ambient temperature conditions showed that higher ambient temperatures result in a smaller temperature change and a smaller color change in both samples.

Controlling the ambient temperature conditions plays an important role in the application of thermochromic inks, which is particularly important for industries such as security printing, packaging, or fashion design. Understanding how ambient temperature affects the performance of thermochromic inks can contribute to their optimization and more efficient use in practical applications. Further research focuses on testing different types of thermochromic inks and studying the long-term effects of exposure to changing temperature conditions.

ACKNOWLEDGEMENT

This research has been supported by the Ministry of Science, Technological Development and Innovation (Contract No. 451-03-65/2024-03/200156) and the Faculty of Technical Sciences, University of Novi Sad, through project “Scientific and Artistic Research Work of Researchers in Teaching and Associate Positions at the Faculty of Technical Sciences, University of Novi Sad” (No. 01-3394/1).



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PECTIN/CHASTE BERRY OIL NANOEMULSIONS AND NANOFIBERS FOR WOMEN'S MEDICAL TEXTILES

Original scientific paper
DOI: 10.5937/CT_ITI240160

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ABSTRACT: Pectin(P)/chaste berry oil (CBO) nanoemulsions (NEs) and nanofibers (NFs) were generated and characterized in this study. First, processing conditions of CBO NEs were optimised employing ultrasonication process by using aqueous pectin solutions. An ultrasonication time of 5 min in the absence of a surfactant, i.e., Tween 80, delivered the smallest droplet sizes of 329 ± 10 nm. Electrospinning solutions containing P/CBO NEs were prepared with the addition of polyethylene oxide (PEO), dimethyl oxide (DMSO), and Triton X-100. Electrospinning processing conditions were optimised to obtain stable and homogeneous fibrous membranes of P/CBO NEs. Neat pectin nanofibers exhibited a fiber diameter of ca. 400 nm. Addition of CBO increased the fiber diameters (ca. 500 nm) and pore sizes generally.

Keywords: Pectin, chaste berry oil, nanoemulsion, nanofiber.

NANOEMULZIJE ULJA PEKTINA/ČEDNIH BOBICA I NANOVLAKNA ZA ŽENSKI MEDICINSKI TEKSTIL

APSTRAKT: U ovoj studiji su generisane i okarakterisane nanoemulzije (NE) i nanovlakna (NF) pektin(P)/ulje čednih bobica (CBO). Prvo, uslovi obrade CBO NE su optimizovani korišćenjem procesa ultrazvučne obrade korišćenjem vodenih rastvora pektina. Vreme ultrazvučne obrade od 5 minuta u odsustvu surfaktanta, tj. Tveen 80, dalo je najmanju veličinu kapljica od 329 ± 10 nm. Electrospinning rastvori koji sadrže P/CBO NE pripremljeni su dodatkom polietilen oksida (PEO), dimetil oksida (DMSO) i Tritona Ks-100. Uslovi obrade elektrospinovanjem su optimizovani da bi se dobile stabilne i homogene vlaknaste membrane P/CBO NE. Čista pektinska nanovlakna su pokazala prečnik vlakana od ca. 400 nm. Dodavanje CBO povećalo je prečnik vlakana (oko 500 nm) i veličinu pora uopšte.

Ključne reči: Pectin, chaste berry oil, nanoemulsion, nanofiber.

1. INTRODUCTION

Pectin is a natural polysaccharide, which is extensively extracted from citrus fruit peels and apple pomace [1,2]. Pectin mainly consists of D-galacturonic acid units, joined in chains by means of α (1–4) glycosidic linkages [2,3] with alternating side chains of α (1–4) D-galactose and D-arabinose (1,4). The carboxylate groups of the uronic acids are often present as methyl and carboxamide esters, which are formed as a part of commercial treatment. Thus, pectin is widely represented as the methyl ester of poly(galacturonic acid) [2]. The ratio of esterified galacturonic acid groups to the total galacturonic acid groups is termed as the Degree of Esterification (DE). Pectin with an esterification degree of higher than 50% is regarded as High methoxyl (HM) pectin and with less than 50% is termed as low methoxyl pectin [5]. The chemical structure of pectin is given in Figure 1.

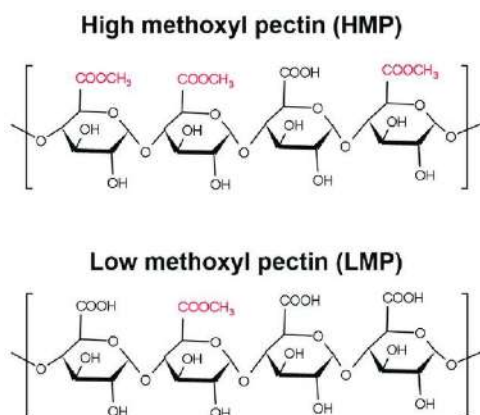


Figure 1: Pectin structure [6]

Pectin has recently received significant attention in biomedicine as drug delivery agents. Several pectin and herbal extract containing formulations have been used in biomedical applications [7-9]. One of their formulation forms is nanofibers, which are defined as the fibres having the diameter of 50 to 500 nm. Electrospinning is the most effective and advanced method for generating nanofibers. It is a process of making nanofibers through high electric charge and voltage. The system consists of polymer solution/melt in a syringe, mounted on a syringe pump, operating at a constant slow speed. High voltage (5-20 kV) direct current supply is connected to the needle of the syringe to charge the fluid. With sufficient voltage, the fluid forms a Taylor cone and then jet erupts from the cone towards the collector plate [10,11] (Figure 2).

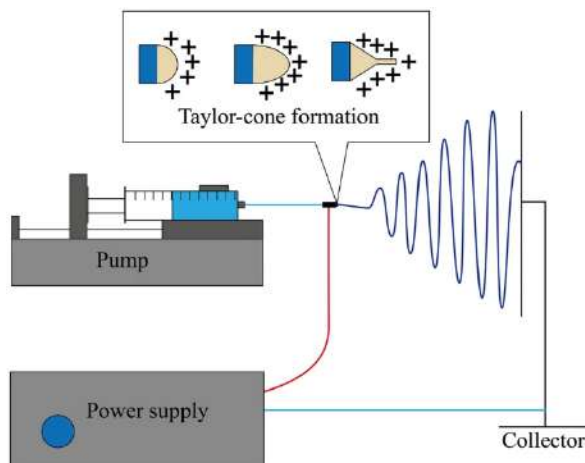


Figure 2: Experimental setup for electrospinning [12].

Many herbal extracts and oils including chaste berry oil (CBO) have been traditionally used for women's health. CBO has a reputation for regulating female menstrual cycles [13,14]. Pectin and herbal essential oils can be brought together in the form of an emulsion. Emulsion is defined as the dispersion of two immiscible liquids. Here, spherical droplets form the dispersed phase, while the liquid surrounding it forms the continuous phase [15,16]. Nowadays, nanoemulsions having a droplet size of 20 to 500 nm [17] have attracted great attention. This is the first study, in which pectin/chaste berry oil nanoemulsions and nanofibers were generated and characterized.

2. EXPERIMENTAL PART

2.1. Materials

Low methoxyl citrus pectin and poly (ethylene oxide) (PEO) (4000 kDa), dimethyl sulfoxide (DMSO) (ACS Reagent, >99.90), Triton™ X-100 (laboratory grade), Tween® 80 and all other chemicals and solvents were purchased from Sigma Aldrich Pty. Ltd, Australia.

2.2. Preparation of Pectin Chaste Berry Oil Nanoemulsions

First, pectin and PEO solutions were prepared. Pectin (6 wt.%) and PEO (2 wt.%) were added to pre-heated ultrapure water and stirred overnight at 75°C, 1000 rpm and 90°C, 1400 rpm, respectively (**Figure 3**). CBO to Tween80 (T80) ratio was chosen as 1:0, 1:1, 1:2, 1:4. For preparing the nanoemulsions, calculated amounts of T80 were added to pectin solution and vortexed for 2 min. After that, CBO was added and vortexed for 2 min again. Finally, ultrasonication (US) process was carried out employing Omni Ruptor 400 (Omni International, Inc, USA). Emulsions were ultrasonicated at 20 kHz, 50% power (400 Watts), 70% pulse for 0, 1, 5, 10, and 20 min. Notations used for pectin/CBO NEs are given

in Table 1. Just vortexed samples were designated as 0 min ultrasonication. Emulsions without surfactant (T80) were also prepared as reference.



Figure 3: Preparation of pectin and PEO solutions.

Table 1: The notation used for preparing P/CBO NEs.

Explanation		Notation				
		0 min	1 min	5 min	10 min	20 min
CBO/T80 ratio	1/0	P.0	P.1	P.5	P.10	P.20
	1/1	PT1.0	PT1.1	PT1.5	PT1.10	PT1.20
	1/2	PT2.0	PT2.1	PT2.5	PT2.10	PT2.20
	1/4	PT4.0	PT4.1	PT4.5	PT4.10	PT4.20

2.3. Preparation and Electrospinning of Pectin Solutions with Chaste Berry Oil

5% DMSO and 1% Triton™ X-100 were added to the previously prepared P/CBO NEs and stirred for 1 hour at 1000 rpm. Afterwards, 2 wt.% PEO 4000 kDa was added and stirred at ambient temperature for 3 hours. The generated solutions were able to be electrospun with a feed rate of 0.5 ml/h under the applied voltage of 15 kV. Needle-to-collector distance was 21 cm.

2.4. pH, Electrical Conductivity, and Surface Tension of Nanoemulsions and Electrospinning Solutions

The pH and electrical conductivity of solutions and nanoemulsions were measured using a pH meter (Mettler Toledo SevenEasy pH-Meter) and conductivity meter (TPS, WP-Plus), respectively. Surface tension measurements were performed in air atmosphere and room temperature using the Attension Theta Flow Premium Contact Angle Optical Tensiometer (nanoScience Instruments Inc.).

2.5. Droplet Size Measurements of Pectin/CBO Nanoemulsions

Droplet size measurements were performed with the Zetasizer Nano ZS (Malvern Panalytical Ltd, UK).

2.6. Scanning Electron Microscopy of Pectin/CBO Nanoemulsions and Nanofibers

Morphology of the P/CBO nanofibers was observed by field emission gun scanning electron microscopy (FE-SEM) (Zeiss Supra 1555 VP). Images were acquired using the secondary electron detector at an accelerating voltage of 2-5 kV and a working distance of 9-11 mm.

3. CONCLUSION

3.1. pH and Electrical Conductivity of Pectin/CBO Nanoemulsions

pH and electrical conductivity are given in **Table 2**. Ultrapure (UP) water has a pH value of 5.53 ± 0.02 . The pectin solution (6 wt.%) prepared using UP water has a pH value of 3.78 ± 0.01 . Independent of ultrasonication time, P/CBO NEs without surfactant exhibited nearly the same pH values changing between 3.83 ± 0.01 and 3.88 ± 0.01 . Incorporation of surfactant delivered the same results. Their pH values increased only slightly.

Ultrapure (UP) water used has an electrical conductivity value of $0.055 \mu\text{S/cm}$. P/CBO NEs prepared without T80 delivered substantially increased conductivity values (P.0: $2595 \pm 101 \mu\text{S/cm}$). However, application of ultrasonication didn't change the electrical conductivity considerably (P.1: $2645 \pm 87 \mu\text{S/cm}$ and P.20: $2561 \pm 95 \mu\text{S/cm}$). Usage of T80 in PT1 denoted samples didn't have any notable effect on the conductivity, either.

Table 2: pH and electrical conductivity of P/CBO NEs.

Notation	pH	Conductivity (μScm^{-1})
P.0	3.88 ± 0.01	2595 ± 101
P.1	3.84 ± 0.02	2645 ± 87
P.5	3.87 ± 0.01	2700 ± 120
P.10	3.88 ± 0.04	2480 ± 201
P.20	3.83 ± 0.01	2561 ± 95
PT1.0	3.93 ± 0.04	2680 ± 125
PT1.1	3.88 ± 0.01	2784 ± 101
PT1.5	3.76 ± 0.01	2721 ± 200
PT1.10	3.81 ± 0.03	2703 ± 142
PT1.20	3.96 ± 0.06	2801 ± 187

3.2. Droplet Size Distribution of P/CBO NEs

Droplet sizes of P/CBO NES are presented in **Table 3**. The smallest sizes were achieved when no surfactant was used. And, the smallest droplet sizes (329 nm) could be obtained in the absence of surfactant applying an ultrasonication time of ca. 5 min. Accordingly, pectin acted as an emulsifier to prepare P/CBO nanoemulsion. However, addition of surfactant increased droplet sizes in all experiments. Apparently, surfactant usage was detrimental to formation and stability of pectin/CBO nanoemulsions.



3.3. pH, Electrical Conductivity, and Surface Tension of Pectin Electrospinning Solutions

The results are presented in **Table 4**. Comparison of these data with those obtained from the P/CBO NEs delivered the following results: Generally, pH values increased 0.3 unit and conductivity decreased 300 units. UP water has a high surface tension value of 71.26 ± 0.24 mN/m. On the other hand, the neat Tween 80 and the neat CBO have substantially lower surface tension values of 31.68 ± 0.05 and 27.61 ± 0.32 mN/m, respectively. P/CBO electrospinning solutions delivered surface tension values varying between 29.72 ± 0.09 and 30.56 ± 0.04 mN/m.

Table 3: Droplet size of P/CBO NEs.

Notation	0 day	
	Z-Aver. (nm)	STD Dev.
P.0	379	19
P.1	337	25
P.5	329	10
P.10	384	10
P.20	345	13
PT1.0	813	2
PT1.1	612	3
PT1.5	497	2
PT1.10	472	5
PT1.20	526	14
PT2.0	880	5
PT2.1	792	26
PT2.5	762	12
PT2.10	680	1
PT2.20	594	7
PT4.0	778	2
PT4.1	819	57
PT4.5	779	2
PT4.10	570	18
PT4.20	541	7

3.4. Morphology of Pectin/CBO Nanofibers

Pectin nanofibers presented an average diameter of 389 ± 87 nm. CBO containing samples delivered either nearly the same (364 ± 61 nm for only vortexed sample, ES.PSCBO.0) or slightly increased (474 ± 131 nm for 10 min ultrasonicated sample, ES.PSCBO.10) average

diameter. Addition of surfactant resulted in either constant (341 ± 53 nm for only vortexed sample, ES.PSCBOT.0) or considerably increased (601 ± 98 nm for 10 min ultrasonicated sample, ES.PSCBOT.10) fiber diameters.

3.5. Pore Size Distribution of Pectin/CBO Nanofibers

Porometer measurements were done to quantify pore sizes of pectin nanofibers generated. To do so, the instrument performs first wet and then dry measurements. Reference material, i.e., pectin nanofibers, had a mean value of 6.63 ± 1.24 μm . Addition of CBO to the nanofibers generally led to a decrease in pore sizes. Usage of surfactant further decreased the pore sizes.

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A JOURNEY FROM WASTE TO DYEING OF WOOL

Original scientific paper
DOI: 10.5937/CT_ITI24017B

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ABSTRACT: Waste management has become a critical issue for sustainable development in manufacturing industries and therefore in textile processing. In the light of this argument an approach for the valorization of a waste come out in yarn spinning processes is presented in this paper. The waste valorized in this context is the dust absorbed from the spinning mill by air conditioners during yarn production. The “air conditioning dust (ACD)” belongs to a cotton yarn spinning line was subjected to a dye extraction process by soxhlet and the solution obtained from the extraction period was used in the coloration of the wool. It was observed that ACD has potential for the coloration of the wool in brown shades. Since the waste was assumed as containing cellulosic structures along with some other dust, the process was called as natural dyeing and different mordants during the dyeings were tested. Additionally, the different dye bath pHs were investigated too. For the evaluation of the results, fastness values and the color analysis of the dyed samples were conducted. It was observed that the ACD has the potential for the coloration of the wool and so can be valorized by this way.

Keywords: Waste, wool, textile, dyeing, natural dyeing, sustainability.

PRELAZAK OD OTPADA DO BOJENJA VUNE

APSTRAKT: Upravljanje otpadom postalo je kritično pitanje za održivi razvoj u proizvodnim industrijama, a samim tim i u preradi tekstila. U svetlu ovog argumenta u ovom radu je predstavljen pristup za valorizaciju otpada koji nastaje u procesima pređenja. Otpad koji se valorizuje u ovom kontekstu je prašina koju klima uređaji

Savez inženjera i tehničara tekstilaca Srbije



apsorbuju iz predionice tokom proizvodnje prediva. Prašina za klimatizaciju (ACD) koja pripada liniji za pređenje pamučnog prediva je podvrgnuta procesu ekstrakcije boje soxhletom, a rastvor dobijen tokom perioda ekstrakcije je korišćen za bojenje vune. Primećeno je da ACD ima potencijal za bojenje vune u smeđim nijansama. Pošto se pretpostavljalo da otpad sadrži celulozne strukture zajedno sa nekom drugom prašinom, proces je nazvan prirodnim bojenjem i testirani su različiti jedlači tokom bojenja. Pored toga, ispitani su i različiti pH vrednosti kupatila. Za procenu rezultata sprovedene su vrednosti postojanosti i analiza boje obojenih uzoraka. Primećeno je da ACD ima potencijal za obojenje vune i da se može valorizovati na ovaj način.

Ključne reči: *Otpad, vuna, tekstil, bojenje, prirodno bojenje, održivost.*

1. INTRODUCTION

The global textile industry provides significant employment opportunities with its complex production chain and has an important place in the global market. On the other hand, the textile industry may contribute to climate change by consuming significant amounts of natural resources, causing high levels of water pollution and greenhouse gas emissions [1]. It would not be wrong to say that the textile industry is in transformation in terms of sustainable development demands. Three concepts related to sustainable development, namely social, economic and environmental, actually come to life in the textile industry. Solid waste related to textile production-consumption can be in huge amounts [2]. Because of this, waste management is an important issue for textile industry. In this study, an approach to valorize a waste from the cotton yarn spinning line is shared. Different wastes/byproducts can come out during the cotton yarn spinning process and in a previous study filter waste was used in paper making as a raw material [3]. In current study, filter waste in other words “air conditioning dust (ACD)” belongs to a cotton yarn spinning line was valorized as a dye source. Usage of natural sources in this respect has classified in 3 different approaches, one of which was set on the use of natural wastes within the scope of waste management [4]. Natural dyes are obtained from natural materials and commonly classed as plant, animal, mineral, and microbial based [5,6]. Because the source of this waste (ACD) was assumed as mostly related about cotton fibers, cellulosic seeds and coats, minerals/dust belongs to ambient; the waste was evaluated as a natural dye source and employed in coloration of wool.

2. MATERIALS AND METHODS

Natural dyeing of the woven wool fabrics with air conditioning dust (ACD) was managed after an extraction process on ACD by water. Standard soxhlet equipment shown in Figure 1 was employed for this purpose and 5 g ACD was extracted with 250 ml of water for 5 hours. Then the obtained solution was used as dye bath for dyeing of the wool fabrics. Dyeings were performed with these extract without use of any mordant at three different pHs (4-8-10). In natural dyeing, mordant usage is a general practice to fix the color on fiber

and improve fastness [7]. Hence different mordants were employed in this paper (Figure 1). For this purpose $K_2Cr_2O_7$, $SnCl_2 \cdot 2H_2O$, $FeSO_4 \cdot 7H_2O$ and $CuSO_4 \cdot 5H_2O$ were utilized at a concentration of 2% (owf) and $KAl(SO_4)_2 \cdot 12H_2O$ was used at 20% (owf). On the other hand, it should not be forgotten that some metal based mordants such as Cr-based mordants have harmful effects. However, they were tested in this study to see their effects on colors and fastness in dyeing with this new dye source.

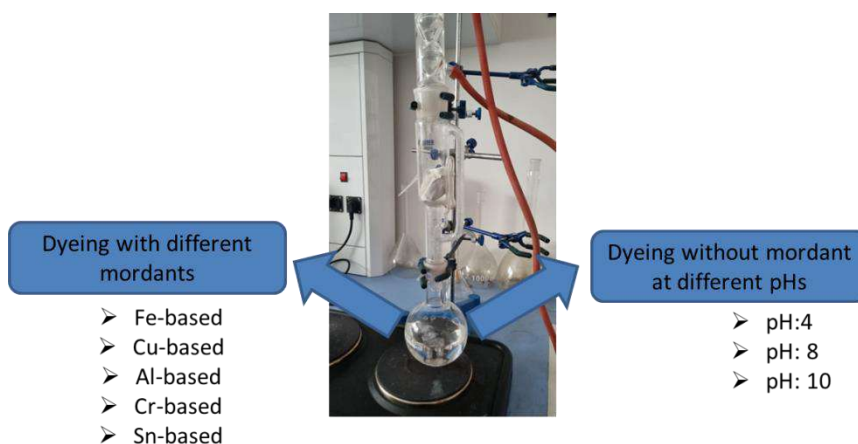


Figure 1: Soxhlet system and dyeing parameters in ACD based wool dyeing

In the light of the details shown in Figure 1, dyeing of the wool was conducted at a liquor ratio of 1:40 (fabric weight to extract volume ratio). Fabric was directly added to the dye solution (extract) after the pH adjustments in mordant-free dyeings or after the addition of the mordants without any pH adjustment in mordant based dyeings. After addition of the fabrics to bath at 30° C the dyeing was carried out for 10 min and then the dye bath temperature was raised to 98° C with a heat rate of 1.5° C/min. At this temperature the dyeing was conducted for 40 minutes and then the dyeing was finished and samples were washed to get rid of excess dye.

The dyed samples were then tested in terms of light and washing fastness according to the standards; ISO 105-B02 [8] and ISO 105-C06 [9] respectively. Furthermore the color analysis that means CIE $L^*a^*b^*$ color values and K/S – color strengths of the samples were obtained by the use of Konica Minolta CM 3600d spectrophotometer (Konica Minolta, Inc., Japan). Meanwhile, the extracts were analyzed with the help of PG Instrument T70 UV/VIS spectrophotometer (PG Instruments Limited, UK).

3. RESULTS AND DISCUSSION

Yarn production is a complicated procedure comprised the processes belongs to the fiber cleaning, drawing and spinning. During these processes, waste may occur at different steps. One of them is air conditioning dust (ACD) and in this study ACD belongs to a cotton yarn

spinning line was subjected to extraction and used in dyeing of wool. As seen from the Figure 2, it contains dust, dirties, cellulosic wastes and also cotton fibers.

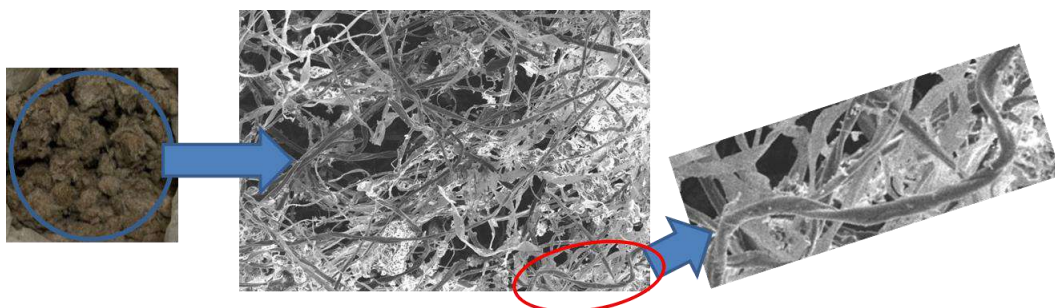


Figure 2: The ACD belongs to cellulosic yarn spinning line

This waste was applied to soxhlet based extraction process as detailed in materials and methods part and as seen in Figure 3 a colorful bath which will be employed as dye bath can come out. The absorbance curve shown in Figure 3 was obtained after a dilution and no specific-significant peak was observed within the range of 400-700 nm because of the color of the extract.

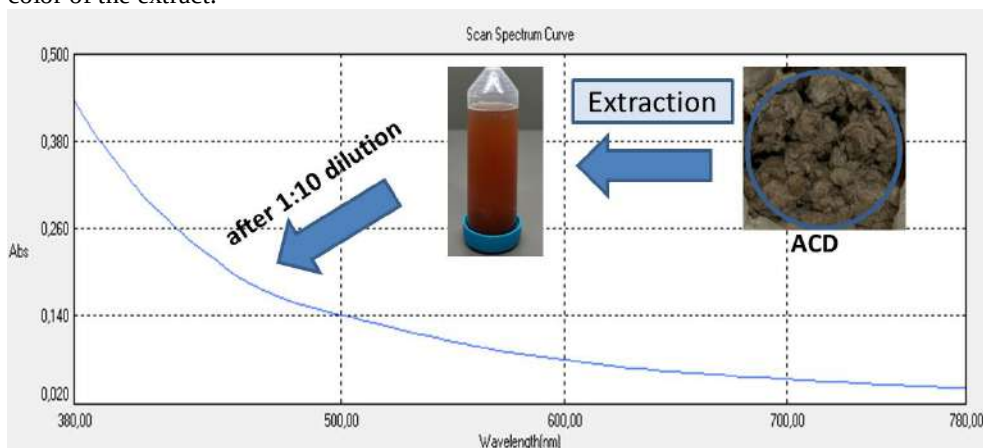


Figure 3: Absorbance curve of the ACD extract after 1:10 dilution

A red-brown bath was obtained by this extraction as presented in Figure 3 and as shown in Table 1 and 2 brown colors in different shade were obtained in general by using this bath/extract for the dyeing of the wool. The dyeing procedure was applied at 2 different steps as detailed. Firstly, the only use of extract at different pHs was tested. pH 8 was the own pH of the extract and at this pH the bath/extract was found as able in dyeing of wool. In other word without any intervention to the extract like pH adjustment or mordant addition, wool dyeing can be managed successfully. Color strength of 3.25 can be obtained

with a light fastness of 4/5 and washing fastness of 4/5 (staining on wool) and 5 (color change).

Table 1: ACD based dyeing without use of any mordant at different pH

	Washing Fastness		Light Fastness	Color Values						Photos of samples
	Sta.	C.C.		L*	a*	b*	C*	h ^o	K/S	
pH:4	4/5	4/5	5	62.31	3.84	21.36	21.7	79.8	3.34	
pH:8	4/5	5	4/5	62.88	6.83	20.14	21.27	71.27	3.25	
pH:10	4/5	5	5	64.73	4.37	19.19	19.69	77.17	2.64	
Sta.: Staining of wool; C.C.: Color Change										

The increase in the dye bath pH from 8 to 10 was found as caused a slight decrease in color strengths to 2.64. Meanwhile the lightness of the color was lighten and L* value was found as increased from 62.88 to 64.73. But no significant changes in fastness values were observed, just an increase (from 4/5 to 5) in light fastness was found. On the other hand, the dyeing at pH 4 was also tested and in terms of the color strengths near results obtained from the samples dyed at pH 8 was observed. The L* values of the samples (dyed at pH 4 and 8) were near to each other as well (Table 1). The hue angels of all samples were all in same region (yellow-red) and so the samples were all in brown colors with different shades. But the redness of the sample dyed at pH8 was found higher than the other ones with an a* value of 6.83.

The mordant addition to the extracts and dyeing with these baths were also tested within the scope of the study. The results of these experiments were presented in Table 2. It was clearly observed that addition of the mordants to dye baths/extracts was caused higher color strengths with darker shades. Besides, addition of different mordants was cause different shades so color shifts. Highest color strength was occurred by the use of copper salts and K/S:7.28 was observed. Meanwhile the lowest color strength among mordant based dyeings was observed from the sample dyed with Cr-based mordant which was 4.13. Meanwhile the darkest color was found by the use of copper salt with the lowest value of redness (L*:51.94; a*:4.73). The use of tin salts in dyeing was caused highest L* value of 63.18 and highest yellowness (b*: 24.76). For this case the hue angle was found as 77.96. On the other hand, the Cr-based mordant usage caused b* value of 18.55 which was the lowest one among the whole mordant based dyed samples. For the other mordants; Al and Fe – based mordants the K/S values were found as 5.52 and 4.7 respectively. For these two samples the hue angel was almost same.

**Table 2:** ACD based dyeing with use of different mordants

	Washing Fastness		Light Fastness	Color Values						Photos of samples
	Sta.	C.C.		<i>L</i> *	<i>a</i> *	<i>b</i> *	<i>C</i> *	<i>h</i> ^o	<i>K/S</i>	
Al-based mordant	4/5	5	5	55.95	8.92	23.23	24.88	69	5.52	
Fe-based mordant	4	4/5	5	58.27	8.49	22.52	24.07	69.34	4.7	
Cu-based mordant	4	4/5	5	51.94	4.73	22.61	23.1	78.19	7.28	
Cr-based mordant	4/5	5	4/5	57.86	4.8	18.55	19.17	75.48	4.13	
Sn-based mordant	4/5	5	5	63.18	5.28	24.76	25.32	77.96	4.9	
<i>Sta.: Staining of wool; C.C.: Color Change</i>										

The fastness values of the mordant based dyed samples were found good like the mordant free dyed samples. Except the Cr-based dyed sample, the light fastness of the samples was evaluated as 5 (Table 2) which shows the good light fastness by ACD. In terms of the washing fastness values Al, Cr and Sn-based mordant usage in dyeings ensured same results which were 4/5 for staining on wool and 5 for color change in washing. These values were perfect. By the use of Fe and Cu based mordants instead those one, a decrease of 0.5 point has been observed but still good values were available. As a general attitude the fastness value about staining on wool was lower than the color change during washing procedure.

As an overall summary, the results showed the usability of the ACD as a dye source even in absence of any mordant. By the use of different mordants and dye pHs, the color shifts were observed but no dramatic deflection from the brown color was observed. The fastness values were nice and interestingly it showed good light fastness values by differing from the common feature of the natural dye sources.

3. CONCLUSION

It is a clear fact that natural dyeing has a historical adventure. This historical adventure has begun to gain different approaches today. One is related with testing different sources for coloration purposes. In this respect, ACD - air conditioning dust has been investigated in dyeing of the wool. The extract from ACD was applied on wool at different pH values firstly without use of any mordant. It was found that depending on the pH the shades can be differed from each other and brown colors can be come out. Besides without any pH adjustment but addition of the different mordants provided higher color strengths and darker shades. The color shifts and changes by the use of mordants were observed as more

dramatic in case of using different mordants. The overall evaluation of the fastness results were also found as striking because the washing and light fastness of the samples were found as good. Especially the strength of the obtained colors against light was found high when the general attribute of the natural dyes were taken into account. Because contrary to their highly promising features their use has some drawbacks in terms of low light fastness and different methods to improve the light fastness has been investigated previously [10]. The light fastness of the samples dyed with ACD was around 5 which has presented as a promising result for the natural dyeing. As a result it can be concluded that ACD as a waste can be good source for natural dyeing of the wool and this approach can be a good way for the waste valorization.

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SUSTAINABLE DYEING OF WOOL FABRICS WITH A BIO-WASTE PISTACHIO TREE (*PISTACIA VERA* L.) BRANCH

Original scientific paper
DOI: 10.5937/CT_ITI24018B

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ABSTRACT: The issue of waste management is one of the most important issues both today and in the future. Therefore, lots of scholars are endeavoring to add to the economy substances such as paper, glass, and vegetable waste. In this study, the pistachio tree (*Pistacia vera* L.) branch was used for the first time as a bio waste material as a natural dye source for coloring textile material. For this purpose, waste pistachio branches were collected from Gaziantep province in the south of Türkiye. And then, the dried and grinded branches of pistachio were used for the dyeing of textiles. Dyeing was started at room temperature. The simultaneous-mordanting method was used. The method was performed at a materials-to-liquor ratio of 1:40 for one hour at 100°C. And then it was cooled, washed with soap (1 g/L non-ionic surfactant), and then dried at room temperature. Alum ($KAl(SO_4)_2 \cdot 12H_2O$) and iron sulfate ($FeSO_4 \cdot 7H_2O$), which are environmentally friendly, were used as metal salts to increase the efficiency of the dyeing process. The CIE $L^*a^*b^*$ values and K/S values of the dyed fabrics were measured using a spectrophotometer. In addition, washing, perspiration, and rubbing fastness tests were applied to colored fabrics. The results show that fabrics can be colored with sufficient fastness using pistachio tree branches.

Keywords: Pistachio tree branch, textile, natural dyes, bio-waste, eco-friendly, sustainability.

ODRŽIVO BOJANJE VUNENIH TKANINA SA BIO-OTPADNOM DRVO PISTAĆA (*PISTACIA VERA* L.)

APSTRAKT: Pitanje upravljanja otpadom jedno je od najvažnijih pitanja kako danas tako i u budućnosti. Zbog toga mnogi naučnici nastoje da u ekonomiju dodaju supstance kao što su papir, staklo i otpad od povrća. U ovoj studiji, grana stabla pistacije (*Pistacia vera* L.) je prvi put korišćena kao biootpadni materijal kao prirodni izvor boje za bojenje tekstilnog materijala. U tu svrhu prikupljene su otpadne grane pistacija iz provincije Gaziantep na jugu Turske. Zatim su osušene i samlevene grane pistacija korišćene za farbanje tekstila. Bojenje je počelo na sobnoj temperaturi. Korišćen je metod simultanog mordiranja. Metoda je izvedena u odnosu materijala prema tečnosti od 1:40 tokom jednog

sata na 100°C. Zatim je ohlađena, isprana sapunom (1 g/L nejonskog surfaktanta), a zatim osušena na sobnoj temperaturi. Kao soli metala za povećanje efikasnosti procesa bojenja korišćeni su stipsa ($KAl(SO_4)_2 \cdot 12H_2O$) i gvožđe sulfat ($FeSO_4 \cdot 7H_2O$), koji su ekološki prihvatljivi. Vrednosti CIE $L^*a^*b^*$ i K/S vrednosti obojenih tkanina merene su pomoću spektrofotometra. Pored toga, testovi postojanosti pranja, znojenja i trljanja primenjeni su na obojene tkanine. Rezultati pokazuju da se tkanine mogu bojati dovoljno postojano korišćenjem grana drveta pistacija.

Ključne reči: grana pistacija, tekstil, prirodne boje, biootpad, ekološki prihvatljiv, održivost.

1. INTRODUCTION

These days, eco-friendly products are critical to both commercial and academic study. Green products and production processes, as well as techniques to lessen pollution in the environment, are the focus of intense efforts. In this regard, the topic of agricultural wastes and their valuation is among the most fascinating recent developments. It is well known that a large amount of agricultural waste is created daily to meet the growing demands of the fast growing population [1]. By-products of the production and processing of agricultural goods, agricultural wastes may contain components that are valuable to humans. Pistachio tree (*Pistacia vera* L.) waste can be an important industrial and agricultural waste. The tree, also known as the cashew family, is widely planted throughout the Mediterranean region and is native to the arid regions of Central and West Asia [2]. Commercial pistachio cultivation occurs in the USA, Türkiye, Iran, Iraq, Italy, Tunisia, and other nations [3]. Hosseinzai et al. (2022)[4] report that the production of pistachios reached a peak of 1.1 million tons worldwide in 2020. In previous studies, shells, a waste of pistachios, have been used to color woven cotton fabrics [5] and carpet yarns [6], as well as as a bio-mordant [7-8]. Unlike other studies, in this study, pistachio tree branches were used as a dye source to color woolen fabrics. Türkiye is one of the world's leading producers of pistachios, and this modern agricultural cultivation can leave behind a sizable amount of waste. Concurrently, one of Türkiye's most significant industrial sectors is the textile industry. Using the information collected as a result of this study, it is expected to suggest a different source of natural dyestuffs to dyehouses across the country and to show how their wastes can be a useful resource for companies that grow pistachios. The primary objectives of the study were to determine whether pistachio tree branches could be used as a source of color for textile products.

2. MATERIAL AND METHODS

2.1. Materials

A 150 g/m² 100% wool and 220 g/m² 100% cotton fabric that was ready for dyeing was used in this investigation. The pistachio tree's bio-waste branches (Figure 1) were used in

this investigation as a natural color source. All of the branches were dried and powdered before being dyed. All dyeing processes directly utilized this powdered form.



Figure 1: Pistachios (a), branches (b), ground form (c), and dye solution (d)

2.2. Mordanting & Dyeing Procedure

The kind and concentration of the mordant, as well as the coloring agent, are significant factors in natural dyeing studies. It is well known that employing a mordant and raising the dye concentration will intensify the colors produced. Various mordant substances were used in dyeing wool and cotton fabrics. For this, iron (II) sulfate and alum were used at concentrations of 3% and 30% (owf), respectively. In addition to metal salts, many different sources are also used as biomordants [9]. The dyeing process took place together with the mordanting process (simultaneously mordanting). All procedures in this research were performed for one hour at 100°C with a constant liquor ratio of 1:40.

2.3. Evaluation of colors and fastness

Using a Konica Minolta 3600d spectrophotometer, color strength (K/S) and CIE $L^*a^*b^*$ values of dyed wool and cotton materials were determined. Kubelka-Munk equation 1 was used to calculate the K/S values [10].

$$\frac{K}{S} = \frac{(1 - R)^2}{2R} \quad \text{eq. (1)}$$

where "R" is the highest color reflectance of the cloth, given as a decimal percentage. "K" stands for the absorption coefficient and "S" for the scattering coefficient. In addition, washing [11], rubbing [12], and perspiration [13] fastness tests were applied to dyed woolen and cotton fabrics. In the meantime, for visible region the VWR UV-3100PC spectrophotometer was used to evaluate the extracts.

3. RESULTS AND DISCUSSION

Pistachios are a major industrial agricultural crop, and Türkiye is one of the world's leading producers of pistachios for snacking. Despite the fact that wild pistachio trees can be found almost anywhere in Türkiye, the majority of these plants are located in the southeast [14]. Türkiye holds the top spot on the globe as of 2021, with 389.5 thousand hectares of land used for pistachio harvesting. Plant waste may include a considerable amount of tree branches and the hard and soft shells of pistachios as a result of this enormous production,

processing, and consumption. In our previous study, the hard and soft shells of pistachios were used as a dye source [5].

In this study, pistachio tree branches were used as a dye source for the first time. In the study, two different environmentally friendly metal salt and mordant-free dyeing processes were carried out, and the color photos obtained from these studies are presented in Table 1. The colors of wool and cotton dyed without mordant are pink and have light ecru tones. The color strengths (K/S) in the no-mordanting technique were discovered to be excessively low, indicating inadequate dyeing in the absence of any mordant. In the dyeing made with tree branches, a color strength of 2.13 for wool and 0.34 for cotton was determined. Although the lightness values for wool and cotton were determined to be 75.2 and 81.5, respectively, both samples were too light. The a^* (1.56) and b^* (1.6) values as well as sample images showed variations in color. However, the application of mordants resulted in modest color alterations. In addition, it was found that when alum salt was used, both wool and cotton were dyed in yellow hues. When iron salt was used, the color tones were quite dark, with wool dyed gray and cotton dyed blue. When wool was used with alum, the a^* value measured from the sample dyed without using any mordant changed from 1.56 to -3.1. When cotton was used with alum, the a^* value measured from the sample dyed without using any mordant changed from 1.6 to -3.1. When wool was used with iron (II) sulfate, the a^* value measured from the sample dyed without using any mordant changed from 1.56 to 2.2. When cotton was used with iron (II) sulfate, the a^* value measured from the sample dyed without using any mordant changed from 1.6 to 2.2. The color obtained from wool dyeing using alum mordant is clearly yellow (b^* : 32.2). A distinct blue hue was obtained in cotton dyeing using iron salt ($FeSO_4$). The hue angle (h° : 323) clearly shows this. The highest L^* values in both wool and cotton dyeing were obtained from experiments with Fe-based mordants and were determined to be 50 and 58.5, respectively. No significant relationship was found between mordant changes in terms of color tone.

Table 1: Photographs of dyed samples and color values

Fabric type	Mordant type	Dyed samples	Color Values					
			K/S	L^*	a^*	b^*	C^*	h°
Wool	Unmordanted		2.13	75,2	1,56	19,1	19,1	85
	$KAl(SO_4)_2 \cdot 12H_2O$		1.79	80.9	-3.1	32.2	32.3	96
	$FeSO_4 \cdot 7H_2O$		2.94	50	2.2	5.8	6.1	69
Cotton	Unmordanted		0.34	81.5	1.6	7	7	77
	$KAl(SO_4)_2 \cdot 12H_2O$		0.44	86.2	-3.1	19.4	19.7	99
	$FeSO_4 \cdot 7H_2O$		0.98	58.5	2.2	-1.7	2.8	323



Some color fastness tests were performed on dyed wool and cotton fabrics. In general, the results of all fastness tests were obtained in the range of 4-5 points, and it can be stated that the results are very good. However, it was also determined that the fastness values of fabrics dyed without mordant were half a point lower. In general, wet rubbing fastness values were half a point lower among themselves.

Table 2: Color fastness test results of dyed fabrics

Fabric type	Mordant type	Washing Fastness		Rubbing Fastness		Perspiration Fastness			
						Acidic		Alkaline	
		Sta.	C.C.	Dry	Wet	Sta.	C.C.	Sta.	C.C.
Wool	Unmordanted	4/5	4/5	4/5	4	4/5	5	4/5	5
	$KAl(SO_4)_2 \cdot 12H_2O$	5	5	5	4/5	4/5	5	5	5
	$FeSO_4 \cdot 7H_2O$	4	4/5	4/5	4	4	4	4/5	4
Cotton	Unmordanted	4/5	4/5	4/5	4	4/5	5	4/5	5
	$KAl(SO_4)_2 \cdot 12H_2O$	5	5	5	4/5	4/5	5	5	5
	$FeSO_4 \cdot 7H_2O$	4	4/5	4/5	4	4	4	4/5	4

Sta.: Staining of wool; C.C.: Color Change

The dye source was evaluated in terms of the visible region. Following dilution, the absorbance curve depicted in Figure 2 was produced, and no notable peak was found within the range of the visible region. As shown in Figure 1 (d), the color of the blind dye bath obtained from the branches is beige. This solution dyes wool and cotton in different colors with different mordant substances. The absorbance curve of the solution obtained at a certain dilution ratio is shown in Figure 2, and no notable peak was observed in the visible region in the range of 400–700 nm.

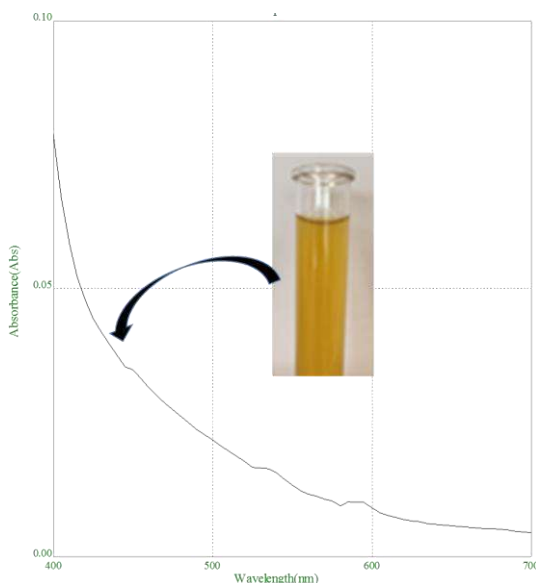


Figure 2: Absorbance curve of the Pistachio tree branch extract after 1:50 dilution

The idea of recycling waste should work toward encouraging a sustainable way of living in the future, not just because it helps the environment but also because it creates new jobs, sources of income, and technological advancements. Crop leftovers, including leaves, maize stovers, rice, wheat, oats, barley straws, and seed pods, are among the wastes generated in agricultural areas. Crop wastes have historically been utilized to create paper, matchsticks, compost, animal feed, roof thatch, and fuel [1]. However, there are currently a number of additional uses that can be mentioned.

4. CONCLUSION

The one discussed in this study uses waste materials to naturally dye cotton and wool. Pistachio tree (*Pistacia vera* L.) branches were used to dye cotton and wool for this purpose. The branches were employed in dye baths without first going through an extraction procedure during this procedure. The outcomes thus show how these wastes could be used to dye cotton and wool. In the meantime, various color shifts were noticed, depending on the type of mordanting and the mordanting chemical utilized. The results showed that the fastness values for the washing, rubbing, and perspiration fastnesses were good to ideal. A few minor variations were noted based on the dyeing parameters, but no systematic impact of these parameters was noted. Further investigation into the application of various solvents and/or extraction techniques to improve *K/S* would be intriguing. It is believed that the application of these wastes in the coloring of various fibers may be intriguing for future research, and concurrently, the potential application of these wastes in the functionalization of textiles may also be a worthwhile area of study.



ACKNOWLEDGMENTS

This work was supported by the Research Fund of Kayseri University. Grant Numbers: FBA-2023-1101.

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AIR PERMEABILITY AND PHYSICAL-MECHANICAL PROPERTIES OF FABRICS FOR PRODUCTION OF AIRBAGS IN AUTOMOBILES

Original Scientific paper
DOI: 10.5937/CT_ITI24019N

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ABSTRACT: This paper describes the analysis of raw material composition and structural parameters on the mechanical properties of fabric for the production of airbags. It is about polyamide and polyester fabrics. The breaking force and breaking elongation measurements were performed on a dynamometer, while air permeability measurements were performed on an air permeability device. Five different measurements were taken for each sample and the mean values were determined. All sample analyzes were conducted in a standard atmosphere and the samples were left for 24 h before testing. The mechanical characteristics of fabrics depend on their structural parameters, as well as on the technological conditions of fabric production in the weaving process. Fabric tearing is mainly the result of individual fibers tearing. In fabrics, individual fibers or threads are interwoven, so the application of an external load leads to a rearrangement of the fabric structure, which to a greater or lesser extent results in the stretching of fibers and threads along the axis, which results in anisotropy of mechanical properties. It is noticeable that higher breaking force values were observed for polyamide fabric compared to polyester fabric. Higher breaking force values were observed for the polyamide fabric. Higher air permeability is noticeable with polyester fabric

Keywords: airbags, mechanical properties, fabric, air permability.

PROPUSTILJIVOST VAZDUHA I FIZIČKO-MEHANIČKA SVOJSTVA TKANINA ZA PROIZVODNJU VAZDUŠNIH JASTUKA U AUTOMOBILIMA

APSTRAKT: U radu je opisana analiza sirovinskog sastava i strukturnih parametara u odnosu na mehanička svojstva tkanine za izradu vazdušnih jastuka u automobilima. Reč je o poliamidnim i poliesterskim tkaninama. Merenja prekidne sile i prekidnog izduženja su obavljena su na dinamometru, a merenje propustljivost vazduha na uređaju za propustljivost vazduha. Za svaki uzorak obavljeno je pet različitih merenja i određene su



srednje vrednosti. Sve analize uzoraka urađene su u standardnoj atmosferi i uzorci su ostavljeni 24 h pre ispitivanja. Mehanička svojstva tkanina zavise od strukturnih parametara, kao i tehnoloških uslovima proizvodnje tkanina u procesu tkanja. Kidanje tkanine je uglavnom rezultat kidanja pojedinačnih vlakana. U tkaninama su pojedinačna vlakna ili niti isprepletene, pa primenom spoljašnjeg opterećenja dolazi do menjanja strukture tkanine, što u većoj ili manjoj meri rezultira rastezanjem vlakana i niti duž osi, što rezultira anizotropijom tkanine mehaničkih svojstava. Primetne su veće vrednosti prekidne sile za poliamidnu tkaninu u poređenju sa poliesterskom tkaninom. Vrednosti prekidnog izduženja su veće vrednost za poliestersku tkaninu u poređenju sa poliamidnom tkaninom. Kod poliesterske tkanine uočene su veće vrednosti propustljivosti vazduha.

Ključne reči: vazdušni jastuci, mehanička svojstva, tkanina, propustljivost vazduha.

1. INTRODUCTION

Polyamide is widely used because of their excellent properties such as the possibility of processing and low cost. Despite this widespread use, polyamide suffers various types of degradation that lead to major modifications of their mechanical properties during use [1-3].

Polyester fiber is, by definition, a fiber composed of linear macromolecules that have at least 85% by weight of diol ester and terephthalic acid in the chain. Regardless of the properties achieved during spinning, polyester fibers have a relatively high degree of crystallinity and therefore low absorption of water and moisture from the air [4].

Air bags are designed to act as an additional safety device in addition to the seat and seat belts. There is a significantly greater reduction in moderate to severe head injuries for people who use airbags and seat belts together than for people who use only seat belts, compared to drivers who do not use seat belts [5, 6].

Over the last two decades, the airbag has become an essential safety device in cars. The airbag is composed of a woven fabric that inflates quickly during a crash. It disperses the passenger's kinetic energy and thus reduces injuries and the escape of gas through the ventilation openings. Thus, the performance of the airbag is greatly influenced by the mechanical properties of the fabric [7].

Air permeability is a very important factor in the performance of a textile material. It is particularly considered for clothing, parachute sails, vacuum cleaners, airbag fabrics and industrial filter fabrics. Air permeability mainly depends on fabric mass and construction (thickness and porosity) [8].

The air permeability of a fabric is a measure of the passage of air through the fabric itself. Air permeability is important for technical textiles, the standard measure of air permeability is the speed of air passing through the sample depending on its surface and pressure drop [9].

The aim of this paper is to compare the most important properties of raw polyester and polyamide fabric for the production of airbags. It is about analyzing the different properties of these two fabrics in controlled laboratory conditions. Fabrics used to make airbags must have high density, good wear resistance, high level of durability.

2. MATERIALS AND METHODS

In the experimental part, two types of fabric were used: 100% raw polyester fabric (PES) and 100% raw polyamide fabric (PA). The fabrics were kindly obtained from a textile factory (Autostop Interiors, Leskovac). The basic characteristics of raw polyester and polyamide fabrics are given in table 1.

Table 1: Basic characteristics of raw polyester and polyamide fabric

Properties		PES fabric	PA fabric
Longitudinal mass of yarn, tex	warp	66	56
	weft	70	46
Wire density, cm ⁻¹	warp	19	18
	weft	15	18
Surface mass, g·m ⁻²		233	217
Interlacement		Linen	Linen

Figure 1 shows a microscopic image of samples of (a) raw PES fabric and (b) raw PA fabric. The thickness of the PES fabric sample was 0.35 mm, and that of the PA fabric was 0.40 mm. A stereomicroscope (Leica M50 stereomicroscope, Germany) was used to record the samples (figure 1). Fabric samples were 10 × 10 cm in size. The surface of the test tube was 5 cm². This samples used to measure the air permeability.

The fabric samples used to measure the breaking force were 25 mm × 200 mm in size. The width of the test tubes was reduced from 50 mm to 25 mm due to the range of the dynamometer which is 5 kN. The speed of movement was 300 mm/min. Breaking force measurements were performed on a dynamometer (Tinius Olsen H5KS, Horsham, USA) according to the ISO 9237:1995 standard.

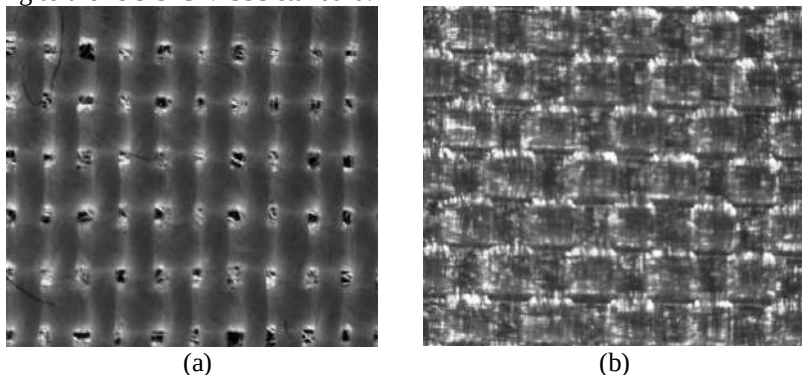


Figure 1: Microscopic image of a raw sample of (a) polyester and (b) polyamide fabric. The methods for checking the properties of importance are as follows:



• Air permeability measurements, device Air permeability tester - SDL M021S according to standard EN ISO 9237:1995. The pressure at which the samples were tested was varied: 200 Pa, 400 Pa, 600 Pa, 800 Pa, 1000 Pa and 1200.

• Weaving is calculated according to the equation [10]:

$$u = \frac{l-L}{l} \cdot 100 (\%) \quad (1)$$

where: l is the length of the straightened thread (mm), L is the length of the test tube section (mm).

• The linear filling of the fabric, filling by warp and weft, (l_o) and (l_p), are determined according to the following equations [11]:

$$L = l_o + l_p \quad (2)$$

$$l_o = \frac{d_o \cdot g_o}{10} \quad (3)$$

$$l_p = \frac{d_p \cdot g_p}{10} \quad (4)$$

where: d_o – conditional warp diameter (mm), d_p – conditional weft diameter (mm), g_o – warp density (cm^{-1}), g_p – weft density (cm^{-1}).

• Fabric void (C) is calculated using the following equations [12]:

$$C_o = 1 - I_o \quad (5)$$

$$C_p = 1 - I_p \quad (6)$$

$$C = C_o + C_p \quad (7)$$

• The surface coverage of the fabric (I_A), is calculated using the equation [13]:

$$I_A = I_o + I_p - I_o \cdot I_p \quad (8)$$

where: I_o - surface filling of warp, I_p - surface filling of weft.

• The volumetric mass of the fabric (γ) is calculated as [13]:

$$\gamma = \frac{M \cdot 10^{-4}}{h} (g \cdot \text{cm}^{-3}) \quad (9)$$

where: h - thickness of the test tube (cm), M - surface mass of the fabric ($\text{g} \cdot \text{m}^{-2}$).

• The porosity of the fabric (P) is determined according to the equation [14]:

$$P = \left(1 - \frac{\rho_{fabric}}{\rho_{fiber}} \right) \cdot 100 (\%) \quad (10)$$

$$\rho_{fabric} = \frac{m}{d \cdot 1000} \quad (11)$$

where: m – sample mass, d – sample thickness, ρ_{fiber} – fiber density, ρ_{fabric} – fabric density. Based on all the experiments that were carried out in the laboratory and aimed at checking the different properties of raw polyester and polyamide fabric, the OriginPro software was used to process the data and display the results.

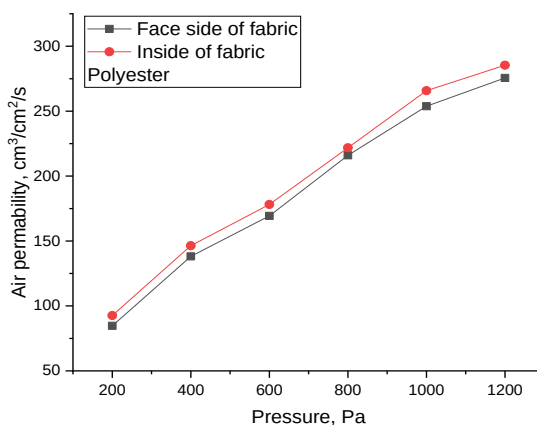
3. RESULTS AND DISCUSSION

In designing of airbag fabric, precise control of air permeability is crucial. After deployment, controlled deflation through vents, seams and fabric pores protects vehicle occupants to minimize injury. Therefore, it is important to fully understand the mechanics of fabric permeability in product development and process optimization. Synthetic fabrics such as polyester and polyamide and their mixtures are most often used for the production of airbags to improve certain properties for better performance fabrics and thus can be economical to produce compared to commercial fabrics for the production of airbags [15]. Figure 2 shows the diagram of air permeability on the face and back of raw polyester and polyamide fabric at different pressures. In the case of polyester fabric, it was observed that the lowest air permeability is on the face of the fabric, i.e. $84.68 \text{ cm}^3/\text{cm}^2/\text{s}$ at the lowest pressure of 200 Pa, and the highest value $275.6 \text{ cm}^3/\text{cm}^2/\text{s}$ at the highest pressure of 1200 Pa, while on the innermost fabric the permeability at the lowest pressure was $92.62 \text{ cm}^3/\text{cm}^2/\text{s}$, and at the highest pressure $285.4 \text{ cm}^3/\text{cm}^2/\text{s}$. It was observed that the air permeability is higher on the reverse than on the face of the fabric.

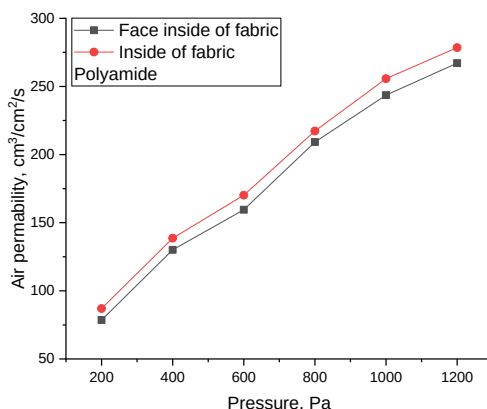
Polyamide fabric showed the lowest value of air permeability on the face of the fabric $78.56 \text{ cm}^3/\text{cm}^2/\text{s}$ at a pressure of 200 Pa, and the highest value $267 \text{ cm}^3/\text{cm}^2/\text{s}$ at a pressure of 1200 Pa. Higher air permeability values are noticeable on the reverse side of the fabric, i.e. $86.99 \text{ cm}^3/\text{cm}^2/\text{s}$ at a pressure of 200 Pa and $278.5 \text{ cm}^3/\text{cm}^2/\text{s}$ at the highest used pressure i.e. 1200 Pa.

The results show that there is a small difference in the air permeability of the examined fabrics determined from the face and back of the material. It can be seen that with both analyzed fabrics, higher values of air permeability were obtained on the reverse than on the face of the fabric. Air permeability increases with increasing pressure.

Polyester fabric has a higher air permeability compared to polyamide fabric due to its higher porosity and lower fabric thickness. It is necessary to adjust the values of fabric thickness and porosity, because thickness improves thermal insulation, and porosity conditions air permeability.



a)



b)

Figure 2: Air permeability of a) face side, b) face inside of polyester and polyamide fabric at different pressures

Table 2 shows the structural parameters of polyamide and polyester fabric. Based on the porosity values of both fabrics, 46% for polyamide and 67% for polyester fabric, it is generally considered that when a fluid (liquid or gas) flows through the material, the pressure drop is due to viscous and inertial forces. Inertial forces can be neglected unlike viscous forces. Therefore, the structural and geometric properties of the textile material that determine the resistance to the movement of the air flow define its ability to pass air. Air permeability through the fabric is one of the more important characteristics of the clothing fabric because it directly affects the feeling of comfort of the user of the textile product. The ability of the fabric to retain and pass air affects the thermal insulation properties of the clothing, because the air present in the clothing significantly increases the thermal properties of the clothing item. The warm feeling of the product is primarily due to the thermal insulation caused by the presence of air in between fibers in yarn and fabric. To increase air permeability in the finishing process, treatments can be applied that change the thickness, porosity and surface structure of the fabric. Processing can also lead to greater porosity of the fabric.

In this sense, in addition to the overall porosity of the textile material, air permeability is directly conditioned by the number, shape and size - cross-sectional area and length - of macropores. With the decrease in the size of the macropores in the material, the resistance to air flow increases, which reduces its air permeability.

The results of the research showed that the same coating has similar values of surface filling and therefore air permeability, i.e. it was found that the type of interweaving has an effect

on the air permeability of the fabric. Different types of interlacing patterns showed higher or lower permeability.

Table 2: Structural properties for used fabrics

Type of fabric	Volume mass fabric, $\text{g}\cdot\text{m}^{-3}$	Linear coverage of fabric	Incompleteness of fabric	Surface coverage of the fabric	Porosity of fabric, %
PES	0.05	1.15	0.84	0.52	67
PA	0.06	1.04	0.96	0.77	46

Knowing the mechanical, surface and physical properties of fabrics is important for the entire process of making fabrics, because the designer chooses the appropriate fabric based on the knowledge of the properties. Table 3 shows the results of breaking force and breaking elongation of the warp and weft of polyamide fabric for airbags. The average value of the breaking force is 1435 N. The breaking elongation is 61.75%. The quality of the material is linked to these parameters and they represent a plastic example. The appearance of damage directly affects the mechanical and physical properties of fabrics. Fabric tearing is mainly the result of individual fibers tearing. In fabrics, individual fibers or threads are interwoven with each other, so by applying an external load, the structure of the fabric is rearranged, which results to a greater or lesser extent in the stretching of fibers and threads along the longer axis, which results in anisotropy of mechanical properties. The tensile stress itself is resisted by the weft or warp threads when they match. The directions of their axes with the direction of the acting loading as well as of standing in the structure under the influence of forces whose directions do not coincide with the directions of the weft or warp.

Table 3: Results for breaking force of polyamide and polyester fabric

Number of samples	Breaking force of polyamide fabric (N)		Breaking force of polyester fabric (N)	
	Warp	Weft	Warp	Weft
1.	1385	1355	1135	556
2.	1485	1375	1195	926
3.	1505	1385	1165	883
4.	1405	1305	1195	946
5.	1395	1295	1185	874
X_{sr}, N	1435	1343	1175	837
SD, N	49.79	36.61	22.83	143
$CV, \%$	0.04	0.30	0.02	0.19



Table 4 shows breaking force and breaking elongation in warp and weft direction of polyester fabric for airbags. The average value of the breaking force is 837 N. The breaking elongation is 66.09%. Although the work of tear is determined by the specific breaking force and the breaking elongation of the fabric, it seems that the breaking elongation, at least within the experimental material, is the determining factor of the breaking work. Thus, the highest breaking work was recorded in the polyamide fabric characterized by a significantly higher breaking elongation compared to the polyester fabric.

Table 4: Results for breaking elongation of polyester and polyamide fabric

Number of samples	Breaking elongation of polyamide fabric (mm)		Breaking elongation of polyester fabric (mm)	
	Warp	Weft	Warp	Weft
1.	62.19	42.86	41.18	70
2.	62.70	42.78	41.69	69.80
3.	64.59	44.38	42.69	62.99
4.	58.88	42.27	43.09	64.49
5.	60.39	41.98	42.08	63.19
X_{sr}, mm	61.75	42.86	42.15	66.09
SD, mm	1.96	0.82	0.68	3.15
$CV, \%$	0.35	0.02	0.18	0.05

In figure 3, the diagram shows the dependence of breaking elongation in relation to the breaking force in the warp and weft direction for polyamide fabric. From the results shown in figure 3, there is a noticeable difference between the breaking force determined on the samples in the longitudinal and transverse directions. The reason for this behavior is probably due to the different orientation of the fibers in the analyzed samples. The diagram in figure 3 shows that the breaking force and breaking elongation have higher values in the warp direction than in the weft direction.

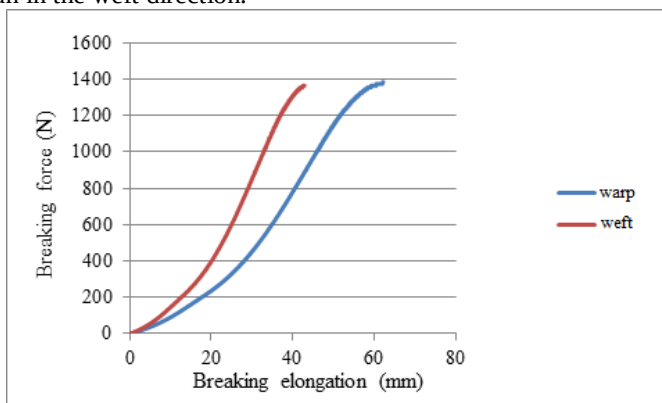


Figure 3: Dependence of breaking elongation in relation to breaking force for polyamide fabric in warp and weft direction

Figure 4 shows the dependence of elongation at break in relation to the breaking force in the warp and weft direction for polyester woven fabric. A difference was observed between the breaking force and the breaking elongation determined on the samples in the longitudinal and transverse directions. The reason for this behavior is probably due to the different orientation of the fibers in the analyzed samples. It is noticeable that breaking force and breaking elongation have higher values in the direction of the warp than in the direction of the weft.

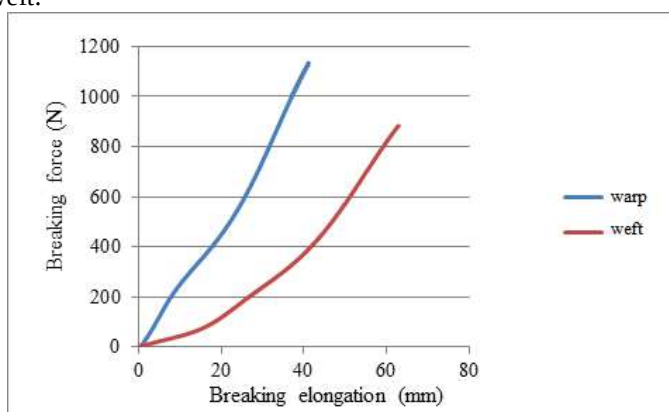


Figure 4: Dependence of breaking elongation in relation to breaking force for polyester fabric in warp and weft direction

4. CONCLUSION

With polyester fabric, it is noticeable that air permeability increases with increasing pressure. A higher air permeability is visible on the reverse than on the face of the fabric. By analyzing the permeability of the polyamide fabric, it was observed that the air permeability, just like that of the polyester fabric, increases with increasing pressure. By comparing the permeability of polyamide and polyester fabric on the face, it is noticeable that the polyester fabric has a higher permeability. The air permeability of polyester compared to polyamide fabric on the reverse side of the fabric showed that the polyester fabric has a higher permeability. Polyester fabric has less filling and a greater number of pores on the surface of the fabric, thus less air permeability.

The mechanical characteristics of fabrics depend on their structural and constructive solutions, as well as on the technological conditions of fabric production in the weaving process. Therefore, the most important role is played by the composition of the raw materials, the structural and physical-mechanical characteristics of the applied fabrics, the density of the warp and weft wires, the weaving of the wires, as well as the applied interweaving of the fabric. In addition, by knowing the connection of characteristics at the break boundaries, it is possible to simulate the behavior of fabrics during exploitation, which is a condition for the proper design of fabrics depending on their future purpose.



It is noticeable that higher breaking force values were observed for polyamide fabric compared to polyester fabric. Elongation at break has a higher value for polyester fabric compared to polyamide fabric. Higher breaking force values were observed for polyamide fabric.

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ECO-FRIENDLY NONWOVEN COVERS FOR AGRICULTURAL USE PRODUCED FROM POST-CONSUMER WASTE

Original scientific paper
DOI: 10.5937/CT_ITI24020T

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ABSTRACT: The global rise in population and growing demand for high-quality crops are the main challenges for agrotexiles improvement. The world needs more sustainable and eco-friendly nonwoven crop covers to replace the use of synthetic nonwoven crop covers to prevent pollution. The article considers the problem of processing textile waste from the post-consumer sector (PCW). The main directions of their use in producing nonwoven fabrics are briefly described. The use of post-consumer textile waste (PCW) based on used cotton T-shirts in the manufacture of nonwovens by wet laying process using the circular economy principle is considered. Samples of nonwovens were obtained and characterized through the mass per unit area, thickness, mass per unit volume, and linear density, and the attained results were compared with market-available ones. The thickness and linear density of obtained samples were slightly higher than the market-available samples, but the mass per unit volume was very similar to market-available ones. The coefficient of variation in the thickness of the obtained materials was about 10 %. The obtained materials can be used in the manufacture of crop covers in agriculture.

Keywords: nonwoven, post-consumer waste, cotton, agrotexiles, used textile.

EKO-PRIJATELJSKI NETKANI PRESKRIVAČI ZA POLJOPRIVREDNU UPOTREBU OD POTROŠAČKOG OTPADA

APSTRAKT: Globalni porast stanovništva i rastuća potražnja za visokokvalitetnim usevima su glavni izazovi za unapređenje agrotekstila. Svetu su potrebni održiviji i ekološki prihvatljiviji netkani pokrivači za useve koji bi zamenili upotrebu sintetičkih netkanih pokrivača za useve kako bi se sprečilo zagađenje. U članka se razmatra problem prerade tekstilnog otpada iz post-potrošačkog sektora (PCW). Ukratko su opisani glavni pravci njihove upotrebe u proizvodnji netkanih tkanina. Razmatra se upotreba post-potrošačkog tekstilnog otpada (PCW) na bazi korišćenih pamučnih majica u proizvodnji netkanog materijala ostupkom mokrog polaganja po principu cirkularne ekonomije. Dobijeni su i okarakterisani uzorci netkanog materijala kroz masu po jedinici površine, debljinu, masu



po jedinici zapremine i linearnu gustinu, a dobijeni rezultati su upoređeni sa tržišno dostupnim. Debljina i linearna gustina razvijenih uzorka bile su nešto veće od uzorka dostupnih na tržištu, ali je masa po jedinici zapremine bila veoma slična tržišno dostupnim uzorcima. Koeficijent varijacije debljine dobijenih materijala je oko 10 %. Dobijeni materijali mogu da se koriste u proizvodnji pokrivača za useve u poljoprivredi.

Ključne reči: netkani tekstil, tekstilni otpad iz post-potrošačkog sektora, agrotekstil, korišćeni tekstil.

1. INTRODUCTION

In recent years, there has been a growing concern about environmental issues and high energy consumption. Textile wastes has a significant impact on the environment and public health, as millions of tons of clothes are produced and disposed of every year, causing a large accumulation of waste in landfills, with very negative consequences [1]. Textile wastes comes from various sources, such as household use and waste from production lines, and environmental degradation, both of which are increasing considerably [2]. Waste management is important to minimize the consequences on the environment. At the end of the products' life cycle, there are several approaches that can be followed: recycling, incineration, biodegradation and landfill [3]. This allows economic growth to be decoupled from the negative consequences of resource depletion [4]. Based on sources, textile waste is classified as pre-consumer/post-industrial (PCPIW) and post-consumer (PCW). The maintenance cycle has an impact on the quality properties of textile products [5-8]. Restoring to several reproducing technologies, it is possible to recover fibers from textile waste and assign them a new application. The recovered fibers can be once again used in the textile industry or be given new applications, such as in the non-woven, agriculture, carpet, building, and paper industries. Agricultural textile is one of the widening technical textile groups that are also known as agrotexiles. Depending upon their final use and its requirements, different kinds of textile structures, namely woven, nonwoven, and knitted are used [9]. These structure are flexible, porous, and permeable to air and water, among other properties [10]. Implementation of highly effective textile technologies in agricultural industry is anticipate to surge crop yield, and hence, impact the overall productivity. Nonwoven structures are used as direct cover on plants to protect cultivation. Nonwovens have an advantage over plastic bags, because these agro-textiles are ventilated, may prevent fruit from rotting in summer and protect fruit from freezing in the winter. In addition, natural fibers have high moisture retention capacity, help reduce evaporation, and prevent the soil from drying out. Crop protection is a major challenge faced by farmers in the agriculture industry. Nowadays, environmental-friendly materials like plant natural fibers have gained much attention due to their remarkable properties [11]. Now, the world needs more sustainable and eco-friendly materials to replace and reduce the use of synthetic materials to prevent pollution. Natural fibers are biodegradable and renewable and have neutral CO₂ emission, high mechanical strength, modulus, and moisture absorption, low elongation and elasticity, low density, and generally low cost, making them an important

economic focus for developing countries [10]. The circular rconomy (CE), often termed a „closed-loop economy“, prevents the generation of excessive waste by transforming it into valuable resources for producing new goods.

This study aims to produce eco-friendly nonwoven from used cotton T-shirts as post-consumer textile waste using wet laying nonwoven technology and characterize their structure.

2. EXPERIMENTAL PART

2.1. Materials

The T-Shirts used in this study were obtained from the consumer after the T-shirts had no more use value. Market available nonwoven intended for crop cover was used as referent material.

2.2. Treatment process

Used T-shirt was converted in fiber. Wet-laid nonwovens were prepared by dispersing the fiber in water and deposited on the mesh. The fibers within the web were entangled by means of fiber-to-fiber friction.

2.1. Methods

Using a digital balance, the mass per unit area was measured in accordance with ISO 9073-1 standard. The thickness of the obtained samples was measured at five points using standard ISO 9073-2 at thickness gauge K-200 instrument (KOHR Handels-GmbH, Germany). The 7 findings were the reported values. The linear density of the sample shows how much mass 1 km of nonwoven has.

The mass per unit volume of the nonwovens was determined from the ratio of the mass per unit area to the thickness of the nonwoven.

3. RESULT AND DISCUSSION

To determine the structural parameters of nonwoven fabric, 100% cotton waste fiber was derived from a used T-shirt. The mass per unit area is shown in Figure 1. By the results of the mass per unit area was identified that the mass per unit area of obtained nonwovens increased than the market-available one. The larger the weight, the thicker the thickness of the nonwoven. It can be explained as in general, thickness depends on the mass per unit area.

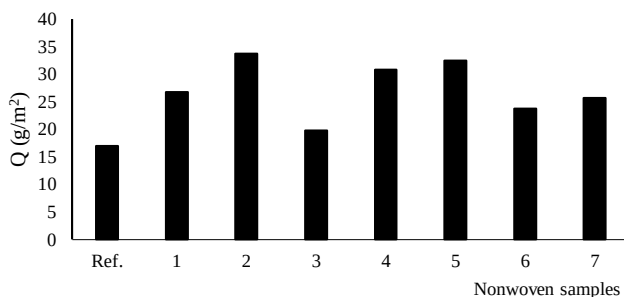


Figure 1: Mass per unit area of obtained nonwoven fabrics

The results of the sample thickness are shown in Figure 2. If we compare the results of the research with the performance of the nonwoven fabric market available, the thickness of developed nonwoven increased by 58 %. The thickness of the coefficient of variation in the thickness of the obtained nonwoven fabrics was about 10 %. The most important factor that provide consumer satisfaction in nonwoven fabrics is nonwoven thickness.

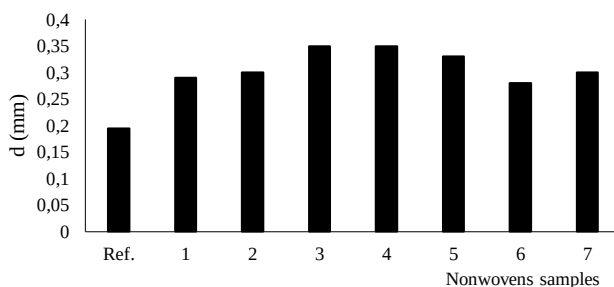


Figure 2: Thickness of obtained nonwoven fabrics

By the results of the study was identified that the linear density of nonwovens increased by about 60%. Linear density of obtained nonwovens is shown in Figure 3.

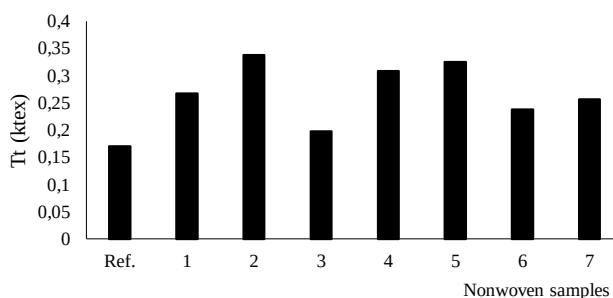


Figure 3: Linear density of obtained nonwoven fabrics

Mass per unit volume of obtained nonwovens is shown in Figure 4. By comparing market available nonwoven with developed nonwovens it can be seen that changes in the mass per unit volume are relatively small, except sample 2 was noticeable higher than market available. Through all experiment mass per unit volume was in the range from 0.08475 to 0.09836 g/cm³.

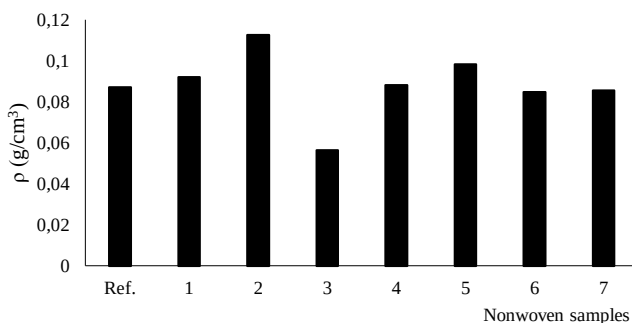


Figure 4: Mass per unit volume of obtained nonwoven fabrics

4. CONCLUSION

A structure assessment of recycled nonwoven for crop covers obtained from used T-shirts of post-consumer waste indicates that in spite of the repeated process, their structure enables them to be exploited in wet nonwoven manufacturing. These results are particularly attractive for industrial-scale cellulose nonwoven fabrics for crop cover production because cellulose nonwoven is more environmentally friendly than market-available one. The results of this study demonstrate that a sustainable strategy used in this process offers hope for the decades-long global use of post-industrial waste. In addition, this work expands the use of wet lay nonwoven technology to the quick fabrication of eco-friendly nonwoven fabric for crop covers in the technical textile industry.

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COMPARISON OF THE REAL AND VIRTUAL FALLING BEHAVIOUR OF TEXTILE FABRICS

Original scientific paper
DOI: 10.5937/CT_ITI24021R

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ABSTRACT: The mechanical deformation behaviour of textiles can be divided into textile drape and drapability. Both determine the overall appearance, aesthetics and fit of garments. In garment simulation, this behaviour must be simulated as realistically as possible in order to enable a meaningful evaluation of design and construction. It is important to understand the relationships between physical textile properties and textile fall. In this study, the real and simulated textile drop are examined and compared. The drop coefficient serves as a numerical measure. The real textile drape according to Cusick and the simulated textile drape are determined for three cotton fabrics with different weave constructions. A subjective image comparison evaluates the simulation quality. As a result of this study, a considerable deviation between simulated and real fabric behaviour can be observed, especially with regard to the anisotropy of textile material. Therefore, further research should focus on the development of simulation algorithms that take into account the anisotropic nature of textiles and ensure that the simulations accurately reflect the behaviour of the fabric in different directions. In addition to the need to ensure access to the simulation algorithms, the introduction of standardized data collection methods is essential for the further spread of simulation in the apparel industry. A coordinated effort to define these standards and best practices will facilitate collaboration and enable more accurate and reliable simulations across different organizations and platforms.

Keywords: 3D simulation fabric drape, garment drape simulation.

POREĐENJE STVARNOG I VIRTUELNOG PONAŠANJA TEKSTILNIH TKANINA PRI OPUŠTANJU

Savez inženjera i tehničara tekstilaca Srbije



APSTRAKT: *Mehaničko deformaciono ponašanje tekstila može se podeliti na opuštanje tekstila i sposobnost opuštanja. Oba faktora određuju ukupni izgled, estetiku i pristajanje odeće. U simulaciji odeće, ovo ponašanje mora biti simulirano što realističnije kako bi se omogućila značajna procena dizajna i konstrukcije. Važno je razumeti veze između fizičkih svojstava tekstila i opuštanja tekstila. U ovoj studiji, stvarno i simulirano opuštanje tekstila se ispituje i upoređuje. Koeficijent opuštanja služi kao numerička mera. Stvarno opuštanje tekstila prema Cusick-u i simulirano opuštanje tekstila određeni su za tri pamučne tkanine sa različitim konstrukcijama tkanja. Subjektivno poređenje slika procenjuje kvalitet simulacije. Kao rezultat ove studije, može se primetiti značajna devijacija između simuliranog i stvarnog ponašanja tkanine, posebno u pogledu anizotropije tekstilnog materijala. Stoga bi dalja istraživanja trebalo da se fokusiraju na razvoj algoritama za simulaciju koji uzimaju u obzir anizotropnu prirodu tekstila i osiguravaju da simulacije tačno odražavaju ponašanje tkanine u različitim pravcima. Pored potrebe za osiguravanjem pristupa algoritmima za simulaciju, uvođenje standardizovanih metoda prikupljanja podataka je ključno za dalju primenu simulacija u industriji odeće. Koordinisani napor da se definišu ovi standardi i najbolje prakse će olakšati saradnju i omogućiti tačnije i pouzdanije simulacije između različitih organizacija i platformi.*

Ključne reči: 3D simulacija, Opadanje tkanine, Simulacija opadanja odeće.

1. INTRODUCTION

Deformation behaviour is an important factor in material selection, especially in the clothing industry. It influences the appearance, the visual effect and the fit on the body and thus the quality of the garment [1, 2]. The shaping behaviour can be divided into two applications: textile drape and drapability. In addition to the mechanical properties, other parameters are decisive for describing the deformation behaviour of textile surfaces: the drape coefficient, the drape spacing ratio, the pleat depth index, the pleat amplitude and the number of knots [3]. The focus of this paper is on the drape coefficient, as it is used as a numerical indicator for the formation of wrinkles during textile drape [4].

Three different cotton fabrics are compared in terms of their textile-physical deformation behaviour in reality and in the simulation. The results provide information on the reliability of the simulation.

The basis for the test series is the drape test according to Cusick, which is carried out in accordance with DIN EN ISO 9073-9 [5] and provides the textile drape in the form of a drape pattern and the drape coefficient as results.

Clothing simulation is becoming increasingly important in the clothing industry. It has great potential, especially for fit analysis and optimisation in the product development process. The realistic representation of textile fabrics in 3D simulations depending on the material properties remains a fundamental challenge [6]. If the three-dimensional representation accurately reflects reality, it could revolutionise the clothing industry [7].

2. THEORIE

2.1. Textile drape

Textile drape is the ability of a fabric to deform under its own weight and is a key property that influences the aesthetics and functionality of textiles [8]. It is not an isolated property, but depends on various mechanical material parameters such as bending stiffness, elongation and shear stiffness. These in turn are influenced by the type of fibre, construction properties and finishing methods [3, 9]. The textile drape plays an important role in the selection and development of textiles for clothing [10]. Despite the complexity of these relationships, drape can be quantitatively assessed using parameters such as the drape coefficient and the drape distance ratio. These measured variables, which are analysed using digital image processing techniques, can provide the clothing industry with important findings that are helpful for simulation-supported product development and improved communication [3].

2.2. Drape test and drape coefficient

The formation of folds in textile material is due to its ability to deform in three dimensions. The drape test was introduced to measure this three-dimensional deformation. This makes it possible to overcome the limitations of two-dimensional stiffness measurement, as used in the cantilever method [11].

The result of the method is a drape image of the material, which can be visually assessed for an initial impression and described by the number of folds, fold shape and alignment of the folds.

The drape coefficient (DC) is used to numerically analyse the drape pattern. It describes the difference between a deformed and a non-deformed surface of the textile material and represents the extent to which a fabric deforms under its own weight [9]. The DC is given as a percentage measure of the ratio of the projected surface of the draped material to the undeformed surface of the material before draping (Figure 1) [12]. Thus, the DC enables an objective description of the drape [9]. In terms of interpretation, a low DC indicates a material that deforms easily, while a higher DC indicates less deformation [13]. However, it should be noted that the DC alone is not sufficient to fully describe the aesthetic appearance of a draped fabric. Fabrics with the same DC can still be characterised by a different drape pattern due to different geometric factors such as the number of knots and the curvature of the draped fabric [4, 14].

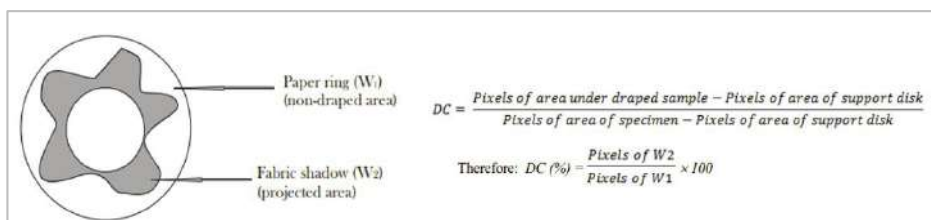


Figure 8: Configuration of the covers [Rudolf] Copyright (2020), originally published under a CC-BY licence



The drape coefficient is determined using a Cusick Drape Tester [2]. In this test, the shadow of the draped fabric is projected onto a flat surface and recorded as a digital image. The drape coefficient (DC) is calculated based on the area of the images before and after draping [15].

In order to obtain a more comprehensive understanding of the draping of fabrics, other parameters such as the drape distance ratio (DDR), the amplitude, the wave depth index (FDI) and the number of waves are often taken into account in addition to the DC [16, 17]. The roundness of the drape profile (CIRC) also serves as a measure of the shape of a drape profile [18]. These parameters provide a robust, multidimensional view of the drape behaviour of a fabric [3].

2.3. Determining the simulation-relevant material parameters for VStitcher

VStitcher, a 3D software for pattern makers, cutters and technical designers is developed and offered by Browzwear (Browzwear Solutions Pte. Ltd) [19]. Browzwear's digital ecosystem also includes the Fabric Analyser (FAB). The FAB is a proprietary device for recording the physical properties of fabrics, which simultaneously converts the data into a digital format. By using the FAB, the 3D design process is rationalised and the accuracy of the simulation is increased [20]. To analyse the material with the FAB, three test strips are cut: one in the warp direction, one in the weft direction and one diagonally. The physical analysis of the fabric with the FAB includes the mass, thickness, bending stiffness, elongation and shear stiffness, whereby only the mass must be determined separately with a scale [20].

2.4. Selection of materials

The selected materials are available in three basic weaves: plain weave, satin weave and twill weave.

Table 1 shows the description of the materials in terms of composition, surface construction and basis weight.

Table 2: Tested Materials

Code	Composition	Weave Type	Yarn Density (wrap/weft)	Weight (g/m ²)
M05	100% Cotton	Atlas Weave	36/25	144,3
M08	100% Cotton	Plain Weave	24/25	201,9
M15	100% Cotton	Twill Weave	36/22	216,1

3. METHODS

For the study, the drape images of the materials M05, M08 and M15 were generated using the Cusick Drape Tester and simulated using the VStitcher software. Both results are

evaluated in a subjective and visual image comparison. The calculation of the above-mentioned numerical parameters is the subject of a second study.

3.1. Cusick Drape Test

The Cusick Drape Tester (Cusick Drape Tester by James H. Heal in Halifax, United Kingdom), with which the drape images of the materials are created, is a recognised testing device for measuring the drape behaviour of textiles (2.). For subsequent image processing, the Drape Tester is coupled with a digital camera and the OBS software (Open Broadcaster Software, version 29.1.3) for image acquisition.

3.2. Virtual simulation of the draping behaviour with VStitcher

In addition, the draping behaviour of the materials is simulated virtually using the VStitcher® software (Version 2021.2.0 51910). For this purpose, the drape test according to Cusick was implemented in the simulation programme. In order to be able to generate comparable results, the test conditions were defined on the basis of the physical drape test [10]. These include the geometries of the test specimen and the specimens, parameters for positioning and fixing the specimen over the holding plate, settings for the virtual camera and lighting and specifications for rendering. In addition, a description of the test process ensures the reproducibility of the test procedure.

The material parameters required for the simulation are determined by Vizoo GmbH from Munich/Germany using FAB and made available digitally.

3.3. Image processing for graphical representation with Adobe Photoshop CC 2023

The image processing for analysing the digital drape images obtained with the Cusick Drape Tester and the digital drape images obtained in VStitcher is carried out with the image processing software Adobe Photoshop CC 2023. The digital colour images are converted to greyscale images and then to binary images so that the comparison can be displayed graphically. Automatic conversion of the drape images is useful for calculating numerical parameters (2.2). The MATLAB software (The MathWorks, Inc., version R2023a 9.14.0) will be used for this in a follow-up project.

4. REALISATION

4.1. Cusick drape tester

As described in 3.1, drape images of the selected materials are created using the Cusick Drape Tester. According to the standard, three different sample diameters are possible: 24 cm, 30 cm and 36 cm. After a preliminary test with a sample diameter of 30 cm, which did not provide any clear results with regard to the textile drape, all tests are carried out with a sample diameter of 36 cm. All materials are preconditioned under standard climatic conditions [5]. The marking of the centre point and warp direction allow the correct and comparable alignment of all samples and the evaluation with regard to the anisotropic material behaviour of textiles [5]. In deviation from the standard, only the right side of the fabric is tested, as it is not possible to differentiate between the right and left side of the fabric in the simulated drape test. The shadow image of the projected drop image is

recorded with the evaluation software [5]. Figure 2 shows a picture of each of the tested materials.

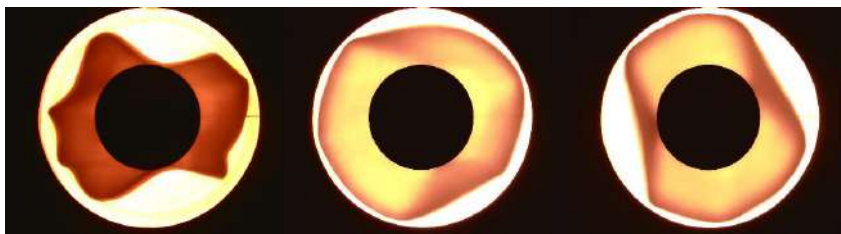


Figure 9: Draping images of materials M05, M08 and M15

4.2. Virtual simulation of the draping behaviour with VStitcher

As described in 3.2, this is based on the previously described physical drape test according to Cusick. The three materials to be tested are implemented in VStitcher using the digital data previously determined with the FAB. The visibility of the support plate must be ensured for the image evaluation, which is why the transparency of the materials is set to 50%. The material behaviour is not affected by this.

4.3. Comparative visualisation of the drape images with Photoshop

The drape images are converted into binary images for better visualisation. The digital colour images consist of pixels, each of which is assigned a colour value. The conversion to binary images involves reducing the colours to black and white. In addition to the clear representation, the software can process these two colours as 0 or 1 and enable calculations based on the number of pixels (3.3). To create binary images, the colour images in Adobe Photoshop CC 2023 are first converted into grey scale images (Figure 3a). Regardless of the colours, the grey scale value represents the brightness of a pixel [21]. The threshold value is then determined (Figure 3b), which defines the brightness at which the pixel colour changes from black to white.

Figures 3a and b show the process for generating the binary images. To compare the drape images from the real test and the simulation, they are superimposed (Figure 3c). The draping image from the simulation is given a unique colour to clearly distinguish the two images.

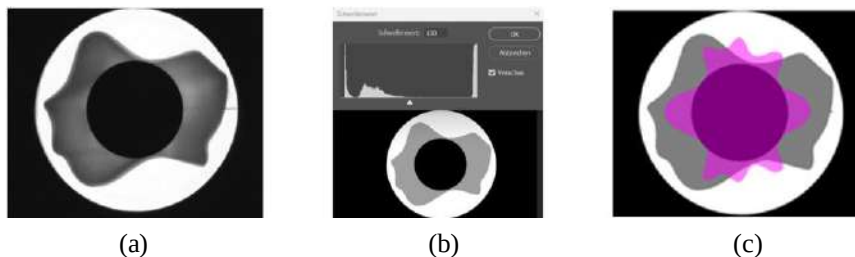


Figure 10: (a) Binary image; (b) Threshold; (c) Overlaid drape test images from the real test and the simulation (grey - physical drape test; purple - virtual drape test).

6. RESULTS

The drape images from the physical and virtual drape test show the ability of textile fabrics to deform in multiple dimensions. In order to compare the results of the physical drape tests with those of the simulation, the categories number of waves, wave shape and wave position are used [22]. They form the basis for the characterisation of the drape patterns. The results for all three materials are shown in Figure 4.

6.1. Result for material M05

The image of the physical drop test for material M05 (Figure 4a, grey) shows pronounced waves in the contour. The material tends to undulate in the transverse direction. One wave is clearly pronounced at the top left. Seven waves can be counted along the contour. The waves are also more clearly recognisable in the simulated drape test (Figure 4a, magenta). Eight waves can be counted. Two clearly defined waves can be recognised in the transverse direction and three in the longitudinal direction. However, the position of the waves and the distances of the contour to the plate do not correspond to the drape image of the physical drape test; here the simulated material appears to be more flexible.

6.2. Result for material M08

The image of the physical drape test for material M08 shows hardly any waves along the contour, only slight flattening in the transverse direction (Figure 4b, grey). In the simulation, however, eight waves are clearly visible (Figure 4b, cyan). The position and shape of the waves is almost vertically and horizontally symmetrical. Three waves can be seen in the longitudinal direction and one wave in the transverse direction. The contours of the two overlap only once in the top centre and bottom right. Otherwise, the distances to the plate are shorter in the simulation.

6.3. Result for material M15

The drop image of the physical drape (figure 4c, grey) test shows a material concentration in the longitudinal direction with maximum distances between the contour and the plate. No clear waves can be recognised. Eight waves can be counted in the image of the

simulated drape test (figure 4c, green). At the top left, the contours overlap; on the left, the contour of the simulation is much further away from the plate. The simulation does not reach the maximum distances to the plate of the drop image of the physical drape test. VStitcher simulates the material M15 much more flexibly than was found in reality.

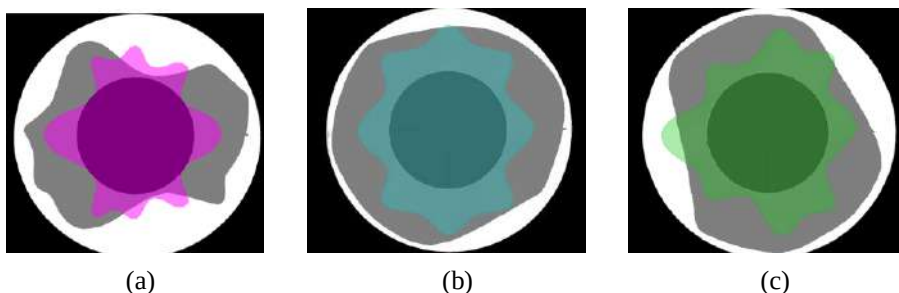


Figure 11: Comparison of physical and virtual case images (a) M05, (b) M08, (c) M15

7. DISCUSSION

These visually and subjectively assessed comparisons clearly show that the simulation does not reflect reality. On the one hand, the materials are shown to be softer in the simulation. On the other hand, the anisotropic properties of textiles are not visible in the simulation. The material behaviour is reproduced almost symmetrically.

The application of the drape test shows the special deformation behaviour of textiles. Due to their inhomogeneous structure, which is characterised by the fibres, yarn and surface construction, a sample behaves differently in several tests with the drape tester and provides different drop patterns. This confirms the need to determine further parameters to describe the textile drape. Further investigations must therefore be carried out in order to be able to draw truly scientifically sound conclusions.

The comparison should be verified with numerical calculations of further parameters as described in 2.2 (2.2) These analyses can provide a better understanding and a more comprehensive and objective description of the drape properties of a material.

The Fabric Analyser (FAB) is a useful device for determining material parameters, particularly because it allows several properties to be tested in one operation. However, it should be noted that the device can only be used for Browzwear's own software. It is therefore advisable to develop the procedure for material testing with the FAB on the basis of standards in order to ensure comparability, traceability and reproducibility.

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INVESTIGATION OF COLOR REMOVAL PERFORMANCE IN DYEHOUSE REACTIVE DYEING WASTEWATER USING DENDRIMER TECHNOLOGY

Original scientific paper
DOI: 10.5937/CT_ITI24022A

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ABSTRACT: In this study, the color removal performance of polyamidoamine (PAMAM) dendrimer was examined in real reactive dyeing bath wastewater (that is, waste water in which the dye is in hydrolyzed form and contains other auxiliary chemicals used in dyeing besides the dye). These experiments were carried out on three reactive dye bath wastewaters, one for trichromatic light color, one for trichromatic dark color, and one for turquoise color dyeing, supplied from a dyehouse. Studies conducted on real plant dyeing wastewater showed that the optimum conditions were 50-100 mg/L dendrimer and 15-30 minutes centrifugation. Color removal efficiency was between 75-90%. In the light of all these results, it can be said that dendrimer technology can be an alternative to other existing techniques in decolorizing reactive dye bath wastewater.

Keywords: reactive dye, color removal, dendrimer, dyehouse.

ISTRAŽIVANJE PERFORMANSE UKLANJANJA BOJE U OTPADNIM VODAMA ZA REAKTIVNO BOJENJE KORIŠĆENJEM DENDRIMER TEHNOLOGIJE

APSTRAKT: U ovoj studiji ispitan je učinak uklanjanja boje poliamidoaminskog (PAMAM) dendrimera u stvarnoj reaktivnoj otpadnoj vodi kupke za bojenje (odnosno otpadnoj vodi u kojoj je boja u hidrolizovanom obliku i sadrži druge pomoćne hemikalije koje se koriste u bojenju pored boje). Ovi eksperimenti su izvedeni na tri otpadne vode iz



kupatila sa reaktivnim bojama, jednom za trihromatsku svetlu boju, jednom za trihromatsku tamnu boju i jednom za farbanje u tirkiznoj boji, koje se snabdevaju iz farbanja. Studije sprovedene na otpadnim vodama pravih biljnih boja pokazale su da su optimalni uslovi bili 50-100 mg/L dendrimera i 15-30 minuta centrifugiranja. Efikasnost uklanjanja boje bila je između 75-90%. U svetlu svih ovih rezultata, može se reći da tehnologija dendrimera može biti alternativa drugim postojećim tehnikama u dekolizaciji otpadnih voda iz kupatila sa reaktivnim bojama.

Ključne reči: reaktivna boja, uklanjanje boje, dendrimer, farba.

1. INTRODUCTION

In the textile industry, reactive dyes, which have a wide range of color options due to their high fastness and brightness, are widely used in the dyeing process [1, 2]. Since dyes are generally stable and contain complex aromatic molecular structures, their biological purification is quite limited, and when discharged into the environment without purification, it causes toxic and carcinogenic effects on living things [3].

Therefore, color removal from wastewater containing dye is a very important issue.

Dendrimers consist of branched polymer compounds of various sizes containing different functional groups and whose functionality can be adjusted, and they have physical properties such as flexibility, viscosity and density distribution compared to polymers [4, 5]. Among dendrimers, poly(amidoamine) (PAMAM) is a dendrimer consisting of an ethylenediamine core, a certain number of repeating units and certain endings, and is one of the dendrimers used in water and wastewater treatment [6].

Studies show that dendrimers are effective in the removal of reactive dyes [3, 4, 7-10]. With chitosan-polypropylene imine (PPI) dendrimer, Reactive Black 5 and Reactive Red 198 dye removal was achieved as 97.0% and 99.4%, respectively [4]. Reactive Blue 19 dye removal was achieved as 72% and 88% with PAMAM dendrimer and PPI dendrimer, respectively [9]. In Reactive Black 5 dye removal with magnetic PAMAM dendrimer, the adsorption capacity was obtained as 70.4 mg/g [7]. In the study investigating Reactive Blue 21 removal with Chitosan/PAMAM dendrimer microparticles, it was stated that 89.3% Reactive Blue 21 removal could be achieved, while the adsorption capacity was 556 mg/g [3]. It has been stated that the adsorption capacity of Reactive Red 3BS with PAMAM dendrimer increases depending on the generation of PAMAM dendrimer and can increase up to 323 mg/g with the 4th generation [8].

However, when these studies are examined, it is seen that dye removal in synthetic dye solution has been investigated and no studies have been conducted with real dyehouse wastewater. In this study, the color removal performance of dendrimer was examined by taking real reactive dyeing wastewater from a dyehouse. For this purpose, the effects of dendrimer concentration and centrifuge time on color removal in three different wastewaters taken from a dyehouse were examined. Since there is no study in this scope and with this approach in the literature, it can be said that the study is innovative and original.

2. MATERIAL AND METHODS

In this study, to determine the optimum dendrimer dosage in the decolorization of real reactive dyeing wastewater with PAMAM dendrimer (Figure 1), 6 different dendrimer concentrations (5-10-25-50-75-100 mg/L) and 3 different centrifuge times (15-30-60 min.) (to determine the optimum time) were used. After adding the required amount of dendrimer to the real reactive dyeing wastewater, the solution pH was adjusted and the solutions were stirred in a mechanical mixer at 90 rpm. At the end of the determined periods, samples were taken from the upper waters of the solutions, centrifuged, and color measurements were made with a UV/Vis spectrophotometer.

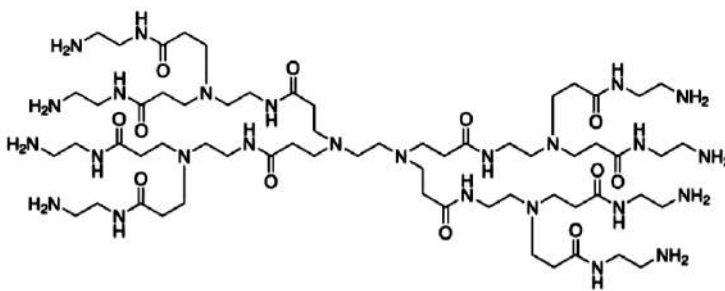


Figure 1. Chemical structure of the dendrimer used in the study [11]

Within the scope of the study, the color removal performance of PAMAM dendrimer was examined in real reactive dyeing bath wastewater (that is, waste water where the dye is in hydrolyzed form and contains other auxiliary chemicals used in dyeing besides the dye). These experiments were carried out on three reactive dyebath wastewaters, one of which was obtained from Özen Mensucat company with thrichromatic light color, the other with thrichromatic dark color and the third with turquoise color dyeing. In fact, it is important to determine the color removal efficiency of dendrimer in the final waste water of the operation. However, a wide variety of dyes are mixed in the final wastewater of a dyehouse. In order to evaluate the color removal performance of dendrimer in our study, it is necessary to know what dyes the wastewater contains. For this reason, in the experiments, after the dyeing in the enterprises, final wastewater samples were taken directly from the dyeing machine and their color removal with dendrimer was studied. However, normally the wastewater generated after a dyeing process is highly concentrated. In the actual operation, the final wastewater contains dyebath waste water as well as various washing baths, bleaching baths, and many more baths are mixed and dilution occurs. For this reason, the real enterprise dye bath wastewater collected in this experimental group was diluted and then subjected to color removal studies with dendrimer. The dyes used in these dyeing recipes and their usage percentages are given below.

- **Light color dyeing:** 0,66% Reactive Yellow 145, 0,15% Reactive Red 195, 1,35% Reactive Blue 221



- **Dark color dyeing:** 0,358% Reactive Red 195, 0,453% Reactive Yellow 145, 1,781% Reactive Blue 250, %8,195 Reactive Black Mix

- **Turquoise color dyeing:** 0,735% Reactive Yellow 160, 0,0382% Reactive Blue 221, 2,915% Reactive Blue 21

Information on the properties of the reactive dyes used in this study is given in Table 1.

Table 1: Reactive dyes used in dyeings

C.I. Number	Chromophore group	Formula	Source
Reactive Yellow 145	Azo		[12]
Reactive Red 195	Azo		[13]
Reactive Blue 221	Cupper formazan		[14]
Reactive Blue 250	Disazo		[15]
Reactive Yellow 160	Azo		[16]

3. RESULTS AND DISCUSSION

Within the scope of the study, the color removal performance of PAMAM dendrimer in real reactive dyeing bath wastewater was examined. These experiments were carried out on three reactive dye bath wastewaters, obtained from Özen Mensucat company one of which was with trichromatic light color (Green), the other with trichromatic dark color (Black) and the third with turquoise color dyeing.

The result of variance analysis regarding the color removal of light colored real reactive dyeing wastewater with dendrimer is given in Table 2.

Table 2: Analysis of variance result for color removal of light colored real reactive dyeing wastewater with dendrimer

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Dendrimer Conc. (mg /L)	5	16962.7	3392.54	1773.58	0.000
Centrifuge Time (min.)	3	28.4	9.48	4.95	0.014
Error	15	28.7	1.91		
Total	23	17019.8			

When Table 2 is examined, it is understood that the effects of both dendrimer concentration and centrifuge time parameters on the color removal of the light colored real reactive dyeing wastewater with dendrimer are statistically significant ($p < 0.05$). Tukey analyzes were also conducted to see the source of the difference and the results are given in Tables 3 and 4.

Table 3: Tukey analysis result on the effect of dendrimer concentration on the color removal obtained in light colored real reactive dyeing wastewater

Dendrimer Conc. (mg/L)	N	Average	Grouping
100	4	75.0000	A
75	4	73.3642	A
50	4	68.9198	B
25	4	57.8704	C
10	4	24.1667	D
5	4	5.4321	E

Table 4: Tukey analysis result on the effect of centrifugation time on the color removal obtained in light colored real reactive dyeing wastewater

Centrifuge Time	N	Average	Grouping
60	6	51.6255	A
30	6	51.4609	A
15	6	51.1523	A B
0	6	48.9300	B

When Table 3 is examined, it can be seen that dendrimer concentrations of 5, 10, 25 and 50 mg/L are each in a separate group, and concentrations of 75 and 100 mg/L are in the same group. Accordingly, it can be said that 75 mg/L is the optimum concentration. When Table 4 is examined, it can be said that color removal is low when centrifugation is not performed, but increasing the centrifugation time beyond 15 minutes does not provide any additional benefit. According to these results, it can be said that the optimum process conditions for light-colored real dye wastewater are 75 mg/L dendrimer and 15' centrifuge. The highest color removal of 76.05% was achieved for this wastewater. All these results can be clearly seen from the “Main Effects Plot for Color Removal” given in Figure 2.

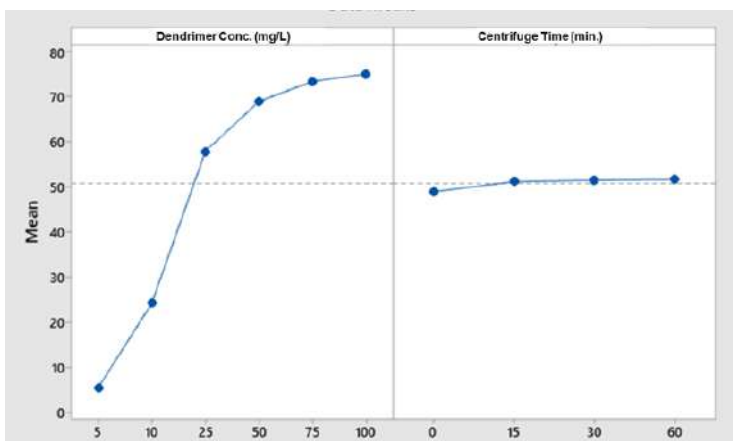


Figure 2. Main effects graph for color removal in light colored dye wastewater

The result of variance analysis regarding the color removal of dark colored real reactive dyeing wastewater with dendrimer is given in Table 5.

Table 5: Analysis of variance result for color removal of dark colored real reactive dyeing wastewater with dendrimer

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Dendrimer Conc. (mg/L)	5	20794.6	4158.91	175.21	0.000
Centrifuge Time (min.)	3	1371.4	457.15	19.26	0.000
Error	15	356.0	23.74		
Total	23	22522.1			

From Table 5, it is understood that the effects of both dendrimer concentration and centrifuge time parameters on the color removal of the dark colored real reactive dyeing wastewater with dendrimer are statistically significant ($p < 0.05$). Tukey analyzes were also conducted to see the source of the difference and the results are given in Tables 6 and 7.

Table 6: Tukey analysis result on the effect of dendrimer concentration on the color removal obtained in the dark colored real reactive dyeing wastewater

Dendrimer Conc. (mg/L)	N	Average	Grouping
100	4	83.4792	A
75	4	82.1116	A
50	4	80.7713	A
25	4	68.7363	B
10	4	34.0536	C
5	4	5.3884	D

Table 7: Tukey analysis result on the effect of centrifuge time on the color removal obtained in dark colored real reactive dyeing wastewater

Centrifuge Time (min.)	N	Average	Grouping
30	6	63.7491	A
60	6	63.6214	A
15	6	62.9832	A
0	6	46.0066	B

When Table 6 is examined, it can be seen that dendrimer concentrations of 5, 10 and 25 mg/L are each in a separate group, and concentrations of 50, 75 and 100 mg/L are in the other group. Accordingly, it can be said that 50 mg/L is the optimum concentration. When Table 7 is examined, it can be said that color removal is low when centrifugation is not performed, but increasing the centrifugation time beyond 15 minutes does not provide any additional benefit. According to these results, it can be said that the optimum process conditions for dark colored real dye wastewater are 50 mg/L dendrimer and 15' centrifuge. The highest color removal of 87.42% was achieved for this wastewater. All these results can be clearly seen from the “Main Effects Plot for Color Removal” given in Figure 3.

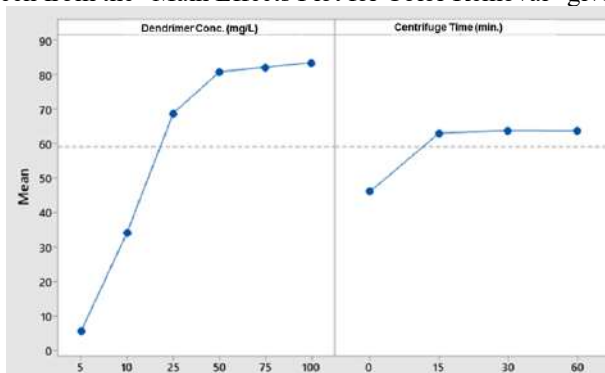


Figure 3. Main effects plot for color removal in dark colored dye waste water



The result of variance analysis regarding the color removal of real turquoise reactive dyeing wastewater with dendrimer is given in Table 8.

Table 8: Analysis of variance result for color removal of turquoise colored real reactive dyeing wastewater with dendrimer

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Dendrimer Conc. (mg/L)	5	302.485	60.4970	510.01	0.000
Centrifuge Time (min.)	3	11.609	3.8698	32.62	0.000
Error	15	1.779	0.1186		
Total	23	315.874			

When Table 8 is examined, it is understood that the effects of both dendrimer concentration and centrifuge time parameters on the color removal of the light colored real reactive dyeing wastewater with dendrimer are statistically significant ($p < 0.05$). Tukey analyzes were also performed to see the source of the difference and the results are given in Tables 9 and 10.

Table 9: Tukey analysis result on the effect of dendrimer concentration on the color removal obtained in real reactive dyeing wastewater in turquoise color

Dendrimer Conc. (mg /L)	N	Average	Grouping
100	4	76.4324	A
75	4	73.0710	B
50	4	72.7368	B
5	4	68.9649	C
25	4	67.9240	D
10	4	65.9664	E

Table 10: Tukey analysis result on the effect of centrifuge time on the color removal obtained in real reactive dyeing wastewater in turquoise color

Centrifuge Time	N	Average	Grouping
60	6	71.5877	A
30	6	71.3649	A
15	6	70.6328	B
0	6	69.8116	C

When Table 9 is examined, it can be seen that the dendrimer concentrations of 50 and 75 mg/L are in one group, and the concentrations of 5, 10, 25 and 100 mg/L are each in a different group. Accordingly, it can be said that 100 mg/L is the optimum concentration. When Table 10 is examined, it can be said that color removal is low when centrifugation

is not performed, but increasing the centrifugation time beyond 30 minutes does not provide any additional benefit. According to these results, it can be said that the optimum process conditions for turquoise colored real dye wastewater are 100 mg/L dendrimer and 30' centrifuge. The highest color removal of 76.81% was achieved for this wastewater. All these results can be clearly seen from the “Main Effects Plot for Color Removal” given in Figure 4.

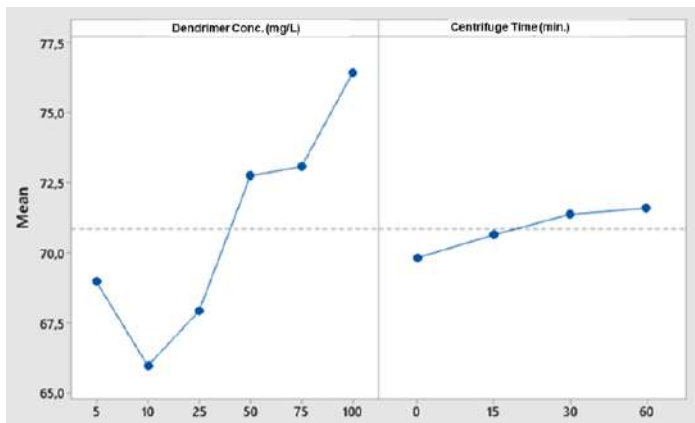


Figure 4. Main effects plot for color removal in turquoise dye wastewater

3. CONCLUSION

Studies conducted on real plant dyeing wastewater showed that the optimum conditions were 50-100 mg/L dendrimer and 15-30 minutes centrifugation. Color removal efficiency was between 75-90%. In the light of all these results, it can be said that dendrimer technology can be an alternative to other existing techniques in decolorizing reactive dye bath wastewater.

ACKNOWLEDGMENT

We would like to thank TÜBİTAK for financially supporting this study within the scope of project no. 123M627. We would also like to express our gratitude to the company ÖZEN MENSUCAT, which provided the wastewater used in the trials.

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WASTE POTASSIUM BASED RECYCLE AGENT PREPARATION AND NANOFIBER PRODUCTION

Original scientific paper
DOI: 10.5937/CT_ITI24023RS

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ABSTRACT: The low potassium content in the foods consumed daily and the absence of potassium in most foods direct people to potassium intake directly through supplementary foods. It is known that large amounts of potassium are present in banana fruit and peel. This study is aimed at utilizing banana peel waste to produce an easy-to-use, thin, lightweight, biocompatible, and innovative nanofibrous material. First of all, waste banana peels were lyophilized with a freeze-dryer device and pulverized with a mixer blender. Next, EDX conducted an elemental analysis of the potassium-containing banana peel powder. Then, PVP-based nanofibers with recycled potassium-containing banana peel powder were produced. PVP solutions containing different concentrations of banana peel powder were prepared under equal conditions, and the solution properties such as conductivity, viscosity, pH, and surface tension were determined. Finally, Scanning Electron Microscopy (SEM) was used to analyze the structural properties of PVP-banana peel powder nanofibers, such as fiber diameter, fiber diameter uniformity coefficient, and elemental analysis with EDX to confirm the presence of potassium in the nanofibrous material. It is thought that these nanofiber surfaces, which can be transformed into a high-value-added product by evaluating the waste food material, will be especially useful for a treatment for supralingual application of potassium.

Keywords: Waste, recycle, potassium, PVP, nanofiber, electrospinning.

PRIPREMA RECIKLAŽNIH SREDSTAVA NA BAZI OTPADNOG KALIJUMA I PROIZVODNJA NANOVLAKNA

APSTRAKT: Nizak sadržaj kalijuma u namirnicama koje se svakodnevno konzumiraju i odsustvo kalijuma u većini namirnica usmeravaju ljude na unos kalijuma direktno putem dopunske hrane. Poznato je da su velike količine kalijuma prisutne u plodovima i kori banane. Ova studija ima za cilj korišćenje otpada od kore od banane za proizvodnju tankog, laganog, biokompatibilnog i inovativnog nanofibroznog materijala koji je jednostavan za upotrebu. Pre svega, otpadne kore od banane su liofilizovane pomoću uređaja za sušenje zamrzavanjem i usitnjene mikserom. Zatim je EDKS sproveo



elementarnu analizu praha kore banane koji sadrži kalijum. Zatim su proizvedena nanovlakna na bazi PVP-a sa recikliranim prahom od kore banane koji sadrži kalijum. PVP rastvori koji sadrže različite koncentracije praha kore banane pripremljeni su pod jednakim uslovima i određena svojstva rastvora kao što su provodljivost, viskozitet, pH i površinski napon. Konačno, skenirajuća elektronska mikroskopija (SEM) je korišćena za analizu strukturnih osobina nanovlakna u prahu od kore banane PVP, kao što su prečnik vlakana, koeficijent uniformnosti prečnika vlakana i elementarna analiza sa EDKS-om da bi se potvrdilo prisustvo kalijuma u nanovlaknastom materijalu. Smatra se da će ove površine od nanovlakna, koje se mogu transformisati u proizvod sa visokom dodatkom vrednošću procenom otpadnog materijala hrane, biti posebno korisne za tretman supralingvalne primene kalijuma.

Ključne reči: *otpad, reciklaža, kalijum, PVP, nanovlakna, elektropredenje.*

1. INTRODUCTION

Sustainability of waste materials is of great importance in the world, and in this study, it is planned to evaluate banana peel waste and transform it into a value-added product. Banana is the second most consumed tropical fruit worldwide. However, this consumption generates a lot of waste. Banana peels are a carbon-rich waste that can take up to two years to decompose and biodegrade, creating odors and producing excessive greenhouse gas emissions that contribute to climate change. Banana peels, which make up about 35% of the banana by weight, generate 3.5 million tons of waste annually [1]. Today, the value of sustainability and an environmentally friendly approach is increasing day by day, and recycling and using banana peel waste instead of harming the environment maintains its importance in terms of both human and natural health. When the textile-related studies on the utilization of banana peel wastes in the literature are analyzed, the adsorption properties of banana peels in the removal of dyes from textile wastewater were examined [2]. In another study, heavy metal adsorption with banana peel wastes and the efficiency of textile dyes were analyzed [3]. Another study on banana peel in the textile sector examined the effect of banana peel extract on the flame retardancy of cotton and cotton-polyester blended fabrics. The study determined that banana peel, after finishing processes using banana peel wastes, positively contributed to flame retardancy [4].

Nanotechnology is a multi-disciplinary field that includes both textiles and many other disciplines (medical, electronics, chemistry, biology, etc.). Nanofibers are one of the subunits of nanotechnology, and nanofiber production, especially by the electrospinning method, has gained great importance in recent years, both in R&D and industrial applications. Fiber spinning from many natural and synthetic polymers can be realized in nanofiber production by the electrospinning technique. Nanofibers have recently become an increasingly important research topic due to their microstructural properties, such as small pore sizes, high porosity, high specific surface area (m^2/g), and very fine fiber diameter.

It is thought that the nanofiber material containing potassium produced in this study will be useful in sublingual applications. In the literature, there are studies on the production of

nanofibers using different active ingredients and supralingual applications. In a study conducted by [5] in 2022, supralingual application of PVA-based and paracetamol-loaded nanofibers was performed in rabbits, and paracetamol concentration values in the blood were determined. It was stated that nanofibrous materials have an important potential for such supralingual applications.

2. MATERIALS AND METHODS

2.1. Materials

In this study, PVP (Mw 360.000 g/mol) was used as a polymer, distilled water and ethanol (absolute $\geq 99.8\%$) were used as solvents, banana peel powder was used as a potassium agent, and Cremophor RH40 was used as a surfactant.

2.1. Methods

In general, the study was carried out in five stages. Firstly, waste banana peels were lyophilized using a freeze dryer. After the lyophilization process, potassium was concentrated in the dried peel, and then the dry peels were powdered by passing through a mixer. EDX elementally analyzed the potassium-containing powder material. Preparation of polymer solutions with optimum properties (polymer and agent concentration, appropriate solvent selection, solution preparation techniques, etc.) is very important in terms of fiber spinning performance and fiber morphology in the production of nanofibers. In the study, PVP polymer concentration was kept constant at 12 wt %, and ethanol and distilled water were used as solvents in a 50:50 ratio. When a homogeneous solution was obtained, banana peel powder was added to the PVP solution at different concentrations, such as 0.1, 0.3, 0.5, 0.7 and 0.9 wt %. In nanofiber production by electrospinning, determination of the solution properties used as raw material is very important in terms of fiber spinning performance and morphological properties of fibers (fiber diameter, uniformity, etc.) [6]. The solution properties, such as surface tension, conductivity, viscosity, and density, of PVP-based solutions with different concentrations of potassium agents were determined. Nanofibers were produced from the prepared polymer solutions under equal conditions by the electrospinning method by applying optimum process parameters voltage (22.3 kV), distance between electrodes (22 cm), and feed rate (0.4 mL/h). For the structural and morphological characterizations of PVP-based nanofiber, images were taken at different magnifications (x1.000 and x20.000) with SEM. Average fiber diameter and fiber diameter uniformity coefficients were calculated from SEM images with Image J software. At least 100 different measurements were carried out on each sample. Thus, as the potassium concentration increased, changes in fiber diameter and morphology were analyzed. EDX analysis was also performed on the nanofibers to demonstrate the presence of potassium in the structure of the fibrous material. Finally, fiber diameter uniformity coefficients were calculated [7].

3. RESULTS AND DISCUSSION

3.1. Polymer Solution Characterization

Polymer solution properties were measured in terms of understanding the effect of banana peel powders on solution properties and fiber spinning performance. Viscosity, conductivity, and surface tension graphs of polymer solutions are given in Figur

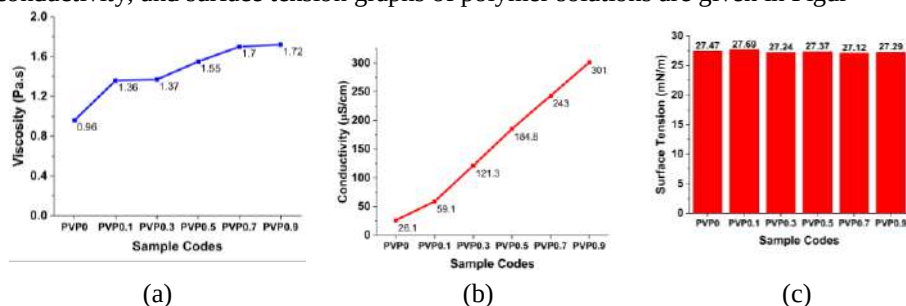
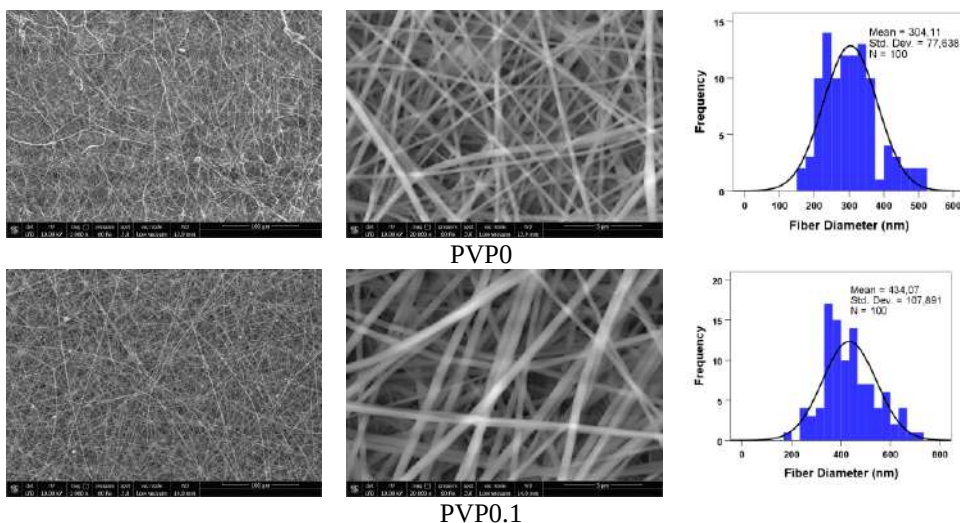


Figure 1: Solutions properties of PVP based polymer solutions with different concentrations of banana peel powder a) Viscosity b) Conductivity c) Surface tension

According to the polymer solution results; viscosity and conductivity increases and surface tension does not change with banana peel powder concentration increasement.

3.2. Fiber Morphology Results

SEM images of PVP nanofibers with various concentrations of banana peel powder are given in Figure 2.



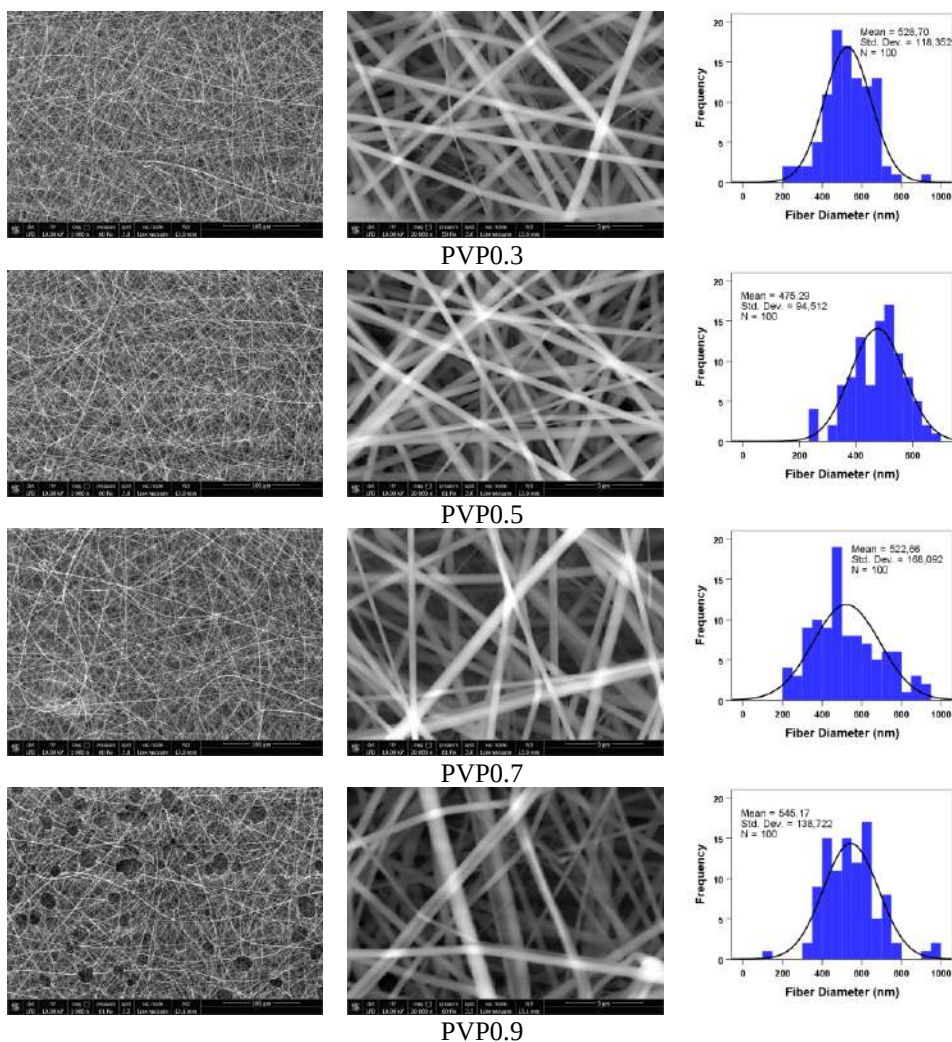


Figure 2: SEM images (1.000x-20.000x) and histograms of PVP nanofibers produced with various concentrations of banana peel powder

When SEM images were analyzed, as the concentration of banana peel powder increased, nanofiber morphology was negatively affected, and stickiness were formed in the nanoweb structure. In general, nanofibers were smooth, fine, uniform and without beads. It is possible to say that average fiber diameter and viscosity increased with banana peel powder concentrations. Average fiber diameter values were between 304-545 nm. Figure 3 illustrates the variation of average fiber diameter and fiber diameter uniformity coefficient with banana peel powder concentration.

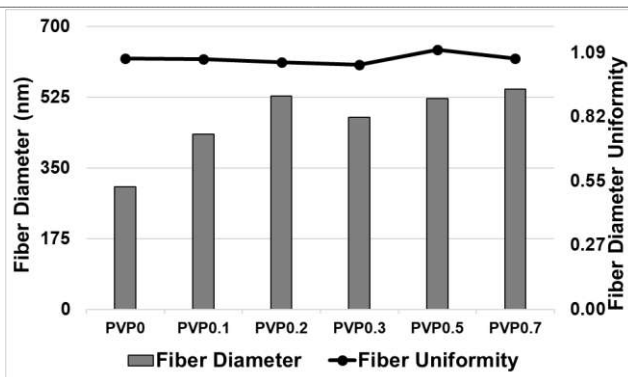
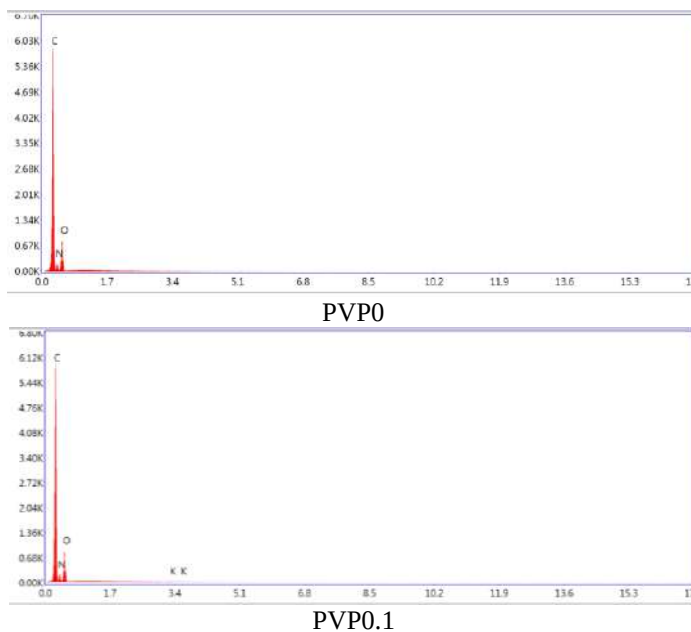


Figure 3: Average fiber diameter and diameter uniformity results of PVP nanofibers with various concentrations of banana peel powder

The existence of potassium (K) entrapped within the PVP nanofibrous webs was confirmed by the EDX spectrums (Figure 4).



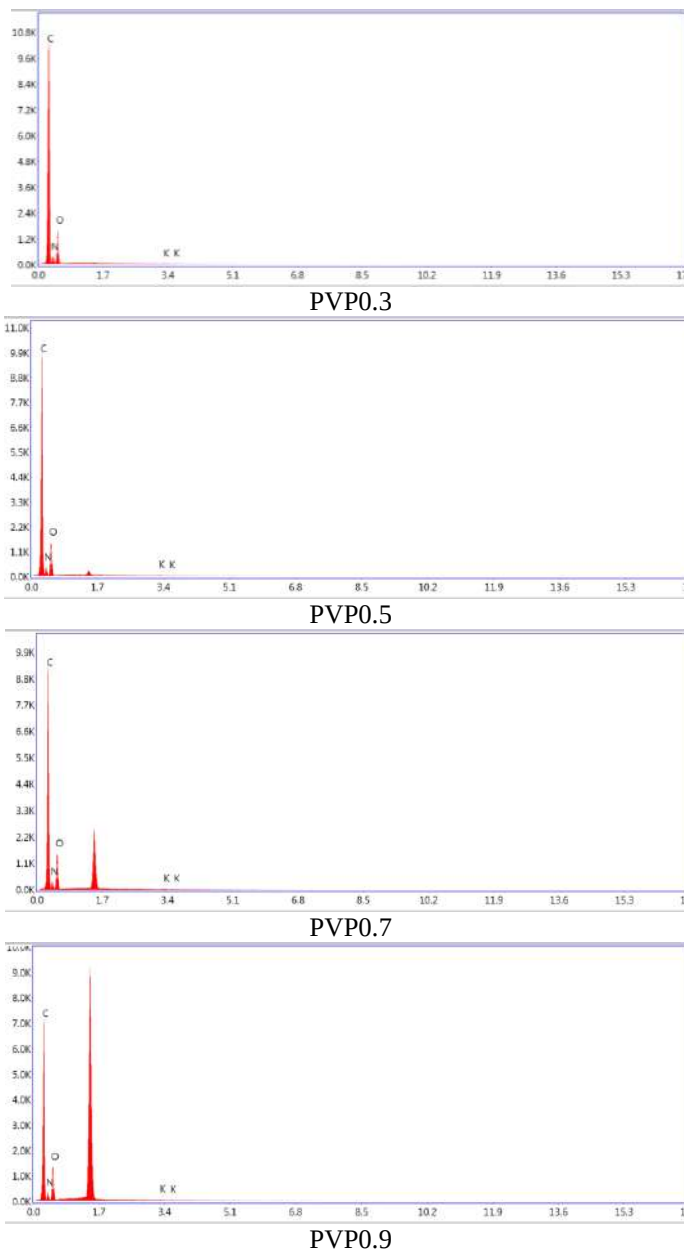


Figure 4: EDX analyses of PVP nanofibers with various concentrations of banana peel powder



In the EDX spectrum of pure PVP nanofibers, only the peaks assigned to the K α peaks of carbon (C), nitrogen (N), and oxygen (O) were found, as expected. In other samples, potassium appeared in different concentrations in addition to these elements. Table 1 shows the elemental analysis of elements existence into the PVP nanofibrous structure. It is clearly seen that amounts of K increased with banana peel powder concentration.

Table 1: SEM-EDX results of PVP nanofibers with various concentrations of banana peel powder

Sample Code	C (%)	O (%)	N (%)	K (%)
PVP0	67.08	18.05	14.87	-
PVP0.1	66.67	18.31	14.91	0.10
PVP0.3	65.70	19.38	14.79	0.14
PVP0.5	65.13	19.18	15.33	0.12
PVP0.7	65.03	20.01	14.62	0.34
PVP0.9	62.50	22.25	13.79	0.45

4. CONCLUSION

The potassium-loaded nanofibers produced in the study are thought to be an alternative to potassium capsules taken orally as food supplements on the market. This situation creates significant problems, especially for the elderly, children, and those who have difficulty swallowing medication. Therefore, it is thought that these problems can be eliminated with the sublingual application of a nanofiber preparation with a high potassium content.

ACKNOWLEDGE

The authors would like to thank the Scientific and Technological Research Council of Turkey (TÜBİTAK) for their support under the 2209-A - Undergraduate Students Research Projects Support Program.

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THEORETICAL ANALYSIS OF COMPRESSION OF RIB KNITTED FABRIC

Original scientific paper
DOI: 10.5937/CT_ITI24024A

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ABSTRACT: Lateral compression of polymer fibrous materials is of great interest for various applications such as textile products, and fiber-reinforced composites. The ability of the fabric to deform under the force applied normally to its plane is determined by fiber properties, the compressibility and surface properties of the constituent yarn, and the fabric's structural characteristics. Many scientists have been working on modeling fibrous assembly's compression and recovery behavior. Van Wyk's compression theory was the first theoretical model explaining the compressional behavior of fiber mass. This theory is the simplest but most realistic model of compression. The process of plying or folding yarns balances the torque of the novel linear fibrous assembly and improves evenness, strength, and surface characteristics. Some properties of folded yarns have been extensively investigated but, there are no investigations of the effect of the ply twisting of yarns on the compression ability of rib knitted fabrics. This investigation continues the research attempting to provide insight into the potential of yarn folding in terms of compressional behavior. A mechanical model based on van Wyk's compression theory was applied to describe the multicyclic compression behavior of rib knits, both in the compression and relaxation phases. A high correlation between experimentally and theoretically obtained compression curves was established.

Keywords: yarn, ply twist, rib knitted fabric, compression, van Wyk's compression law.

TEORIJSKA ANALIZA KOMPRESIJE REBRASSTIH PLETENINA

APSTRAKT: Lateralna kompresija polimernih vlaknastih sistema je vrlo interesantna sa aspekta različitih primena kao što su tekstilni proizvodi i kompoziti ojačani vlaknima. Sposobnost tekstilnog materijala da se deformiše pod dejstvom sile normalne na njegovu ravan određena je svojstvima vlakana, kompresibilnošću i svojstvima površine pređe i strukturnim karakteristikama samog materijala. Mnogi istraživači su radili na modelovanju kompresionog ponašanja vlaknastih snopova. Prvi teorijski model, koji je predložio van Wyk, je i najrealističniji model kompresije. Končanjem pređe se uravnotežava torzioni momenat čime se poboljšava jačina, ravnomernost i površinska



svojstva novonastale strukture. Određena svojstva končanih pređa su dobro ispitana, međutim, nema istraživanja efekta končanja na kompresiono ponašanje rebrastih pletenina. Ovo istraživanje predstavlja nastavak istraživanja sa namerom da se ispita efekat končanja pređe na kompresiono ponašanje pletenina. Mehanički model zasnovan na van Wyk-ovoj teoriji kompresibilnosti je primenjen sa ciljem da se opiše ponašanje rebrastih pletenina pri višecikličnoj kompresiji i relaksaciji. Ustanovljena je visoka korelacija između eksperimentalno i teorijski dobijenih kompresionih kriva rebrastih pletenina.

Ključne reči: pređa, končanje, rebrasta pletenina, kompresija, van Wyk-ov zakon kompresije.

1. INTRODUCTION

The mechanical properties, such as the compression of textile materials, are crucial for the tactile comfort of clothing since it is closely related to the smoothness and softness of the material. The compressibility of a fabric is defined as its ability to deform under the influence of applied force normal to its plane. Most clothing materials can change their thickness under very low pressures. The compression behaviour of textile materials is influenced by fiber properties, the compressibility and surface properties of the constituent yarn, and the fabric's structural characteristics. There have been many investigations of the compression properties of textile materials in dependence on fiber, yarn, and fabric characteristics. However, there are only a few investigations of the effect of the ply twisting of yarns on the compression behavior of textile materials [1, 2]. The plying or folding of yarns enhances properties such as uniformity, strength, resilience, and surface qualities. Stankovic et al. [3] indicated that using folded yarn in knitted fabric enables better thermal insulation. In the research conducted by Stankovic and Bizjak [2], single jersey knitted fabric made from two-folded hemp yarn exhibited higher compressibility than knit made from single hemp yarn. In more recent research, Stankovic et al. showed that an increase in the folding twist intensity of cotton yarn reduced compressibility but increased the resilience of rib knitted fabrics [1]. This study continues the research by theoretical analysis of the compression behavior of the rib knitted fabrics attempting to provide deeper insight into the effect of yarn folding on this mechanical property.

Many scientists have been working on modeling fibrous assembly's compression and recovery behavior. Van Wyk's compression theory was the first theoretical model explaining the compressional behavior of fiber mass [4]. Although this model was developed for wool with randomly oriented fibers, many scientists demonstrated that the model is also valid for fabrics with oriented fibers. However, Van Wyk's model does not account for compression hysteresis. Yet, starting from van Wyk theory and de Jong model, the compression hysteresis of rib knitted fabrics containing folded yarns were developed.

2. MECHANICAL MODEL FOR THE LATERAL COMPRESSION OF TEXTILE MATERIALS

Van Wyk's theory relates the pressure and volume of a randomly oriented fiber mass during compression. He derived the equation that correlates Young's modulus for the fiber, mass of the fibers, density of the fiber and intrinsic volume or the volume of the mass at zero pressure [4]. Later van Wyk corrected the equation by including the incompressible volume (Equation 1):

$$P = KE \frac{m^3}{\rho^3} \left(\frac{1}{(V-V')^3} - \frac{1}{(V_0-V')^3} \right) \quad (1)$$

gde je E – Young's modulus for the fiber, m – mass of the fibers, ρ - fiber density, V_0 – intrinsic volume (volume of the fiber mass at zero pressure), K – dimensionless constant determined by the structure of fiber assembly (included due to assumptions made).

Based on van Wyk's theory, de Jong et al. proposed a mechanical model for the lateral compression of woven fabrics describing the compression curves [5]. According to the model, the fabric is considered a three-layer structure one of which is a relatively incompressible inner layer occupied by two outer layers on either side as illustrated in Figure 1. The inner layer consists of assemblies of fibers forming yarn with a small amount of air space. Fibers projecting from the fabric's surface with a large content of air between them form the compressible outer layers.

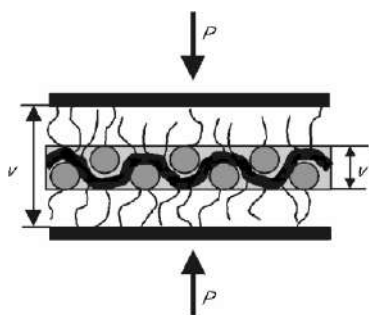


Figure 1: Three-layer structure of textile materials according to de Jong and al. mechanical model [5].

At lower compression force, the protruding fibers from the outer layers are compressed, which is considered elastic deformation. When the compression force overcomes inter-yarn and inter-fiber friction, fiber slippage takes place. The fabric thickness undergoes deformation nonlinearly in this stage. A further increase in compression force results in a slight reduction nonlinearly in fabric thickness, forming a densely packed fiber assembly. The initial elastic deformation of fibers themselves takes place in this stage. Optical measurements confirmed this three-layer model [5]. Starting from Equation 1, de Jong evaluated the three-parameter model with three unknown parameters: the volume at zero pressure, the

incompressible volume, and the mechanical parameter determined by the mass of fibers in the compressible surface layers and their orientation. To simplify the model, de Jong assumed that the volume at zero pressure is relatively high, simplifying equation 1. This way, the two-parameter model with the incompressible volume V' (Equation 2), and mechanical parameter a' (Equation 3) is derived [5].

$$V' = V - \frac{2W}{P} \quad (2)$$

$$a' = \frac{8W^3}{P^2} \quad (3)$$

gde je W – compression energy, V – the volume of the fiber mass under pressure applied, P – applied pressure.

3. MATERIALS AND METHODS

Single hemp and cotton yarns with 50 tex were used for the production of three two-folded yarns: hemp yarn (FCs) with folding twist intensity of 300 m^{-1} , and two cotton yarns with the folding twist (secondary twist) of 300 m^{-1} and 600 m^{-1} (FCo1 and FCo2, respectively). These yarns were ply twisted in the S direction, opposite the spinning twist. These three two-folded yarns and two assembled hemp yarns (2Cs) were used to produce rib knitted fabrics. By combining one of the two cotton folded yarns (FCo1 and FCo2) with one of the two complex hemp yarns (FCs and 2Cs), four variants of 1x1 rib knitted fabrics were obtained:

- FCo1+ 2Cs: two-folded cotton yarn with lower folding twist level + two assembled hemp yarn;
- FCo1+ FCs: two-folded cotton yarn with lower folding twist level + two-folded hemp yarn;
- FCo2+ 2Cs: two-folded cotton yarn with higher folding twist level + two assembled hemp yarn;
- FCo2+ FCs: two-folded cotton yarn with higher folding twist level + two-folded hemp yarn.

The rib knitted fabrics were compressed and relaxed for five cycles starting with a minimal load (0.29 N), through a progressively increased load from 1.67 N (4.12 N, 6.57 N, 11.48 N) to approximately tenfold load (16.38 N). When the maximum compressive force was applied, the test was reversed until the sample was relaxed completely. The compression behavior of these knitted fabrics was evaluated elsewhere [1]. In that paper, the energy properties of the knitted fabrics were calculated based on the compression-release curve for each compression cycle. In addition, the percentages of plastic (D_p) and viscoelastic (D_{ve}) deformation components were calculated. The data necessary for van Wyk's parameters calculation are given in Table 1.

		FCo1+2Cs	FCo1+FCs	FCo2+2Cs	FCo2+FCs
Energy dissipated, $\times 10^{-3}\text{J}$	1. cycle	3.00	2.70	2.50	2.90
	5. cycle	0.88	0.88	0.75	0.92
Plastic deformation (%)		51.4	50.0	52.5	50.7
Viscoelastic deformation (%)		48.6	50.0	47.5	49.3

Table 1: Data for van Wyk's parameters calculation [1]

4. RESULTS AND DISCUSSION

To construct the theoretical compression curves, van Wyk's parameters - incompressible volume (V') and mechanical parameter (a') were calculated according to equations 2 and 3, respectively. The calculated values of these parameters of the two-parameter compression model are given in Table 2. Based on these parameters, the sample volume values were calculated for each level of compression load within all five compression cycles. This paper presents the data for the first and fifth cycles.

Table 2: Van Wyk's parameters for the two-parameter model of compression

Knitted fabric designation	Incompressible volume, V' (mm^3)	Mechanical parameter, a' ($\text{N}\cdot\text{mm}^7$)	Correlation coefficient, r^2
1. cycle			
FCo1+2Cs	88.625	3296.413	0.74
FCo1+FCs	96.025	2403.085	0.71
FCo2+2Cs	103.155	1907.647	0.71
FCo2+FCs	100.862	2977.638	0.70
5. cycle			
FCo1+2Cs	102.884	83.200	0.67
FCo1+FCs	108.004	83.200	0.66
FCo2+2Cs	114.460	51.506	0.64
FCo2+FCs	113.772	95.070	0.65

The correlation coefficients ranging from 0.64 to 0.74, indicated a high coincidence of the calculated values of the sample volume with the experimentally measured data. This means that a two-parameter model can be successfully applied for the description of the compression curves of the rib knitted fabrics. On the other hand, it is generally considered that van Wyk's theory does not explain hysteresis caused by fiber slippage and friction effects. Despite this, Stankovic successfully implemented a two-parameter model to determine the compression hysteresis of plain [6] and rib [7] knitted fabrics. Starting from de Jong's consideration of fabric compression, in this study, the release or decompression curve of the compression cycle was determined by the same line of approach. Using the data from Table 1, van Wyk's parameters for a decompression curve were calculated (Table 3). The incompressible volume and mechanical parameter for the first and fifth cycles are

presented in Table 3. An extremely high correlation coefficient (0.91 – 0.92) confirmed the possibility of using a two-parameter model for describing the decompression curve.

Table 3: Van Wyk's parameters for the two-parameter model of decompression

Knitted fabric designation	Incompressible volume, V' (mm^3)	Mechanical parameter, a' ($\text{N} \cdot \text{mm}^7$)	Correlation coefficient, r^2
1. cycle			
FCo1+2Cs	100.032	445.903	0.92
FCo1+FCs	106.572	300.386	0.92
FCo2+2Cs	112.433	276.042	0.91
FCo2+FCs	112.032	388.057	0.92
5. cycle			
FCo1+2Cs	106.228	11.274	0.92
FCo1+FCs	111.442	10.400	0.92
FCo2+2Cs	117.244	7.453	0.91
FCo2+FCs	117.316	12.390	0.92

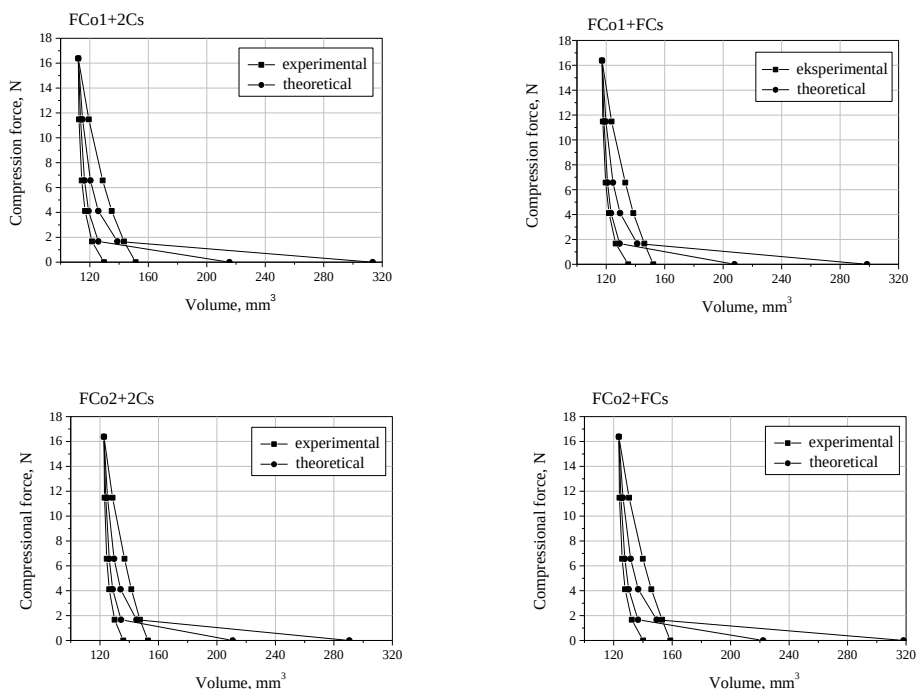


Figure 2: Compressional curves of the first cycle for multicycle compression of rib knits

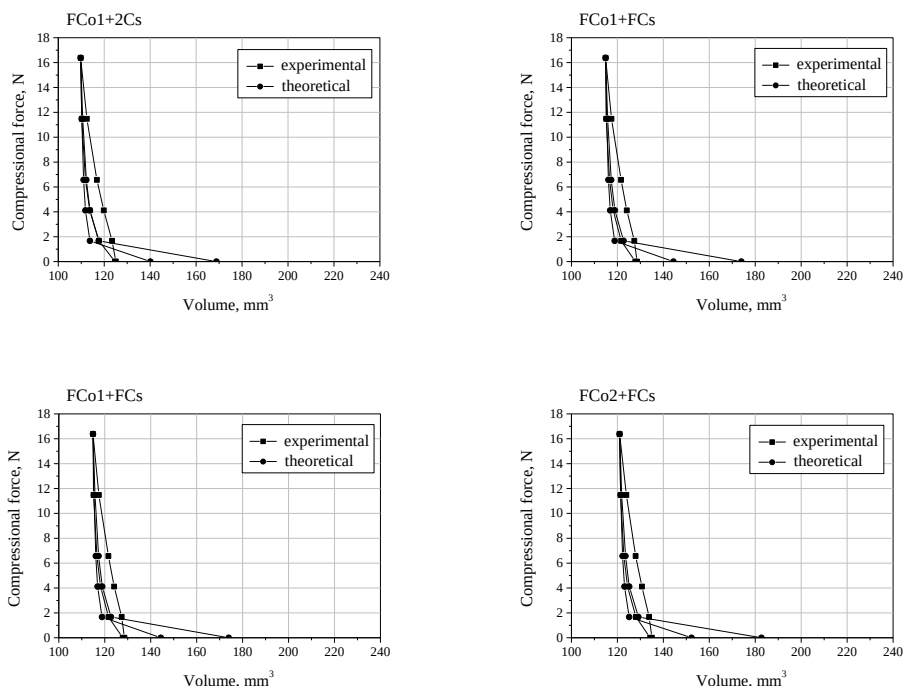


Figure 3: Compressional curves of the fifth cycle for multicycle compression of rib knits

The graphs in Figures 2 and 3 show the experimental and theoretical compression curves for the 1st and 5th cycles of multicycle compression of rib knitted fabrics. Almost identical theoretical and experimental relaxation curves can be observed, except in the case of complete relaxation of the sample. Larger deviations were observed between the sample's theoretical and experimentally determined initial thickness. This is believed to be due to the two-parameter compression model applied.

5. CONCLUSION

The two-parameter model derived from van Wyk's compression theory was applied successfully to approximate the compression curves of the rib knitted fabrics in the pressure range from 0.45 to 2560 cN/cm². Moreover, the decompression curves were also successfully described with the same model based on the nonelastic deformation components. For this two-parameter model, which has a linear character, to be applied to the compression behavior of knitted fabrics, it is necessary to use it on the outer



compressible layers of knitted fabrics, which are considered to deform linearly under compression force.

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BED MICROCLIMATE MANAGEMENT PERFORMANCES OF MATTRESS TICKING FABRICS ACCORDING TO THEIR TRANSFER CHARACTERISTICS

Original scientific paper
DOI: 10.5937/CT_ITI24025K

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ABSTRACT: Sleep quality is affected by mattress components, mainly thermal comfort management ability of the microclimate border layers. Knitted quilted mattress ticking fabrics made of polyester, polypropylene, viscose, lyocell, wool and their blends combined with polyester mid-layer were investigated for their effects on thermal comfort of the bed microclimate. For this aim water vapor, liquid absorption and transfer tests and microclimate measurements on the simulated bed microclimate were carried out. Results showed that lyocell viscose and its blend with linen have better breathability, liquid absorption and transfer characteristics and can be suggested for better sweat management within the bed microclimate system.

Keywords: bed microclimate, mattress ticking, quilted fabric, sweat transfer, thermal comfort.

PERFORMANSE UPRAVLJANJA MIKROKLIMOM KREVETA TKANINA DUŠEKA PREMA NJIHOVIM PRENOSNIM KARAKTERISTIKAMA

APSTRACT: Na kvalitet spavanja utiču komponente dušeka, pre svega sposobnost upravljanja toplotnom udobnošću graničnih slojeva mikroklimе. Ispitivani su uticaji pletenih prošivenih madraca od poliestera, polipropilena, viskoze, liocela, vune i njihovih mešavina u kombinaciji sa srednjim slojem poliestera na toplotnu udobnost mikroklimе kreveta. U tu svrhu izvršena su ispitivanja vodene pare, apsorpcije i prenosa tečnosti i merenja mikroklimе na simuliranoj mikroklimi korita. Rezultati su pokazali da liocel viskoza i njena mešavina sa lanom imaju bolju prozračnost, apsorpciju tečnosti i karakteristike prenosa i mogu se predložiti za bolje upravljanje znojem u okviru mikroklimatskog sistema kreveta.



Ključne reči: mikroklima kreveta, kucanje dušeka, prošiveni materijal, prenos znoja, toplotna udobnost.

1. INTRODUCTION

Problems related to sleep quality sourced from temperature, light, noise and bed quality parameters, adversely affect health and life quality of 40% of the US adult population [1]. Especially for people who spend their lives in bed, and infants, the thermal comfort properties of mattress fabrics are much more important as they are more vulnerable to heat stress and fluctuations [2-3]. Sleepwear, bedding textiles enclosing microclimate and body, ambient environmental conditions all contribute to the bed microclimate conditions. The mattress ticking fabric, constituting the lower layer of the bed microclimate may be produced from double-layer quilted knitted fabrics besides spacer and woven fabrics and quilted fabrics provide many advantages for thermal comfort parameters such as breathability and liquid transfer. These fabrics, that may also include in-laid yarn layers, have two independent layers, connected by tuck or loop stitches to create different physical characteristics. The requirements of bedsheet and mattress ticking layer are season specific but common necessities are quick liquid transfer and drying features, breathability with good water vapor and air permeabilities [4-5]. Therefore, thermal, breathability and moisture absorption and transfer properties of the mattress ticking fabrics are crucial for creating a warm/cool but always dry bed microclimate besides hand features such as surface roughness and these thermal comfort features were investigated by preceding studies [6-8]. Moreover, bed microclimate conditions were also investigated by a simulated bed microclimate as in this study and microclimate conditions were recorded for different sandwich fabrics with and without active air flow and viscoelastic foam [9]. Zhang et al. [3] investigated the effects of bedding insulation and indoor air temperature on bedding temperature and thermal comfort under different indoor air temperatures and bedding system insulations subjectively. A multilayer bedding system was simulated consisting of woven and knitted fabrics, fiber, sponge interlinings differing in physical characteristics and material/structural effects on air permeability and thermal conductivity of the bed system were reported [10].

In this study, we aimed to investigate the effects of mattress ticking fabric material on sleeping microclimate, hence sleep quality. Part of a wider project, simulated bed microclimate measurements (temperature and relative humidity) and liquid absorption and transfer features of quilted mattress ticking fabrics were conducted. Results were put forward about the performances of quilted fabrics made of regenerated cellulosic fibers, wool, polyester and polypropylene with different layer combinations for maintaining bed thermal comfort.

2. MATERIALS AND METHODS

2.1. Material

Quilted mattress ticking fabrics were knitted with the yarns whose properties were compiled in Table 1. 335D/72F/2 texturized semi-dull continuous polyester filament was used as laying-in yarn. All samples were produced on a Mayer & Cie-OVJA 1.6E Double Jersey Jacquard Knitting Machine having a gauge of 20E and diameter of 38 inches.

Table 1: Physical properties of yarns [11]

Fabric Code	Material	Yarn Linear Density	Areal Density (g/m ²) [S.D.]*	Thickness (mm) [S.D.]*
(TEN-TEN)	100% Tencel LF®	24.6 tex	514.92 ^{bc**} [3.80]	4.36 ^b [0.04]
(PP-PP)	100% Polypropylene	22.2 tex (200D)	452.86 ^d [7.42]	4.13 ^{cd} [0.03]
(PET-PET)	100% Polyester	19.7 tex	432.26 ^e [6.92]	4.14 ^d [0.02]
(CV-CV)	100% Viscose	24.6 tex	521.06 ^b [7.98]	3.99 ^{bc} [0.05]
(CV/WO-CV/WO)	70/30% Viscose/Wool	19.7 tex	377.88 ^f [2.57]	3.72 ^d [0.09]
(CV/LI-CV/LI)	80/20% Viscose/Linen	21.1 tex	552.12 ^a [5.62]	4.43 ^a [0.06]
(PET/CV-PET/CV)	65/35% Polyester/Viscose	21.1 tex	507.40 ^c [5.57]	4.39 ^a [0.06]

*: Standard Deviation, **: Superscript letters show statistical significance of the results; same letters meaning statistically identical performances.

Areal densities were determined according to TS EN 12127. Water vapour permeability test was carried out according to ASTM E96/ E96M-16 Cup Method. Drop, vertical wicking and immersion period tests were conducted according to AATCC TM-7, AATCC 197 and AATCC 79 Method B standards in turn. These tests give idea about the liquid sweat removal performances of the mattress ticking fabrics for enabling a drier microclimate with other clothing and bed components.

Moreover, bed microclimate temperature and relative humidity measurements were taken from a simulated bed microclimate environment including the investigated mattress thickening layer and other standard bed components located in a laboratory where environmental temperature and relative humidity were 22 ±1 °C and 43 ±2 % in turn. The body was simulated by a polyethylene tank heated to the body core temperature. Temperature and relative humidity of the created bed microclimate were recorded by KIMO KTH 350 (USA) Datalogger system with a frequency of 10 seconds for 2 hours. Described system can be seen schematically in Figure 1.

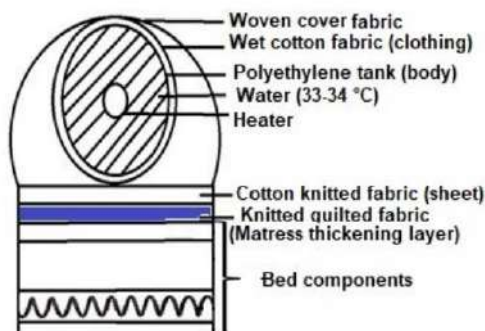


Figure 1: Simulated bed microclimate system

3. RESULTS AND DISCUSSION

Microclimate management and liquid absorption-transfer features of the quilted fabrics were reported according to their materials and structural properties. As can be seen in Table 1, quilted fabric areal density values do not differ directly according to yarn linear density values that the fabric made of viscose/linen (CV/LI) have the maximum value followed by the fabrics made of Tencel LF (TEN) and viscose (CV) fabrics who have identical and maximum linear densities. Fabric thickness values ranging from 3.72-4.43 mm have also significant differences that CV/LI and PET/CV fabrics have the maximum and statistically identical values. Despite lower linear density of PP, it has identical thickness values with TEN and VIS fabrics. PP has also identical performances with PET and CV/WO showing the effect of yarn structure, mainly bulkiness or crimp within the yarn, other than linear density on fabric thickness [11].

Water vapor permeability is a characteristic related to the pores where water vapor molecules can pass through and largely independent of fiber hygroscopicity. Water vapor permeability of a mattress ticking fabric is important in terms of drying and bed microclimate conditions although there is not a wide air space out of the ticking fabric as it is attached to the mattress surface. While differences among the quilted fabrics are statistically significant, most of the fabrics have identical performances except for the maximum value of TEN fabric (Table 2). CV and PET/CV transferred comparatively lower water vapor. Merino wool's better performances for buffering temperature extremes and changes in humidity [12] could not be observed for its blend with viscose in this study.



Table 2: Permeability and liquid absorption and transfer characteristics of the quilted fabrics

Fabric Code (Face-Back)	Water vapor permeability (g/24s/m ²) [S.D.]	Absorption Period (Drop T.) (s) [S.D.]	Liquid Height of Vertical Wicking Test/24 hour (cm) [S.D.]	
			Wale Direction	Course Direction
TEN-TEN	2027.56 ^a [133.50]	1.66 [0.34]	17.00 [0.00]	17.00 [0.00]
PP-PP	1917.64 ^{ab} [77.25]	-	2.60 [0.00]	3.43 [0.12]
PET-PET	1873.36 ^{abc} [96.63]	-	6.63 [0.90]	6.63 [0.90]
CV-CV	1691.78 ^{bc} [233.22]	2.14 [0.41]	17.00 [0.00]	17.00 [0.00]
CV/WO- CV/WO	1821.82 ^{abc} [141.24]	6.87 [0.58]	17.00 [0.00]	11.50 [0.30]
CV/LI-CV/LI	1967.57 ^a [128.67]	1.43 [0.19]	17.00 [0.00]	17.00 [0.00]
PET/CV- PET/CV	1646.28 ^c [70.08]	25.43 [9.05]	11.27 [0.12]	8.53 [0.35]

Wetting is the first condition of the liquid transfer and mattress ticking layer should absorb and transfer body liquid while sleeping with other clothing and bed system components. According to absorption period results, while CV/LI and TEN fabrics absorbed liquid within the minimum period, PET/CV's absorption period was the maximum, over the 5-second limit determined for hydrophilic materials. PP and PET fabrics did not absorb liquid due to their hydrophobic natures. CV and CV/WO fabrics had also acceptable performances in case of wetting characteristics.

Wicking phenomenon gives idea about the transfer within the fabric after wetting. The more transfer occurs, the more evaporation, hence drying takes place for enabling thermal comfort. Liquid heights of the vertical wicking test are compiled in Table 2. As can be seen, the maximum transfer was achieved by TEN, CV and CV/LI fabrics. Besides height of the liquid transferred, liquid absorbed was also measured and percentages were calculated according to the dry fabric weights (Figure 2). According to the results, maximum liquid was absorbed by CV fabric both in wale and course directions. CV fabric's performance is statistically identical with CV/LI fabric both in wale and course directions. Considering blends of CV, CV/LI transferred liquid better than CV/WO in both directions. Is interesting to note that wicking performance of PET/CV is worse than blends of other natural fabrics despite the better transfer features of polyester.

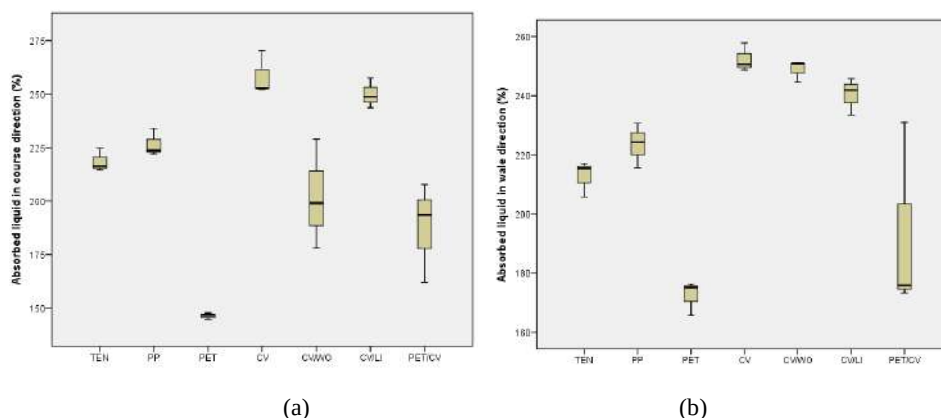


Figure 2: Box-plot diagrams of absorbed liquid in wale (a) and course (b) directions during vertical wicking test

Immersion test results did not give comparable values that none of the fabrics sank probably as a result of the polyester filament laying-in yarn located horizontally within the quilted fabric structure.

Temperature measurement results obtained from the simulated bed microclimates which include the investigated mattress thickening fabrics do not give statistically significant differences and ranged 24.61 °C and 24.97 °C for the PP and PET/CV fabrics in turn. Relative humidity measurements of the bed microclimate do not differ significantly either and they ranged from 41.65 to 44.89 % for CV and PET/CV fabrics in turn. It is thought that the percentage of the quilted fabric within the bed textile system (consisting of bed layers, quilted fabric, sheet and upper cover) is very low to be discriminated, therefore, identical measurements were taken for the investigated mattress thickening layers.

4. CONCLUSION

According to the results, TEN and CV/LI fabrics having the maximum breathability values, meaning a better transfer of the sweat from the microclimate in vapor form. All the quilted fabrics absorbed water within 5-seconds limit except for the CV/WO and PET/CV fabric which is an advantage as wetting is the first step of liquid transfer. Wicking test results showed that CV and CV/LI fabrics transferred liquid faster than the other fabrics in both wale and course directions. None of the quilted fabrics sank as a result of the immersion period test. Temperature and relative humidity values recorded from the simulated bed microclimate did not give statistically significant differences. Summing up, TEN and blends of CV can be suggested as mattress ticking fabrics to enable a drier feeling necessary for both summer and winter uses.



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IMPACT PROTECTION IN BODY ARMOUR USING SHEAR THICKENING FABRIC

Review scientific paper
DOI: 10.5937/CT_ITI24026D

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ABSTRACT: A brief discussion of body armour is provided in the current work, with a focus on the use of shear thickening fluid and the technological issues that prevent its widespread adoption. This paper first discusses the many categories of body armour. Furthermore, several methods for improvising energy absorption for body armour have been offered, along with assessment requirements for bullet-resistant jackets. The review covers the components of sheer thickening fluid as well as how it is incorporated into the fabric. Shear thickening fluid (STF) application amplifies the impact. The Kevlar fabric performs better in terms of impact resistance when shear thickening fluid (STF) is applied. Furthermore, several new STF-based applications are presented to illustrate the challenges that still need to be addressed and provide some more deterministic directions for future research.

Keywords: Sheer thickening fluid, energy absorption, thickness, body armour, impact resistance.

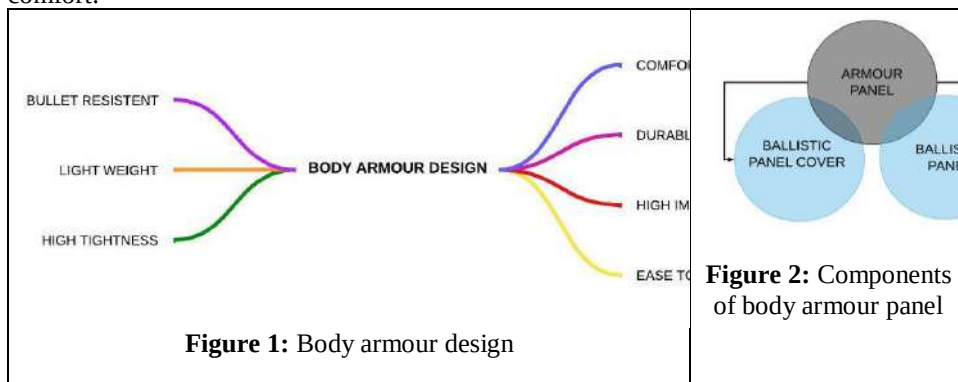
TKANINA ZA ZAŠTITA OD UDARA U PANCIRIMA

APSTRAKT: U ovom radu je dat kratka rasprava o pancirima, sa fokusom na upotrebu tečnosti za zgušnjavanje smicanjem i tehnološkim problemima koji sprečavaju njegovo široko usvajanje. Ovaj rad najpre govori o mnogim kategorijama pancira. Štaviše, ponuđeno je nekoliko metoda za improvizaciju apsorpcije energije za pancire, zajedno sa zahtevima za procenu jakni otpornih na metke. Pregled pokriva komponente čiste tečnosti za zgušnjavanje, kao i način na koji je ugrađen u tkaninu. Primena tečnosti za zgušnjavanje smicanja (STF) pojačava udar. Kevlar tkanina ima bolje performanse u pogledu otpornosti na udar kada se primeni tečnost za zgušnjavanje smicanja (STF). Štaviše, predstavljeno je nekoliko novih aplikacija zasnovanih na STF-u kako bi se ilustrovale izazovi kojima se tek treba pozabaviti i dali neki deterministički pravci za buduća istraživanja.

Ključne reči: Prozirna tečnost za zgušnjavanje, apsorpcija energije, debljina, pancir, otpornost na udar.

1. INTRODUCTION

Body armour is a type of protective gear or clothing that is intended to ward against physical assaults from projectile bullets fired from contemporary weapons as well as sharp items [1]. The evolution of armour materials over time has coincided with advancements in weaponry threats. Throughout history, there has been a penetrating/defeating race between body armour and weaponry. In order to defend service personnel personally [2] from violence and the hazards of war, body armour is essential equipment. Although there is no such thing as completely bulletproof armour, ballistic-resistant body armour is capable of withstanding a variety of pistol and rifle ammunition. It is ideal to have lighter weight protective gear that offers adequate protection [3]. The continual advancements in weaponry and ammunition technologies have created a demand for more efficient body armour. Figure 1 & 2 illustrates several features of the body armour design and armour panel components respectively. The primary obstacle to producing successful bulletproof armour is creating lightweight vests that offer the best possible protection and optimum comfort.



Body armour can be categorized according to the risks posed by projectiles, sharp objects [4], and bullets.

1. Bullet resistant
2. Splinter resistant and
3. Stab resistant [5].

Bullet resistant body armours can be further classified into two categories [6] such as

1. Hard body armour and
2. Soft body armour.

Ceramic plate composite or metal is used to make hard body armour. Usually, aluminium oxide, silicon carbide, or boron carbide is used to make ceramic tiles. The decision between

different kinds of ceramic materials is influenced by a number of factors, among the most significant of which are cost, weight limitations, and threat level [7]. The primary component of soft body armour is layers of high-performance fiber-based fabric. The primary use of soft body armours by soldiers on the battlefield either for small-arms ammunition [8] or is in conjunction with hard body armour to provide sufficient ZZ ballistic protection. Low-modulus binding materials, such as elastomers or soft polymers, are employed to sew or glue (Figure 4) which has many stacked layers of high-strength woven fibre textiles to create soft armour. This armour's fundamental function is to shield against ballistic strikes without impairing wearer's ability to move [9]. Law enforcement officers, who are more likely to encounter lower levels of ballistic threat, also wear soft body armour alone. As a result, there are three main categories of armour materials that need to be reviewed, understood, and described: Formable, technical textiles, fiber-reinforced polymeric laminates, and hard, brittle, strike-face materials such as high-hardness steels and ceramics are the three categories. These three components are displayed in Figure 3 along with consistent camouflage material [10].

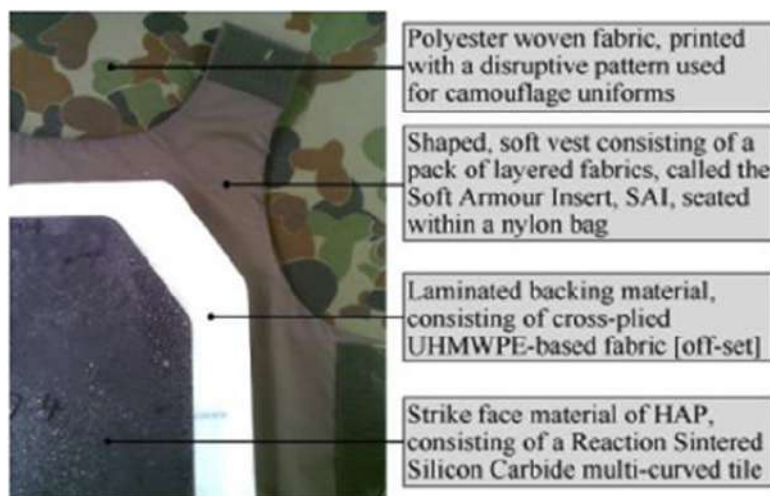


Figure 3: Categories of armour materials [10]

2. EVOLUTION OF BODY ARMOUR

Depending on what kind and speed of the attack, several manufacturing techniques were used to create effective body armour. The various forms and methods of body armour panel production are depicted in Figure 4. There are two types of personal body armour: soft armour and hard armour. Stitched and stiff body armour is other classifications for soft armour [11]. Table 1 displays the progress of soft body armour. Figure 5 reflects the time line diagram illustrating the emergence of high altitude platform system (HAPs) and, specifically, the impact of novel compounds and threat level on the final product's areal density.

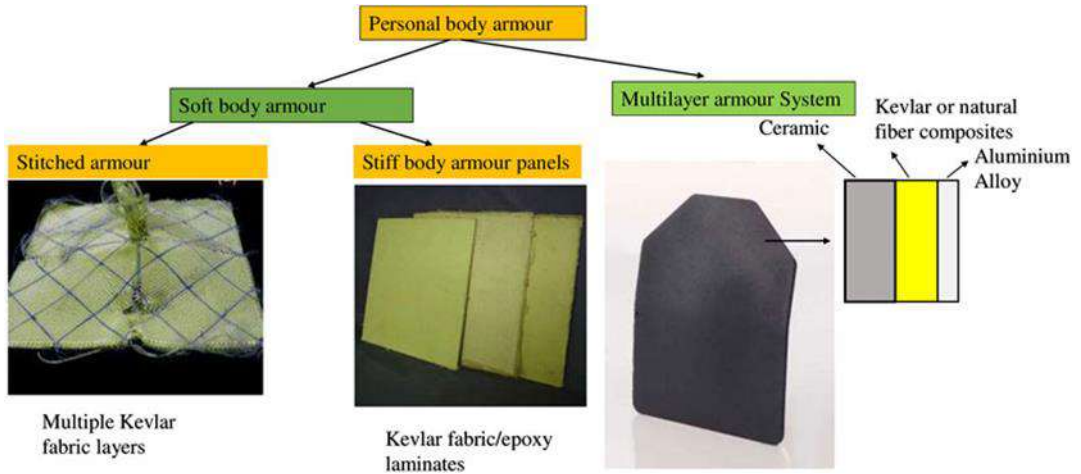


Figure 4: Classification of body armour system [12]

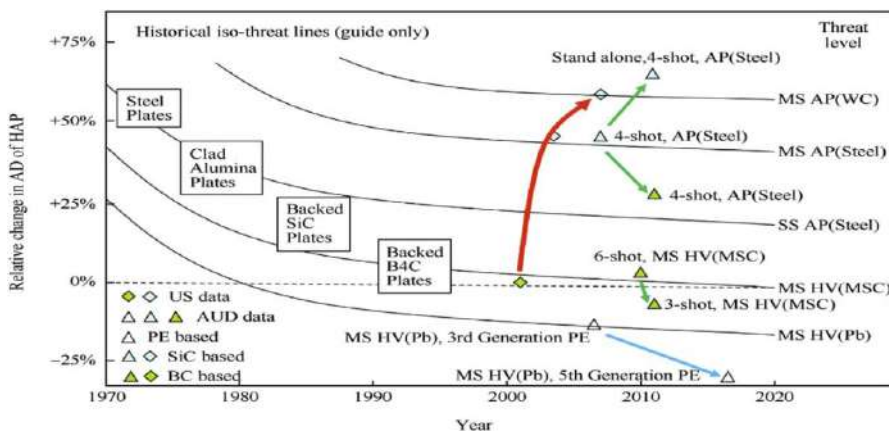


Figure 5: Evolution of Hard Body armour [10]

Table 1: Evolution of soft body armour [13]

Timeline	Material	Threat	Fabric structure
World war I	Silk	Low velocity Projectiles ~120 m/s to 180 m/s	Woven fabric
World War II	Nylon Flak	Munition fragments failed against pistol and rifle rounds	Woven fabric



Post World War II 1960 to 2020	Para aramid, UHMWPE**, Zylon, M5, PBO	NIJ* level IIIA, III and III+(in conjunction with HAP)	Woven fabric and unidirectional fabric
Future	Shear Thickening fluid coated fabric, Nano particles+STF coated fabrics	NIJ level IIIA, III and III+(in conjunction with HAP) in less weight	Impregnated woven fabric 3d woven fabric STF pads

NIJ*: National Institute of Justice (NIJ)

UHMWPE**: Ultra-High Molecular Weight Polyethylene

3. COMPOSITES

Body armour is divided into types called disruptors and absorbers. Bullet Resistant Vests are classified as absorbers because they have a trauma cushion and many layers of ballistic materials. In that order, disruptors and absorbers are bullet resistant jackets with ceramic plates and high-performance fabric panels [14]. Strong, durable materials like ceramics disrupt, whereas polymer composites absorb. Composites are described here as the joining of hard ceramic and high performance (HP) fabric layers compacted into panels. Ceramic plates come in three different shapes: flat, curved, and monolithic [15]. For multiple performances, tiles are recommended. Epoxy or polyurethane-based bonding solutions are recommended for joining ceramic plates and HP panels together.

Types of ceramics used in body armours are alumina, boron carbide, silicon carbide, and titanium diboride. Ceramics are the preferred strike face materials as it is kept in front of body armours to distort the shape of bullets by the hardness of the ceramics. Nowadays although alumina is not as popular as it once was because of its high density, it is still used in vehicle armouring. In body armour, silicon carbide and boron carbide are utilised; while silicon carbide performs better overall, boron carbide is more expensive and lighter[16]. Their properties of ceramics are given in Table 2.

Table 2: Properties of ceramics

Class of material	Density (kg.m ⁻³)	Hardness (GPa)	Elastic modulus(G Pa)	Flexural strength (MPa)	Fracture toughness (MPa.m ^{-1/2})
Alumina	3920	14.1	370	375	4-5
Silicon carbide	3200	23.5	460	570	7
Boron carbide	2500	25.5	460	410	4

The selection of textile materials for soft body armour is accessible. The two fibres that are favored for body armour are Ultra High Molecular Weight Polyethelene (UHMWPE) and



Para Aramid. Para aramid is produced by Teijin (Japan) under the brand name Twaron and Dupont (US) under the Kevlar trademark. DSM (Netherlands) produces UHMWPE under the Dyneema brand. Honeywell (US) produces it under the Spectra brand [17]. Manufacturers provide a range of grades with varying GSM, width, and roll length that are appropriate for varying danger levels. General characteristics of both fabrics are listed in the table 3.

Table 3: Para aramid and polyethelene fabric characteristics

Fibre type	Density kg/m3	Tensile strength MPa	Specific strength m2/s2	Elastic modulus GPa	Failure strain %
Para aramid (low modulus)	1440	2900	$2.01 \cdot 10^6$	60	3.6
Para aramid (high modulus)	1450	2900	$2.00 \cdot 10^6$	120	1.9
Polyethelene (low modulus)	970	2700	$2.78 \cdot 10^6$	89	3.5
Polyethelene (high modulus)	970	3200	$2.30 \cdot 10^6$	79	3.7

Fabric structures preferred for body armours are

1. Woven fabrics
2. Unidirectional laminated (UD).

There are three different configurations of woven fabrics: 1 × 1 plain, 2 × 1 twill, and 2 × 2 matt. Plain weave is often favoured because to its increased cover factor [18]. Numerous crossing points in the structure of woven fabric limit the yarn's transverse deflection during projectile contact, which is a drawback. A lower weave density may enable the projectile to pass through, whereas a greater weave density will restrict traverse deflection more. This is woven ballistic material's main disadvantage [19]. Unidirectional (UD) laminated technology was created as a solution to this issue.

Every fibre layer of a cross plied UD material, referred to as the lamina, is orientated in opposition to the layer before it. The final laminated fabric is created by bonding the fibre layers together using a matrix of thermoplastic or thermoset resin. Depending on the needs, ballistic UD materials typically comprise of two, four, six, etc. plies with an orientation of either 0/90 or 0/90/45 degrees. In addition to maximising traverse deflection, this orientation lowers the likelihood of projectile penetration due to each ply's increased fibre density. In general, armour solutions made using UD textiles weigh less than those made with traditional woven material systems [20]. Currently, this method is used by the majority of manufacturers to create lightweight composite materials for ballistic applications.

Bullet resistant Jackets evaluation standards [21] are given below:

International Standards:

1. USA National Institute of Justice (NIJ): NIJ 0101.06,
2. NATO STANAG 4569,
3. Home Office Scientific Development Branch (UK),
4. European Ballistic Standards (EU),

5. GOST Ballistic Standards (Russia),
6. German SCHUTZKLASSE standard,
7. International Ballistic Standards,

Indian Standards:

1. MHA GSQR
2. BIS IS 17051:2018
- 3.

Figure 6 & 7 depict the different threat levels in NIJ and BIS respectively.

Armor Type	Weapon Type	Test Round	Test Bullet	Bullet Mass	Conditioned Armor Test Velocity*	New Armor Test Velocity*	Hits Per Panel at 0 Angle	Maximum RFS Depth	Hits Per Panel at 30 or 45 Angle†	Shots Per Panel	Panel Size	Panel Condition	Panels Required	Shots Required	Total Shots Required
IIA		1	9mm FMJ RN	8.0g (124gr)	355m/s (1165ft/s)	373m/s (1225ft/s)	4	44mm (1.73in)	2	6	Large Small	New Conditioned	4 2 4 2	24 12 24 12	144
		2	.40 S&W FMJ	11.7g (180gr)	325m/s (1065ft/s)	352m/s (1155ft/s)	4	44mm (1.73in)	2	6	Large Small	New Conditioned	4 2 4 2	24 12 24 12	
II		1	9mm FMJ RN	8.0g (124gr)	379m/s (1245ft/s)	398m/s (1305ft/s)	4	44mm (1.73in)	2	6	Large Small	New Conditioned	4 2 4 2	24 12 24 12	144
		2	.357 Magnum JSP	10.2g (158gr)	408m/s (1340ft/s)	436m/s (1430ft/s)	4	44mm (1.73in)	2	6	Large Small	New Conditioned	4 2 4 2	24 12 24 12	
IIIA		1	.357 SIG FMJ FN	8.1g (125gr)	430m/s (1410ft/s)	448m/s (1470ft/s)	4	44mm (1.73in)	2	6	Large Small	New Conditioned	4 2 4 2	24 12 24 12	144
		2	.44 Magnum SJHP	15.6g (240gr)	408m/s (1340ft/s)	436m/s (1430ft/s)	4	44mm (1.73in)	2	6	Large Small	New Conditioned	4 2 4 2	24 12 24 12	
III		1	7.62mm NATO FMJ	9.6g (147gr)	847m/s (2780ft/s)	-	6	44mm (1.73in)	0	6	All	Conditioned	4	24	24
IV		1	.30 Caliber M2 AP	10.8g (166gr)	878m/s (2880ft/s)	-	1 to 6	44mm (1.73in)	0	1 to 6	All	Conditioned	4 to 24	24	24

Figure 6: Details of Threat levels in NIJ standard



Threat levels

Threat Level	Ammunition	Impact Velocity, m/s	Bullet weight, g	Remarks
1	9 × 19 mm, SM, MP-5, Carbine)	430 ± 15	7.4 - 8.2	For all flexible panels
2	7.62 × 39 mm, AK 47, MSC	710 ± 15	7.45 - 8.05	—
3	7.62 × 51 mm, NATO ball, SLR/BAR	840 ± 15	9.4 - 9.6	In addition, shall be compliance with threat level 2
4	5.56 × 45 mm, INSAS	890 ± 15	3.5 - 4.0	In addition, shall be compliance with threat level 3
5	7.62 × 39 mm, AK 47, HSC	700 ± 15	7.45 - 8.05	
6	7.62 × 54R, API	830 ± 15	10.3 - 10.5	

Figure 7: Details of Threat levels in BIS IS 17051:2018



3. APPROACHES FOR IMPROVING ENERGY ABSORPTION OF BODY ARMOURS

The development of armour necessitates striking a compromise between protective requirements and requirements for low weight, comfort, and flexibility. A material that can deliver the same ballistic performance as current body armour materials while being noticeably more compact and flexible is required to increase comfort and flexibility of the armour [22]. The several layers of ballistic materials used in current body armour make it stiff and hefty. In order to distribute projectile energy over the body armour in a perpendicular direction, energy absorption is crucial. Some of the methods being researched to increase textiles' ability to absorb energy are listed below[23].

1. Application of polymer coating to cloth to increase friction
2. Shear thickening fluid (STF) use on textiles
3. Fabric surface modification by the creation of metal oxide nanorods and
4. Application of STF and 3D woven textiles

4. SHEAR THICKENING FLUIDS

Shear thickening fluids, also known as non-Newtonian fluids, are characterised by concentrated colloidal dispersions that display a dramatic increase in viscosity above a critical shear rate [24]. This transformation of a liquid dispersion into a substance with solid-like qualities is a common indicator of shear thickening behaviour. The behaviour of shear thickening is reversible with strain rates associated with the wearer's typical motion, shear-thickening fluid (STF) is intended to have a low viscosity but to stiffen rapidly under the high strain rates associated with a ballistic impact [25]. When a projectile strikes cloth coated with STF, the shear rate suddenly increases, causing the fluid to instantly become more viscous and harden. This strengthens the armour and accelerates its absorption of energy. A bullet event will finish its impact in about 100 milliseconds. It should be planned such that the shear thickening is finished in the least amount of time.

Mechanisms for improved energy absorption in STF treated fabric [26] are Greater friction (yarn pull out energy) between yarns; improved coupling and load transmission between yarns; and energy dissipation as a result of shear thickening behavior

5. MATERIALS USED IN STF

The two phases of STF are the dispersed phase and the dispersion medium, often known as the carrier [27]. The dispersion medium of STF can be water, silicon oils, polyethylene glycol (PEG), polypropylene glycol (PPG), or 1-butyl-3-methylimidazolium tetrafluoroborate. The dispersed phase of STF is composed of nano-scale or sub-micron particles of silica, calcium carbonate, or polymethylmethacrylate (PMMA), among other materials. 50% of the phase volume is maintained for shear thickening [28]. Before being applied to the Kevlar textiles, these dispersions are diluted with ethanol to increase the wettability of the Kevlar fabrics with STFs. Dilution improves STF penetration into the

Kevlar fabric structure by lowering both the viscosity and surface tension of the material [29]. The ratio of STF to ethanol solvent can range from 3:1 to 5:1, dependent on the STF quantity. Figure 8 depicts the procedures involved in process of STF incorporation to fabric. The table 4 shows that the target's ability to create ballistic resistance is greatly enhanced by the STF's presence within it.

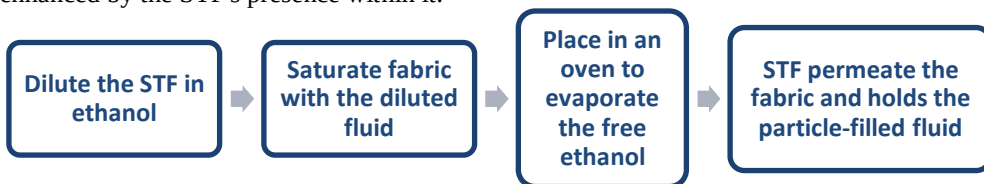


Figure 8: Process of STF incorporation to fabric

Table 4: Ballistic performance of targets with 4 layers of KEVLAR and different volumes of impregnated STF.

S.No.	Description	Sample Weight(g)	Impact Velocity(m/s)	Penetration Depth (cm)
1.	4 layers of KEVLAR	1.9	244	2.12
2.	2 ml STF impregnated in 4 layers of KEVLAR	4.8	243	1.23
3.	4 ml STF impregnated in 4 layers of KEVLAR	7.9	244	0.886
4.	8ml STF impregnated in 4 layers of KEVLAR	13.9	253	0.673

5. EXAMINATIONS OF STF-TREATED TEXTILES

1. Test for yarn pull-out

In 2019, Balet all performed a quasi-static test called yarn pull-out, which simulates yarn-to-yarn friction in a woven fabric is used to carry out. The Instron tensile tester's fixed jaw gripped one end of the cloth strip. Subsequently, the moveable jaw extracted a single free yarn at a consistent speed from the cloth, since it was not caught by the fixed jaw. The maximum force necessary to extract the yarn from the cloth is noted and the strength is calculated [30].

2. Test of dynamic impact

In accordance with ASTM D3763, Majumdar et all performed dynamic impact tests with a drop-weight testing apparatus (CEAST). Ballistic tests were conducted in aero ballistic range facility [31]. The impact velocity was 8 m/s. Pneumatic pressure was used to clamp the fabric samples that were placed on the circular jaws with an inner diameter of 7.6 cm. The impact features a hemispherical head and measures 13 cm in diameter [32]. The impact energy was measured by the device in Joules.

The results indicated that the elastic zone in the STF-treated samples was found to be broader than in the unprocessed samples, indicating a greater absorption of impact energy and an accumulation of force in the elastic zone [33].

3. Ballistic impact test at low velocity

In 2014, Majumdar et al tested the single layer Kevlar textiles (200 g/m²) underwent a low velocity ballistic impact test using the apparatus depicted in Figure 9. The ammunition weighed 11.62 g and was fired at a mean velocity of 165.2 m/s using a 0.380 calibre revolver. There were nine rounds fired for every sample. The before and after impact bullet velocities were measured using four optical screen-based velocity measuring units. In order to evaluate the pre impact velocity, two optical screens (screens 1 and 2) were positioned before the test sample, and two more optical screens (screens 3 and 4) were positioned after the test sample to measure the post impact velocity. When there was no sample, it was discovered that the bullet's velocity dropped by less than 1 m/s across a distance of 4 m, and as a result, the energy lost to air resistance was disregarded. The following equation was used to determine the ballistic energy absorbed by the sample [34].

$$E = \frac{1}{2} m(v_1^2 - v_2^2)$$

Where, E is the energy absorbed (J), m is the mass of the bullet (kg), v₁ is the pre impact velocity (m/s) and v₂ is post impact velocity (m/s).

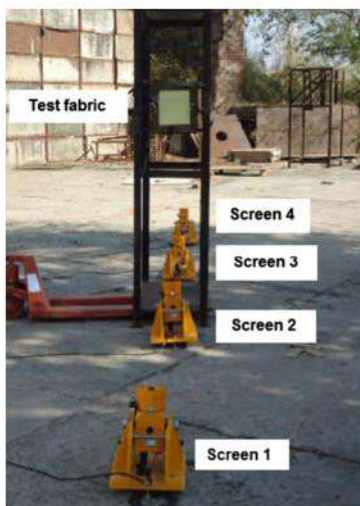


Figure 8: Low velocity ballistic impact test set up

6. SHEAR THICKENING FLUIDS APPLICATION IN BODY ARMOUR RESEARCH BY COMMERCIAL AND ARMY OF DIFFERENT COUNTRIES

1. United States Army Research Laboratory - At the US Army Research Laboratory in Adelphi, Maryland, in 2002. Norman Wagner, a chemical engineering professor at the University of Delaware, and Eric Wetzel, a laboratory employee, headed the development team. The patent for "Advanced Body Armour Utilising Shear Thickening Fluids," US Patent No. 7,226,878, was filed in 2003 and granted four years later [35].

2. Armour holdings - During 2006, Patent STF was created by the Centre for Composite Materials at the University of Delaware, in collaboration with the U.S. Army Research Laboratory's Weapons and Materials Research Directorate. Armour Holdings is the only licensee of STF. American company ArmourHoldings, Inc. produced equipment for police enforcement, the military, and personnel safety. Renamed BAE Systems Mobility & Protection Systems, it was bought by BAE Systems on July 31, 2007 [36].
3. BAE systems - Body armour composed of Kevlar and shear-thickening fluid was introduced by BAE in 2010. A Memorandum of Understanding (MoU) was signed in 2017 between Helios Global Technologies and BAE Systems to further the development of liquid armour technology. British multinational military, security, and aerospace corporation BAE Systems plc. With activities all around the world, its headquarters are in London and Farnborough, United Kingdom. The business is Europe's biggest defence contractor. Technology for safety and survival is provided by Helios Global Technologies. They are working on projects including sensors for danger detection from a distance and sophisticated materials for protection against blasts and ballistics [37].
4. The Military Institute of Armament Technology and Institute of Security Technologies in Poland (Moratex) created a specifically formulated shear thickening liquid in 2015 and stopped using fibres for impact applications and body armour [38].
5. A UK-based business called D3O applies armour using STF gel. D3O is an energy-absorbing polyurethane substance with several additives and polyborodimethylsiloxane, a non-Newtonian dilatant fluid [39].

7. PRACTICAL ISSUES IN STF TREATED FABRIC

Variables such the employment of different sized silica and other particles, their added weight to textiles, fabric weaves, fabric materials, layer arrangements, bullets and fsp, varying velocity, energy absorption, etc. are all covered in research publications. Following issues with respect to practical usage require some insight [40].

1. During usage or shelf life, the gravity action causes the bottom of the fabric or garment to get thicker.
2. STF leakage from treated cloth under stress during use, regardless of whether protective coverings were placed over the treated fabric by the researchers
3. Degradation/evaporation when exposed to the environment
4. Humidity sensitivity.

8. CONCLUSION

According to YueXu (2016) in her master's thesis, STF-impregnated fabric was retained both horizontally and vertically for 30 days, with an increase in thickness (0.3 to 0.49 mm) at the bottom of the material. UPTTI - STF specialists have suggested that STF be kept in situ to prevent it from flowing due to gravity by incorporating it into 3D woven materials.



Following a conversation with STF experts at IIT Delhi, the thickness of the cloth treated with STF is only a few microns, and the STF coating is incredibly stable.

Since the critical shear rate for the initiation of shear thickening reduced with lowering temperature, research on shelf life and in various settings is necessary. Furthermore, a body armour must pass the service life evaluation, which entails a ballistic test following conditioning in an environmental room with temperature and humidity controls ($65 \pm 5^\circ\text{C}$ and $80 \pm 5\%$, respectively) and a tumbling apparatus (with a rotation speed of 5 ± 1 rpm and a total rotation of 72000 ± 1500). According to the research, chemical adjustments must be made so that STF impregnated materials can endure the impacts of temperature and humidity.

Another method was also proposed in this study, to retain the shear thickening properties of STFs. In this, the STFs were preserved by two different methods: in the first method, the STF was kept in a closed jar under nitrogen atmosphere at ambient temperature, whereas in the second method the STF was encapsulated in silicone and placed in a chamber with 100% RH. It was found that the encapsulated STF behaved rheologically similar to the freshly synthesized STF, whereas a slight change in the rheological behavior was observed for the STF stored under the nitrogen environment. Hence, this study revealed the ideal storage conditions and methods for STFs to maintain their shear thickening properties with time.

This study also suggested a different approach to preserve STFs' shear thickening characteristics. The STFs in this were maintained using two distinct techniques: in the first, they were stored at room temperature in a closed jar with nitrogen atmosphere, and in the second, they were sealed in silicone and kept in a chamber with 100% relative humidity. The rheological behaviour of the newly synthesised STF and the encapsulated STF were found to be identical, but the STF kept in a nitrogen environment showed a minor deviation in rheological behaviour. As a result, this study identified the best ways to store STFs and how long they can keep their shear thickening qualities.

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PVDF FILMS WITH OPTIMIZED POROUS STRUCTURE USING NON-SOLVENT INDUCED PHASE SEPARATION FOR PASSIVE RADIATIVE COOLING

Original scientific paper
DOI: 10.5937/CT_ITI24027M

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ABSTRACT: Today, as personal thermal management gains importance for both increased comfort and energy saving advantages, body cooling through the clothing system by using natural energies has come to the fore. In this study, as the first step of a cooling garment design project, radiative cooling films having porous structures with tailored optical structures to enhance UV-VIS-NIR reflectivity were produced from polyvinylidene fluoride (PVDF), via non-solvent-induced phase separation method using two solvents and water. The porous structure of PVDF films was optimized by differing polymer (5 and 10wt. %), water concentrations (3-10%) and drying conditions. Besides SEM analyses to determine the pore characteristics, cooling performances were evaluated by a hotplate apparatus combined with a halogen lamp as a sun simulator. Indirect emissivity calculations were carried out from the IR camera images of the films heated at the same temperature with a fabric whose temperature was measured with sensors. According to SEM images, PVDF films having 10 wt.% polymer and 3% water concentrations had the most porous structure. The emissivity of the optimized PVDF film with a hierarchically porous structure was enhanced to 96.6% with a temperature decrease of 1.06°C under a solar irradiance of 600 W·m⁻² indicating a good potential for a further cooling structure as a nanocomposite and coated fabric forms.

Keywords: Thermal management, passive cooling, phase separation, porosity, solvent.

PVDF FILMOVI SA OPTIMIZOVANOM POROZNOM STRUKTUROM KORISTEĆI RAZDVAJANJE FAZA NERASTAVAČIMA ZA PASIVNO ZRAČENJE

APSTRAKT: Danas, kako lično upravljanje toplotom dobija na značaju kako za povećanje udobnosti tako i za prednosti uštede energije, hlađenje tela kroz sistem odeće korišćenjem prirodnih energija je došlo do izražaja. U ovoj studiji, kao prvi korak u projektu dizajna odeće za hlađenje, filmovi za hlađenje koji imaju porozne strukture sa prilagođenim optičkim strukturama za poboljšanje UV-VIS-NIR reflektivnosti proizvedeni su od poliviniliden fluorida (PVDF), putem razdvajanja faza koje nije izazvano



rastvaračem. metoda pomoću dva rastvarača i vode. Porožna struktura PVDF filmova je optimizovana različitim polimerima (5 i 10 tež. %), koncentracijom vode (3-10 %) i uslovima sušenja. Pored SEM analiza za određivanje karakteristika pora, performanse hlađenja su procenjene pomoću aparata za grejanje u kombinaciji sa halogenim jagnjetinom kao simulatorom sunca. Proračuni indirektno emisivnosti vršeni su na osnovu slika IR kamere filmova zagrejanih na istoj temperaturi sa tkaninom čija je temperatura merena senzorima. Prema SEM snimcima, PVDF filmovi sa koncentracijom polimera od 10 tež.% i 3% vode imali su najporožniju strukturu. Emisivnost optimizovanog PVDF filma sa hijerarhijski porožnom strukturom povećana je na 96,6% sa padom temperature od 1,06°C pod sunčevim zračenjem od 600 W•m⁻², što ukazuje na dobar potencijal za dalju strukturu hlađenja kao nanokompozit i obložen. tkanine forme.

Ključne reči: *Upravljanje toplotom, pasivno hlađenje, razdvajanje faza, porožnost, rastvarač.*

1. INTRODUCTION

With the aggravation of global warming and extreme weather, cooling demand has witnessed a continuous increase and is expected to increase tenfold by 2050 [1]. Radiative cooling without any pollution and energy consumption has drawn worldwide attention in the past few years [2]. Having a cooling feature with the management of sun and body radiation energy components, functional clothes used in sports and working environments, which have an increasing market in the world will provide higher performance due to late or less fatigue during sports/work with increased comfort. Passive radiative cooling performance could be enabled by spectrally selective materials, which simultaneously have high solar reflectance and infrared thermal emittance as these features help simultaneously reflecting sunlight and radiating infrared thermal radiation. Recently, multilayer photonic structures, composite structures with distributed particles, metamaterials, biomaterials, bio-inspired materials, and porous structures are used for cooling [3]. Nonetheless, developing these materials/structures generally requires sophisticated processing steps and costs which limits their acceptability for large-scale production and cost-effectiveness. Therefore, a facile, cost-effective, and highly efficient approach is highly desirable for widespread practical radiative cooling applications. In this respect, recent studies in developing radiative cooling materials have focused on porous polymer films for their high solar reflection and mid-IR emission. Constructing porous polymer films for passive radiative cooling has proved an efficient way to dissipate heat to cold outer space in the form of thermal radiation and concurrently reflect incident sunlight without additional energy input [4]. Among production methods of porous radiative cooling films, nonsolvent-induced phase separation has attracted considerable attention owing to their cost-effectiveness and wide applicability [5]. The passive radiative cooling performance of these porous films correlate with their porous structures and unfortunately porous structure formed by nonsolvent-induced phase separation could not be finely regulated. In this study, PVDF

films with porous structures using two solvents were produced with varying solubility parameters and water.

2. MATERIALS and METHODS

2.1. Materials

For production of passive radiative cooling film, PVDF polymer (Kynar 720), a spectrally selective polymer with a high emissivity [6] was used. Additionally, PVDF offers excellent processability, resistance to aging, weathering, UV radiation, and robust mechanical properties, making it suitable for various textile applications. N, N dimethyl acetamide (Sigma Aldrich) and acetone (Acros Organics) were used as solvent/co-solvent. In one-step non-solvent-induced phase separation film formation method, deionized water was used as non-solvent.

2.2. Methods

PVDF porous films having different polymer concentrations (5 and 10 wt. %) were produced through one-step non-solvent-induced phase separation method which is simpler and cheaper compared to the other methods [7]. In the first step, PVDF powder at 5 and 10 wt. % was dissolved in N, N dimethyl acetamide and acetone with same ratios at 50°C in a three-necked flask for 6 h under 400 rpm magnetic stirring. Then appropriate amounts (other solvent amounts were arranged accordingly) of water (3, 5, and to 7%) were added dropwise by a syringe pump at a feeding rate of 0.2 ml/min for another 1 h until it became clear. In the last step, the solutions were cast in the form of a thin layer of 300-400 μm thickness into petri-dishes and dried for 6 h at 120°C.

2.3. Characterization

Surface morphology and cross-sections of the PVDF films were analyzed by using scanning electron microscope (SEM, Fei Quanta FEG 250) with an accelerating 20 kV voltage and 10 μA current.

Cooling performance of the PVDF films were tested using a designed hotplate system equipped with a hotplate simulating skin (34°C), 8 sensors, a halogen lamp for sun simulation and a data acquisition system. The films were placed on the hot plate face side up under the lamp (600 W m^{-2}) at a distance of 25 cm. Environmental temperature was 22-26°C and relative humidity was 49-50% during the tests. The test was starting with a 1-minute stabilising part while lamp is off followed by a 10-minute lamp-on part to see the cooling performances and another 10-minute lamp-off part to see the heat releasing performances of the films. Temperatures were recorded with a frequency of 5-second and three replications were conducted for each sample.

Indirect emissivity measurements of the films were carried out by the mentioned hotplate system combined with an IR camera (Fluke Ti100 Thermal Imager). The films were placed on the hotplate (34°C) which was covered with black fabric having 99% emissivity. The sensors were located both on the black fabric and the films. After a stabilizing period of 1 min, the upper surface temperatures of the films were recorded as the actual temperature.

The thermographic images of the films were taken simultaneously with the IR camera placed at a distance of 25 cm. Finally, the recorded thermographic images were processed using SmartView Classic 4.4 software and emissivity values were determined by adjusting the emissivity in the thermal camera until the apparent temperature read by the IR camera was equal to the average temperature measured with the sensors.

3. RESULTS

In this study, radiative porous cooling films were prepared through one-step non-solvent-induced phase separation method using co-solvent and non-solvent by the multistage solvent displacement. Effects of the polymer and water concentrations on the pore formation and cooling performance were investigated. SEM images of PVDF porous films (Figure 1 and Figure 2), show that films produced without water has a dense structure. As the water content was increased, especially for 10 wt. % polymer content, heterogenous pore formation on both surface and cross-sections increased. PVDF films having 10 wt.% polymer and 3% water concentrations had the most porous structure with smaller droplets and wrinkles. 5 wt.% polymer concentration led to the formation of larger droplets and wrinkles. Within the film production plan, gelation was occurred during the process of adding 7% water and film could not be produced for 5 wt.% polymer content. The pore formation within the films may be result of accelerating N,N dimethyl acetamide evaporation with acetone having low boiling point and changing solvent polarity and solubility, hence phasing out of PVDF polymer from solvent-non-solvent system [8].

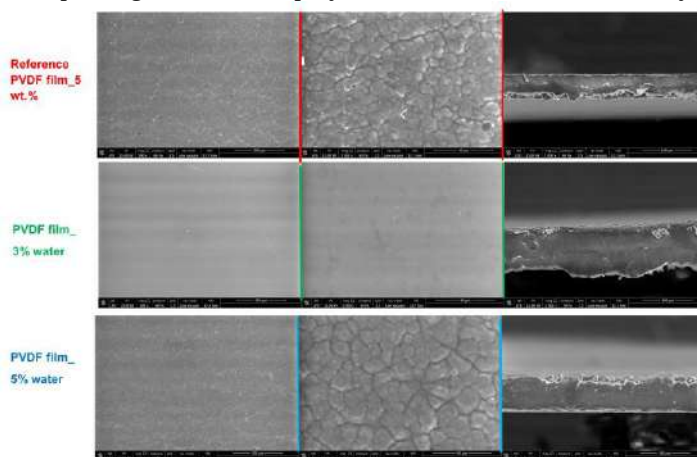


Figure 1: Surface morphology and cross-section images of PVDF films having 5 wt. % polymer and 3 and 5% water contents.

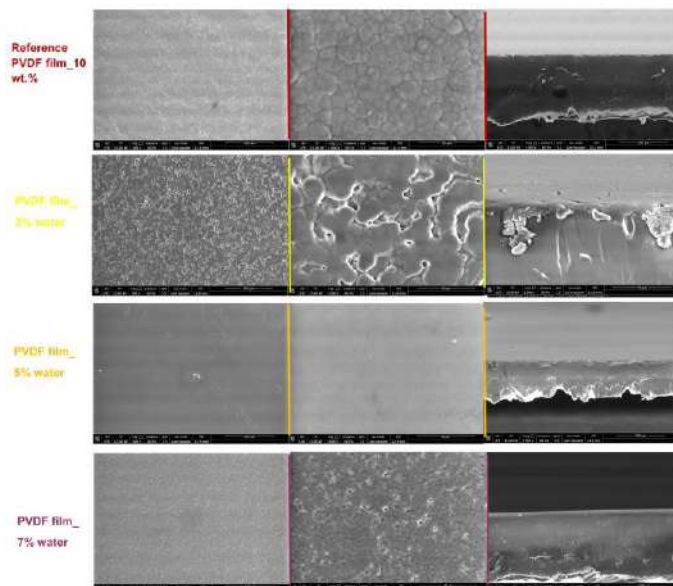


Figure 2: Surface morphology and cross-section images of PVDF films having 10 wt. % polymer and 3, 5, and 7% water contents.

Cooling performances of the PVDF films were reported in Figure 3 and 4. As can be seen in Figure 3 and Figure 4, cooling effect was obtained with the produced porous films.

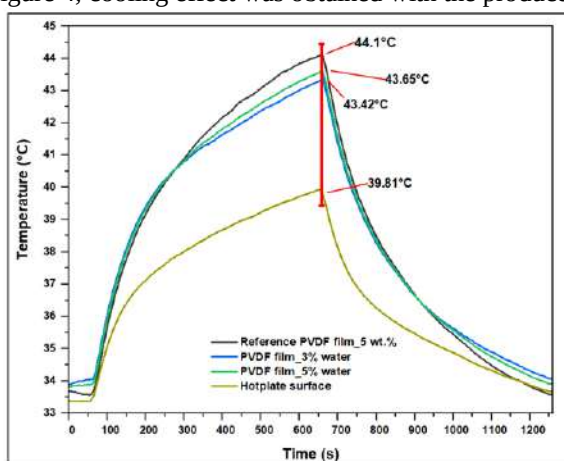


Figure 3: Cooling performance test results of PVDF films having 5 wt. % polymer and 3 and 5% water contents.

Porous films specially produced with 10 wt.% polymer and 7% water contents exhibit a temperature drop of ~ 1.06 °C compared to their nonporous forms. Meanwhile, this film also possess an infrared emittance of $\sim 96.6\%$ over the atmospheric transparency window (8-13 μm), providing a cooling effect by enabling higher heat loss to the colder outer space. On the other hand, by adding 3% water to the same polymer ratio, a porous film structure was obtained, cooling effect could not be obtained.

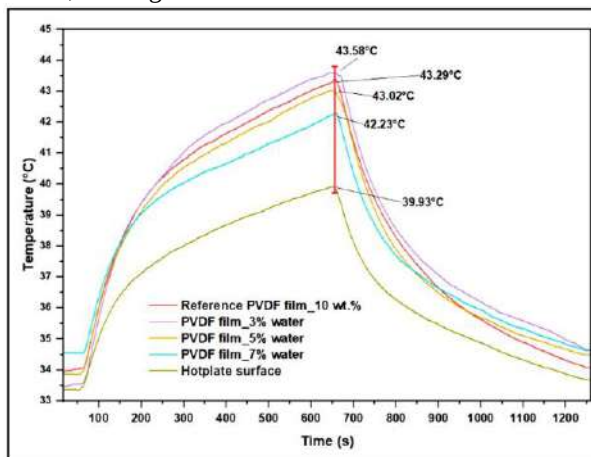


Figure 4: Cooling performance test results of PVDF films having 10 wt. % polymer and 3, 5, and 7% water contents.

According to the test results of the infrared emissivity given in Table 1, the emissivity of the films increased with polymer concentration and the pore ratio. The highest emissivity value (96.6%) was measured for the film produced with 10 wt.% polymer and 3% water concentrations while the lowest value was obtained for sample produced with 5 wt.% polymer without water (90.6%). The produced PVDF films especially porous ones have higher infrared emissivity with the effect of many functional groups/bonds such as C-F and C-O emit overlapping with the atmospheric transmittance window and porous structure [9].

Table 1: Emissivity measurement results of the film samples

Sample code	Emissivity (%) (at 34°C) [S.D]
Reference PVDF film_5 wt.%	90.6 [0.19]
PVDF film_5 wt.%_3 % water	91 [0.01]
PVDF film_5 wt.%_5 % water	91.8 [0.03]
PVDF film_10 wt.%	92 [0.06]
PVDF film_10 wt.%_3 % water	92.6[1.08]

PVDF film_10 wt.%_5 % water	95 [1.08]
PVDF film_10 wt.%_7 % water	96.6 [1.08]

4. CONCLUSION

Radiative cooling PVDF films with porous structures were prepared by non-solvent induced phase separation method containing two solvents water as non-solvent. PVDF films having 10 wt.% polymer and 7% water concentrations having the most porous structure, exhibited an infrared emissivity of 96.6%. These films achieved a maximum cooling temperature of approximately 1.06°C under a solar irradiance of 600 Wm⁻². The results indicate that the proposed films present a potential for radiative cooling textiles in the form of coating or lamination.

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CLASSIC COMMON FASTENERS FOR TEXTILES AS CONNECTIONS IN ELECTRONICS ON TEXTILES

Review scientific paper
DOI: 10.5937/CT_ITI24028N

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ABSTRACT: Classic common fasteners in textiles can be good as connections in electronics on textiles. They are mostly made of electrical conductors or covered with an electrical conductor. They can also be insulators in the form of some clips or magnets. They have in common that they are not specially made for electronics, but are common textile accessories.

Keywords: Electronics on textiles, classic common fasteners in textiles, snap on button, conductive hook and loop, zip, magnets, clips.

KLASIČNI UOBIČAJENI ELEMENTI ZA KOPČANJE KOD TEKSTILA KAO KONEKCIJE U ELEKTRONICI NA TEKSTILU

APSTRAKT: Klasični uobičajeni elementi za kopčanje kod tekstila mogu da budu dobri kao konekcije u elektronici na tekstilu. Uglavnom su od električnih provodnika ili prekrivene električnim provodnikom. Mogu biti i izolatori u obliku nekih štipaljki ili magneta. Zajedničko im je da nisu posebno pravljene za elektroniku nego su uobičajeni tekstilni dodaci.

Ključne reči: Elektronika na tekstilu, klasični uobičajeni elementi za kopčanje kod tekstila, drikeri, provodna čičak traka, rajsferšlus, magneti, štipaljke.

1. INTRODUCTION

Electronics on textiles is becoming more and more interesting and applicable. Connectors are one of the most important components [1-4]. Clip-on connectors for electronics, from DC to microwave, are sometimes unwieldy for clothing and require modification or special fabrication. For this reason, classic fasteners in textiles are also used. They are easy to obtain and go well with textiles, both functionally and in appearance. One example is

shown in Fig. 1 [3] showing the application of embroidered vias, folded strips of metalized fabric, eyelets, and snap-on buttons.

Classic fasteners in textiles that are easy to put on and easy to take off will be dealt with here. This ensures changeability and modularity (interchangeable parts) which is often important in clothing. In doing so, we insist on the least possible damage to textiles and thus sustainability, which is so important today.

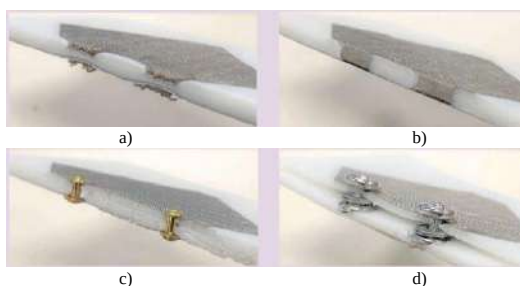


Figure 1: Realization of antennas with metalized fabric in [3]. The four considered shorting strategies: (a) embroidered vias, (b) folded strips of metalized fabric, (c) eyelets, and (d) snap-on buttons

Some specific classic common fasteners in textiles will be considered here: snap on button [3,5-11], conductive hook and loop (Velcro) [12-19], zip [15,20-23], magnets [24-28] and clips [14].

2. SNAP ON BUTTON

Snap on button enables easy putting on and taking off of textile parts and other modules. One striking example is shown in Fig. 2 [5].



Figure 2: Putting the module on the prepared piece of clothing using snap on button [5]

One drawback may be the need to drill the textile when installing both the male and female parts. However, there is a way to fix the parts with self-adhesive conductive tape without drilling. Such a case is shown in Fig. 3 [6]. It is shown that the snap on button can be used down to lower microwave frequencies.



Figure 3: Fixed snap on button with self-adhesive conductive tape without drilling [6]

3. CONDUCTIVE HOOK AND LOOP

Conductive Hook and Loop, or "Velcro" according to the company that produces them, is also good for easy putting on and taking off of textile parts and other modules. One set of hook and loop is shown in Fig. 4.



Figure 4: Silver-plated conductive hook and loop [2]

They must also be fixed to the textile, glued or sewn, at least one half of the structure. One application where only one side is fixed is given in Fig. 5 [15] and Fig 6 [17].

Hook and loop systems can be used as a connector at low microwave frequencies. Reusable connector allows the electronics to be removed from a textile for security or other reasons, such as washing [12].



Figure 5: The effective way of using conductive hook and loop to interchange a textile slot patch antenna [15]



Figure 6: Conductive hook and loop connecting the electrode to the outside of the pants [17]

4. ZIP

The use of zip connectors has already been presented before. They were especially used as switches, Fig. 7, [20,21]. The application for antennas is also interesting, Fig.8 [23] and Fig. 9 [15].



Figure 7: Switching via zip via conductive threads (arrows) [20,21]



Figure 8: Zip as an antenna [23]



ZIP-CLOSE

ZIP-OPEN

Figure 9: The effective way of using conductive zip to interchange a textile slot patch antenna [15]

5. MAGNETS

Magnets can generally be used to apply pressure to conductive surfaces to make them adhere better and thus have better contact [24-27]. The problem is that on the other side there must be a magnet or something that the magnet attracts, Fig.10 [26].

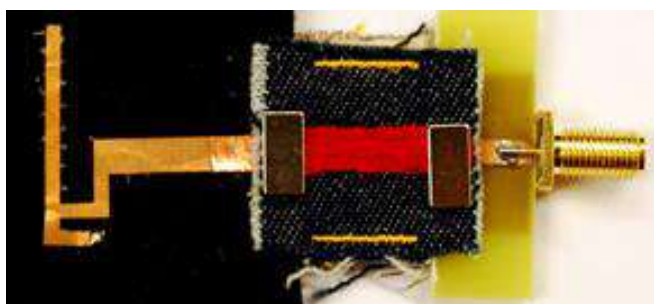


Figure 10: Magnets exert pressure on conductive surfaces

On the other side is also a magnet or something that a magnet attracts [26]

Another logical application is with electrically conductive magnetic snaps [28], Fig. 11.

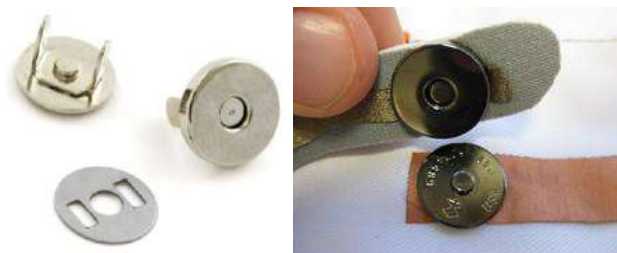


Figure 11: Conductive magnetic snaps to make contact [28]

6. CLIPS

Clips can also be used to apply pressure to conductive surfaces to make them adhere better and thus have better contact [14], Fig. 12.



Figure 12: Clips apply pressure to the conductive surfaces to better adhere and thus have better contact [14]

7. CONCLUSION

Classic common fasteners in textiles are briefly presented as connectors in electronics on textiles. Examples in the literature show that this application can be effective even down to lower microwave frequencies. The emphasis was on the least potential damage to the textile and thus on sustainability.

ACKNOWLEDGEMENT

This work was financially supported by the Minister of Science, Technological Development and Innovation of the Republic of Serbia (Grant No. 451-03-47/2023-01/200026).

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ANTIMICROBIAL PROPERTIES OF INSOLES PRINTED WITH MODIFIED BENTONITE AND EXTRACT OF *PICEA OMORIKA*

Original scientific paper
DOI: 10.5937/CT_ITI24029G

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ABSTRACT: In order to remove harmful microorganisms, textile materials are subjected to various types of antimicrobial treatments. Skin infections represent a permanent diagnostic and therapeutic challenge, and can be caused by bacteria, viruses, fungi and parasites. In this paper, the impact of printing insoles with alginate paste, modified bentonites and *Picea omorika* plant extract on their antimicrobial, dielectric and sorption properties was investigated. It was found that the printed insoles show a certain antimicrobial effect on the bacteria *Staphylococcus aureus* and *Escherichia coli* and the yeast *Candida albicans*. The obtained values of specific conductivity are in agreement with the tested parameter of the sorption properties of the insoles.

Key words: insoles, bentonites, *Picea omorika*, antimicrobial and dielectric properties.

ANTIMIKROBNA SVOJSTVA ULOŽNIH TABANICA ŠTAMPANIH MODIFIKOVANIM BENTONITOM I EKSTRAKTOM *PICEA OMORIKA*

APSTRAKT: U svrhu uklanjanja štetnih mikroorganizama tekstilni materijali podliježu raznim vrstama antimikrobnih obrada. Infekcije kože predstavljaju trajan dijagnostički i terapijski izazov, a mogu biti uzrokovane bakterijama, virusima, gljivicama i parazitima. U ovom radu istraživao je uticaj štampe uložnih tabanica alginatnom pastom, modifikovanim bentonitima i ekstraktom biljke *Picea omorika* na njihova antimikrobna, dielektrična i sorpciona svojstva. Ustanovljeno je da štampane uložne tabanice pokazuju određeno antimikrobno dejstvo na bakterije *Staphylococcus aureus* i *Escherichia coli* i



kvasnicu Candida albicans. Dobijene vrijednosti specifične provodljivosti su u saglasnosti sa ispitivanim parametrom sorpcijskih svojstava uložaka.

Ključne riječi: uložne tabanice, bentoniti, Picea omorika, antimikrobna i dielektrična svojstva.

1. INTRODUCTION

The contamination of textile materials by microorganisms, such as pathogenic bacteria, bacteria that create unpleasant odors, fungi and viruses, is a major concern for public health, as they can cause, at the very least, discomfort, but also skin irritation, hypersensitivity, numerous diseases, and infections in the hospital environment as well as in everyday life [1-3]. Insoles are in constant contact with the foot, so the materials from which they are made should not contain toxic pigments, heavy metals, polyvinyl chloride, chlorofluorocarbon, formaldehyde and harmful volatile solvents, which imposes the need for continuous monitoring of their quality and composition. The most common causes of fungal infections are dermatophytes, aerobic fungi that can enter and infect the keratinized layers of the skin, hair and nails. Skin infections can be caused by bacteria, viruses, fungi and parasites. Some bacteria can cause disease in individuals who have an open wound through which bacteria can enter the body or in individuals with weakened immune functions. Antibiotic resistance generally makes it harder to fight bacterial infections. Even the World Health Organization, in an alarming report on antimicrobial resistance, warned of the danger of entering the "post-antibiotic era", in which frequent infections and minor injuries can be fatal [4].

Antimicrobial agents for textiles include inorganic salts, organo-metallic compounds, iodoforms, phenols and thiophenols, antibiotics, heterocyclic compounds with anionic groups, oxygen compounds, urea, formaldehyde derivatives and amines. Most of these agents have an unfavorable effect on the biosphere, which is why biodegradable and more environmentally friendly antimicrobial agents, including plant extracts, have come into use. In order to improve the effect, compounds or nano-particles of different metals that exhibit antimicrobial properties are added to the extracts, and the most commonly used are silver, copper and zinc. The effect of silver ions on the bacteria *Staphylococcus aureus* and *Escherichia coli* was demonstrated through the separation of the cytoplasmic membrane from the bacterial cell wall [5]. Silver nanoparticles can completely inhibit the growth of bacterial cells, destroy the permeability of bacterial membranes and reduce the activity of some membrane enzymes, which ultimately causes the death of bacteria [6]. The results of experiments performed with ZnO nanoparticles, which were synthesized in diethylene glycol (DEG), confirmed that *E. coli* cells were damaged after contact with DEG and ZnO, due to the disruption of the cell membrane structure of this bacterium [7]. Optimized sterilization efficiency against *E. coli* and *S. aureus* bacteria of 99.4% and 98.0%, respectively, was obtained in research with ZnO/C-ZnFe₂O₄ coral structure, which was illuminated with visible light [8]. The effectiveness of textiles with an active antimicrobial effect is based on the principle of diffusion, that is, bioactive substances are dispersed at a



variable rate from the surface of the fibers by the effect of ion exchange, replacing cations from sweat [9].

Reducing the content of unpleasant odors can be achieved with antimicrobial treatments and by reducing the activity of sweat glands. The number of types of bifunctional textiles with antimicrobial activity has increased considerably in the last twenty years [10]. The goals of using antimicrobial finishes are to significantly limit the frequency of bacterial growth, reduce the formation of odors as a result of the microbiological degradation of sweat, and to avoid the transfer and spread of pathogenic microorganisms [11]. Due to the fact that biologically active substances from plants can slow down or prevent the growth of microorganisms, there is a growing interest in studying their application in textile processing [12,13]. Colored solutions are usually used for dyeing textiles, which give the textile product a certain degree of coloration, as well as antimicrobial and deodorizing properties, UV protection, etc. [14,15].

For the antimicrobial treatment of textiles with extracts of medicinal plants, plants with deodorizing properties and a beneficial effect on the skin were selected for research, where special emphasis was placed on plants with a high content of bioactive components that alleviate sweat allergies. In this paper, the medicinal plant *Picea omorika* was selected, whose extract shows antimicrobial and deodorizing properties.

Picea omorika is an evergreen tree with a pleasant smell. The extract is obtained from spruce needles, which are 1 to 2 cm long and up to 2 mm wide, flattened with two characteristic bluish-white stoma stripes [16]. Female spruce cones are purple-brown in color and are located at the top of the tree. In the mature state, they reach a length of up to 6.5 cm [17]. Medicinal and antimicrobial components are extracted from these plants, as well as essential oils, which are further used for various purposes. The content of phenols and flavonoids affects the effectiveness of plant extracts in removing fungi, bacteria and viruses.

Bentonite is a type of highly plastic clay that has the ability to expand and turn into a gel when it comes into contact with water. The two basic types of bentonite are sodium bentonite and calcium bentonite. The main difference between these two types of bentonite is that sodium bentonite has the ability to expand while calcium bentonite does not. By modifying bentonite, the specific surface area and total pore volume are reduced, as well as the mean mesopore diameter is shifted towards larger diameters. Zn-modified bentonite showed a better antibacterial effect than Cu- and Na-bentonite samples, while Cu/2Zn had the highest antibacterial effect among Cu/Zn bentonite samples. Cu/2Zn was integrated on non-woven textiles and knitwear using the screen printing method and showed good antibacterial activity [18]. Zn-modified bentonites have a better antimicrobial effect on Gram-positive than on Gram-negative bacteria [19-21].

Given that the World Health Organization pays more and more attention to the prevention of health protection and that there is a very small number of published works related to the prevention of foot health protection with natural materials, such as bentonites and plant extracts, this work is focused on the antimicrobial treatment of insoles. Therefore, the aim of the work was to find an adequate way of processing insoles for footwear using the screen printing process modified with bentonite and *Picea omirika* extract, in order to obtain a product with certain antimicrobial, dielectric and deodorizing properties.

2. MATERIALS AND METHODS

Picea omorika extract was chosen for the antimicrobial treatment of insoles. The insole SS-WL5H3 (Ovnak, Vitez) with a thickness of 2.8 mm and a surface mass of 76.8 gm⁻² is made of polyurethane foam (lower part of the insole) and polyester non-woven textile (upper part of the insole). The appearance of insoles and the research plan is shown in Figure 1.

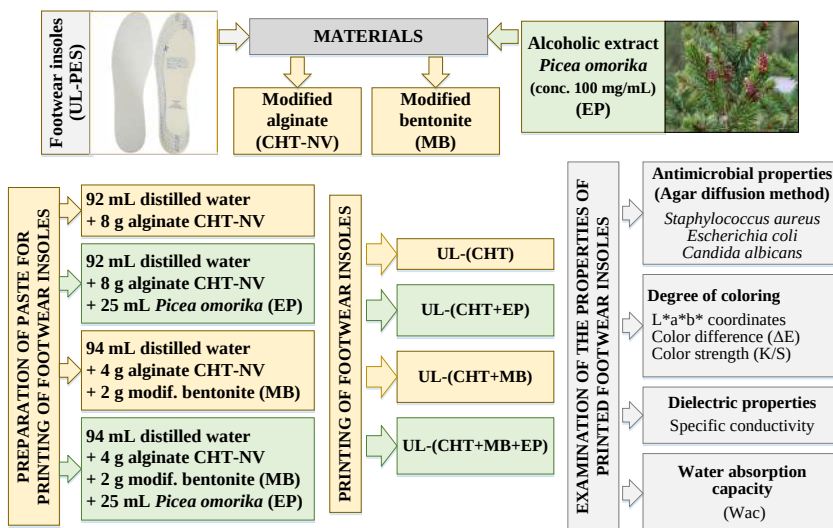


Figure 1: Experiment plan

2.1. Testing of water absorption capacity

The ability to absorb water is expressed by the water absorption capacity (Wac) that the textile material can absorb under defined conditions. The tests were performed according to the DIN 53923 standard [22].

2.2. CIE L* a* b* color coordinates and color intensity measurements

Calculation of the color difference is based on the determination of the differences in coordinates in the color space (ΔL^* , Δa^* , Δb^*) [23,24]. CIE L* a* b* coordinates were determined using a Konica Minolta diffuse spectrophotometer, model CM-2600d. Differences in color (ΔE) between the original insoles and printed insoles were calculated according to equation (1) [25]:

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (1)$$

where ΔL is the color brightness difference between the two samples, Δa is the red/green difference between the two samples, and Δb is the yellow/blue difference between the two



samples. The color strength values (K/S) of the printed samples were calculated using the Kubelk-Munk equation:

$$K/S = (1 - R)^2 / 2R \quad (2)$$

where R is the obtained reflectance at the wavelength of minimum reflection, K is the absorption coefficient, and S is the light scattering coefficient [26].

2.3. Examination of the antimicrobial effect by the diffusion method in agar

The antimicrobial effect of printed knitwear samples was tested using the agar diffusion method [27,28]. Cultures of the bacteria *Staphylococcus aureus* and *Escherichia coli*, as well as the yeast *Candida albicans*, were used for testing. For this test, the processed textile material was cut into samples with dimensions of 2.5 cm x 2.5 cm. After incubation, the zone of inhibition was measured.

2.4. Examination of dielectric properties

For all measurements of dielectric properties, an LCR Hameg 8118 device was used, in the frequency range from 20 Hz to 200 kHz, at an average temperature of 21°C. Samples with dimensions of 2 cm x 2 cm were placed between two electrodes. The voltage between the electrodes is 1V. [29]. Two conductance G and susceptance B were measured. The specific values of conductance and susceptance are calculated according to the following formula:

$$G_{spec}(ili B_{spec}) = G(il B)x \frac{d}{S} \quad (3)$$

Dielectric permittivity (ϵ_r) is calculated according to the following formula:

$$\epsilon_r = \frac{C \cdot d}{\epsilon \cdot S} \quad (4)$$

where: $C = B / 2\pi f$ and $B = B_m - (B_b - 2\pi f \epsilon_0 S / d)$, f is the frequency, C is the capacity, d is the distance between the electrodes, S is the surface of the electrode, ϵ_0 is the dielectric permittivity of the vacuum.

3. RESULTS AND DISCUSSION

This section presents the results of testing the properties of footwear insoles printed with alginate paste, modified bentonite and *Picea omorika* plant extract. The results of tests on water absorption capacity, degree of coloring, dielectric and antimicrobial properties are presented.

3.1. Results of the water absorption test

The results of testing the water absorption capacity of footwear insoles printed with alginate paste, modified bentonite and *Picea omorika* extract are shown in Figure 2.

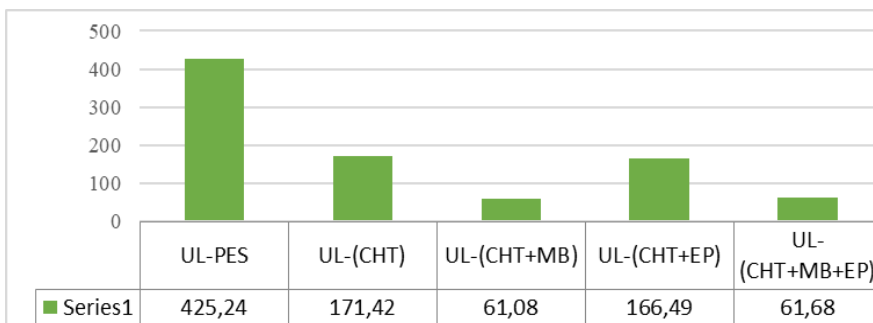


Figure 2: The amount of water absorbed by printed footwear insoles

From the results of the water absorption test, Figure 3.1, it can be seen that the highest W_{ac} was measured in the untreated UL-PES sample (425.24 %), while the lowest W_{ac} was measured in the insole sample printed with alginate paste and modified bentonite UL-(CHT+MB), and was 61.08 %. In general, it can be said that the addition of modified bentonite to alginate printing paste reduces the W_{ac} of printed insoles. Also, it can be seen that the addition of *Picea omorika* extract to the alginate paste with modified bentonite had no significant effect on the increase in the amount of absorbed water (W_{ac} increased by less than 1%), compared to the UL-(CHT+MB) sample, Figure 2.

3.2. Results of determination of $L^*a^*b^*$ color coordinates and color strength

$L^*a^*b^*$ color coordinates of printed footwear insoles, calculated values for color difference (ΔE) and color strength (K/S) are shown in Table 1.

Table 1: $L^*a^*b^*$ color coordinates, calculated color difference (ΔE) and color strength (K/S)

Sample labels	L^*	a^*	b^*	ΔE	K/S
UL-PES	86.79	-1.37	0.50	/	1.72
UL-(CHT)	84.35	-1.22	4.15	4.39	1.80
UL-(CHT+MB)	83.31	-4.44	4.38	6.05	1.75
UL-(CHT+EP)	76.69	-1.51	14.40	17.18	4.02
UL-(CHT+MB+EP)	75.01	-2.66	15.37	19.01	3.44

On the basis of reflectance measurements at wavelength range from 360 nm to 740 nm, spectral curves of printed insoles were obtained, Figure 3, which confirm the results for K/S.

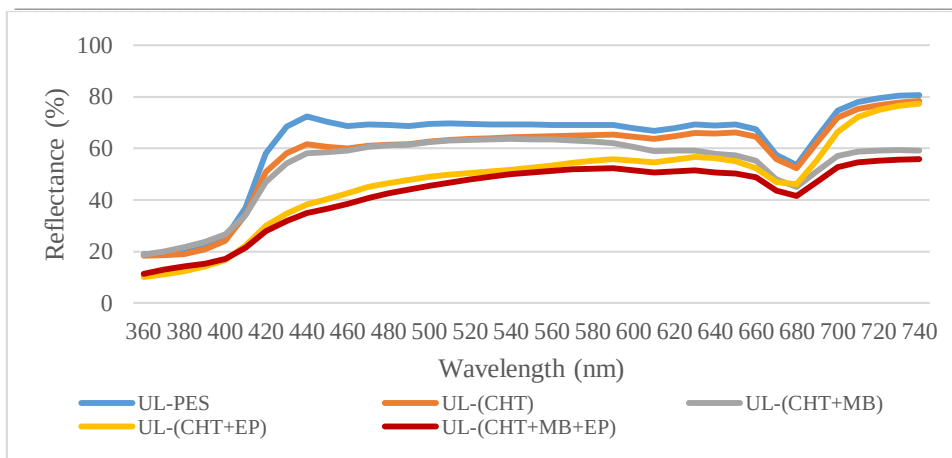


Figure 3: Spectral curves of printed insoles

Based on the measured values of $L^*a^*b^*$ coordinates and calculated color differences (ΔE), Table 1, it can be seen that the samples of footwear insoles printed with alginate paste, modified bentonite and *Picea omorika* extract UL-(CHT+MB+EP) have the biggest difference in color ($\Delta E = 19.01$), compared to the initial sample (UL-PES).

The calculated values (K/S), Table 1, show that the color strength is the highest in the sample printed with alginate paste and *Picea omorika* extract UL-(CHT+EP). By adding modified bentonite to the alginate paste, the K/S value decreases, so K/S for sample UL-(CHT+MB+EP) has a 14.4% lower value compared to sample UL-(CHT+EP).

Spectral curves for insoles, Figure 3, show that the initial sample (UL-PES) has the highest value of reflectance, which is in agreement with the measured color coordinate L^* (86.79). This means that the untreated UL-PES sample is the lightest and has the lowest K/S value (1.72), while the most intensely colored UL-(CHT+EP) samples have the highest K/S (4.02).

3.3. Results of dielectric properties

Using the method of dielectric spectroscopy, the conductance and susceptance were measured for all samples in the frequency range from 20 Hz to 7.5 kHz, at a measuring voltage of 1 V. The measurements were obtained at a temperature of 21°C, and the results were processed in the Origin program and graphically shown on the Figures 4 and 5.

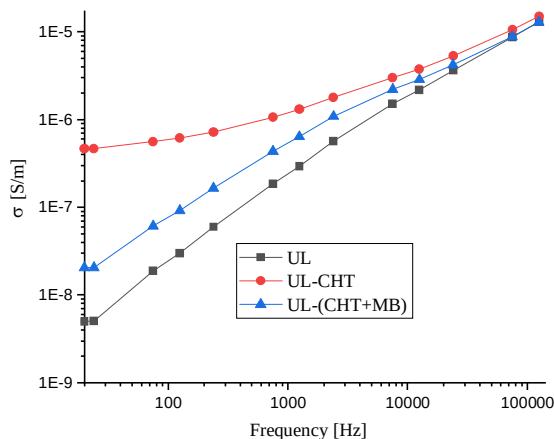


Figure 4: Specific conductivity as a function of frequency for samples UL, UL-(CHT) and UL-(CHT+MB)

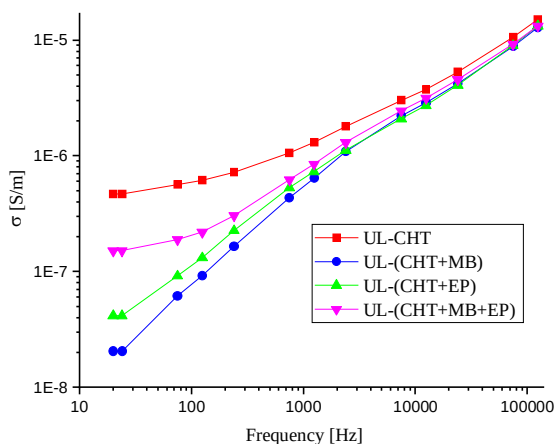


Figure 5: Specific conductivity as a function of frequency for samples UL-(CHT), UL-(CHT+EP), UL-(CHT+MB) and UL-(CHT+MB+EP)

Based on the results of specific conductivity (σ) as a function of frequency for samples UL, UL-(CHT) and UL-(CHT+MB), Figure 4, it can be seen that the lowest specific conductivity has the initial sample UL-PES. Also, it can be observed that there was a decrease in specific conductivity when modified bentonite was added to the alginate paste, i.e. the values of σ are lower for the UL-(CHT+MB) sample compared to the UL-(CHT) sample. The obtained values of σ are in agreement with the water absorption capacity (W_{ac}).

Sample printed with alginate paste and modified bentonite UL-(CHT+MB) has the lowest specific conductivity. By adding *Picea omorika* extract in alginate paste with modified bentonite UL-(CHT+MB+EP), an increase in specific conductivity was observed, Figure 5. In paper [30], fabrics modified with copper ferrite nanoparticles and *P. omorika* extract were examined and it was found that polyester fabrics have a lower specific conductivity than cotton ones.

3.4. Antimicrobial properties test results

The results of testing the antimicrobial effect of insoles printed with alginate paste, modified bentonite and *P. omorika* extracts are shown in Table 2 and in Figures 6 -8, where a) shows a petri dish with a sample and b) after removing the sample.

Table 2: Results of testing the antimicrobial effect of printed insoles for shoes

Sample labels	Antimicrobial activity on microorganisms		
	<i>Staphylococcus aureus</i>	<i>Escherichia coli</i>	<i>Candida albicans</i>
UL	NA	NA	NA
UL – (CHT)	NA	NA	CI
UL – (CHT+MB)	Zi = 0.25 mm	CI	CI
UL – (CHT+EP)	WCI	NA	CI
UL – (CHT+MB+EP)	CI	WCI	CI
WCI – weak contact inhibition (25% to 50% - reduction of microorganisms under the sample); PCI – partial contact inhibition (more than 50% - reduction of microorganisms under the sample); CI – contact inhibition (100% - reduction of microorganisms under the sample); Zi – zone of inhibition (mm); NA – no activity			

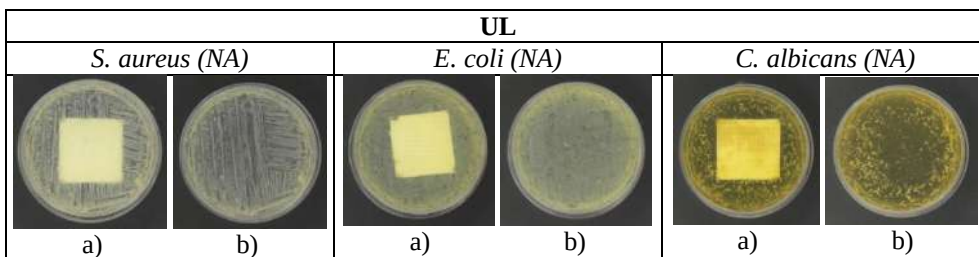


Figure 6: Examination of antimicrobial properties of insoles UL – PES

From the results of testing the antimicrobial properties of insoles, Table 2. and Figure 6, it can be seen that the insole SS-WL5H3, i.e., the starting sample labeled UL-PES, does not show any activity against the bacteria *S. aureus* and *E. coli*, as well as against the yeast *C. albicans*.

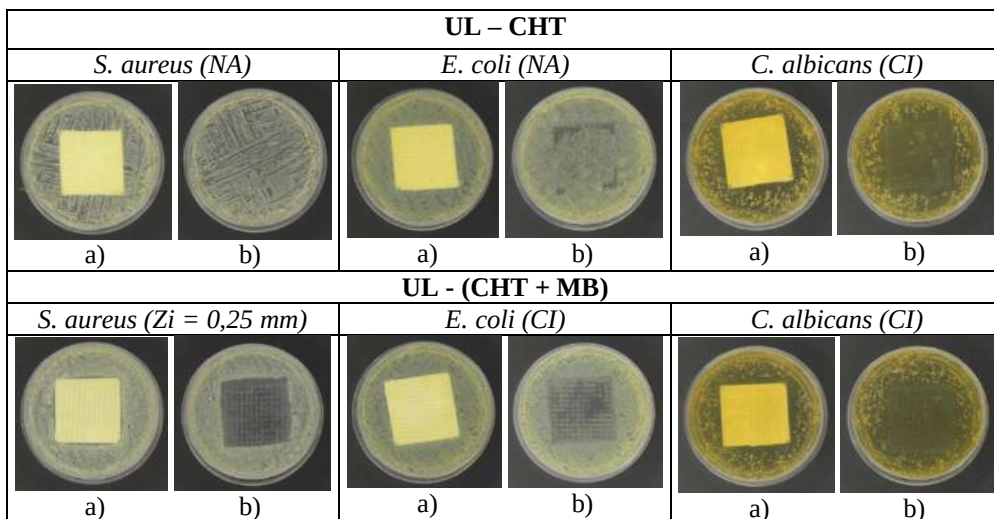


Figure 7: Examination of the antimicrobial properties of insoles printed with alginate paste and modified bentonite

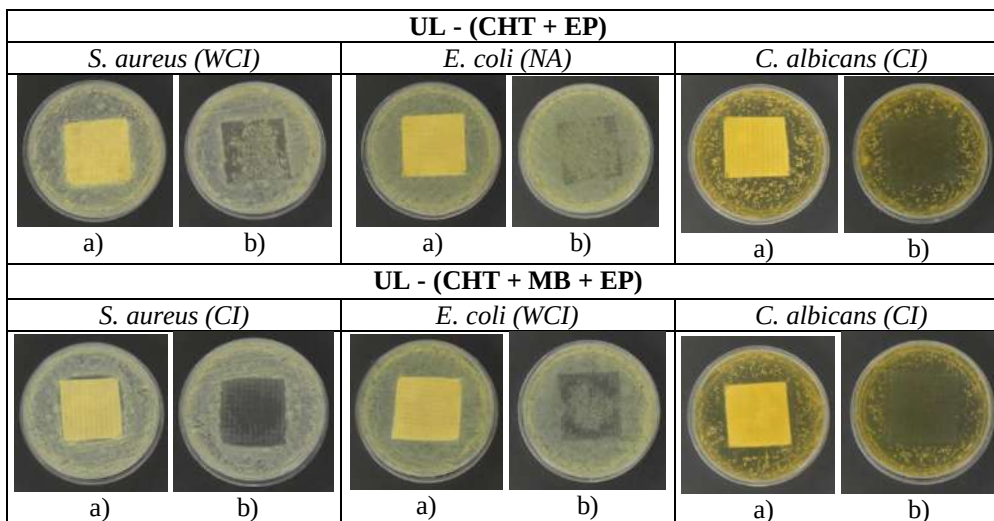


Figure 8: Examination of the antimicrobial properties of insoles printed with alginate paste and modified bentonite with the addition of *Picea omorika* plant extract

Based on the results of testing the antimicrobial properties of insoles printed with alginate paste (CHT-NV) and modified bentonite (MB), Table 2 and Figure 7, it can be concluded that the antimicrobial effect on selected microorganisms (*S. aureus*, *E. coli* and *C. albicans*) improved when modified bentonite was added to the alginate paste.



The antimicrobial effect of printed insoles UL-(CHT+MB) is reflected in the zone of inhibition ($Z_i = 0.25$ mm) on the bacterium *S. aureus* and contact inhibition (CI) on the bacterium *E. coli* and the yeast *C. albicans*. In other studies, the antimicrobial effect of textiles printed with modified bentonite (Cu/2Zn) on bacteria *Escherichia coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus* and *Bacillus cereus* has been proven, as well as that the antimicrobial effect increases with an increase in the concentration of modified bentonite [18].

For insole samples printed with alginate paste and *Picea omorika* extract UL-(CHT+EP), Table 3.2. and Figure 3.7, a certain antimicrobial activity is observed in the form of weak contact inhibition (WCI) on the bacterium *S. aureus* and contact inhibition (CI) on the yeast *C. albicans*, while it did not show any activity on the bacterium *E. coli*. Also, from the presented results it can be seen that added modified bentonite improved the antimicrobial activity of the sample UL-(CHT+MB+EP), from WCI to CI for *S. aureus* bacteria and for *E. coli* bacteria from NA to WCI, Table 2 and Figure 8.

5. CONCLUSION

By analyzing the results of testing the properties of footwear insoles printed with alginate paste, modified bentonite and *Picea omorika* plant extract, such as the ability to absorb water, color strength, dielectric and antimicrobial properties, the following can be concluded:

- Samples treated with modified bentonite and *Picea omorika* extract significantly reduce the water absorption capacity of insoles (61.68%) compared to the initial sample (425.24%).
- With the addition of modified bentonite to the alginate paste, the K/S value decreases, so the K/S for the sample UL-(CHT+MB+EP) has a 14.4% lower value compared to the sample UL-(CHT+EP).
- At lower frequencies sample printed with alginate paste and modified bentonite UL-(CHT+MB) has the lowest specific conductivity. By adding *Picea omorika* extract in alginate paste with modified bentonite UL-(CHT+MB+EP), an increase in specific conductivity was observed. However, those changes are not observed at higher frequencies.
- Adding modified bentonite increases the reduction of microorganisms under the sample. Samples of insoles printed with modified bentonite and *P. omorika* extract showed a certain antimicrobial effect, mainly in the form of contact inhibition, against all three tested microorganisms (bacteria *S. aureus* and *E. coli* and yeast *C. albicans*).

ACKNOWLEDGMENT

The work was supported by the Ministry of Science and Technology Development and Higher Education of the Republic of Srpska through projects (19.032/961-54/23 and 19/6-020/966-19-1/23) and the Erasmus project (101129078).

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COMPARISON OF PHYSICAL AND MECHANICAL PROPERTIES OF CHROME AND VEGETABLE TANNED LEATHER

Original scientific paper
DOI: 10.5937/CT_ITI24030L

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ABSTRACT: *Leather making is a very long process and consists of many different chemical and mechanical operations. The most important operation of the whole leather making process is the tanning, which is performed mainly by vegetable or chrome tanning. With this work, we wanted to establish a connection between the way leather is tanned and its physical and mechanical properties. For this purpose, certain physical and mechanical properties of bovine, sheep and goat leather, which were obtained by chrome and vegetable tanning, were examined. Tests were performed on commercially available leathers. The selected leather samples were tested for thickness, mass per unit area, apparent density, braking force and breaking elongation, while other dimensions were calculated based on previously measured values. After the measurements, the results were compared according to the type of leather and the method of tanning. The obtained results showed better physical and mechanical properties of chrome-tanned leather compared to vegetable-tanned leather, with the highest breaking strength of chrome-tanned bovine leather (70.7 N/mm²). However, for a more precise analysis, when examining the physical and mechanical properties, it is necessary to have more precise data of the origin, tanning parameters and applied leather finishing. The chrome tanning process has advantages in terms of the shorter duration of the tanning process, but chrome tanning process has significant limitations in terms of environmental requirements, which is why the vegetable tanning process is becoming more relevant again.*

Keywords: leather, chrome-tanned, vegetable-tanned, breaking strength.

POREĐENJE FIZIČKO MEHANIČKIH SVOJSTAVA HROMNO I BILJNO ŠTAVLJENE KOŽE

APSTRAKT: *Process prerade kože je veoma dug i sastoji se od mnogo različitih hemijskih i mehaničkih operacija. Najvažnija operacija u procesu prerade kože je štavljenje, koje se najčešće izvodi biljnim ili hromnim štavilima. Ovim radom želeli smo da uspostavimo vezu između načina štavljenja kože i njenih fizičko-mehaničkih svojstava. U tu svrhu ispitivana su određena fizičko-mehanička svojstva goveđe, ovčije i kozije kože, koje su dobijene hromnim ili biljnim štavljenjem. Ispitivanja su izvođena na komercijalno dostupnim kožama. Na odabranim uzorcima kože ispitivani su: debljina, površinska masa, prividnu gustina, prekidna sila i prekidno izduženje, dok su druge veličine izračunate na osnovu prethodno izmjerenih vrijednosti. Nakon mjerenja, rezultati su upoređeni prema vrsti kože i metodi štavljenja. Dobijeni rezultati su pokazali bolja fizičko-mehanička svojstva hromno štavljenih koža u poređenju sa biljno štavljenim, sa najvećom prekidnom jačinom hromno štavljene goveđe kože (70.7 N/mm^2). Međutim, za precizniju analizu, pri ispitivanju fizičko-mehaničkih svojstava, neophodno je imati detaljnije podatke o porijeklu, parametrima štavljenja i primenjenoj završnoj obradi kože. Proces štavljenja hromom ima prednosti u pogledu kraćeg trajanja procesa štavljenja, ali i ograničenja u pogledu ekoloških zahtjeva, zbog čega biljno štavljenje ponovo dobija na značaju.*

Ključne reči: *koža, hromom štavljena, biljno štavljena, čvrstoća na kidanje.*

1. INTRODUCTION

The most significant process in leather making is the tanning operation. This process involves introducing tanning agents (tannins) into the leather structure and binding them with the functional groups of the leather's collagen, creating cross-links. Depending on the charge, the tannin will bind to the positive amino or negative carboxyl groups of the collagen [1].

Collagen has a spatial structure with a certain number of cross-links (hydrogen bonds). During reactions between the active groups of collagen and the active groups of the tannins, stronger and more durable bonds are formed. The strength of these bonds depends on the type of tanning agent and the method of tanning. By creating stronger and more durable bonds, the collagen's resistance to enzymes and hydrolyzing substances is increased, swelling is reduced, and resistance to tearing is enhanced [2,3].

Chrome and vegetable tannins are the most commonly used tanning agents. Research shows that up to 85% of the world's leather production is based on chrome tanning [4]. Studies also show that chrome-tanned leathers have good tensile properties, but they also have a negative impact on the environment and human health, which is why efforts are being made to reduce their use [4-6].



The main advantages of chrome tanning include the speed of tanning, the production of light, strong, and durable leathers that are easy to dye [3]. Vegetable-tanned leathers have lower thermal insulation, lower resistance to sweat, and contain more bound tanning agents, making them heavier and thicker compared to chrome-tanned leathers [2].

To compare the physical and mechanical properties of chrome and vegetable-tanned leathers, tests were performed on the following parameters: mass, mass per unit area, apparent density, breaking force, breaking elongation, and breaking strength. These tests aimed to identify differences in the structure of the finished leather resulting from the applied tanning process.

2. MATERIALS AND METHODS

2.1. Materials

Different leather samples were used as material for the experimental work, according to origin (bovine, sheep and goat leather) and according to the method of tanning leather (chrome tanning and vegetable tanning). All leathers were Full grain leathers. Table 1. gives an overview of the types of leather used and type of tanning.

Table 1: Type of leather samples and type of tanning

Sample	Type of leather	Type of tanning
Sample I	Bovine leather	Chrome tanning
Sample II	Bovine leather	Chrome tanning
Sample III	Bovine leather	Chrome tanning
Sample IV	Bovine leather	Chrome tanning
Sample V	Bovine leather	Vegetable tanning
Sample VI	Sheep leather	Vegetable tanning
Sample VII	Goat leather	Vegetable tanning

2.2. Methods

The test samples were prepared in accordance with the EN ISO 2418 [7] and conditioned in accordance with the EN ISO 2419 [8]. The following tests were performed on the prepared leather samples in order to determine the physical and mechanical properties:

- EN ISO 2589 [9] for the leather thickness measurement. Ten measurement were taken, disposed across the sample and obtained results expressed as the arithmetic mean of measurements. Used apparatus: thickness gauge J-200 (Scmidt Control Instruments, Germany) whit measuring range 1-10 mm and resolution of 0.01 mm.

- EN ISO 2420 [10] for the leather apparent density (D_a) and mass per unit area (m_a). Apparatus that are used: square steel press knife (dimension 100 mm x 100 mm), and previously mentioned thickness gauge. Calculation of the apparent density was performed by using equation 1. Calculation of mass per unit area was performed by using equation 2.

$$D_a = \frac{10^6 \cdot m}{t \cdot a \cdot b} \quad (1)$$

$$m_a = \frac{10^6 \cdot m}{a \cdot b} \quad (2)$$

where:

t – the mean thickness of the test piece (mm); a – is the mean distance AC of the test piece in millimeters (mm); b – is the mean distance BD of the test piece in millimeters (mm); m – mass of the test peace in grams (g).

- EN ISO 3376 [11] for leather breaking force and breaking elongation. From the sample, ten test pieces were cut in standard dimensions to the leather surface - five test pieces with the side parallel to the backbone and five test pieces with the side perpendicular to the backbone. Breaking force (F), and breaking elongation (E_b), were measured using Tensile tester model AGS-10kNX (Schimadz, Japan) whit load capacity to 10 kN and test speed from 0.001 mm/min to 1000 mm/min. Breaking strength (T_n) in N/mm^2 , was calculated using equation 3:

$$T_n = \frac{F}{w \cdot t} \quad (3)$$

where: F - the maximum force recorded (N); w - the mean width of the test piece (mm); t - the mean thickness of the test piece (mm).

3. RESULTS AND DISCUSSION

The mechanical and physical properties of the samples were systematically analyzed through various parameters such as breaking force, breaking elongation, mass per unit area, apparent density and breaking strenght.

Figure 1. shows the dependence of breking strength and mass per unit area for samples of chrome-tanned bovine leather, observed in the direction parallel and perpendicular to the backbone. Based on the results, we can conclude that the highest breaking strength in the direction parallel to the backbone is found in Sample II ($70.7 N/mm^2$), while the lowest breaking has Sample III ($65.9 N/mm^2$). The breaking strength of the tested samples in the direction parallel to the backbone, decreases with the reduction of mass per unit area. The breaking strength measurements in the direction perpendicular to the backbone are approximately the same for Sample II ($40.8 N/mm^2$) and Sample III ($40.4 N/mm^2$), while the highest breaking strength has Sample I ($46.2 N/mm^2$). The breaking strength of the tested samples in the direction perpendicular to the backbone doesn't follow changes in mass per unit area as it does in the direction parallel to the backbone.

The higher breaking strength observed for samples parallel to the backbone could be linked to specific factors such as denser collagen fiber networks or more effective cross-linking during the tanning process [2].

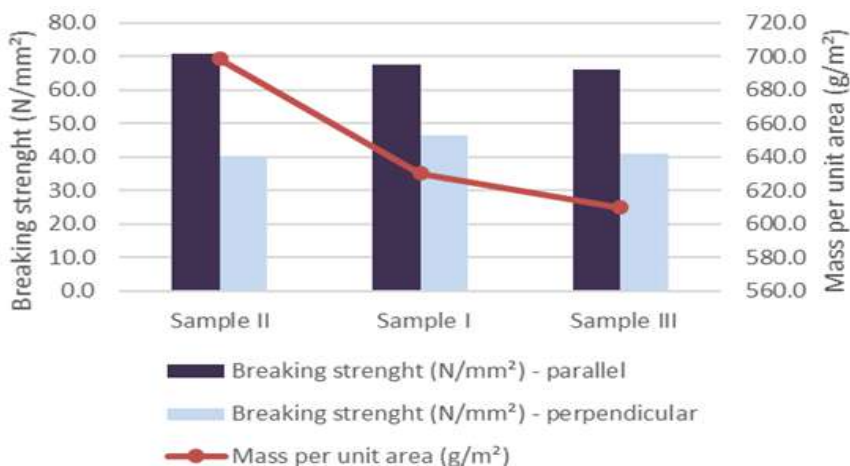


Figure 1: Dependence of breaking strength on mass per unit area – Chrome-tanned leathers

Dependence of breaking elongation and apparent density for samples of chrome-tanned bovine leather is shown in Figure 2, observed in the direction parallel and perpendicular to the backbone. It is noticeable that the highest breaking elongation in the direction perpendicular to the backbone has Sample III (49.0 %), while the lowest breaking elongation has Sample II (37.5 %). The breaking elongation in the direction parallel to the backbone are lower compared to the direction perpendicular to the backbone. Moreover, the breaking elongation for samples parallel to the backbone shows greater uniformity and are not significantly different from one to another. This consistency suggests a more uniform mechanical behavior along the backbone's parallel axis. The greatest breaking elongation in the direction parallel to the backbone has Sample III (32.9 %), while the smallest breaking elongation has Sample II (31.1 %). The cross-links between collagen fibers in the direction perpendicular to the backbone are significantly weaker and have a lower density compared to the direction parallel to the backbone, resulting in their greater breaking elongation [12]. Observing the dependence between breaking elongation and apparent density of chrome-tanned bovine leather, we notice that the breaking elongation of the tested samples in both directions increases with the decrease in apparent density.

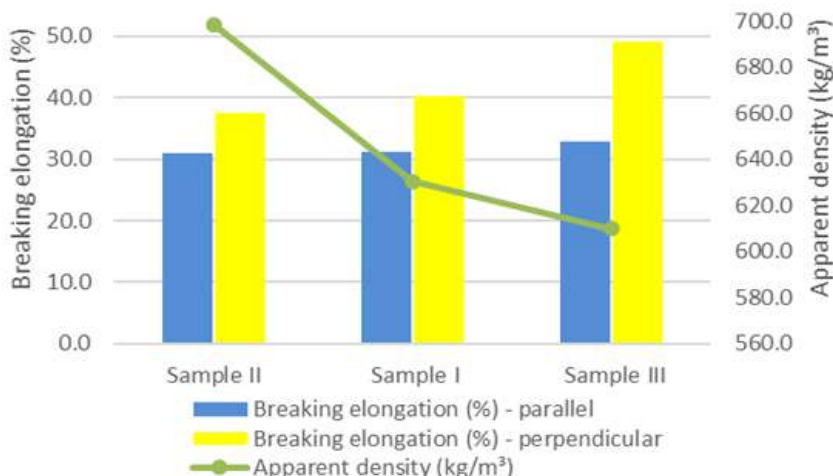


Figure 2: Dependence of breaking elongation on apparent density
 – Chrome-tanned leathers

Figure 3. shows the dependence between breaking strength and mass per unit area for samples of vegetable-tanned bovine, goat and sheep leathers, analyzed in the parallel and perpendicular directions relative to the backbone. The data indicate that Sample IV has the highest breaking strength in the direction parallel to the backbone (45.3 N/mm^2), while Sample VII shows the lowest breaking strength (19.2 N/mm^2). In the direction perpendicular to the backbone, Sample IV also shows the highest breaking strength (24.5 N/mm^2), with Sample VII again displaying the lowest (19.1 N/mm^2). A clear trend is observed where the breaking strength of the tested samples decreases in both directions as the mass per unit area is reduced. Notably, bovine leathers exhibit significantly higher breaking strength compared to goat and sheep leathers. This can be attributed to the greater weight, thickness, and density of bovine leathers, which confer superior mechanical properties. Conversely, goat and sheep leathers, derived from related animal species, are characterized by their lighter weight, flexibility and softness [1].

In the analysis of sample VII, we observed that the breaking strength values in both the parallel and perpendicular directions to the backbone are approximately equal. This uniformity in breaking strength is indicative of a balanced and homogeneous fiber structure, which is a sign of high-quality leather [12].

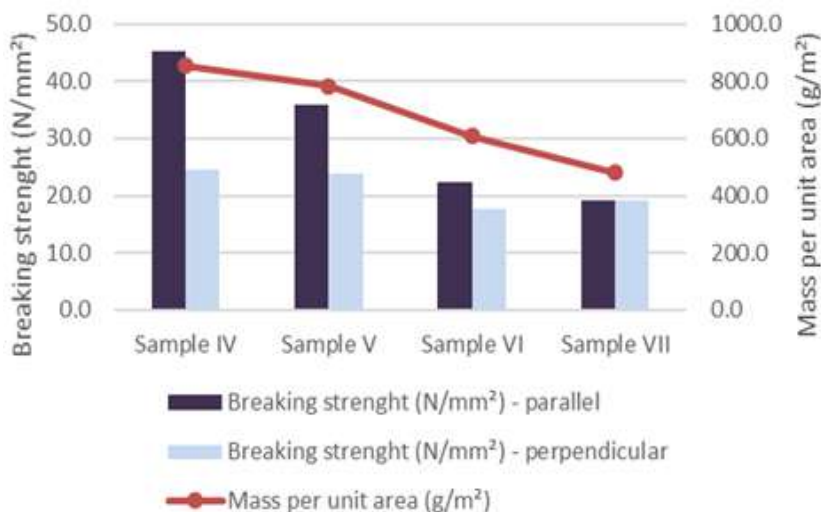


Figure 3: Dependence of breaking strenght on mass per unit area –Vegetable-tanned leathers

Figure 4. shows the dependence between breaking elongation and apparent density for samples of vegetable-tanned bovine, goat and sheep leather in directions parallel and perpendicular to the backbone. Based on the results, we can conclude that the highest breaking elongation in the direction perpendicular to the backbone has Sample VII (34.1 %), while the lowest breaking elongation has Sample IV (28.9 %). The highest breaking elongation in the direction parallel to the backbone has also Sample VII (27.9 %), while the lowest breaking elongation has Sample IV (23.3 %). In general, the breaking elongation of all tested samples in both directions (parallel and perpendicular to the backbone) increases with a decrease in apparent density. The highest breaking elongation in perpendicular and parallel direction has Sample VII (goat leather), which is 34.1 % and 27.9 %, respectively. The superior performance of Sample VII (goat leather) in both directions could be attributed to its unique structural properties. Goat leather is known for its tight and fine grain, which can enhance both strength and flexibility. The lower density of goat leather compared to bovine and sheep leather might contribute to its higher elongation [12].

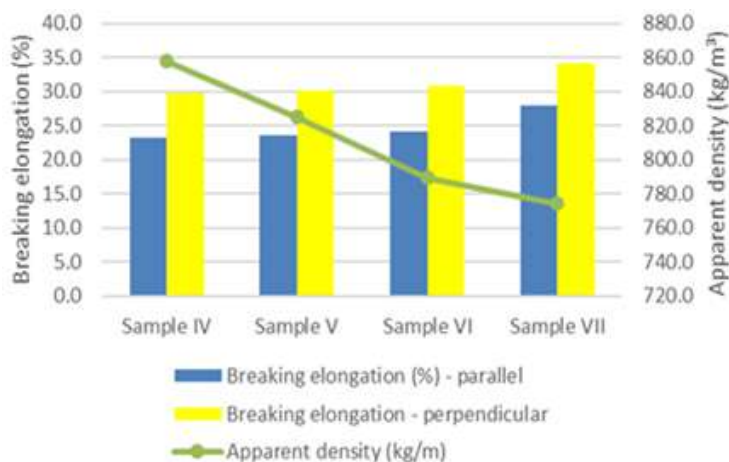


Figure 4: Dependence of breaking elongation on apparent density – Vegetable-tanned leathers

In order to compare the physical and mechanical properties of vegetable-tanned and chrome-tanned leathers of the same origin, samples of vegetable-tanned and chrome-tanned bovine leathers are observed in Figures 5. and 6. Based on Figures 5. and 6., we can see that the results for breaking strength and breaking elongation for the samples of chrome-tanned leathers are significantly higher compared to the samples of vegetable-tanned bovine leathers.

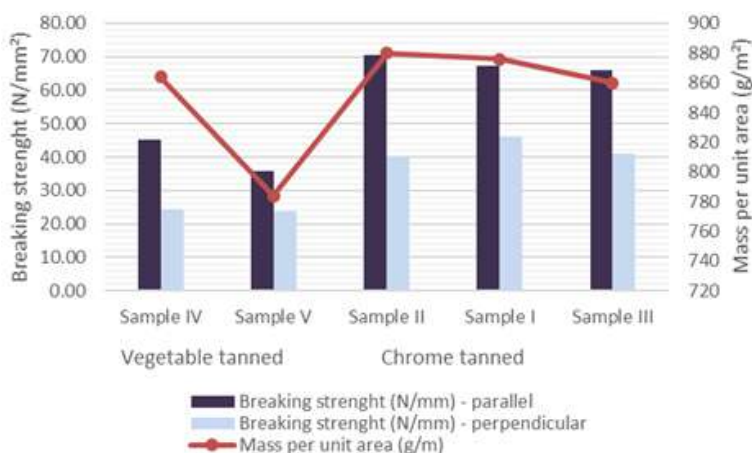


Figure 5: Comparison of breaking strenght on mass per unit area – Vegetable-tanned and chrome-tanned bovine leathers

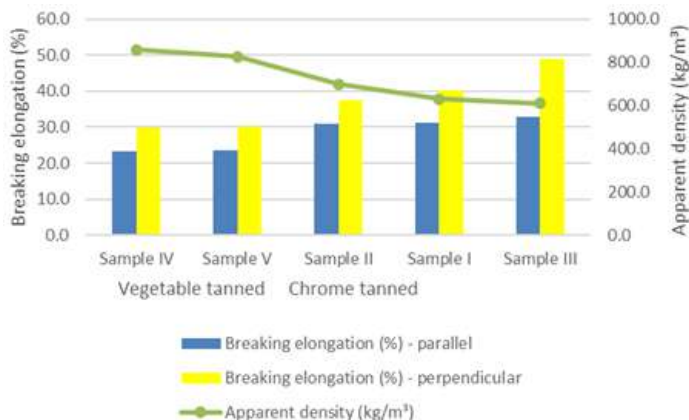


Figure 6. Comparison of breaking elongation on apparent density – Vegetable-tanned and chrome-tanned bovine leathers

4. CONSLUSION

The obtained results provide insight into the structural integrity and usability of the leather samples in potential applications. Physical and mechanical properties of leather are not influenced only by the tanning method but also by the origin of the animal. Certain deviations from expected results can be attributed to the lack of precise information regarding the finishing process, as well as the gender, age of the animal, ect. These factors, in conjunction with the tanning method and the animal's origin, are crucial in determining the physical and mechanical properties of the leather. Although, chrome-tanned leather has superior physical and mechanical properties, its environmental impact is a significant concern. Consequently, vegetable-tanned leather is recommended for applications where extreme physical and mechanical properties are not critical, thereby balancing performance with ecological considerations.

ACKNOWLEDGMENTS

This work was supported by European Union, Erasmus+ project: FOOTWEAR FAST FORWARD COOPERATION – Innovative agile training program and training opportunities for the digital and green twin transition in Bosnia (3F-COOP, Project No. 101129078).

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INNOVATION OF USING 3D PRINTING FOR TEXTILE FIBERS

Review scientific paper
DOI: 10.5937/CT_ITI24031D

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ABSTRACT: Textile fibers are produced in a natural way, and more and more often we have the opportunity to see impossible textile structures that retain desirable properties, such as non-creasing, long-term coloring, temperature stability, resistance to insects and the like. For the expansion of the use of printed textiles, a well-organized system in which technology is connected with economy, ecology, resources, informatics and marketing will have a great merit. Many filament (material) input methodologies are similar, and the difference is in the materials used, as well as in the process of general application and combining and joining of materials, so that the product is used for a long time. Fashion trends are something that negatively affects products, but this is solved by recycling and refurbishing clothes or shoes. The key moment for the development of 3D printing in the textile industry will be widely available printing technology, broadband internet and broad social acceptance of innovative materials. This paper presents the technologies that use different filaments in the production of textile fibers, and then also final products that do not have to be only clothing, but also for the needs of construction, defense and agriculture. The reason that every industry is looking for the use of artificial material that has similar characteristics to natural ones, where some properties will be improved and competitive in the market.

Keywords: 3D printing, textile fibers, innovations, technologies.

INOVACIJE U KORIŠĆENJU 3D ŠTAMPE ZA TEKSTILNA VLAKNA

APSTRAKT: Tekstilna vlakna se proizvode na prirodan način, a sve češće imamo priliku da vidimo nemoguće strukture tekstila koji zadržavaju poželjna svojstva, poput negužvanja, dugoročne obojenosti, postojanosti na temperature, otpornost na insekte i slično. Za širenje upotrebe štampanog tekstila veliku zaslugu će imati uređen sistem u kome je tehnologija povezana sa ekonomijom, ekologijom, resursima, informatikom i marketingom. Mnoge metodologije unosa filameta (materijala) su slične, a razlika postoji u samim



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materijalima koji se koriste, kao i u procesu opšte primene i kombinovanja i spajanja materijala, tako da proizvod bude dugotrajno korišćen. Modni trendovi su nešto što negativno utiče na proizvode, ali je to rešeno reciklažom i doradom odeće ili obuće. Ključni moment za razvoj 3D štampe u tekstilstvu će biti širokodostupna tehnologija štampe, širokopojasni internet i širokodruštveno prihvatanje inovativnih materijala. U ovom radu se predstavljaju tehnologije koje koriste različite filamente u proizvodnji tekstilnih vlakana, a onda i konačnih proizvoda koji ne moraju biti samo odevni, već i za potrebe građevinarstva, odbrambene svrhe i poljoprivrede. Razlog koji svaka industrija traži je korišćenje veštačkog materijala koji ima slične karakteristike kao prirodni, pri čemu će neka svojstva biti poboljšana i konkurentna na tržištu.

Ključne reči: 3D štampa, tekstilna vlakna, inovacije, tehnologije.

1.INTRODUCTION

Textile fibers are an important part of the product range of the textile industry. User needs in changing conditions require the textile industry to turn to innovation. With the help of innovative strategies, it is possible to eliminate the outdated technological processes of dyeing, washing, rinsing, and drying from the textile industry, and to bring speed and better quality of textiles through shortening. This can be achieved with the help of 3D printing of textile products.

With the modernization of equipment, the introduction of new technological solutions and innovations, production phases can be shortened and the processing process can be automated. With additional investments, production and distribution lines can be set up in the warehouse, with machines and tools that can change the functioning process. Computers and the development of the information society contributed significantly to all this, and microprocessors are installed in machines and optimization of drawings and transfer to fabrics is carried out. Research and development centers must encourage innovation, hire highly skilled engineers and technicians to research, connect with science centers for laboratory conditions, and test raw materials and molecules. With nanotechnologies in industries, noticeable results are achieved, because the technologies are integrated into a system that collects all the necessary information. Laser application of small furrows on the surface of the thread or microhermetization, the fabric can be printed in color and without dyes, so that the color changes depending on the change in external conditions.

Three-dimensional (3D) printing is seen as a process in which, during one stage, materials are deposited in layers according to a geometric configuration set through a digital record. The beginning of the prototype of the device was in the 80s of the last century, where UV rays were used to harden the polymer and obtain a structure that has three dimensions. The development of the 3D printer production methodology for the market was established by 3D Systems with the stereolithography patent. Clothing designers have used affordable printing technology to reduce the environmental impact of fast fashion and enable materials to be recycled to reduce production waste.



2. 3D PRINTING TECHNOLOGIES

Production using 3D printing enables the creation of shapes that are not available using ordinary technologies, and is characterized by uniqueness and the absence of molds. 3D printing is an additive manufacturing (AM) technology that produces objects by depositing materials in thin layers. The deposited material layers are interconnected in different ways depending on the 3D printing technology and the material used.

The impact of technology is great, especially in the textile and fashion industry, as new and personalized products are produced. These products can be used as technical textiles, protective clothing, for medical products, interior, clothing and affect the modernization of the process that requires production to be done without waste.

Using computer-aided design (CAD) to create three-dimensional objects in layers, 3D printing is created. From the very creation of graphic models of the objects to be printed, they are designed using software and the files are imported into the 3D printer. This printing of an individual object takes much longer than printing text on paper.

Refinement of textiles is always necessary for longer use, decoration and individualization, but the smart function of textiles is obtained by using smart fibers or through the printing process. The most commonly used printing techniques for printing smart textiles are screen printing and ink jet printing. In addition to them, the 3D printing technique is also used for printing on smart textiles [1].

2.1 Types of 3D printing in textiles

In textile and clothing design, 3D printing is used in three different forms, such as direct printing on textiles, printing rigid elements that can be folded into flexible structures similar to textiles, and printing elastic materials that resemble textiles. Each of these forms can be realized with different printing technologies [2]. In 3D printing on textiles, the material is applied directly to the textile substrate and the desired 3D objects, patterns or designs are created on its surface. For this purpose, fused deposition modeling (FDM) technology is commonly used. In addition, stereo-lithography (SLA) [3] and PolyJet technology can be used, where aesthetics, detail and surface treatment are most important [4].

Among the various 3D printing techniques, FDM is most often used, followed by SLA, then selective laser sintering (SLS) or melting (SLM).

- 1) **FDM (Fused Deposition Modeling)** technology is used in approximately 70% of 3D printers worldwide. The FDM method involves melting thermoplastic material using a temperature-controlled nozzle. The molten material is automatically pushed into the print head and comes out in a thin layer onto the printing table to form the model. The schematic diagram of the FDM 3D printer is shown in Figure 1.

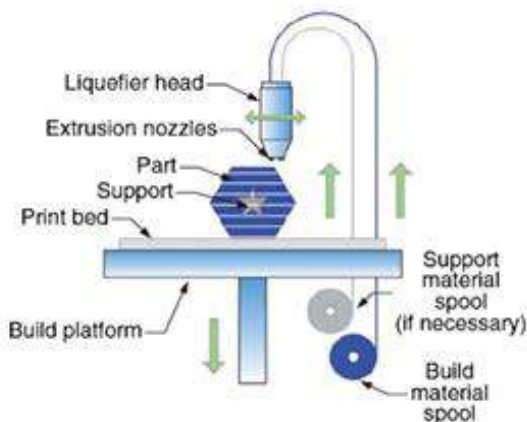


Figure 1: Schematic diagram of FDM 3D printing [5]

2) **SLA technology** is most often used in the photo-hardening process of liquid resin. Here, liquid resin is placed in a tank and a position-programmed laser scans the surface to begin photopolymerization. When the resin changes from a liquid to a solid state, chemical cross-linking occurs [6]. Schematic diagram of the SLA 3D printer shown in Figure 2.

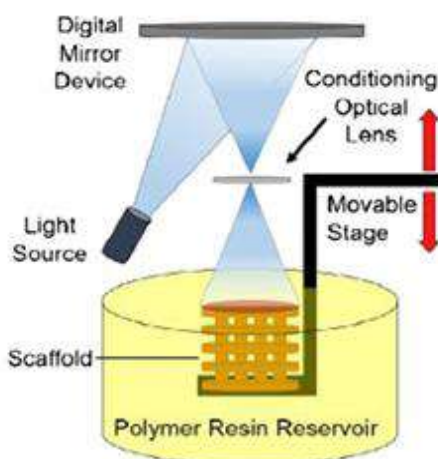


Figure 2: Schematic diagram of SLA 3D printing [5]

3) **SLS (Selective Laser Sintering)** is a selective laser sintering technology based on the hardening of resin materials in layers. This method uses Charles Hull's laser that patented stereolithography technology. A schematic view of SLS printing is shown in Figure 3, and this method is known as powder fusion [7].

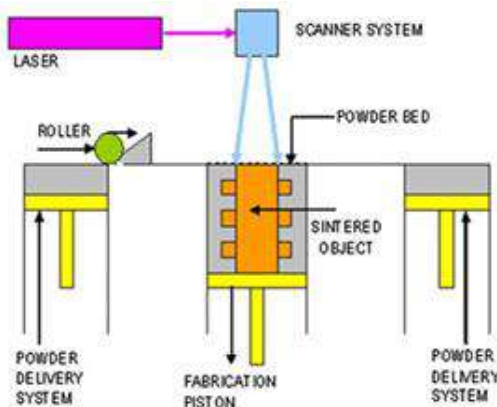


Figure 3: Schematic diagram of SLS 3D printing [5]

3. INNOVATIONS IN TECHNOLOGIES AND MATERIALS

Innovation always drives change, which means that the revolutionary development will be in 3D printing that encourages creativity and sustainability in the textile industry, which is at the top in terms of pollution compared to other industries.

New textile and additive manufacturing technology will affect textile production [2], so the printing of flexible structures will be based on:

- with rigid materials and that the structures are made to create some properties of the textile,
- another way is printing flexible materials,
- the third way is 3D printing on textiles.

The adhesion of 3D printed objects to textiles is affected by the preparation of the 3D model for printing, printer setup, placement of the fabric on the print table, and fabric construction parameters. Various polymers can be printed on textile surfaces in prepared forms to create multi-material objects that combine the advantages of technology and materials [8,9].

3.1 Clothing printing software

There are softwares that have 3D scanners for the body of the person who wants personalized clothes. Such scanners create a digital copy of the exterior of the human figure and then custom-made clothes are produced. With 3D human body scanning technology, there are no complaints about wrong measurements.

Computer-aided design (CAD) is a software tool that gives apparel designers a virtual representation of the garments they are designing. CAD software enables textile designers to utilize their creativity to the fullest when designing knits, printed and woven patterns. CAD can be used to design curves and figures in 2D and can be subsequently converted to 3D CAD for a better representation, as well as virtually prototype 2D designs through Browzwear's 3D clothing design software, VStitcher. By utilizing VStitcher, textile

designers can design fabric while simultaneously having the capability to visualize the finished garment in real time, giving the designer more room to control and minimize any errors.

The 3D clothing design software gives designers the capacity to visualize completed garments virtually, which has streamlined and accelerated product development from concept all the way to creation (See Figure 4).

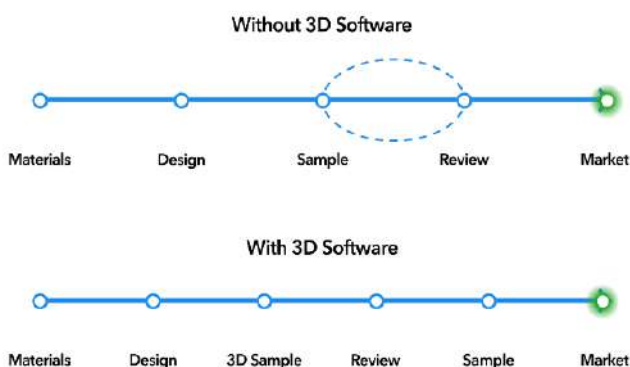


Figure 4: Schematic of proces without and with 3D Software
 (<https://browzwear.com/products>)

The removal of physical models for evaluation means that textile designers can create digital samples to alter and evaluate until prototyping. This procedure saves time and thus determines the best product that fits in terms of measurements, durability, and shape, and only then is it styled and placed on the market.

3.2 Innovations in polymer materials in 3D printing

The most important properties of multi-material objects made from 3D printed layers on textile substrates are good adhesion while maintaining the flexibility of the fabric. Adhesion of the polymer to the substrate is done with mechanical coupling, molecular bonding and thermodynamic adhesion [10].

In FDM, a 3D printer uses a process in which thermoplastic filaments are extruded and deposited in thin layers based on a previously designed 3D model [11]. During this process, the printer provides precise control over factors such as temperature and speed to regulate the flow of polymer material [12].

The most common polymer for 3D printing on textiles using FDM technology is polylactic acid (PLA-PolyLactic Acid). This biodegradable polymer is used on a textile substrate, because it has a low extrusion temperature [13]. After PLA, the most commonly used material is acrylonitrile butadiene styrene (ABS), followed by polycarbonate (PC), a mixture of PC and ABS, and others [14].

Thermoplastic polyurethane (TPU) has exceptional mechanical properties, such as tensile strength, hydrolytic stability, flexibility, durability and corrosion resistance, abrasion

resistance. The soft and hard segments in the polymer contribute to the unique properties and behavior of TPU [15]. In particular, it is expected that natural materials will be introduced into 3D printers and thus enable the biodegradability of materials and the use of natural pineapple, potato or kiwi skins.

3.3 Innovative technologies in 3D printing

The optimal technique for producing 3D printing polymers on textile fabrics may combine top-down printing, where the material would be placed only at the desired location with a low-viscosity printing material, i.e. resin or ink. This combination can be found in PolyJet Modeling (PJM) where liquid photopolymers are injected onto defined positions of the substrate and solidified there [16].

Poly-jet systems are better than SLA systems because the resins come in cartridge form and the devices are clean and quiet. With Polyjet technology, more than one material can be used simultaneously in production. Thus, it is possible for the material to be transparent and soft. A material that can be dissolved in liquid is used as an auxiliary material [17]. The schematic diagram of the polyjet 3D printer shown in Figure 5.

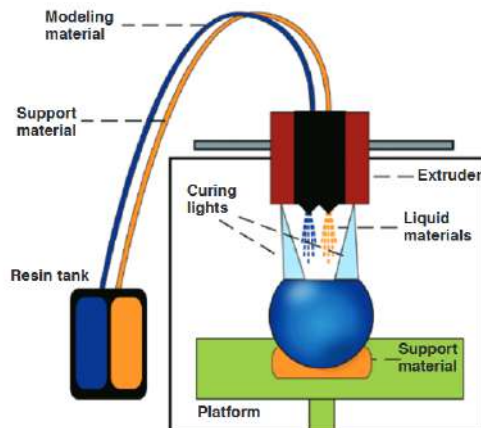


Figure 5: Schematic diagram of polyjet 3D printing [18]

A big advantage of using PJM technology for making composite models in combination with textiles is the possibility of using several different materials (hard and soft) as well as mixing them to make a new one.

Binder Jetting is a jet technology, known as 3D color printing. When the powder material is placed on the printing table, the 3D printer head passes over the powder and sprays the glue and paint. With the application of the next layer, the powder material is applied with a roller, and in this layer it is finished by re-spraying the glue and paint from the print head and it is repeated until the model is made in layers. Curing of the model is done in an oven, and after the production of the model is completed, the process is carried out with the help of a brush and water to remove the remaining dust. Schematic diagram of binder jetting 3D printer shown in Figure 6.

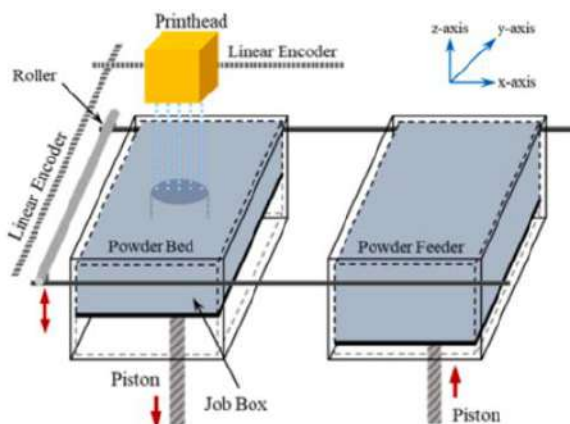


Figure 6: Schematic view of Binder jetting 3D printing [20]

Mold making, which takes time in the fashion industry, is being replaced by CAD software. With the help of CAD software, live model measurements can be transferred to a computer within minutes. With the help of this technology, the consumer becomes his own designer as well as a producer. One of the advantages of 3D printers is mass production and recycling, and the pollution that currently exists in factories is prevented.

Conventional fabrics have a thickness that is small compared to the width and length, and these are 2D fabrics. 3D fabrics have characteristic values in all three physical dimensions and can be created through yarn architecture or fabric architecture [19]. A split fabric is a 3D fabric consisting of two separate outer layers joined together but separated by spacer threads.

4. MATERIALS FOR 3D PRINTING IN TEXTILES

Input components are important because of the future structure of the subject. The properties of the materials to be entered must meet the requirements of being flexible, unbreakable, not colored when washed, not damaging the structure, healthy, compact, reusable and not polluting the environment.

The materials, or filaments, as fibers used in printing textile items depend on the printer and the project. In textiles, the object of manufacture may be fabric, footwear or a prototype garment, where heat resistance, impact resistance, ease of use, flexibility, visual appeal and similarity to the desired materials are considered.

The World Advanced Savings Project - WASP states that the most common filament for clothing is thermoplastic polyurethane (TPU). The reason for using TPU is that it has great durability and is resistant to wear and tear, due to the elasticity of the undercut rubber, and it can be an insulator and resistant to shocks.

Flexible filaments are easier to print and are important for 3D printing and the textile industry (Figure 7).



Figure 7: Flexible filaments and part of dresses

Flexible filaments are easier to print and are important for 3D printing and the textile industry. Combined with the holographic refraction pattern it transfers to the printed medium and enhances the style and appeal. Embossing of 3D printed components is done directly on the fabric and is integrated into the garment, so that sequins or various colors can be added at the same time on the material. Biodegradable polymers or two-color filaments of polylactic acid (PLA) are used to create 3D prints.

4.1 Innovative materials and printing technologies

Polyethylene terephthalate (PET) copolymer is a modified version of polyethylene with additional monomers or additives incorporated into the polymer chain. This modification introduces specific properties that make it suitable for use in 3D textile printing. A slightly higher temperature is required for 3D printing than PLA (240 °C) [13].

3D printing on textiles enables a variety of new aesthetic and functional properties because they have a visual identity that is more difficult to achieve with an analog way of working. Recently, the advanced technology of 4D printing (4DP), which combines functional materials and 3D printing, has been developed. By introducing time as the fourth dimension, the basis is created for the development of smart materials that have the properties of dynamism and adaptability of the structure based on external stimuli or environmental conditions. Compared to knitted textile backings, which are stretchy, flexible and more elastic, these offer greater stability and the possibility of using stronger yarns. This is suitable for achieving certain properties in the production of protective clothing, technical textiles and apparel textiles, making them an ideal textile substrate for many different 3D printing applications.

The improvement of adhesion is achieved by increasing the roughness and porosity of the textile material, thus increasing the thickness of the fabric, double weaving, lower thread density, etc. A very important part is pre- and post-treatment, which has a great influence on the adhesion of 3D printing to textiles. Apart from the composition and construction of the fabric, the distance between the print head (nozzles) and the fabric is increasingly important.

3. CONCLUSION

The fashion industry has to adapt to the new technological paradigm, because there is no more mass production and consumption. It is produced exclusively, on demand, with customizable products that are meant to last. It is certain that printed textiles will be a sustainable solution to reduce waste and encourage creativity. Printing a 3D object can be completed quickly and modified in a short time. All 3D files are stored in the cloud and printed alongside 3D models as CAD or STL files, so they are easily located and printed as needed. Parts can be created on a 3D printer that can be heat resistant or water repellent. With 3D textile printing, parts are produced as needed, so there is no waste, and due to the reduced use of fuel and some materials, there are no negative effects on the environment. In this way, the entire product is printed in one printer, which reduces the cost of transferring from one machine to another. Additionally, printer availability is greater as there are more local service providers to hire. In the medical sector, 3D printing can save many lives by printing human organs for emergency interventions. 3D printed clothing can be made from recycled and biodegradable materials, offering a sustainable solution. 3D printing has the advantage that it allows design variability, possibility of individualization, produces strong parts that are not heavy, short maturation period-life cycle, waste reduction, cost-effective, access from distance-online, ecologically and medically applicable. The disadvantages of 3D printing include limited materials, build size, and post-processing. The density of the fabric has the greatest influence on the adhesion force. With the new technology, which is recognized as 3D printing, designers can create unique pieces that were once unattainable, so that the clothes are exactly the order of the customer.

ACKNOWLEDGMENT

The research presented in this paper was carried out with the financial support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, as part of the funding of scientific research work at the University of Belgrade, Technical Faculty in Bor, according to the contract with number 451-03-65/2024-03 /200131.

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VII Međunarodna naučna konferencija
„Savremeni trendovi i inovacije u tekstilnoj industriji“
19-20. septembar 2024. Beograd, Srbija



SESSION II

TEXTILE AND FASHION DESIGN



VII International scientific conference
„Contemporary trends and innovations in the textile industry“
19-20th September, 2024, Belgrade, Serbia





CONNECTION OF WOMEN'S FASHION DESIGNS AND ARCHITECTURAL CONSTRUCTIONS

Original scientific paper
DOI: 10.5937/CT_ITI24032J

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ABSTRACT: Ideas of societal, cultural, and personal identity have long been expressed through the fields of architecture and fashion design. But in the last year, practitioners in both fields have expressed more nuanced and thought-provoking challenges related to ideas of identity, going beyond the idea of just denoting value, status, and belonging. The aim of this paper is to present the relation between architecture creations and fashion design, creating women's dresses inspired by Gothic architecture. Initially, technical sketches of the model are performed. The basic constructions of women's dress and tight sleeves are used as a starting point for designing. Later, with modeling, the desired type of model is performed. The ornaments from Gothic architecture are used for printing on fabric, and then these elements are sewn on the clothing. In the end, the combination of high fashion and architecture is proof of the inspiration and correlation between both disciplines and the long-lasting value of artistic expression.

Keywords: Architecture, fashion design, clothing, aesthetic, interrelationship.

POVEZIVANJE ŽENSKOG MODNOG DIZAJNA I ARHITEKTONSKIH KONSTRUKCIJA

APSTRAKT: Ideje društvenog, kulturnog i ličnog identiteta dugo su se izražavale kroz oblasti arhitekture i modnog dizajna. Ali u poslednjih godinu dana, praktičari u obe oblasti su izrazili više nijansiranih i izazovnih izazova u vezi sa idejama identiteta, prevazilazeći ideju samo označavanja vrednosti, statusa i pripadnosti. Cilj ovog rada je da prikaže odnos između arhitektonskih kreacija i modnog dizajna, kreirajući žensku haljinu inspirisanu gotičkom arhitekturom. U početku se izvode tehničke skice modela. Osnovne konstrukcije ženske haljine i uskih rukava služe kao polazna osnova za dizajn. Kasnije se uz modelovanje izvodi željeni tip modela. Ornamenti iz gotske arhitekture se koriste za štampanje na tkanini, a zatim se ovi elementi prišivaju na odeću. Na kraju, spoj visoke



mode i arhitekture je dokaz inspiracije i povezanosti obe discipline i dugotrajne vrednosti umetničkog izraza.

Ključne reči: Arhitektura, modni dizajn, odeća, estetika, međusobni odnos.

1. INTRODUCTION

Two applied arts disciplines that directly aim to cover and protect the human body are architecture and fashion [1,2]. Traditionally, they support human lifestyles, in which architecture creates homes for people and fashion gives them garments to wear. As creative techniques that rely on emerging technologies, presentation, and branding, these two disciplines cross paths, overlap, collaborate, and are sometimes blended. Today's fashion is imprinted with architectural inspiration and techniques, and architects are becoming increasingly visible in the fashion sector [3]. Therefore, despite their differences in scale and use, both may be understood in terms of their aesthetic attributes as well as their artistic tenets, designs, and methods [1, 4]. Their relationship has always existed on the periphery of each other's lives; it did not emerge abruptly or spectacularly. For their comparison, Riegelman writes, "Draping is like architecture: the body is the armature, the internal structure, and the fabric, like skin, glides over this frame. The fabric falls and twists, forms knots, bends and curves, like a river it ebbs and flows over the contours of the body" [5]. Since both fields are primarily made of flat, 2D materials and because "form follows function" is a common idea in both, it is not unexpected that practitioners in each draw inspiration from the methods, surfaces, and forms of the other [6]. Thus, fashion designers and architects aim to provide human body forms that are flawless, cozy, and exquisite. Both designers and architects are concerned with volume, and space, and supply the body with a covering, shielding it from the surrounding, and serving as a platform for social and cultural commentary [7].

Fashion and architecture share an intriguing similarity in that they both take shape, structure, and sometimes even the ability to make seemingly impossible physics feats conceivable into reality. Thierry Mugler, Pierre Balmain, Tom Ford, Pierre Cardin, and Zaha Hadidwent, among others, transitioned from dressing buildings to dressing the body [2]. Additionally, a lot of fashion designers first trained as architects, like Gianfranco Ferré, Tom Ford, and the late Pierre Balmain. "Dressmaking is the architecture of movement," declared Balmain, demonstrating his excitement for fusing architectural details into his creations [8]. Garcia affirms that his degree is still relevant in his capacity as a fashion designer, particularly in terms of a general sense of proportion. "They are both visually driven expressions of personal taste and the times we live in," stated the style director at Architectural Digest, Jane Keltner de Valle [9]. Architecture and fashion are closely linked; both are human-centered and oriented, directly addressing issues of motion, physiology, anatomy, time, proportion, and scale [10]. However, the primary distinction between them is the fashion shorter lifespan than that of eternal architectural designs. While architecture is enormous and timeless, fashion is also heavily influenced by marketing and consumption.

Parallel studies in architecture and fashion is a growing topic in both fields. Thus, the papers [11,12] explore the shared traits and terrain of modern architecture and fashion, emphasizing and proposing avenues for further advancement in both fields, including novel approaches to design, new techniques for manufacturing, and new directions in aesthetics. Further research by Matthew Huston and Tori Rodrigues in January 2016 found that our clothing can affect hormone levels, heart rate, and even how we think and negotiate [13]. Numerous writers have examined the impact of the classic Arab oriel window, or "mashrabiya" as a potent environmental component in contemporary architecture, on fashion. [14, 15, 16]. Remarkably, the emerging forms in every field appear to resonate with each other. Architect Greg Lynn's 2008 Slavin House is one example of this [17]. Nonetheless, deconstruction was employed by both fields to refute notions of "form," "function," and "beauty" and to introduce fresh perspectives on both fashion and architecture [18]. The technique of using geometry to create form is one that both fashion designers and architects employ.

Both professions make use of some complicated forms as well as simpler shapes like ellipses, squares, and circles, such as The 21st Century Museum of Contemporary Art in Kanazawa, Japan [19] and Meejin Yoon's Möbius Dress [20]. Even while the concept of using printed materials in garment designs is not new [21], several contemporary printing-related fashion applications have brought novel and unusual concepts, especially those that reference the grammar of ornamentation or the language of architecture. Fashion designers are employing high-performance textiles, integrating concepts of safety, mobility, and identity, and reevaluating how clothes may meet the needs of the contemporary "urban nomad" [22]. In order to produce more adaptive, sustainable, and multifunctional buildings that may address humanitarian needs, architects are simultaneously challenging the function of conventional "bricks and mortar" constructions and utilizing novel materials and construction methods. A comparable look results from the fact that fashion designers and architects frequently use the same 3D rendering and scanning technologies [10]. For both disciplines, using advanced computer technologies is liberating. Numerous manuscripts [23–26] provide examples of how CAD systems are used for 2D and 3D designing in the fashion design industry.

The aim of this paper is to present the relationship between architecture and fashion design transferable in a women's dress, similar to our previous research [27]. Gothic architecture was the inspiration, which was an inspiration for other papers [28].

2. EXPERIMENTAL PART

Consequently to the above, the aim of this paper is presentation of female dress model, with a design related to architecture. So, the designs from the architectural works are mirrored in women's clothing. The produced sample is related to Gothic architecture and Figure 1 presents the design of dress model and architecture inspiration. The technical sketch are shown on Figure 2.



Figure 1: Model of dress concerning Gothic architecture

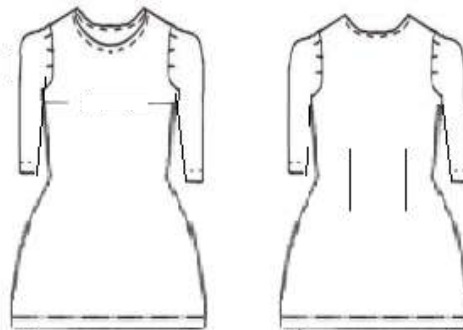


Figure 2: Technical sketch of dress model

The front of the dress has two laterally darts in the chest area. On the upper part, an image printed on fabric is sewn, and on the lower part, two images are sewn (created in the same way as the first one). The back of the dress has two darts above and below the waistline. The length of the dress is above the knees. The sleeves are narrow elbow-length, and puffy in the upper part.

3. RESULTS AND DISCUSSION

The default model is derived from the basic construction of a woman's dress and a tight sleeve according to established construction measures and construction rules [29].

To obtain the patterns according to the technical sketch, modelling is the next step. The modeling of the dress front part is performed in several steps, presented in Figure 3:

- The chest dart is closed and a new one is opened in the area of the armpit (2,5 cm down), with a width of 5,0 cm and length of 12,5 cm;
- The waist dart is removed;
- The dress length is shortened by 20,0 cm.

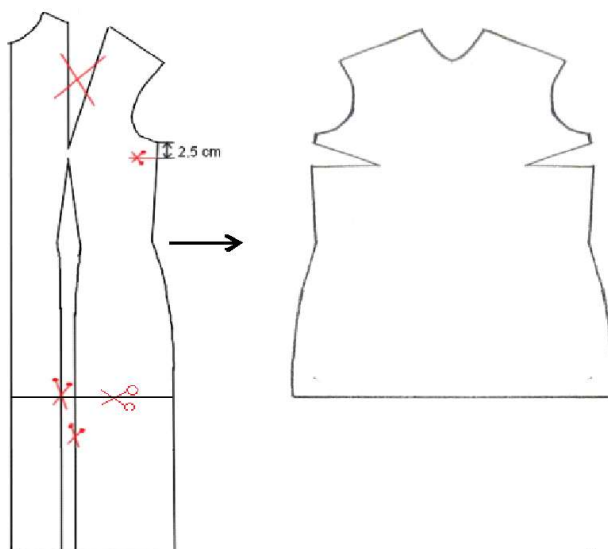


Figure 3: Front part modelling of model

Figure 4 present the picture designs (from Gothic architecture) which are printed on fabric and later are sewn onto the dress.

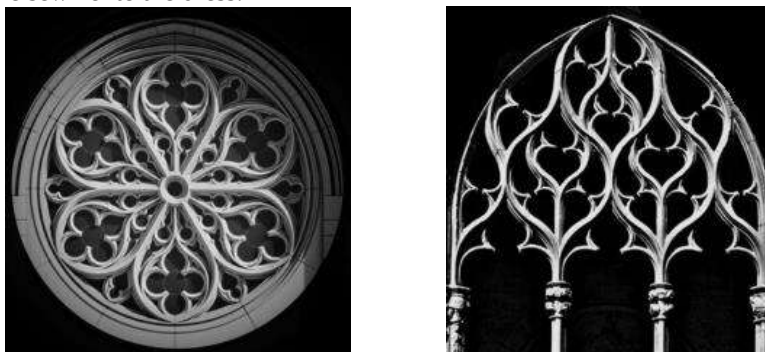


Figure 4: Ornaments of Gothic architecture

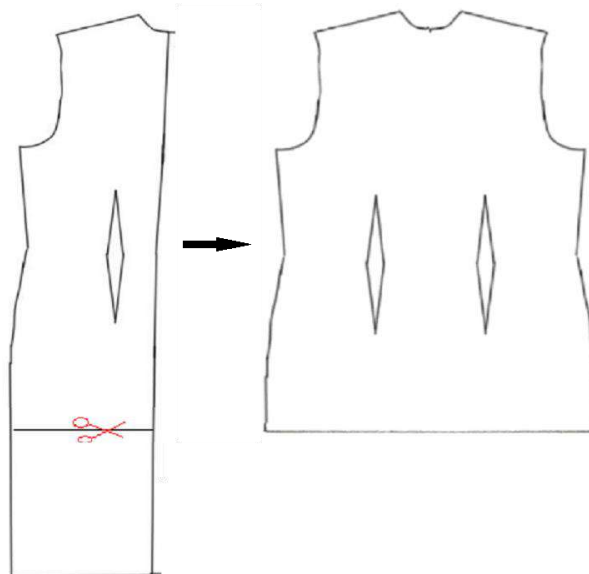


Figure 5: Model 1- back part modeling

The modeling of the back part is shown in Figure 5 and consists of the following steps:

- The length of the dress is shortened by 20,0 cm.
- The location of the darts remains the same. Their length is 27.0 cm, and their width is 3.0 cm.

Technical sketch and sleeve modelling are presented on Figure 6. First, length is shortened to the length of the elbows and the width half is marked. Through this line the sleeve is cutted and both parts are rises up by 5,0 cm.

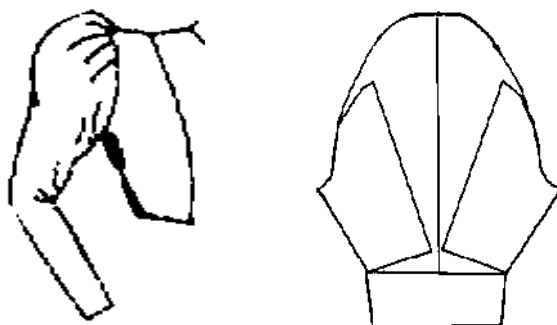


Figure 6: Technical sketch of puffy wide sleeve and sleeve modelling

For both patterns, the sleeve and dress a 1,0 cm wide seam allowance are added to all sides except the hems, where the seam allowance is 3.0cm. The front and back patterns are tailored once, and the sleeve is tailored twice. Also, with aim the sleeve stand firm, non-woven fabric is used, tailored with the same pattern of the sleeve, but reduced by 1,0cm from all sides. Also at the shoulders area, tassels are used for a more voluminous look. The final look of the created garment is shown on the Figure 7.



Figure 7: Final model

4. CONCLUSION

To change the very essence of structures and clothing, emerging generations of designers in both disciplines are set to create even more creative ways of using and modifying each other's shapes and approaches. Architectonic designs are a great source of inspiration for details and silhouettes in clothing, as it was presented in this research too. Women's dress model was created and decorated with printed ornaments from Gothic architecture. A building's unexpected component could turn into one of the garment design's most amazing elements when the designer looks into the architecture. High fashion and architecture together symbolize a dynamic partnership based on common values of expression, beauty, sustainability, and technical progress. This collaborative relationship between architecture and design is always pushing the boundaries of design, from cross-disciplinary partnerships to the influence of architecture on fashion and the usage of architectural spaces for high-end events.

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COLOURS AND MOTIFS OF THE TRADITIONAL HAND-KNITTED SOCKS OF AĞRI PROVINCE OF TURKEY

Original scientific paper
DOI: 10.5937/CT_ITI24033G

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ABSTRACT: The sacred land Anatolia, the cradle of many civilizations, covers many crafting traditions as clothing, kitchen tools, dowry items, carpets, rugs, socks, booties, jewellery works, pottery, or wooden products. These products, which people use daily from past to present, reflect the experience and knowledge accumulated over a long period of time, and carry historical values within themselves, ensuring cultural continuity. In this sense, it can be said that handicrafts are a part of life with their production and have a great value in terms of cultural history. Ethnography with a deeper understanding of culture, accept hand-knitted items not as mere garments worn on the body, but as non-verbal communication tools conveying the region, social life, feelings, and thoughts of the knitter through the colours, compositions and motifs. This paper aims at supporting the strong relationship between craft and ethnographic research by documenting it with the use of both traditional examples of handknitted socks and the identification of their common elements. Motifs used in traditional textiles play an important role in reflecting Turkish culture and identity and transferring it from generation to generation. In this context, 22 socks knitted in Ağrı were examined and the motifs used on the socks were determined. The motifs of hand-knitted socks, which are generally knitted for daily use and dowry, are stripes, diagonal stripes, cleats and hooks; It was concluded that black and white were preferred as colours. Nowadays, with the development of technology, the motifs in the products traditionally made in the regions have become more important, especially for use in culturally based textile products. For this reason, it is important to document and introduce the motifs that reflect our cultural identity to future generations.

Keywords: Handknitted socks, color, motif, Ağrı province, Turkey.

BOJE I MOTIVI TRADICIONALNIH RUČNO PLETENIH ČARAPA POKRAJINE AĞRI U TURSKOJ

APSTRAKT: Sveta zemlja Anadolija, kolevka mnogih civilizacija, pokriva mnoge zanatske tradicije kao što su odeća, kuhinjski alati, predmeti za miraz, tepisi, ćilimi, čarape, čizme, nakit, grnčarija ili proizvodi od drveta. Ovi proizvodi, koje ljudi svakodnevno koriste od

prošlosti do sadašnjosti, odražavaju iskustvo i znanje stečeno tokom dugog vremenskog perioda i nose istorijske vrednosti u sebi, obezbeđujući kulturni kontinuitet. U tom smislu, može se reći da su rukotvorine svojom proizvodnjom deo života i da imaju veliku vrednost u kulturno-istorijskom smislu. Etnografija sa dubljim razumevanjem kulture, prihvata ručno pletene predmete ne kao obične odevne predmete koji se nose po telu, već kao neverbalno komunikaciono sredstvo koje kroz boje, kompozicije i motive prenosi region, društveni život, osećanja i misli pletača. Ovaj rad ima za cilj da podrži čvrstu vezu između zanatskih i etnografskih istraživanja tako što će ih dokumentovati korišćenjem tradicionalnih primera ručno pletenih čarapa i identifikaciju njihovih zajedničkih elemenata. Motivi koji se koriste u tradicionalnom tekstu igraju važnu ulogu u odražavanju turske kulture i identiteta i prenošenju sa generacije na generaciju. U tom kontekstu, ispitane su 22 čarape pletene u Agriju i utvrđeni su motivi korišćeni na čarapama. Motivi ručno pletenih čarapa, koje su uglavnom pletene za svakodnevnu upotrebu i miraz, su pruge, dijagonalne pruge, kvačice i kuke; Zaključeno je da se crno-bela preferiraju kao boje. U današnje vreme, razvojem tehnologije, motivi u proizvodima koji se tradicionalno proizvode u regionima dobijaju na značaju, posebno za upotrebu u tekstilnim proizvodima kulturnog porekla. Iz tog razloga, važno je dokumentovati i predstaviti motive koji odražavaju naš kulturni identitet budućim generacijama.

Ključne reči: Ručno pletene čarape, boja, motiv, provincija Agri, Turska.

1. INTRODUCTION

The English word “culture” is derived from the Latin term “cult or cultus” meaning tilling or cultivating or refining and worship. In sum, it means cultivating and refining a thing to such an extent that its end product evokes our admiration and respect [1]. From the eighteenth century onwards, this sense of culture as cultivation was particularly associated with the spiritual and moral progress of humanity [2]. Moreover, anthropology, as an academic discipline, became established in the early years of the twentieth century, with its sub-branch of cultural anthropology generally understood to be “the comparative study of preliterate people”, in which culture is defined as the whole way of life of a particular society [3]. As a result, by the twentieth century, there were three broad categories of definition in general usage. Williams identifies these as follows:

- a general process of intellectual, spiritual and aesthetic development
- a particular way of life, whether of a people, a period, a group or humanity in general
- the works and practices of intellectual and especially artistic activity [4]

Culture is a way of life with its structure that changes and develops in every period along with the thoughts, beliefs and values of the society. In this context, people's attitudes in all areas of life such as clothing, eating, drinking, communication, respect, love, belief, tradition and customs embody culture. It can be explained as the reflection of one's feelings and thoughts into life [5]. To a general understanding, the word culture covers “all the material and spiritual values created in the process of historical and social development,



and the whole of the tools used in creating and transmitting them to the next generations, showing the extent of domination of man and his natural social environment" [6]. Aman states that culture constitutes one of the important subjects of sociology and social anthropology [7].

Crafts carry the spirit and traditions of a culture, transforming raw materials into expressions of identity and history. Handicrafts are the most vivid and meaningful documents that form the cultural infrastructure of a society, that connects generations, enriches human's collective experience, and nurtures the continuity of human creativity. As culture brings crafts to life, these creations preserve and celebrate the diverse stories and practices that define people.

One of the oldest handicrafts in Turkey is hand-knitting as in other cultures and communities. In almost every region of Anatolia the purpose of hand-knitting socks continues to be similar to the past. For example, it is seen that young girls knit as dowry items, gifts, decorations, accessories, or just as a piece of ordinary clothing which will protect them from cold. As for the hand-knitting techniques, which are found to be similar to those of the past, knitting starts from the toe with five needles or double needles. Wool yarn or mostly orlon¹ yarn is used as the traditional sock materials. However, through the time domain, the researchers witness a very drastic change in the colours and motifs of the handicraft's items. The artisan handcrafters are no longer knitting and young people on the other hand, prefer buying machine-produced socks. The result happens to be the loss of traditional motifs and compositions as in any other handicraft.

This case is about the hand-knitted socks collected during a field-visit in the Ağrı province. With a broader perspective, this research report aims to catalogue 22 hand-knitted socks as the findings of a field research and determine the colour and motif features made in Ağrı province in the Eastern Anatolia region. The results of the research shall later be used for the construction of a knitted textile collection.

2. HAND-KNITTING TRADITION

Here we shall look through the historical examples of handknitting. One of the known examples of old socks is a children's sock found in a sinkhole in the town of Sheikh Ibada, in the old Antinoöpolis or Antinöe, south of Oxyrhynchus, on the right bank of the Nile, and preserved at the Jevry Wall Museum in Leicester. The socks, with a 12 cm sole, were made with strips of different sizes in blue, red, violet and green colours. These socks were made in the 3rd to 5th century (AD200-400) and were excavated in Egypt at the end of the 19th century (Fig.1). They have a nipped toe and are designed to accommodate a sandal [8]. Three knitting fragments of the oldest sock sample, found in Dura Europos on the banks of the Euphrates River, are today at Yale University (Fig.2). The Yale University Art Gallery dates the fragment to c. AD 200-256 [9]. In London's Victoria and Albert Museum, there are pairs of plain cotton socks, one brown-purple and the other red, dating back to the 4th and 5th centuries, unearthed from Coptic tombs [10]. The technique used for making these

¹ orlon specifically, is an acrylic fiber, known for its wool-like feel, warmth, and resistance to moths, oils, and chemicals. It is commonly used in clothing, blankets, and other textiles orlon yarn

socks are commonly confused with knitting. They were made in the technique nâlbinding, sometimes called knotless netting or single needle knitting - a technique closer to sewing than knitting (Fig.3). These socks were made using three-ply wool [10]. An example showing that the Anatolian Turkish knitting art existed in the previous period is the embroidered felt socks unearthed from Pazyryk kurgans [11].

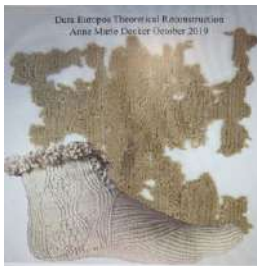


Figure 1:(left) Egyptian child's sock AD 200-400, Sheikh Ibada, Egypt [8]

Figure 2:(middle)Patterned fragment from Dura-Europos, AD 200-256 ,Syria [9]

Figure 3:(right) Pair of socks, AD 250-420, Egypt [10]

In all times, cultures and civilizations of the world, handmade products have always had a special and distinctive character, it being not only formalistic, but also aesthetic. Suffice it to compare one amphora of the Mycenaean period with an equivalent one of the Minoan periods or another of the Etruscans or the Incas, to realize the magnitude of their cultural specificity [12]. Just as in other places, Anatolian handicrafts intertwined with the traditions and customs of long years of civilization, carry culturally fragile elements from past to present with rich techniques and diversity. The sacred land Anatolia, the cradle of many civilizations, covers many crafting traditions as clothing, kitchen tools, dowry items, carpets, rugs, socks, booties, jewellery works, pottery, or wooden products. These products, which people use daily from past to present, reflect the experience and knowledge accumulated over a long period of time, and carry historical values within themselves, ensuring cultural continuity. In this sense, it can be said that handicrafts are a part of life with their production and have a great value in terms of cultural history. However, handicraft production has always been vulnerable to the financial crisis caused by Industrialization. Particularly in sectors like weaving, shoemaking, tanning and felt-making, artisans were suffering from downsizing in their businesses through an increase in mass produced and imported equivalents of their products which were cheaper in price and more appealing aesthetically [13]. The fragility of handicrafts is due to the loss of these arts over time, especially with the changing culture of life due to urbanization and the development of technology.

Especially important in the formation and dissemination of the aesthetic and technical standards as well as in the encouragement of the new crafts movements was the upgraded role of the folk, craft and decorative arts museums which inspired many individuals to revive the craft ideal of the past [14]. Both as a folk art and traditional art, knitting is as old as human history and is used in the production of clothing, household goods, needs and



ornaments, maintains its importance today, as in the past. Knitting can be done anytime, anywhere because the material is easy to obtain and is portable. Handknitting is not only a method to produce clothing and accessories, but also a tool to reflect the feelings and thoughts of Anatolian women. In hand knitting, crochet hooks, shuttles, hairpins, and needles are used as tools. Art elements colour, texture, pattern, proportion, composition, form and harmony are employed to form aesthetics in colour, form, and composition. The motifs on traditional hand-knitted socks or booties have special richness. The researchers conclude that motifs are used as a language of emotion and communication through the symbols of shared culture, religion and tradition.

3. ETHNOGRAPHY AS A METHOD

Ethnography, which is a scientific explanation effort, is based on a qualitative idea to understand and describe a group of people or a group's culture [15]. Ethnography is a qualitative research method used to study cultures and communities through direct observation, participation, and in-depth interviews. The daily lives of participants, the rituals, beliefs, interactions, or responses on occasions and concepts are all subject to the researchers' interest. This method aims to provide a detailed and nuanced portrayal of the group being studied, capturing the complexities of their real experiences and the meanings they attach to their behaviours and artifacts. Tavory and Timmermans argue that, in essence, there are only two research strategies available to ethnographers – grounded theory and the extended case method [16]. Atkinson explains that craft, art, and performance applies equally to the conduct of ethnographic research. He defines ethnography as a creative work, dependent on improvisation that is in turn dependent on repetitive, disciplined work. Atkinson concludes as follows:

The creative processes are dependent on that work: on careful, methodical, and repetitive activities. But such work is never mechanical. It does not depend just on the precise replication of formulaic procedures. It depends on a creative, improvisatory engagement with several things. Like the craft worker, the ethnographer engages directly with her or his materials, physically and imaginatively. Embodied skills and educated eyes – the gaze of the craft – interact. Aesthetic and intellectual imaginations, traditions, and innovations interact in the craft of ethnography, just as they do in the ethnography of craft [17].

The craft tradition in Anatolia, which includes textiles, knitting and weaving, pottery, metalwork, woodworking, and stone carving, is frequently the subject of ethnographic research in an academic context. Ethnography with a deeper understanding of culture, accept hand-knitted items not as mere garments worn on the body, but as non-verbal communication tools conveying the region, social life, feelings, and thoughts of the knitter through the colours, compositions and motifs. However, when it is not possible to delve into the symbolism of the artifacts for a socially grounded theory, extended case studies shall suffice to search, observe, and define historical, cultural items, products or traditions. Then the findings can be used as inspiration sources for the textile designer willing to design culturally significant collections. Even without much grounded expectation, benefit from the findings of ethnographic research as a cultural context is more than satisfactory.



Since each field research provides varied findings like a valuable database of motifs and their compositions from region to region, researcher shall witness wit and taste of the artisan hand-knitters. And it shall be the contemporary textile designer who will be influenced or inspired from them. Hand-knitting socks is a general handicraft that integrates with the lifestyle of individuals, especially women, living in Ağrı province. The local people of Ağrı province and its surroundings, whose history dates back to ancient times, earn their living from agriculture and animal husbandry, have effective practices in traditional handicrafts, especially hand knitting.

This research is a qualitative case study conducted in an ethnographic pattern. The population of the research consists of traditional sock knitting products of Ağrı province, written and verbal sources about them. The research sample consists of a total of 22 sock samples accessed in 4 different places. Research data was collected through literature review, visual analysis, mechanical observation and semi-structured interview techniques. To achieve the purpose of the research, field research was conducted in Ağrı province (Central District, Yazılı Village, Yoncalı Village and Eskiharman Village). Motif details and motif features of the socks examined are presented as research findings.

4. FINDINGS

In the research conducted by G. R. Batmaz in 1998 in Ağrı Centre and three villages, it was determined that the socks examined were handknitted between 1975 and 1998. The researcher has interviewed eight informants in four places for the study. Most of the socks (16 out of 22) were found in Ağrı Yoncalı Village. Socks knitted in the region, presented in Fig.4, are generally made using coloured plain knitting and patterned plain knitting techniques for dowry and daily use purposes. Wool and orlon yarns are used as materials. As a tool, socks were knitted with five needles and were generally knee pads (dizlik), knee patches (dizleme), women's socks, sports socks and men's socks in the region.

Colour and Motif Characteristics of Socks Identified in Ağrı Province

The two most important elements of these handknitted socks are colours and motifs used. The colours of the socks examined within the scope of the study are presented in Table 1. When Table 1 is examined, it is seen that the colours used in hand-knitted socks are black (%28.6) followed by white (%15.9) and red (%15.9) respectively; cream (%9.5); blue (%7.9); yellow, green and light green (%4.8); It was determined that brown and purple colours followed (%3.2).



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Figure 4: The socks found in the Ağrı province

towards abstraction and tends towards the abstract within its own structure. The most basic shapes in nature are triangle, square and circle. Circle has been accepted as the strongest form as the expression of the infinite in almost every society. It has been the basis of universe order and unity and centralism in the universe.

Table 2: Motifs used on the handknitted socks

Samples	Types of motifs used				
	Geometric	Floral/ vegetal	Figurative	Symbolic	With objects
1	lines, chevron, diagonal, rhombus	flower			lightbulb
2	lines, chevron, diagonal, triangle		ram's horn	hook	
3	lines	vetch			
4	lines, diagonal, triangle, rhombus		ram's horn		
5	lines, diagonal		ram's horn		
6	lines, diagonal			hook	
7	lines, diagonal		ram's horn		
8	lines	flower		eye	
9	lines, parallelogram	flower			
10	lines, diagonal, rhombus, square			hook	
11	lines, square	flower	ram's horn	eye	
12	lines, diagonal, square			hook	
13	lines		ram's horn		
14	lines, diagonal	flower	ram's horn		
15	lines, diagonal, square, chevron, triangle			hook	
16	lines, diagonal, rhombus	vetch			
17	lines, diagonal, rhombus, triangle	vetch	ram's horn		
18	diagonal, rhombus, triangle				
19	lines, rhombus	vetch			
20	lines, rhombus			hook	
21	lines, square			hook	
22	diagonal, rhombus			hook, star	

It has been understood that in Turkish art, geometric patterns and simple forms such as triangles, squares, rectangles, circles, diamonds (rhombus) and stars symbolize the infinity of the universe in meaning [20]. Combinations of lines and diagonal lines were used extensively in the hand-knitted socks examined in the study. It was determined that stripes and diagonal stripes were mostly used on the motif edges and heel part of the hand-knitted socks examined.

Floral/Vegetal Decorations: Flowers, leaves, fruits, branches and trees, which are one of the basic elements of Turkish Decorative Arts, are widely used in their natural shapes or stylized, alone or together with other ornamental motifs. In the hand-knitted socks examined, it was determined that stylized floral motifs and the vegetal motif, which symbolizes protection from the evil eye and abundance were used [20].

Figurative Decorations: Figurative decorations can be classified as animal-derived and human-origin. Decorations of animal origin; ram's horn, wolf's mouth, wolf's mark, beast's foot, scorpion motif, bird motif. Human-origin figural decorations are eye, hand, finger and comb motifs. It was determined that the ram's horn motif was used in the hand-knitted

socks examined within the scope of the study. The ram's horn motif is used in the front, side and top view of the ram, stylized with shapes such as spirals and crescents [21].

Symbolic Decorations: These are motifs that represent an idea based on abstract meaning, used to depict any element [22]. It was determined that the hook motif was used in the hand-knitted socks examined within the scope of the study. Hook: It was used with the desire to eliminate the effect of the evil eye and was used as a bridge between feminine and masculine concepts. It expresses opposite concepts such as man-woman, mountain-valley, sea-wave and wind-water [23]. It is also related to marriage and fertility. This motif consists of geometrically stylizing the "S" shape in vertical and horizontal positions in weavings. This motif, which is used on the floors of rugs to protect against the evil eye, has different names in Anatolia such as "lighter", "crooked trout", "little black fish" [24].



Figure 5: Examples of geometric decorations found on the socks



Figure 6: Examples of floral/vegetal decorations found on the socks



Figure 7: Examples of Ram's horn decorations found on the socks



Figure 8: Examples of eye and hook decorations found on the socks



Figure 9: Examples of bulb motif decorations found on the socks

Decorations with objects: These are decorations consisting of depicted shapes of items such as medallions, vases, and rosettes [25]. It was determined that the motif called Lightbulb, which is frequently encountered in Eastern Anatolian hand socks, was used as object decoration in the hand-knitted socks examined.

5. CONCLUSION

There is no doubt that the craft has been always a genuine poetic element, a precursor for the message of progress and reform power that design has induced during the Industrial Revolution, it being for centuries an intimate, traditional way of producing utilitarian objects in such domains as pottery, jewellery, furniture, construction, textiles, metalwork, even bookbinding and the manufacture of toys [14].

According to the above, this paper aims at supporting the strong relationship between craft and ethnographic research by documenting it with the use of both traditional examples of handknitted socks and the identification of their common elements. Motifs used in traditional textiles play an important role in reflecting Turkish culture and identity and transferring it from generation to generation. In this context, 22 socks knitted in Ağrı were examined and the motifs used on the socks were determined. The motifs of hand-knitted socks, which are generally knitted for daily use and dowry, are stripes, diagonal stripes, cleats and hooks; It was concluded that black and white were preferred as colours. Nowadays, with the development of technology, the motifs in the products traditionally made in the regions have become more important, especially for use in culturally based textile products. For this reason, it is important to document and introduce the motifs that reflect our cultural identity to future generations.

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DIGITAL TOOLS FOR DESIGN AND MANUFACTURING OF FOOTWEAR PARTS AS HEELS

Original scientific paper
DOI: 10.5937/CT_ITI24034S

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ABSTRACT: Digital tools are implemented in various steps, such as production, merchandising, retailing, and customer service. Their implementation includes the fashion industry where product development such as garments, heels, jewelry, and accessories, is essential within all steps of production. Starting with the concept of creating 3D models, simulating, and direct digital manufacturing, including complex geometry, depicts the advantages of these technologies in the fashion industry. Reducing time, waste, and the advantages of creating, visualizing, and evaluating products at the early stages of product creation improves the process of product development. In this paper we present a methodology to implement these digital tools for design and manufacturing of shoe parts as heels. Due to the important role that heels play in shoe stability, an attempt to create heel shapes by inspirations taken from solid geometries is presented. To complete the whole design of these models the same shapes are used to create the upper part of the sandals. The methodology presents accurate and convenient manufacturing of footwear products based on product customization. Moreover, it shows a sustainable way of manufacturing footwear products.

Keywords: 3D modeling, heels, accessories, simulation, 3D printing.

**DIGITALNI ALATI ZA DIZAJN I PROIZVODNJU DELOVA
OBUĆE SA POTPETICOM**

Savez inženjera i tehničara tekstilaca Srbije



APSTRAKT: Digitalni alati se implementiraju u različitim koracima kao što su proizvodnja, merchandising, maloprodaja i korisnička podrška. Njihova implementacija uključuje modnu industriju u kojoj je razvoj proizvoda kao što su odeća, potpetice, nakit i dodaci neophodan u svim fazama proizvodnje. Polazeći od koncepta kreiranja 3D modela, simulacije i direktne digitalne proizvodnje, uključujući složenu geometriju, oslikava prednosti ovih tehnologija u modnoj industriji. Smanjenje vremena, gubitka i prednosti kreiranja, vizuelizacije i evaluacije proizvoda u ranim fazama kreiranja proizvoda poboljšava proces razvoja proizvoda. U ovom radu predstavljamo metodologiju za implementaciju ovih digitalnih alata za projektovanje i proizvodnju delova cipela kao potpetica. Zbog važne uloge koju potpetice igraju u stabilnosti cipela, predstavljen je pokušaj kreiranja oblika potpetice inspiracijom preuzetim iz čvrste geometrije. Da bi se kompletirao dizajn ovih modela, isti oblici se koriste za kreiranje gornjeg dela sandala. Metodologija predstavlja tačnu i praktičnu proizvodnju obuće zasnovanu na prilagođavanju proizvoda. Štaviše, pokazuje održiv način proizvodnje obuće.

Ključne reči: D modeliranje, potpetice, dodaci, simulacija, 3D štampa.

1. INTRODUCTION

Footwear products are a necessity for human beings. Their function is not only related to offering consumers protection and comfort but also to the aesthetic side. There are three most important factors in purchasing decision as “price”, “brand” and “product design and style” [1], where the last one is linked with long-term use [2]. Studies reveal that fit and comfort of footwear products are of great importance to improve gait performance [3], and reducing fear of falling [4]. Moreover, well-fitted, lightweight shoes with soft midsoles and curved rocker-soles are generally perceived to be most comfortable [5]. This would reduce the different problems created with ill-fitted footwear. Evidence results that 63 to 72% wearing in appropriately sized footwear based on length and width measurements [6], are associated with various foot pains as reduced mobility according to target group [7]. In addition, these findings try to attract consumers’ attention and make them more conscious about their buying decision and in the meantime provide evidence to companies and shoe pattern makers to use these data to improve their product. These products are also constantly changing in terms of their design and the materials used for production.

Shoe modelling is a complex process that requires advanced knowledge of the human foot, which is a very complex shape. All the parts of the foot work together to offer the body support and mobility. Also, heels are an important part of the shoes and used especially for women’s shoes. Usually, heels are designed based on some basic styles by making variations. However, designers try to create heels based on different shapes. Cases were presented and even implemented for heel models. However, the shoe pattern maker tries to approve them based on some important requirements that every heel model should fulfil. For heel designing the top surface should be the same as the outsole.

This paper is organized as follows: Section 2 continues with a literature review of digital tools for heel designing and production. Section 3 gives a detailed description of the a



methodolgy used to model and produce new heel models. Following the methodolgy Section 4 presents results of heel models designed and produced though digital tools. Moreover product assembly in a footwear company. At the end the conclusions of this work are presented.

2. DIGITAL TOOLS FOR FOOTWEAR PRODUCTS

Shoes are garments worn by feet but with high requirements compared to other items. Shoes design and production are based on the 3D shapes of the last, which is the main part of the shoe modelling process and anatomically, the converted shape of our feet. Sizing systems used for footwear production are based on anthropometric data taken from anthropometric studies. Even though they try to accommodate all foot sizes regarding length, width and girths, there are still problems that lead to ill-fitted footwear. This is related to foot shapes which are different. As a result, companies try to offer consumers personalized products.

Advanced technologies such as 3D foot scanning systems offer the possibility of taking digital information of the foot, and further elaboration of the 3D foot model aligned with a standard shape of the last, a new last model personalized according to customer's foot is created. Furthermore, the custom last is used for shoe modelling. Nowadays, designers have the necessary tools and capabilities to create more efficient and customized designs [8]. It is evident that integration of digital transformations can strongly drive waste reduction to support sustainable production [9]. Up to 80% of a product's environmental impacts can be determined at the design phase [10]. CAD designers can integrate design simulation in their projects. Known as the heart of Industry 4.0 and the main driver of it [11], simulation is a process that tries to mimic the product or the system to evaluate, avoid mistakes, reduce labour costs and material waste by improving it at the first steps of designing. The simulation process is found for product process, including assembly lines where an increase of the production can result [12]. In the footwear digital prototyping can significantly contribute to environmental and economic sustainability [13].

Here we present the cases of shoe customization through heel models. Heel models differ from the shoe models and designers present a wide range of them, from the normal shapes to the strangest ones. It is well-known fact that high heels are attractive but the problems are created with the distribution of foot pressure and displacement of the centre of pressure [14] by leading to discomfort [15] and evidence shows that pathological alternations are found even in younger users [16]. To keep both fashion and comfort researchers have developed an adjustable heel with low and high height. The results taken from 3D finite element analyses depict the higher stress in the soft tissue related to high heel height [17]. The methodology developed based on synergies existing between parametric designs, design optimization, and additive manufacturing presented as a case for heel modelling applicable from an ergonomic and mass customization point of view [18]. A study presented to design high-heeled shoes exploits the synergies between modeling and experiments to improve and optimize the shoe design process [19].

Taking inspirations from nature approach help designers to create various fashion products [20]. Even heel models are items that express individuality and, in the same time should fill the requirements to withstand body weight. Bearing in mind the weight of customer and material selection according to the manufacturing technology chosen for heel production, 3D heels models have undergone structural simulations and topological optimization.

This study evaluates or analyses the 3D modeling, simulation, and 3D printing for fashion products as heels of the shoes. Three heel models are designed based on various geometries.

3. METHODOLOGY

The methodology followed in this work includes 3D modeling and 3D printing of heel models. Figure 1 depicts the main steps from 3D modeling to additive manufacturing of footwear products.



Figure 1: From 3D modeling to additive manufacturing of footwear products.

The shoe's last shape is designed based on the anthropometric parameters of the foot, and the heel shape is directly related to the last which is the support of the foot in high-heeled shoes. When lifting onto a heel, the foot is in an unnatural position, which causes a change in the relative position of the bones of the foot [21] and a redistribution of the load. Figure 2 depicts an x-ray showing the anatomical position of foot structures in a high-heeled shoe. To ensure the stability and normal functioning of the heeled structure, we need to consider the main parameters that must be taken into account during the design. When standing on a heel, body weight is distributed between the metatarsal-toe area and the center of the heel.

Proper design of the heel is especially important since it accounts for a significant portion of the total body weight.

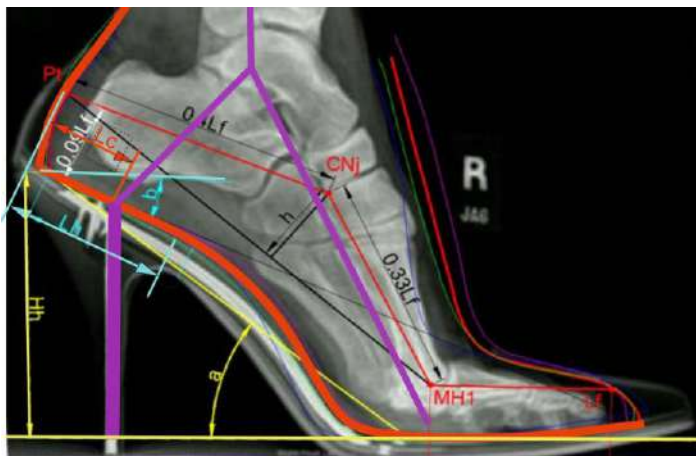


Figure 2: x-ray of the foot wearing high heels

The top surface of the heel depends on the shape of the heel area of the shoe's last bottom surface. The most important design parameters for a stable heel structure are the wedge angle (the angle of the top surface of the heel) and the location of the vertical axis of the heel. The heel axis should be located under the center of the heel, that is, at a distance $L_c = (0.16 \div 0.18) L_f$ (L_f - foot length, mm) from the Pternion point. While the wedge angle depends on the height of the heel $\text{WedgeAngle} = 0.25H_h - 2$. Figure 3 depicts shoe last measurements with a high heel.

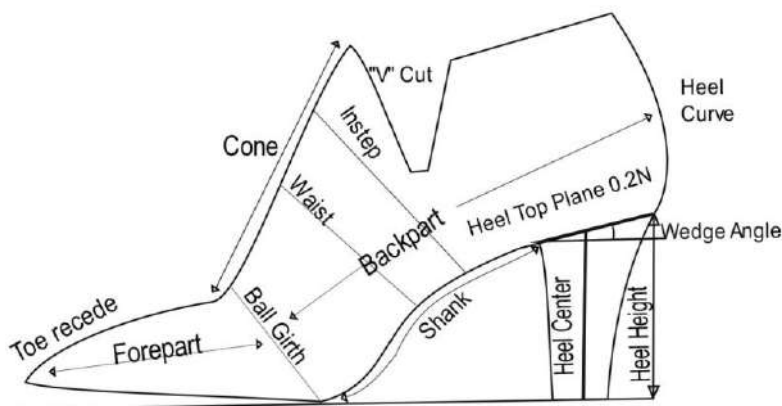


Figure 3: The high heel shoe last measurements

To design the shape of a heel for 3D printing, several methods can be used:

- 1) Solid modeling based on functions of extrusion and rotation of designed projections with next application of Boolean operations of subtraction and intersection
- 2) Solid modeling based on a set of flat horizontal sections

- 3) Surface modeling, during which the side, top, front and bottom surfaces of the heel are designed, which form a closed 3D body
- 4) Solid modeling using simple geometric bodies, Archimedean solids, etc. - for fantasy heel shapes.

In the current work, the software used for 3D modelling shoes is ShoeMaker 2015 R2. The software for heel shape design – is PowerShape. The 3D heel models were converted to STL file for next preparing in slicer software Ultimaker Cura 4.5 for 3D printing. Heel production is realized on a FFD 3D printer GEEETECH A30 3D and the material used is PLA. Table 1 depicts the main parameters used for 3D printing.

Table 1: The main 3D printing parameters

3D printing parameters	Value
Material	PLA(Polyactic acid)
Layer thickness	0.2 mm
Bed temperature	60°C
Nozzle temperature	220°C

4. RESULTS

4.1. Heel designing and manufacturing through additive manufacturing

In recent years, we have often seen unusual fantasy heel shapes on fashion catwalks, which have expressive plasticity based on complex 3D shapes. In fact, the shape of the heel is the freest spatial element of the shoe, which has limited parameters only in the top part, attached to the shoe last. In this work, at first, we attempted to customize the bottom of the shoe using different heel shapes, modeled based on the same parameters of the heel part of the last and half-insoles. Heel shapes can be designed using solid or surface modeling functions.

Inspirations taken from solid geometries are implemented for shoe heel designing. First, the last model is modified according to heel height and the standard heel is used as a base for the new heel models. Heel height is personalized with the value of 10.5 cm and the modified last is then 3D printed, which can be further used for shoe production. All models are based on the 3D cube solid geometry at the lower and upper parts of the heel. In the middle of all models are included the Archimedean solids which are well-known for having a very high symmetry. The solids of Icosahedron and Rhombicuboctahedron models are included in the heel models. Figure 4 presents the view in the front side, side view and 3D view of both heel models. Moreover, these models are produced with an FDM printer with PLA material. Produced models arranged with the personalized last according to heel height are also presented in Figure 4.

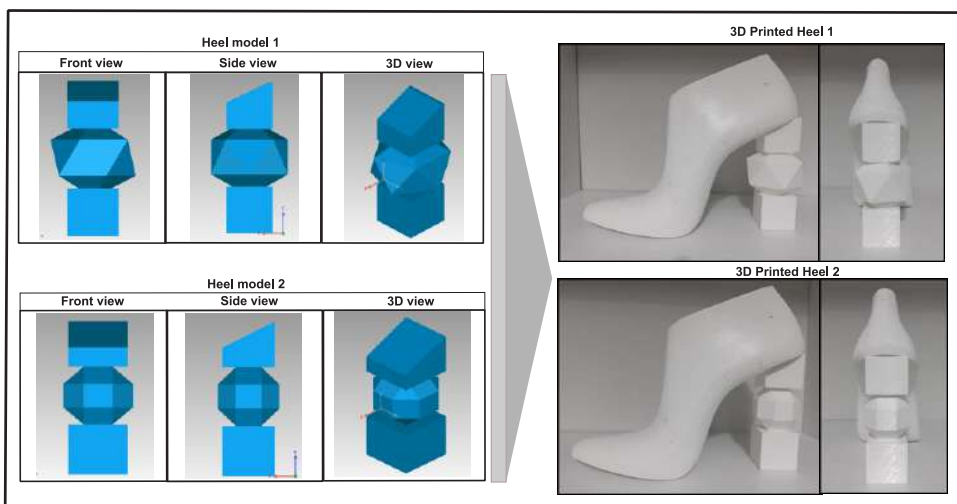


Figure 4: 3D heel models in front, side, and 3D view, modelled and produced in 3D using solid modelling.

4.2. Sandals manufacturing

Based on heel models and 3D printed last, the following step includes footwear production. In this work three different sandal models are selected, where the upper part is modeled by considering the same geometric models of the heel on the 3D modeling software ShoeMaker 2015 R2. Figure 5 depicts 3D models of numbers 0 and 1 merged, where the upper part or heel seat is from the standard heel (22).

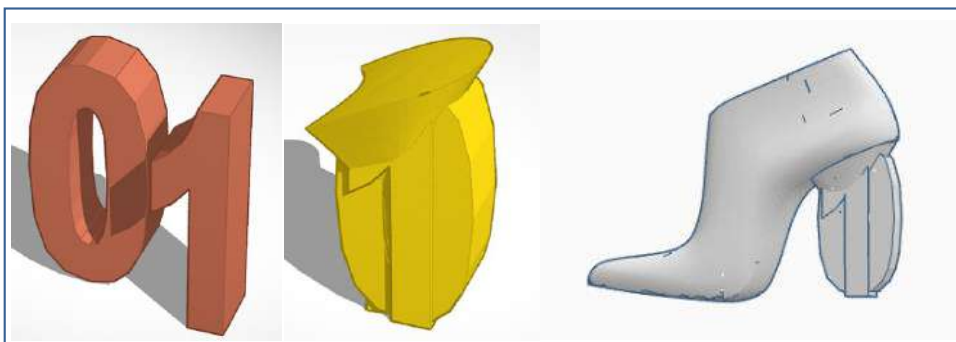


Figure 5: New 3D heel model: left) 3D models of numbers 0 and 1; center) new heel model and right) last and the new heel model.

From Figure 6 is evident that the upper part of the sandal is modeled based on the heel geometry where are visible 0 and 1. This is a semi-finished product where the assembly with the sole part must be taken.



Figure 6: Different views of sandal model 1 during production process over 3D printed last.

Following, Figures 7 and 8 depict the other two sandal models during the production process. Even here, the upper parts are modeled based on heel geometries, such as the solids of Icosahedron and Rhombicuboctahedron models.



Figure 7: Different views of sandal model 2 during production process over 3D printed last.



Figure 8: Different views of sandal model 3 during production process over 3D printed last.

5. CONCLUSION

The work presented here brings back case studies from the fashion industry on the use of digital tools. The key study presented here depicts the importance of implementing these digital tools in the modelling and production of these models. Product customization presents the benefits in terms of time and material waste management. This workflow can be used by different companies that would like to offer customized products.

As part of future work, the authors intend to focus on utilizing parametric design tools to create personalized footwear products as the sole, based on foot pressure maps. By employing appropriate design software and leveraging modern technological tools, it is possible to develop customized products tailored to the preferences and needs of individual users. Additionally, conducting research to select suitable materials can further optimize the final product, ensuring it meets the highest standards of quality and functionality.

Acknowledgment: The authors would like to thank the footwear company “**Caterina Firenze**” located in Berat, Albania, for their support in the realization of these sandal models.

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COMBINING COMPUTATIONAL DESIGN AND BIOMIMETICS: A CASE STUDY

Original scientific paper
DOI: 10.5937/CT_ITI24035L

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ABSTRACT: Designers receive a great deal of inspiration from nature thus offering opportunities for unusual product concept development. These concepts together with technological tools i.e. computational design, additive manufacturing, prototyping, can lead to automate the design process and shorten significantly the time to market needed. The present paper considers the inspiration from bioluminescent bacteria cultures and offers design opportunities for wearable products within the jewelry industry. More specifically, a family of earrings were designed considering both aesthetics and the unique experience that the end user receives. They include a soft circuit and, seamlessly integrated set of LEDs that emit a soft glow. A family of 3D earring models were generated using *Rhinoceros3D™* and *Grasshopper™* as the basic computational product design tools. The objective of this research was to explore the potential of integrating the technologies into fashion design, by pushing boundaries and exploring new possibilities. The interdisciplinary approach blurs the conventional distinction between style and function. Finally, it offers insight into the future of wearable technology and its implications for the accessories related industry.

Keywords: E-textile earrings, Biomimetic, Computational design, Wearables.

KOMBINOVANJE RAČUNARSKOG DIZAJNA I BIOMIMETIKE: STUDIJA SLUČAJA

ABSTRACT: Dizajneri dobijaju veliku inspiraciju iz prirode i tako nude mogućnosti za razvoj neobičnog koncepta proizvoda. Ovi koncepti zajedno sa tehnološkim alatima, kao što su računarski dizajn, aditivna proizvodnja, izrada prototipa, mogu dovesti do automatizacije procesa projektovanja i značajno skratiti vreme potrebno za izlazak na tržište. Ovaj rad uzima u obzir inspiraciju iz bioluminiscentnih kultura bakterija i nudi mogućnosti dizajna za nosive proizvode u industriji nakita. Tačnije, porodica minđuša je

dizajnirana uzimajući u obzir i estetiku i jedinstveno iskustvo koje dobija krajnji korisnik. Uključuju meko kolo i besprekorno integrisani set LED dioda koje emituju meki sjaj. Porodica 3D modela minđuša je generisana korišćenjem Rhinoceros3D™ i Grasshopper™ kao osnovnih računarskih alata za dizajn proizvoda. Cilj ovog projekta bio je da se istraži potencijal integracije pomenutih tehnologija u modni dizajn, pomeranjem granica i istraživanjem novih mogućnosti. Interdisciplinarni pristup zamagľjuje konvencionalnu razliku između stila i funkcije. Konačno, nudi uvid u budućnost nosive tehnologije i njene implikacije na industriju povezane opreme.

Keywords: E-tekstilne minđuše, biomimetika, računarski dizajn, nosivi.

1. INTRODUCTION

Biomimetic design, is a powerful tool for designing novel and innovative solutions in a variety of fields. It has been said that nature is the world's best designer, and biomimetic design aids in harnessing that power to create aesthetically pleasing and highly functional products [1]. For example, Morphotex™ is another biomimetic innovation. Teijin researchers noticed that color in plants and animals can be achieved using two different mechanisms: pigment and structural coloration. They developed a fiber composed of 61 alternating layers of polyester and nylon, that can produce basic colors like red, blue, and green without the use of pigments. The fiber's design was based on the wing design of the South American Morpho butterfly [2].

E-textiles (electronic textiles) are fabrics with electronic counterparts and electrical interconnects knitted into them, providing flexibility, stretchability, and a particular length scale that are not possible with other electronic manufacturing processes now available. Other technologies used in e-textile integration, include sewing, embroidery, and even single fiber-based manufacturing [3]. Fashionable wearables enable new forms of self-expression while being accessible to the general public. The incorporation of technology into fashion has transformed how we interact with our clothing, blurring the distinction between style and function [4]. One way to create textile-based electronic devices that avoid poor mechanical qualities and maintain long-term stability is to weave fiber-shaped electronics into commercial fabrics [5].

Another design tool that has caused a lot of change and innovation in the design process is computational design tools, such as Rhinoceros3D™ and Grasshopper™. With tools like these, complex tasks, such as the generation of intricate patterns in nature according to a set of parameters, are now automated [6, 7, 8]. The importance of computational design tools in the product development cannot be overstated. Rhinoceros3D™ and Grasshopper™ are two sophisticated tools that have transformed the design landscape. The ability they have to quickly generate and modify complex geometries makes them ideal for biomimetic design, where natural forms and patterns can be accurate [9].

The present paper explores the integration of biomimetic inspiration and computational design in the development of a family of e-textile based earrings that combine both aesthetics and the unique experience that the end user receives. They include a soft circuit and a integrated set of LEDs. The objective of this research was to explore the potential of

integrating these technologies into fashion design by pushing boundaries and exploring new possibilities. Finally, it offers insight into the future of wearable technology and its implications for the fashion related accessory industry. A thorough review of these three key areas can aid in the contextualization of this paper within the broader trends and innovations in the textile industry. Biomimicry offers a substantial source of inspiration; e-textiles and wearable technology provide the functional framework; and computational design tools enable the realization of parametric designs.

2. PROPOSED METHODOLOGY

Fig. 1 depicts the workflow that was followed and the tools that were used. The objective was to design a set of earrings that were e-textile based but also inspired by biomimetic on a 2D level. The process began with extensive research about the applications of e-textiles, specifically in the fashion industry. The microcosm of bacteria was explored to determine the source of inspiration for the product to be designed. After identifying bioluminescence as a unique and intriguing concept, understanding the mechanisms behind it in bacteria was next. This level of understanding was important in translating natural phenomena into wearable technology.

The design process was structured into several key stages. During the conceptual sketching phase, more than one type of wearable product was considered (e.g., footwear, clothing, different types of jewelry, etc.). However, in the end, it was determined that the solution that was going to be developed in this case study was a pair of earrings. Drafts were created to conceptualize the shape and form of the earrings (fig. 2). These sketches served as a foundation and reference for further development in Rhinoceros3D™, where the 3D models were constructed.

Based on the initial idea a computer aided design based algorithm was built. The parameters include the thickness of the top module, the connective hoop between the two modules, and the diameters of each module, among others. The parameters that affect the geometry of the earrings are few and simplistic, but by setting different values, a family of earrings with different proportions can be generated in an automated way (Fig. 3).

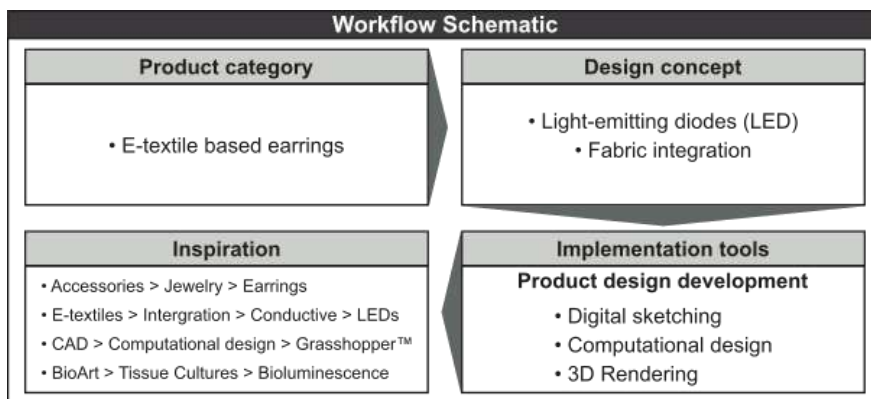


Figure 1: E-textile earrings design workflow schematic

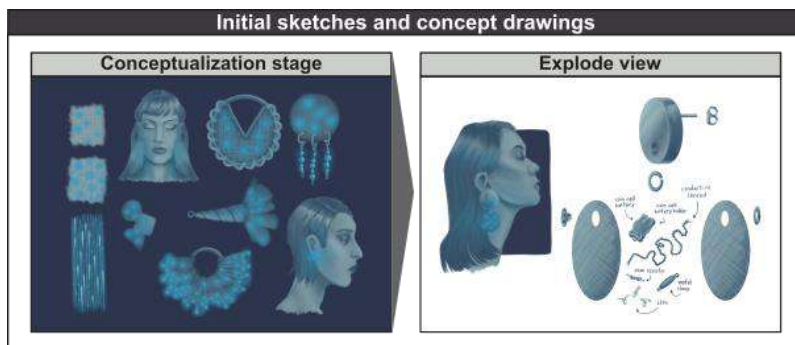


Figure 2: Initial sketches of form exploration and the parts of the earrings

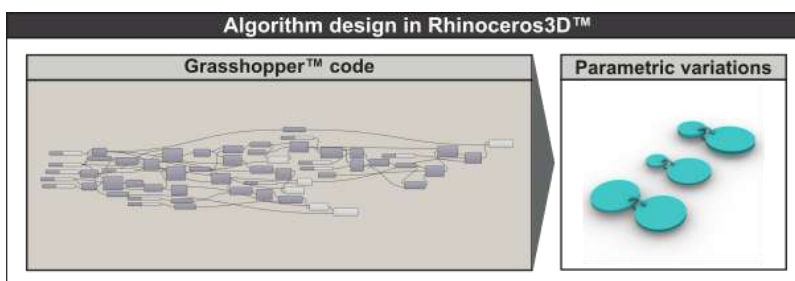


Figure 3: Algorithm design in Rhinoceros3D™ achieving parametric variations

The final 3D renders of the e-textile earrings were produced using Blender™, a powerful open-source 3D modeling and rendering software. These renders were essential for visualizing the intricate details and aesthetic qualities of the designs. The completed designs of the e-textile earrings are shown in figure 4a, which draws attention to the LEDs by displaying the light diffusion effects that show the LEDs' gentle glow. This isolated view allows for a closer examination of the e-textile based earrings with an aim to provide a realistic representation of how the earrings would appear, when in use. Figure 4b shows how the earrings are modeled on a 3D female figure. This aids in contextualizing the size, fit, and overall appearance of the earrings, providing insights into how they interact with the wearer's features, and enhancing the user experience.

Prototyping serves as a vital step in the design process, enabling designers to translate digital models into tangible products. Visualization through prototyping also provides an opportunity to assess the integration of electronic components within the physical design. Prototypes can be used to test the placement and performance of LEDs, ensuring that they emit the desired glow and are securely embedded within the structure of the earrings. Additionally, this allows for evaluation of user interaction and comfort, which is critical for wearable products. Here, prototyping methodologies and technologies were used to depict what the finished product appearance is (fig. 4c).

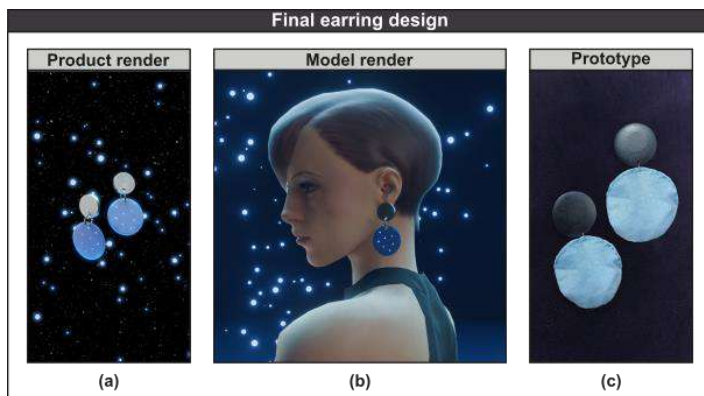


Figure 4: Realistic 3D depictions of the e-textile based earrings

Table 1 provides details that outline the materials used in the development of the e-textile earrings, including their properties and purposes.

Table 1: Table of materials

Materials	Properties	Purpose
Earring backings	Hypoallergenic, secure, light	Secure attachment to the ear
3D Filament	Easy to print, various colors	Creating the earring structure
Jewelers wire	Malleable, strong, various gauges	Structural support, connections
Fabric	Flexible, durable, embroidered	Base for embedding circuits
Eyelets	Metal, structural reinforcement	Aid in access to circuitry
Thread	Strong, flexible, various colors	Sewing fabric pocket
Conductive thread	Electrically conductive, flexible	Creates electrical connections
Coin battery holders	Insulating, durable, lightweight	Holds and secures the batteries
Coin cell batteries (3V)	Lightweight, consistent voltage	Power for the LEDs
220 Ohm resistors	Controlling current flow	Ensure LEDs safe operation
Metal clasps	Durable, secure, resistant	Act as the switch of the current
Needle	Sharp, durable	Used for stitching

3. CONCLUSION

This interdisciplinary approach, that combines principles of biomimetics, computational design, and e-textile technology, highlights the potential for future innovations using wearable technology. The e-textile earrings designed in this research offer a glimpse into the future of fashion accessories, where technology and aesthetics are seamlessly integrated to create unique user experiences. As the field of e-textiles continues to evolve, further research and development will likely explore new materials, advanced manufacturing techniques, and enhanced functionalities. The insights gained from this research can serve



as a foundation for future projects, driving innovation and expanding the possibilities for wearable technology in the fashion industry.

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THE COSTUME IN EGYPT AS INSPIRATION FOR THE REDESIGN OF MEN'S CONTEMPORARY CLOTHES

Professional paper
DOI: 10.5937/CT_ITI24036R

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ABSTRACT: In this paper, the look at Ancient Egypt culture and fashion in Egypt is given. By way of preface to what will be the subject of interest, a brief review of life in Egypt was made. Fashion, materials and people's culture through a new redesigned model of men's costume are presented. The model is innovative and creative for the modern fashion world through hand painted applications and their contemporary interpretation. The unbreakable connection between the contemporary and ancient fashion is also given.

Keywords: fabric, clothing, history, trends, materials.

NOŠNJA U EGIPITU KAO INSPIRACIJA ZA REDIZAJN MUŠKE SAVREMENE ODEĆE

APSTRAKT: U ovom radu dat je pogled na staroegipatsku kulturu i modu u Egiptu. Kao uvod u ono što će biti predmet interesovanja, napravljen je kratak osvrt na život u Egiptu. Moda, materijali i kultura ljudi predstavljeni su kroz novi redizajniran model muškog kostima. Model je inovativan i kreativan za savremeni modni svet kroz ručno oslikane aplikacije i njihovu savremenu interpretaciju. Takođe je data neraskinjliva veza između savremene i antičke mode.

Ključne reči: tkanina, odeća, istorija, trendovi, materijali.

1. INTRODUCTION



Fashion is a global industry that is invested in expectation what we wear and how we wish to perform to others. Fashion is not just a business, it is also a cultural and social phenomenon, steer by the desire for the new.

Fashion is always dynamic and open to change. Fashion is everywhere. It is now one of the main ways in which people present their selves to others, signaling what they want to communicate about their style, wealth, professionalism, subcultural and political allegiances, social status, even their mood. It is also a global industry with huge economic, political and cultural impact, from the impact of the catwalk on mainstream retail, to sweatshop production and celebrity branding [1].

The apparel industry is a heterogeneous entity where the design, technology and management of fashion activities are geared towards mass production, limited edition, high fashion clothing, crafts, exports and other niche segments. The design process involves multiple creative processes such as research, analysis and decision making. Throughout the entire design process, sources of inspiration play a major role in creating special and unique designs. Inspiration is considered a magical tool for all designers and can be found everywhere.

Designers in the textile and fashion industry are under constant pressure in terms of developing new design ideas where the design should be distinct and striking to keep the customer's attention. Creative ideas are elevated by experience and expertise. It is said that those who don't learn from history are doomed to repeat it [1,2, 3].

Sources of inspiration, both technically and visually, are crucial in increasing creativity in the process of design. Visualisation can be a source of inspiration. At every level of the marketplace and from every corner of the globe, the ancient costumes are inspiration for designers who can appreciate its beauty and who wish to interpret it for themselves. Designers can take a cue from ancient cultures and explore the degrees of separation that link them and any of their ideas to kindred historical counterparts [3, 4, 5].

1.1. Ancient costume in Egypt as an inspiration

Ancient early civilizations such as Egypt and Mesopotamia are characterized by a rich history, with a huge number of documents from this early period, as much as 5000 years before our era. So, today we have a lot infomations about the clothing of the ancient Egyptians, primarily on the basis of the preserved cultural heritage - numerous statuettes and wall paintings that, thanks to the extremely dry climate, have been preserved in huge numbers. The documentation available is much larger compared to other ancient civilizations, especially in terms of their preservation/good condition. Based on the preserved data, can be state that in a long period of over three thousand years, minimal changes in the costumes can be observed.

The lifestyle of an Ancient Egyptian depended on one's social class. The pharaoh and his vizier with the nobles would devote their time work to administrative tasks to maintain the kingdom. Priests played an active role in society. Religion in Egypt was a vital part of culture, and the gods were believed to take active roles in punishing and promoting the people. Keeping the gods satisfied was extremely important, and it was the role of the priests to perform the necessary rituals. They were also responsible for preparing bodies



for burial. The process of mummification gives them an opportunity to learn something more about the human body, knowledge which enabled them to become surgeons. To be a priest required extensive training, so the priests were highly respected in their society.

Scribes were responsible for housekeeping, legal matters, trade, military, and for every aspect of Egyptian life. It was very hard to become a scribe, and it required many years of dedicated work. To learn to read and write in hieroglyphics, they had to be familiar with the topics they wrote about, so they got training in religion in particular so that all records of the gods could be kept.

The Egyptian equivalent of paper was Papyrus. Papyrus was made from the reeds of the papyrus plant. The process of making papyrus was expensive and time-consuming process, scribes often take notes on ostraca, which is broken pottery pieces easy to make inexpensive.

When discussing ancient Egyptian fashion It seems most appropriate to use the word “unwrap”, which means unwrap the clothing usually made of linen used during mummification. The act of wrapping and unwrapping cloth was a significant activity in ancient Egypt, and the same item of cloth could be used and reused in numerous ways. Each time a cloth was wrapped, it gave protection in a literal or symbolic/figurative sense.

Egyptian garments were in a form of rectangular pieces of cloth that were used and worn in many different ways. On the first sight, they are simple rectangular shapes, but they look significantly different when draped over the body in a tomb or as depicted in art.

In a broadest sense we can define clothing as everything that is worn on the body, such as various garments, but also headgear, shoes, adornments, and accessories.

This definition can be narrowed and limited to the items that literally cover different parts of the human body. So, in ancient Egypt, those body covers were divided into two major groups:

1. Untailored/wraparound (kilts, skirts, and dresses, shawls and cloaks.)
2. Tailored/cut-to-shape garments (tunics, hip-cloths, loincloths, body-sashes or neck-sashes, etc.).

Additionally, the wardrobe of ancient Egyptians consists of a variety of accessories, such as belts, headbands, socks, mittens and gloves.

One of the most usual cut-to-shape garments was a tunic, a garment that was usually worn by men, women, and children. This garment was made of a rectangular piece of cloth that was folded in half and sewn on both sides. At the top of each side, an armhole was left along with a V-neck opening on top for the head. The basic pattern of tunic was sleeveless. Separate sleeves could if needed be attached to the armholes.

In the period of the so-called Old Kingdom (2700–2200 BC) characteristic clothing was schenti (Figure 1), a piece of cloth that was wrapped around the hips and was tightened at the waist with a belt. For some types of dignitaries this piece of clothing was more wrinkled and stiffer and sometimes decorated. In the period of the Old, Middle and New Kingdom, ancient Egyptian women also wore a long pleated tunic called "Kalasiris" which was transparent and underneath it could be seen the underwear that covered the hips.

Kalasiris (Figure 2) was a thin, form-fitting dress made of nearly transparent linen, and was worn by women in ancient Egypt. It was noticed in the court and among the upper class,

as well as by artisans and farmers. This dress was tight and tube-shaped, sewn together on one side to make a slim skirt that goes from the ankles and up to the chest, continues under the armpits and was held up by two straps on the shoulder, attached behind the neck, meeting in front and exposing the breasts.

The dress evolved into a simple tunic that was also worn by men, usually over the shendot. Children did not wear clothes until the period of maturity, which was around the age of 12, and at this age the boys were circumcised and their heads were shaved. Mothers were responsible for caring for the children, and fathers provided the income for the families[4, 5, 6].



Figure 1: Apperiance of Shenti
 Source: seekpng.com



Figure 2: Apperiance of Kalasiris
 Source: <https://malevus.com/kalasiris/>

1.2. Elements of Egyptian clothing

In ancient Egypt, the most common used textile was linen. Because of the high temerature this material helped people to be comfortable in the subtropical heat.

Linen material is made from the flax plant by spinning the fibers from the stem of the plant. Spinning, weaving and sewing were very important techniques for all Egyptian societies. There was possibilty for plant dyes to be applied to clothing but this clothing was usually used in its natural color. Wool was also known, but they considered it as impure fiber.

The pharaohs were monarchs of ancient Egypt. They ruled from the First Dynasty (c. 3150 BCE) until the annexation of Egypt by the Roman Republic in 30 BCE. Pharaoh was often



considered to be divine incarnation of Horus, and the unifier of Upper and Lower Egypt. In their appearance the often wear animal skins, usually lion or leopard.

Ornaments were main decorative part in Egyptian clothing with some symbolic elements. During Old Kingdom period Egyptians wore different types of amulets, magic pendant which later were turned into ornaments. Round necklaces were woven with gold, jewels and coloured glass beads symbolized sun disk. Arm and leg bracelets, rings, pendants, gold diadems beads, and belts were also widely used.

Wigs were also used, usually made of plant fibre or wool. The elite wore long wigs with slender braids or pipe curls. Small wigs were specific for slaves and peasants and they also wear caps made of linen. Men shaved their beards, but it was also usual to wear artificial beards made of wool varnishing them over and plaiting metal threads into them. Golden beard of Pharaoh symbolized his power. The sandals of palm leaves, leather and papyrus were worn only by Pharaoh and his suite. Sandals had simple forms, without side and back and with turned up sole [7, 8].

2. EXPERIMENTAL

2.1. Design inspired by Ancient Egypt

2.1.1. Inspiration for the Model

The main decorative value in the Egyptian costume consisted of decorations that included symbols as the main element. During the ancient kingdom of the Egyptians, all kinds of charms, magical attachments gradually became decorations. The circular decorations of the neck symbolized the solar disc, so this circular decorations are also used as an inspiration for the collar in the new redesigned model.

The new model is a man costume, inspired by the most common symbols from the ancient Egypt mythology. The symbols used as an inspiration are given below.

The Egyptian eye (Figure 3), commonly known as the eye of Horus, is one of the most common symbols of Egyptian mythology. The eye of Horus plays a big role in the fight between Horus and Set and still has an influence in Egyptian culture today.

The Egyptians wore this eye as a talisman, believing that it had therapeutic capabilities and was able to protect the wearer from all forms of disease.

Many of the people used it as a sort of good-luck charm, and it was like a guardian of its owner's physical and spiritual health. This symbol was also used in funeral rituals, believing that will offer protect on his journey to the realm of the dead.

The Uraeus is the symbol of the Egyptian snake goddess Wadjet. Wadjet was protector of the Lower Egypt worshiped as the patroness of the Nile Delta. The term "Uraeus" was known by the Upper Egyptian scholar Horapollo at the end of the 5th century AD in his treatise Hieroglyphica, where he gives an ideographic interpretation of hieroglyphic writing.

The snake (Figure 4) symbol was worn by the pharaohs symbolize Wadjet's protection of the pharaoh and her approval of his claim of sovereignty.

The snakes and cobra were symbols of resurrection. They were associated with the solar myths depicting the Sun's journey through the sky and the underworld, known as the Duat [9,10].

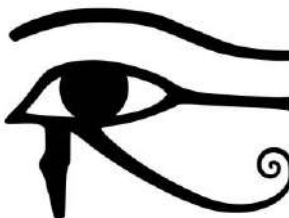


Figure 3: The eye of Horus as an inspiration for the Model (© Jeff Dahl)



Figure 4: The Uraeus as symbol of the Egyptian snake goddess Wadjet
Source: (<https://study.com/academy/lesson/egyptian-uraeus-definition-symbol-meaning.html>)

3. RESULT AND DISCUSSION

3.1.1. New redesigned model of men's costume

The redesigned model was inspired by a men's costume in Ancient Egypt, with a special emphasis at jewelry color and design. The gold color was applied to the new model in a form of handwork, which gives the model decay and freshness. The model consists of a jacket and trousers with long belt.

The Egyptian shenti was artfully transformed into a modern pattern of trousers with a lowered saddle that shows the freedom of movement and comfort offered by the Egyptian shenti. Minimalist design, with a simple cut, was enriched with hand-drawn segments of Egyptian mythology. The color of the model was deliberately left to be white and natural, so that it can bring the new model closer to Egyptian culture, where the natural color of the linen was the most commonly used color in the ancient Egyptian costume.

The cheerful colors can be seen in the new model around the collar. These colors describe the vibrancy of the Egyptians. The mixing of green, red and blue in a form of triangle as the main construction form of shenti, gives the model more colorful and fresh look. These colors supplemented by the golden tresses, shown the power and nobility of the Egyptian people.

Two gold-colored snakes are drawn by hand on the bottom of the model, representing the power divinity, sovereignty. Through the drawn eye are shown the beauty, protection and moderation. The cobra symbol on the new model is made of rope and is located on the back of the model, as a symbol of protection the vital parts of human body. The model also have a soft belt that contains the same colors as the collar of the shirt complemented the bottom of the design.



Figure 5: The appearance of handwork in the redesigned model

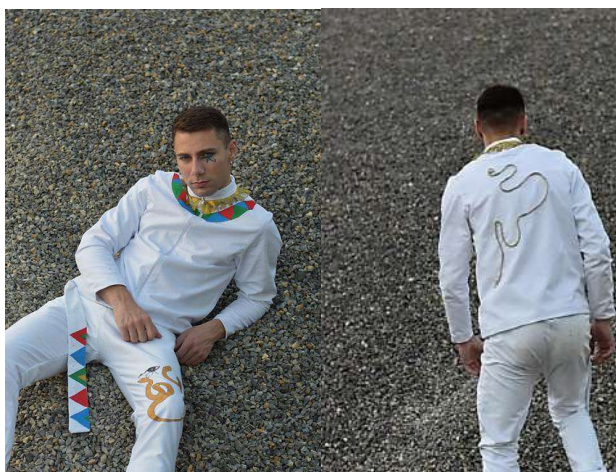


Figure 6: The final appearance of the model (front and rear)

4. CONCLUSION

The Egyptians were a people who liked to dress up and who were involved in fashion. Whether it was men or women, peasants or kings or queens. They were all marked in the colors of life of happiness. They believed in gods, they were showered in gold and luxury. The most used material in Egyptian costume was linen. Children did not wear clothes until



the period of maturity, which was around the age of 12, and at this age the boys were circumcised and their heads were shaved. Mothers were responsible for caring for the children, and fathers provided the income for the families.

The main clothing of the women was the "Kalasiris", which later men began to wear as well. New elements of clothing began to appear over time. One of them was the upper robe. It was a kind of shawl, which gathered gently in folds from above the waistcoat and crossed over the chest to form short sleeves.

The main decorative value in the Egyptian costume is characterized by ornaments that include elements of symbols. During the ancient kingdom of the Egyptians, all kinds of amulets, magical pendants, gradually became decorations.

The circular ornaments on the neck symbolized the solar system. Egyptians enjoyed the modern, that they adored color and decorations.

Egyptian culture is a great treasure trove of ideas and inspirations for fashion designers. Through the analysis of that culture, clothing and fashion accessories, a redesign of a male model that is wearable in the 21st century has been made.

The new model is inspired by men's clothing in Egypt, and the model itself incorporates details that take us back to an ancient civilization. The new redesigned model is representative of a modern age in which traces of ancient civilizations and their perfect artistic creation are still felt.

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FASHION FROM DIFFERENT ERAS IN A MODERN VIEWING

Review scientific paper
DOI: 10.5937/CT_ITI24037K

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ABSTRACT: This development shows how different cultural and historical eras have shaped national costumes and how they can be interpreted in a new and innovative way today. A brief presentation of the costumes of different historical eras was made, and based on them, modern clothing designs were proposed. By sharing the author's views presented in this development, designers and fashion lovers can be inspired. The contemporary garments on offer look back to the past with love and inspiration. Through them, models are created that are both unique and significant to society. In this way, the fashion heritage is preserved.

Keywords: National costumes, Historical eras, Modern reinterpretation, Fashion design, Cultural heritage.

MODA IZ RAZLIČITIH EPOHA U MODERNOM SAGLEDAVANJU

APSTRAKT: Ovakav razvoj događaja pokazuje kako su različite kulturno-istorijske epohe oblikovale narodne nošnje i kako se one danas mogu tumačiti na nov i inovativan način. Urađen je kratak prikaz nošnji različitih istorijskih epoha, a na osnovu njih predloženi su savremeni dizajni odeće. Deljenjem autorskih stavova predstavljenih u ovom razvoju, dizajneri i ljubitelji mode mogu biti inspirisani. Savremeni odevni predmeti u ponudi gledaju u prošlost sa ljubavlju i inspiracijom. Kroz njih se stvaraju modeli koji su jedinstveni i značajni za društvo. Na ovaj način se čuva modno nasleđe.

Ključne reči: narodne nošnje, istorijske epohe, moderna reinterpretacija, modni dizajn, kulturno nasleđe.

1. INTRODUCTION

Fashion is a reflection of time, culture, and society. It is multi-layered and constantly evolving, being inspired by different historical eras and cultures [1]. Fashion vision involves combining traditional elements with modern trends to create a unique and contemporary style that brings the spirit of the past into the present.

Fashion means not just a way for self-expression but is part of the cultural heritage left to humanity [2]. Every historical period has left its mark on the way people dress and present

themselves. Sharing views on fashion and its involvement in contemporary patterns is important because it provides an opportunity for a deeper understanding of the interrelationships between the past and the present, as well as a better appreciation of the cultural influences that shape contemporary style [3].

The purpose of this development is to present a designer's vision of fashion, focusing on the importance of influences throughout the ages and their integration into contemporary fashion.

Through this development, it is shown how different cultural and historical eras have shaped national costumes and how they can be interpreted in a new and innovative way today.

2. DESIGN DEVELOPMENT INSPIRED BY THE MINOAN CIVILIZATION

The Minoan civilization, which flourished around 2000–1400 BC. on the island of Crete, is known for its intricate and exquisite textiles. Women wore long, open-breasted, high-waisted dresses with rich embroidery that emphasized their figure and social status [4]. This era left an indelible mark on fashion with its exquisite and intricate textiles.

A modern 2-piece model, a sukman and a blouse, is offered (figure 1). The beautiful cut of the wide belt with ovals in the shape of the chest characteristic of the Minoan period and the blouse with a high neckline are a connecting key detail. The short bombshell skirt with an interesting pattern in several colors defines the model with a more youthful and modern line.

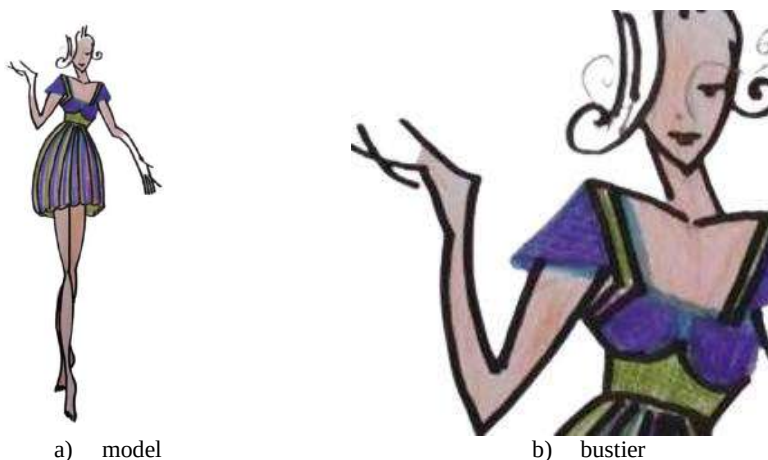


Figure 1: Contemporary design inspired by Minoan national costume

3. DESIGN DEVELOPMENT INSPIRED BY ANCIENT EGYPT

Egyptian fashion from the time of the pharaohs is known for its clean lines and use of linen and gold details. This allows to preserve the spirit of Egyptian elegance, while at the same

time certain elements are also suitable for the modern style [5]. The women wore tight, tight dresses with pleats and ornaments of gold and precious stones.

Included in the proposed design (Figure 2) is a clean, slightly fitted dress with symmetrical pleats in a variety of painted patterns. The chosen accent is related to this era, the gorgeren – a large decorative collar, which in my model is a check embroidered with geometric elements and modern textures and materials to give the dress a contemporary look, but at the same time I kept the spirit of Egyptian elegance and beauty.



Figure 2: Modern design inspired by Egyptian costume

4. DESIGN DEVELOPMENT INSPIRED BY ROMANTICISM STYLE

19th century romanticism was an era that allowed fashion designers to unleash emotion and individualism. The fashion of this period is known for its wide skirts, corsets, and intricate lace. This era gives lightness and romance in fashion, with the fabrics being light and airy with beautiful pastel colors and floral elements on the patterns [6].

Inspired by Romanticism, a model of a women's dress with straps was created (Figure 3), which can be combined with a plain blouse. The wide, slightly flared short skirt made of pleats and delicate lace elements reveals the connection of the modern model with the retro style. Sheer fabrics and light layers are used to give the dress airiness and contemporary elegance without losing the romantic look.

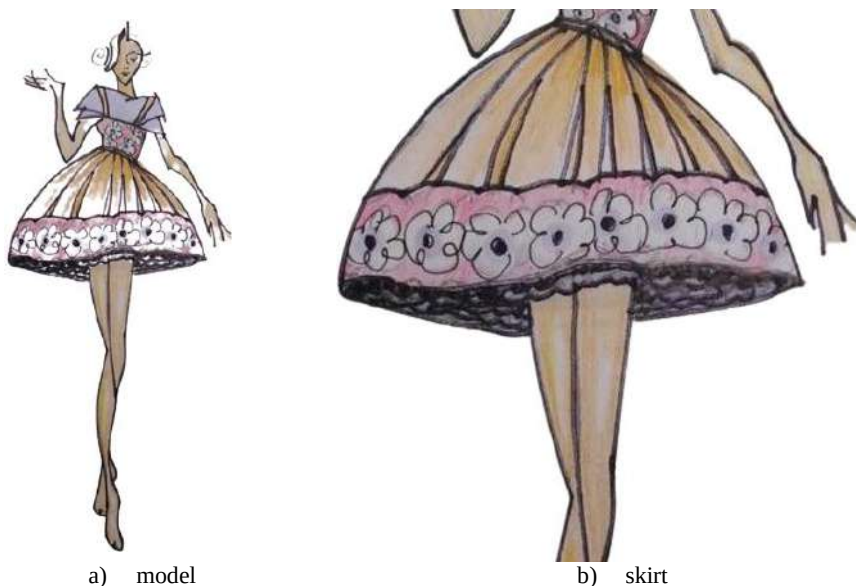


Figure 3: Modern design inspired by romanticism style

5. DESIGN DEVELOPMENTS INSPIRED BY BAROQUE, CHINESE, JAPANESE AND BULGARIAN COSTUME

A brief description of the characteristics of baroque, Chinese, Japanese, and Bulgarian costumes is presented. Contemporary clothing designs inspired by these costumes have been proposed (Figure 4).

Baroque fashion from the 17th century was lavish and rich in ornamentation. It features intricate embroidery, lavish fabrics, and an abundance of gold details [7]. Baroque Opulence Baroque fashion is known for its opulence and rich ornamentation.

The featured baroque dress features intricate diamond-shaped lamé embroidery with modern technology while retaining classic baroque motifs. They also make it comfortable and relevant for today. The skirt is long and has rich draperies and wraps. This women's dress model combines classic baroque motifs with contemporary luxury and elegance.

Traditional Chinese fashion is known for its rich silks, exquisite embroidery, and symbolic motifs such as dragons and phoenixes. Chinese Motifs. Traditional Chinese fashion is a symbol of elegance and symbolism [8]. The grace and beauty of Chinese neatness in Chinese national costume are well known. Intricate interweaving of ribbons and belts wraps wide rectangular pieces of fabric. The cleaner and more modern look of the model is in its simple and pastel silhouette.

Included in the proposed model is a delicate ladies' short dress with a colorful hem made of silk fabric. Added a sleeveless kimono form of equal parts triangle pieces that form the line of the kimono through the belt.

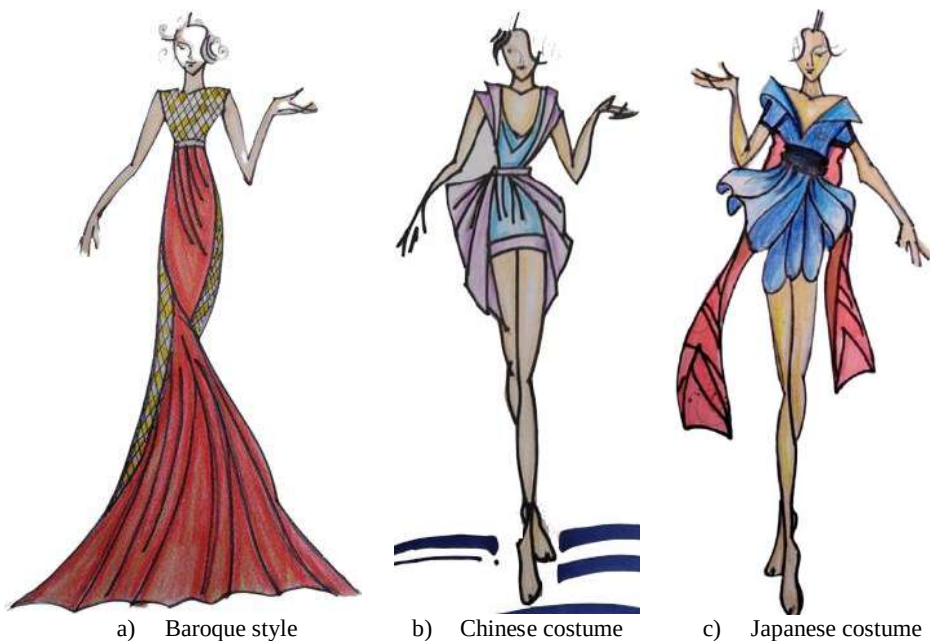


Figure 4: Contemporary designs inspired by historical styles

Japanese fashion, especially the kimono, is a symbol of elegance and minimalism. Saturated with richly colored painted firebirds and other floral, highly developed designs show the extensive capabilities of the Japanese woman [9]. The diligence and perfectionism even in their gait when they are dressed in their national costumes reveal how perfect Japanese women are.

The proposed Japanese dress is inspired by this perfection to create beauty and finesse, but with few means and with less color. A beautiful two-tone belt wraps perfectly arranged pieces of fabric with an interesting cut at the waist. Their symmetry and accuracy distinguish several layers of imitation kimono. The design of the model ends with a beautiful ribbon on the back. The created model is partly traditional for Japanese culture, which can be safely used in the present.

The Bulgarian national costume is saturated with colors and shapes, embroidery, and is very rich in symbols. It mainly consists of a shirt, cloth, and apron, which are decorated differently according to the region [10]. In recent times, it has been increasingly integrated into modern fashionable clothing [11, 12].

The model that is proposed is a woman's long bodice, which is also unique (Figure 5). From the creation of the design of the product, tailoring, painting of each part, and joining, where sewing is minimized. Only in the shoulder part there is a seam on both sides of the belt, which hugs the back of the woman's long bodice. The clean design is mostly ornamented by the painted frieze elements. The particular idea is enhanced with a triangular-shaped

headscarf. The women's bodice in a modern version is suitable for complementing a set of trousers and blouse or skirt and blouse.



Figure 5: Design inspired by the Bulgarian national costume

6. CONCLUSION

Fashion is a bridge between the past and the present. Fashion is a dynamic and multi-layered art. By combining traditional elements from different national costumes and eras with modern techniques and materials, the present development has created unique patterns that tell a story and bring cultural richness to the modern world. The approach to fashion used here is not only visually impressive but also deeply connected to cultural heritage and its preservation and rediscovery in our time.

By sharing the author's views presented in this work, the author hopes to inspire designers and fashion lovers to look back to the past with love and inspiration, to create patterns that are both unique and meaningful to them and to society, in order to preserve the fashion heritage.

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SUSTAINABLE DESIGN AND ITS IMPORTANCE IN CONTEMPORARY FASHION – AN ANALYSIS OF THE WORK OF FASHION DESIGNER STELLA MCCARTNEY

Review scientific paper
DOI: 10.5937/CT_ITI24038K

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ABSTRACT: The question of sustainable design and sustainable fashion is a part of the daily life of every modern or (non)modern individual, and it integrates and subconsciously imposes the question of the way of life of a modern man in the new century. Therefore, we can say that sustainable fashion is an aspect of sustainable design and supports sustainability and modernity. Sustainable design is a design that is in function of sustainable functioning and living in clothes, which supports and benefits nature and natural laws. In relation to the latter, emphasis is placed on ecology as a driving force and the most important element of life. The importance of nature and the preservation of its beauty became especially important in the period after the pandemic. The reason is to preserve human health and live in natural conditions, in which man, as the most perfect creature, will fully enjoy all its benefits and beauties. Therefore, ecology and design sublimatively create a new branch, so called eco-design, which finds great application in fashion design. This type of fashion design is primarily supported by environmentally conscious fashion designers, those who strive for design forms and tendencies, who are driven by the desire to preserve nature and urbanize clothing into body shapes that will give new, avant-garde, but above all functional performance and strength of clothing. One of the first fashion designers, a pioneer who bravely performs and joins this wave of creating the so-called sustainable fashion is English designer Stella McCartney. When we talk about sustainable fashion, we must first mention this popularly known sustainable fashion queen. Her name is emblematic and it is inevitable to be mentioned and analyzed in this context. She is one of the few fashion designers who is aware of the importance of nature, the importance of renewing and maintaining natural resources, and last but not least, creating visual forms that will not harm them in any way.

Key words: sustainable design, sustainable fashion, nature, ecology, Stella MaCartney.

ODRŽIVI DIZAJN I NJEGOVO ZNAČAJ U SAVREMENOJ MODI – ANALIZA RADA MODNE DIZAJNERKE STELE MAKARTNI

APSTRAKT: Pitanje održivog dizajna i održive mode deo je svakodnevnog života svakog savremenog ili (ne)savremenog pojedinca, i ono integriše i podsvesno nameće pitanje načina življenja savremenog čoveka u novom veku. Shodno tome, možemo reći da je održiva moda aspekt održivog dizajna i podupire održivost i modernost. Održivi dizajn je



dizajn koji je u funkciji održivog funkcionisanja i življenja u odeći, koji podržava i koristi prirodu i prirodnim zakonima. U odnosu na poslednje, akcenat se stavlja na ekologiju kao pokretačku snagu i najvažniji element života. Značaj prirode i očuvanje njene lepote posebno je postao značajan u periodu posle pandemije. Razlog je očuvanje ljudskog zdravlja i život u prirodnim uslovima, u kojima će čovek, kao najsavršenije stvorenje, u potpunosti uživati u svim njegovim blagodatima i lepotama. Prema tome, ekologija i dizajn sublimativno stvaraju novu granu, tzv. eko-dizajn, koja nalazi veliku primenu i u modnom dizajnu. Ovakvu vrstu modnog dizajna prvenstveno podržavaju ekološki osvešćeni modni dizajneri, oni koji teže dizajnerskim formama i tendencijama, koji su vođeni željom da održe prirodu i urbanizuju odeću u oblike tela koji će dati novu, avangardnu, ali iznad svega funkcionalne performanse i snagu odeće. Jedan od prvih modnih kreatora, pionira koji hrabro nastupa i uključuje se u ovaj talas osmišljavanja tzv. održiva moda je engleska dizajnerka Stela Makartni. Kada govorimo o održivoj modi, prvo moramo pomenuti ovu popularno poznatu kraljicu održive mode. Njeno ime je amblematično i neizbežno je da se pominje i analizira u ovom kontekstu. Ona je jedna od retkih modnih kreatora koja je svesna značaja prirode, značaja obnavljanja i održavanja prirodnih resursa i na kraju, ali ne i najmanje važno, kreiranja vizuelnih formi koje joj ni na koji način neće škoditi.

Cljučne reči: održivi dizajn, održiva moda, priroda, ekologija, Stela Makartni.

1. INTRODUCTION

Fashion gives an opportunity to stylistic leaders (designers, non-standard, unconventional creatives, charismatic leaders) to show themselves as initiators of change and carriers of diversity. Based on the history of fashion and costume, the most significant stages in the development of human civilization, human spirit and creativity can be marked, including general, social, cultural and gender changes [1]. Many of the fashion designers do not fail to emphasize the spiral character of fashion and the effect of the law of the new - like the well-forgotten old. Thoughts similar to the latter create associations with human nature and the ability to periodically repeat their actions, trying to enrich their past experience and reproduce at a higher level what has already been achieved in art and culture. Today's fashion is a form of contradiction between elitism and democracy and it is an announcement that the time has come to destroy the old qualifications for it as high fashion (haute couture), ready-to-wear (prêt à porter) and street fashion [2].

Fashion strives to express its era, that is, everything that happens in a certain period. The kind of civilization determines the fashion. The type of clothing changes when the type of civilization changes as well. If we change the type of civilization, the form of clothing will completely change. In order to build the new, the old must be torn down first. For example, before building a new temple, the Egyptians would first destroy the old one and replace it with parts of the old temple. Today many world designers are doing the same, they are destroying old structures and creating new forms, new materials with new techniques on top of that void. It is a creative process – to know the past, old and already tried, destroy it and create something new based on it. But you have to be well aware of social changes and

movements, this is very important, because social changes are a way to understand cyclicity and the direction in which fashion design itself will move [3].

2. SUSTAINABLE DESIGN – DEFINITION

Sustainable fashion is fashion that uses and supports nature and natural laws, does not harm the planet or people, but on the contrary, encourages people's awareness of a smarter lifestyle, more environmentally conscious and in favor of well-being in the environment itself. It is a fashion that is complementary and related to slow fashion, which opposes fast fashion and short-lived fashion trends. The fashion industry is one of the most powerful (and at the same time most influential) industries in the world. It is the branch that supports the social system, the narrative and is a complex tool that directly affects the lifestyle of millions of people around the world. From here, the modern clothing industry keeps up with all the world changes, such as ecology, climate change, human resources and social inequality and labor exploitation. Its significance is great, because it seriously influences social changes and movements. From here, the emergence of sustainable fashion and sustainable design is completely understandable, at the same time inevitable in today's increasingly fast-paced, digitalized and dynamic lifestyle. Sustainable fashion supports nature, man, ecology, culture, economy and sociology [4].

According to Wikipedia, "sustainable fashion is a term that describes efforts within the fashion industry to reduce its impact on the environment, protect the workers who produce the clothing, and maintain animal welfare. Sustainability in fashion covers a wide range of factors, including reducing CO2 emissions, tackling overproduction, reducing pollution and waste, supporting biodiversity and ensuring that garment workers are paid a fair wage and have safe working conditions."

The goal is to create fashion that will last longer and ultimately be more practical. In order for this idea to come true, radical changes are needed, even in the production of the raw materials themselves, up to the final textile and fashion product. In this context, it is important to produce modern materials, which will have a longer lifespan than the existing ones, the continuation of short-term seasonal and sub-seasonal fashion trends, the creation of fashion lines and trends that will be maintained for a longer period of time and which will ultimately lead to a reduction in textile waste, damages to nature etc. The main goal is to create a better environment for a more successful and better life of future generations [5].

3. SUSTAINABLE DESIGN AND ITS IMPORTANCE IN CONTEMPORARY FASHION

A fashion designer is a key figure in shaping a fashion trend. Fashion designers usually come from a rich cultural background and have completed a suitable design school. Even if they do not have a degree in fashion design, they are a special category of people, who have a specific view of the world and attitude towards fashion and have a great influence on the construction of visual taste in society. A designer works either for his own brand or



for a particular fashion company. Regardless of both, he is obliged to present two collections at least twice a year. When it comes to world fashion, designers are increasingly faced with difficult challenges imposed by an increasingly fast-paced lifestyle, often dictated by wealthy trendsetters. In addition to two collections of classic fashion lines, they also design a number of other additional collections, such as pre-collections, resort, cruises, etc. In this context, we will also mention special fashion lines, such as men's, women's, teenage, children's, that is, for each of them a separate collection of high fashion, ready-to-wear fashion, etc. This means that the number of collections of one designer or fashion house during the year is really large (considering that on average each collection contains 40-50 models, and even 120, which makes the total number of models on an annual level endless!). This is one of the reasons that many of the designers face strong pressures and uncontrollable effects that also affect their health, all in order to be one step ahead of everyone else and meet the increasingly capricious demands of the market [6]. Today, well-known and established designers use their positions in the fashion industry to promote and impose certain concepts constructed through discourses that take shape in the fashion world through various channels. These conceptions mainly relate to issues of identity, distribution of power and formation of different social and cultural resonances [7].

In recent years, the fashion industry has been facing significant changes in the design, production and sale of clothing items. The transition from the traditional way, which consists of two fashion seasons: spring-summer and autumn-winter, soon turns into the "fast fashion" method, [the term "fast fashion" is a retail strategy, which represents a highly profitable business model in which high fashion trends are replicated and mass produced at significantly lower prices] that includes numerous seasons and sub-seasons. In the past, designer pieces were not available to the public for several months, and at that time celebrities wore them to make them look affordable to consumers until they were available in stores. This model is still used today, especially by high fashion brands. Today, the goal of fast fashion is for consumers to buy more clothes in less time, because new trends are launched every week. Fast fashion brands create about 52 "micro-seasons" per year (!). They have a huge number of products and an extremely wide target market and are able to offer lower prices (due to the lack of quality production). Examples of such fast fashion companies are H&M and ZARA, which are organized differently from high-end fashion brands, which operate according to the traditional seasonal model and that is every few months. For example, ZARA, which is a pioneer in this whole concept of fast fashion, makes new deliveries twice a week to its stores [8]. Considering that fast fashion creates new designs on a weekly basis, the psychology of such companies is to make the customer feel out of trend after the first wear of the purchased item of clothing. The bottom line is that fast fashion creates a number of problems that make it more of a problem than a benefit. One of the main problems it faces is that much of that clothing is made of petroleum-based synthetic fibers, which means it will take decades to break down. This kind of industry also contributes to the worsening of climate change, pesticide pollution and huge amounts of waste.

The psychology of modern man is interesting, according to the latest statistics, he consumes 400% more clothes compared to the period before the millennium [9]. The modern

consumer buys more clothes than ever, and wears them much less often or only once. In the past two decades, the speed and change of fashion trends have experienced expansion. Fast lifestyles and excessive consumption of cheap clothes lead to a massive increase in textile waste, as well as pollution and depletion of natural resources. In addition, it raises social issues, such as the violation of human and labor rights. From here it is inevitable to notice that we have to take measures and change this too fast and unhealthy way of life. The best thing we as consumers can do is to stop supporting this industry. Let's avoid fast fashion brands and instead start supporting sustainable clothing brands, thus completely changing our overall lifestyle [10].

The opposite of this term is the so-called "slow fashion", which is developing as an alternative to fast fashion. It is sustainable, has higher quality and higher prices, does not follow trends as a whole and is committed to raising environmental and ethical awareness. Instead of synthetic, non-biodegradable and environmentally conscious materials, slow fashion uses 100% organic materials, such as cotton, linen, wool, lyocell, etc. for the production of which no toxic chemicals are used, and at the same time cheap and child labor is not abused. This type of fashion is inspired by slow (and healthy) food and supports a slower, and therefore a healthier and more stable way of life, which will bring benefits to the modern man, which will make his life easier and make him more relaxed, flexible and far more practical, and life itself a longer and much healthier.

An example of a designer who practices this slow fashion is Iris van Herpen, who is known for her unique 3-D prints, laser cutting, but at the same time relies on the traditional way of embroidery and draping, thus making a hybrid in high fashion - a designer-pioneer in today's world of fashion. Another significant example is the English designer Stella McCartney, who is proof that the name and brand are deserved and do not depend on the origin, but on the offered design, quality and personal talent. In the context of sustainable design, McCartney is without precedent among the most successful, influential and profitable fashion designers in the world.

4. CENTER FOR SUSTAINABLE FASHION AND SUSTAINABLE FASHION GLOSSARY

The Condé Nast Fashion Center, in cooperation with the London College of Fashion, University of Arts London (Centre for Sustainable Fashion, London College of Fashion, University of Arts London) forms an open platform to support an industry that values and respects our planet and communities - the so-called Center for sustainable fashion (Center for Sustainable Fashion - CSF). The main idea of this Center is to introduce a new era of life, which will help to reinterpret natural laws, will be based on respect and appreciation of the land and all its inhabitants and finally, which will establish an absolutely new fashion system and order. The way to achieve all this is to unite general world leaders in the fields of ecology, sociology, culture, economy, design and fashion, establishing new forms, which will inspire the birth of a new vanguard of creative leaders, who will shape the direction of the future and form a community of creators of positive changes. Part of the founders of this platform, as well as the ideas, are academics and creative minds, with



known and recognized achievements in the field of fashion design. Some of these are: Professor Dillis Williams, Director and Professor of Fashion Design for Sustainability, Center for Sustainable Fashion, London College of Fashion, University of the Arts London; Mila Burcikova, Ph.D., postdoctoral research fellow, Center for Sustainable Fashion, London College of Fashion, University of the Arts London; Sara Needam, Knowledge Exchange Manager, Center for Sustainable Fashion, London College of Fashion, University of the Arts London; Monika Bukan-Ng, Knowledge Sharing Project Coordinator, Center for Sustainable Fashion, London College of Fashion, University of the Arts London; Vogue's Editors-in-Chief and their editorial teams; academic researchers, professors of fashion and sustainable design at institutes of fashion technology and fashion design, Condé Nast School of Fashion and Design, students of fashion media, communication, entrepreneurship and design, etc.

This established policy document supports the strengthening of sustainability literacy among the population globally by providing the correct guidelines for the most appropriate conditions around sustainability in fashion design: cultural practices, raw materials, production, consumer habits and maintenance practices on purchased clothing. For this reason, designers, innovators and spokespeople, who support this action, work in turn with the fashion media, as a serious means of establishing and implementing this novelty. This process can be defined as the crystallization of her research and educational practice, bringing academic rigor and accuracy to her content. The philosophical principles by which this center works are three: repair, reuse and repurpose. It represents an established framework between industry, academia and life cycle. In addition to the academic staff from the recognized and renowned London Academies for Fashion Design (London College of Fashion, University of the Arts, London), editors of fashion magazines such as VOGUE, Condé Nast, Center for Sustainable Fashion, students of the London College of Fashion Design, make up the faction which establishes this new doctrine. They are considered leaders-pioneers of a new generation and a new world order.

One of the eminent members of this Center and a passionate supporter of its ideas and norms is Stella McCartney, an English creator of world fame and a serious contribution to the contemporary fashion industry.

5. ANALYSIS OF THE WORK OF THE FASHION DESIGNER STELLA MACARTNEY

It is an interesting fact that life habits acquired from childhood, education and life philosophy can affect the way of thinking and directly reflect on the way of designing fashion clothes. The English designer Stella McCartney is without a doubt such an example.

Raised on a farm in East Sussex, England by well-known vegetarian parents, McCartney found a deep connection with nature, the seasons and animals from an early age. In her later years she moved to London, where she studied fashion design at the prestigious Central Saint Martins College. From here is an inevitable fact that highlights her turbulent nature and temperament (in imitation of her father, one of the most beloved and richest rock icons in the world, Paul McCartney), as well as an unconventional taste for creating

clothes during her studies by renowned fashion experts (after all, England is the country of the most rebellious subcultural movements and styles!) [11].

Mac Cartney is a woman with the right to vote and her influence is a social fact! From here she created her personal fashion brand more than 20 years ago and later launched a campaign to protect animals and ban the use of animal fur in fashion design (see picture 2). She proclaimed this idea in the English Parliament with the intention of having a positive influence on the way of thinking of young designers. Interestingly, she is not a radical, nor a typical eco-fanatic or political activist, but a smart thinker, aware of her role as a fashion designer. Thanks to her unconventional nature, experimental spirit and progressive fashion leader, she has her own life and fashion philosophy and serves it to the market unobtrusively. The idea is indirectly, through her personal example of a vegetarian, a woman who loves the planet, animals, respects people, workers and humanity as a whole, to revive a progressive social thought and trend that will start a new social order and will cause serious changes for the benefit of humanity.

McCartney is one of the few fashion designers who really thinks seriously and contemplates, while looking at things from afar. The reason why she is the subject of analysis in this paper is that "McCartney" is the first luxury fashion brand that supports and proclaims sustainable fashion. In the words of the designer, people are too conventional and have an outdated system of functioning. She believes that the way people look at things is irrational, that they lead an incorrect lifestyle in terms of nutrition (imposed by outdated habits and upbringing), and that they are not aware of the harmfulness and cruelty of such food. In addition to being a passionate advocate of veganism, she is also a serious environmentalist, declaring that rainforests should be protected, that eating meat is unnecessary, that chemical skin treatments are harmful, etc. According to her philosophy, changing these habits will lead to a cleaner planet and a healthier human being and a world where people behave and function in accordance with natural laws.

It is inevitable to mention that this philosophy of life is also reflected in her designer collections, as she skilfully propagates the sustainability of used materials and designer shapes in the name of practical and contemporary women's and men's clothing. In the 1990s, McCartney undoubtedly proved herself as a designer who knows well what women want, to be modern, elegant, feminine, but above all to feel comfortable. The designer once again confirms this epithet, proving that fashion should work in accordance with nature and its laws, and fashion design to satisfy aesthetic preferences, should support the idea of longevity, sustainability and quality. At her shows, you can often see a combination of elegant with sporty and practical - like sneakers in combination with dresses or comfortable and loose clothing.

After establishing her brand in 2001, in 2009, relying on her ideology, Stella McCartney designed the first vegan bag, the so-called *Falabella* made of vegan leather. If it was made of natural animal skin, the skin of 400,000 cows would be needed for 1 million copies sold! In the trends she has imposed in the last few years, McCartney markets fashion collections made from sustainable raw materials – 80-90% ecologically conscious materials, such as organic cotton, patchwork technique, beech wood shoe soles, etc. Through this, she introduces a new principle of design, simultaneously bringing freshness to contemporary



design, bringing it closer to the rural idyll where she grew up. In the fall season of 2021, she shot an interesting advertising campaign promoting animal protection (see picture 1). The concept of the campaign is for the animals to reclaim the urban areas that were thoughtlessly taken from them. Modern artificial fur is often made from materials such as modacrylic, which is not friendly to nature. "Fur without fur" - KOBA by McCartney is made of almost 40% plant-based materials and is recyclable. Nylon and polyester are recycled, the bags are vegan with aluminum chains, which are easy to recycle. The viscose is produced from certified forests in Sweden, without damaging old or threatened forests. According to her, it should be illegal to cut an old tree without planting a new one first. Also through fashion campaigns and extraordinary fashion shows, the designer promotes human rights organizations, advocates for the banning of PVC materials as carcinogenic, for increasing the minimum wage, for the terrible working conditions of workers in fast fashion factories, for the devastating climate impact of animals, breeding and the eradication of child labor [12].

This unwavering commitment culminated in the publication of a 2006 UN report that stated that livestock production was responsible for more emissions than the entire global transportation sector [13]. In response, McCartney is launching a "Meatless Monday" campaign in the UK, encouraging the public to adopt a meat-free day and exploring how to make her lines more sustainable. According to statistics for the year 2018, the manufacturing industry of the UK, France and Germany is responsible for more than 2 billion metric tons of greenhouse gas emissions. More than 60% of the world's total clothing produced annually ends up in landfills or incinerators, the equivalent of a truckload of used clothing being thrown away or burned every second. The leather industry, on which luxury fashion houses depend, is involved in the slaughter of over a billion animals, while tannery workers are exposed to toxic chemicals. This is an indicator that shows that the glamorous and luxurious fashion world has nothing in common with miserable and inhumane conditions, nor with inhumane resources for its creation. The period of the pandemic influences the designer to want to reduce the harmful impact on the environment even more. That's why McCartney calls herself a pioneer in fashion, collaborating with startups on sustainable materials such as vegan leather from grape waste, viscose from friendly trees and recycled cashmere.

McCartney's work is increasingly going beyond the scope of her fashion brand. Over the past few years, she has held high-profile meetings with world economic leaders at the G7 and the UN Climate Change Conference and co-founded the \$200 million Collab SOS Climate Solutions Fund. In 2019, McCartney joined forces with LVMH (Moët Hennessy Louis Vuitton), where she was appointed as a special sustainability advisor to CEO Bernard Arnault, one of the world's richest men. According to Arno, Stella is the first fashion designer to raise questions about sustainability in fashion design. According to the editor-in-chief of Vogue, Anna Wintour, Stella McCartney is the only designer who knows how to think about luxury and sustainability at the same time.

In the Fall 2023 collection, Stella finds an unconventional way to present her fashion collection, with a style and manner that suits every Central Saint Martins educator. The fashion show was held in an improvised barn, where horses are housed on one side, while

models walk on a sand-covered floor on the other - an improvisation of the idyll in which she herself grew up (see Figure 4). Designs consist of faux leather fur coats, blazers, comfortable heels and asymmetric flowy dresses. This collection also includes the iconic Falabella bag made of so-called Mirum, and the high boots are made of Vegea, a material obtained from the waste of wine grapes, as well as an artificial crocodile bag made of apple peel, interesting isn't it! There's a special thrill McCartney feels when customers have no idea they're buying shoes made from grapes or a blouse made from regenerative cotton. The collection for the summer of 2023 also includes T-shirts made of 100% regenerative cotton, etc.

Regardless of all this idyll and positive ideology for the well-being of people and the preservation of the environment, sustainable fashion is still in its infancy and has many drawbacks and disadvantages. For example, there are vegan leathers made from polyurethane (PU) or polyvinyl chloride (PVC), which release microplastics into the environment. From here, a team of designers works on their improvement, with the aim of minimizing and completely eliminating these negative characteristics, in order to find greener alternatives that will match the quality and durability of natural leather [14]. The process of creating alternatives to natural leather is extremely long, complex and expensive - first, samples of new materials are made, their physical and chemical parameters are tested, after which a fashion product prototype is made, which goes through a series of tests, e.g. like durability, strength and color retention [15]. Scientists create new material based on this data and the process becomes long and exhausting. According to this principle, in 2022, the so-called Mirum (see Figure 3), plant-based, plastic-free vegan leather. Given that the structure of this material is quite solid, it is estimated to be the most ideal for making thicker fashion items, such as bags and shoes. In the same year, Stella McCartney produced the world's first luxury Milo bag from mycelium, a root-like fungal system, but the production of this material was suspended, as the company failed to raise enough funds for its production. The latest challenge faced by the designer is finding an analogue of PVC [16]. All this and many other novelties and ideas are reason enough, as she herself declares, to wake up and create. Behind all this philosophy is the desire to connect his designs with potential customers, to whom he wants to convey his message. She sees fashion as a service industry. When working on a collection, she thinks about how a piece designed by Stella McCartney should make you feel: confident, comfortable, alive, light, sensual. "I want to feel like the best version of myself," she says, her eyes shining. "I want to feel great."

The McCartney Empire sees sustainability built from the ground up. Today, this company has a total of 51 stores worldwide, from L.A. to Tokyo. Interestingly, she also applies sustainability to the design of her fashion stores – most of the furniture is made from recycled materials, including reclaimed wood for sculptural columns, vintage furniture; the dolls are made of bioplastic material consisting of 72% sugarcane derivatives (which allows for a significant reduction in CO2 emissions). All this reflects the brand philosophy of reduce, reuse and recycle (see Figure 5).

Interestingly, almost none of her employees believed in sustainable design and its success in the company. McCartney stands out here as a woman of strong character and a designer,



who boldly approaches social changes, adapts to them, introducing a new and progressive philosophy of fashion. The fashion industry is cruel, merciless and harsh on anyone who is not ready to fight and change/progress. From here it is normal that she still does not support the idea that fashion as a whole should be conscious or sustainable, because it is still guided by principles imposed from past centuries. McCartney is among the few not only designers, but also people in general, who passionately and decisively fight for the demolition of the old system and the introduction of a new progressive and positive social arrangement in its place.

And last but not least, in addition to McCartney, the list of fashion brands supporting sustainable fashion includes Levi's, Girlfriend Collective, Allbirds, Mejuri, Everlane, Mara Hoffman, Autumn Adeigbo, Ninety Percent, E.L.V. Denim, House of Marici, Sézane, Gabriela Hearst, Omnes, Mother of Pearl.

6. PRACTICE OF DAILY LIFE AND POSITIVE CHANGES IN BENEFIT OF SUSTAINABLE DESIGN

After this extensive analysis of the work and efforts of designers and world economic leaders to propagate the modern fashion system and the process of creating sustainable fashion, it would be nice to give a general conclusion on what would be good to apply not only in fashion, but also in life in general. From a biological point of view, a positive change would be to avoid the use of synthetic and animal materials and ordinary cotton and replace them with materials that, although in the process of improvement, are far better alternatives, such as organic cotton, vegetable cotton, base materials etc. Some of the alternatives for a healthier and more humane life are more practical maintenance of clothes, through reductive rationalization of washing time (reduction of CO₂ emissions and water consumption) [17, 18, 19], repair of damage, purchase of high-quality and long-lasting second-hand clothing at a lower price as well as avoiding fast fashion collections. A great shopping habit is to look for products certified by the Global Standard for Organic Textiles (for cotton and wool), the Working Group (for leather) and the Forest Stewardship Council (for viscose) to ensure that the materials used to make the clothes have a less harmful impact. to our planet. Recycled materials also have a lower impact than virgin materials, but it is worth considering whether they can be recycled and reused.

From a commercial and marketing point of view, some of the key activities that will significantly help in propagating this type of fashion design (as well as lifestyle) are - finding influential fashion icons (modern trendsetters and jet setters) whose popularity will influence the expulsion of mega-fast and short-lived fashion trends, as well as the choice of quality, sustainable designs with a long-term outlook on many young people; propagating the gravity of the natural resource deficit; the propaganda of educated and authoritative people, who will encourage smart thinking about healthy lifestyle habits, both in nutrition and in clothing, with their personal example; reforms of the social system; implementation of subjects in education for sustainable living practices and study of all chains and key segments in the ecosystem - raising awareness from the earliest age; subsidizing companies engaged in the production of ecological fashion; increasing the

penalty for companies that emit a serious base of toxic gases during production, that use toxic substances and that abuse work, etc. [20 and 21].

When it comes to sustainability, even though the fashion industry is far from becoming fully circular, considering whether clothing can re-enter the system in any of these ways is crucial to achieving peace and harmony in the modern world.



Figure 1: McCartney's Fall 2021 fashion campaign (source Google)



Figure 2: Stella McCartney as an activist against the use of animal fur (source Google)



Figure 3: Flabella bag made of Mirum (source Google)



Figure 4: Stella McCartney's Winter 2023 Womenswear Show in Paris (Source Google)



Figure 5: McCartney's fashion store in London (source Google)

7. CONCLUSION

Sustainable design and sustainable fashion are novelties that are inevitably analyzed and taken into account in today's modern industrialized and increasingly digitized society. Sustainable design is a function of sustainable functioning and living in clothing, which supports and utilizes nature and natural laws. The goal is to preserve people's health and live in natural conditions, where man, as the most perfect creature, will fully enjoy all its treasures and beauties. The idea is to create a complementary new ecological, economic, health, production, design and industrial system, which will enable functioning in a way that will enable the production of smart (healthy) raw materials and their proper use for the creation of design, which with its age will cause the birth of an absolutely new design principle, so-called sustainable design. The basic goal is humanity, which is the preservation of nature in its complete authenticity and enabling a healthy and ecologically balanced ecosystem for future generations.

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INTEGRATING TEXT-TO-IMAGE IN FASHION ACCESSORIES DESIGN

Professional paper
DOI: 10.5937/CT_ITI24039I

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ABSTRACT: This research used AI text-to-image generators in fashion design. By providing detailed textual descriptions, digital images are created that generate both sketches and photorealistic effects of fashion accessories with high-quality aesthetics and intricate design details. The research highlights the potential of these AI tools to assist fashion designers in creating accessories that meet design criteria and consumer needs. The limitation of AI tools, which usually create completely digital models and elements, has been reduced, and we have successfully translated them into real products. This demonstrates the feasibility of converting AI-generated designs into real fashion accessories, enhancing the practical application of AI in fashion design.

Keywords: Text-to-Image AI, Fashion Design, Digital to Physical Translation, AI-Generated Designs, Design Automation, Consumer Aesthetics.

INTEGRACIJA TEKSTA U SLIKU U DIZAJNU MODNIH DODATAKA

APSTRAKT: Ovo istraživanje je koristilo AI generatore teksta u sliku u modnom dizajnu. Pružajući detaljne tekstualne opise, kreiraju se digitalne slike koje generišu i skice i fotorealistične efekte modnih dodataka sa visokokvalitetnom estetikom i zamršenim detaljima dizajna. Istraživanje naglašava potencijal ovih AI alata da pomognu modnim dizajnerima u kreiranju dodataka koji zadovoljavaju kriterijume dizajna i potrebe potrošača. Ograničenje AI alata, koji obično kreiraju potpuno digitalne modele i elemente, je smanjeno, a mi smo ih uspešno preveli u prave proizvode. Ovo pokazuje izvodljivost



pretvaranja dizajna generisanih od veštačke inteligencije u prave modne dodatke, poboljšavajući praktičnu primenu veštačke inteligencije u modnom dizajnu.

Ključne reči: AI za pretvaranje teksta u sliku, modni dizajn, digitalno u fizičko prevođenje, dizajni generisani od veštačke inteligencije, automatizacija dizajna, estetika potrošača.

1. INTRODUCTION

The fashion industry is increasingly interested in the use of artificial intelligence (AI). AI technologies have already made strides in areas such as trend forecasting, inventory management, and personalized shopping [1]. On the other hand, there is a notable gap in research related to the application of modern artificial intelligence image generation systems based on diffusion modeling for fashion design and merchandising [2]. These advanced systems can create highly realistic and innovative fashion images that could revolutionize the design process, marketing strategies, and even virtual fitting for customers. However, the integration and application of diffusion modeling-based AI in fashion remain largely untapped, offering a vast field for future research and innovation [3].

As of 2021, AI text-to-image generators that use machine learning and modeling are gaining attention from both academics and practitioners. These technologies have sparked a wave of research and discourse focused on their potential applications in various fields [4]. The ability of these generators to convert textual descriptions into highly detailed and realistic images opens up new opportunities in creative industries, including fashion, advertising, and entertainment. Researchers are exploring how these tools can streamline the design process, improve creative workflows, and create innovative visual content. As a result, the academic and professional communities are increasingly interested in understanding and exploiting the capabilities of these AI systems [5].

A major limitation of existing developments in AI design is that only digital solutions are available. To a very small extent, these designs are not realized in physical products. The research aims to integrate advanced AI systems to create realistic and innovative design solutions.

2. MATERIAL AND METHODS

Online text-to-image generators were used in the present study:

- ✓ OpenArt-AI (<https://openart.ai>, accessed 21.05.2024);
- ✓ Microsoft Bing (<https://www.bing.com/images/create>, accessed 18.05.2024).

OpenArt-AI is an AI-driven art platform that allows users to create images using pre-built or trained models. It includes imaging tools such as InPainting for filling in missing parts and removing objects. The platform showcases various AI-generated artistic styles from different genres and eras and allows users to train models that reflect their unique artistic vision. OpenArt-AI aims to make art creation accessible to everyone, regardless of their traditional artistic skills.

Microsoft Bing's text-to-image feature allows users to generate images based on text descriptions. This functionality is part of Bing's broader AI capabilities, which aim to improve the search and content creation experience. Text-to-image generation is powered by advanced AI models, such as DALL-E, which can create detailed and varied images from simple text notations.

The creation of images from text descriptions was done according to the methodology presented in [6], with some modifications. The methodology used is presented in Figure 1. The methodology is implemented by initially defining a textual notation describing the desired image in detail. The AI platform generates several images from which those that match the designer's wishes are selected. Finally, a design solution is created with the generated image.

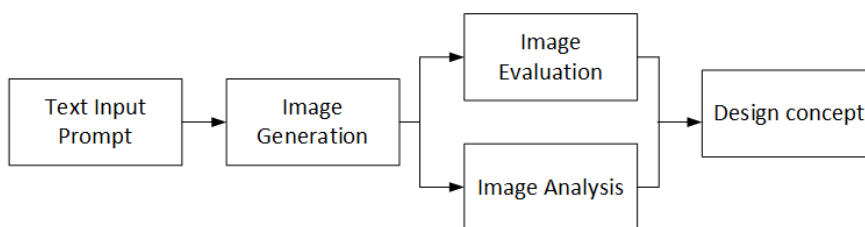


Figure 1: Generation workflow of text-to image design

The developed designs are made on a 3D printer Ender-3 Neo (Creality 3D Technology Co., Ltd., Shenzhen, China).

The following software products were used: Inkscape ver. 1.2.2 (<https://inkscape.org>, accessed on 4 May 2024); AUTODESK TinkerCAD online application (Autodesk Inc., San Francisco, CA, USA); UltiMaker Cura ver. 5.3.1 (Ultimaker B.V., Utrecht, The Netherlands).

3. RESULTS AND DISCUSSION

Four images were created using the text-to-image generators. The following notations are attached:

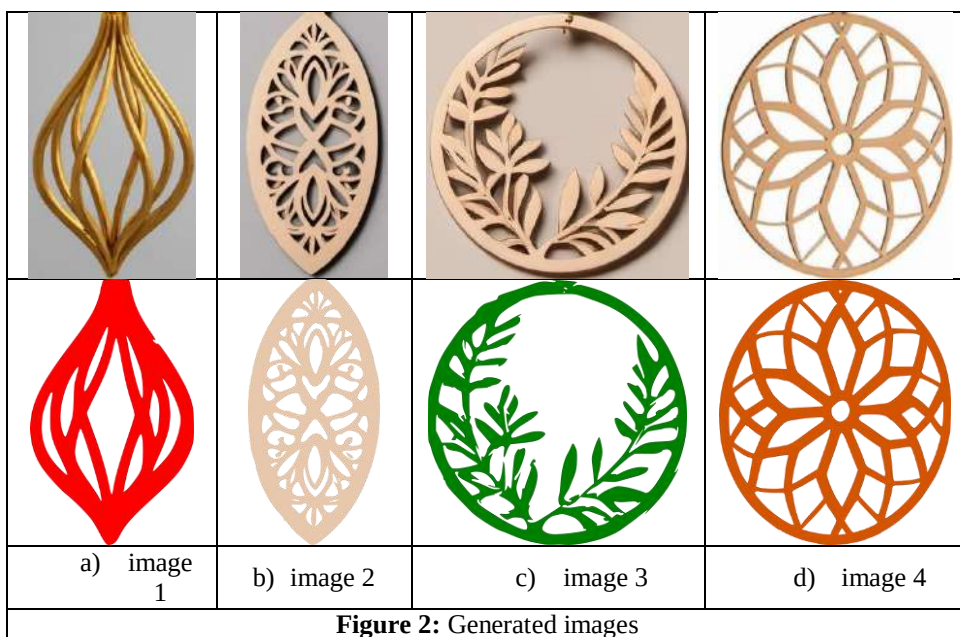
Image 1: "Simple earring, appropriate for 3D printers on a neutral background."

Image 2. "Simple earring, appropriate for laser cut on a neutral background, geometric and floral combination, ellipse."

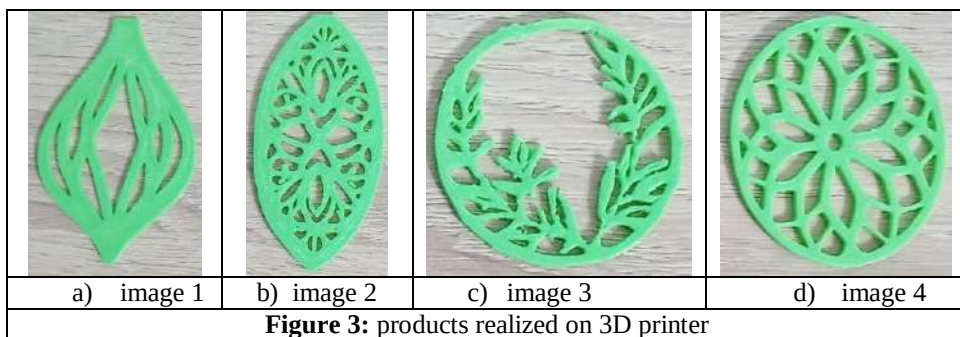
Image 3. "Simple circular flat earring that combines flora and fauna elements, appropriate for laser cutting, on a neutral background."

Image 4. "Circular flat earring with geometric elements that is appropriate for laser cut on white background, drawing."

The designs are presented in Figure2.



The physical products produced are presented in Figure 3. Close-ups are included to highlight intricate details, and shadows are subtly included to give a sense of depth.



After detailed text descriptions were defined for the text-to-image AI generators of the design concepts, the resulting digital images exceeded our expectations. AI tools generate both fashion accessory sketches and photorealistic effects, with many results displaying visually pleasing aesthetics and high quality. Complex design details have been successfully defined in digital fashion images, such as color, shape, material choice, and manufacturing method.



4. CONCLUSION

This research demonstrates the potential of text-to-image AI tools in the generation and development of fashion accessories. These AI tools can be used to assist fashion designers in creating attractive and expressive fashion accessories that meet design criteria and meet consumer needs in terms of functionality, expression, and aesthetics.

In this development, the main limitation of existing AI design developments, which usually only offer digital solutions with minimal implementation in physical products, is removed. By integrating text-to-image tools into our design process, we have successfully translated digital designs into real fashion accessories, bridging the gap between virtual concepts and physical production. The results of this research demonstrate the possibility of converting AI-generated designs into real-world products, greatly improving the practical application of AI in fashion design.

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THE ETHNOGRAPHIC RESEARCH FOR CULTURAL SUSTAINABLE DESIGN

Professional paper
DOI: 10.5937/CT_ITI24040G

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ABSTRACT: The contribution of the designers using ethnographic research in any phase of implementation of design seems to have rooted in the deep understanding of 3Cs of design: concepts, contends, and contexts. Using ethnographic research, designers meticulously document the cultural practices, traditions, and daily routines of the communities they study. This detailed record helps create a comprehensive archive of cultural elements that can be referenced and preserved for future generations. Culturally significant design can profoundly impact sustainability by fostering environmental stewardship, social responsibility, and economic resilience. By utilizing traditional materials and techniques, these designs often employ sustainable practices that have been refined over centuries, such as organic farming methods for natural dyes or hand-weaving techniques that minimize energy consumption. Culturally significant design supports local artisans and communities, promoting fair trade and economic equity, which in turn helps preserve cultural heritage and craft traditions. Moreover, these designs emphasize durability and timelessness over disposable fashion trends, encouraging consumers to invest in high-quality, meaningful items that reduce waste. This approach not only honours cultural heritage but also aligns with sustainable development goals, creating a holistic model that benefits both people and the planet.

Keywords: ethnographic research, textile design, sustainability, culture.

ETNOGRAFSKO ISTRAŽIVANJE KULTURNOG ODRŽIVOG DIZAJNA

APSTRAKT: Čini se da je doprinos dizajnera koji koriste etnografsko istraživanje u bilo kojoj fazi implementacije dizajna ukorenjen u dubokom razumevanju 3C dizajna: koncepta, konkurencije i konteksta. Koristeći etnografska istraživanja, dizajneri pažljivo dokumentuju kulturne prakse, tradicije i svakodnevne rutine zajednica koje proučavaju. Ovaj detaljni zapis pomaže u stvaranju sveobuhvatne arhive kulturnih elemenata koji se mogu referencirati i sačuvati za buduće generacije. Kulturno značajan dizajn može duboko uticati na održivost negovanjem upravljanja životnom sredinom, društvenom odgovornošću i ekonomskom otpornošću. Koristeći tradicionalne materijale i tehnike, ovi dizajni često koriste održive prakse koje su usavršavane tokom vekova, kao što su metode

Savez inženjera i tehničara tekstilaca Srbije



organske poljoprivrede za prirodne boje ili tehnike ručnog tkanja koje minimiziraju potrošnju energije. Kulturno značajan dizajn podržava lokalne zanatlije i zajednice, promovirajući fer trgovinu i ekonomsku jednakost, što zauzvrat pomaže očuvanju kulturnog nasleđa i zanatskih tradicija. Štaviše, ovi dizajni naglašavaju izdržljivost i bezvremenost u odnosu na modne trendove za jednokratnu upotrebu, podstičući potrošače da ulažu u visokokvalitetne, smislene predmete koji smanjuju otpad. Ovaj pristup ne samo da poštuje kulturno nasleđe, već je i usklađen sa ciljevima održivog razvoja, stvarajući holistički model koji koristi i ljudima i planeti.

Ključne reči: *etnografska istraživanja, dizajn tekstila, održivost, kultura.*

1. INTRODUCTION

Cross noted that unlike animals and machines, humans have an innate ability to design [1]. He described design as the pinnacle of human intelligence [2]. As we all know, design involves conceptualization, imagination, and interpretation, and rather than prescribing a specific course of action for task accomplishment, it happens to be a vague, ambiguous process of genesis and formation, often with uncertain starting points, origins, or processes [3]. Due to its application in various processes and interfaces, designers can develop a general theory of design. The most critical step in contemporary design practice is translating the problem into a design, which always relies on intuition because design is inherently imaginative and inspirational [4].

Many researchers have identified a lack of in-depth research and appropriate methods to guide designers on how to consciously integrate culture into product design [5]. Current design approaches with their standards, rules, and guidelines are seen as limited when addressing cultural aspects in design. A specific method is needed in the textile design field to incorporate cultural elements effectively. Methodologically, there is no robust theoretical framework to assist craftsmen in consciously integrating their culture into product design. On the other hand, ethnographic research is one Design-Research (DR) method well-suited for cultural design applications. This method allows designers to identify unmet needs and comprehend the impact of a product within a specific context, thereby aligning products and services more closely with market and consumer needs and reducing the risks associated with introducing new products [6]. It also helps designers understand consumers' actions, desires, attitudes, perceptions, and behaviours.

Many anthropologists and sociologists use ethnographic techniques to understand everyday product experiences and design processes [7,8]. Design researchers have also adopted ethnographic approaches to study the organization of design and engineering processes [9]. Given anthropology's roots in cross-cultural understanding, ethnography has significant potential to enhance our understanding of modern design process. Presenting this extensive activity related to ethnography and design to a broader design audience can prompt discussions about its applicability and value in design education [10]. By engaging from the earliest design iterations, ethnographic approaches can be applied throughout



most stages of the design process, from exploring future users' contexts to testing experience prototypes in situ [11].

This paper outlines a brief framework on how an ethnographic researcher contributes to the preservation of culture within the design domain, discussing impact of culturally significant design on sustainability together with the designer's benefit from ethnographic information.

2. HOW DOES AN ETNOGRAPHIC RESEARCH CONTRIBUTE TO THE PRESERVATION OF THE CULTURE

The concept of culture was first used by natural law philosopher Samuel von Pufendorf in the 17th century [12]. Culture can be expressed as everything that humans produce in order to survive together with nature [13]. Geertz (1973) defines the concept of culture as a system of symbols that informs actions, social order, and world views [14]. This concept has survived until today as a result of nations' maintaining their own beliefs, traditions, customs, lifestyle, understanding and art within themselves and transferring them from generation to generation throughout the historical process. Turkish culture is especially important in terms of understanding of art, as nomadic communities have kept their culture alive in the regions where they have lived for centuries and have been influenced by existing cultures to create new cultural syntheses [15]. One of these cultural syntheses is traditional textile arts.

It is to our belief that using ethnographic research, designers meticulously document the cultural practices, traditions, and daily routines of the communities they study. This detailed record helps create a comprehensive archive of cultural elements that can be referenced and preserved for future generations. Whether it is arts or crafts or other means, the contribution of the designers using ethnographic research in any phase of design seems to have rooted underneath of 3Cs of design: concepts, contends, and contexts. Let's discuss these aspects now:

Concepts

We know that ethnographic research involves observation, field research, and participation to explain the history or the present-day artifacts, routines, symbols, beliefs, rituals, and interactions as well as the historical and emotional significance of the cultural elements. These all form the concepts of cultural design. Designers can use cultural narratives, which tell the story of a community in designing a product. Through personal interviews and storytelling, the designer derives important concepts, which can be incorporated into the product design, packaging, or marketing materials. Designers learn about the shared stories and values associated with their traditions, which helps them understand and uncover the deeper meaning behind these practices, artifacts, and symbols. Through exploring these cultural concepts ethnographic research supports an iterative design process. Initial findings from ethnographic studies can inspire early design concepts, which can then be prototyped and tested within the user community. Feedback from these interactions can be used to refine and improve the design continuously.



The ethnographic methods ensure designers to identify gaps in the market that users themselves may not articulate directly. Observing users in their natural settings can reveal unmet needs and opportunities for innovation that might otherwise be overlooked. Designers often challenge their own assumptions about what users want or need. By demonstrating a clear connection between the research findings and the design choices, designers can build a stronger case for their proposed solutions.

Contents

Designers can emphasize the symbolic meanings of cultural elements in their work. For instance, a traditional symbol representing strength or unity can be integrated into a modern product for awareness and appreciation for the cultural concepts. By witnessing and experiencing the users' realities first-hand, designers develop a deeper emotional connection to their work, which can lead to more thoughtful and human-centered design solutions.

Through their work, designers can help revive and sustain traditional crafts and skills. By incorporating these traditional elements into modern design, they can provide new economic opportunities for artisans and craftspeople, ensuring that these skills are passed down through generations.

Contexts

The cultural context of their target audience results designers to create products and services that are culturally sensitive. This helps to ensure that the cultural values and norms of the community are respected and maintained within the design. By integrating these elements into their designs, they create products that not only resonate with the target community but also educate and inspire a broader audience, fostering appreciation and respect for cultural diversity.

Ethnographic research allows designers to gain a profound understanding of the users' daily lives, challenges, and desires. By immersing themselves in the users' environment, designers can gather rich qualitative data that informs the design process, ensuring that the products or services they create truly resonate with the target audience. This is the user-centric insights which prevent the designer from making mistakes in needs analysis.

Designers often work collaboratively with community members during ethnographic research. This collaboration empowers communities by involving them in the design process and ensuring that their voices and perspectives are represented. This inclusive approach helps preserve cultural identity and fosters a sense of ownership and pride.

The insights and findings from ethnographic research can be shared through various platforms such as publications, presentations, and exhibitions. By educating others about the cultural practices and values of a community, designers can contribute to a greater understanding and respect for cultural diversity. Ethnographic research helps designers understand the importance of cultural continuity.

Designers gather contextual information about how and why certain cultural elements have developed and persisted. This includes understanding the socio-economic, religious, and historical contexts that shape cultural practices and artifacts. Designers benefit from ethnographic research by understanding the broader cultural and social contexts in which



users operate. This context is crucial for creating designs that are not only functional but also culturally relevant and sensitive to users' lifestyles and values.

3. THE IMPACT OF CULTURALLY - SIGNIFICANT DESIGN ON SUSTAINABILITY

Sustainability as a concept was first discussed in 1972 with environmental protection and conscious development issues. In 1987, the Brundtland Report defined sustainability and drew attention to increasing threats. At the Earth Summit held in Rio de Janeiro in 1992, the issue of sustainable development was discussed and Agenda 21, which determined the measures to be taken by the participating countries, was adopted. It was accepted as a three-dimensional model at the World Sustainable Development Summit held in Johannesburg in 2002. After this date, sustainable development was included in the economic and social development goals of the accepting countries and its scope gradually expanded. Essentially, sustainable development is the development process in which the needs of this generation can be met without taking away the opportunities of future generations to meet their needs [16]. Elkington emphasizes that sustainable development should be considered in three dimensions: ecology, sociology and economy - or more commonly known as planet, people and profit (Planet, People and Profit) [17]. Duxbury and Gillette (2007) state that the social dimension has evolved into a cultural dimension [18] as time went by. Therefore, this paper, considers four dimensions of sustainability as ecological sustainability, social sustainability, economic sustainability and cultural sustainability.

The ecological dimension, which is expressed as the first pillar of sustainability, focuses on preserving the vitality of the entire natural environment such as the atmosphere, lithosphere and hydrosphere, with which humans interact, and preventing the waste of natural resources. Thorpe writes, "Everything we use and waste from one of these spheres comes back to us from the other sphere [19]". The social dimension of sustainability means ensuring that everyone participates in production by creating a fair environment and taking measures to include disadvantaged groups in economic life. A socially sustainable system must ensure adequate provision of social services, including equity distribution, health and education, gender equality, political responsibility, and participation. In the economic dimension of sustainability, it is necessary to produce goods and services based on principles that avoid sectoral imbalances and unfair competition that harm other sectors such as agricultural and industrial production. Cultural sustainability, which basically overlaps with the preservation of culture, was proposed as a fundamental dimension in sustainability by UNESCO in 1995 and was defined as the fourth pillar by Jon Hawkes in 2001 [20].

It is for sure that employing cultural significance in design will no doubt provide economic benefits to local communities. By creating demand for culturally enriched products, designers can support local artisans and craftspeople, contributing to the sustainability of traditional crafts. Consider a designer working with an indigenous community known for its unique weaving techniques. Through ethnographic research, the designer learns about the cultural importance of specific patterns and colours used in traditional textiles. By



integrating these patterns into modern fashion items, the designer will not only create a product-line that appeals to contemporary consumers but also raises awareness of the community's rich cultural heritage. The product's marketing might include information about the traditional weaving techniques and the stories behind the patterns, further educating and engaging consumers. At a certain degree, products designed with a focus on cultural significance can educate consumers about different cultures. This can foster a greater appreciation and respect for cultural diversity and add more on cultural sustainability.

Sustainable development highlights the importance of maintaining cultural diversity in any piece of work. Through culturally-significant design, designers can influence public opinion and policy and demonstrates how cultural preservation benefits communities and society as a whole. They can create sustainable solutions that align with the traditional practices and ecological knowledge of a community. By doing so, they help preserve not only cultural practices, artifacts, customs, etc. but also the environments and resources that are integral to those cultures. Using cultural elements in contemporary designs can help bridge the gap between generations, making traditional practices and symbols relevant to younger audiences. This ensures the transmission and preservation of cultural knowledge. When culturally significant designs reach audience, they promote cultural exchange. People from different backgrounds can learn about and appreciate the cultural heritage of others, fostering mutual respect and understanding. In summary, designers using ethnographic research play a crucial role in cultural preservation by documenting, respecting, and integrating cultural elements into their designs. Their work not only preserves cultural heritage but also promotes its appreciation and sustainability in a modern context.

4. CONCLUSION: HOW CAN A DESIGNER BENEFIT FROM ETHNOGRAPHIC INFORMATION?

Textile and fashion designers have been influenced by local ethnic cultures that disappeared years ago and re-adopted these elements to the contemporary taste. The example to this may be given through the case of YSL's African collection of 1967, inspired by Malian and Senegalese culture. The so-called ethnic fashion has come to the fore in the fashion scene at least once every decade since then. Ethnic fashion refers to employing cultural meanings and historically significant elements in clothing and fashion items such as African wax prints, Indian silk saris, Japanese kimonos, and Native American beadwork. Ethnic fashion often aligns with sustainable fashion principles and supports small artisans and local economies by using eco-friendly traditional methods and materials. However, it differs greatly from culturally sustainable production in its concern and context. Being sensitive to cultural sustainability or designing culturally significant collections can be explained in a deeper approach than ethnic fashion production. Culturally significant design aims at preserving and respecting cultural heritage whereas ethnic fashion focuses on aesthetic appeal and commercial viability. Culturally significant design is often created by the members of the culture with a deep understanding of its

significance, making it authentic and original. Whereas ethnic fashion is created by designers who may or may not belong to the culture being represented for the runway collections. We see that culturally significant design is intrinsically respectful of cultural norms and values, whereas ethnic fashion can sometimes cross into cultural appropriation. In all design-driven industries efforts should be given to invest in culturally significant design approach.

The designers who know their own history and culture, who know how to acquire valuable ethnographic information from field-research or ethnographic research methods and who know how to benefit from ethnographic information while designing culturally significant and unique collections, will emphasize the concepts of design (such as methods of research and design, historical and traditional items, tools, equipments etc); contents of design (such as usage habits, values, customs, and rituals of his own culture and society) and contexts of design (such as cultural values and norms of the community, daily lives, community members, shared platforms, design events, competitions, projects, and educational environments etc.) in a culturally significant manner. As the complete revival of the local cultural identity, the creative professionals should generate creative ideas depending on their local culture with the need of refreshment. The only problem lies under the question of how a designer benefits from ethnographic information and how a designer reflects this information on products. This can be explained as follows:

4.1. Expanding the Target Audience:

The ethnographic information can be used to expand the target audience of a design or a collection. Today, touristic-souvenir product designs are becoming increasingly important and play a very important role in the development of products. Instead of focusing on presenting the existing design in different forms, the textile designer should focus on the cultural being or historical value of the item and marketing the product together with the story valuable for the target audience. Finding and creating the idea to change and expand the target audience of the product, shall create a leap in sales figures, and thus shall contribute to its commercial sustainability. Internet sales are always one of the first measures to be considered in expanding the target audience.

4.2. Increasing the Functional Value of the Object:

The ethnographic information can be used to increase the functional value of the product. The commercial sustainability of a textile product is related to the size of the audience it appeals to in the market or simply its sales figures. Without commercial sustainability, it is not possible to transfer a textile product to the next generation even if it is loaded with cultural values. For this reason, the textile designer must also conduct studies on the functional value of a product, determine the habits of the target audience, the purpose for which they use this product through functional analysis and market research, and work on these issues in order to increase or popularize the functional value of the product. In this regard, it is a research subject for ethnography to study the past and present functions of products, the changes in habits, etc. The designer can study modular designs by creating garments with interchangeable parts or simply by adapting items to different functions or



styles. The designer also can incorporate adjustable elements such as drawstrings, zippers, or Velcro to fit different body types and preferences. It is also the designers must to study sustainability principles such as eco-friendly materials, utilizing recycled fibres, organic cotton, or biodegradable materials to reduce environmental impact. The functional value lies also in energy-efficient production activities. Implementing processes that require less water and energy, contributing to the overall sustainability of the product will also add much on the increasing the functional value of the design.

4.3. Increasing the Design Value of the Object:

The ethnographic information can be used to increase the design value of the product. A textile designer must have a different perspective than a traditional craftsman when evaluating a textile product. The textile product must undoubtedly be functional and meet the needs of the user, facilitate human life, in short, be useful. However, it should also have design value. Design is a problem-solving act. When solving the problem, you need to achieve aesthetic results with optimal resources and rational decisions. However, the designer is responsible for ensuring that this design differentiates itself from other products. In this case, the textile designer should focus on details that no one else thinks about and create a valuable and original product that is innovative, up-to-date and compatible not only with technological developments but also with cultural/historical stories. Only in this way does this textile product become a product with high design value. Placing technological innovations in a daily-use product or embodying a scientific invention in a textile product will be as effective as embedding a culturally significant story in the product. By these factors the designers would increase the design value of the object and increase its preference among its counterparts.

4.4. Increasing the Aesthetic Value of the Object:

The ethnographic information can be used to increase aesthetic value of the object. It is generally accepted that the impact of design costs on the market share and value is around seventy percent, as they account for five percent of the production costs in the textile industry and generally deal with aesthetic elements such as form, surface design and material design. Studies on the aesthetic value of textile design will lead to the product being understood and accepted by a wider audience. An effort to improve the aesthetic value of the textile product will be effective in creating an identity for the visual effect of the textile product. The textile designer should also strive to increase the aesthetic value of the object by creating a link between the generally accepted aesthetic values of the society and the design identity. Because, as sociologists have stated, aesthetic judgments are generally formed as a result of the acceptable visual effect. It is through methodological cultural research that the designer will understand the symbolism and the cultural significance of the motifs, or the techniques. Studying the historical evolution of designs within the culture to appreciate how traditional aesthetics have developed and adapted over time will ensure that the cultural context and thoughtfully integrating of the traditional elements into designs. The designers shall create objects that not only enhance aesthetic



value but also honour and celebrate cultural heritage with incorporating elements that communicate cultural narratives, myths, or historical events.

4.5. Increasing the Added Value of the Object:

Today, sustainability and nature-friendly production have become an important goal in the textile industry, as in many other sectors. As a result of the environmental movement that emerged in the early 1970s, environmental awareness and conscious consumption issues have become important for consumers, and environmentally friendly production has become important for consumers who produce within the framework of social responsibility. Products of sensitive companies have started to be preferred. Over the past fifty years, the awareness experienced in the purchasing decisions of consumers around the world has also manifested itself in an industry with high waste levels such as Textile. Many concepts such as Green Textiles, Organic Textiles, Ecological Textiles, Ecological Design, Design for the Environment, Sustainability, Life Cycle Assessment LCA, Sustainable Design (D4S) have entered the design domain. In the ecological production process in line with the demands of consumers, it is of great importance to choose environmentally friendly raw materials and clean production methods. However, from a broader perspective, the evaluation of the ecological aspect of design, which is inextricably linked with technology and adds value to the textile product, should not be ignored. The most important responsibility of a textile designer is not to adopt a design approach that harms the environment and leads to careless use of natural resources in all designs.

To conclude ethnographic research can contribute to the fashion and textile design through 3Cs of design. Ensuring that the design respects the cultural norms and values, avoiding appropriation by understanding and honouring the cultural context, textile designer is responsible in sustainability and tries to carry out positive activities for the planet. Culturally significant design can profoundly impact sustainability by fostering environmental stewardship, social responsibility, and economic resilience. By utilizing traditional materials and techniques, these designs often employ sustainable practices that have been refined over centuries, such as organic farming methods for natural dyes or hand-weaving techniques that minimize energy consumption. Culturally significant design supports local artisans and communities, promoting fair trade and economic equity, which in turn helps preserve cultural heritage and craft traditions. Moreover, these designs emphasize durability and timelessness over disposable fashion trends, encouraging consumers to invest in high-quality, meaningful items that reduce waste. This approach not only honours cultural heritage but also aligns with sustainable development goals, creating a holistic model that benefits both people and the planet.

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DESIGNING EFFICIENCY: ANALYZING THE IMPACT OF PRODUCT DESIGN ON GARMENT MANUFACTURING COSTS

Professional paper
DOI: 10.5937/CT_ITI24041M

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ABSTRACT: This study investigates the influence of product design on the cost of manufacturing garment products. By examining design elements and their direct impact on production expenses, the research aims to identify key factors that contribute to cost efficiency in garment manufacturing. Data was collected from two design approaches to the product, comparing the end results. The findings reveal that strategic design choices can significantly reduce material waste, labor time, and overall production costs. This study highlights the importance of integrating cost-effective design principles in the garment industry to enhance profitability and sustainability.

Keywords: garment industry, design efficiency, production cost, sustainability.

EFIKASNOST DIZAJNA: ANALIZA UTICAJA DIZAJNA PROIZVODA NA TROŠKOVE PROIZVODNJE

APSTRAKT: Ova studija istražuje uticaj dizajna proizvoda na cenu proizvodnje odevnih proizvoda. Ispitivanjem elemenata dizajna i njihovog direktnog uticaja na troškove proizvodnje, istraživanje ima za cilj da identifikuje ključne faktore koji doprinose isplativosti u proizvodnji odevnih predmeta. Podaci su prikupljeni iz dva dizajnerska pristupa proizvodu, upoređujući krajnje rezultate. Nalazi otkrivaju da izbori strateškog dizajna mogu značajno smanjiti otpad materijala, vreme izrade i ukupne troškove proizvodnje. Ova studija naglašava važnost integrisanja isplativih principa dizajna u industriji odeće kako bi se povećala profitabilnost i održivost.

Ključne reči: odevna industrija, efikasnost dizajna, troškovi proizvodnje, održivost.

1. INTRODUCTION

In the competitive garment industry, manufacturing costs are crucial for profitability and sustainability [1]. The cutting room, a pivotal stage in production, offers significant opportunities for cost savings. The design of a garment not only affects its aesthetics but also directly impacts manufacturing efficiency and costs. Effective product design decisions, such as pattern layout and fabric selection, can substantially reduce fabric waste and material costs. Optimizing cutting techniques further enhances labor productivity and minimizes resource expenditure [2].

This study examines the impact of product design on garment manufacturing costs, focusing on savings in the cutting room and fabric consumption reduction. By comparing two design approaches, the research aims to identify key factors that enhance cost efficiency [3]. The findings will provide valuable insights for designers and manufacturers seeking to improve profitability and sustainability in the garment industry.

2. METHODS

To investigate the impact of product design on garment manufacturing costs, we conducted a comparative analysis of two sweatshirt designs. The first design featured a single front, back and sleeves pattern piece, while the second design consisted of a front, back and sleeve pieces each composed of three pattern pieces. This study aimed to evaluate fabric consumption and cutting efficiency for both designs. Specialized CAD software is used for this experiment [4,5].

Design and Pattern Layout

Sweatshirt 1 (Single Piece Design):



Figure 1: Sweatshirt 1 (Single Piece Design)

Front, back and sleeves each made from a single pattern piece.
Simple, continuous design.

Sweatshirt 2 (Multi-Piece Design):



Figure 2: Sweatshirt 2 (Multi-Piece Design)

Front piece, back piece and sleeves each composed of three separate pattern pieces.
More complex, segmented design.



Figure 3: 3D simulated layout of the patterns for the Sweatshirt 2 [6]

Marker Creation

Markers were created using CAD software for both sweatshirt designs in three sizes: Small (S), Medium (M), and Large (L). The width of the fabric used for both designs was kept constant at 160 cm to ensure consistency in comparison.

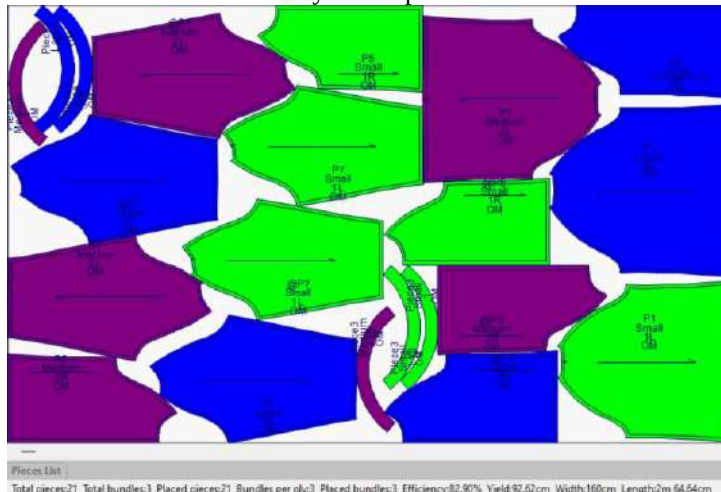


Figure 4: CAD marker layout result for Sweatshirt 1

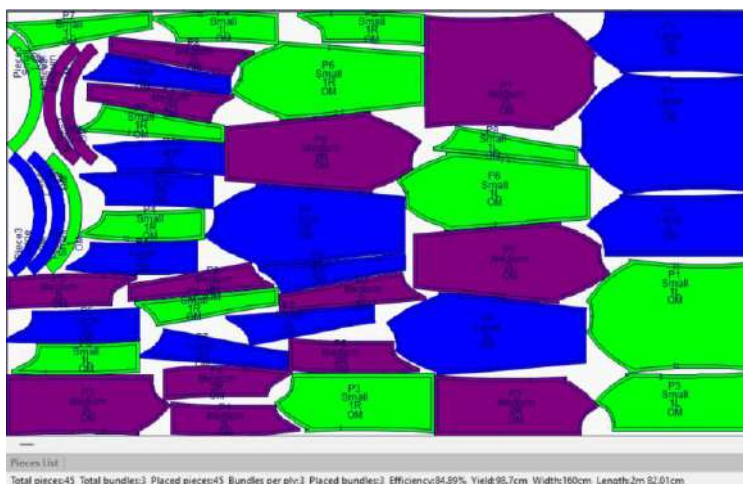


Figure 5: CAD marker layout result for Sweatshirt 2

Fabric Utilization

The length of the marker, which represents the total length of fabric required for cutting all pattern pieces of a single sweatshirt in all sizes, was measured for both designs. For the Sweatshirt 1, the marker length was 2.65 meters. For the Sweatshirt 2, the marker length was 2.81 meters.

Results

The comparison of fabric consumption between the two sweatshirt designs revealed significant differences:

Sweatshirt 1:

Marker length: 2.65 meters, 82.90% utilization.

Fabric utilization: This design demonstrated more efficient use of fabric due to fewer pattern pieces, resulting in less fabric waste.

Sweatshirt 2:

Marker length: 2.81 meters, 84.89% utilization.

Fabric utilization: The increased number of pattern pieces in this design led to a higher marker length, indicating more fabric was required. The complexity of the pattern also likely contributed to increased fabric waste.

Table 1: Results of the analysis

Design	Marker Length (meters)	Fabric Utilization Increase (%)	Fabric Utilization Efficiency (%)	Yield (cm)
Sweatshirt 1	2.65	0	82.9	92.62
Sweatshirt 2	2.81	6.037735849	84.89	98.7

Comparative Analysis

The results indicate that the Sweatshirt 1 design is more fabric-efficient compared to the Sweatshirt 2 design. The marker length difference of 0.16 meters translates to approximately 6% more fabric required for the multi-piece design. This increase in fabric consumption not only elevates material costs but also impacts overall production efficiency. Fabric utilization efficiency percentage wise is better in Sweatshirt 2 design due to the shape characteristics of its pattern pieces, while fabric consumption per product unit is better in Sweatshirt 1 (92.62cm) while Sweatshirt 2 requires 98.7cm. [7]

3. CONCLUSION

This study underscores the significant impact of product design on fabric consumption in garment manufacturing. It showed the importance of considering and adopting a design solution from an economic point of view, depending what effect on the market the manufacturer wants to achieve in terms of competitiveness, quality and expediency, it is important to consider this aspect in the decision-making process. By adopting simpler, faster to produce designs, manufacturers can achieve substantial savings in fabric usage and time savings thereby reducing material costs and enhancing production efficiency, while at the same time this can have an affect on the end product quality in both direction. The findings highlight the importance of considering fabric utilization in the design phase



to optimize manufacturing costs in the garment industry and it calls for further analysis and research of the subject.

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3D VIRTUAL SIMULATION OF CLOTHES FITTING AND FABRIC DRAPING

Original scientific paper
DOI: 10.5937/CT_ITI24042J

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ABSTRACT: The primary goals of CAD/CAM systems are to promote designer productivity and enhance design quality. Simultaneously, the general level of competition among the companies in the industry can also be increased. Recently, many CAD systems have offered the construction of three-dimensional models, which may be seen on various avatar models and from multiple angles. One of the largest obstacles to fashion design and production is the evaluation of garment fit, be preserved, exhibited, and reconstructed in new ways. The aim of this study is to demonstrate how using the computer program Clo3D, it is possible to compare one female dress model on different avatars, and 3D Virtual material draping with various fabric weights may be selected without the need for real sample stitching. Engineers and designers can use many tools and features provided by Clo3D to produce and express 3D clothes in a realistic virtual way.

Keywords: Clo3D, virtual, fit, avatar, drape.

3D VIRTUELNA SIMULACIJA PRISTAJANJA ODJEĆE I DRAPIRANJA TKANINE

APSTRAKT: Primarni ciljevi CAD/CAM sistema su promovisanje produktivnosti dizajnera i poboljšanje kvaliteta dizajna. Istovremeno se može povećati i opšti nivo konkurencije među kompanijama u industriji. Nedavno su mnogi CAD sistemi ponudili konstrukciju trodimenzionalnih modela, koji se mogu videti na različitim modelima avatara i iz više uglova. Jedna od najvećih prepreka modnom dizajnu i proizvodnji je procena pristajanja odeće da se sačuva, izloži i rekonstruiše na nove načine. Cilj ove studije je da se demonstrira kako je pomoću kompjuterskog programa Clo3D moguće uporediti jedan model ženske haljine na različitim avatarima i odabrati 3D virtuelni materijal sa različitim težinama tkanine bez potrebe za šivanjem stvarnog uzorka. Inženjeri i dizajneri mogu da koriste mnoge alate i funkcije koje pruža Clo3D da bi proizveli i izrazili 3D odeću na realističan virtuelni način.

Ključne reči: Clo3D, virtuelni, fit, avatar, drape.



1. INTRODUCTION

Changes in the socio-cultural and economic fields have an impact on the textile and apparel industries. The fashion industry's increasing digitalization is in line with digital fashion, which can adapt quickly to changing consumer desires [1]. The traditional fashion sector is being transformed by digital solutions, which are made necessary by the digital economy [2]. The fashion business was compelled to undergo a digital revolution during the COVID-19 pandemic and other new social and economic conditions due to the rise of a noncontact community [3]. Consequentially, in the fashion sector, a dramatic shift in consumer behavior towards stronger online buying was recently noticed, and e-commerce is increasing at an unprecedented rate too [4]. On the other hand, in reality, a sizable portion of these online orders are returned, mostly for fit and size-related issues. Customer returns have increased significantly over the previous few years, with some categories seeing increases of up to 50% annually [5]. Regarding this, garment producers spend a lot of time trying to get approval for garment fit from their buyers. Therefore, E-fit simulation saves a substantial amount of time and eliminates the requirement for numerous sample approval iterations [6, 7]. Using digital patterns, the E-Fit Simulator creates "virtual cloth" that can be "sewn" on a computer and evaluated on a 3D fit model directly within the software. This allows the user to see exactly how the garment will look before sewing it as an actual sample.

Making cloth is an artistic procedure that entails shaping and cutting a piece of flat material to match the contours of a human body. Fit, which serves as a connection between design and production, is the most crucial element determining whether an item of clothing is eventually accepted or rejected. To ensure a good, customized fit, design drawings must consider the various forms and proportions of each customer [8]. The five main procedures that are typically included in clothing CAD systems are 2D pattern design and prepositioning, drape simulation, virtual sewing, and 2D or 3D design adjustment. Here, the technical difficulty of virtual fit resides in fabric simulation combined with human torso models that consider geometric contact points [9]. In the process of developing new clothing, it's crucial to prototype and evaluate fit. 3D garment simulation offers the ability to do away with the requirement for numerous physical prototypes. Thanks to advancements in 3D simulation technologies, 2D garment models may now be virtually fitted on human body simulations using specific apparel CAD software [10]. "3D pattern making" is the process of employing specialized software to create 3D digital clothing designs [11]. During this process, in a virtual setting, pattern parts must be created, modified, and altered. Compared to traditional 2D manual pattern building, 3D pattern manufacturing offers several benefits, such as enhanced visualization, quicker design iterations, and the capacity to model garment fit and behavior in a virtual setting [8]. It is anticipated that this makes clothing production more exact and productive in terms of time and cost savings of up to 30%, which benefits also in saving money [12]. As a result, there is less waste and more material used. Using fewer samples means fewer fabrics and other materials and a reduced carbon footprint too [13, 14]. Clo Virtual Fashion Inc. created Clo3D, a 3D program for the design and visualization of fabrics and

clothes. An excellent resource for assessing fit, seeing items in action, and experimenting with various fabric and color choices is the virtual design application Clo3D. Furthermore, patterns can be exported in several different formats [15].

According to Liu, Zhang, and Yuen [16], the assembly phase of clothing simulation cannot be based on a standardized model because fabrics are anisotropic throughout their entire surface and will drape differently depending on the cut, type, and components of the garment. The fabric must behave, look, and drape exactly like the actual sample to create a true-to-life virtual clothing sample, or digital copy, and all fabric data can be maintained in one central location [7]. The new virtual showrooms (Hugo Boss, PVH) [17, 18] created by businesses like Hatch and Pixelpool substitute a significant number of B2B samples and colorways with virtual samples backed by actual fabric samples. Studies on the usage of this virtual technology have identified variables such as clothing complexity, material visualization information, and virtual manikin type that could adversely affect the quality of 3D apparel simulation if they are not appropriately selected and imported [10]. The paper by T. Spahiu et al. [9] provides a short review of available CAD systems used by fashion designers. A garment simulation process is performed by using software for virtual design, Marvelous Designer and the used is gathered from the 3D body scanning system named Konica Minolta VIVID 910. In the study [19] 2D pattern for men's shirt are constructed using CAD software and afterward 3D simulation is performed. Another study [20], through avatar personalization, aims to display the outcome of the human body on garment fit, by generating stress, strain, and fit maps. Pressure levels are shown in various color shades throughout the body simulation, allowing for subjective fit assessment. Objective fit valuation is made possible by numerical values shown on a scale bar. Specific apparel CAD tools handle parametric models and body scan avatars as solid objects. The computer-based textile models that are used to mimic clothing have a significant impact on the correctness of virtual fit [21]. The paper [22] present the final model of women's pants in 3D clothing simulation in different avatar poses, their fitting, fabric pressure and distortions.

By analyzing pressure prediction accuracy and process practicability, Brubacher et al. assessed the viability of applying the virtual fit pressure map in a textile CAD program to anticipate pressures applied by sports and recreation compression clothes. Using these specific apparel CAD tools, several researchers have evaluated the accuracy of virtual fit simulations. They have compared virtual and real garment fit on mannikin [23] or human bodies [24, 25]. Although Lee & Park [24], noted issues with the realistic modeling of specific fit indicators, such as tiny fabric creases and draglines, they claimed that overall fit simulations were accurately done [24, 25]. The absence of technical construction data, like stitch tension and thread type, is probably the reason for this, which could lead to the discovery of less fit issues in virtual clothing compared to genuine clothing [25]. Heat maps have been used by other researchers [26, 27] to assess virtual garment fit in CAD programs, but none of them have made a straight examination between heat maps and actual garment fit. Test results from the Kaixuan et al. [28] paper show that data-learning-based clothing fit assessment approaches have much higher prediction accuracy than conventional methods.



Understanding the actual state of manual pattern making and the use of specific 3D fashion design software in the textile industry is the main objective. The Clo approach was evaluated for some fit assessment possibilities, like fabric drape, creation of strain, stress, pressure, and fit maps for specific garments on different avatars.

2. EXPERIMENTAL PART

Using the Clo3D - specific apparel CAD/CAM computer program, this paper presents a comparison of one female dress model on different avatars. The initial step in the creation of clothing is garment design. Historically, clothing has been designed by hand using paper designs or fabric draped over a dress form. However, today's designers convey their ideas through technological tools. So, using Clo3D we can make an informed decision on the final garment, the distribution of contact points, and the pressure distribution range. Also, this software can fully satisfy several design needs, including fabric selection, fashion design, pattern creation, adjustment and alteration, presentation, and release.

Another crucial issue in virtual apparel is the selection of the avatar which can be taken from the computer library or to be adjusted by the designers (height, waist, chest, hip length etc). Therefore, in this research we have used the following avatars: Tall 36, Petite 36, Curvy 40 and Plus 48 for the same model of women's dress.

The clothing size affects the physiological fit component, and tight or loose clothing is the most obvious sign of fit issues brought on by size. For better understanding of virtual garment fit, the Clo3D generate four types of maps: Stress, Strain, Pressure and Fit map. In this research, for the Petite avatar, all 4 types of maps have been created that clarify the fit of the clothes to the body.

The "Stress map" displays the range of color (eight colors) and figures that indicate the amount of pressure in the fabric per part because of a tight-fitting clothing. The blue represents no distortion (0.00 kPa), whereas the red indicates the highest stress (100 kPa). The precise location's kPa value displays when you click on a spot on an article of clothing. Stronger tension is applied from the avatar to the garment and vice versa when the kPa value is larger. The "Strain map" shows the percentage change in the garment's distortion rate as a result of external stress. Thus, the degree to which the garment is stretched while being worn is visible. There are eight colors available for this map: red denotes a distortion rate of 120 %, while blue denotes a distortion rate of 100%. More distortion between the 2D patterns and the 3D patterns (garment) on the avatar is indicated by a greater percentage number, and vice versa. Based on the distortion rate, we can adjust the 2D patterns as needed. The "Pressure map" is really like a Strain map. The strain map shows the amount of tension brought on by the pressure itself, whereas the pressure map depicts the pressure of the garment on the virtual model. Finally, the 3D garment's tightness is displayed on the fit map. The wearable region marked "Can't Wear" is red. "Tight areas" are displayed in yellow, and "Very Tight" appearances are visible in orange. Display Press Points: Display or conceal the points of contact between the avatar and the 3D garment. If the virtual model is appropriate for wearing this dress, it is determined by looking at the fit map.

Besides, the fit prediction and analysis, this program can provide a prediction of the drape of a needed fabric. To generate a digital fabric, this 3D virtual technology combines the physical and mechanical characteristics of the fabric with its weight. So, several materials are analyzed in this manuscript.

3. RESULTS AND DISCUSSION

3.1. Virtual fit of women's dress

Figure 1 represents the different types of avatars in the same dress pattern. All models are presented from the front, back, and side, to see the appearance of the dress more realistically.

This dress model has a length of several centimeters below the knees, except for the first avatar, where, due to its height, it reaches the length of the knees. The folds of the model on the front are less noticeable in the Tall and Petite avatars, while in the other two, they are more pronounced and extend to the side seams.

The difference between the avatars in terms of their height and other body measurements is evident. Using Clo3D it is obtained a visual presentation of how this model will fit clients with body dimensions like those of the corresponding avatar. This virtual presentation is highly accurate, so, in this way, we can avoid real (physical) sewing of the model if the customer is not satisfied with the cloth appearance.

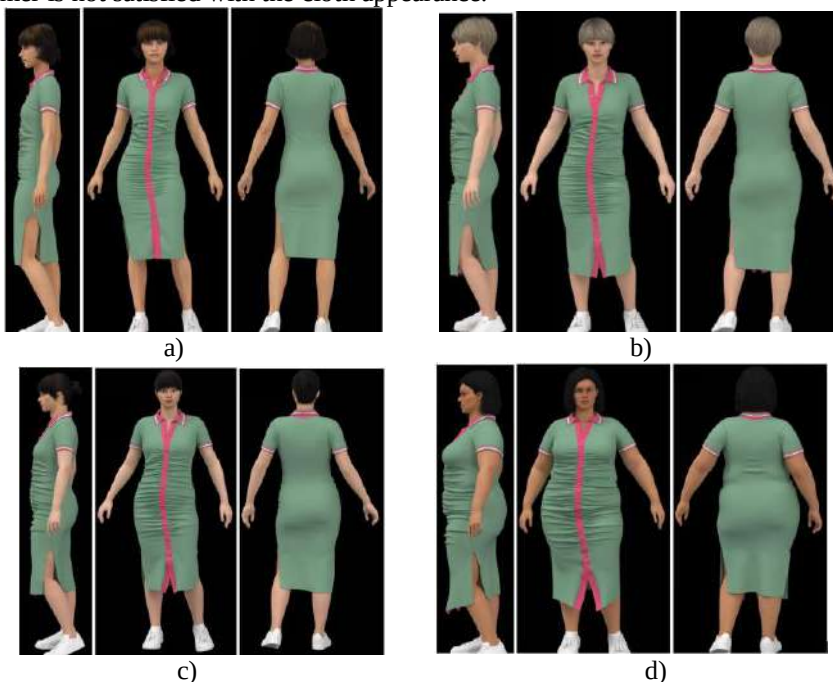


Figure 1: Dress model on four different avatars in front, back, and sides: a) Tall 36;

b) Petite 36; c) Curvy 40; d) Plus size 48

Thus, saving time and money are obtained. Specifically, the time and cost needed to make a real sample of the clothes is reduced, or it will be completely avoided.

For better comparison, Figure 2 presents all types of avatars.



Figure 2: Dress model on four different avatars, lateral side

Next, by using the possibilities offered by the Clo3D software, more precisely the different maps give insight into the fitting of the model to the body of the person/avatar. Figure 3 (3a-3e) shows all four types of maps, for the Petite avatar.



Stress map
a)



Strain map
b)



Pressure points
c)

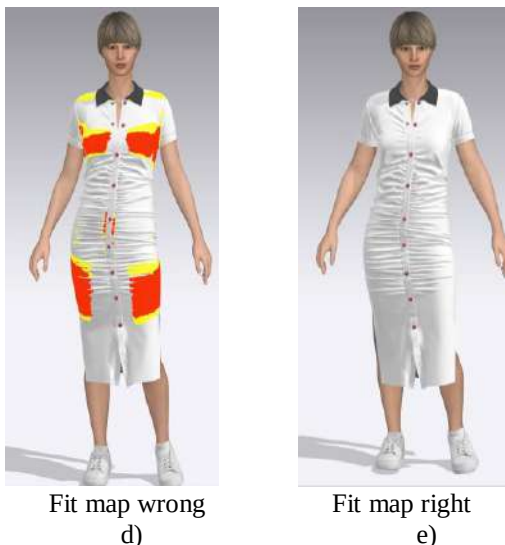


Figure 3: a) Stress, b) Strain, c) Pressure, d) Fit maps wrong and e) Fit maps right for Petite avatar

The stress, strain, and fit maps that were produced during the simulation process of garment models over customized avatars allow for the evaluation of garment fit. So, based on the Stress map (Figures 3a and 3b) and the meaning of its colors, it is evident that this dress is pretty comfortable for the Petite avatar. Slight dress distortion is noticeable in the chest area, hips, and below them (lower thighs). Based on the generated Strain map, it can be concluded that 120% of garment distortion is evident on several points, like: along the armhole, the end of the sleeve, on the sides at the hips, and in the middle along the button fastening part. So, through the strain map, it can be seen how much the deformation of the garment fabric occurs after being worn on the virtual model. While, corresponding to the previous introduction, clothing pressure on the human body has more than the human body can bear (Figure 3c). The Fit maps (Figures 3d and 3e) present the tightness of the 3D Garment, and the model's clothing is divided into two colors. So, in this dress model, “tight areas” (yellow) are in the shoulder, around the chest, and along the upper and down part of the thighs. The “Can’t wear” area stands around the chest and middle part of the thighs (red color). So, in the yellow area, can be made some modifications according to the effect achieved by the clothes. The red part must be adjusted, otherwise, this part of the clothing cannot be worn ordinarily that is, it would be less comfortable to wear.

3.2. 3D Virtual material draping with various fabric weights

Regarding the method of draping different types of materials, an analysis was made with the help of this program. According to the requirements of the program, some of the physical-mechanical characteristics of the fabrics are recorded, and their design is also

recorded. In this way virtual twin of the real fabric can be generated. In Figure 4 several materials of different fibre composition and fabric weight are presented.



Sherpa fleece - 160g



Sherpa fleepoly - 280g



Leather lambskin - 329g



Cotton poplin - 130g



Cotton oxford - 181g



Cotton corduroy - 290g

Figure 4: 3D draping of fabric with different weight

The way of drapery and the number of nodes can be evaluated. So, this activity can help in determinating which fabric is suitable for a particular model of clothing.

4. CONCLUSION

CAD is an inevitable element for the garment industry in order to deal with today's hard competition. 3D technology for clothing design and simulation are promising methods for producers and designers to promptly check the problems related to clothing fit and drape over personal avatars by prevent misunderstanding and subjectivity in representation. This is a new way to increase the cooperation between clothing designer, pattern maker and sellers to meet the client needs and to provide good-wearing clothes for the human body. In this research we have used the Clo3D program for simulation of garment fit on different avatar bodies. Based on the generated maps for the stress, strain, pressure, and fit points, we received information for the further needed modifications and pattern modelling to provide appropriate dress fitting. The program was also used and for drape simulation of several different fabrics. Of course, this software has many other possibilities which can be used. Beside the high accuracy of this kind of programs, still, future evolution in needed to be obtained soft tissue avatars and a more realistic fabric drapability and garment-body interface.

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DIGITAL FASHION CONCEPT: DIGITAL FASHION HOUSES

Review scientific paper
DOI: 10.5937/CT_ITI24043Y

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ABSTRACT: The paper presents fashion houses in the realm of digital fashion. This research considers the potential of cutting-edge digital technologies in fashion design, including the implications of digitalism in this field and the relationship between creativity and sustainability in a digital context. The focus is on the integration of digital technology and fashion design. It is importance to emphasize the positive impact that digital technologies have on sustainability. The expansion of digital technologies has facilitated the emergence of sustainable consumption alternatives.

Keywords: Digital fashion, digital clothing, digital fashion house, fashion industry.

DIGITALNI MODNI KONCEPT: DIGITALNE MODNE KUĆE

APSTRAKT: Rad predstavlja modne kuće u domenu digitalne mode. Ovo istraživanje razmatra potencijal najsavremenijih digitalnih tehnologija u modnom dizajnu, uključujući implikacije digitalizma u ovoj oblasti i odnos između kreativnosti i održivosti u digitalnom kontekstu. Fokus je na integraciji digitalne tehnologije i modnog dizajna. Važno je naglasiti pozitivan uticaj koji digitalne tehnologije imaju na održivost. Ekspanzija digitalnih tehnologija olakšala je pojavu alternativa održive potrošnje.

Ključne reči: Digitalna moda, digitalna odeća, digitalna modna kuća, modna industrija.

1. INTRODUCTION

The term technology, derived from the Greek words technē ("art, craft") and logos ("word, speech"), initially referred to a discourse on the fine and applied arts. By the mid-20th century, the term 'technology' had been redefined by such phrases as "the means or activity by which human seeks to change or manipulate his environment" [10].



If the social conditions and circumstances are conducive, technology develops over time in a progressive manner, whereby each generation is able to utilize the accumulated technical expertise of its predecessor in order to innovate. An important feature of the moving technology forward was the advance in power technology. During the first Industrial Revolution between 1760 and 1830, the introduction of the steam engine enabled the general mechanization of production, replacing the artisanal methods of individual 'know-how' with the high and rapid production of consumer goods [2]. 2nd and 3rd Industrial Revolutions between in the late 19th-20th centuries use of electric power led to the development of computer and automation systems. Current information technology and digital transformation is based on electric power and the process of changing from analog signal to digital data.

The term 'information technology' was first defined in the article named "Management in the 1980's" published in the Harvard Business Review in 1958. According to writers Harold J. Leavitt and Thomas L., [1]. "information technology is summarized by techniques for processing large amounts of information quickly and high-speed computers".

Technological developments continue to change and shape our way to live throughout human history. The 21st century has seen a digital transformation revolution of information and communication technologies (ICTs) have reshaping our world as industrial revolutions had a major impact on the development of the textile and fashion industry. In recent years, digital transformation has emerged as a significant phenomenon in the field of fashion. The integration of 2D and 3D CAD (computer-aided design) software, mobile devices, VR (Virtual Reality), AR (Augmented Reality), ICTs, and social media has led to the emergence of the phenomenon known as 'digital fashion'. The term 'digital fashion' is used to describe clothing that is not physically manufactured, but instead produced digitally [11].

The global COVID-19 pandemic has precipitated that digital transformation in the fashion industry, particularly in the context of the industry's response to the lockdown. In 2021, fashion week live streams, metaverse fashion shows, digital activations, and AR/VR runways were presented online. It became increasingly evident that there is a growing trend of collaboration between technology companies and global fashion brands. Luxury fashion brands have created digital clothing for gaming platforms (Roblox X Gucci Town, Zepeto & Ralph Lauren) or video games player skins (Fortnite X Balenciaga, The Gran Turismo X Dior, Minecraft X Burberry, Need for Speed X Balmain) as well as digital fashion items and fashion NFTs. The growing engagement with the internet, social media, video gaming, and virtual universes is also stimulating interest in digital fashion. Conversely, some forward-thinking fashion designers have established digital fashion houses, which are thought to have a more profound impact on the fashion industry. The advent of VR and AR technologies has enabled designers to create virtual garments and users wear them through virtual reality.

The purpose of this paper is to provide a definition of digital fashion created through digital technologies and to introduce the concept of digital fashion houses.

2. DIGITAL FASHION

The scope of the concept of digital fashion is not yet fully described, and the manner in which it should be defined in the literature is an actual topic that is attracting the interest of academic researchers. Nobile, Noris, Kalbaska, and Cantoni [3].defined the term as “*Digital fashion involves all those processes that include (i) marketing and communicating tangible and intangible products; (ii) the development and implementation of processes that support the advancement of the industry; (iii) the effects of digital advances on society*”. Sayem [6] stated that: The innovations in digital fashion can be grouped into four main categories: “*Digital design and e-prototyping, digital business and promotion, digital human and metaverse, digital apparel and smart e-technology*”. The term is summarized by Baek et al. [4] as “Digital fashion is the virtual creation, production, and representation of one’s identity via computer-generated design”. According to Särnäkari [5]. the term 'digital fashion' is used in various contexts by the media and practitioners to refer to different types of digital products and processes. It encompasses tools for virtual product development and visualization, marketing and educational materials for online stores and virtual museums, and digital end products intended for virtual use. The 3D file serves as a repository for all the garment and material data that can be utilized across various platforms.

The technologies that we had developed over the past centuries have enabled the efficient utilisation of energy resources and increased product capacity. Nevertheless, the advanced technologies generated carbon-intensive industries also resulted in environmental pollution. The environmentally polluting production and consumption cycle of the fashion and textile industry has been leading to the search for alternative solutions in the field of fashion. Although there is a growing emphasis on sustainable products and circular fashion system, the advanced of digitalisation has led to suggestions that it might offer an alternative model to traditional production and consumption behaviors. According to Black [9] there is a widespread opinion that the current state of fashion is undergoing a profound transformation. Development of novel business models for the fashion industry with the dual objective of reducing consumption and increasing delight, while leveraging the advantages of digital technologies, could prove to be a pivotal contributor to a sustainable future. In this context, Särnäkari's definition of 'digital end-products for virtual use' can be interpreted as a reference to digital clothing in the evaluation of digital fashion within the scope of sustainable fashion products.

b. Digital Clothing

Computer-aided design (CAD) programmes has enabled the creation of two-dimensional (2D) designs within the fashion industry since the 1980s. The advent of three-dimensional (3D) virtual reality technology has led to the widespread use of digital clothing as a tool for the design and virtual prototyping of garments and textiles in the field of product design. Some virtual try-on software, such as CLO 3D, MarvelousDesigner, TUKA 3D, Browswear, OptiTex, Lectra 3D Prototype has been in use for several years. Three-dimensional softwares offer a number of advantages such as effective design process, visual fidelity including lower cost, time saving, improved efficiency, ease of access and higher accuracy [7].



According to Chan et al. [8], there is no research that explores digital fashion exclusively as a virtual end-product, with the exception of Särmäkari's (2021) study, which describes it as both a tool and a digital end product.

ICT that have developed with the Internet have enabled social media to emerge as a new form of self-expression. The advent of digital platforms has enabled individuals to disseminate their own comments, images and videos online, thereby facilitating the sharing of their personal lives and experiences. Social media and gaming platforms has transformed the landscape of social interaction. Explained by Särmäkari [5] “Digital-only fashion tackles the expression function, already virtualized by the social media.”

The concept of digital fashion may appear to be a relatively novel phenomenon, but in fact, digital gamers have spent a considerable sum of money purchasing virtual clothing for their avatars for years [12]. Beside gamers, social media users have access to a plethora of digital filter and application that allow them to modify their appearance in pursuit of aesthetic enhancement. The interaction of users with new media results in the creation of alternative digital identities, whereby they manipulated their physical appearance in their posts. The widespread of digital socialisation has also helped give rise to digital fashion, including digital clothing.

Forbes magazine reported in May 2019 [13] that a panel on the topic of sustainability, organised by the London-based enterprise *Favourup* and attended by Instagram-based influencers, discussed the threat of ‘fast-fashion’ and the challenges of conscious consumption. In the question-and-answer session that followed the panel questions were asked “why not wear digital clothing? If your platform of communication is digital, why can’t your clothes be?”

In fact, the concept of digital clothing as a virtual end-product was first presented in 2018 with the Scandinavian retail brand Carlings 19-piece digital-only capsule collection, named 'Neo-Ex' [14]. In the following year, Fabricant sold the inaugural digital-only couture dress, entitled 'Iridescence', on the blockchain [15]. Digital clothing that does not utilise fabric or any tangible material in its creation is based entirely on electrical energy and utilises only computer-aided design software data.

The functionality of garments remains a significant factor in consumer usage. It is unlikely that digital fashion will ever fully replace physical clothing [16]. Digital clothing may be an alternative that could help to reduce the carbon footprint of the fashion industry by eliminating physical production, transport and material waste and disposal processes. The digital fashion concept offers more sustainability than the current fashion industry. The 2023 Digital Fashion Annual Sustainability Report [17] by the American digital fashion company DRESSX indicates that the production of a digital garment emits 97% less CO₂ than the production of a physical garment, while on average saving 3300 liters of water per item.

As the virtual economy grows and 3D technologies improving, digital clothing evolving from prototypes to end products. Digital clothing is blurring the line between 'real' and 'virtual'.

3. DIGITAL FASHION HOUSES

The advent of internet, blockchain technology, Metaverse, VR, AR, 3D modelling, and immersive environments is transforming the way we interact and conduct business in a rapidly evolving digital landscape. These cutting-edge technologies are leading to a restructuring of industries, including the fashion industry, and a redefinition of the value of design. The digital transformation of the fashion business is creating new value and markets. One of the digitalised business models is that of digital fashion houses, which design, 3D model and market digital clothes to consumers as a means of enhancing immersive experiences and end-products.

c. The Fabricant

The Fabricant is a digital fashion house based in Amsterdam that was established in 2018. The first digital couture dress created by the company attracted considerable interest at an auction in 2019. The piece, entitled 'Iridescence' [27] was unveiled at the Ethereum Summit in New York as part of a cryptocurrency conference. This was the first digital-only garment to be sold at auction on the Ethereum blockchain for 54 ETH - \$9,500 at the time [13].

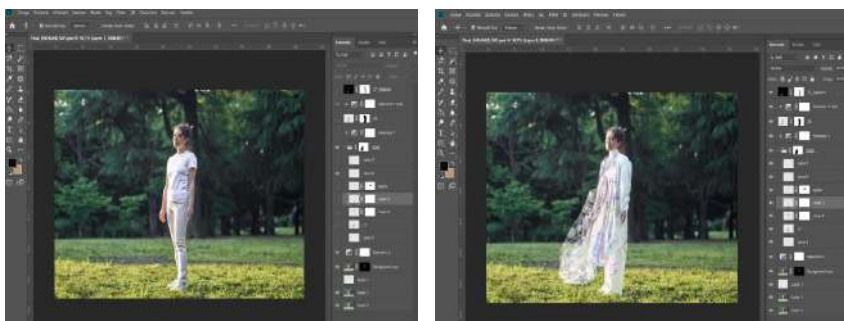


Figure 1: 'Iridescence', The Fabricant, 2019.

The team comprising Kerry Murphy (Founder), Amber Jae Slooten (Co-founder and Creative Director), Adriana Hoppenbrouwer-Pereira (Co-founder), Marco Marchesi (CTO), and Eoin Whelan (CFO). The manifest of the digital fashion house is to construct the wardrobe of the Metaverse and to facilitate the growth of the decentralised fashion industry in collaboration with users. The Fabricant founders describe their business as fashion's tech RenaiXance. The company's founder identifies the Fabricant as a digital fashion house that is pioneering the development of a new sector of digital-only clothing. They specialised in photo-realistic 3D fashion design and animation. Their business model is based on the convergence of fashion and technology, with the objective of creating digital couture and fashion experiences that are entirely digital and do not involve any physical products. The brand's philosophy is to demonstrate that clothing does not require a physical form to exist. The domain of digital fashion represents a vast and largely untapped creative terrain, where previously physically impossible concepts become possible. Furthermore, they posit that the digital-only fashion sector will facilitate the

creation of new creative avenues that extend beyond the limitations of the physical world. They promote sustainability and aim to significantly reduce the negative environmental impact of the current fashion paradigm [18].



Figure 2: 'RenaiXance', RTFKT x The Fabricant, 2021.

The digital fashion house has been engaged in the production of digital clothing collections since 2021, through a series of creative partnerships [28]. Collections in chronological order: Genesis, RTFKT x The Fabricant (2021), The Dawn of Co-Creation, Zodiac Wardrop, World of Woman & The Fabricant (2022), Wholeland-XXories, Wholeland-Kapers, Not in Paris-Highsnobiety, Artifact 001-Weekday, Wholeland-Primal Rave, Deep (2023), Guild-Master Peace, Maison Margiela x The Fabricant (2024). Additionally, the Fabricant engages in collaborative endeavors with global brands and retailers such as *Maison Margiela*, *Tommy Hilfiger*, *Adidas*, *Puma*, *Under Armour*, *Off-White*, *H&M*, and *World of Women*, applying its expertise to the digital realm of fashion. The platform enables users to engage with creative designs that may not be realised in physical products.

d. Auroboros

Auroboros, a digital fashion house pushing the boundaries of clothing through the fusion of haute couture, technology, sustainability and science [20]. The digital fashion house derives its name from the alchemical symbol of infinity, the 'ouroboros', the image of a serpent or dragon devouring its own tail, representing a perpetual cycle of rebirth and reinvention. Reflecting the metaphorical driving force behind Auroboros, the addition of 'AU' (the element of gold) to the brand name reflects the ultimate goal of alchemists to transform any material into gold. Alissa Aulbekova and Paula Sello, co-founders of the digital fashion house, have been working together as creative directors of the brand since 2018 [21]. The avant-garde duo focuses on designing products that are presented in digital formats that can be worn on both physical and virtual body images. They create digital-only couture products that can be worn and purchased through digital platforms, social media, film, avatars, and video games. Brand identity is described as a Metaverse native luxury fashion house that creates for both the physical and digital worlds.

For the first time in fashion history, Auroboros launched a purely digital ready-to-wear line, entitled 'Biomimicry' [29] at London Fashion Week 2021. Designers draw inspiration not only from the realities of science, but also from the fantasy of science fiction films which inspire their 'unreal' materials and utopian fantasy aesthetic [22]. The collection was informed by a number of influences: the cyclical forces of nature, technology and Alex Garland's science fiction films, to Hayao Miyazaki's anime.



Figure 3: 'Biomimicry', Auroboros, 2021.

Aulbekova and Sello aim to expand the boundaries of the luxury industry, reimagining the ways in which they conceptualize, design, and influence consumer behavior with regard to clothing. This approach also encourages the shaping of new discussions around the idea of a utopian future and its relationship to the human body.

Auroboros' digital collections offers an alternative solution to the pollution of the fast fashion industry, allowing creation without physical constraints and producing 97% less material waste than physical production. Additionally, digital clothing is genuinely body and gender inclusive, as each item is digitally tailored to the individual wearing it [21].

Auroboros, which has been featured in the Business of Fashion 500 list, Forbes 30 under 30 in 2022 under Art & Culture and the Netflix series "The Future of Fashion," is a company that mentors the next generation and is dedicated to the pursuit of sustainability. However, it also has a forward-thinking approach to fashion and the digital realm, with a particular emphasis on the potential of Web3 innovation in the domain of digital fashion.

e. Republique

The name "Republique" is a reference to the French roots of the founders of the brand and to the activist mentality that pervades the fashion house. Singapore-based label Republique, led by fashion designer James Gaubert – a designer with over 22 years of experience in luxury fashion – is defined as the metaverse-ready virtual fashion house. As a founder and creative director, Gaubert aimed to identify a creative counterpart to physical clothing that would also help to address the waste and ethical crisis currently facing the fashion industry. The republic is a fully digital/virtual fashion house that produces unique creations, which challenge the norms of the industry by interpreting and creating an extraordinary lifestyle.

The audience for Republic comprises individuals who are motivated by a desire to effect meaningful change and make a difference. The Republique collections are characterised by their provocative nature, raw aesthetic, and unparalleled luxury. They exhibit a meticulous attention to detail and digital craftsmanship, which sets them apart from other digital fashion houses in terms of quality [30]. Furthermore, the cutting-edge fashion garments are entirely digital, fully sustainable, ethically produced and, as they are ‘one size fits all,’ they eliminate any form of discrimination based on body size or shape [23].

In his own words, Gaubert explains the purpose of establishing the digital fashion house as follows: “We are living in times of buying fashion only to share on social media. ‘Disposable outfits’ are the new norm. In response, I founded republique as the perfect solution to the global fast fashion problem” [24]. “Rather than spending money on a garment you only wear once, for social media, why not spend less money on a digital version of it? And have less impact on the environment” Gaubert explains [25].



Figure 4: 'Happy New Year', Republique, 2020.

The creation process begins with the drafting of a pattern, which is subsequently used as a basis for the production of a digital garment. Following completion of this stage, the garment is then converted into either a technical pack on 2D CAD programs. These are then passed on for production in CLO 3D. Using CLO 3D fashion design programme, digital tailors fit digital garments on avatars and rotate them to effectively see how their fabrics fall and flow from every angle. The same level of attention to detail is required for digital design as for physical design. This encompasses hardware components such as buttons and metals, as well as the stitching on garments and accessories. Republique exclusively utilizes high-quality digital fabrics, such as silk or cashmere, sourced from CLO 3D. A textile composed of high-quality fibres will flow and drape in a markedly different manner to a polyester textile of a comparable composition. The quality of digital garments closely resembles that of luxury physical garments. In a matter of hours, the purchaser will receive a fully fitted digital garment, which is ready for sharing on social media. The capacity of digital fashion is that it can generate virtual digital wardrobes, which may be populated with garments that could be easily integrated into different images or videos [26].

Table 1: The purchase of digital clothing via the Internet.

Choose a garment	Upload a photo	Place an order	Digital tailoring	Product delivery
Search the online collection on the Republique website to find a digital clothing.	Upload a high-resolution photo, ensuring that the image clearly depicts the body.	Follow the instructions online to place an order for your digital garment	The digital tailoring process involves the virtual fitting of garments to photographs uploaded by customers.	The finalised digital image was transmitted to the customer in the JPEG format.

5. CONCLUSION

"Data is the new oil" declared British mathematician Clive Humby in 2006. After nearly two decades, data is become the most valuable commercial resource of our time. However, data is not a finite resource, such as oil, which can be depleted or cause pollution. Digital clothing is comprised entirely of data and represents an advancement of the near-future products that will be shaped by information and communication technologies.

The production of digital clothing as an end-product offers several advantages, including zero-waste, cost-effectiveness and limitless creative freedom. The advent of digital clothing represents a new stage in the evolution of fashion, one that does not require the use of any traditional textile raw materials. Nevertheless, it is unlikely to be capable of fulfilling the need for daily wear in reshaping the future of the fashion industry.

The digitalization of the fashion industry is a transformative force that is opening new avenues for designers and consumers to interact with fashion in innovative ways. It also eliminates the challenging constraints associated with fabric and garment production techniques, thereby freeing the designer's original and artistic creativity. The digital realm of fashion offers consumers the opportunity for self-expression. The advent of digital fashion products may provide an alternative to the fast fashion industry's consumption-driven culture. The Fabricant, Auroboros and Republique have inspired a passionate digital fashion community to create their own Metaverse wardrobes. The Fabricant represents a more futuristic and fantastical digital fashion style. Conversely, the Republic appears to offer a more realistic style. The three digital fashion houses utilize comparable design processes to serve their users, particularly through their own websites. This research of digital fashion houses represents that the designs proposed in the field of digital fashion offer a sustainable alternative to the environmental problems created by the fashion industry.

Consequently, it has been demonstrated that by examining the realm of digital fashion houses, a new type of garment has been created that transcends the traditional concepts of materials and manufacturing methods.

The phenomenon of digital fashion is a novel and evolving concept currently under research. It is therefore necessary to allow for a period of maturation before any definitive conclusions can be drawn.



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THE IMPORTANCE OF CONSUMER PERCEPTIONS IN SLEEPWEAR DESIGN

Original scientific paper
DOI: 10.5937/CT_ITI24044C

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ABSTRACT: Sleepwear is an important part of women's, men's and also children's wardrobes, which, in addition to other factors, affect the quality of sleep. Therefore, it is important to pay more attention to the designing and planning of sleepwear. To determine the state of wearing and purchasing sleepwear in Slovenia, we conducted a survey covering various aspects, including consumer perceptions and preferences regarding sleepwear textiles, details, colours and styles, purchasing behaviour and wearing of sleepwear. The results of the research will be helpful in planning and designing of sleepwear, as well in understanding Slovene consumers' perceptions of sleepwear.

Keywords: Consumer behaviour, clothing, sleepwear, purchasing, consumer, consumer perceptions.

ZNAČAJ PERCEPCIJA POTROŠAČA U DIZAJNU ODEĆE ZA SPAVANJE

APSTRAKT: Odeća za spavanje je važan deo ženske, muške, ali i dečije garderobe, koja pored drugih faktora utiče na kvalitet sna. Zbog toga je važno posvetiti više pažnje dizajniranju i planiranju odeće za spavanje. Da bismo utvrdili stanje nošenja i kupovine odeće za spavanje u Sloveniji, sproveli smo istraživanje koje pokriva različite aspekte, uključujući percepcije i preferencije potrošača u vezi sa tekstilom odeće za spavanje, detaljima, bojama i stilovima, ponašanjem pri kupovini i nošenjem odeće za spavanje. Rezultati istraživanja će biti od pomoći u planiranju i dizajniranju odeće za spavanje, kao i u razumevanju percepcije slovenačkih potrošača o odeći za spavanje.

Ključne reči: ponašanje potrošača, odeća, odeća za spavanje, kupovina, potrošači, percepcije potrošača.

1. INTRODUCTION

Depending on the conditions of wearing or the purpose, clothes can be classified into the following groups: everyday clothes, sports and leisure clothes, and special clothes that include work clothes and uniforms. Sleepwear is classified in the group of everyday clothing, which is divided into men's, women's and children's clothing [1].

Sleepwear in addition to other factors, affect the quality of sleep and contributes to a comfortable and pleasant rest. Therefore, when designing sleepwear, it is also important to research and understand consumer's perception and behaviour towards sleepwear. The paper summarizes the findings of a survey on wearing and purchasing sleepwear in Slovenia. The research was conducted in Slovenia in 2024 and covers various aspects, including consumer perceptions and preferences regarding sleepwear textiles, details, colours and styles, purchasing behaviour and wearing of sleepwear. The results of this study could be useful for fashion designers, brands and marketers etc. to understand Slovene consumers' perceptions of sleepwear, and will be helpful in planning and designing of sleepwear.

2. SLEEPWEAR AND TEXTILES

Sleepwear, also known as nightwear or sleep clothing (also nightclothes), refers to garments specifically designed to be worn while sleeping or relaxation at home. Common types of sleepwear include: pyjamas (pajamas), nightgowns (nighties), negligees, chemises, nightshirts (sleep shirts), sleep shorts, sleep pants, robes, peignoirs, adult onesies, babydolls, blanket sleepers. Other types of garments are commonly worn for sleeping, but not exclusively so, including gym shorts, t-shirts, tank tops, sweatpants, as well as underwear, and/or socks, with no outer garment. Also, sleeping without clothing is not uncommon [2, 3]. According to our previous survey made in Slovenia in year 2018 [4] and other surveys made in USA [5] and UK [6], the most popular sleepwear worn are pyjamas and nightgowns.

2.1. Sleepwear textiles

Sleepwear textiles are chosen for their comfort, breathability, durability, sensitivity, and ability to regulate body temperature during sleep. When selecting sleepwear, it is essential to consider also personal preferences, climate, and any specific needs such as allergies or skin sensitivities. Ultimately, the best sleepwear textile is one that ensures comfort and a restful night's sleep. Common textiles used in sleepwear include [7-10]:

- cotton: cotton is natural fibre and a popular choice for sleepwear due to its softness, breathability, durability and ability to absorb moisture, keeping the body cool and dry during sleep;
- flannel: flannel is a warm, soft fabric often made from cotton, wool, and synthetic fibres. Cotton flannel is commonly used in sleepwear for wearing during colder season, as it provides good insulation and comfort;
- silk: silk is a luxurious and lightweight fabric known for its softness, smooth surface and ability to regulate body temperature. Silk sleepwear is prized for its comfort and elegance, making it a popular choice for special occasions or those seeking a touch of luxury;

- satin: satin is a glossy fabric often made from silk, cotton, polyester, or a blend of synthetic fibres. It has a smooth and silky texture, offering a luxurious feel and a hint of sheen. Satin sleepwear is favoured for its softness and elegant appearance;
- modal: modal is a type of rayon produced from beech tree cellulose. It is eco-friendly and known for its softness, breathability, and moisture-wicking properties. Modal sleepwear is prized for its comfortable and lightweight feel;
- bamboo: bamboo fabric is derived from bamboo pulp and is valued for its softness, moisture-wicking properties, and eco-friendly nature. Bamboo sleepwear is breathable, hypoallergenic, and suitable for sensitive skin;
- other textiles also used in sleepwear: viscose, Tencel™ (lyocell), linen, wool, microfiber, polyester, rayon, fleece, terrycloth etc.

3. METHODOLOGY

A quantitative research study was carried out in order to explore consumers' wearing and purchasing sleepwear. The survey was published online using the 1ka program. All data presented are obtained by interviewing. The online survey was made in Slovenia and took place from 22 March 2024 to 23 May 2024. The questionnaire was sent by e-mail and shared via web page of Faculty of Design and social networks. A random sample was used in data collection. The total number of respondents who carried out a survey was 437. Of these, 298 respondents answered the question regarding gender and age, 4 % (11) were men and 95 % (283) were women, 4 respondents were unspecified regarding gender. The age of the respondents is presented in Table 1. The majority of the respondents 28% were up to 24 years of age, followed by the respondents aged between 35 and 44 (27%), between 45 and 54 (22%), and age 55 and more (13%), with the least number of respondents age between 25 and 34 (10%).

Table 1: Age of the Respondents

Age	Frequency	Percent
up to 24	82	28
25-34	29	10
35-44	80	27
45-54	67	22
55 and more	40	13

4. RESULTS AND DISCUSSION

As sleepwear and textiles for them can vary according to the seasons, firstly we wanted to know if respondents wore sleepwear during summer and winter time. Out of a total of 432 answers, 28 % of the respondents answered that they do not wear sleepwear in summer and 16 % of respondents do not wear sleepwear in winter, as presented in Figure 1a and 1b. For respondents who do not wear sleepwear, the survey ended with this question. Next, we were interested in whether they wear the same model of sleepwear in winter and summer time. Only 27 % of the respondents (91 from 342) answered that they wear the same model

of nightwear in summer and winter, which mostly consists of a T-shirt and pants, a two-piece pyjama, only underwear, oversized T-shirts etc.

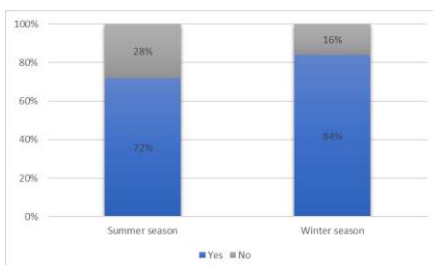


Figure 1: Do the respondents wear sleepwear while sleeping in summer and winter time?

Table 2: What kind of sleepwear do the respondents wear while sleeping?

Sleepwear	Frequency of answers	
	Summer season	Winter season
Two-piece pyjama set (a set of a shirt and pants)	127	220
Two-piece nightwear not in a set (consisting of a shirt and pants)	162	185
Nightgown (nightdress/nightshirt) with short sleeves	174	33
Nightgown (nightdress/nightshirt) with long sleeves	25	80
Short-sleeved T-shirts	243	85
Long-sleeved T-shirts	18	180
Sleeveless top	133	19
Shorts	201	34
Long pants/leggings	37	196
One-piece suit (adult onesie)	9	34
Negligee	81	16
Only underwear	127	17

In the following question, we were interested in what kind of sleepwear the respondents wear for sleep. Several answers were possible; thus, the frequency of answers is presented in Table 2. It was found that the majority of the respondents in winter time wear a two-piece pyjama set (a set of a shirt and pants), two-piece nightwear not in a set (consisting of a shirt and pants), long-sleeved T-shirt and long pants/legging. The least of them wear negligees, tank tops or just underwear in winter. In summer time the majority of the respondents wear short-sleeved T-shirts, shorts, nightgown (nightdress/nightshirt) with short sleeves, and two-piece nightwear not in a set. Negligees (a shorter female undergarment made of transparent materials and lace) are worn in summer by 81 and in winter by only 16 respondents. Only underwear without sleepwear is worn in summer by 127 respondents and in winter only by 17 respondents. We were also interested in whether the respondents liked the textile patterns and prints and inscriptions on the sleepwear. Several answers were possible; thus, the frequency of answers is presented in Table 3. The majority of the respondents like small prints (dots, hearts, teddy bears, etc.) and flower



prints/motifs from nature. 97 of respondents (out of 327) do not like patterns and prints. Some of them like stripes (68), various captions (e.g. Sweet Dreams), and captions/prints of cartoon series heroes/characters (52 of respondents). Checkered patterns are the least liked by the respondents.

Table 3: What prints, inscriptions, and patterns do respondents like on their sleepwear?

Prints, inscriptions, and patterns	Frequency of answers
Small prints (dots, hearts, teddy bears, etc.)	150
Flower prints/motifs from nature	103
Do not like patterns and prints	97
Various captions (e.g. Sweet Dreams)	72
Stripes	68
Captions/prints of cartoon series heroes/characters	52
Checkered patterns	34
Others (e.g. thematic prints of illustrations of animals or others motifs from nature, etc.)	22

Table 4: What kind of details do respondents like or bother them on sleepwear?

Details	Frequency of answers	
	They like them	Bother them
Do not like details / do not mind anything	222	100
Lace	73	26
Pockets	57	35
Trims (e.g. satin)	33	8
Strings and ribbons	33	66
Buttons	27	119
Bows	27	17
Embroidery	25	6
Flounces	18	35
Ruffles (frills)	21	43
Patches	8	53
Zippers	2	116

Table 4 presents results related to details that the respondents like on sleepwear or bother them on sleepwear while wearing it, such as buttons, lace, pockets, embroidery, flounces, ruffles (frills), zippers, and other. Several answers were possible; thus, the frequency of answers is presented. 68 % of the respondents (222 out of 328) do not like details nor the accessories that seem insignificant to them. 73 respondents like lace details, 57 like pockets, 33 like trims (e.g. satin), and 33 of them like strings and ribbons. It was found that only 2 respondents like zippers and 116 of respondents bothered them. The next question was about what currently bothers the respondents on their sleepwear. More answers were possible; thus, the frequency of answers is presented in Table 4. About 31 % of the respondents (100 out of 324) do not mind anything on their sleepwear, 119 of them are bothered by buttons, and 116 respondents are bothered by zippers. 66 respondents are

bothered by strings and ribbons, 53 are bothered by patches, and 50 respondents are bothered by elastic bands. When asked what colour of sleepwear the respondents mostly wear, several answers were possible; thus, the frequency of answers is presented in Figure 2. The most respondents wear blue sleepwear (173 out of 325), followed by grey (122), black (117), white (115) and beige (110) colours. The fewest respondents wear orange (13) and yellow sleepwear (21). 56 of respondents answered that they wear other colours, e.g. pastel, pink, olive, turquoise. In the following question, we were interested in what shades of colours the respondents like. Several answers were possible. 162 of respondents answered that they like light shades, 124 like pastel shades, 116 like dark shades, 86 of respondents like natural shades, and 60 like beige shades.

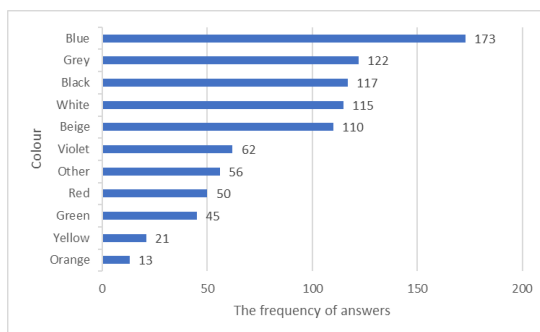


Figure 2: What colour of sleepwear do the respondents mostly wear?

When asked whether the material from which the sleepwear is made is important for respondents, 325 answered, 3 % (10) of which did not care about the material, 5 % do not know (15) and 92 % (300) of respondents answered that the material is important and has to be comfortable, natural, soft and pleasant to the touch, skin friendly, breathable, and flexible. In the following question we were interested in what material the sleepwear of the respondents is made of. As presented in Table 5, most sleepwear is made of cotton textiles, both for summer (265 of respondents) and winter (292) wear. In winter respondents often wear flannel (89) and terry cloth (79) sleepwear, but less often silk, satin, modal and lace nightwear. In summer, the respondents often wear silk (80), bamboo (64), transparent (59), lace (56), viscose (55) and satin (53) sleepwear, and less often flannel, terry cloth and modal nightwear. 75 of the respondents answered that they do not know sleepwear textiles made from modal fibres, 44 from bamboo, 30 from viscose, 24 satin, 31 terry cloth and 27 from flannel. When asked whether the respondents wear sleepwear made from organic and eco textiles, 315 respondents answered. 47 % (148) of the respondents wear sleepwear made from organic cotton, 15 % (46) wear sleepwear made from other eco materials (e.g. bamboo, lyocell), 31% did not know and 19 % of the respondents do not wear sleepwear from organic and eco materials. In the next question we were interested, if the respondents would like to have sleepwear made from organic and eco textiles. Who responded with doubt or negatively (157), 75 % (118 out of 157) of the respondents answered that they would like to have it, and 22 % of the respondents don't care about it.

Table 5: What material is the respondents' sleepwear made of?

Textiles used for sleepwear	Frequency of answers		
	Winter season	Summer season	Don't know
Cotton	292	265	8
Silk	17	80	18
Bamboo	34	64	44
Modal	19	18	75
Viscose	32	55	30
Satin	15	53	24
Terrycloth	79	1	31
Flannel	89	6	27
Lace	21	56	19
Transparent textiles	9	59	18
Others (wool, plush, hemp textiles)	4	3	10

When asked what is important to the respondents when wearing and buying nightwear, an assessment was conducted on a scale from 1 to 5, where 5 presents the most important value. It was found that comfort is the most important factor for the respondents when wearing (287 out of 313) and buying (251 out of 297) nightwear, followed by the material and quality, price, appearance/design, and colour, as presented in Figure 3a and b. It was also found that fashion trends are the least important to the respondents when wearing (56 % of the respondents) and buying (50 %) sleepwear. When asked whether the name of the brand was important to the respondents when buying sleepwear, 269 respondents answered, of which 93 % (250) did not care about the brand name. When asked how much the respondents spent on average for the purchase of their nightwear, 268 respondents answered. It was found that 28 % (76) of the respondents spend an average of up to € 20 for the purchase of nightwear, 47 % (127) of the respondents spend € 20-40 for the purchase of their nightwear, 14 % spend € 40-60 and 5 % spend € 60 and more for the purchase, as presented in Figure 4. 74 % (197) of the respondents (out of 267) when asked where they buy nightwear answered that in the store, 16 % (43) buy them online, 4 % (12) of them wear old T-shirts, leggings, promotional T-shirts or other pieces of clothing, and 3 % (9) of the respondents make their own sleepwear. It was also found that 83 % of the respondents (out of 197) buy sleepwear in Slovenia.

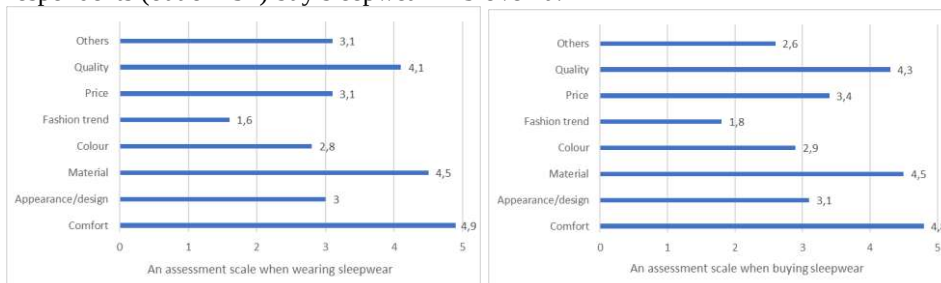


Figure 3: What is important to the respondents when wearing (a) and buying (b) sleepwear?

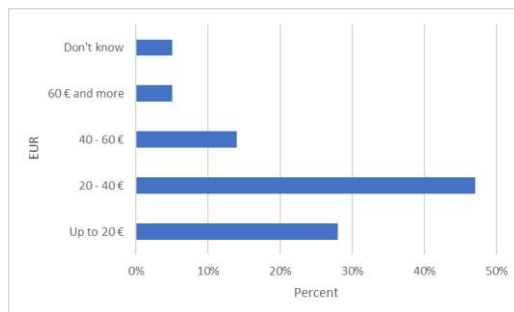


Figure 4: How much do the respondents spent on average for the purchase of sleepwear?

When asked how often the respondents buy sleepwear, 267 respondents answered. 30 % of the respondents buy sleepwear once a year, 10 % seasonally (summer, winter), 30 % of the respondents buy sleepwear once every 2 years, and 24 % buy them in period from 3 to 5 years and the rest (6 %) as the need occurs. When asked whether the respondent buys sleepwear as a gift, 302 respondents answered, of which 49 % answered that sometimes buy them for family members, friends, relatives, husband, wife, children, parents etc., 4 % often buy them, and 45 % of the respondents never buy sleepwear for a gift. 70 % of the respondents (out of 301) answered that they already received sleepwear as a gift. We were also interested in whether the respondents wear sleeping eye mask, socks, underwear, bathrobe and slippers before/while sleeping. Eye mask wear while sleeping only 3 % (9) and sometimes 9 % (28) of the respondents (out of 301). 28 % of the respondents (out of 302) wear socks while sleeping in the colder season, 4 % always wear them and 20 % of the respondents wear them occasionally. 48 % of the respondents wear underwear under their sleepwear in the summer, and 63 % of the respondents in the winter time. 12 % of the respondents wear only underwear in the summer. 9 % of the respondents (out of 292) wear a bathrobe before going to bed in summer and 17 % wear them only occasionally, while in winter season 22 % of the respondents wear a bathrobe and 23 % of them only occasionally. It was found that slippers wear at home 85 % of the respondents (out of 299) and 7 % wear them only occasionally. On the trip 74 % of the respondents wear slippers and 14 % only occasionally. The last question was whether the respondent would like to have an additional product that matches the style of the sleepwear, such as a bathrobe, slippers, socks, a textile storage bag, and an eye mask. Several answers were possible; thus, the frequency of answers is presented in Figure 5. 119 out of 296 respondents answered that they would like to have a bathrobe, 115 slippers, 88 socks, 32 a textile bag for storage, 25 an eye mask and 61 of the respondents answered that they would have nothing.

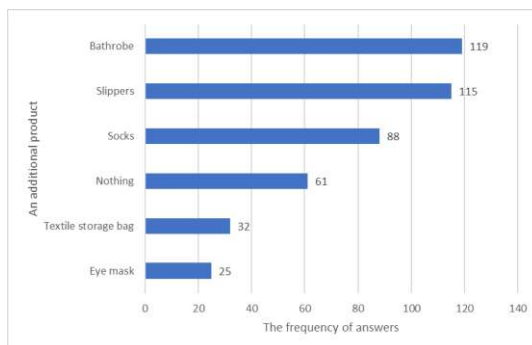


Figure 5: Whether the respondents would like to have an additional product that matches the style of the sleepwear?

5. CONCLUSION

The results of the study show that consumers wear sleepwear during sleep, both in summer and winter time, but not the same model of clothing. It was found that 27 % of the respondents wear the same model of nightwear in summer and winter, and that 28 % of the respondents do not wear sleepwear in summer and 16 % of them do not wear it in winter. It has been established that in winter consumers mostly wear two-piece sleepwear, such as pyjamas set (set of shirt and pants), or a combination of a long-sleeved T-shirt with long pants or leggings. In summer the majority of the respondents wear short-sleeved T-shirts, shorts, nightgown with short sleeves, and two-piece nightwear not in a set. It has also been established that the majority of the respondents like small prints e.g. dots, hearts, teddy bears, etc. and flower prints or motifs from nature. The results also show that about 30 % of respondents do not like patterns and prints at all and 68 % of the respondents do not like details nor the accessories that seem insignificant to them (e.g. buttons, pockets, flounces, ruffles, zippers etc.). About 31 % of the respondents do not mind anything on their sleepwear, while a few respondents do not mind buttons and zippers. Consumers wear blue sleepwear the most, followed by grey, black, white and beige sleepwear. 92 % of the respondents confirmed that the material of sleepwear is a very important factor and has to be comfortable, natural, soft and skin friendly, breathable, and flexible. Most sleepwear is made of cotton textiles, both for summer and winter wear. In winter, the respondents often wear flannel and terrycloth sleepwear, but less often silk, satin, modal and lace sleepwear. In summer, the respondents often wear silk, bamboo, transparent, lace, viscose and satin sleepwear, and less often flannel, terry cloth and modal nightwear. Several respondents answered that they do not know textiles made from modal fibres, bamboo, viscose, and satin. It was also found that 47 % of respondents wear sleepwear made from organic cotton, and 14 % wear sleepwear made from other eco materials (e.g. bamboo, lyocell). The most important factor for the respondents when wearing and buying nightwear is comfort. This is followed by the material and quality, price, appearance/design, colour and the latest fashion trends. The brand name of the sleepwear is important only to 7 % of the respondents. 74 % of the respondents buy nightwear in stores and 16 % buy them online.

This means that the percentage of online purchases of sleepwear increased compared to the previous survey from 2018, when only 3 % of respondents shopped online [4]. The rest wear old T-shirts, leggings, promotional T-shirts or other pieces of clothing, and 3 % of respondents make their own sleepwear. It was also found that 83 % of the respondents buy sleepwear in Slovenia, 30 % of the respondents buy sleepwear once a year, 10 % seasonally, 30 % of the respondents buy sleepwear once every 2 years, and 24 % buy them in period from 3 to 5 years. 49 % of the respondents answered that sometimes they buy nightwear for family members, friends, parents, relatives, etc. and 70 % of the respondents that they already received sleepwear as a gift. The results also show that some respondents would like to have a bathrobe, slippers, and socks that matches the style of the sleepwear. We can conclude that the findings of this study are useful for fashion designers, brands and marketers etc. to understand Slovene consumers' perceptions of sleepwear, and will be helpful in planning, designing and marketing of sleepwear.

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A GEOMETRIC TRANSPOSITION OF TRADITIONAL WEAVED MOTIFS INTO NATURAL STONE MOSAICS

Original scientific paper
DOI: 10.5937/CT_ITI24045D

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ABSTRACT: Inspired by the ethnographic collection, brought together by Serbian ethnologist Hristifor Crnilović (1886 – 1963), today on display in Manak's House in Belgrade, a series of experiments have been done within the Mosaic School Kamen & Lom, tending to transpose traditional Balkan motifs into the natural stone mosaics. After briefly introducing the notion of transposition between the two techniques, and the Crnilović Collection, in this study we analyse selected motifs and their stone mosaic interpretations, paying a special attention on geometric characteristics of the two ancient techniques. Similarities and differences of the two techniques has been analysed and some important aspects of the process of geometric transposition are highlighted. The paper is accompanied by the exhibition of mosaics inspired by Pirot rugs, titled "Stone Weaving", that was previously displayed in Manak's House in Belgrade, as well as in the city of Pirot and in other cities around Serbia.

Keywords: Traditional weaving, natural stone mosaic, geometry, transposition.

GEOMETRIJSKO TRANSPONOVANJE TRADICIONALNE TKANE GEOMETRIJSKE ŠARE U MOZAIKE OD PRIRODNOG KAMENA

APSTRAKT: Inspirisana etnografskom zbirkom koju je prikupio etnolog Hristifor Crnilović (1886 – 1963), a koja je danas izložena u Manakovoj kući u Beogradu, realizovana je serija eksperimenata u okviru Škole mozaika Kamen & Lom, sa težnjom da se tradicionalni balkanski motivi transponuju u mozaike od prirodnog kamena. Nakon opisa etnografske kolekcije Hristifora Crnilovića, u ovom istraživanju su analizirani izabrani motivi i njihove interpretacije u mozaiku od prirodnog kamena. Pri tome se



posebna pažnja obraća na geometrijske karakteristike dve drevne tehnike. Analiziraju se sličnosti i razlike ove dve tehnike i izdvajaju se važni aspekti geometrijske transpozicije. Uz ovaj rad pripremljena je za prikazivanje i izložba mozaika inspirisana pirotskim ćilimom, pod naslovom “Tkanje kamenom”, koja je ranije organizovana u Manakovoj kući u Beogradu, kao i u Pirotu i drugim gradovima u Srbiji.

Ključne reči: Tradicionalno tkanje, mozaik, prirodni kamen, geometrija, transpozicija.

1. INTRODUCTION

The influences of Eastern and Western cultures have intertwined and permeated the Balkan region since ancient times, forming, alongside various ethnic, national, social, and other differences, a treasury of similar and unique forms of folk creativity throughout history.

Traditional weaving in the Balkans, especially in Serbia, holds a significant cultural and historical role, reflecting the region's rich heritage and artistic expression [2]. This craft, practiced for centuries, showcases the unique blend of influences from Eastern and Western cultures, as well as the distinct identities of various ethnic groups within the region. Weaving has been an integral part of Balkan culture since ancient times. The region's strategic location as a crossroads between East and West [3] facilitated the exchange of techniques, patterns, and materials, enriching the local weaving traditions. In Serbia, weaving was not just a practical activity for producing household textiles but also an important artistic expression and a means of cultural preservation [4]. Traditional Serbian weaving often utilizes vertical looms (Figure 1), which have been in use since at least the 19th century. This type of loom, also known as a “standing” or “upright” loom, allows weavers to create large, intricate patterns and is particularly suited for rug-making [5].

Horizontal looms are also used, especially for making narrower items like belts and sashes. The primary materials used in traditional Serbian weaving include wool, cotton, and flax. Wool, sourced from local sheep, is particularly valued for its durability and warmth. Cotton and flax are used for finer textiles, such as clothing and decorative household items. Natural dyes derived from plants, minerals, and insects are traditionally used to color the yarns. These dyes produce a range of vibrant and earthy tones, which are characteristic of Balkan textiles. The designs in Serbian weaving are rich in symbolism and vary significantly across different regions. Common motifs include geometric shapes, floral patterns, and stylized animal figures. Each motif carries specific meanings and is often associated with local folklore, beliefs, and social status [6].

Geometric Patterns are among the most prevalent in Serbian textiles, with intricate combinations of squares, diamonds, and other shapes creating complex, symmetrical designs. Traditional Serbian weavings often feature bold color combinations, with reds, blues, blacks, and whites being dominant. The choice of colors and their arrangement is not only aesthetic but also culturally significant.



Figure 1: Weaving on a vertical loom, Pirot, second half of the 19th century, Photograph, reproduction of the watercolor by Carl Peter Goebel (1824-1899), Ethnographic Museum in Belgrade, Inv. No. 7903., [1]

Different regions of Serbia have distinct weaving styles and traditions:

Pirot: Known for the famous Pirot carpet (Pirotski ćilim), this region's textiles are characterized by their high quality and intricate patterns. Pirot carpets are often woven with wool and feature vivid geometric designs [5], [7].

Sjenica and Zlatibor: These regions are known for their woolen textiles, particularly blankets and rugs, which are often decorated with simple, bold patterns.

Kosovo and Metohija: This area is renowned for its elaborate textiles that often incorporate gold and silver threads, reflecting the influence of Byzantine and Ottoman aesthetics.

Traditional weaving in Serbia is more than just a craft; it is a cultural legacy passed down through generations. Weaving techniques and patterns are often taught within families, preserving the knowledge and skills of ancestors. This craft plays a vital role in community identity, especially in rural areas, where woven textiles are used in everyday life, from clothing to home decoration.

On the other hand, mosaic is one of the oldest artistic techniques [8]. The oldest known mosaics were found in Mesopotamia, featuring geometric patterns made from cone-shaped fired clay. Mosaic art was particularly popular in ancient times, including in Greece (Pella) and during the Roman Empire [9]. It was used to decorate homes, markets, religious buildings, and public spaces across numerous locations from ancient times onwards. From this period, one could observe a division into two main styles of mosaic art: Western and Eastern. The Western style is characterized by simple geometric forms and monochromatic color schemes suited for functional spaces. In contrast, the Eastern style is complex, vibrant in color, and highly decorative, often reminiscent of modern rugs [10].

In the act of research and creative boundary-pushing [11], blending seemingly incompatible techniques and materials, the exhibition "Stone Weaving" and the experiments in transposition weaved patterns into mosaics, inspiringly explored and utilized Serbia's cultural heritage, specifically the Pirot carpet [12].

2. MANAK'S HOUSE AND THE COLLECTION OF HRISTIFOR CRNILOVIĆ

Manak's House, known as „Manakova kuća“ in Serbian, is a historic building and museum located in Belgrade, Serbia. It is part of Ethnographic Museum in Belgrade. The house dates back to the 1830s and is one of the few surviving examples of traditional Serbian urban architecture from that period in Belgrade.

Hristifor Crnilović (1886-1963) was a prominent Serbian ethnographer and collector who dedicated his life to preserving the cultural heritage of Serbia and the broader Balkan region. His extensive collection is displayed in Manak's House and is one of the most comprehensive ethnographic collections in Serbia [13]. The collection includes a wide variety of traditional Serbian costumes, representing different regions and time periods.

These garments showcase the intricate embroidery, weaving techniques, and vibrant colors typical of Serbian folk attire. Among the most valuable items are the handwoven textiles and rugs, including the famous Pirot carpets. These pieces highlight the skill and artistry of Serbian weavers and provide insight into traditional weaving techniques (Figure 2).

Manak's House, or Manakova kuća, is a precious landmark in Belgrade that offers a unique window into the past. As both a museum and a cultural hub, it serves to educate and inspire visitors about the traditions, craftsmanship, and everyday life of 19th-century Serbia. Its preservation underscores the importance of safeguarding historical buildings and promoting cultural heritage for future generations to appreciate and cherish.



Figure 2: Motifs from the collection of Hristifor Crnilović



3. THE EXHIBITION „STONE WEAVING“

Artistic schools have existed since ancient times. Their significance is immense because they reflect the continuity of achieved skills and enable the ongoing life of what we call tradition. Thus, in ancient times, weavers in the Balkans received technology and patterns for their work, but their personal experience and talent added to the meaning and artistic and/or craft expression and achievement. This element of expanded creative field during work is extremely valuable and contributes to the uniqueness of the local scene [14], [15]. Discovering these elements nowadays does not mean merely repeating old patterns but transposing them into a contemporary expression in a completely new way. This is preceded by the path of studying the work process and interpreting the depth of usable symbols. This is precisely what forms the core of the project “Stone Weaving”. It aims to give a higher meaning to the very learning of the artistic craft, but also to uncover the most valuable aspects of tradition, thereby enabling it to have a new life, providing with great artistic inspiration and personal achievement [1].

Members of the Kamen & Lom studio have been "weaving" collective mosaic carpets for over a decade, giving these works a specific character, and inspiring studio members through new inspiration and challenging tasks/undertakings, which allows for a deeper and different way of exploring both the past and personal improvement and acquaintance with the possibilities of mosaic expression. Collective work is particularly important, as it determines not only the work itself but also the character of life and Eastern peoples and the Balkans.

This area of tradition was chosen because it allows for a direct and easy view of some contemporary trends and directions in fine arts [16], [17]. For example, dealing with symbolism but even more so with the choice of forms from traditional carpets, and then reducing them to basic expressions and fitting them in with the choice of colors and basic tones, students gradually "enter" into the visual problems of suprematism and modern abstraction, especially those of geometric direction.

The exhibition, where the work is presented, was especially important. It was the Gallery of Manak's House (an exceptional building in itself), which houses the splendid ethnographic collection of Hristifor Crnilović. In addition to direct contact with the motifs and objects that inspired this project, there was another very important moment for the organizers. Namely, during his schooling in Skopje, Alexander Tomasevic, the founder of modern mosaic in the 20th century, was a student of Hristifor Crnilović. He often helped his professor draw artifacts that he collected on his travels through the Balkans. This, among other things, significantly influenced Tomasevic's artistic expression, especially his work in mosaic.



Figure 3: Mosaics from the exhibition “Stone Weaving”

By combining these two moments, ethnological material and contemporary mosaic, at the exhibition and workshop that accompanies it, the intention was to achieve an atmosphere in which visitors can see and experience the heritage of their ancestors in a new way (Figure 3, Figure 4). To see that the past is not over, it's not finished, but that people still live it today, although they often aren't aware of it, and that it largely determines their current life.

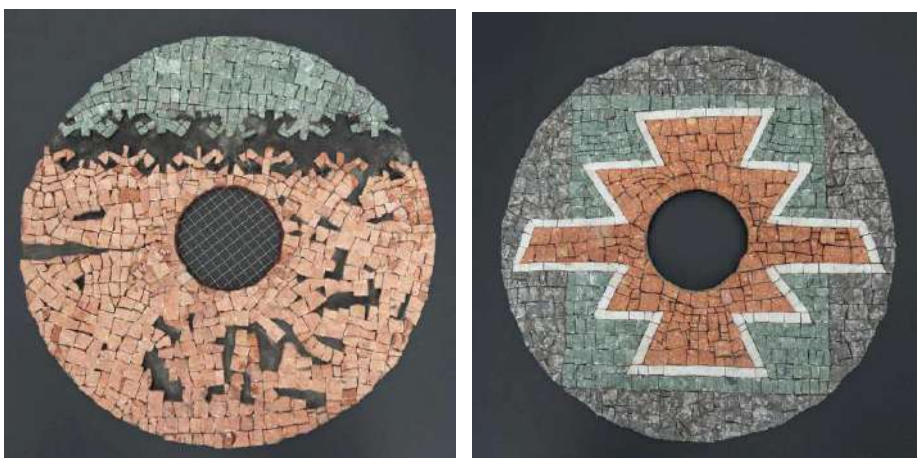


Figure 4: Mosaics from the exhibition „Stone Weaving“

3. THE PROCESS OF TRANSPOSITION – STUDY OF THE CASE

The process of the transposition of a traditional geometric pattern into a mosaic, started with a careful selection of a motif. In the presented case the motif is selected from the rich

collection of Hristifor Crnilović in Manak's House, and is part of a traditional towel (Figure 5, left). The selected motif was photographed, and the desired detail was cropped.

The nature of the pattern and the geometry were then examined through several sketches, two manual and one digital. The first manual sketch (Figure 5, middle) served to get familiar with the pattern. In this sketch the horizontality of the pattern was highlighted and the number of horizontal threads of weaving was reduced. It was obvious that, thinking about the stone mosaic, the horizontal lines couldn't be thin as in weavings.

The second manual sketch (Figure 5, right) served to simulate a natural stone mosaic. Compared to the previous sketch, the number of horizontal threads was further reduced, in terms of accomplish desired horizontality of the mosaic rows. In this sketch the colour was introduced and the three characteristic colours were identified for the future mosaic.

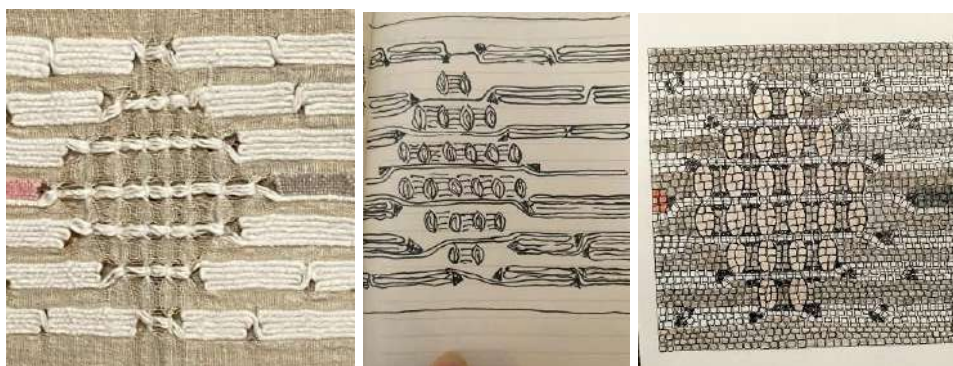


Figure 5: From left to right: selected motif, transposition into a sketch, mosaic-like sketch

Finally, a digital sketch/simple drawing was created, to serve as a base for claying stones (theserae) of the future mosaic, which has been completed in an inverse mode. Figure 6, left, shows the printed digital sketch and a selection of natural stones was prepared.

The completed mosaic is given on the Figure 6, right. The horizontality of the threads was preserved thanks to the white stone rows, while the rhomboid pattern has been realized in the beige stone. The size of the stones (tesserae) was maximally reduced, so that it could be appropriate to represent the nature of the woven tissue.

The mosaic is selected to be exhibited at the Belgrade Mosaic Festival IV in June 2024 in the Kuća Legata Gallery in Belgrade [10].



Figure 6: Usage of digital drawing as a base (left) and the completed mosaic

3. CONCLUSION

The connection between traditional weaving and stone mosaic is quite captivating, as both techniques often use geometric motifs to create intricate and meaningful designs. Similar to the process of weaving where threads are interlaced to form patterns, in mosaics stones are meticulously placed to form the desired design. The careful arrangement ensures that the geometric integrity of the pattern is maintained.

Mosaic designs inspired by traditional weaving, can be used in flooring, wall decorations and architectural accents in smaller spaces, public buildings and places of worship. Transpositions of traditional woven motifs into stone mosaics, yields a continuity of cultural expression. This can be particularly expressive in public and sacred spaces.

By transposing traditional woven geometries into natural stone mosaics, the timeless beauty and cultural significance of these patterns can be preserved and showcased in new and enduring forms. This approach not only honours the heritage of weaving, but also expands its reach into different artistic and architectural domains.

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TECHNICAL DESIGN CONCEPT FOR A PROTECTIV SUIT INSPIRED BY BIOMIMETICS

Professional paper
DOI: 10.5937/CT_ITI24046S

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ABSTRACT: Stunt choreography frequently necessitates specialized protective attire due to its rigorous demands. While such clothing typically derives from equipment used in extreme sports, certain activities, given their distinctiveness, still present significant health risks to performers. Locomotion serves as a prime example. Exploring the potential of biomimetics, the concept of employing a suit modeled after snake skin was contemplated. Such a suit would offer enhanced protection, minimize friction, and boost performance efficiency.

Keywords: protective clothing, locomotion, biomimetics, snakeskin, friction, stunt.

TEHNIČKI PREDLOG ZA DIZAJN ZAŠTITNOG ODELA INSPIRISANOG BIOMIMIKRIJOM

APSTRAKT: Zahtevnost kaskaderskih koreografija nemalo puta iziskuje posebne vrste zaštitne odeće. Ta odeća je najčešće deo opreme za neki ekstremni sport, premda pojedine aktivnosti, zbog svoje unikatnosti, i dalje predstavljaju veliku pretnju za zdravlje izvođača. Lokomocija je jedan od primera. Koristeći se biomimikrijom, razmotrena je mogućnost zaštite pomoću odela konstruisanog prema uzoru na zmijsku kožu, čime bi se obezbedila bolja zaštita, smanjilo trenje i povećala učinkovitost performansa.

Ključne reči: zaštitna odeća, lokomocija, biomimikrija, zmijska koža, trenje, kaskada.

1. INTRODUCTION

The film costume emerges from the collaborative efforts of two distinct industries: film and textile. It serves as an essential element on every film set while also functioning as a textile product. Its creation involves two main stages: the artistic phase, which encompasses conceptualization and sketching, and the technical phase, focused on actualizing these designs. Mastery of both artistry and technical craftsmanship is essential in this process.

However, costume is not the only segment of the clothing industry on the film. The safety of performers on set demands protective gear for scenes involving risky stunts, vital for safeguarding their health. In the past year alone, US theaters showcased films with a staggering 5,903 stunt credits. Each performance necessitated some form of protective clothing, tailored to the specific choreography and requirements. Given the lack of a dedicated industry for stuntmen's protective wear, much of the gear is repurposed from extreme sports such as mountaineering or motorcycling. While serving its primary function to a large extent, it falls short of being considered ideal. The issue discussed in the paper underwent analysis in collaboration with the Serbian Stunt Association.

One reason these garments fail to offer optimal protection is because many stunt demands aren't typical for any extreme sport. This paper will address the challenge of safeguarding performers during the horizontal pulling of a contractor on a specific surface. We sought a solution to this issue by turning to nature. Employing biomimicry, we endeavored to create a suit inspired by the texture of snakeskin. By utilizing the same materials found in existing protective gear but innovatively redesigning its segments into a suit, we aimed not only to enhance protection but also to enhance the effectiveness of the performance itself.

2. BIOMIMICRY AS INITIAL INSPIRATION

Biomimetics or biomimicry is the emulation of the models, systems, and elements of nature for the purpose of solving complex human problems [1]. Biomimetics holds promise for application across numerous fields. Given the diversity and intricacy of biological systems, there exists a vast array of features ripe for imitation. Biomimetic applications span various stages of development, ranging from emerging technologies with potential for commercial viability to prototype stages. The term 'biomimetics,' coined by Schmitt [3], originates from the Greek words 'bios,' meaning life, and 'mimesis,' meaning to imitate [4]. This emerging science is grounded in the notion that nature tends to pursue the path of least resistance, often employing readily available materials to achieve its objectives with minimal energy expenditure. Ideally, biomimetics should involve integrating principles that echo nature's sustainability practices, encompassing everything from raw material utilization to recyclability, mirroring nature's lifecycle from inception to reuse.

Camouflage fabric stands as one of the earliest iterations of such materials. Now widely adopted by military forces globally, its origins trace back to 1850, when English troops deployed it during India's colonization. These fabrics aim to diminish the visibility of individuals by mimicking their surroundings. One of the most notable examples is the emulation of the lotus plant. This plant boasts a natural self-cleaning mechanism attributed to its surface morphology, featuring numerous tiny warts covered in hair-like structures akin to wax crystals. This blend of micro and nanostructures significantly minimizes molecular contact with the water surface, giving rise to the renowned "lotus effect".

2.1. Structure of snake skin

The snake skin is comprised of two primary layers: the "dermis" and the "epidermis." The dermis, situated deeper of the two, consists of connective tissue abundant with blood vessels and nerves. Meanwhile, the epidermis is made up of layers called "strata," densely

packed with cells. These strata encompass seven layers, forming a protective outer coating of the body.

At the base of the epidermis lies the "stratum germinativum," housing cells capable of rapid division. Subsequently, six additional layers form each "epidermal generation," representing both the old and new skin layers. These layers include the clear layer and the lacunar layer, which mature in the old skin layer as new skin grows beneath it. [6, 7].

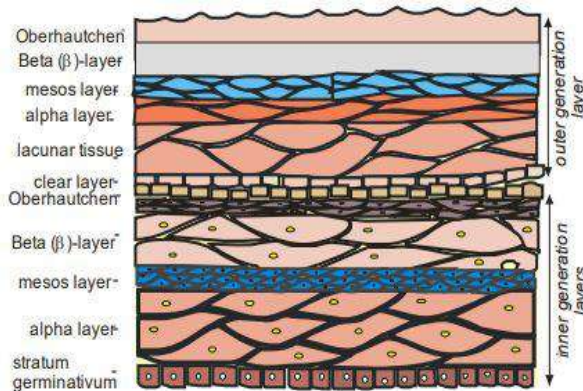


Figure 1: Cross section of reptile skin [6]

The alpha (α), mesos, and beta (β) layers consist of cells that undergo keratinization, producing two types of keratin (α and β keratin). This ongoing keratinization process gradually transforms these layers into a tough, protective outer layer. At the outermost level lies the "oberhautchen" layer, the toughest layer of keratinized dead skin cells. On the ventral side, this layer directly engages with the substratum during locomotion and features micro-ornamentation on both the dorsal and ventral surfaces [6, 7].

Snakes, like other reptiles, possess scales of various shapes and sizes covering their skin. These scales originate from the differentiation of the snake's underlying skin or epidermis, with each scale having an outer and inner surface. The number of scales remains fixed from birth, although they grow larger and may alter in shape during molting. In snakes, cell division in the "stratum germinativum" occurs periodically, leading to the replacement of upper layers above the division area. As a result, a second skin forms underneath the old one, which is then shed [6, 7].

Approximately two weeks before shedding, active growth begins in the stratum germinativum, leading to the gradual formation of a second set of layers beneath the old ones. During this process, the lowest layers of the old skin, including the clear and lacunar layers, undergo final maturation, culminating in the formation of a "shedding complex." Fluid is exuded, creating a thin liquid layer between the old and new skin layers. Enzymes present in this fluid break down the connections between the layers, causing the old skin to lift, which the reptile then actively removes [6, 7].

3. TECHNICAL DESIGN CONCEPT FOR A PROTECTIV SUIT

The absence of extremities in snakes has significant tribological implications, as their ventral body surface maintains almost constant contact with the substrate during locomotion. To facilitate movement, snake skin needs to exhibit low friction for sliding forward while simultaneously generating high friction for propulsive force along the substrate. The frictional properties between two materials in contact depend on several factors, including surface energy, material properties of both surfaces, and notably, the surface roughness of both bodies. Therefore, the specific roughness of the substrate on which the snake moves plays a crucial role in frictional force generation [11].

Moreover, the ventral surface of the snake is not smooth but comprises caudally-oriented scales covered with unique caudally-oriented nanostructures called microdermatoglyphics. Previous studies have highlighted the significance of this specific ventral surface in generating anisotropic friction and facilitating snake locomotion. Atomic force microscopy and confocal laser scanning microscopy have revealed regular denticle-like nanostructures on ventral scales of most snake species. These structures, typically $2.46 \pm 0.45 \mu\text{m}$ long and $0.60 \pm 0.11 \mu\text{m}$ wide, are oriented in the caudal direction and parallel to the longitudinal body axis [11].

To address the locomotion requirements of stunt performers, protective gear is essential for the back, elbows, buttocks, intimate region, and knees. The concept revolves around a full-body suit featuring precisely arranged small scales, replacing the need for bulky partial shields. Namely, the concept is to improve multiple performances by textural alternation of already existing materials. The idea arose from the observation of snake skin, and the fabric itself would mimic the shape of the scales.

High-performance polyethylene fibers are an ideal choice for such products. Polyethylene (PE) is a polymer derived from the polymerization of ethylene. These fibers are synthesized through melt spinning. High-performance polyethylene encompasses a range of fibers modified from polyethylene, including high-density polyethylene (HDPE) and ultra-high molecular weight polyethylene (UHMWPE). The exceptional performance of these fibers is achieved by altering their structure, primarily by increasing chain length and crystallization. HDPE fibers, commercially known as Dyneema in Japan, have gained global recognition, although in the United States, they are marketed under the name Spectra [12-14].

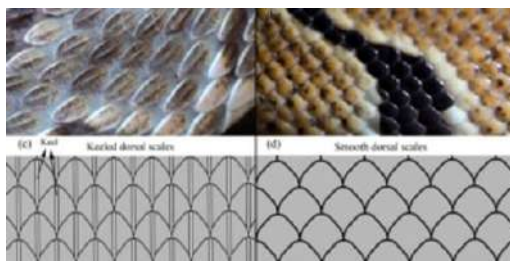


Figure 2: Example of the scales and how texture can mimic them [8]

Key characteristics of these fibers include[12-14]:

- Specific density less than 1, making them lighter than water
- Comparable strength to para-aramid fibers
- Excellent abrasion resistance, along with good electrical and chemical resistance
- High breaking strength even when wet
- Capable of bleaching and easy sterilization
- Low melting point
- Continuous operating temperature up to 250°F

Those familiar with the texture of snake skin will recognize that its scales align uniformly in one direction. These articulated scales serve to assist the snake in its forward movement while resisting backward motion. This implies that one of the basic parameters that needs to be investigated experimentally is precise angle of the scales. Some of the the basic characteristics that must be determined by research are:

1. Size of the scales
2. Scale density
3. Scale thickness
4. Overlap area

The primary traits of the material carrier should encompass exceptional elasticity and excellent air permeability. Implementing such texturing on the elastic material would enhance wearer comfort and significantly expand the range of motion.

Another crucial aspect of the concept is the stratification of materials. Essentially, the concept revolves around dividing the suit into three segments, each containing multiple layers of material. This layering primarily serves the purpose of mechanical protection, with the most layered sections strategically placed on the body's most vulnerable areas—whether they're in direct contact with surfaces or prone to injury. As mentioned earlier, the serration of snake epidermis has been proven to reduce overall friction, further justifying this design approach. Additionally, this design offers the added benefit of increased shock absorption by distributing force across the layers and by created air pockets between them. The layout scheme of materials with different layers is shown in Figure 3, where the thickest layer is shown in dark blue, light blue is of medium thickness and finally pink is the thinnest.

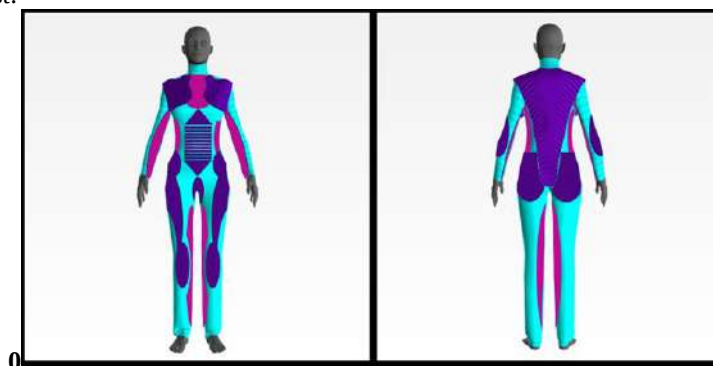


Figure 3: Technical drawing of the suit

In addition to the already mentioned performances, it should be noted that the operational period of such a product would be longer. In the article Wear Resistance Improvement of Keeled Structure and Overlapped Distribution of Snake Scales [8] revealed the study that investigates enhancing wear resistance by focusing on the keeled structure and the overlapped distribution of snake scales. Keeled and smooth snake scales were 3D printed and arranged in overlapped or parallel configurations on a substrate. Alongside these configurations, a reference sample with uniform thickness was included. Tribology testing revealed that samples with keeled structures exhibited higher groove counts compared to those with smooth surfaces, indicating a substantial enhancement in wear resistance, particularly vertically. However, surface morphology experimentation significantly influenced the tribology test results. Additionally, the keeled structure offers protection to the underside of snake scales, while overlapped distribution shields the central region, providing dual-layer protection for the snake's body. Overall, the keeled structure and overlapped distribution significantly bolster wear resistance in snake skin, offering valuable insights into reptile-mimicking surface structures and potentially benefiting the development of military uniforms for high-wear conditions [8].

4. CONCLUSION

Throughout history, humans have continuously sought to alter themselves through clothing. Initially, it served as an existential necessity, where animal furs replaced skin to survive harsh weather conditions. As human thought evolved, the significance of clothing shifted, transitioning to displaying status or adhering to beauty standards of the time. However, the fundamental purpose of protection remained unchanged. With advancements in the arms industry, the textile sector also flourished, producing specialized garments primarily for specific professions. Today, with widespread accessibility, such clothing has become commercialized.

While traditional clothing once defined individuals, recent decades have seen a new trend emerge: adapting clothing to fit individuals. Fueled by the demands of a fast-paced lifestyle that requires heightened productivity, there's a growing recognition that clothing should regulate and maintain physiological parameters to enhance work readiness.

In some industries, this type of clothing has become a necessity. Stunt choreography often requires specialized protective gear due to its demanding nature. Although such attire usually originates from equipment used in extreme sports, certain activities pose unique health risks to performers. Locomotion is a notable example. By delving into biomimetics, there's consideration for developing a suit modeled after snake skin.

It was determined that mimicking the texture of snake skin scales would offer superior mechanical protection, enhance comfort, facilitate greater flexibility, improve performance quality by reducing friction, enhance surface impact cushioning, thereby enhancing the physiological functionality of the entire suit and contributing to overall health protection.



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SESSION III

MANAGEMENT AND MARKETING IN THE FASHION

INDUSTRY



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INNOVATIVE ENTREPRENEURSHIP AS A KEY FACTOR IN CREATING A SUSTAINABLE TEXTILE AND FASHION INDUSTRY

Original review paper DOI:
10.5937/CT_ITI24047K

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ABSTRACT: This paper studies the impact of applying innovative entrepreneurship in the process of realizing sustainable business practices in the textile and fashion industry. The paper begins with the main characteristics of sustainable development which tries to reconcile economic, ecological and social aims, and which is realized through a large number of activities manifested in the principles of green and circular economy, bioeconomy, waste management, clean technologies etc. Firstly, the necessity of applying new business models based on innovation and sustainability is studied closely, then the attention is directed to the possibility of their application in the textile and fashion industry. Special attention in this paper is devoted to the role of innovative entrepreneurship in sustainable business practices in this sector. The conclusion is that the textile and fashion industry have considerable opportunities for the application of innovative entrepreneurship and the realization of the sustainable development principles, as well as that innovative entrepreneurship today represents one of the main driving forces of its innovative sustainable business models.

Key words: sustainability, innovation, entrepreneurship, business models, textile and fashion industry.

INOVATIVNO PREDUZETNIŠTVO KAO KLJUČNI FAKTOR U KREIRANJU ODRŽIVE TEKSTILNE I MODNE INDUSTRIJE

APSTRAKT: U ovom radu proučava se uticaj primene inovativnog preduzetništva u procesu realizacije održivog poslovanja subjekata tekstilne i modne industrije. U radu se polazi od glavnih karakteristika koncepta održivog razvoja koji teži da pomiri ekonomske, ekološke i socijalne ciljeve, a koji se realizuje kroz veliki broj aktivnosti, ispoljenih kroz principe zelene i cirkularne ekonomije, bioekonomije, upravljanje otpadom, čistije tehnologije, itd. Posebno se proučava neophodnost primene novih modela poslovanja koji



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su zasnovani na inovativnosti i održivosti, zatim se pažnja fokusira na mogućnosti njihove primene u sektoru tekstilne i modne industrije. Posebna pažnja u radu posvećuje se ulozi inovativnog preduzetništva u procesu održivog poslovanja ovog sektora. Zaključuje se da sektor tekstilne i modne industrije ima izuzetno široke mogućnosti za primenu inovativnog preduzetništva i za realizaciju principa održivog razvoja, kao i da inovativno preduzetništvo predstavlja danas glavni pokretački faktor njegovog inovativnog održivog poslovanja.

Ključne reči: održivost, inovacije, preduzetništvo, poslovni modeli, tekstilna i modna industrija.

1. INTRODUCTION

The necessity of applying new, sustainable and innovative business models has arisen as a consequence of numerous negative consequences of the liner model, which was in use for many years as the only business model. The most adverse consequences of the liner business model are massive environmental pollution, low quality of life, excessive depletion of natural resources, enormous waste production and so on. Seeing that such business model has led not only to worse economic results but also to the threat to humanity's and this planet's survival, the need has arisen for radical changes of the ruling business model as well as the entire value system and priorities.

The concept of sustainable development which tries to reconcile economic, ecological and social aims represents the only long-term solution to the existing problems. The given concept is realized through a large number of activities manifested in the principles of green economy, circular economy, bioeconomy, waste management, clean technologies etc. In the framework of sustainable development, green economy, circular economy and bioeconomy play a particularly important role in its realization, even though the other elements of sustainable development cannot be disregarded either.

Seeing that the application of sustainable development concept implies implementing numerous key changes in business processes, the given changes have to be for the most part accompanied by innovative solutions, but also the readiness to invest in new fields and new ways of doing business. This way innovation and entrepreneurship, and particularly innovative, sustainable entrepreneurship, can play a significant role in the process of building and developing sustainability.

Since the textile and fashion industry have a major role in the environmental pollution, waste generation, and the creation of numerous social issues, their further development will to a great extent depend on the ability to solve the mentioned problems. Therefore, it is thought that creating sustainable business models, as well as applying innovative entrepreneurship can contribute greatly to a sustainable development of this sector.

2. THE NECESSITY OF APPLYING NEW BUSINESS MODELS BASED ON SUSTAINABILITY AND INNOVATION

Some of the main causes of the necessity and urgency of applying new, sustainable and innovative business models are ever more intense depletion of natural resources which is exceeding the possibility of their renewal, urbanization and the decline in the quality of life, economic losses and structural waste, bigger price risks, the emergence and constant improvement of clean technologies, accepting alternative business models, ever more intense degradation of the environment due to the climate change, the loss of biodiversity and natural capital, the degradation of land and water pollution.

Green economy represents the foundation of sustainable development realization. Its main elements are: bioeconomy, circular economy, clean technologies, and hierarchy in waste management, industry ecology and solutions based on nature conservation [1, 2]. Green economy advocates for using the untapped potential of ecological processes (i.e. ecosystem services), for improving social welfare, but in a way which does not threaten their sustainability, together with substantially lower risk to the environment. This concept offers a solution for reducing carbon emission, upgrading energy and resource efficiency and preventing the loss of biodiversity and ecosystem favors [3].

Circular economy is the economy which is regenerative in its design and which aims to ensure the greatest utility and value of products, components and materials at all times [4]. So as to achieve the mentioned goal, it is necessary to apply the integrative approach, starting with the choice of business models and product design, to the design of supply chains and the choice of materials. Circular economy strives to reduce solid waste, landfills and emissions through activities such as reuse, reproduction and/or recycling. Like the concept of sustainable development, the concept of circular economy is also a global developmental concept which takes care of the current state of the economy, industrial production and consumption which can endanger future generations, and it can as well represent the source of untapped competitive advantage [5]. Both concepts are also based on the transformation of economic system, collaboration between different economic entities, innovation of business models and application of multi and interdisciplinary approaches.

It is important to emphasize that the implementation of the circularity principle in business models and supply chains represents a prerequisite for sustainable production which is necessary for improving economic and ecological performances of developed and developing countries [6]. The European Commission presents circular economic systems as useful for different dimensions of sustainability (productivity of resources, job openings and GDP growth), but it does not specify whether they present the necessary or sufficient condition and in which way they are connected with other concepts which promote and encourage sustainability. Circularity and systems based on services are necessary, but not sufficient conditions for a sustainable economic system. For long-term sustainability, in addition to establishing the closed circle system, it is necessary to ensure other conditions as well, such as the change in the way of life, behavior patterns and spending habits.

Other than the listed similarities, the literature points out certain main differences between the concept of sustainable development and the concept of circular economy. The mentioned differences are: *time of origin* (the concept of sustainable development is older), *aims* (unlike the sustainability goals which are different and changeable, circular economy



aims to close the circle), *motives* (circular economy is motivated by the idea of better resource utilization and waste and emissions reduction using circular rather than linear systems), *priorities* (the concept of circular economy prioritizes economic prosperity first, and then environmental benefits, while the concept of sustainable development is conceived of as a holistic approach which sees economic, social and ecological dimensions as equal and balanced), *users* (sustainability aims to be of use to the environment, economy and society as a whole, while the main users of circular economy are economic actors who apply a circular system) and *responsibility* (in the debate on sustainability responsibilities are shared, but not clearly defined, while in the literature it is thought that the responsibility for the transition to circular system rests primarily with private businesses and policy makers).

On the other hand, circular bioeconomy is a political (intergovernmental), industrial and social initiative, which requires, among other things, the following [7]:

- introducing flexible and encouraging culture of organizational changes in value chains;
- strengthening public-private partnerships;
- readiness to develop bio-based industries so as to ensure self-sufficiency in basic goods;
- systemic way of thinking at all levels and building appropriate institutions at a local and regional level;
- efficient mixture of policies, appropriate legal framework and innovative approach;
- appropriate changes in terms of quality standards with the aim of accepting recycled bio-products.
- mutual effort and collaboration between researchers, technological centers, industry, primary sector, new entrepreneurs, consumers, civil society and public policy makers.

In the process of constructing the three main building blocks of circular economy, business entities have a role in realizing the following: *circular product design and production, development of new business models* and *existence of reverse logistics and treatment methods* which ensure that materials return to the market. In addition to this, a successful transition to new, more adequate business models requires the construction of the fourth block which refers to *enabling and creating favorable systemic conditions* in whose development the key role belongs to educational and financial institutions as well as platforms for collaboration (between sectors or enterprises and policy makers) and new economic framework.

3. THE POSSIBILITIES OF APPLYING INNOVATIONS AND SUSTAINABLE BUSINESS MODELS IN THE TEXTILE AND FASHION INDUSTRY

The textile and fashion industry are the trades with a wide spectrum of possibilities for applying innovations and sustainable business models. Todeschini et al. (2017) pinpointed five socioeconomic and cultural macro-trends which lead to initiating the application of sustainable and innovative business models in the textile and fashion industry. These are:

applying the circular economy concept in industrial processes which enable innovations in product design, services and business models, the adoption of corporate social responsibility measures, sharing economy and collaborative consumption which promote economic growth based on innovations and entrepreneurship and reducing the negative impact on the environment, technological innovation (using alternative raw materials rather than scarce natural resources, recycled materials, natural dyeing techniques, improving clothing durability, reducing waste etc.) and consumer education and increased consumer awareness of the advantages of sustainable and green products.

Based on the conducted research and practice it can be said that innovations in textile industry enterprises have a vital role in the process of encouraging their business. A study by Wongwilai et al. (2022) which explored the importance of innovative ideas and their contribution to the business sustainability of textile industry enterprises takes into consideration three factors in the studied processes [8]. These are: innovative processes, innovative production and innovative supply chains. The results of the given study point out that innovative ideas have a key role in business sustainability. They increase the innovative production and supply chains which then leads to positive effects on business sustainability.

In the textile and fashion industry there is a wide range of possibilities for increasing the value of the existing clothing by extending its life span and enabling new ways of using it, for creating zero waste and for slow fashion. Table 1 shows the mentioned trends which foster innovations in fashion sustainability-related business models, as well as their impact on the nine main areas of the business model.

Table 1: Trends and drivers of sustainability-related business model innovation for fashion businesses

Macro-trend	Driver of sustainable innovation	Where does it drive innovation in sustainable business models in fashion?
Circular economy	Recycling	Cost structure, key activities, key partners
	Vegan	Key partners, key resources, channels, value proposition
	Upcycling	Key resources, key activities, value proposition
Corporate social responsibility	Sweatshop free	Customer relationship, key resources, key activities
	Fair trade	Customer relationship, key partners
	Locally sourced	Customer relationship, value proposition, key partners
Sharing economy and collaborative consumption	Fashion library	Customer relationship, value proposition, revenue streams
	Second hand	Value proposition, channels, customer relationship, key activities, revenue streams
	Collaboration	Key partners, key activities, key resources, delivery channels, customer relationship
Technological innovation	Sustainable raw materials	Key resources, customer relationship, cost structure



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	Zero waste	Key resources, key activities, cost structure
	Wearables	Key resources, key activities, key partners, value proposition, cost structure
	Capsule wardrobe	Customer relationship, value proposition, revenue streams
Consumer awareness	Lowsumerism	Customer relationship, value proposition, revenue streams
	Slow fashion	Value proposition, customer relationship

Source: Todeschini et al., 2017, p. 763.

The literature also emphasizes the importance of the diffusion of open innovation models for enterprises in the textile and fashion industry with a view to ensuring ecological sustainability of their processes and products. It is also highlighted that the possibility of increasing innovative performance of enterprises by adopting the open innovation model depends on two elements; those are [9]: a) the capacity to collaborate with enterprises which do business in different sectors; b) internal investment in research and development so as to ensure the necessary absorption capacity for collaboration. It is very important to emphasize that contemporary innovations in the textile and fashion industry, especially product innovations, are very complex and that they necessitate acquiring technological knowledge in different scientific fields, such as materials science, nanotechnologies, medicine, chemistry and alike.

Water, fuel and chemicals are used as basic resources in large quantities in business operations in the textile industry enterprises. Chemicals released in the environment from processing and dyeing of textile make up a third of all chemicals released into the environment [10]. Because of this, so as to mitigate the damage already done to the environment, and to reduce and prevent the future negative impacts, it is necessary to introduce and apply the principles of sustainable business in the textile industry enterprises. Sustainable business implies the change in the value system, priorities and the entire business philosophy, which, on the other hand, points to the necessity of a constant introduction of sustainable innovations.

The application of *sustainable innovations* in the textile industry means that the products which are produced are *safer, more efficient, healthier and ecologically more acceptable* and that they use *less material, create less waste and spend less energy*. Eco design can significantly reduce energy consumption, as well as energy loss. The tools used in eco design, which are popular in the textile industry, include the eco sign, carbon footprint, life cycle analysis, sustainability design and water footprint [11]. Eco signs in the textile industry promote ecological practices such as sustainable production and reduction of harmful chemical in textile.

Other than the abovementioned, the assessment of the life cycle is also very important in the textile industry, because each phase of an industrial process has a potential to significantly influence the ecology and society, from using toxic chemicals or large amounts of energy, to the lifespan end phase, where some products emit harmful chemicals after being disposed of on landfills. In the materials domain, sustainable innovations should contribute to the reduction, replacement or usage of more sustainable materials. This form

of sustainable innovations is critical because the majority of materials used in the textile industry are unsustainable, since fibers used are obtained from fossil fuels.

One kind of sustainable innovation in practice are sustainable process innovations, which include cleaner production, ecological efficiency, waste management, supply chain management, as well as enzyme-based technology and textile processing. *Cleaner production* represents an integrative preventative ecological business strategy which aims to increase the overall efficiency and reduce human and environmental risks by producing high-quality products [12]. *Eco efficiency* is the capacity of an organization to provide goods and services at competitive prices with minimal harmful influence on the environment and using resources during their life cycle, with the idea of “creating greater value with less impact on the environment” [13]. *Waste management* is a form of sustainability innovation which is focused on reducing, reusing and recycling waste.

One of huge global problems in the textile industry is waste. With a view to managing waste efficiently, strategic steps proposed by peer-reviewed literature include focus on raw materials, waste management and shaping consumer behavior.

Supply chain management is directed towards the attitude a company has towards upstream processes (raw materials) and downstream processes (distribution), which are very complex in the textile industry and which include complex local and international networks. A few innovative points related to supply chain management are the following: traceability of supply chains and upstream and downstream connection in the process of forming value chains.

One of the key driving forces of sustainability innovations is organizational innovative practice. There are a few practices which refer to organizational innovations, and they include environmental management systems and corporate policies, collaboration, business models, culture and knowledge management and risk management. Environmental management systems and corporate environmental policy could make it easier for companies to reconcile their ecological and social responsibility in a way understandable and acceptable for every interested party in a company. Collaboration is critical in this process because main challenges in the textile industry entail collaboration between different social actors (industries, universities, research institutions and public policy makers) so as to reach more sustainable solutions in this sector.

The new business model which contributes to sustainability innovations is particularly related to circular business models, which enables companies to create value for increasing the efficiency of resources with a longer product lifespan and closing material loops. Numerous authors claim that, in order to enable the realization of circular economy, it is necessary to formulate an innovative business model, not just to apply product and process innovations. Only in this way will it be possible to realize product and material reuse. The key players in the process of developing innovative business models in the textile industry with a greater potential are young entrepreneurs and consumers.

As one of the most significant fields of research tackled in almost all peer-reviewed articles are obstacles to applying sustainable innovations in the textile industry. The mentioned obstacles can be of internal or external character [14]. A typical example of an internal barrier is the lack of awareness of the need for sustainable innovations, which can be a



consequence of the lack of knowledge of the existing impact of innovations on ecological and social aspects, as well as the lack of information concerning the market needs for innovative and sustainable products. The barriers often mentioned also refer to investment and production costs, primarily related to technology replacement, research and development costs or material replacement, which affect the increase in the selling price which customers can find unacceptable and which can make the product less attractive on the market. An external obstacle in the development of innovative sustainable practices in the textile industry can be, for example, the lack of support from the government in terms of financial incentives and non-financial aid. Another obstacle can refer to the challenges subjects face when searching for potential partners for collaboration, and which are related to culture compatibility and different abilities needed. Unstable macroeconomic conditions are also considered a barrier to the development of sustainability innovations.

4. THE IMPACT OF INNOVATIVE ENTREPRENEURSHIP ON SUSTAINABLE BUSINESS PRACTICES IN THE TEXTILE AND FASHION INDUSTRY

The possibility of innovating business models and reducing the negative impact of business activities on the environment is particularly great in the textile and fashion industry. By introducing the concept of sustainable development, green and circular economy, entrepreneurship has more and more “green” characteristics. This particularly refers to environmental entrepreneurship, eco-entrepreneurship, green (or ecological) entrepreneurship and sustainable entrepreneurship. Many studies pointed out the unbreakable bonds that exists between green entrepreneurship and innovations [14]. Designing and placing new products and services and creating new jobs while simultaneously solving ecological problems (such as the loss of biodiversity and global warming) is the main idea of green entrepreneurship. The idea of green entrepreneurship is manifested first and foremost in actions and motivation which stem from the desire to solve specific ecological problems or to transform the sector so that alternative and more sustainable products and practices become more common.

Green (or ecological) entrepreneurship advocates for designing and implementing business models which offer solutions for reducing or preventing negative effects of fast fashion on ecological and social sustainability by implementing different types of eco-innovations. Its aim is transformation, i.e. “greening” of the sector so as to make it more sustainable, as well as the creation of not only economic, but social and ecological value as well [16]. The key characteristics of green entrepreneurs are the following [15]:

- Using new business opportunities and a lack of aversion to risk;
- Strong intrinsic motivation and desire to offer their contribution in terms of ensuring a more sustainable future;
- Focus on ensuring both direct financial benefits and positive impact on the environment by fostering innovations related to the environment and sustainable development;
- Awareness of creating a more sustainable future.

However, we should not forget that the implementation of sustainable development causes the increase in business expenses. Due to this, entrepreneurs who run their businesses in

accordance with the principles of sustainable development are often on the brink of extinction, and one of the main reasons for this is insufficient involvement of the public sector in the support of entrepreneurs in the sector. This is why it is necessary for local and regional authorities to build and apply individualized approaches to entrepreneurs. This is because green entrepreneurs represent a very heterogenous group with different motives and strategic aims, but also diverse financial and ecological goals.

The importance of sustainable entrepreneurship, as a potential solution to different problems, has drastically increased worldwide. Owing to new sustainable business models, products and services, entrepreneurs can contribute to the solution of environmental problems. The latest studies have tried to integrate entrepreneurship with sustainability and to encompass a wide concept of sustainable entrepreneurship, which includes financial, ecological and moral criteria [17]. Entrepreneurs, small and middle-sized enterprises have a particularly important role to play in this process. Fast, great and often unpredictable changes in the surroundings face entrepreneurs, small and medium-sized enterprises with numerous challenges of finding possibilities for solving problems and improving business success. Entrepreneurs, small and medium-sized enterprises can play a major role in a country's development, which is why they are generally thought of as a key pillar of economic development in developing countries. Therefore, entrepreneurial abilities and knowledge are of essential importance for the development of sustainable entrepreneurship.

In contemporary business conditions innovative aspect of entrepreneurship is of crucial importance in almost all sectors, including the fashion industry. Doing business in the fashion industry, just like fashion employers themselves, requires a high level of innovation and entrepreneurship so as to achieve high performance and high efficiency. Studies show that there is a large number of individuals in the fashion industry who are at the same time inventors, owners and fashion company managers. Such companies were created as a result of commercialization of fashion ideas and design methods, production, as well as the application of such business or marketing methods which have led to revolutionary or incremental changes in the fashion industry. Global fashion business today entails, other than a high level of creativity and innovation, sophisticated management techniques. The given management methods have to adjust to a fast development of business strategies in fashion management.

Entrepreneurs are market actors who: manage businesses in an entrepreneurial way, establish new organizations, bring innovations into the market (either new products or services, or new processes), identify market possibilities etc. [18]. Entrepreneurship is a process of using the possibilities that exist in the surroundings or which are made by innovations in an attempt to create value. They often include creating and managing new business ventures by individuals or teams [19]. Mutual aspects of entrepreneurs' and innovators' creativity appear in different areas such as: design, science, technology, art and organizational development. This enables creative entrepreneurs to work in many different types of organizations.

Joseph Schumpeter thought that “without innovations, there are no entrepreneurs” and that an entrepreneur is actually an innovator who creates something new for an organization



and customers. Also, forced innovations are of fundamental importance, seeing that innovations are necessary for restarting, recreating and reflecting at all levels of an organization. Besides, corporate entrepreneurship is regarded as a necessary element in the process of creating continuous innovation and achieving competitive advantage on dynamic markets, as well as in building organizational skills which enable a company to create capacity for continuous innovation. In this context, entrepreneurs are motivated people who are able to seize an opportunity and transform it into their own market opportunity. Studies show that there is a high level of correlation between high-performance enterprises and innovative entrepreneurs, which is in accordance with the literature that voices the opinion that innovations improve company performance, and thus their competitive advantage as well.

There is a very strong bond between creativity and innovation in new markets, products, processes and technologies. It is particularly important to emphasize that the innovation in fashion is a continuous and almost endless process, which significantly improves the competitiveness of textile enterprises and fashion business. The market is constantly looking for new products in the area of product innovation. Because of this, universities continuously come up with new inventions and try to commercialize their new technologies. The commercialization of mentioned innovations depends on business models applied, marketing and finance, as well as industrial partners and management methods. The driving force of innovation are creative and venturesome individuals. In addition to a high level of creativity and innovation, doing business in the textile and fashion industry requires sophisticated management techniques. Two dimensions of “creativity and innovations” are associated with this industry [19]. The first one refers to product innovations associated with fashion/textile designers’ creativity which is important in creating stronger international brands and leading world competitive products. The second dimension refers to innovations in “business operations,” marketing techniques, supply chain management etc.

Seeing that solving environmental problems is related to high level of uncertainty, this offers great possibilities for realizing entrepreneurial activities. Entrepreneurial actions can compensate for ecological market failures by revealing, assessing and taking the chances contained in these failures, so as to initiate the process of using the environment and natural resources and to get to the development of ecologically more sustainable economy [20].

Circular entrepreneurship represents a special type of entrepreneurship and can be defined as a process of researching and exploiting the possibilities in the circular economy domain [21]. Circular entrepreneurship represents a special type of sustainable entrepreneurship which aims to protect the population and the environment. It is also connected with other types of entrepreneurship, especially organic entrepreneurship (focus on health and wellbeing), green entrepreneurship (focus on climate and ecosystems) and blue entrepreneurship (focus on clean water and sea life) [22]. New enterprises, whose business operations are based on circularity, should significantly contribute to solving ecological problems by creating new ecologically sustainable processes, products and services.

At the same time, circular entrepreneurship can represent a challenge for growing circular enterprises, as well as for all companies that are switching to sustainable business models and the application of circularity principles [23]. Entrepreneurial companies that apply

innovative business models can fill in the gap and provide critical links for corporations in reverse supply chains, while, on the other hand, they create new business opportunities for numerous social benefits [24]. Studies on these topics show that entrepreneurs are able to implement innovative business models, to develop innovative products and services, as well as to explore possibilities that arise from circular economy. This way they can solve numerous problems that occur in the social and ecological field. Realizing innovative sustainable business models represents the main driving force of implementing circular economy in the fashion industry.

5. CONCLUSION

Implementing the principles of sustainable development in business models and supply chains represents one of the main production requirements in contemporary economic conditions. The concept of sustainable development which aims to reconcile economic, ecological and social goals represents one of long-term solutions to the problems caused by applying the linear business model. The given concept can be realized through a large number of activities, manifested in the principles of green economy, circular economy, bio-economy, waste management, cleaner technologies etc. The application of the sustainable development principles implies radical changes in business operations, the way of thinking and the value system. The given changes require the application of new solutions in all areas of human activity, and new solutions are the result of innovative activities and adequate business ventures. This paper points out that the textile and fashion industry are trades with a wide variety of possibilities for applying innovations and sustainable business models. Based on the analysis of research conducted it can be concluded that innovations in textile industry enterprises have a vital role in the process of encouraging their business operations. The conclusion is that three elements have a particularly important role in the process of applying innovative ideas and their contribution to sustainability. These elements are: innovative process, innovative production and innovative supply chains.

The paper emphasizes that contemporary innovations in the textile and fashion industry, particularly product innovations, are very complex and entail acquiring technological knowledge in different areas. Specifically, the application of *sustainable innovations* in the textile industry means that *safer, more efficient, healthier and ecologically more acceptable* products which use *less material*, create *less waste* and spend *less energy* should be produced.

The paper also points to the obstacles that occur in the process of applying sustainability innovations in the textile industry. The lack of awareness of the need for sustainable innovations, as well as high investment and production costs are stated as internal obstacles. The lack of governmental support in terms of financial incentives and non-financial support, the challenges subjects are faced with when looking for potential partner for collaboration, as well as unstable macroeconomic conditions are stated as external obstacles. Hidden unethical practices in textile supply chains, then modern slavery practices which include employment agencies etc. represent hidden obstacles in this process.



This paper pays special attention to the characteristics of green entrepreneurship which advocates for designing and implementing business models which offer solutions for reducing or preventing negative impact of fast fashion on ecological and social sustainability by introducing different types of eco-innovations, with a view to transforming, i.e. “greening” the sector so as to increase its sustainability and create not only economic, but also social and ecological value.

The conclusion is that entrepreneurial companies which apply innovative business models can fill in the gap and provide critical links for corporations in reverse supply chains, while, on the other hand, they create new business opportunities for numerous social benefits, as well as that innovative entrepreneurship is the main driving force of innovative sustainable business operations in the textile and fashion industry.

ACKNOWLEDGEMENTS

This work was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract No. 451-03-65/2024-03/200135)

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ANALYSIS OF NORMS METHODS IN THE GARMENT INDUSTRY

Professional paper
DOI: 10.5937/CT_ITI24048C

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ABSTRACT: Several norms methods are used in production today, and garment manufacturers are often at a loss as to which method to use. That is why in this paper we have analyzed 3 different methods - Method with coefficients, REFA and MTM-2.

Keywords: garment industry, Method with coefficients, REFA, MTM-2.

ANALIZA METODA NORMIRANJA U INDUSTRIJI ODEĆE

APSTRAKT: Danas se u proizvodnji koristi nekoliko metoda normiranja i često su proizvođači odeće u nedoumici koju metodu da koriste. Zato smo u ovom radu analizirali 3 različite metode normiranja - Metodu sa koeficijentima, REFA i MTM-2.

Ključne reči: odevna industrija, Metoda sa koeficijentima, REFA, MTM-2.

1. INTRODUCTION

Companies of the production sector are exposed to drivers like globalisation, which lead to a high amount of challenges, such as customisation of products as well as a reduction of the time-to-market. [1] According de Almeida and Ferreira with the continuous growth of competitiveness among companies, the increase in productivity has become an important requirement for many of those companies.

Garment production deals with norm working. Norm is the time the average skilful worker of appropriate expertise needs to perform a specific technological operation with normal effort and fatigue, at normal environmental action and under normal conditions of work. This definition suggests the following three conditions [3]:

1. Qualified and well trained worker;

2. Working at a normal pace with which a trained worker performs the task under normal conditions with a normal level of consumption of his own energy. Normal human consumption of energy is the one at which the employee can withstand the pace of work - neither too fast nor too slow. Carrying out of time norm that most of the skilled workers can perform is 100%.

3. Performing a specified task which has a certain prescribed method of work, materials specification, specification of tools, accessories and the equipment used, position of intermediate storage before and after performing the task, displaying additional requirements related to safety, quality, workplace regulations and activities to ensure the carrying out of the task.

2. METHODS

In order to calculate the time norm methods can be used, such as: Method is with three coefficients, Michelin methods, The method of average value, The method of maximum frequency, REFA and MTM.

A time method with stopwatch timer is most widely used in our garment industry. This method is with three coefficients: the fatigue coefficient, the coefficient of environmental influence and the supplementary coefficient.

The fatigue coefficient is required because of the reduction of performance due to physical and mental fatigue of workers during working time caused by monotony, hard work, body position, etc. With physical fatigue, as a consequence of dynamic muscle strain, exhaustion and fatigue may occur (if the work is limited to some constant movements and muscle groups), and as a result of static muscle strain (if the limbs are immobile and if there is a permanent contraction of muscle groups). Muscle fatigue is a lack of oxygen, and occurs whenever a bigger impact within a unit of time is required than it corresponds to the amount of oxygen that is available. [3] For determining of supplementary coefficient about 15% are taken, including [3]:

- 5% for personal needs,
- 4% for interruptions caused by personal fatigue,
- 2% for a very unfavourable position of the body
- 2% for insufficient light,
- 2% for precise work.

Methods-Time-Measurement system (MTM) is a system of predetermined times and is used for the design of working processes. Therefore, manual tasks are analysed, described, structured and planned by means of defined process modules. These are systematically structured and arranged, in order to visualise influence factors and to design working systems already in the planning phase. [4] MTM is the most famous one in the world and it is mostly used in garment industry. It is used for the rationalization of existing work procedures and for providing objective data to design new work processes. This system is a time system which divides every manual technological operation into basic movements (Reach, Grasp, Move, Position, and Release) which are given certain time values

depending on the nature of movements and the conditions in which they are carried out. [3].

The MTM methodology is in continuous development and today in use are: MTM-1, MTM-2, MTM-3, MTM-UAS, MTM-MEK, MTM-EAWS, MTM-SAM, MTM-SD and MTM-VI.

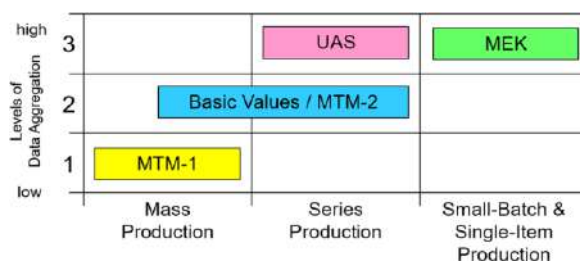


Figure 1: Application fields for different MTM standards [5]

REFA is a method for the systematic observation, capture and measurement of work processes. [6] The REFA method works with a so-called performance level which is used for correction of measured time so that different intensities of work by individual employees can be taken into account. If a man is aware that he is being measured he can consciously or unconsciously perform his work at a different speed. [7] According to Buresa and Pivodova REFA performance level enables the observer to adjust and recalculate the measured time to so-called normal performance level with value 100%. Under the normal performance level we understand performing harmonious, natural and balanced motions and their coordination. It can be performed during the whole shift permanently by every worker who is experienced, educated and trained and is following safety instructions.

2. ANALYSIS OF NORMS METHODS

For better optimization and standardization of workplaces, the production of men's denim shirts was analyzed. In order to determine the required norming method, several workplaces were analyzed with 3 different methods: Method is with three coefficients, REFA and MTM-2. In this paper, we will show you the analysis of the production of the collar, where the worker has 3 phases of work:

- Sewing stand collar on collar (Ordinary sewing machine).
- Cutting and turning the stand collar (Hand makes).
- Topstitch the stand collar (Ordinary sewing machine).



Figure 2: Collar

The size of the observations was 10 for the Method is with three coefficients and REFA and 3 videos for the movement analysis when working with the MTM-2 method. The Table

1. shows the results of measurements by the Method is with three coefficients where is the norm of this technological operation 129,39s. The results have been obtained with SE-ERGO calculator.

Table 1: Results of measurements by SE-ERGO calculator

tn =	129,395
coefficients	
Kn =	0,11
Ka =	1,3
ts =	147,8985
Kd =	0,15

Figure 3 shows a part of Z2 the REFA norming methodology form with detailed statistical data processing. The resulting norm amounts to 129.3s.

Zy	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	$\Sigma L / n$	$\bar{L}$	$t = \bar{L} / 100 \cdot t_i$	Vrsta ča
m _x																$\Sigma t_i / n$	t_i		
																1040	104	67,8	
L	95	105	95	100	115	95	100	105	115	115						10			
t _i	66	65	66	66	65	66	64	65	64	65						652	65,20		
F																10			
																1040	104	23,5	
L	95	105	95	100	115	95	100	105	115	115						10			
t _i	23	23	23	22	22	22	22	23	23	23						226	22,60		
F																10			
																1040	104	38,0	
L	95	105	95	100	115	95	100	105	115	115						10			
t _i	37	37	37	36	36	37	37	37	36	35						365	36,50		
F																10			
$\bar{t}_i = \Sigma t_i / n = 124 \text{ HM}$																$\Sigma t_i = 1243 \text{ HM}$	$n = 10$	Zbir vremena za ciklus iz:	
$s = 1,3 \text{ HM}$																$v = s / t_i = 1\%$	$c = 0,7\%$	$c' =$	$n' = \# \text{DNV/OI}$
																$\Sigma t =$	129,3	HM	

Figure 3: Part of Z2 the REFA

The methods MTM-1 and MTM-2 are excellent methods for analyzing clothing production, but we opted for a simpler MTM-2 method. Figure 4. shows a part of MTM-2 form with results. When calculating the norm, because only movements are analyzed, it is necessary to add Performance Rating and Allowance Factor.



Left hand	Symbol	TMU	Symbol	Right hand
takes the top collar	GB 30	14		
takes the stand collar	GB 45	18		
places the parts	PC	26	PC	places the parts
sewing				sewing
release	GW 3	1	GW 3	release
		18	GB	takes the scissors
cutting and turning the stand collar	C	15	C	cutting and turning the stand collar
places the part	R	6	R	places the part
sewing				sewing
release	GW 3	1	GW 3	release
TMU		99		
SMV = Basic Time×Performance Rating×Allowance Factor/100 = 128.8 s = 2.12 min				

Figure 4: Part of MTM-2 form

The analysis of the application of 3 norms methods on the same technological operation is shown in the Table 2.

Table 2: Analysis of the application of 3 methods

Method	Norm (s)
Method is with three coefficients	129.39
REFA	129.3
MTM-2	128.8

3. CONCLUSION

In this paper we by applying three different norms methods, we obtained similar results, which indicates that we can use all these methods in the production of garments. The Method with three coefficients and REFA are much simpler and faster for workplace analysis than MTM-2. MTM-2 requires more experience in analysis.

In order to increase productivity and efficiency, it is necessary to deal with work analysis and target norms in order to standardize all workplaces in garment production. Targeted standards will shorten production time and reduce production costs. In order to achieve this, regardless of which method we use, it is necessary to perform an analysis of the movements as with the MTM method and thereby reduce or combine the movements, because in the production of clothes we have a lot of manual work.



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CONSUMER BEHAVIOR FOR BUYING CLOTHES

Scientific paper
DOI: 10.5937/CT_ITI24049Z

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ABSTRACT: The clothing industry is highly competitive, with rapidly changing trends, diverse customer preferences, and intense market competition. Therefore, gaining insight into consumer behavior in this specific area becomes essential for apparel retailers who want to create successful business strategies. Understanding the motivations, preferences and patterns of consumer behavior is crucial for market orientation and the creation of effective marketing strategies that will meet customer expectations and at the same time increase the competitive advantage of clothing stores on the market. The basic purpose of our research was to determine the most important factors that influence the purchasing decision of consumers, the influence of fashion trends and influencers, the choice of clothing stores and the choices of online and physical stores.

Keywords: Consumer behaviour, clothing store, online sales, clothing brand.

PONAŠANJE POTROŠAČA PRI KUPOVINI ODEĆE

APSTRAKT: Industrija odeće je veoma konkurentna, sa trendovima koji se brzo menjaju, raznolikim preferencijama kupaca i intenzivnom tržišnom konkurencijom. Stoga, sticanje uvida u ponašanje potrošača u ovoj specifičnoj oblasti postaje od suštinskog značaja za trgovce odećom koji žele da kreiraju uspešne poslovne strategije. Razumevanje motiva, preferencija i obrazaca ponašanja potrošača je ključno za tržišnu orijentaciju i kreiranje efikasnih marketinških strategija koje će ispuniti očekivanja kupaca i istovremeno povećati konkurentsku prednost prodavnica odeće na tržištu. Osnovna svrha našeg istraživanja bila je da utvrdimo najvažnije faktore koji utiču na kupovnu odluku potrošača, uticaj modnih trendova i uticaja, izbor prodavnica odeće i izbor online i fizičkih prodavnica.

Ključne reči: Ponašanje potrošača, prodavnica odeće, online prodaja, brend odeće.

1. INTRODUCTION



Fashion industry plays a critical role as people's living standards are growing. The most significant features or representations in the fashion industry are apparel, footwear, and accessories. For people with low income and low social status, they cannot afford the apparel of famous brands, which means the purpose of purchasing clothes is merely to meet the physiological needs and security needs. For people with stable and high level of income, the basic needs are already satisfied, and they would shift their attention to luxury goods to meet their self-esteem needs, such as representing social status or gain more respect from others. [1]

In this paper, we analysed the shopping behaviour of customers in a clothing store. By examining the factors that influence consumer decision-making processes and exploring various theoretical frameworks, we have gained a comprehensive understanding of how consumers navigate the apparel retail environment. For retailers, studying the decision-making process consumers go through when shopping for clothing is also crucial. Understanding each stage of this process allows retailers to adjust their marketing strategies, product offering and customer experience to align with consumer preferences, thereby increasing customer satisfaction and loyalty.

2. CONSUMER BEHAVIOR IN CLOTHING RETAIL STORES

Consumer buying behaviour can vary greatly from individual to individual and can be shaped by a wide range of factors. Factors such as personal motivation, past experiences, cultural norms, economic circumstances, and family and peer influence contribute to consumer decisions. Understanding these diverse influences is essential for businesses that want to effectively target their customer base, align their products and services with customer needs, and foster long-term relationships that drive lasting success. Understanding consumer buying behaviour is at the heart of creating successful marketing strategies, building brand loyalty and achieving sustainable business growth. The key to success lies not only in understanding the current state of consumer behaviour, but in anticipating future trends and staying aligned with evolving customer needs and expectations. In this ever-changing environment, companies that prioritize a deep understanding of their customers and the factors that influence their purchasing decisions will not only survive but thrive in a competitive market.

Customer buying behaviour in retail refers to the patterns of how individuals or groups select, purchase, use, or dispose of products, services, experiences, or ideas to satisfy their needs and desires within a retail environment. Many factors, including personal preferences, cultural norms, social influences, and psychological drivers, influence this intricate dance of decision-making [2].

By understanding customer behaviours, retailers can strategically design their stores to enhance the customer experience and influence purchasing decisions. Retailers can nudge customers towards certain products by placing popular items at eye level, creating enticing product displays, or offering samples and promotions. The layout of the store, the ambiance, and even the background music are all carefully curated elements that can subtly affect a shopper's mood and willingness to buy. Incorporating this understanding into sales



strategies, marketing initiatives, and advertising campaigns allows for a more targeted approach that can significantly increase effectiveness.

This profound insight into customer behaviour can inform the development of personalized marketing messages, tailored advertising content, and strategic product placements, all of which can lead to increased customer engagement, higher sales, and enhanced brand loyalty. By aligning sales strategies, marketing, and advertising with customer behaviour insights, retailers can create a cohesive and compelling shopping experience that resonates with their target audience, driving immediate purchases and long-term customer relationships [3].

The apparel industry, being highly consumer-driven, necessitates a deep understanding of consumer behaviour to ensure success. Consumer behaviour research provides invaluable insights into what influences customers' purchase decisions. This article delves into the types of consumer behaviour, methods of research, the major focus of such research, and a detailed guide on conducting consumer behaviour research specifically for the apparel industry [4].

One of the main factors influencing the purchase of clothing is the individual's taste and style identity. Personal preferences, shaped by factors such as personality, cultural background, and lifestyle, guide consumers in choosing clothing that matches their expression. Social and cultural trends play an important role in shaping the fashion space. Cultural influences, including traditions, values, and norms, affect the types of clothing that are considered appropriate or fashionable in each context. In addition, social trends promoted by influencers, celebrities and the media contribute to changing fashion preferences [5].

Several studies about the fashion industry have discussed consumer buying behaviour, which can be classified into compulsive buying and impulsive buying. Compulsive buying is a buying habit that is exposed by excessive buying—with a lack of impulse control [6]. On the other hand, impulsive buying is spontaneous and immediate without any pre-shopping intentions [7]. It positively affects personality variables such as shopping enjoyment, which urge consumers to purchase. This shopping enjoyment is categorized as a hedonic motive, a type of motivation characterized by a desire for pleasure and fun. Aside from the hedonic motive, another type of shopping motive is the utilitarian motive. It is a type of motivation that considers shopping as a functional or practical task. Hedonic and utilitarian motives are considered as types of shop browsing [8].

3. EMPIRICAL FINDINGS

We prepared a completely anonymous and short survey questionnaire on the web portal www.1ka.si. The link to the online questionnaire was shared via online social platforms Facebook and. The total number of respondents for carrying out a market survey was 104 of this, 83 were women and 21 were men.

We shared the link to the survey via e-mail and distributed it to various groups on Facebook and Instagram.

First, we wanted to know the age of the respondents.

Table 1: Age of the respondents

Age (years)	Frequency	Percent
Up to 18	1	1 %
18-24	39	37 %
25-34	18	17 %
35-44	14	15 %
45-54	22	21 %
55 and more	10	9 %
Total	104	100 %

Among all those who took part in the survey, the largest number of respondents were between the ages of 18 and 24, namely 37%, which represents 39 respondents, followed by the age group of 45 to 54 years, which was 21% or 22 people. In third place are people aged 35 to 44, with 16% of them. From the age of 55, 10 people answered the survey.

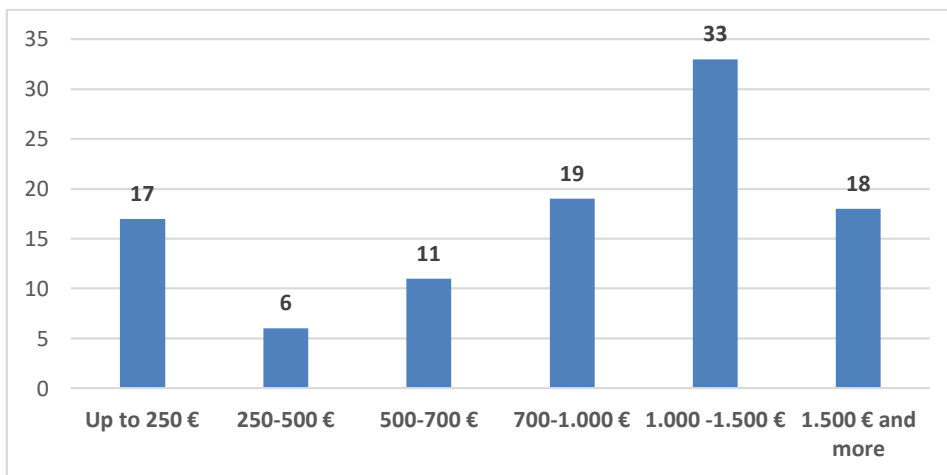


Figure 1: Net monthly income

We asked the respondents what their average monthly net income is. From the figure 1 we can see that the largest share is income from €1,000 to €1,500, which was answered by 31% of respondents, in second place 18% of respondents answered from €700 to €1,000, followed by 17% of respondents with income over €1,500. 16% of the respondents have an income of up to €250 and 10% of the respondents have a monthly income of €500 to €700. The smallest number of respondents has a monthly income of between €250 and €500, which is only 6% of the respondents.

The next question related to the frequency of visiting a clothing store.

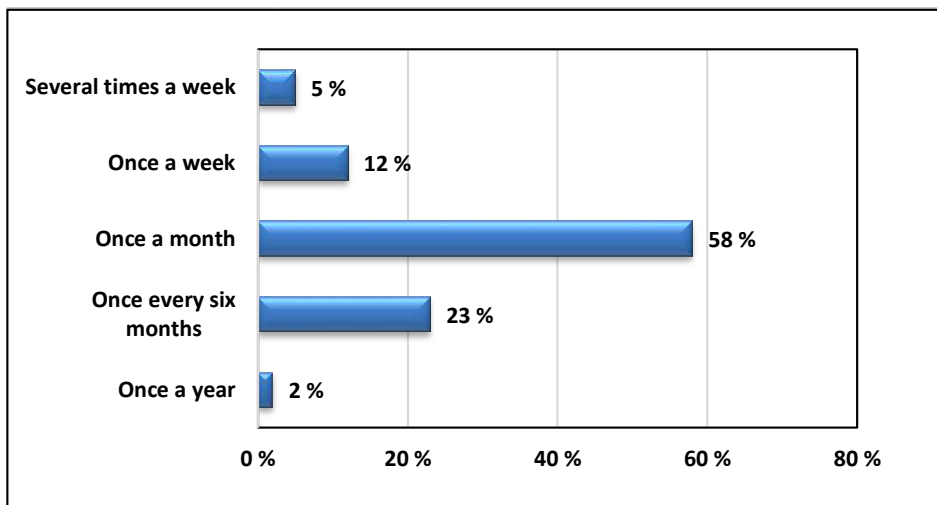


Figure 2: Visiting stores

Five different answers were available, from which respondents could choose only one. As seen in Figure 2 the largest percentage of respondents visit a clothing store about once a month, which represents more than half of the respondents, namely 60 respondents. This is followed by 24 respondents who visit a clothing store approximately once every six months. 13 respondents visit the store about once a week, 5 respondents visit the store several times a week. The answer once a year or less was chosen by 2 respondents.

In the next question, we were interested in in which store the respondents buy clothes.

Table 2: Clothing stores

Store	Frequency	Percent
Zara	68	65
H&M	61	58
About you	44	42
Nike	30	29
New Yorker	25	24
Stradivarius	23	22
Zalando	22	21
Hervis	22	21
Peek&Cloppenburg	18	17
Shein	15	14
Boss	8	8
Emporium	8	8
Other	36	34

For this question, the respondents could answer with several possible answers Table 2. They had an array of different fashion brands and stores selling clothes. In addition, they could write their answer under the "other" option. The largest percentage of respondents buy in stores: Zara (65%), H&M (58%) and About you (42%).

The other was chosen by 34% of respondents, with the following answers: Mana, Pepco, Sinsay, Kik, Hugo, C&A, Modiana, Intersport, s.Oliver, Mango, Tom Tailor, Reserved, Jager, Best secret, Second hand, COS and Massimo Dutti

We were also interested in the influence of clothing brands on purchases.

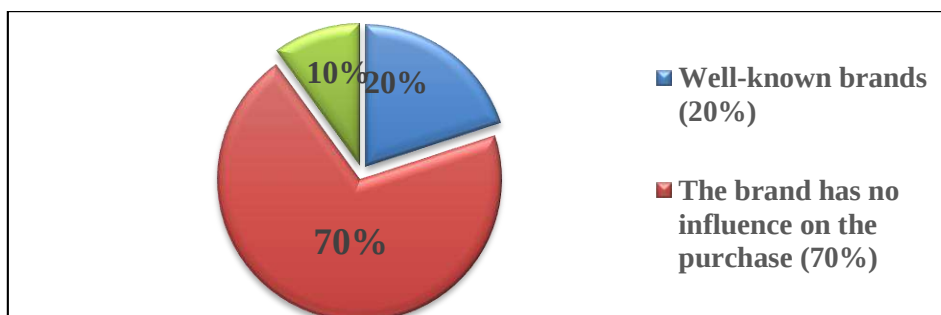


Figure 3: Brand influence on purchase

When buying clothes, 20% of respondents prefer to choose from recognized brands, while 10% prefer to choose from less well-known brands. While for 70% of the respondents, the clothing brand does not influence their purchase decision. Figure 3.

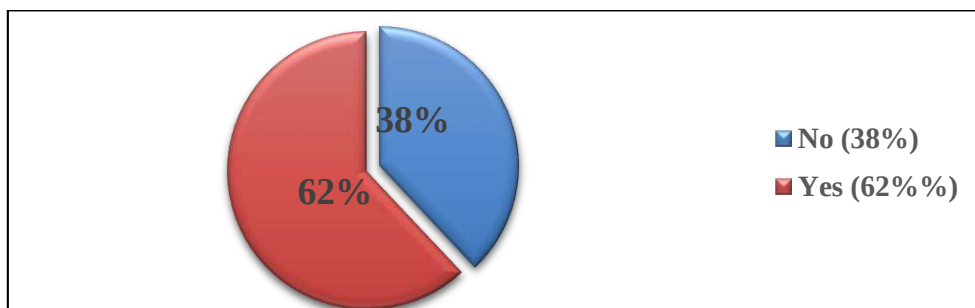


Figure 4: The influence of fashion trends on the purchase of clothing

Regarding the influence of fashion trends on the purchase of clothes, 62% of respondents answered positively, while 38% of respondents said that fashion trends have no influence on their purchasing decisions Figure 4.

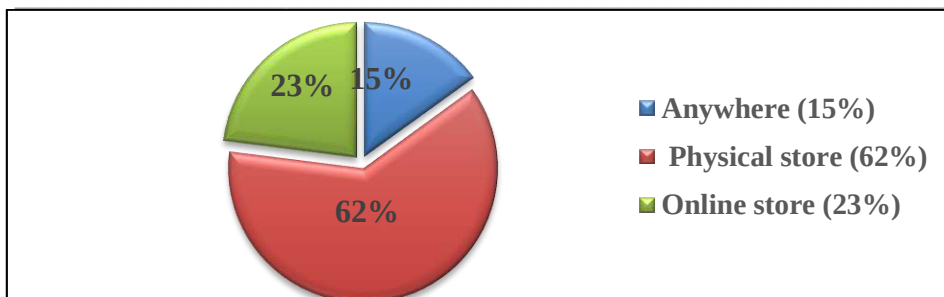


Figure 5: Brand influence on purchase

When asking where the respondents prefer to buy clothes, we mainly focused on the place of purchase, physical stores, or online stores. 65 respondents answered that they prefer to buy clothes in physical stores, which represents 62% of the respondents. 24 respondents, which is 23%, prefer to buy clothes through an online store. 15 respondents (15%) do not care where they buy clothes, whether online or in a physical store.

CONCLUSION

Buying fashionable clothes is a complex process for consumers. Consumer purchasing behavior in the fashion industry generally involves emotional aspects of self-concept; impulse buys and ever-changing fashion combined with cost, personal circumstances, massive overconsumption, and a lack of awareness of the fashion industry. Therefore, the purchasing behavior of consumers plays an important role in the success of the company. In the survey, we found that the most important factor for respondents to buy clothing is the quality of the material. Also, more than half of the respondents believe that the brand does not influence their final decision and they would not buy the clothes if it exceeded their financial capabilities. More than half of clothing shoppers are not looking for clothing that conforms to current fashion trends, nor are they influenced by the opinions of influencers, even though they believe that influencers set fashion trends. Among the respondents, buying in a physical store still dominates, but they decide to buy online because of the wide selection of products, saving time and easy searching.

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THE EFFECT OF PRICE DISCOUNTS ON SHOPPING BEHAVIOR IN A CLOTHING STORE

Original scientific paper
DOI: 10.5937/CT_ITI24050Z

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ABSTRACT: Consumer buying behaviour is the process by which customers decide to purchase products or services. This includes factors such as needs, wants, beliefs, environmental influences and decision making. Consumer buying behaviour research is used to understand how people choose and buy products and services and to adjust marketing strategies to better match customer needs and wants. Stores must thus determine which factors will best satisfy the needs of their customers. Among the well-known promotional methods is the reduction of the price of the product or services are the most successful and most common lure used to convince the consumer to buy. The aim of the survey was to find out which promotional methods customers use when purchasing. We also wanted to find out which product price reductions are most attractive to customers.

Keywords: purchasing behaviour, discounts, lower prices, sales promotion methods.

EFEKAT SMANJENJA CENE NA ODLUKU O KUPOVINI U PRODAVNICI ODEĆE

APSTRAKT: Kupovno ponašanje potrošača je proces kojim se kupci odlučuju da kupe proizvode ili usluge. Ovo uključuje faktore kao što su potrebe, želje, uverenja, uticaji okoline i donošenje odluka. Istraživanje ponašanja pri kupovini potrošača se koristi da bi se razumelo kako ljudi biraju i kupuju proizvode i usluge i da bi se prilagodile marketinške strategije kako bi bolje odgovarale potrebama i željama kupaca. Prodavnice stoga moraju odrediti koji faktori će najbolje zadovoljiti potrebe njihovih kupaca. Među poznatim promotivnim metodama je smanjenje cene proizvoda ili usluge su najuspešniji i najčešći mamac koji se koristi da se potrošač ubedi da kupi. Cilj istraživanja je bio da se otkrije koje promotivne metode kupci koriste prilikom kupovine. Takođe smo želeli da saznamo koja su sniženja cena proizvoda najatraktivnija za kupce.

Ključne reči: kupovno ponašanje, popusti, niže cene, metode promocije prodaje

1. INTRODUCTION

Discounts can have a significant impact on customer purchasing behaviour. Typically, customers are looking for products that offer the best value for their money, so discounts can prove to be attractive. Discounts can attract customers' attention, encourage them to buy and increase their satisfaction with the purchase.

As already mentioned, discounts can be used as a pricing strategy to attract consumers and increase sales. Discounts can be given in different ways, for example, coupons, discount cards, promo codes (online shopping) etc. Discounts can also encourage customers to buy more. For example, if we offer them a discount when they buy two or more products, customers may buy more products than they would otherwise. This, in turn, can increase the company's sales and revenue. In addition, offering discounts can affect customer loyalty. If customers have a positive experience with a product that was on sale, they may return to the store in the future to look for other discounts and offers. In general, discounts can have a positive effect on the buying behaviour of customers, but we must be careful not to offer them too often, as this could reduce the value of the products in the eyes of the customers and thus reduce profitability.

2. THE EFFECT OF PRICE DISCOUNTS ON PURCHASING BEHAVIOR

Discounts are a powerful pricing tool to motivate buying behaviours, typically applied at the point of purchase to reduce the buying price for a set amount of time: when you shop, you pay the discounted value straight away.

The purpose of a company offering a discount is to increase short-term sales, move out-of-date stock, reward valuable customers therefore creating better relationships, and make sure sale targets are met. Customers may also choose your product or service over your competitors if the price is discounted enough.

Just be cautious how you apply your discounts, lowering your prices might bring in customers, but if you don't execute your sale properly, you could cut into your profits and even damage your brand and reputation [1].

Discount pricing is a type of promotional pricing strategy where the original price for a product or service is reduced with the aim of increasing traffic, moving inventory, and driving sales.

People are drawn to lower prices because consumers love feeling as if they are scoring a good deal. Discounting strategies also create a sense of urgency that might drive more customers to convert. Companies usually do discounts for holidays, volume purchases, and cash payments [2].

A price discount is a very prevalent marketing strategy to attract consumers by providing an extra value or incentive, which encourages consumers to purchase the promoted products immediately [3].

Sales promotion is a common marketing approach used in the clothing industry to attract customers and increase sales, resulting in the effect of sales promotions on consumer purchasing behaviour. Discounts, coupons, flash sales, and loyalty bonuses are all forms of sales promotions. Advertising and marketing of a product increase its reach to more



people [4]. A price discount is a very prevalent marketing strategy to attract consumers by providing an extra value or incentive, which encourages consumers to purchase the promoted products immediately [5].

Price discount is one strategy that companies can use to compete in the future and maintain the store's image and form a positive image in the minds of consumers [6]. Price discounts are not only helpful in attracting consumers but can also increase the number of company consumers. The increasing number of consumers certainly provides benefits for the company. This is the target of every company, which has made the company exist for a long time [7].

One aspect of consumer behaviour that influences decision-making in the face of discounts is the perception of value. Consumers evaluate the worth of a discounted item by comparing it to its original price.

The larger the discount, the greater the perceived value. For instance, the 2 Visions report states, “Shoppers are approximately 2x more likely to purchase a product with a 20% discount over a product at average cost. This likelihood rises dramatically to 99% when the discount offered is 50% as opposed to 20%.” Price comparison websites and apps have empowered consumers to seek the best deals, making it essential for retailers to offer competitive discounts to capture their attention [8].

3. EMPIRICAL FINDINGS

The research sample was determined according to the objectives of our research. The survey was published online using the 1ka program. We shared the link to the survey via e-mail and distributed it to various groups on Facebook and Instagram.

The total number of respondents for carrying out a market survey was 128 of this, 82 were women and 46 were men.

First, we wanted to know the age of the respondents.

Table 1: Age of the respondents

Age (years)	Frequency	Percent
Up to 18	3	2 %
19-29	65	51 %
30-40	37	29 %
41-60	23	18%
61 and more	0	0 %
Total	128	100%

Of the 128 respondents, the age group 19-29 was the most marked, as much as 51%. They were followed by respondents aged between 30-40 with 29%. Respondents between the ages of 41 and 60 also took a large share, as much as 18%. The least number of respondents were up to 18 years old represent.

Table 2: Net monthly income

Net monthly income	Frequency	Percent
Up to 400 €	18	14 %
From 400 to 800 €	25	19 %
From 801 to 1200 €	51	40 %
More then 1200 €	29	23 %
I don't want to answer	5	4%
Total	128	100%

We asked the respondents what their average monthly net income is. Graph 2 shows that most (40%) answered from €801-1200. This is followed by net income more then €1,200, which was chosen by 23% of respondents. 19% indicated that their monthly net income is from €400 to €800, and 14% up to €400. 4% of respondents did not want to answer this question.

In the next question, we were interested in how many times in a month the respondents buy a new piece of clothing, footwear and accessories.

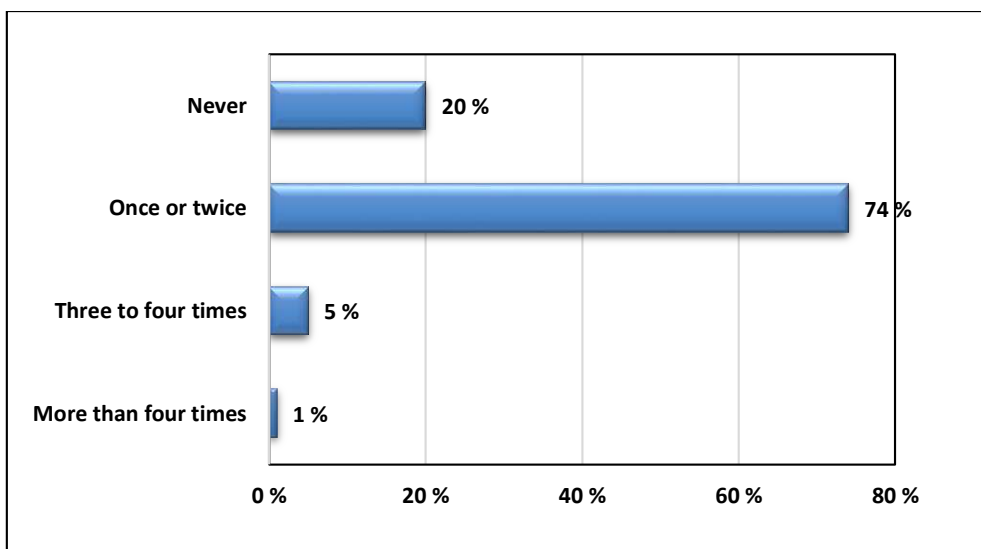


Figure 1: Purchase the product within a month

Figure 1 shows that as many as 74% of respondents buy a new product once or twice a month. There are 20% who do not buy a new product within a month. 5% buy them three to four times a month and 1% are those who buy a new product more than 4 times in one month.

Then we were interested in which methods of sales promotion the respondents use most often. We gave them 11 different methods. Several answers were possible.

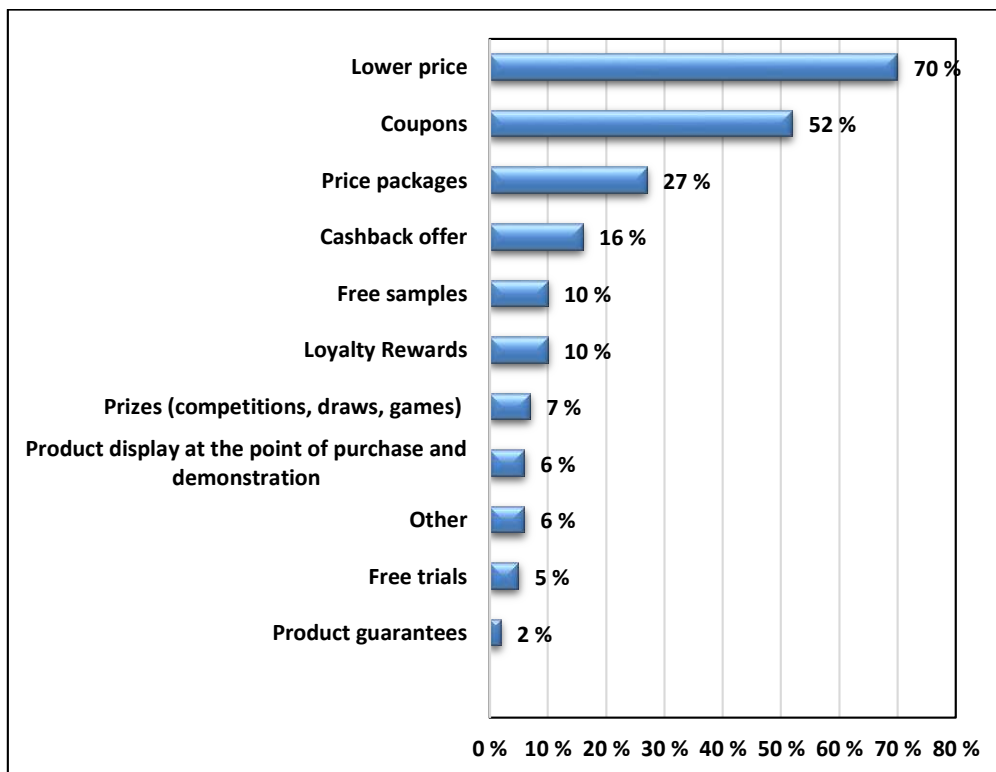


Figure 2: Sales promotion methods

Figure 2 shows that the lower price method is the most useful, as many as 70% of the respondents marked the indicated method. It is followed by coupons with 52%, price packages with 27% and an offer with cash back with 16%. Free samples and rewards for regular customers are used by 10% of respondents. Under 10%, however, the methods were labelled; awards; product displays at the point of purchase and demonstration; free tests, product guarantees. The second option was selected by 6% of the respondents, who wrote the following answers: "discounts"; "none of these"; "as needed when I need a piece"; "ecological"; "I don't use it".

The next question was about respondents' purchasing decisions for discounted products. Most respondents (52%) indicated that they often buy products that are on sale. It is followed by 22% of respondents who indicated that they rarely buy such products. 10% of respondents always buy during the discount period. However, 3% of respondents never buy during this time (Figure 3).

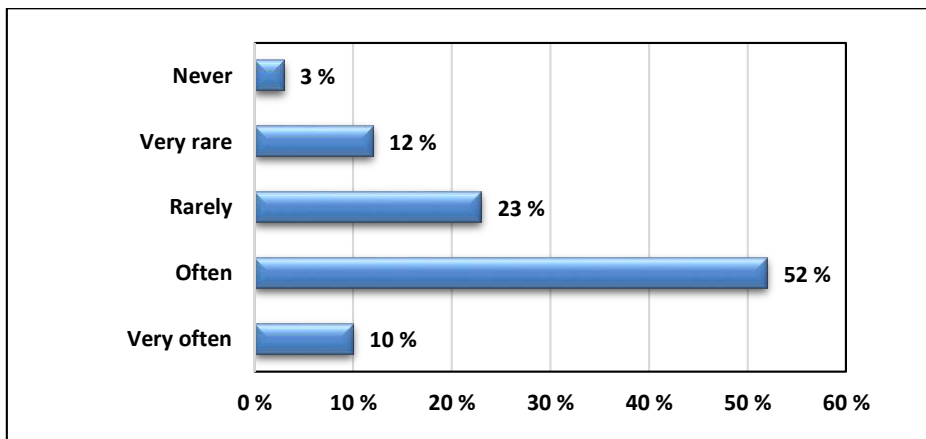


Figure 3: Purchase of products based on discounts

We also wanted to find out at which price reduction of the product in % the respondents decide to buy.

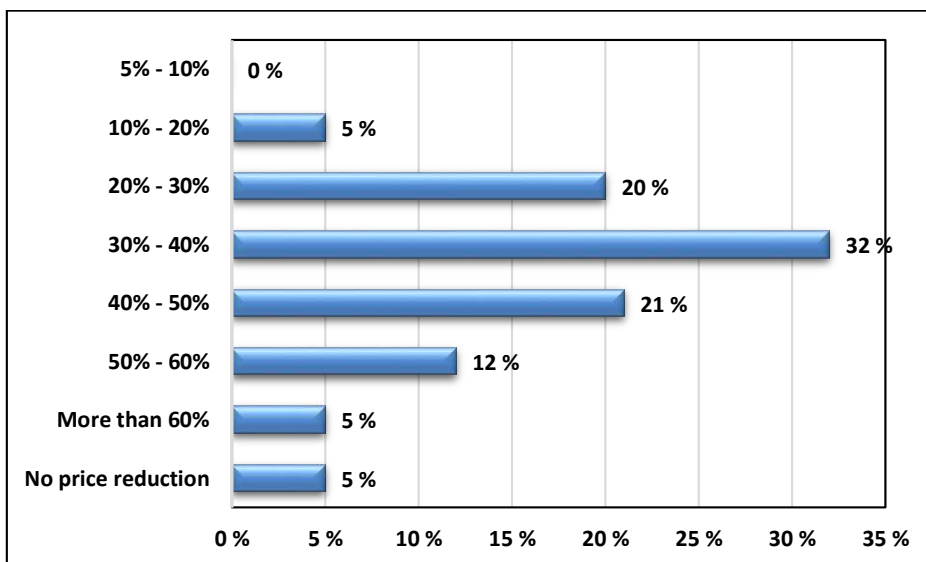


Figure 4: Product price reduction in %

Figure 4 shows that most respondents (32%) decide to buy a product when the price is reduced by 30%-40%. It is followed by respondents (21%), who decide to buy when the price of products is reduced by 40%-50%. 20% of respondents are encouraged to buy when



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prices are reduced by 20%-30%. When the price of products is reduced by 50%-60%, 12% of respondents decide to buy.

5% of respondents decide to buy when the product is discounted by more than 60%. The same % of respondents decide to buy at a reduced price of the product by 10%-20%. Also, 5% of the respondents decide to buy the product, even if it is not discounted.

It is interesting, however, that when the price of the product is reduced by 5% to 10%, none of the respondents decide to buy it.

4. CONCLUSION

Discounts can influence customer behaviour in several ways. First, discounts can encourage customers to buy products that they would not otherwise buy. Second, discounts can encourage customers to buy more products because discounts allow them to save money. Third, discounts can encourage customers to buy products faster because they fear that the discounts will expire soon. However, discounts can also have a negative effect on customer purchasing behaviour, as customers may start waiting for discounts before purchasing a product, thus delaying their purchases. This can lead to reduced sales and lower profits as marketers must lower prices to attract customers. In practice, this most often occurs when stores have larger discounts on a certain day of the year, for example Black Friday; night shopping, where shopping centres are open until 11 or 12 at night ("Late night shopping"); Valentine's Day, Christmas discounts, New Year's discounts, discounts in January, where most of last year's stock of clothes is reduced,... and customers wait for these days of the year, because they know that there will be bigger discounts.

The problem also arises that discounts are not always positive but can also have a negative note. So, discounts can affect customers' perception of a product's value. If the discounts are too frequent or too large, customers may think that the product is worth less than the actual price. This can influence their purchase decision and discourage them from purchasing the product even if they would otherwise. Also, discounts can affect customer loyalty. If customers are told about regular discounts, they may become less loyal to the brand and start looking for discounts from other providers. This can affect the company's long-term sales and profits. Marketers should be careful when using discounts and use them judiciously to avoid negatively impacting customer purchasing behaviour and maintain long-term sales and profits.

From the obtained results of the survey, we found that discounts have a great influence on purchasing decisions. Many customers decide to buy because the product is on sale. Most often, they use a lower price as a method to promote sales. As the most important factor that contributes to the purchase decision, the survey participants say that product quality is still the most important.

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SUPPLY CHAINS AND LOGISTICS OF TRANSPORT IN SME TEXTILE AND CLOTHING INDUSTRY

Review scientific paper
DOI: 10.5937/CT_ITI24051D

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ABSTRACT: Today, in times of general globalization of business, efficient business optimization measures are necessary, as well as innovative ways of organizing supply chains and transport systems, which are based on the exploitation of invariant and adaptable possibilities, i.e. on the efficient exploitation of information system flexible modules, with a high degree of automation of all activities and comprehensive implementation of ICT. By the way, one of the most important links in the process of business or production supply chains for companies in the textile and clothing industry is the transport of materials and goods, which with its adequate technological or organizational solutions enables cost reduction and increase in productivity and business efficiency, thereby strengthening the competitiveness of the company. These are precisely the elements of innovative logistics of transport systems that, as key components in the supply chain organize, regulate and monitor the process of transport (goods and materials) and adequate storage, but also optimize the control of process stocks, finished products and raw materials, with minimal costs and acceptable impact on the environment, which enables an increase in the effectiveness and economic efficiency of all technical and organizational systems. Based on the current global state of the clothing industry, as well as trends in business, the future development of supply chains and logistics of transport (of all kinds) can be anticipated as a diffusion spillover in the field of artificial intelligence and virtual show or quantum computing, with self-regulation and taking appropriate actions, with a direct prediction of anomalies in logistics costs and performance, as well as in the needs of artificial intelligence and automation of some parts or complete areas of business processes, whereby as a result, the obvious need for quantitative-qualitative strengthening and increasing the capabilities of human resources will be imposed.

Keywords: supply chains, logistic of transport, digitization logistics of transport.



LANCI SNABDEVANJA I LOGISTIKA TRANSPORTA U MSP TEKSTILNE I ODEVNE INDUSTRIJE

APSTRAKT: *Danas su, u vremenima opšte globalizacije poslovanja, neophodne efikasne mere optimizacije poslovanja, kao i inovativni načini organizacije lanaca snabdevanja i sistema transporta, koji se baziraju na eksploataciji invarijantnih i adaptibilnih mogućnosti, odnosno na efikasnoj eksploataciji modula informacionih sistema, sa visokim stepenom automatizacije svih aktivnosti i sveobuhvatnom implementacijom IKT. Inače, jedna od najvažnijih karika u procesu poslovnih ili proizvodnih lanaca snabdevanja preduzeća tekstilne i odevne industrije predstavlja transport materijala i roba, koji svojim adekvatnim tehnološkim ili organizacionim rešenjima omogućava smanjenje troškova i povećanje produktivnosti i efikasnosti poslovanja, čime jača konkurentnost preduzeća. Upravo to su elementi inovativnih sistema logistike transporta koji, kao ključne komponente u lancu snabdevanja, organizuju, regulišu i nadziru proces prevoza (robe i materijala) i adekvatnog skladištenja, ali i optimizuju kontrolu procesnih zaliha, gotovih proizvoda i sirovina, uz minimalne troškove i prihvatljiv uticaj na okruženje, čime se omogućuje povećanje efektivnosti i ekonomske efikasnosti svih tehničkih i organizacijskih sistema. Na osnovu trenutnog globalnog stanja industrije odeće, kao i trendova u poslovanju, budući razvoj lanaca snabdevanja i logistike transporta (svih vrsta), može se anticipirati kao difuziono rasipanje u oblasti veštačke inteligencije i virtuelnih prikaza ili kvantnog računarstva, uz samoregulisanje i preduzimanje odgovarajućih radnji, sa direktnim predviđanjem anomalija u logističkim troškovima i performansama, kao i u potrebama veštačke inteligencije i automatizacije nekih delova ili kompletnih oblasti poslovnih procesa, pri čemu će se kao rezultat nametati očigledna potreba kvantitativno-kvalitativnog jačanja i povećanja sposobnosti ljudskih resursa.*

Ključne reči: lanci snabdevanja, logistika transporta, digitalizacija logistike transporta.

1. INTRODUCTION

Globalization processes are radically changing the position of companies on the market, by imposing accelerated work and continuous reduction of costs, i.e. requirements to create conditions for sustainable competitiveness by increasing productivity and business efficiency, whereby the way out of such a situation is sought in various innovative content and adequate technological solutions, of course with reengineering and optimization of business processes, through mass implementation of ICT and adequate information systems. It is obvious that new ways of doing business impose a need for business systems that have a high degree of automation of all activities, starting from planning and design to production and sales, which requires innovative solutions and the implementation of new technologies in such processes, which are otherwise based on flexible automation and efficient implementation of adequate information systems – IS [1].



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As each functional unit of the organization has its own IS, the IS of companies can be divided according to functional areas. Business systems, which otherwise represent a special group of information systems with an original organizational structure and the task of collecting and processing data and connecting management and executive functions, as well as the goal of generating and transforming information - data into IT products for end users, consist of several subsystems, i.e. from several so-called of separate systems with the possibility of different functioning (internal logistics management, material management, planning of production and business operations, etc.), complement each other and represent a whole, in which integration into one multi-level system is possible, useful and necessary. On the other hand, it is known that business processes represent a series of logically connected activities in a certain time and space, which are necessary in order to complete a business transaction, achieve a business result or realize value for the customer, whereby each business process (production, technological, processing) has its own information system with information about users within the business system or other subjects in its environment, as well as the so-called service or support systems, which should contribute to harmonious and optimal functioning (Enterprise Resource Planning - ERP, Supply Chain Management - SCM, Marketing Systems, Decision Support Systems - DSS, etc.) [4].

Today, as one of the most common problems of inefficient work of SMEs in the textile and clothing industry, the elements of business organization are highlighted, which are otherwise explicitly connected with constant demands for continuous changes in production programs, as well as with changes and improvements in process tools and implemented IS, which can be divided on several relatively independent, but interconnected subsystems of certain functions of business processes (planning, supply, production, sales, finance, investments, human resources, research and development), and they are different due to the specificity of each company, they are included in innovative models of electronic business (which enables the connection of internal and external processes of the company, but also the implementation of processes with suppliers and business partners in a more efficient way, while reducing total costs and achieving a significant competitive advantage) [2]. It should be pointed out that, in contrast to previous criticisms addressed to the management or owners of SMEs in the textile and clothing industry, due to the slow, inadequate and insufficient implementation of information systems in production processes (CAD-CAM), which to the greatest extent depended precisely on them themselves (of course not forgetting the bad and inadequate marketing of such systems, as well as high prices, insufficient supply and lack of experts), in cases of implementation of the so-called business and service information systems, criticism is absent for the reason that the whole process depends primarily on the state and its involvement in the creation of the so-called favorable economic environment and business milieu, i.e. directly from the level of generating the basis for such a way of doing business by creating infrastructure through the parameters of a strong and high-quality Internet, internal and external networking, harmonization with global systems, etc., or harmonizing the functioning of the state administration with such a way of doing business. The needs of expert knowledge of new ways of organizing business, with various innovative ways of working of certain necessary parts of the overall system, are the cause of research and



explanation of one of the most important constituent elements of the modern way of doing business - of explanation the elements of new ways of organizing supply chains, with special reference to the elements of transport and transport logistics , with efficient exploitation of the invariant possibilities of ICT technologies and systems and compatible Just In Time and Quick Response System ways of doing business.

2. SUPPLY CHAIN MANAGEMENT

Considering the current situation and the possibilities of economic development, it can be said that in times of global economic and especially energy crisis, with a decrease in production and a drastic increase in the prices of energy sources, otherwise universally necessary elements of efficient and successful economic growth and development , and especially in the transportation phase (goods and materials), it is obvious that the policy of optimal and sustainable business must insist on cost reduction, and then on reengineering and optimization of business, with special reference to efficient optimization of the supply phase. Therefore, it is clearly necessary to specifically investigate the possibilities of modern, adequate, adaptable and efficient information systems for the organization and management of the supply phase in production, or in general in business processes [2]. Effective optimization of the supply phase is closely related to the effective implementation of ICT technologies, observed through the software support of supply chains and class of systems such as: ERP - enterprise resource planning systems, CRM - customer relationship management systems, WMS - warehouse management systems, TMS - transport management systems, APS - applications used to forecast future production and required supplies, SRM - supplier relationship management systems [12]. For example, by uniting a large number of adequate applications under one interface, modern ERP information systems automate and integrate the information systems of individual parts of the so-called integrated business - production, procurement, distribution, planning, marketing, etc., while the company by introducing an ERP system, which constantly adapts and changes in accordance with changes in the market and in accordance with changes in the needs of consumers and suppliers, as well as its customization, standardization and by implementing additional modules (CRM, SCM, etc.), they generate a good business environment for their business [3].

As the success of business systems is generally based on the ability to manage the flow of materials, information and money, solving and overcoming this problem is possible with a high-quality and efficient organization of supply chain management, from where it originates, that is, it can be said that with ERP and CRM, as well as marketing information systems, one of the most important business information systems for quality and efficient business - Supply Chain Management system - a system that through its activities essentially represents integrated planning and management of the flow of goods, services, information and money, and aims to achieve efficient and effective coordination of participants in the procurement, production and sales processes. SCM systems rely heavily on the application of innovative electronic business technologies in order to achieve efficient and successful optimization of production, logistics, distribution, as well as the reduction of costs related to these activities, because traditional approaches cannot respond

to the requirements of modern business and enable complex management of e-supply chains [5, 11]. It can be said that thanks to the Internet and other achievements of information technology, the concept of supply chain management has changed, so today modern, so-called the e-procurement system is based on the concept of information, that is, on the idea of sharing and exchanging information between the most important participants (customers, suppliers, contractors, consultants, etc.) in the production-business chain, along with logistics and payment systems (Figure No. 1), while it should be emphasized that the supply information system - SCM must include the flow of materials, products, services and information from the initial - supplier to the final exponent - user - customer in the business chain, which requires precise and timely coordination between different participants (manufacturers, suppliers, distributors, carriers and sellers), with the ultimate goal of delivering the right product, to the right place, at the right time, under the right conditions and at the right price. That's why such chains, as basic processes within themselves, must contain customer and supplier relations management processes, procurement processes and production management processes, as well as physical product distribution processes - transport and warehouse management processes, and therefore, as the most developed concepts of SCM, they can highlight: quick response - QR, inventory management by seller - VMI and supplier - SMI, continuous replenishment of inventory - CRP, efficient response to the consumer - ECR, etc. [8].

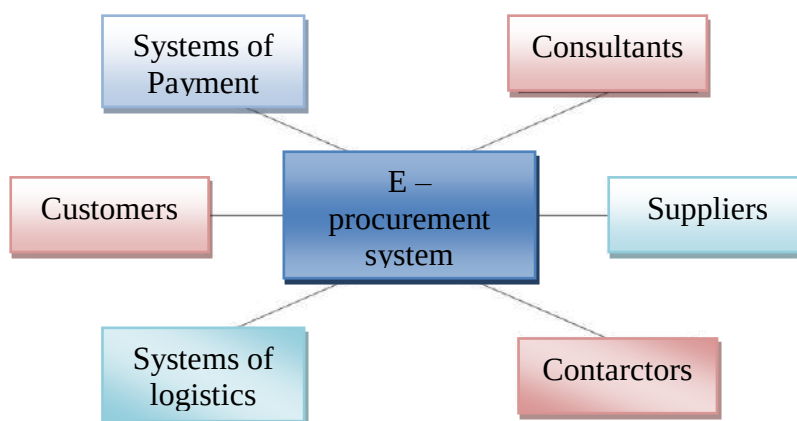


Figure 1: Structure of the e-procurement system [6]

As supply chain management can be interpreted as the handling of the entire production process of goods or services - starting from raw components to the delivery of the final product, it follows that companies should create networks of suppliers that drive the entire process of product movement, from suppliers of raw materials and information systems of the organization to marketing and sales, which would specifically deal with leads or end consumers, whereby the E-supply chain must ensure: integration and connection of partners on a strategic and operational level, a framework for well-defined chain strategy, visibility of information along the chain, higher speed, lower price and better quality of



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services for end users. Therefore, it is necessary to correctly select and generate the most important components of the supply chain management system, such as: planning (the total resources necessary to satisfy customer demand for the company's product or service), sourcing (selection of suppliers who will provide the goods and services needed to create the product), manufacturing (as an organizer of activities required for acceptance of raw materials, direct production of products, quality testing, packaging for shipment and delivery schedule); shipping and logistics (for coordinating customer orders, scheduling deliveries, dispatching loads, etc.), etc. [7]. In addition to the above, it is necessary to highlight the connectivity component, as one of the key features of efficient supply chain management, i.e. the ability to access unstructured data from social media, structured data from the Internet and more traditional data sets available through traditional tools for ERP and B2B (business to business) integration. Finally, as some of the key characteristics, the factor of cooperation with suppliers, using digitalization and commercial networks based on the cloud, as well as cognitive self-improvement through automation, unification, coordination and implementation of decisions and actions, but also the necessary protection, i.e. the necessity of existence cyber protection, as well as analytical comprehensiveness.

Otherwise, practice data directly show that the supply chain is the best indicator of the quality of business and the company in general, because good and efficient management of the supply chain, as well as analytical skills, indicate minimized business costs (time, material and quantitative and qualitative aspects of human resources), so therefore, on long-term sustainability and business reputation. The evolution of supply chain management is evident in the basic elements of business, because the previous focuses were on the availability, movement and price of physical assets, while today's focuses relate to the management of data, products or services, thus affecting the quality of products and services, delivery, costs, user experience, and even the profitability of the business itself. As modern supply chains take advantage of the vast amount of data generated by the processes of the chains themselves, analysts or future leaders in supply chains, as well as ERP systems, are likely to focus on their optimization and real-time analysis.

As a special segment in the supply chain, the so-called order management, which starts when the customer orders and ends when he receives the ordered product, thus enabling the company to actively participate and coordinate the entire process, from sending and confirming the order, through generating invoices, packaging and shipping, to inventory management, with a special with reference to transport processes and transport logistics systems. Digital order lifecycle management or Order Management System - OMS tracks all information and processes, including order entry, inventory management and fulfillment and after-sales service, thus providing transparent visibility (both to the company and the customer) in near real time. It is obvious that order management is closely and directly correlated with every part of the system and process in the supply chain, so modern global companies increasingly do not have an order management sector within their organization, but include other partners (parts and components suppliers, implementation of assembly services and packaging, distribution centers, etc.).



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In each, and especially in digital ways of managing supply chains, as one of the most important components of the efficiency of the system of such chains, supply chain analytics should be singled out, which otherwise represents a real possibility of making data-based decisions based on a summary of relevant and reliable data, with the frequent use of visualization in the form of charts, diagrams and other means, which can be descriptive, predictive, prescriptive or cognitive. Supply chain analytics can help businesses reduce costs, better understand risks, increase planning accuracy, etc., and based on that, make smarter, faster and more efficient decisions, which are important for business success, as well as minimize risks, demonstrate competitiveness and strengthen sustainability. It should be noted that supply chain analytics, with its characteristics such as connectivity, collaboration, comprehensiveness, speed and automation, while strengthening defense systems against cyber intrusions and hacks, represents a good basis for the application of cognitive technologies, such as artificial intelligence, which represents introduction to the new era of supply chain optimization [8, 9]. Significant changes and evolution of analytics can be seen in data previously limited mainly to statistical analysis and measurable performance indicators for planning and forecasting demand, whereby data obtained from various participants in the supply chain were stored in tables, in order to adopt systems in a later period electronic data exchange - EDI or enterprise resource planning systems - ERP, which enabled easier access to data and more precise and high-quality analysis. Successful global as well as local business, with new demands on manufacturers and customers, leads to a situation where supply chain analytics is becoming more and more complicated, which requires the development of various types of performance optimization software, where further development and deeper knowledge of supply chain networks directs towards the implementation of business intelligence and predictive analytical software solutions, all with the aim of better and more efficient analyzes of structured and unstructured data in real time, as well as proactive event predictions [8, 9, 11].

It should be pointed out that one of the major problems of digitization and global e-business is the various technologies that these companies implement internally, which can be solved by optimization and adequate B2B tools, which otherwise represent the automation of business processes and communications between two or more organization and enable companies to be more agile and capable of efficient business. The concept of adaptable B2B networks, which connect: supply, planning, production, distribution, retail and logistics, provides the possibility to ensure the visibility and availability of information in real time with the help of information technologies, and the operations of several connected companies can quickly and efficiently adapt to environmental conditions, without jeopardizing operational and financial efficiency. That is why the optimization of supply chains, and for the purpose of improving efficiency and performance in the supply network, implies the effective implementation and exploitation of adequate technologies and resources, such as Artificial Intelligence - AI, sensor technology - Internet of Things - IoT, or decentralized databases - blockchain.

By the way, the optimization of supply chains had to evolve and change its identity in a very short period of time, because today the principles of global manufacturers, trade and networks, with maximum time requirements, so from the phase of focusing on investments in the design phase, moved to supply phase with real-time responses [9, 11]. In addition, it

is an obvious fact that today are the times of major global crises and uncertainty in business, which directs the flow of efficient optimization of supply chains towards the efficient exploitation of modern technologies and innovations and the business of superior exception management, and for the sake of better visibility in supply chains and decision-making in real time, which of course ultimately enables survival and sustainable competitiveness. Observing and analyzing all information systems in the chain of efficient operations of a company, where information flows and money flows are constantly intertwined, it can be observed that procurement information systems - SCM, with all its accompanying elements (strategic, logistic, planning, ...) and connections, occupy a central position (Figure 2).

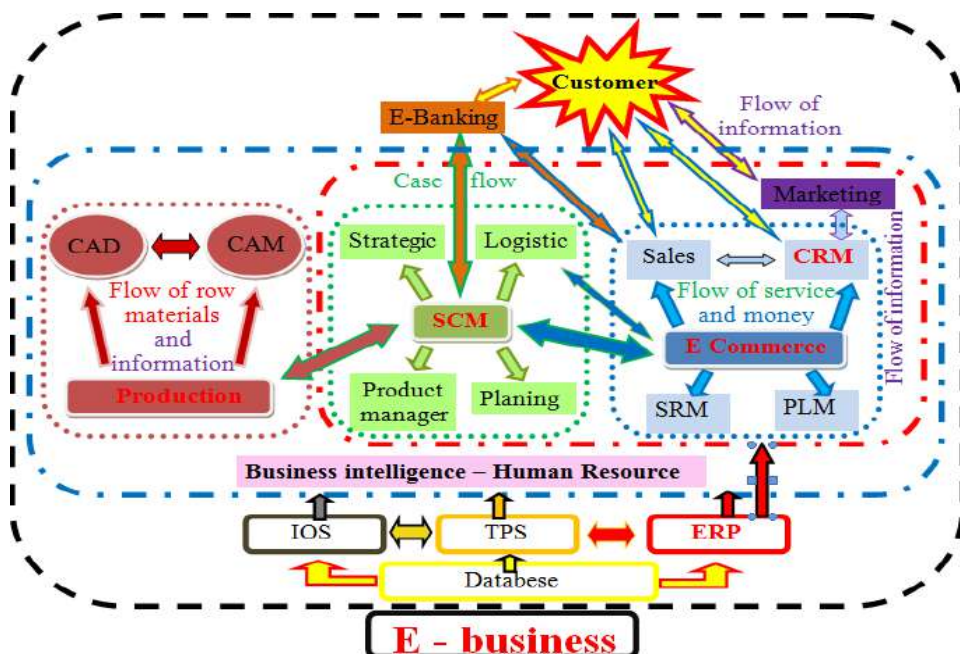


Figure 2:Information systems of e-business [1]

The central position of the procurement system also indicates the necessary coherent role, as well as the necessary compatibility of all business, production or service information systems in the processes of the so-called. e-business. Of course, the cohesion of procurement information systems with the production part (CAD and CAM systems), on the one hand, indicates the necessity of the practical realization of separate procurement and transport systems, known in practice as internal procurement and transport, while on the other hand, it indicates the connection with the elements of sales and trade (CRM, PLM, marketing and other systems), which shows the existence of the so-called external procurement and transport, where it should be emphasized that the effective



implementation of such systems in companies is a prerequisite for modern, efficient and successful business (Figure 2).

3. LOGISTICS OF TRANSPORT - AN IMPORTANT ELEMENT OF THE SUPPLY CHAIN IN SME TEXTILE AND APPAREL INDUSTRY

Just as in the part of information business systems, necessary for successful and efficient operations, procurement and marketing systems are singled out, so in the analysis of procurement systems, as the most important elements, i.e. the most important sub-processes and systems, logistics systems are singled out and as subsystems - logistics of transport. Logistics, because it represents a system that ensures the smooth functioning of the supply chain, and logistics of transport, because it monitors and optimizes the organization of the transportation process and adequate storage, but also regulates the routes by which goods are transported and ultimately represents the backbone, that is, the most important component of the supply chain [10]. The needs of modern society, as well as the drastic increase in the demand for goods of all kinds on the global market today, lead to the position of continuous logistical demands for a continuous increase in efficiency, effectiveness and speed of implementation, but also to continuous demands for a continuous reduction of business costs, which at the same time implies a continuous, adequate and efficient automation and digitization of all business segments. All this stems from the basic position of the mission of logistics, which is defined as the right thing in the right place in the right condition and with minimal costs and an acceptable impact on the environment, that is, from the main goal of logistics, which can be defined as the delivery or transportation of goods and materials in the most efficient possible way, whereby the purpose of carrying out logistics activities can be stated as increasing the effectiveness and economic efficiency of technical and organizational systems in order to plan, implement and control the efficiency of the costs of raw materials, process supplies and finished goods. Complex production and business processes and systems of the clothing industry indicate that the clothing industry has several types of transport, and therefore there are several types of adequate logistics of transport, i.e. two types of transport of clothes, parts of clothes and materials require two types of logistics, where the transport of materials from the warehouse, the transport of workpieces - parts of clothing and the transport of finished products to the warehouse (which means during the entire production process), known as internal or interphase transport (and, accordingly, interphase transport logistics systems exist), while the delivery of raw materials to the warehouse and the transportation of finished goods to the customer or to stores is the so-called external transport (external logistics of transport systems are adequate) [10].

3.1. Internal transport

The names themselves, as well as the roles they have or the jobs they deal with, indicate two quite different types of transport, because the internal subjects of such processes and systems are also different, i.e. it is obvious that in the cases of external and internal transport, the same process actions are indicated, but with different subjects. In fact, from the point of view of information systems, external transport clearly requires the

coordination of businesses to business - B2B subjects, or companies supplying repro-materials and manufacturing companies, as well as business to consumer - B2C subjects, i.e. coordination of producer-seller and consumer-buyer companies, while on the other hand, internal transport can be treated through production information systems, because it obviously represents an integral part of the organization of the production process. In the clothing industry, repro-materials are transported from the warehouse of raw materials to direct production, as well as articles or parts of clothing items and finished products, within the production process itself, where certain production phases are connected, which is why it is known as interphase transport. By the way, today, SMEs in the textile and clothing industries most often use two methods of internal transport:

- Manual transport - mainly used in small and medium-sized enterprises, and is carried out with carts of solid and durable construction, made of bars, with two, three or four wheels and light weight, adapted for heavy loads and weights (up to 100 kg). In order to increase the carrying capacity of such carts, battery-powered engines are used, or less often with internal combustion, which have a carrying capacity of about 2000 kg, with a speed of 5 km/h to 10 km/h, with and without load.
- Mechanical transport - means transport with automatic, and today most often with computer control of specially designed means of transport, such as: running conveyor belts, which are endless rubber, plastic or textile impregnated belts, which are transferred over rollers with electric drive, while in recently more and more often they install belts between two rows of production places on two floors, one above the other, and which move in opposite directions, with the upper ones supplying the workplaces and the lower ones taking away the products; and the so-called hanging conveyor belts, which are mounted on poles, wall or ceiling supports, which is their main advantage, because they leave a free working surface in the work rooms, while another positive feature is that the products do not wrinkle, because they are in a hanging position.

By the way, many researches and analyzes show that internal transport in the clothing industry directly affects the increase in productivity, even up to 30%, which is a sufficient indicator and reason for special research of this type of logistics of transport in the processes of clothing production. Of course, it should be noted that both types of logistics of transport require superior knowledge of the production process, where the direct influence, as well as the finesse of the implementation of internal logistics of transport, indicate and require a much greater reliance on expert knowledge of the production process, as well as on information, data and documents of the design process workplaces and work studies, so that the repro-material or parts of clothing - workpieces, are in the right place, at the right time and in adequate quantities, i.e. with a precise and adequate frequency or flow of goods and materials, and for the purpose of quality and efficient functioning of the production process, without delays and distractions [10, 11].



3.2. External transport

Of course, the process of globalization, as well as the economic and political crisis, directly affect all elements of business, but as the world energy crisis is especially pronounced today, which directly and strongly affects the organization, i.e. the logistics of external transport, as well as the price of products, obviously, radical changes and innovative ways of looking at and solving this problem are necessary. External transport involves the organization and coordination of all necessary elements of business, from delivery - transport of raw materials from suppliers to production plants, and to the delivery of finished products from the manufacturer to the consumer - the customer. In fact, external transport can be defined as a necessary activity for the efficient and safe transportation of goods from point to point, where in order to carry out this process in the most economical and optimal way, it is necessary to know the elements of exploitation of logistics of transport, where as elementary and unavoidable functions include: transportation planning, creation of optimal routes for transportation, realization and organization of transportation, regulation of movement of goods and organization of storage of goods. It should be noted that today, due to the complexity process of the logistics of transport, external transport operations, as well as storage, packaging, consulting, etc., are increasingly carried out according to the principle of third-party logistics - 3PL, i.e. they are assigned to specialized companies for the transport of goods and materials, the so-called logistics providers.

3.3. Modern technologies in logistics of transport - digitization logistics of transport

While traditional logistics of transport is based on analog tools - spreadsheets, paper documentation, PDF documents, etc., digital **logistics of transport** uses modern technologies, which makes common tasks simpler, shorter and, ultimately, cheaper. The first visible results of savings by using modern technologies in **logistics of transport** are reflected in saving the time of delivery of products or materials, as well as in reducing delays in transport, which has proven to be effective, with an average saving of as much as 35% [5]. However, a much more important or key difference between traditional and modern logistics is in the connection of participants in the supply chain, whereby in the traditional way of doing business and logistics, employees are not provided with data visibility of all sectors of the supply chain, which affects the flexibility and agility of the entire process, while in digital logistics, data is entered into the system and is always available to all participants of the supply chain [10]. The modern market especially requires certain changes in the logistics of external transport, in order to be able to fulfill all the needs of both producers and consumers-buyers, so specialized logistics companies are required to constantly improve, upgrade and follow trends, where digitization participates and helps in many ways, because they are internet and innovative technologies have become imperative in all spheres of business, especially in logistics (for reasons of faster and more efficient communication, easier exchange of necessary information, as well as better compliance of all participants). It is a fact that with the digitalization of logistics of transport, the situation is significantly improved on established manual operations subject to errors, that processes of logistics have been improved, as well as that the compliance of participants in the supply chain has been raised to a new-higher level, but it should be emphasized that the implementation of new technologies in logistics of transport, is by no

means a substitute for the human factor in the supply chain, but only a tool that achieves better coordination between principals, customers, warehouses and carriers in the best possible way.

Today, some of the modern technologies, which are applied in logistics of transport, reduce business costs by 10% (eg Digital Twins technology, which is based on the method of creating a virtual copy of the supply chain in real space and time, thereby achieving easier control of transport and protection goods, as well as more accurate forecasting and more successful prevention and removal of traffic jams), some others by 15% (e.g. Artificial Intelligence, as a leading technology among modern technologies, whose contributions are reflected in the precise management of goods stocks and fast delivery, better insight into customer needs and efficient warehouse management), the third for 20% (e.g. *IoT sensor* technology, which helps systems to track goods and warehouse stocks, enabling real-time monitoring of transportation, with continuous data loading into the electronic system), and some even for a 30% reduction (e.g. *Blockchain* technology, which is a decentralized database with information storage in electronic blocks, thus reducing errors to a minimum, and achieving a more coordinated supply chain network and a safer and faster exchange of information, where it should be emphasized that the strength of blockchain technology dynamically improves in combination with AI and IoT, migrating from the traditional business network and pooling good quality data among partners) [10, 11].

It can be said that the digitalization logistics of transport, with benefits such as: faster delivery time - by reducing the number of intermediaries in the chain, improving the user experience - thanks to digital platforms, improving efficiency - by monitoring events in real time and precisely planning routes for transporters, sustainability - by reducing delays in transport and fuel consumption, and according to green logistics models with the aim of reducing negative impacts on the environment, enabled a greater dedication to the needs of clients and a quantitative-qualitative increase in business. On the other hand, it is known that for the successful implementation of modern technologies in logistics of transport, high-quality computers are needed, with high software requirements for the smooth digitalization logistics of transport, which requires high initial investments and high-quality and well-trained professional staff, thus representing one of the disadvantage of digitization logistics of transport [8]. Data security can also be mentioned as a disadvantage, given that technologies of logistics are started and will be with the help of the Internet, and given the fact that all data is networked in such a way of doing business, there is a risk of hacker attacks and compromise of user data. Finally, as a drawback, it should be mentioned that the very process of modernization and transition to digital procedures logistics of transport is difficult and complex, with the addition of also complicated requalification of the workforce [8].

In the end, it should be pointed out that the implementation of information systems in small and medium enterprises of the textile and clothing industry is a problem, because the existing SCM models fail to solve the needs and problems of the supply chain of small enterprises, that is, it is a problem because at the very beginning of the idea of implementation for many reasons, from which are the most important for supply and transport information systems: quantitative aspect of production - small batches, large



initial investments, qualitative aspect of human resources, supplier selection, supply chain coordination, dynamic management of customer orders, etc. [8, 11], so a small number of such companies work in such a way and, of course, are not involved in the processes of global market competition.

4. CONCLUSION

The policy of optimal and sustainable business today must insist on the accelerated implementation of innovative technologies and modular flexible ways of business organization, but also on reducing costs through processes of reengineering and optimization of business, with special reference to efficient optimization of the supply phase. For the efficient optimization of supply chains, precisely defined elements of network design and quality design, elements of plan generation, as well as the implementation process itself, are necessary, implemented through applications and systems that incorporate the most important elements of such processes, such as visibility, (artificial) intelligence, adaptation and management, analytics, control, etc.

An indispensable element of efficient business today is the implementation of the so-called business logistics, which represents the integration of two or more activities in order to plan, implement and control the efficiency of the costs of raw materials, process supplies and finished goods from the starting point to the point of consumption, with the purpose of increasing the effectiveness and economic efficiency of technical and organizational systems, noting that the constituent part business logistics and optimization of supply chains is represented by logistics of transport, which through internal and external logistics of transport monitors and optimizes the organization of transport and adequate storage. While the internal logistics of transport implies being based on expert knowledge of the production process, as well as on information, data and documents of the process of designing workplaces and work studies, and for the purpose of quality and efficient functioning of the production process, external logistics of transport jobs are, due to the complexity of the process, increasingly assigned specialized transport companies, so-called logistics providers, who provide transportation, storage, packaging, consulting, etc.. Regardless of the fact that digitization has made the process of organization and planning of supply chains and logistics of transport easier, more precise and cost-effective, it should be emphasized that it is by no means a substitute for the human factor, but only a means for a better connection of all participants, i.e. a means of better coordination between principals, customers and carriers in external, or principals and executors - employed in internal transport, as well as regardless of the disadvantages, such as high initial investments or complexity and security of data, digitalized logistics of transport still shows better results in all the most important elements of efficient business (time, human resources and material).

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E-BUSINESS IN THE GARMENT INDUSTRY

Professional paper
DOI: 10.5937/CT_ITI24052S

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ABSTRACT: All fashion houses try to find the best way to reach their customers, so they use different strategies. In recent years, clothing manufacturers have increasingly applied e-business to promote and sell their products. Online media helps fashion houses market take their products worldwide with a minimum investment of money and maximum visibility. Considering that many fashion houses implement e-business, it is necessary to make the product unique and recognizable.

Keywords: E-business garment industry, product, unique.

E-POSLOVANJE U ODEVNOJ INDUSTRIJI

APSTRAKT: Sve modne kuće pokušavaju da nađu najbolji način da stignu do svojih kupaca, i zato koriste različite strategije. Poslednjih godina proizvođači odeće sve više primenjuju e-poslovanje za promociju i prodaju svojih proizvoda. Online mediji pomažu modnim kućama da svoje proizvode plasiraju širom sveta uz minimalno ulaganje novca i maksimalnu vidljivost. Obzirom da mnoge modne kuće primenjuju e-poslovanje, potrebno je proizvod učiniti jedinstvenim i prepoznatljivim.

Ključne reči: E-poslovanje, odevna industrija, proizvod, jedinstven.

1. INTRODUCTION

E-commerce, or electronic commerce, is the buying and selling of goods and services over the internet. In the fashion industry, this means selling clothing, accessories, shoes, and other fashion items online. But it's not just about the selling—it's also about how these products are marketed, delivered, and serviced. [6]

Thanks to the Internet, fashion houses can reach customers all over the world and achieve global business. The Internet enables long-distance communication, which speeds up the whole process and makes it easier and cheaper.

By opening a website, a fashion brand creates its identity. A well-designed website attracts a large number of customers, introduces customers to its products, and provides necessary information about product features. Fashion houses can also connect their websites to social networks and thus reach more customers. In this way, fashion houses advertise their products all over the world, with a minimal investment of money.

Fashion giants, who have already made a mark for themselves in the industry, also realize the importance of e-business and e-marketing. They have their official websites which help them in promoting their products to a global audience. Nike, a leading fashion manufacturer of fashion products, saw a growth of 30 percent in its e-commerce sales in the year 2012. Debenhams, an online fashion retailer, saw its online sales increase by 40 percent in a four month period of 2013. John Lewis saw a rise of 20.7 percent in the year 2012. It is easy to market products through the medium of internet, as the marketing strategies involved are innumerable and the results are overwhelming from a long term point of view [6].

2. TOP FASHION ECOMMERCE TRENDS FOR 2024

- 1) Embracing AI
- 2) Sustainability at the forefront
- 3) Personalizing the customer journey
- 4) The continuation of the metaverse
- 5) Social commerce and shoppable content
- 6) The rise of resale and secondhand shopping
- 7) Buy now, pay later
- 8) The transition back to brick-and-mortar
- 9) Expanding into repair services
- 10) The shift to wholesale [7].

1) Despite the fact that artificial intelligence provides many benefits, the use of AI (artificial intelligence) in the fashion industry is not easy to accept.

According to McKinsey, generative AI may end up adding between \$150 and \$275 billion dollars to the fashion industry in the next five years. This same report also notes that, from a creative perspective, AI can help with the design stage, development, 3D imaging, and creating realistic looking models for campaigns [7].

2) It is known that the clothing industry represents a major polluter of the environment, due to the way of production and rapid changes in fashion trends.

In light of these criticisms making mainstream news, plus consumers' increasing commitment to eradicate climate change, some 70% of shoppers say they are willing to



pay more for sustainably produced goods. Statista's research shows 42% of global customers purchase eco-friendly and sustainable products. The fashion resale market is booming for this reason-growing 11 times faster than traditional retail and tipped to reach a \$77 billion valuation in the next five years [7].

3) Customers who buy clothing items online expect clothing manufacturers to take care of their requirements. More than 70% of customers expect brands to tailor their shopping experiences and anticipate customer needs.

Customers also expect retailers to give certain discounts or gifts for birthdays and holidays. Although too much personal data leads to fear of misuse and unauthorized use of available data.

4) The idea of *metaverse* is that people can conduct daily activities—like connecting with friends, playing a game, and purchasing products—by using augmented reality (AR) and virtual reality (VR) technology.

Retailer Forever 21 partnered with Roblox to create virtual fashion ecommerce stores in their metaverse, appropriately named the Forever 21 Shop City. Players run the virtual store as if it were their own, and they purchase merchandise for their avatar through the game.

Fashion brands are using Roblox to create immersive experiences for users and reach Gen Z audiences [7].

5) In fact, social commerce sales are expected to nearly triple by 2025, with 70% of Instagram users looking to the social media platform for their next purchase.

And when it comes to which types of content are working for fashion brands, it's all about transparency. Some 66% of consumers watch videos to learn about a product or brand before they buy. Platforms like TikTok and Instagram are praised for driving sales for large fashion brands since shoppers can visualize the product on a real person. Bonus points if it's a social media influencer they already trust [7].

6) Secondhand apparel is becoming a global phenomenon. The resale market grew 24% in 2022 alone, and is expected to reach a \$218 billion market valuation by 2026.

Leading the trend are North American consumers, who have supercharged the region's secondhand apparel market-propelling its growth eight times faster than the overall apparel market. Technology and online marketplaces are driving this trend, with 70% of consumers saying it's easier now to shop secondhand than it was five years ago.

Maybe the most compelling stat? Secondhand displaced 1.4 billion new clothing purchases in 2022.

Fashion brands are taking notice. Dôen, a California-based premium fashion brand, is launching a resale program called Hand Me Dôen. The program will allow customers to send in preowned Dôen products in exchange for store credit [7].

7) According to a report by Coherent Marketing, the BNPL market and platforms currently sits at nearly \$11 billion in valuation, and it's expected to reach more than \$59 billion by 2030.

With a lot of new technology and ecommerce offerings, many assume millennials and Gen Z are the dominant demographics of BNPL's success and forward momentum. *Harvard Business Review* proves that's not entirely true with data showing Gen X are a driving demographic and Gen Z only a little ahead of boomers.

BNPL often allows customers to pay a set price without any interest. With credit card use on the decline, BNPL is an attractive purchase for those making big purchases without the extra cash to pay for it right away [7].

8) The shopping experience is more complex than ever-especially in the fashion space. Some 56% of online returns happen because the product ordered online doesn't match the description. It's this never-ending challenge that's driving many fashion brands back into traditional retail.

Modern consumers want both online and offline sales channels-and synergy between the two:

Half of Gen Z shoppers, who famously spend more time online than any other age group, favor in-store shopping.

59% of consumers say they're likely to browse online and buy in store, and 54% are likely to look at a product in store and buy online.

9) Fixing items rather than throwing them away is becoming a trend for fashion brands. Bottega Veneta now offers all customers a lifetime warranty on their handbags. Louis Vuitton will also repair any bag for a price, depending on the item and type of repair.

The expansion into repair services comes at the helm of sustainability. The fashion industry is becoming more aware of its environmental impact, and repairs are a cost-effective way to keep clothes in good condition longer.

Brands like Patagonia and Arc'teryx have opened repair centers, as have fast fashion retailers like Zara and Uniqlo. Repair-focused startups have raised millions as interest in sustainable fashion and resale boosts demand [7].

10) Inflation, supply chain issues, and lack of consumer spending is pushing DTC brands toward wholesale. A Glossy and Modern Retail survey showed that DTC brands are investing in other types of sales partnerships to diversify income.

Digitally native brand in search of retail partnerships isn't a new concept. Harry's entered Target in 2016, and DTC brands like Quip and Native followed suit into big-box retailers shortly after [7].

But 2024 marks a turning point for DTC brands going into wholesale. Sales are up at mass retailers like Target and Walmart. Ongoing supply chain disruptions are making direct channel fulfillment increasingly harder, harming profits [3].

Trends for improving the success of E-business indicate that it is necessary to take care of the customer's needs and provide him with better purchasing conditions than the competition.

It has been shown that customers want sustainable production, which does not pollute the environment, and production which is not excessive. In order to achieve such customer requirements, production must be equipped with modern machines.



Figure 1: From idea to sample [4]

From the idea to the creation of a suitable model, in classic production, it takes a lot of time, and it is necessary to make all the samples in order to arrive at the final solution. In this way, unnecessary samples are produced which increase the amount of waste.

By using E-design it is possible to see in advance how the sample will look like as a final model, and it is possible to make the sample to be appropriate at the design stage. Then a sample is produced which is adopted as a virtual model without unnecessary repetition. In this way, the number of samples is reduced by 80%. This saves time, saves resources, improves efficiency and reduces environmental pollution.

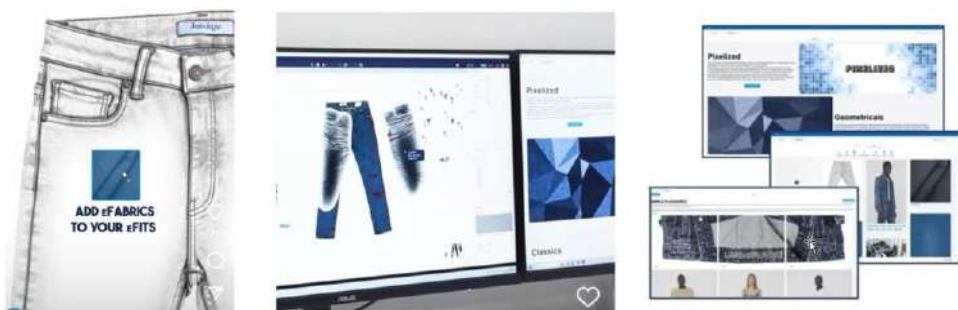


Figure 2: Creating a sample using the E designer [4]

Using Compact laser technology has been designed for maximum production flexibility, precision, and power, with a compact design and high cost-efficiency. It meets the needs of large production, with versatile garments and detailed and accurate designs.



Figure 3: Application made on embroidery machine and laser [4]

The use of laser technology allows the garment to be personalized according to the customer's wishes in a very short time. Unlike traditional production where machine embroidery is used, the whole process takes a very long time, and it is only possible to produce in series. Using a laser, individual production is possible.

By using a laser, different effects can be achieved on denim in just a few seconds (the effect from the picture is achieved in 5 seconds), according to the idea that was processed in E design. In this way, in addition to a very short production time, the working environment is preserved, and the workers are completely protected. In the manual finishing of denim, these effects are achieved through several stages, which requires more time and the workers are exposed to chemicals and dust.



Figure 4: Different effects induced by the use of lasers on denim [4]



Figure 5: Different effects achieved on denim by hand



Figure 6: Different effects induced by the use of lasers on denim [5]

Using a laser: With less water, less energy, less emission, one standard for production, and easy operation, multi models to satisfy different request.

S-Denim Crafts Master: Achieves the same clear and natural appearance as traditional manual processes, delivering well-defined and naturally finished denim jeans.

By using Ozone bleaching technology, no water is used, therefore there is no waste water and no pollution of rivers.

The rapid development of digital devices has enabled their use in various areas of electronic business. In parallel with the ubiquitous use of digital devices, various abuses and frauds have been made possible. In the meantime, Internet technologies, protection systems and Internet payments have developed significantly. The aforementioned aspects of electronic business required urgent legal regulation. The environment for the introduction of electronic business includes political, legal, technical-organizational, semantic, and infrastructure context [1].

From the buyer's point of view, e-business enables shopping, but also communication with sellers and service providers in a fast and efficient way. In such cases, customers can actively participate in product creation, distribution methods, and even price formation, and at the same time services with relevant information are at their disposal. Given the reduced costs of production, distribution and marketing, product prices are automatically lowered, so it can be seen that e-business thus leads to stronger competition, improved service quality and lower prices [2].

3. CONCLUSION

The application of E-business in the clothing industry is very widespread, and a further increase in application is expected. The pros of E-business in the fashion industry are more numerous than the cons. E-business allows products to be available to all customers regardless of where they are. They are available at any time, and can be ordered from the comfort of your chair.

Disadvantages of e-business are the customer's fear of abuse of privacy and possible account abuse during payment. All brands are making an effort to eliminate these shortcomings.

E-business fashion houses can attract customers with a carefully designed website, which should be connected to social networks. The most effective is Instagram, followed by



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19-20. septembar 2024. Beograd, Srbija

Facebook, Pinterest, TikTok. It is necessary to determine the generation for which the product is intended and in this way to design marketing.

Production should be equipped with modern equipment that gives original and fast results. The equipment in the production of denim should definitely have a laser for different types of finishing. The possibilities offered by the laser are almost unlimited. By using such equipment in production, it is possible to achieve economical, sustainable production, and it is also possible to provide customers with personalized clothing items. There is also a high degree of environmental protection in these conditions.

A website that would offer all these benefits to the customer would surely be very noticeable and unique.

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PROCESS MANAGEMENT IN THE CLOTHING INDUSTRY

Professional paper
DOI: 10.5937/CT_ITI24053M

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ABSTRACT: This study investigates the impact of the production process on the example of T-shirt production, with the aim of improving the existing production process. By examining priority and key processes, the research aims to identify key factors that need to be improved through the application of modern CAD technology. In addition to the change in technology, it is necessary to change the way the organization functions and the need for new management methods and implementation tools for continuous improvement of the performance of companies in the clothing industry.

Keywords: clothing industry, process management, improvement, performance.

UPRAVLJANJE PROCESIMA U ODEVNOJ INDUSTRIJI

APSTRAKT: Ova studija istražuje uticaj procesa proizvodnje primeru izrade majica, sa ciljem da se postojeći proces proizvodnje poboljša. Ispitivanjem prioriternih i ključnih procesa, istraživanje ima za cilj da identifikuje ključne faktore koje je potrebno unaprediti kroz primenu savremene CAD tehnologije. Pored promene tehnologije neophodno je da se promeni način funkcionisanja organizacije i potreba za novim menadžment metodama i alatima za implementaciju za kontinualno poboljšanje performansi preduzeća u odevnoj industriji.

Ključne reči: odevna industrija, upravljanje procesima, poboljšanje, performanse.

1. INTRODUCTION

The goal of every organization is to increase business efficiency while simultaneously reducing costs. That is why it is necessary to support the process approach of business

process management (Business Process Management - BPM). BPM as a concept is located between IT and management, and related employees, parts of the organization, applications, documents and other sources of information. Operational business process is defined as a recurring business process, which is performed by an organization as part of its daily activities [1]. The performance level of any process tends to decline over time, unless an effort is made to maintain it. If the business system is not improving, its competitors most certainly will. In the competitive garment industry, manufacturing costs are crucial for profitability and sustainability [2]. Today's users are always looking for more, which requires an increase in the quality of the offer, which causes an even greater increase in expectations. Process models are graphic presentations of business processes that describe step-by-step activities that should be performed in a certain order in order to complete a process, from start to finish. The purpose of well-defined processes is to graphically represent the essence of a business process. The most significant shift was made by the organization Business Process Management Initiative (BPMI), which defined a graphic notation for process display - Business Process Modeling Notation (hereinafter referred to as BPMN). BPMN was created to standardize and facilitate the graphical representation of business processes, the understanding of diagrams. A standard way of describing business processes has been defined, as well as the possibility of generating meta language code for describing and managing business processes from diagrams (Business Process Execution Language - hereinafter referred to as BPEL).

There are two versions of BPMN:

1. Simpler intended for managers and

2. More complex, which contains all the details needed to generate software code and is intended for IT experts. The basic requirement of the BPR approach is to change the organization of the company from a traditional, functional to a process way of doing business, given that the implementation of most business processes involves human resources from different organizational units, i.e. company functions. Regardless of whether the improvement, redesign or reengineering of business processes is carried out, after the completion of the changes, it is desirable to simulate or test the process. In this way, it would be determined whether the process is proceeding according to the desired course and whether the planned performance level of the process has been reached. If the change was successful, the process is implemented in the organization.

With the implementation of the redesigned process, one business process management cycle ends and a new one begins, which ensures continuous monitoring and improvement of business processes. Business process management is not a one-time procedure, but rather an iterative process that "lives" and unfolds as long as the organization itself "lives". A process-oriented organization strives to achieve the strategic goals of the organization through the improvement, management and control of critical processes [3].

Continuous improvement of business processes is related to the role of BPM and is usually achieved through the BPM life cycle. The concepts of the BPM life cycle differ in terms of the sequence and execution time of the phases. This form of management implies the need to change the way the organization functions and the need for new management methods and tools for implementation [4].

2. METHODS

Analyzing is a critical process in a company that produces men's and women's T-shirts. The biggest problem occurs in the structural preparation, when grading the T-shirts that this company produces. Modelers, technologists and quality controllers are participants in the mentioned operation. The operation is performed using the manual grading method. The operation is time-consuming and requires a lot of manual work. Based on the management survey, the business process related to BPM was analyzed at the same time.

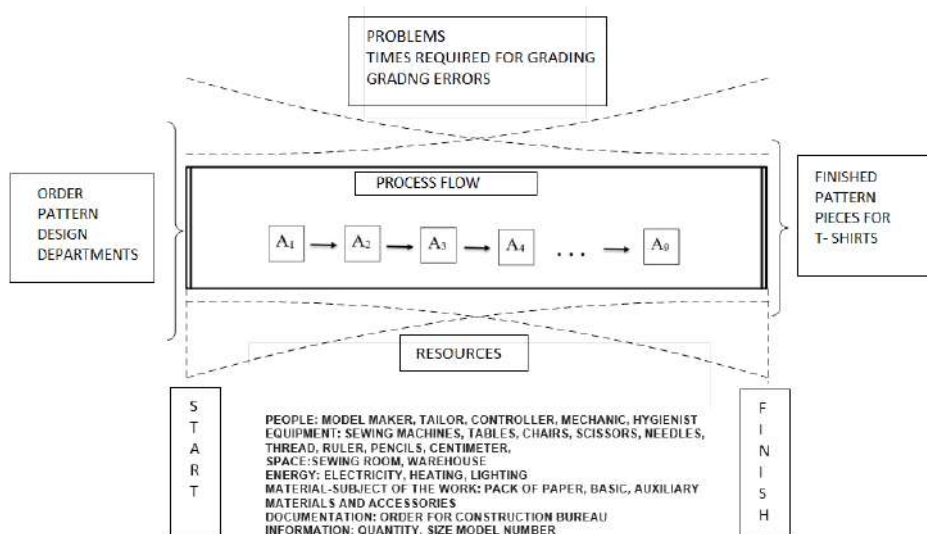


Figure 1: Representation of the process for making a T-shirt

- A1 - Basic pattern making for T-shirts,
- A2- T-shirt pattern design,
- A3- Production preparation for T-shirts,
- A4- Tailoring of the test sample
- A5- Sewing a trial pattern
- A6- T-shirt grading
- A7- Fitting the cropped image

The t-shirt grading operation requires a lot of work depending on the t-shirt model. The total time required for this operation is 1 hour. This is a significant waste of time, especially when you consider that this operation is done manually by measuring the grading time on the CAD system, this operation takes 6 minutes. The entire process was analyzed, the times compared where the entire process is accelerated 10 times compared to the classic one. One of the main problems in this process is that the operation is performed manually, this is a demanding task that leads to errors. Errors are common and controllers must inspect

each cut individually and determine errors during grading. Table 1 shows the subjects and points for checking.

Table 1: PQCDSM checklist

SUBJECT OF CHECK	CHECK POINTS
PRODUCTIVITY (P)	The time of the t-shirt grading process is longer than the planned required time. It is necessary to shorten the production time.
QUALITY (Q)	The quality is at a high level, it should not be changed.
COSTS (C)	Costs have increased due to energy consumption.
DELIVERY (D)	There is a possibility of faster delivery, by shortening the construction preparation time, i.e. gradation of the base model.
SECURITY (S)	Security is at a high level.
MORAL(M)	There is a problem between the workers and the delivery date of the ordered goods.

Training for workers in construction preparation - t-shirt grading on the CAD system aims to train new workers to perform tasks and adapt old workers to process changes. The duration of the training is 5 working days. The training methods are lecture, demonstration, practical exercise and testing. The training is carried out by a professional and experienced lecturer, who evaluates the workers after the training. The training takes place in the company's premises. This will help to make maximum use of the training workers and to acquire the necessary knowledge and skills to create a new way of grading T-shirts.

From the point of view of the process, and with the aim of achieving added value for the end user, it is important to: Analyze the process and test the capacity, understand interactions with the process, analyze the participation of human resources. BPM implies a permanent and continuous organizational commitment to manage business processes [5]. This permanent and continuous commitment is implemented through a BPM life cycle model with clearly defined steps and feedback. It is the basis for achieving continuous improvement as well as ensuring the alignment of the organization's business processes with strategic business goals.

Process measurement can be defined as the application of the management cycle with an emphasis on organizational processes [6] and can be performed through the BPI model of integral process performance management, which belongs to the group of methods known as BPI (Business Process Intelligence). BPI is a process-oriented system for measuring the success of an organization's operations, which enables insight into the process structure in the segment where critical data is generated. It enables active, precise and quick monitoring of operational business at all times with the ability to react. BPI enables the definition of process goals and key indicators of success for those goals, determination of target values of indicators, continuous monitoring of process efficiency and effectiveness, as well as the



use of methods, techniques and information technology that facilitate the management of company processes.

3. CONCLUSION

After analyzing the existing situation, it was determined that the state of the process is not satisfactory and that it is necessary to move on to solving the problem. By improving the t-shirt grading operation, we speed up model making. The proposal to solve the problem is to introduce a CAD system, which would drastically reduce the total time required for this process and increase the quality of the performed operation. Train existing human resources to work on the CAD system This can significantly improve the economic efficiency of production. At the same time, it is necessary to model the business process in which equipment, human resources, the introduction of IT technology will be carried out faster and processes and information will be processed. Process modeling contributes to determining the justification of process improvement, so the proposal is to apply the BPI model of integral management of process performance.

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FINAL QUALITY CONTROL OF SHIRTS

Original scientific paper
DOI: 10.5937/CT_ITI24054J

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ABSTRACT: Final control is the last step of the shirt inspection system which performed before shipment. Thanks to the final control it is still possible to correct some mistakes in the shirts by their re-entering in the production process, and damaged products or those with irreparable defects can be classified into a lower class with a reduced price. In this paper, a final control of a total of 2790 men's and women's shirts in two apparel companies was made in order to determine the most common errors and, if it is possible, remove them. The errors that appear most often depend on the model, in women's shirts the most common error is an unevenly gathered ruffle, while in men's asymmetric pockets and bad position or damaged button.

Keywords: men's shirt, women's shirt, quality, control.

FINALNA KONTROLA KVALITETA KOŠULJA

APSTRAKT: Završna kontrola je poslednji korak sistema kontrole košulje koji se vrši pre otpreme. Zahvaljujući završnoj kontroli još uvek je moguće ispraviti neke greške u košuljama njihovim ponovnim ulaskom u proces proizvodnje, a oštećeni proizvodi ili oni sa nepopravljivim nedostacima mogu se svrstati u nižu klasu uz sniženu cenu. U ovom radu izvršena je završna kontrola ukupno 2790 muških i ženskih košulja u dve konfekcijske firme kako bi se utvrdile najčešće greške i ako je moguće, otklonile. Greške koje se javljaju najčešće zavise od modela, kod ženskih košulja najčešća greška je neravnomerno skupljen volan, dok kod muških asimetrični džepovi i loš položaj ili oštećeno dugme.

Ključne reči: muška košulja, ženska košulja, kvalitet, kontrola.



1. INTRODUCTION

The term shirt was first used to name the simplest women's clothing. The shirt has been used in different form for thousands of years. Most of the time, the women's shirt was made from two rectangular pieces of material, which were joined along the shoulder and side seams. At first the shirt was collarless and sleeveless made from cotton, linen and silk. The more luxurious shirts were decorated. In the 19th century, the men's shirt got its present appearance. Until that time, shirts were only produced in white, and later other colors, including pink, began to be used. A shirt is a garment that is worn often and has close contact with the body. The material from which it is made should have a soft touch and be pleasant to wear. Woven as well as knitted materials are used to make the shirts [1,2].

90% of men's shirts are made of cotton fibers or their combination with other fibers, for example, with artificial or polyester fibers, which reduces the price of the product. The most common types of fabric for the production of shirts are: Popelin - canvas, smooth and soft texture of the fabric, Oxford - fabric made of thick (coarse) yarn in which the base is colored, while the core is white and Keeper or twill fabric in twill diagonal or weave, more often used for plain shirts, [3]. Some parts of the shirt, such as the collar, cuffs, pockets and buttons, have a great influence on the final appearance of a men's shirt. Also, the overall impression and quality of the shirt is influenced by the fabric from which the shirt is made.

2. FINISHING AND QUALITY CONTROL OF SHIRTS

Every step in the manufacturing process of men's shirts is vital to the overall quality of the final product. The finishing process of the shirts is extremely important, because their final appearance depends on it. In the technological process of finishing, various activities of finishing the garment are carried out in order to achieve a certain quality of the finished product that will satisfy the customer and that will ensure the building of a good image of the manufacturer on the market, [4]. The technological process of finishing consists of the following technological activities: preparation for the technological process of finishing, preparation of machines for the technological process of finishing, final ironing, sewing on buttons, thread cleaning, final control of the product, packaging and sending the product to the warehouse (warehouse) for finished products. Thanks to the final control it is still possible to correct some mistakes in the shirts by their re-entering in the production process, [5].

The quality of the shirt is the most important moment from the customer's point of view and much attention should be paid to the selection of suitable machines, devices and equipment that will provide the required quality. The final ironing plays a major role in the final appearance of the shirts and therefore in its attractiveness. Smaller apparel companies and fashion studios mostly use simple steam presses and tables for ironing of all parts of the clothes which extends the finishing time. Larger and modern companies are equipped with modern and productive machines and finishing devices, as well as with professional staff, [4]. Manufacturers of ironing equipment and machines are constantly working on the development of new possible solutions and ironing techniques. Their efforts are aimed at fully automating the machines with the possibility of precise programming of the ironing parameters. During the ironing, special attention is paid to the collar, cuffs and front parts

in the chest area. These are the parts that are visible after the shirt is folded for packing, [2].

There are several garment quality control procedures, and optimally these should be taken at various stages of the production, including pre-production level, during- and post-production levels, to check the quality of a garment. Quality control of finished garments is an inspection before the merchandise are shipped to the customer and is done when at least 80% of the order has been packed for shipping. This process helps to detect any defects and reduces the risk of complaints from customers. The inspection process typically includes: visually inspecting the garment for any flaws visible to the human eye finished product, checking the labeling, and counting the items in the production lot [6, 7]. Controllers who perform the final inspection are usually employees of the factory that produced the shirts, but they can also be employees of the buyer. This second variant is becoming more common among clothing factories that produce clothing intended for foreign markets, [8].



Figure 1: Men's shirt packaging elements (a) and packaged shirt appearance
Source: [9].

At the end the shirt is folded and packed in a polyethylene bag. In order to get a better sales appearance when folding the shirt, an elastic band is placed under the collar. In the front part, under both ends of the collar, a specially tailored collar holder is placed, caught by the button. Both parts are important to keep the collar straight and smooth. To bend the shirt, it is necessary to use sewing pins. The shirts of a high quality are packed in special boxes (Figure 1), [9].

3. EXPERIMENTAL

3.1. Result and discussion

In the practical part of the paper, the final quality control of three models of women's shirt in MK Angelo and three models of men's shirt in MK Grand Tex was performed. The practical part was carried out during 2023, in the period from May to July. The results obtained are given in Table 1, 2, 3, 4, 5 and 6 (a document named the final control protocol). In the case of the women's shirt - Akkonrad melange/classic fit (Table 1), out of a total of 1000 checked pieces, 925 are without errors, that is, 7.5% of the shirts have errors.



In this order, there was a need for only one repair, which is also one of the most difficult. Out of a total of 1000 pieces, 48 new collars were cut due to an unevenly gathered ruffle. Due to the errors, the following corrections were made:

- 5 repairs to the positions of the elastic band.
- 8 repairs for omitted bias tape
- 12 pieces returned from final ironing of the bias tape.

In the case of the women's shirt - Akkarsten flannel check shirt (Table 2) from the order S4255, the number controlled pieces is 280. 256 are good pieces, while 24 pieces with mistakes were found. This means that errors occur in 8.6% of the shirts. The most common mistake is again an unevenly gathered ruffle.

Table 1: Final control of the women's shirt, S4951

Company: Angelo Order: S4951 Model: Women's shirt-Akkonrad melange/classic fit	
Total pieces controlled	1000
Good pieces	925
Pieces with mistakes	75
Unevenly gathered ruffle	48
Outer stitch of the sleeve	/
Sewing on the elastic	5
Bad position or damaged label	/
Button holes: poorly made	/
Bad position or damaged button	/
Omitted bias tape	8
Hem of the shirt	1
Final ironing of the bias tape	12
Adjustment	/
Other common mistakes	/

Table 2: Final control of the women's shirt, S4255

Company: Angelo Order: S4255 Модел: Women's shirt-Akkarsten flannel check shirt	
Total pieces controlled	280
Good pieces	256
Pieces with mistakes	24
Unevenly gathered ruffle	22
Folde of the back	3
Button hole repair	5
Bad position or damaged label	/
Button holes: poorly made	/
Bad position or damaged button	/
Omitted cuff	8
Slit on sleeve	12
Final ironing of the bias tape	12
Adjustment	/
Other common mistakes	/

Due to the errors, the following corrections were made:

- 5 repairs to buttonholes on the right front part,
- 8 omitted cuffs,
- 12 repairs to the sleeve slit,
- 3 repairs of the folde on the back (it was not nicely centered in the middle)

For the Madewan women's shirt (with 2 pockets, 2 pocket flaps, 2 shoulder epaulets and 2 sleeve epaulets) from order S4545 (Table 3), a total of 400 pieces were controlled, of which 322 were error-free, and 78, i.e. 19.5%, had errors. The most common mistake with this model is the outer stitch on the sleeve.

The following corrections were made:

- 12 side seam repairs,
- 28 corrections on the outer stitch on the sleeve,
- 16 corrections on the pocket folds due to different widths,
- 7 repairs of the outer stitch of the yoke on the plates on the back,
- 15 corrections on the shoulder epaulet button.

Table 3: Final control of the woman's shirt, 4545

Company: Angelo Order: S4545 Model: Women's shirt-Madewan	
Total pieces controlled	400
Good pieces	322
Pieces with mistakes	78
Unevenly gathered ruffle	/
Outer stitch of the sleeve	28
Side seam	12
Bad position or damaged label	/
Outer stitch of the yoke	7
Bad position or damaged button on the epaulet	15
Omitted bias tape	/
Folde of the pocket	16
Final ironing of the bias tape	/
Adjustment	/
Other common mistakes	/

Table 4: Final control of the man's shirt, S2890

Company: Grand Tex Order: S2890 Model: Men's shirt-Cypres	
Total pieces controlled	300
Good pieces	257
Pieces with mistakes	43
Unremoved thread	5
Outer stitch of the sleeve	/
Sewing on the elastic	/
Bad position or damaged label	/
Button Holes: poorly made	/
Bad position or damaged button	21
Unequal shoulder width	17
Hem of the shirt	/
Final ironing of the bias tape	/
Adjustment	/
Other common mistakes	/

In addition, the protocols of the final control of the man's shirts are given. Out of a total of 300 controlled shirts from the Cypres model (Table4), 257 pieces are without errors, that is, 14.3% have some error or errors. The most common error is a bad button position or a damaged button.

The following corrections were made:

- 21 pieces returned for finishing due to defective buttons,
- 13 repairs returned for finishing due to unremoved threads,
- 17 repairs for uneven shoulder width.

Table 5 shows the data of the final control of the man's shirt model Ihcensev2 from the S5482 work order. Of the 100 controlled pieces, 66 are without error, while 34 or 34% have some mistake. The most common mistake is asymmetric darts.

The following corrections were made:



- 14 repairs for asymmetric darts
- 10 repairs for button holes sloppy stitched
- 8 repairs for too small pockets

Two shirts were with stains, a specific mistake which can not be simply corrected. These shirts will be disassembled and re-tailored.

Table 5: Final control of the men's shirt, S5482

Company: Grand Tex Order: S5482 Model: Men's shirt-Ihcensev2	
Total pieces controlled	100
Good pieces	66
Pieces with mistakes	30
Outer stitch of the sleeve	/
Sewing on the elastic	/
Pocket too small	8
Poorly made button holes	/
Bad position or damaged button	/
Button holes sloppy stitched	10
Stains (blemishes)	2
Final ironing of the bias tape	/
Asymmetric darts	14
Other common mistakes	/

Table 6: Final control of the man's shirt, S3487

Company: Grand Tex Order: S3487 Model: Men's shirt-V8Granstgrey	
Total pieces controlled	700
Good pieces	646
Pieces with mistakes	54
Unevenly made collar	11
Shoulder seam uneven	19
Sewing on the elastic	/
Bad position or damaged label	/
Poorly made button holes	/
Bad position or damaged button	/
Omitted bias tape	/
Sleeve hem	4
Asymmetric pockets	20
Adjustment	/
Other common mistakes	/

Table 6 shows the protocol final control of the man's shirt model V8GranstGrey from the S3487 work order. Of the 700 pieces 646 are without error, while 7.7% have some error.

In this case the most common mistake is asymmetric pockets.

The following corrections were made:

- 20 repairs for asymmetric pockets,
- 19 repairs for uneven shoulder seam,
- 11 repairs for unevenly made collar,
- 4 repairs for sleeve hem.

4. CONCLUSION

From the results of the final control of women's shirts (1680 pieces from three work orders) in one apparel company, it can be noted that the most common errors are: unevenly folded ruffle (in the first two models) and outer stitch on the sleeve in the third model. In men's

shirts, 1110 pieces from three work orders were controlled. Although the percentage of shirts with an error is very high, a very large percentage of the errors that occur will be simply corrected. The most common mistakes were bad button position or a damaged button, asymmetrical darts and asymmetrical pockets. Most of them can be eliminated by re-entering of the shirts in the production process, and damaged products or those with irreparable defects can be classified in a lower class with a reduced price.

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SESSION IV

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TRANSFORMABLE CLOTHING TO REDUCE PRE AND POST CONSUMER TEXTILE WASTE

Professional paper
DOI: 10.5937/CT_ITI24055N

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ABSTRACT: Using transformable clothing designing methods a single textile item can be worn as multiply styles. Transformable clothing can extend the life cycle of garments and reduce amounts of pre and post consumer textile waste. Two brands by Sandra Garratt present are a good sample of industrially manufactured transformable garments. Their great commercial success in 1980's was based on the use of stretchy knitted fabrics and simple, loose shapes of her garments. In the experimental part of the research a set of textile goods for industrial manufacturing were created to promote currently very actual sustainable fashion concept. Its versatility and constructive solutions could ensure effective fabric use, simple manufacturing process, as well as, attractive outfits for their consumers.

Key words: transformable clothing, sustainable fashion, pre consumer textile waste, post consumer textile waste.

TRASFORMABILNA ODEĆA ZA SMANJENJE TEKSTILNOG ODPADA

APSTRAKT: Korišćenjem transformabilnih metoda dizajniranja odeće jedan tekstilni predmet može da se nosi kao više stilova. Transformabilna odeća može produžiti životni ciklus odevnih predmeta i smanjiti količine tekstilnog otpada pre i posle potrošnje. Dva prisutna brenda Sandre Garratt predstavljaju dobar primer industrijski proizvedene transformabilne odeće. Njihov veliki komercijalni uspeh 1980-ih bio je zasnovan na upotrebi rastegljivih pletenih tkanina i jednostavnih, labavih oblika njenih odevnih predmeta. U eksperimentalnom delu istraživanja kreiran je set tekstilnih proizvoda za industrijsku proizvodnju kako bi se promovisao trenutno veoma aktuelni koncept održive



mode. Njegova svestranost i konstruktivna rešenja mogu da obezbede efikasnu upotrebu tkanina, jednostavan proizvodni proces, kao i atraktivnu odeću za svoje potrošače.

Ključne reči: transformabilna odeća, održiva moda, pre potrošača dobijeni tekstilni otpad, posle potrošača dobijeni tekstilni otpad.

1. INTRODUCTION

Transformable clothing is a concept offers to fashion designers creating garments with changeable shapes or functions, designing multiply styles from a single item [1]. It can be obtained using specific constructive solutions, modular designs or advanced textile materials [2]. Next to versatility, such textile goods support currently very actual sustainability strategy in textile industry [3,4]. Transformable clothing extends the life cycle of garments and with it reduce amounts of post-consumer textile waste accumulated as a result of up normal shopping supporting fast fashion business model [5,6].

Many designers, such as, Marfa Stance, Petti Pli, Issey Miyake work with transformable design methods creating their unique garment styles or whole collections [1]. However, the greatest samples of industrially manufactured transformable clothing are garments of American designer Sandra Garratt [7].

2. TRANSFORMABLE CLOTHING BY SANDRA GARRATT

In 1980's two brands of clothing by Sandra Garratt "Unites" and "Multiples" were sold in USA with big commercial success. The styles of the brands were called modular, however, the most part of them belong to group of *transformable garments* - the garments with easy changeable shapes to obtain different design variations and different outfits. The collections were created from up to 50 simply shaped garments: tops, dresses, tunics, wraps, skirts, pants, leggings, shorts, and different size tubes (see Fig.1).

The tubular items included in the collections could be transformed and used as a skirt or a dress, a hood or a scarf or a belt. Some styles were modular - had detachable sleeves or other parts. The styles could be worn in different transformable ways alone or combined with other items. All garments were manufactured from cotton-polyester jersey fabric in few colours - black, red, white, gray, olive, navy.



Figure 1: Transformable clothing by Sandra Garratt

The ready goods were sold packed in plastic bags with guidelines “Multiples Memo” (see Fig.2). The guidelines showed to a consumer how to wear obtained parts and which other items of the collection are advisable to purchase to create new individual outfits [7,9,10]. The collections, transformation and combination ideas of garments were also promoted in press and specially organized fashion shows.



Figure 2: Wearing guidelines “Multiples Memo”

The affordable price level and possibility to create numerous outfits from few items of the collection made the *transformable* clothing very popular to huge number of American women [7,8,10]. As the result, brand shops were opened also in Europe, Australia and Japan. At the end of 1986 more than 47,000 pieces of the collection were sold a day and the *transformable clothing* line "Multiples" became one of the most successful brands in USA [7]. The success of *transformable* garments by Sara Garratt gave idea to many another



American companies to start business with similar goods. However, during 1990's weekend by growing competition and attracted by new fashion ideas, clothing manufacturers left *transformable garment business* [7].

Analyzing the above described *transformable* garment collections by Sandra Garratt it can be seen that their commercial success were based on several important qualities (see Table 1):

1. *Knitted stretchy fabrics* - elasticity of the material ensured possibility to create easy transformable, simply shaped and maximally comfortable clothing, clothing which manufactured in a single size could be worn by purchasers of more than one size group.
2. *Simple shapes* - simple geometrical shapes of the garments ensured efficient fabric use, simple manufacturing process, easy packing of ready goods and, as the result of all mentioned, affordable price level for consumers. Geometrical shapes of garments also gave possibility to create unisex clothing acceptable for both genders - women and men.
3. *Tubular items* - tubular items were specific part of the collections that by themselves cannot be even called garments. However, created from stretchy fabrics they were easy transformed on a human body in different kind of garments - dresses, skirts, hoods, scarves or belts. They ensured high diversity and good fit to wide range of different size group consumers.
4. *Cotton-polyester blend* - polyester added to the natural origin material ensured additional comfort - wrinkle and ironing free, easy care garments.

Table 1: The most important qualities of transformable clothing collections by Sandra Garratt

	Qualities	Benefits
1.	Stretchy fabrics	comfortable garments, single size, easy transformation, simple shapes
2.	Single size	loose garments, comfortable garments, simple shapes, stretchy fabrics, simple manufacturing, low price, unisex
3.	Simple shapes	comfortable garments, single size, modularity, efficient fabric use, simple manufacturing, easy packing, low price, unisex
4.	Tubular items	comfortable garments, easy transformation, stretchy fabrics, efficient fabric use, simple manufacturing, low price
5.	Modularity	simple shapes, stretchy fabrics, tubular items, plain fabrics
6.	Cotton-polyester blend	comfortable garments, ironing free, easy care
7.	Plain fabrics	easy coordination, current trend
8.	Fabrics with geometric pattern	current trend
9.	Simple manufacturing	Single size, simple shapes, easy packing, low price
10.	Easy packing	ironing free, single size, simple shapes
11.	Low price	simple shapes, stretchy fabrics, efficient fabric use, simple manufacturing, easy packing

However, the critical and most important quality of transformabile clothing of two described brands was the material used - *stretchy knitted fabric*. By help of such material the most important benefits of the collections were obtained:

- transformability of styles,
- possibility to sell garments in single size,
- simple manufacturing process,
- low prices for consumers.

All these four benefits made the collections maximally attractive for wide range of consumers. Transformability of collections were obtained from two kind of garment styles: simply shaped loose styles and close fitting tubular items.

3. EXPERIMENT

A set of textile goods which could be industrially manufactured and sold to promote sustainable fashion concept were created using above researched qualities of *transformable* garment collections by Sandra Garratt (see Fig. 2,3). The textile goods were designed from stretchy 100% cotton plain fabrics in three basic colours - white, black, red.



Figure 3: Transformable dress A with a hood (a) and draped dress B (b)
Photos by A. Blanuša

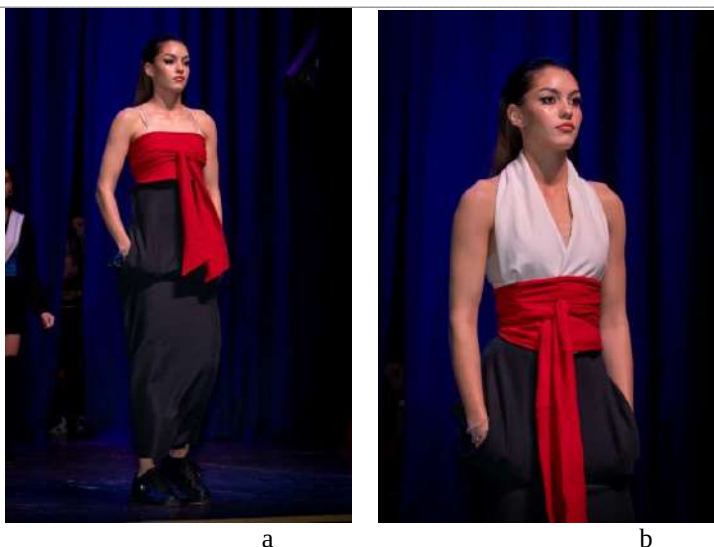


Figure 4: Transformable skirt C (a,b) with a red belt (a,b) and a scarf/top (b)
Photos by A. Blanuša

The set of transformable goods consists of: a black dress/skirt, a red belt/top and white scarf/top. The simply shaped dress has three constructive elements:

- a tubular upper part - used as a hood of the dress A (see Fig.3a), draperies on one shoulder of the dress B (see Fig.3b) and a top part of the skirt C (see Fig.2a,b).
- a tubular bottom part - use as a bottom part of the dress A and B (see Fig.1) and a bottom part of a skirt C (see Fig.2).
- two tubular elements in between upper and bottom parts - used as sleeves of the dress A (see Fig.1a) and conditional pockets of the skirt C (see Fig.2a,b)

The red wide belt can be used as a top or belt with the skirt C (see Fig. 2a,b). White scarf can be added separately or creating the top for the skirt c (see Fig.2b).

The dress/skirt and other two parts of the transformable set could be manufactured in a single size to be used by consumers of S and M size groups. Geometrical shapes of all components ensure effective material use, as well as, simple manufacturing process (see Fig.5). Only two kind of industrial sewing machines are needed to join all components of the set - overlock machines of stitch type 514 and interlock sewing machines of stitch type 406. The set can be simply folded and sold in a packed way adding instructions how to create all designed combinations from three parts of the set. In future new design elements for the dress /skirt could be designed and offered to the purchasers.

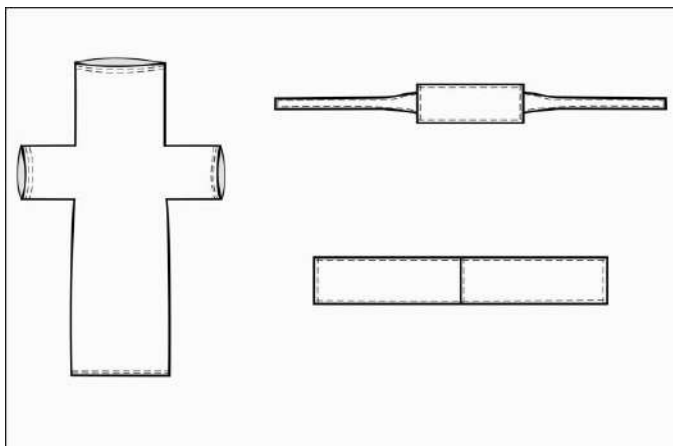


Figure 5: Transformable dress A, with a red belt and a skarf/top

4. CONCLUSIONS

In the article transformable clothing concept and the most important qualities of transformable garments were described on the bases on already commercially successfully sold clothing collections of similar concept. As well as, a set of transformable textile goods for industrial manufacturing needs were designed. On the bases of all theoretical and practical research following conclusions were made:

- Transformable clothing can extend the life cycle of textile goods and with it reduce post-consumer textile waste. Such kind of garments have to be actively promoted and manufactured industrially.
- Analyzing industrially manufactured collections of transformable clothing by Sandra Garratt, it was found that their commercial success was based on following important qualities: the use of stretchy fabric in basic few colours and simple and loose shapes of garments.
- Stretchy fabrics, simply shaped and loose garments can ensured transformability to styles, possibility to sell garments in single size, simple manufacturing process, as well as, affordable price level to different age and gender consumers.
- Respecting the most important qualities of transformable clothing, a set of textile goods were designed for industrial manufacturing needs. The set is created from three parts: a dress/skirt, a belt/top, a scarf/top. Four different outfits can be designed from the set of transformable textile goods.
- Transformability concept of designed goods could help to extend their use period, and with it, reduce post-consumer textile wastes. Geometrical shapes of goods and their manufacturing in a single size could ensure efficient fabric use, and with it, reduce pre-consumer textile waste.



ACKNOWLEDGEMENTS

This research was supported by the Provincial Government of the Autonomous Province of Vojvodina, Provincial Secretariat for Higher Education and Scientific Research of the Republic of Serbia (Decision on Approval Funds No 001064141 2024 09418 003 000 000 001 04 003).

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IMPACT OF CO₂ EMISSIONS REGULATIVE ON TEXTILE INDUSTRY

Original scientific paper
DOI: 10.5937/CT_ITI24056S

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ABSTRACT: Textile industry produces serious environmental impact through land, water and energy use. To lower CO₂ emissions very sophisticated obligatory mechanisms are imposed in many countries. In European Union this is EUETS based on trading with CO₂ emissions. Among covered activities there is no textile industry. Observing life cycle of various textile products significant carbon footprint of textile industry can be seen. Analysis of selected dying process is presented in order to illustrate how indirect carbon dioxide emission is generated. Interaction between textile industry, resulting waste from used textile products and our habits is discussed.

Keywords: Textile industry, CO₂ emission, EUETS, recycling of textile.

UTICAJ REGULATIVE O EMISIJAMA CO₂ NA TEKSTILNU INDUSTRIJU

APSTRAKT: Tekstilna industrija ima snažan uticaj na okolinu zbog upotrebe različitih resursa poput vode, sirovina i energije. Kako bi se smanjile emisije CO₂, mnoge svetske države su uvele obavezujuće zaštitne mehanizme. U Evropskoj Uniji, ovaj mehanizam se naziva EUETS i bazira se na trgovini emisijama CO₂. Među aktivnostima obuhvaćenim tim sistemom nije i tekstilna industrija. Prilikom sagledavanja životnog ciklusa tekstilnih proizvoda primećuje se značajan ekološki trag uzrokovan emisijom ugljenika u ovoj industriji. Na primeru konkretnog procesa bojenja tekstila, prikazano je kako nastaju indirektno emisije ugljen-dioksida. Razmatrana je interakcija između tekstilne industrije, nastanka otpada od korišćenja tekstilnih proizvoda i naših životnih navika.

Ključne reči: Tekstilna industrija, emisije CO₂, EUETS, recikliranje tekstila.

1. INTRODUCTION

Textile industry produces serious environmental impact. Some amazing facts, as experienced by author, came up through this citation from reference [1]: “Per average person in the EU, in 2020, textile consumption required nine cubic metres of water, 400 square metres of land, 391 kilogrammes of raw materials, and caused a carbon footprint of



about 270 kg. Most of the resource use and emissions took place outside of Europe.” From polluter’s point of view textile is the third highest source of pressure on water and land use in European Union (EU), the fifth highest use of raw materials and greenhouse gas (GHG) emissions and the third largest employer worldwide after food and housing [2]. And for the end of this devastating and concerning statistics, less than 1% of used textile is recycled worldwide into new products and from total amount of 16 kg of textiles consumed per person in EU 4,4 kg was collected separately to be reused and recycled while the rest of 11,6 kg ended in mixed household waste [2]. This is statistics of developed countries of EU that tripled its export of used textiles to third countries in last decade as stated in the same source.

2. CO₂ EMISSIONS REGULATION

GHG emissions are detected as global environmental issue for long time ago. Very wide range of measures for mitigation of emissions is set worldwide. European Commission brought more directives to arrange obligatory activities to reach goals of climatic policies. One of most important measures is introduction of European Union Emission Trading System (EUETS) based on allocation of free CO₂ emissions to emitters and trading with them as defined by Directive 2003/87/EC and following Directives brought by European Parliament and Council. Other GHG gases are included through equivalent emissions. Directives and activities covered by EU ETS defined by European Commission are implemented in national legislative of EU member countries [3]. Among them is heat energy production in thermal plants over thermal 20MW of thermal power that is closest to textile industry as great consumer of heat energy. Other categories are connected to other energy intensive branches such as pulp and paper, cement, ammonia, nitric acid production etc. Any branch of textile industry is not among them but let us keep in mind facts about its environmental impact mentioned in introduction. It is worth of mentioning that EUETS is not the only one system that regulates CO₂ emissions, other countries all over the World imposed their own rules more or less strict.

2.1. Sources of GHG emissions in textile industry

To determine or better to say to reckon CO₂ emissions from textile industry life cycle of products has to be observed. Textile industry is great consumer of electricity for fabric production and further treatment of textile and heat energy in form of process steam especially in dying process [4]. It is obvious from available facts that any part of textile industry is not subject of CO₂ emissions regulative that seems strange at first glance and at the same time textile industry is marked as fifth source of GHG emissions. Life cycle of textile industry products is very complex as described in reference [4]. Activities that serves to wide range of textile industry products are subject of this regulative, especially transport and heat energy and electricity production. Production of raw materials, for instance cotton, as part of agriculture is not yet covered by EUETS but is under consideration. EUETS is based on trading with CO₂ emissions that generally results in additional cost to final price of product.

2.2. Emission of CO₂ from selected process in textile industry

In order to become more familiar with problem of CO₂ emission, dying process will be analysed from heat energy and electricity consumption point of view. Data and calculation are taken from [5] while origin of data is from facility “VIS tkanine” from Varaždin (Croatia) that does not exist for long time as result of transition trend of Croatian textile industry, similar to trends in Serbian textile industry as analysed in reference [6].

Simplified scheme of all phases of dying process is shown in Figure 1. In mentioned facility it was possible to conduct following processes using appropriate dying machines; process 1: dyeing of polyamide with acid dyestuff on small jigger, process 2: dyeing of cotton with reactive dyestuff on small jigger, process 3: dyeing of cotton with reactive dyestuff on large jigger, process 4: dyeing of viscose with direct dyestuff on small jigger, process 5: dyeing of polyester part of cotton/polyester mixture with disperse dyestuff on high temperature machine, process 6: dyeing of cotton part of cotton/polyester mixture on large jigger, process 7: dyeing of cotton part of cotton/polyester mixture on small jigger, process 8: washing of viscose on jet machine, process 9: dyeing of viscose with reactive dyes on jet machine.

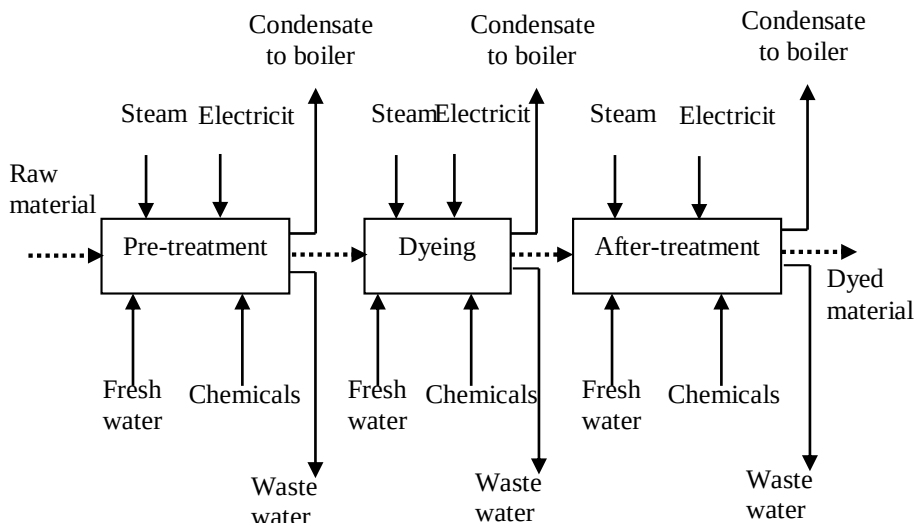


Figure 1: Scheme of dying process

Consumption of heat energy and electricity can be calculated based on data for annual capacity of facility such as mass and length of processed material and duration of processes (see Table 1.). CHP plant is not part of facility which is important for allocation of CO₂ emissions to CHP plant, not to dying facility. Natural gas is taken as primary fuel with assumed composition of 95% of methane CH₄ while rest up to 100% is neglected. Inserting this value to combustion equations [7] lower heating value and volume of CO₂ per 1m³ of natural gas can be calculated.

$$H_d = r_{CH_4} \cdot H_{dCH_4} = 0,95 \cdot 35,93 = 34130 \frac{kJ}{m^3_{natural\ gas}} \quad (1)$$

$$V_{CO_2} = CH_4 = 0,95 \frac{m^3}{m^3_{natural\ gas}} \quad (2)$$

This calculation is approximate, but accurate enough for purpose of further discussion. Assuming overall efficiency of cogeneration plant (CHP) of 60% that supplies facility with heat energy and electricity in total amount given in last row of Table 1., natural gas consumption $V_{natural\ gas}$ can be calculated by dividing sum of these values by lower heating value from Equation 1. and CHP plant efficiency.

$$V_{natural\ gas} = \frac{1687037 + 795480}{9,482 \cdot 0,6} = 436384 m^3_{natural\ gas} / year \quad (3)$$

Table 1: Annual heat energy and electricity consumption in dying process

Process	Energy consumption, kWh/year		Length of died material, m/year
	Heat	Electricity	
1	51015	10320	430000
2	46369	14600	200000
3	55089	4400	200000
4	36417	4500	300000
5	772667	222400	800000
6	92333	29200	400000
7	110011	8800	400000
8	35997	36900	150000
9	487139	464360	760000
Total	1687037	795480	3,64·10 ⁶

When volume of natural gas from Equation 3. is multiplied by volume of CO₂ from Equation (3) and carbon dioxide density $\rho_{CO_2}=1,96kg/m^3$ annual CO₂ emission in tons is derived.

$$Emission_{CO_2} = 436384 \cdot 0,95 \cdot 1,96 = 812547 kg_{CO_2} \quad (4)$$

This emission is result of spent heat energy and electricity for dying of 3,64 million meters of textile material. From author's point of view this is respectable quantity, but still that makes minor share of total world textile industry.

Further illustration of this value could be given as follows: it equals emission of one car with average emission of 110gramsCO₂/km that passed 8 million kilometres, or emission of 430 average households (flat with area of 80m² in building) in continental region of SE Europe that spent 1000m³ of natural gas for space and water heating.

This emission is, as already mentioned, allocated to CHP plant that supplies heat energy and electricity to dying facility. So, all issues connected to CO₂ emission is concern of CHP plant, not of facility. Of course, any additional cost of CO₂ emission is incorporated in price of heat energy and electricity and finally in end product of dying facility. Additional cost



will occur if emitter, in this case CHP plant has to buy CO₂ emissions at the stock exchange in case when emitted quantities exceed allocated free emissions, as imposed by described directives.

3. CONCLUSION

Previous calculation has shown how CO₂ emission indirectly affects one of many technological processes in textile industry which is not subject of CO₂ regulative. This could lead to wrong conclusion of carbon neutrality of textile industry. Introductory notes deny such thinking. Observing life cycle of all textile products it becomes clear that textile industry is serious emitter of carbon dioxide. Further problem is huge amount of textile products, especially clothes that ends in mixed solid waste after being used and much worse, the significant amount of completely new clothes whether not sold or bought and not worn experience the same destiny ending in landfills. Only one percent of textile worldwide is recycled. Statistics is not promising even in developed countries including EU. Especially if seen from point of clothes production, fashion dictates trends that change seasonally and together with products of lower quality results in immense quantity of disposed textile. Most of population doesn't understand or care that this is not only textile, but energy, water and raw material incorporated in final product. If endpoint of any sort of textile life cycle is landfill then all previously mentioned items are irreversibly lost. And suddenly, carbon footprint and rest environmental impacts of textile industry moves from technology field to field of our bad habits, comfort and irresponsibility, from technology to waste. Do we recognize similar pattern in our behaviour using many other products in our everyday life? Solution of problem is not only to press textile or any other industry to be more efficient but also to change our behaviour and increase our consciousness. But, are we ready for that?

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AN OVERVIEW ON THE VIABLE METHODS FOR TEXTILE WASTEWATER TREATMENT

Review scientific paper
DOI: 10.5937/CT_ITI24057V

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ABSTRACT: The textile industry is one of the major polluters of the environment, primarily due to the types and quantities of wastewater it produces. It is estimated that 20% of global water pollution is caused by textile processing, meaning that these processes generate enormous amounts of wastewater. Generally, this wastewater contains high levels of suspended solids, dyes, salts, pesticides, non-biodegradable organic substances, and heavy metals. The decline in water quality, along with increasingly stringent environmental protection regulations, has led the textile industry to turn to sustainable wastewater treatment methods that help reduce the global water footprint. This paper reviews some viable methods used for the treatment of wastewater originating from the textile industry. The focus is on advanced treatment techniques, such as adsorption, membrane-based filtration, electrochemical processes, and advanced oxidation. These methods offer potential solutions to mitigate the environmental impact of textile wastewater and promote sustainable water management practices.

Keywords: textile wastewater, sustainable technologies, advanced oxidation, membrane filtration, electrocoagulation.



PREGLED ODRŽIVIH METODA PREČIŠĆAVANJA OTPADNE VODE TEKSTILNE INDUSTRIJE

APSTRACT: Industrija tekstila je jedan od glavnih zagađivača životne sredine, prvenstveno zbog vrsta i količina otpadnih voda koje stvara. Procenjuje se da je 20% globalnog zagađenja vode potiče od proizvodnje tekstila. Generalno, ove otpadne vode sadrže visok sadržaj suspendovanih čvrstih materija, boja, soli, pesticida, nebiodegradabilnih organskih supstanci i teških metala. Pogoršanje kvaliteta vode, zajedno sa sve strožijim propisima o zaštiti životne sredine, naveli su tekstilnu industriju da se okrene ka primeni održivih metoda prečišćavanja otpadnih voda koje pomažu u smanjenju globalnog vodenog otiska. Ovaj rad daje pregled nekih održivih metoda koje se koriste za prečišćavanje otpadnih voda koje potiču iz tekstilne industrije. Fokus je na savremenim tehnikama prečišćavanja, kao što su adsorpcija, elektrohemijski procesi, oksidacija i membranska filtracija. Ove metode nude potencijalna rešenja za ublažavanje uticaja tekstilnih otpadnih voda na životnu sredinu i promovišu održivu praksu upravljanja vodama.

Ključne reči: otpadne vode tekstilne industrije, održive tehnologije, ozoniranje, membranska filtracija, elektrokoagulacija.

1. INTRODUCTION

One of the most critical worldwide challenges is meeting the rising demand for water, driven by the worldwide expansion of industry, which in turn affects environmental stability, ecosystem health, and long-term economic development [1,2]. The industrial sector accounts for a significant proportion of global water usage, and the textile industry, in particular, is notorious for generating wastewater laden with dyes and chemicals that are detrimental to aquatic environments and the organisms within them. Various stages of textile processing- like sizing, scouring, bleaching, dyeing, and finishing- consume substantial water, with about 100-200 liters needed to process 1 kg of textile product [3,4]. Also, textile processing generates multiple wastewater streams with unique properties based on materials, processes, and chemicals used. Around 60-90% of process water is used for rinsing and washing, which can be cleaned and recycled [5]. Contaminated water with dyes and other various chemicals can also be treated by different techniques to reclaim water and recover chemicals [6,7].

Historically, the primary goal of textile wastewater treatment was the safe disposal of wastewater. However, inadequate treatment and the subsequent release of chemically contaminated water have caused severe pollution of aquatic ecosystems, posing risks to both the environment and human health. Over the past few years, significant advancements have been made in textile wastewater treatment, shifting the focus towards sustainable practices [8-10]. This shift is driven by stringent global regulations mandating sustainable water management strategies, including water reuse [11]. Efficient treatment of textile



wastewater has become a priority for water experts and environmentalists, aiming to operate the textile industry sustainably and prevent environmental damage [12].

The first two stages of wastewater treatment- primary and secondary- have been well-established and standardized over the years [13]. The primary stage involves removing suspended solids and gritty materials, while the secondary stage focuses on reducing oxygen demand, chemicals, and pollutants' color. Beside these advancements, the considerable effort has been dedicated to enhancing the tertiary stage of wastewater treatment, which addresses the removal of any remaining contaminants after the primary and secondary treatments. To achieve the highest treatment efficiency, various tertiary treatment techniques have been proposed [14,15]. The following is an overview of treatment methods for wastewater originated from the textile industry including adsorption, electrochemical processes, advanced oxidation, and membrane-based filtration. The aim is to highlight the potential of these methods to improve the purification process, ensuring compliance with environmental standards. This approach could accelerate the shift towards more sustainable water management practices.

2. TREATMENT METHODS

The treatment of wastewater from textile industry generally involves three main stages: primary, secondary, and tertiary treatment. Each stage removes different impurities, resulting in cleaner water. Primary treatment removes suspended solids, floating debris, and gritty materials. Secondary treatment reduces oxygen demand, other chemicals, and color. Tertiary treatment eliminates any remaining contaminants after the primary and secondary stages. Synthetic dyes are stable and non-biodegradable, making them difficult to remove through physical, chemical, or biological methods. Significant effort has been devoted to developing advanced treatment methods that are effective, affordable, flexible, and user-friendly. However, many of these methods are costly, especially when dealing with large volumes of waste.

2.1 Adsorption

Adsorption methods show great promise for future industrial wastewater treatment due to their effectiveness in removing organic and mineral contaminants, simplicity, and low cost. This physical process involves soluble molecules, called adsorbates, being removed from a solution by attaching to the surface of a solid substrate, known as an adsorbent. Textile dye or heavy metal adsorption can occur through physical adsorption, driven by Van der Waals forces and hydrogen bonds, or through chemical adsorption, which involves a reaction or complex formation between the adsorbent and the adsorbate.

Biosorption, a specific type of adsorption, occurs on living or dead microbial cells, trapping the dye and pollutants within the microbial biomass without breaking the dye's physical structure [16]. Common adsorbents include activated carbon, biochar, chitosan, clay, resins, and zeolite. Researchers are exploring low-cost adsorbents derived from agricultural waste and developing novel adsorbents for the simultaneous removal of heavy metals and organic dyes [17,18]. Nanoparticles, due to their large surface area and porosity, offer better effectiveness and faster removal rates than traditional adsorbents [19,20]. Metal

oxide composites have also shown greater adsorption effectiveness compared to single metal oxides [21].

Key factors influencing adsorption include particle diameter, adsorbate concentration, temperature, and pH. The process has gained significant interest for its high decolorization efficiency for wastewater containing various dyes. However, adsorption is time-consuming and the sludge byproduct can be challenging to manage. Despite these challenges, the potential for developing efficient, low-cost adsorbents and improving adsorption techniques continues to drive research in this area.

Adsorption on activated carbon

Activated carbon is a microporous, homogeneous material with a large specific surface area (1 g has a surface area of up to 500 m²). It is derived from bituminous coal, coconut shells, wood, and anthracite through thermal or chemical activation processes. While not effective in removing all contaminants, it has the ability to bind with substances in liquid, solid, and gaseous states. When treating wastewater from the textile industry with activated carbon, it effectively removes chlorophenols, chlorinated hydrocarbons, dyes (color), surfactants, and substances that cause unpleasant odors. It also significantly reduces contamination from metals (Cu, Hg, Pb) and disinfection byproducts.

Activated carbon is used in the form of powder (PAC- Powdered Activated Carbon) or granules (GAC- Granular Activated Carbon) with a diameter of 1.2-1.6 mm. The process takes place in adsorption columns with activated carbon, more commonly using GAC, which simultaneously filters the water and conducts adsorption. The wastewater flow can be either downward or upward, and it is possible to regenerate GAC (by washing with acids or alkalis, steam, organic solvents, or thermal treatment), with a loss of 10% of the adsorbent. This reduces the problems and costs associated with the disposal and management of contaminated adsorbent and lowers the cost of acquiring new adsorbent (by up to 50%) [22].

2.2 Membrane filtration

In the textile industry, membrane technology is highly versatile and useful. This approach is cost-effective and energy-efficient, requiring fewer chemicals and less equipment, which makes it possible to remove various dyes and contaminants from wastewater and allows for the significant reuse of water. There are different types of membrane filtration available (Figure 1). Generally, microfiltration and ultrafiltration alone are not very efficient for wastewater treatment, so they are often followed by nanofiltration and reverse osmosis to achieve better results [23].

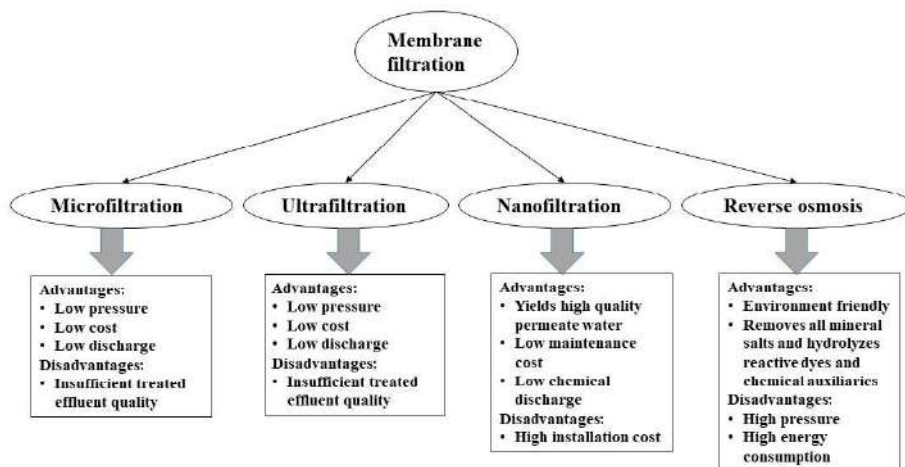


Figure 1: Types of membrane filtration with their advantages and disadvantages [23]

The basis of these operations is the membrane- a thin film (interface) that separates two phases and/or acts as an active or passive thin physical barrier to the transfer of substances between the two phases. This applies to semipermeable membranes and implies that there is a difference in chemical potential between the two phases.

The most common separation mechanisms, which depend on the specific properties of the components to be selectively removed or retained by the membrane, are:

a) Separation based on the difference in particle size and membrane pore size, known as the "sieve effect," through porous membranes that can have macropores larger than 50 nm and nanopores (mesopores) ranging from 2-50 nm. Processes dominated by this mechanism include microfiltration, ultrafiltration, nanofiltration, and dialysis.

b) Separation based on the difference in solubility and diffusivity of the membrane material and the solution in contact with the membrane, known as the solution/diffusion mechanism, using dense membranes in the following processes: gas permeation, pervaporation, and reverse osmosis.

c) Separation based on the difference in the charge of the particles to be separated (electrochemical effect) using ion-exchange (cationic or anionic) membranes. Processes dominated by this mechanism include electrodialysis, Donnan dialysis, and nanofiltration. The membrane pore size defines the process. Table 1 shows the characteristics of membrane systems used in the textile industry.

Table 1: Characteristics of membrane processes used in the textile industry [22].

Process	Membrane pore size (μm)	Contaminants/ molar masses (g/mol)	Description
Microfiltration	0,007-2,00	Bacteria, suspended substances, pigments, oils, etc. >100000	Physical separation; particles with a size of 0.1-0.2 μm are removed, while particles larger than the pore size remain on the membrane
Ultrafiltration	0,002-0,10	Colloids, viruses, proteins, metal hydroxides, metals above 1 ppm, etc. 1000-200000	Best function is with a pressure gradient of 25 bar; Removal of particles either undissolved or suspended in water; retention of macromolecules and colloids; reduction of turbidity (99 %), COD and BOD.
Nanofiltration	0,001-0,07	Bacteria, viruses, dyes, pesticides, multivalent ions, etc. 180-15000	Performed at lower pressures than reverse osmosis, so it is cheaper; Discoloration and water hardness elements (Mg, Ca) removal.
Reverse osmosis	<0,001	Multivalent ions, viruses, bacteria, suspended substances, monovalent ions <200	Pressure is applied from the high-concentration solution side, membrane is permeable to water but impermeable to salt or contaminant molecules; High energy consumption because it requires a hydrostatic pressure gradient of 20–80 bar; high pollutant removal efficiency

According to their geometry, membranes are divided into flat and cylindrical, which can be tubular or in the form of hollow fibers.

According to their chemical nature, membranes are primarily polymers; they are made from modified natural and synthetic materials such as cellulose acetates, polyamide, polysulfone, acrylonitrile, polyethersulfone, teflon, nylon, polypropylene, and polycarbonate. Inorganic membranes are mainly ceramic, made from oxides, nitrides, and carbides of Al, Zr, and Ti, and are used for the separation of organic solvents that cannot be separated by polymeric membranes because they would dissolve.

2.3 Electrochemical processes



Electrochemical discoloration primarily targets the breakdown of reactive dyes, which constitute approximately 20–30% of the total market due to their vibrant and durable color properties. Generally, biological treatments are inadequate for effectively removing these dyes, physicochemical processes often leave behind residues that require further treatment, and absorbent materials need to be regenerated after multiple uses. Heavy metals are also successfully removed by electrochemical processes.

Electrocoagulation

Unlike chemical coagulation, electrocoagulation does not require the use of chemicals but has a better ability to remove pollutants. Electrocoagulation can remove a significantly broader range of pollutants than chemical coagulation, including heavy metals, suspended solids, bacteria, COD, BOD, pesticides, and herbicides. During electrocoagulation, substances are decomposed using electrical energy; direct current passes through metal electrodes, creating charged metal atoms that bind with dissolved contaminants and precipitate out of the solution [24].

Anode half-cell reaction: $M \rightarrow M^{n+} + ne^{-}$

Cathode half-cell reaction: $2H_2O + 2e^{-} \rightarrow 2OH^{-} + H_2$

Formation of metal hydroxide: $M^{n+} + nOH^{-} \rightarrow M(OH)_n$

The electrocoagulation process can be performed in batch or continuous modes. Batch processes are used in laboratory conditions, while continuous processes are ideal for industrial plants. In continuous processes, it is simpler to control operational parameters, making it easier to achieve better efficiency.

One of the drawbacks of this method is the need for frequent electrode replacement, as well as the formation of toxic organic compounds. Additionally, an impermeable oxide layer can form on the cathode, creating resistance to the flow of electric current, increasing power consumption, and consequently raising costs [22].

The advantages include the ability to treat large volumes of water at low cost, significantly less waste sludge generation compared to conventional coagulation, and much easier sludge treatment, drastically reducing disposal costs. The efficiency of electrocoagulation is over 95%, making it an excellent pretreatment for membrane technologies that require high-quality water for use.

2.4 Advanced oxidation processes

Advanced Oxidation Processes (AOPs) are an effective alternative to conventional methods, based on the production and utilization of highly reactive free radicals, particularly hydroxyl radicals capable of oxidizing and thus removing even non-biodegradable organic compounds present in wastewater. The most well-known and extensively researched AOPs include ozone oxidation (O_3), ozone oxidation with hydrogen peroxide (H_2O_2), ultraviolet radiation (UV), and the photo-Fenton process. They are often combined with ozonation at high pH values and the Fenton process. These processes are highly efficient in treating wastewater from the textile industry, especially in removing dyes and slowly biodegradable or non-biodegradable organic components.

Ozonation

Ozone dissolves well in water and can be effectively used for water disinfection. The limiting step in the ozonation process is the mass transfer of ozone from the gas phase to the liquid phase. The driving force and treatment efficiency of ozone vary and depend on the characteristics of the wastewater (pollutant concentration, pH value, etc.).

Ozonation is an eco-friendly wastewater treatment method since it does not create any harmful residues or chlorinated byproducts after oxidizing color, odor, and microorganisms. This process is typically performed in alkaline conditions ($\text{pH} > 9$) because the decomposition of ozone in water increases at higher pH levels. Ozone oxidizes inorganic and dissolved organic substances through two mechanisms [25]:

1. The direct reaction by ozone molecules, which is more selective and occurs slowly, is favored in acidic conditions.
2. The indirect reaction by free radicals, such as $\text{OH}\cdot$ and $\text{HOO}\cdot$, which is less selective and occurs more rapidly, is favored in basic conditions.

Therefore, the reaction pathway depends on the pH of the medium and the ozone dosage [26].

A simple method is used for introducing ozone into a reaction vessel containing wastewater, as shown in Figure 2 [27].

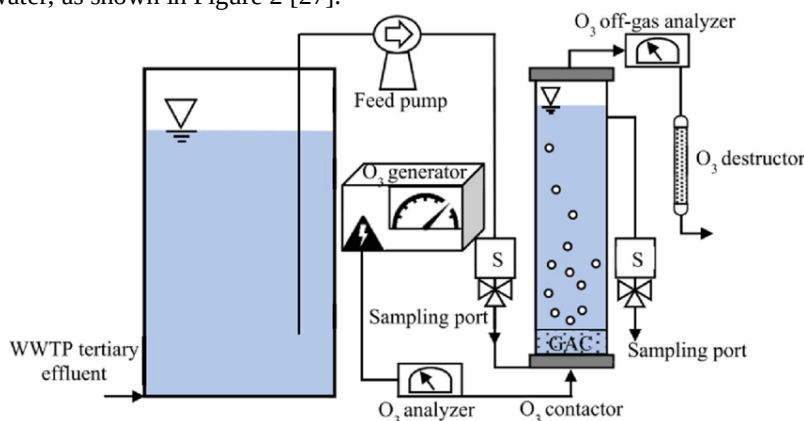


Figure 2: Water treatment by ozonation [27]

Ozone produced by corona discharge or UV radiation is introduced into the reactor with wastewater using a diffuser or turbine mixer. Better ozone treatment efficiency is achieved by optimizing process parameters such as temperature, pH value, and ozone dose [22]. Any remaining ozone that is not consumed in the process is destroyed using a thermal catalytic unit.

Ozone introduced into wastewater reduces the toxicity of textile dyes and enhances their biodegradability. By introducing ozone, the content of toxic substances in wastewater can be significantly reduced.

The advantages of ozonation include simplicity, elimination of conventional coagulation processes, removal of pesticides, organic compounds, reduction in BOD, COD, TOC, and organic load for secondary biological treatment.

Photocatalysis

Photocatalytic oxidation has a wide range of applications for degrading numerous organic and inorganic pollutants in wastewater.

The most widely adopted method for treating wastewater from textiles is the photocatalytic process, which offers the unique benefit of optical absorption not found in other Advanced Oxidation Processes (AOPs). Photocatalytic sensitization involves using a semiconductor as a catalyst to generate free radicals like $\text{OH}^\bullet$, which then oxidize organic compounds, converting them entirely into non-toxic substances such as CO_2 and H_2O through the absorption of photons. Figure 3 provides a schematic illustrating the basic mechanism of the photocatalytic oxidation process.

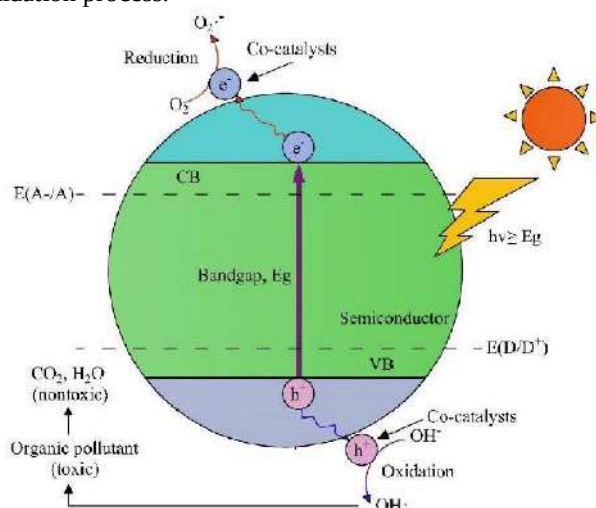


Figure 3: Scheme of the photocatalytic oxidation basic mechanism [28]

Many semiconductor oxides exhibit good photocatalytic activity. Among oxides with excellent photocatalytic activity, nano- TiO_2 stands out due to its advantages such as chemical and biological inertness, low cost, simple production and application, non-toxicity, and environmental acceptability. The photocatalytic properties of TiO_2 stem from the generation of photo-generated holes (h^+) and electrons (e^-) upon absorption of ultraviolet light matching its bandgap energy (E_{bg}). When the photocatalyst surface is irradiated with light energy equal to or greater than E_{bg} , electrons are excited from the valence to the conduction band, resulting in the formation of positive holes in the valence band. The produced electron-hole pairs (h^+e^-) can either recombine with heat release or migrate separately to the semiconductor surface where they can react with species adsorbed on the surface. Positive holes react with adsorbed water molecules, generating hydroxyl radicals ($\text{OH}^\bullet$). Holes and hydroxyl radicals oxidize organic molecules on the TiO_2 surface, while electrons reduce oxygen to form superoxide radical anions ($\text{O}_2^{\bullet-}$). When oxygen

reduction and pollutant oxidation processes do not occur simultaneously, electron accumulation in the conduction band leads to the recombination of electron-hole pairs, thereby reducing photocatalytic efficiency [29].

The most important elements for a successful photocatalytic system are the catalyst, light source, and reactor configuration. Since this process relies on light, the reactor or photocatalyst can be configured to utilize a readily available energy source, namely sunlight, to drive the reaction, thereby minimizing costs [30]. The type of radiation and placement of the light source in the reactor system are crucial for reactor design. In heterogeneous semiconductor photocatalysis, unlike traditional homogeneous processes, reactor design is more complex due to the presence of a solid photocatalyst. Photocatalysis is one of the most effective methods for dye removal, as well as reducing BOD and COD in wastewater from the textile industry.

3. CONCLUSION

In this paper, an integrated literature review of sustainable textile wastewater treatment methods and techniques has been presented. These innovative approaches aim to improve the purification process, ensuring that the treatment of wastewater from the textile industry meets the stringent standards required for environmental sustainability. By adopting these advanced methods, the textile industry can significantly reduce its environmental impact, contributing to the broader goal of viable water management. Additionally, policy frameworks and incentives are crucial to encourage the implementation of sustainable practices in textile wastewater management. The collective effort of industry stakeholders, researchers, and policymakers can continue driving the transformation towards a more sustainable and environmentally friendly textile industry.

ACKNOWLEDGMENTS

This research has been financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract No: 451-03-66/2024-03/200026, 451-03-66/2024-03/200023, and 451-03-65/2024-03/200131).

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STANDARDS OF SUSTAINABILITY IN THE FASHION INDUSTRY

Professional paper
DOI: 10.5937/CT_ITI24058M

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ABSTRACT: *The fashion industry represents an important segment of the world economy and employs over 75 million people worldwide. The fashion industry sector has seen spectacular growth over the past decades, and while the fashion sector is booming, increasing attention is being drawn to the impressive range of negative environmental impacts the industry is responsible for. The fashion industry accounts for 10% of total carbon emissions, drains water sources and pollutes rivers and streams. Over 85% of textiles end up in landfills each year (UNECE, 2018), and washing clothes sends a significant amount of microplastics into the oceans. Given the high impact of the fashion industry on the environment, fashion industry leaders have a great responsibility in developing their business models with integrated sustainable development goals, in order to reduce greenhouse gas emissions and water pollution. A transparent and sustainable fashion industry is a joint responsibility of producers and policy makers and can only be achieved through the cooperation of all stakeholders, including consumers. Harmonized standards and criteria are critical for a common understanding of sustainability globally and for increasing confidence in claims. In this regard, the global Kering Group manages the development of renowned fashion houses that produce clothing, leather goods and jewelry: Gucci, Saint Laurent, Bottega Veneta, Balenciaga, Alexander McQueen, Brioni, Boucheron, Pomellato, DoDo, Keelin, etc. promoting creativity in a sustainable and responsible way, coupled with economic performance. Through its very strict standards, the Kering Group shows its care about the impact of the fashion industry on the planet, on climate change and natural resources, and promotes pioneering ideas aimed at preserving natural resources and empowering future generations. This paper outlines the Kering Standard 2025 requirements for the raw material base for the fashion industry, which suppliers must meet in order to be compliant, as well as additional "best practices" that suppliers should work on in the coming years, all relating to Kering's sustainability principles.*

Keywords: *fashion industry, sustainability, Kering standards.*



STANDARDI ODRŽIVOSTI U MODNOJ INDUSTRIJI

APSTRAKT: Modna industrija predstavlja važan segment svetske ekonomije i zapošljava preko 75 miliona ljudi širom sveta. Sektor modne industrije je zabeležio spektakularan rast tokom proteklih decenija, i dok je modni sektor u procvatu, sve veća pažnja se skreće na impresivan spektar negativnih uticaja na životnu sredinu, za koje je industrija odgovorna. Modna industrija čini 10% ukupnih emisija ugljenika, isušuje izvore vode i zagađuje reke i potoke. Preko 85% tekstila svake godine završi na deponijama (UNECE, 2018), a pranje odeće šalje značajnu količinu mikroplastike u okeane. S obzirom na veliki uticaj modne industrije na životnu sredinu, lideri modne industrije imaju veliku odgovornost u razvoju svojih poslovnih modela sa integrisanim ciljevima održivog razvoja, kako bi smanjili emisiju gasova staklene bašte i zagađenje vode. Transparentna i održiva modna industrija je zajednička odgovornost proizvođača i kreatora politike i može se postići samo kroz saradnju svih zainteresovanih strana, uključujući i potrošače. Harmonizovani standardi i kriterijumi su kritični za zajedničko razumevanje održivosti na globalnom nivou i za povećanje poverenja u potraživanja. U vezi sa tim, globalna Kering Grupa upravlja razvojem renomiranih modnih kuća koje se bave proizvodnjom odeće, kožne galanterije i nakita: Gucci, Saint Laurent, Bottega Veneta, Balenciaga, Aleksander McKueen, Brioni, Boucheron, Pomellato, DoDo, Keelin i sl. tako da promoviše kreativnost na održiv i odgovoran način sa ekonomskim učinkom. Kering grupa preko svojih veoma strogih standarda brine o uticaju modne industrije na planetu, na klimatske promene i prirodne resurse i promoviše pionirske ideje usmerene na očuvanje prirodnih resursa i osnaživanje budućih generacija. U ovom radu prikazani su zahtevi Kering standarda za 2025. godinu za sirovinску bazu za modnu industriju, koje dobavljači moraju da ispune kako bi bili usaglašeni, kao i dodatne „najbolje prakse“ na kojima bi dobavljači trebalo da rade u narednim godinama a sve u vezi sa Keringovim principima održivosti.

Ključne reči: modna industrija, održivost, Kering standardi.

1. INTRODUCTION

The topic of sustainability in the textile industry is very complex. The textile industry is undergoing significant changes under the influence of technological advances, consumer demands, sustainability, the circular economy and global events such as the recent pandemic. Digitization, green production and circular economy are the most important trends in the evolution of the textile industry today. These improvements not only increase operational efficiency and productivity, but also drive sustainability, transparency and customer centricity.

Sustainability has become ingrained in all sectors of the creative industry today, including the fashion industry. Sustainability in fashion is a growing design philosophy and a prevailing trend, with a mission to reduce the carbon and water footprint of the world's second largest economy [1, 2].



Orientation towards ecologically conscious production of textiles and clothing is growing intensively and is encouraged by increasingly obvious signs of climate change. Environmentally conscious generations show an increasing interest in ecologically produced textiles and clothing. After almost three decades of dedicated efforts, the fashion industry has successfully moved closer to the goal of operating within a sustainable, ethical and transparent framework. The sustainable circular economy trend emphasizes efficiency, recycling and waste minimization in fashion supply chains. Transparency, supply chain traceability and ethical sourcing have led to increased scrutiny of supply chains and the introduction of certifications and standards to verify sustainable practices.

In the 21st century, sustainable fashion has gained momentum through various initiatives. The establishment of certification systems and standards have helped consumers identify and support sustainable products. Collaborations between fashion brands, NGOs and governments of many countries have further strengthened sustainable practices, promoting responsible sourcing, reducing carbon and water footprints and supporting the welfare of workers employed in the fashion industry [3, 4].

2. KERING STANDARDS AND REQUIREMENTS FOR THE YEAR 2025.

The global Kering Group manages the development of renowned fashion houses involved in the production of clothing, leather goods and jewelry, and sets very strict standards of sustainability in the fashion industry. Kering standards support innovative raw material sourcing approaches and advanced technological solutions for its supply chains, both for natural and synthesized materials. The Kering Group has a vision of high standards and best practices and encourages a collaborative approach in supply chains, in order to create frameworks for sustainable actions and achieve multiple benefits. Also, the Kering Group prioritizes natural raw materials produced in regenerative agricultural systems, which can bring various social and economic benefits, with clearly defined and evaluated outcomes [5]. Given the fact that renowned brands (Gucci, Saint Laurent, Bottega Veneta, Balenciaga, Alexander McQueen, Brioni, Boucheron, Pomellato, DoDo, Keelin, etc.) use luxurious textile materials made of precious fibers such as cashmere, silk, wool, cotton, as well as synthetic fiber materials, the Kering Group has defined sustainability and green economy requirements for this raw material base.

CASHMERE is the precious fiber of the cashmere goat and 75% of global cashmere production takes place in China. Cashmere production leads to pasture degradation and biodiversity loss. Kering's standards set strict requirements to protect biodiversity, society and animal welfare, while emphasizing transparency and traceability in the supply chain and encouraging the use of a certain level of recycled content. The recycled content can come from fibers that have or haven't been used, or a combination of both types. Where possible, Kering recommends the use of waste raw materials after use, thereby reducing the demand for primary raw materials, which is associated with environmental and social impacts. GRS certification (Global Recycled Standard) is required for recycled cashmere, and as an additional requirement, the recycled content should be at least 20%, with an aspiration to reach 50%.



The production of cashmere materials can have a significant impact on the environment due to the consumption of water, energy and chemicals, so it is necessary to ensure adequate monitoring of the impact on the environment and ensure processing conditions with reduced impacts. Also, it is necessary to ensure that processing conditions comply with the Kering Manufacturing Restricted Substances List (MRSL) and the Kering Luxury Product Restricted Substances List (PRSL) [5, 6].

WOOL is produced in agricultural systems in over 100 countries around the world, but the best quality and largest amount of wool fiber comes from Australia, New Zealand, South America and South Africa. Wool production can be considered more or less sustainable, depending on the impact of farming systems and animal welfare issues, which vary significantly from country to country.

Factors that contribute to the environmental impact of an agricultural system include the conversion of land from natural ecosystems to sheep pastures, pasture degradation, and chemical treatment of pastures and sheep. Sheep farming increasingly relies on chemical inputs (e.g. petroleum-based fertilizers) for pasture maintenance. In addition, in some areas, wool growers also rely heavily on the application of chemical substances to control sheep pests (lice). Most of the chemicals used to treat external parasites bind with the fat of the wool, not the fibers themselves, and are removed during the washing of the wool, resulting in a large amount of waste water pollution. Natural grasslands are degraded by overgrazing, so the issue of conversion of natural ecosystems is still a concern.

Kering's standards for wool are based on compliance with national and international laws and regulations that specifically relate to human rights, fundamental freedoms, health and safety at work and the environment, on the production of wool materials with maximum environmental sustainability, i.e. supporting the production of wool that does not degrade natural ecosystems, but restores and protects soil, plants and wildlife, on wool production with limited use of toxic chemicals, on ensuring high standards of animal welfare and on efficient and responsible water use at farm and wool processing levels. All this can be achieved by applying the Responsible Wool Standard (RWS).

The Kering Group supports the use of materials with recycled wool content, with a regenerative source. Both options (regenerative and recycled wool) are aligned with Kering standards. Recycled content can be pre- or post-consumer or a combination of both, reducing the demand for virgin wool and the associated environmental and social impacts. When using recycled content in a product, the content of recycled material should be at least 20%, with a recommendation that this amount preferably reaches 50%; GRS certification is required for the recycled wool as well.

SILK is a luxurious fiber and thanks to its properties related to softness, comfort and tensile strength, it is widely used all over the world. It is produced in over 30 countries of the world, and the largest producers are China, India and Japan. However, in silk production there are important sustainability issues to consider, including, above all, water consumption, chemical use, energy use, the way land is treated and the impact on natural ecosystems and, importantly, the living conditions of silk farmers. These are all issues in the silk supply chain that Kering is focused on and committed to ensuring best practices through the Kering Silk Standard. Kering supports the use of materials with recycled



VII International scientific conference
„*Contemporary trends and innovations in the textile industry*“
19-20th September, 2024, Belgrade, Serbia

content for silk, in addition to organic silk sources. Both options (organic and recycled silk) comply with Kering standards. Recycled content can be pre- or post-consumer silk or a combination of both. Where possible, Kering recommends the use of post-consumer waste materials, thereby reducing the demand for virgin silk and the associated environmental and social impacts. Where recycled content is used, the recycled content should be at least 20%, with a tendency for this content to be 50%; GRS certification is also required for recycled silk. Also, compliance with all national and local recycled silk laws is insisted upon.

COTTON is an important raw material for Kering brand products. Cotton represents about 22% of global fiber demand. Most of the cotton grown in the world is grown with the use of huge amounts of pesticides and fertilizers. These chemicals have a major impact on the environment and human health, and huge amounts of water are used to grow cotton. In addition, cotton supply chains present significant ethical challenges with examples of forced labor and child labor in cotton cultivation. Very little of cotton production is truly sustainable. For example, it is estimated that only 1.4% of the world's cotton production is organic cotton, and an even smaller percentage is regenerated cotton. Examples of sustainably produced cotton include regenerative or organic production, where cultivation is done without synthetic chemicals, where water use is reduced, soil health is restored, and social/working conditions are well managed. Kering also places the highest level of importance on supporting the wider adoption of regenerative practices in cotton production, primarily to protect and restore biodiversity, to build measurable improvements in soil health, measured through the soil's capacity to retain water and soil carbon content, which can be improved by maintaining the vegetative cover throughout the year on all cultivated lands. Social and environmental aspects drive Kering's strong commitment to use only traceable and sustainably grown cotton in its supply chains and drive the transition to regenerative cotton production.

Kering supports the use of materials with recycled content for cotton, along with organic and renewable sources. All three options (organic, regenerative and recycled) are aligned with Kering standards. Recycled content can be pre-consumer or post-consumer cotton, or a combination of both. Where possible, Kering recommends the use of post-consumer waste materials. This enables the reduction of demand for primary cotton and thus the reduction of accompanying environmental and social impacts. When using recycled content in a product, the content of recycled material should be at least 20%, with the aim of reaching 50%, and GRS certification is required for the recycled cotton. Cotton recycling should comply with all national and local recycled cotton laws.

SYNTHETIC FIBERS are expanding and currently account for about 64% of all fiber consumption in the world, of which 54% are polyester fibers.

There are several sustainability issues associated with conventional synthetic fibers, including the use of fossil fuels as the primary raw material for their production (a non-renewable resource), the amount of carbon emissions released during production, as well as the use of chemicals, energy and water. Synthesized fibers are not degradable and contribute to the creation of large amounts of microplastics, which represent a serious environmental pollutant [7, 8].



Recognizing these issues, Kering's Standard for Synthetic Materials supports the use of recycled synthetic fibers as well as bio-derived raw materials to avoid dependence on fossil fuel sourced raw materials. Recycled materials include pre- and post-consumer waste, and synthetic fibers derived from biological sources include those derived from sugars, starches and lipids, which are becoming increasingly available and are indistinguishable from conventional synthetic fibers from a performance perspective.

Kering prioritizes the use of materials with recycled content. Suppliers should provide recycled versus conventional fossil fuel-based synthesized materials with the highest possible recycled content, aiming for 100%. Also, synthesized materials with recycled content are preferred over synthesized materials with bio-based content. It is necessary to choose synthesized materials that can be recycled and Kering standards recommend fiber to fiber recycling. As another option, the use of materials with bio-based content is preferred. Suppliers should procure synthesized materials with the highest possible bio-based content (at least 30%) instead of that coming from conventional fossil materials.

Synthesized biomaterials on the market today often consist of a mixture of fossil fuels and biomaterials [9]. When procuring such materials, suppliers should request maximum non-fossil fuel content in textile materials and inquire about the origin of the raw material that goes into the production of the biological component of the synthesized material (crops, organic waste, proteins, etc.). The second or third generation of synthesized materials is recommended, for which the raw material is not a food source, but inedible plant parts – resources from forestry, proteins from discarded sources, biomass obtained from algae, fungi and bacteria, etc. and it is necessary to collect all information from the supplier about the bio-content used. Kering standards do not support resources that come from genetically modified organisms (GMO). An official method should be used to determine the biocontent, e.g. ASTM D8666 or EN 16785-1.

Regarding recycled and bio-based materials, all suppliers are required to source synthesized materials only from sources with appropriate certifications (Biobased, OK Biobased). Also, Kering does not accept synthesized materials produced from fossil sources from conflict-affected regions. It is necessary to ensure that no procurement activity is linked to deforestation or conversion of natural ecosystems, as Kering has committed not to procure raw materials in its supply chains that are linked to deforestation or land conversion. When it comes to biosynthesized fibers, this applies to all natural raw materials used and compliance for these raw materials can be ensured through appropriate certifications (Roundtable on Sustainable Biomaterials, International Sustainability and Carbon Certification (ISCC+), Forest Stewardship Council (FSC) for raw materials obtained from forests).

The use of modacrylic fibers is prohibited in Kering products. Modacrylic polymers are copolymers obtained by the reaction of acrylonitrile (at least 50%) and halogen comonomers (polyvinyl chloride or polyvinylidene chloride). Due to the use of these comonomers, modacrylic poses a potential environmental and health hazard, mainly at the end of its life. In addition to the carcinogenic risk to workers, if comonomers are not handled carefully during the manufacturing process, modacryl poses a threat for pyrolytic behavior during disposal through incineration, when dioxins are emitted. Thermal



processes (such as pyrolysis) or chemical recycling of these materials do not allow extraction of the basic chemical components like other polymers. Consequently, modacrylic cannot be mechanically recycled. Kering aims to phase out modacrylic from its collections and products by 2025.

In the production process of synthesized materials, Kering advocates a closed chemical management system, which implies the use of chemicals in accordance with the MRSL, especially when it comes to aromatic and aliphatic volatile organic substances (VOCs), azo dyes, ortho-phthalates, polycyclic aromatic hydrocarbon (PAH), heavy metals, flame retardants, alkylphenols [10]. It is recommended to prevent and reduce chemical emissions into the air, reduce water consumption, minimize chemical impacts and gradually abolish and eliminate hazardous waste. Kering standards do not recommend the use of materials from recycled PET bottles [6, 11].

3. CONCLUSION

The world of sustainable fashion innovation is new and rapidly evolving. Sustainability, by its very nature, is a process of continuous improvement. Consumers around the world are increasingly looking for products and services with less impact on the environment and society. This interest has led to an increased demand for "green" products and services.

In response to this demand, companies have increased their offerings of "green" products and services; however, misleading environmental claims have also increased, which can affect corporate and brand reputation.

The Kering Group encourages its brands to transparently and appropriately communicate their sustainability efforts and results, with statements supported by data when possible. Applying these principles and definitions as a benchmark, Kering's sustainability claims are designed to support its brands and avoid any risk of potential green product claims that cannot be backed up by facts. The Kering Sustainability Claims Guidelines are aimed at brands, suppliers, retailers and consumers and apply to claims made about products sold in-store or via e-commerce. Kering standards support new technologies and solutions for material processing and production, as well as new materials that can supplement or replace the existing, traditional materials [3, 5, 6].

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GREENWASHING AS A MARKETING STRATEGY IN THE FASHION INDUSTRY

Review scientific paper
DOI: 10.5937/CT_ITI24059S

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ABSTRACT: This paper summarizes the concept of greenwashing, a marketing strategy companies use to make false or exaggerated environmental claims about their products and attract consumers interested in the sustainability of the products they buy. Greenwashing has become more common as consumers have become more environmentally conscious, so companies are trying to capitalize on this trend. However, greenwashing can have negative effects on both consumers and the environment, as it can lead to confusion and mistrust among consumers and encourage the production and consumption of products that are not sustainable. As such, it is important for consumers to be aware of greenwashing and to look for evidence to support companies' environmental claims. Additionally, companies can take steps to be more transparent and honest in their ecological claims, build consumer trust, and promote truly sustainable practices.

Keywords: greenwashing, eco-fashion, fashion, sustainability, ecology, marketing.

GREENWASHING KAO MARKETING STRATEGIJA U MODNOJ INDUSTRIJI

APSTRAKT: Ovaj rad rezimira koncept greenwashinga, marketinške strategije koju kompanije koriste kako bi dale pogrešne ili preuveličane ekološke tvrdnje o svojim proizvodima i kako bi privukle potrošače koji su zainteresovani za održivost proizvoda koje kupuju. Greenwashing (zeleno -eko pranje) je postalo sve češće od kako su potrošači postali ekološki svesniji stoga kompanije nastoje da iskoriste ovaj trend. Međutim, zeleno pranje može imati negativne efekte i na potrošače i na životnu sredinu, jer može dovesti do konfuzije i nepoverenja među potrošačima i podstaći proizvodnju i potrošnju proizvoda koji zapravo nisu održivi. Kao takav, važno je da potrošači budu svesni zelenog pranja i da traže dokaze koji podržavaju ekološke tvrdnje kompanija. Pored toga, kompanije mogu preduzeti korake kako bi bile transparentnije i poštenije u svojim ekološkim zahtevima i kako bi izgradile poverenje kod potrošača i promovisale istinski održive prakse.



Ključne reči: *greenwashing, eko moda, moda, održivost, ekologija, marketing.*

1. INTRODUCTION

The fashion industry is under increasing scrutiny for its negative impact on the environment and workers' rights. While some companies have taken steps to address these issues, others have engaged in a practice known as "greenwashing," where they make false or misleading claims about their products' environmental or ethical benefits [1]. This paper will explore greenwashing in the fashion industry, including its definition, examples, and reasons for its persistence.

"Greenwashing," "fake green marketing," or "eco-manipulation" are terms that refer to the act of making exaggerated or false claims about the environmental benefits of a product or service [2]. In the fashion industry, greenwashing often takes the form of false claims about product sustainability or the ethical treatment of workers [3]. For example, a company may claim that its clothing is made from organic cotton when, in reality, only a small percentage of the clothing is made from organic materials. Another common example of greenwashing in the fashion industry is using vague terms, such as "eco-friendly" or "sustainable," which give consumers a false impression of the product's environmental impact.

The persistence of greenwashing in the fashion industry is a pressing issue with significant implications. One key factor is the lack of consumer awareness about environmental and ethical issues, which makes it easier for companies to make false claims [4]. Moreover, the absence of stringent regulations that force companies to meet their environmental or ethical obligations exacerbates the problem. Even when regulations are in place, they are often challenging to enforce. Furthermore, many companies see greenwashing as a profitable strategy, capitalizing on consumers' growing interest in environmentally and socially responsible products, even if their claims are baseless [4].

After all, greenwashing is a major problem in the fashion industry, where companies make false or misleading claims about the environmental or ethical benefits of their products and thereby cause consumers to suffer significant losses, especially financial ones [5]. While greenwashing persists for several reasons, consumers must be informed and vigilant to hold companies accountable for their claims [6]. Consumers who are highly involved in environmental protection are likely to base their opinions about the advertised product on arguments rather than emotional aspects, while consumers who are less engaged in the environment are likely to rely on emotions and feelings to form their opinions [7]. In addition, governments and industry organizations should work together to create regulations that prevent greenwashing and ensure that companies are transparent about the environmental and ethical impacts of their products [8]. Doing so can help build a more sustainable and ethical fashion industry that benefits consumers and the planet.

However, greenwashing is widespread in the fashion industry, and consumers must know how companies can mislead them. When shopping for clothing, it's important to look for products with third-party certifications, such as Global Organic Textile Standard (GOTS) or Fair Trade Certified, which assure that the product was produced in an environmentally and socially responsible manner [9]. In addition, consumers can research the sustainability



practices of specific companies, such as using environmentally friendly materials, labor practices, and carbon footprint, to understand their impact on the environment better.

2. DIFFERENCES BETWEEN ECO FASHION, SUSTAINABLE FASHION, SLOW FASHION, AND GREENWASHING

In general, it is important for consumers to be informed and discerning and to support companies that have demonstrated a commitment to sustainability and ethical practices. This, in turn, will encourage more companies to adopt sustainable practices and reduce the prevalence of greenwashing in the fashion industry.

"Eco-fashion" refers to clothing and fashion accessories made environmentally sustainable, using materials and production methods that minimize their environmental impact [10]. Eco-fashion may also consider social and ethical factors, such as fair labor practices when producing its products. The goal of eco-fashion is to create clothing that is both fashionable and sustainable, and that addresses the environmental and social impacts of the fashion industry [11].

"Sustainable fashion" refers to the design, production, retailing, and disposal of clothing, footwear, and accessories in a manner that minimizes negative impact on the environment and maximizes social responsibility [10]. This includes considering factors such as using environmentally friendly materials, reducing waste, improving working conditions for those in the supply chain, and ensuring that products can be reused, repaired, or recycled at the end of their life.

Sustainable fashion takes a holistic approach and considers the entire life cycle of a product, from the procurement of raw materials to the disposal of the final product. It recognizes the environmental and social challenges facing the fashion industry, such as water pollution, climate change, and labor exploitation, and seeks to address these challenges through innovative and responsible practices.

Sustainable fashion aims to create a more responsible, ethical, and environmentally friendly fashion industry and provide consumers with fashionable and sustainable clothing. Slow and sustainable fashion are concepts often used interchangeably, but important differences exist.

"Slow fashion" refers to a movement that prioritizes quality over quantity and encourages consumers to buy smaller, better-made clothes that should last for many years. The focus is on slowing down the fast-paced, trend-driven fashion cycle and, instead, on producing and consuming clothing more mindfully and sustainably [12]. The production process is slower and often involves traditional hand-crafting techniques and methods, resulting in garments with a higher level of craftsmanship and attention to detail.

On the other hand, sustainable fashion encompasses a much wider range of practices and issues, including environmental sustainability, social responsibility, and ethical production. It aims to reduce the fashion industry's negative impact on the environment, such as water pollution, greenhouse gas emissions, and waste, and improve the working conditions of those involved in the supply chain. This often involves using environmentally friendly materials, such as organic cotton, recycled polyester, and biodegradable materials, and reducing waste through circular business models, such as clothing rentals and repair services [13].



While slow and sustainable fashion share some common goals and values, sustainable fashion is a more comprehensive approach encompassing a wider range of issues and considerations. Slow fashion is an important aspect of sustainable fashion, but it's only one piece of a bigger puzzle. Both concepts offer valuable solutions to the fashion industry and enable consumers to make more responsible and environmentally friendly choices regarding their clothing.

In short, the key difference between eco-fashion and green fashion is that eco-fashion is sustainable and socially responsible, while green wash fashion is only advertised as such. "Greenwashing fashion," on the other hand, refers to clothing and accessories that are advertised as environmentally sustainable or socially responsible but actually do not meet these standards. Consumers can help reduce the prevalence of green fashion by supporting eco-fashion and being informed and discerning about the environmental and social impact of the products they purchase.

3. EXAMPLES OF GREENWASHING IN MARKETING

Here are some common examples of greenwashing in marketing [14]:

- Vague or meaningless terms: Using terms such as "eco-friendly" or "sustainable" without any clear definition or certification to support these claims.
 - Hidden compromises: Making an environmental claim for a product but neglecting to mention other aspects of the product's production or use that harm the environment.
 - Lesser of two evils: Emphasizing the product's environmental benefits but neglecting that the product still significantly impacts the environment.
 - Misrepresentation: Making false or exaggerated claims about the environmental benefits of a product.
 - Eco-washing of a small fraction: The claim that the product is environmentally friendly, but only a small part meets this standard.
 - Irrelevant claims: Making an environmental claim not directly related to the product, such as using recycled packaging paper, but ignoring the product's environmental impact.
 - Misdirection: Emphasizing environmental benefits but neglecting to mention the product's other, more important, ecological impacts.
- Lack of transparency: Companies can make environmental claims without providing information or supporting evidence, making it difficult for consumers to assess a product's environmental impact.



Figure 1: Research conducted by the Terrascope team on different forms of greenwashing [15]

Consumers should look for products with third-party certifications, such as the Global Organic Textile Standard (GOTS) or Fair Trade Certified, ensuring that the product is environmentally and socially responsible.

Greenwashing is a global problem that affects many countries. According to advertising firm Ogilvy and Mather, greenwashing has grown in the past decade to epidemic proportions [16]. The effects of greenwashing can be seen in countries with weak laws and countries with strong regulations and rules, where companies may seek to exploit loopholes or avoid liability [17].

However, some countries and regions are particularly vulnerable to the effects of greenwashing due to weak environmental regulations, limited consumer awareness, and lack of access to reliable information. For example, developing countries with rapidly growing economies like China and India may be more susceptible to greenwashing. They may need more regulatory and institutional frameworks to ensure companies are accountable for their environmental impact [18]. In addition, countries that rely heavily on extractive industries, such as mining and logging, may also be particularly vulnerable to ecological leaching, as companies in these industries may seek to offset their environmental impact by making false or misleading claims about their sustainability practices.

For example, a brand might release a limited edition of clothing with an empowerment message but take no concrete steps to address issues such as underpayment or exploitation of workers in their supply chain. Critics argue that this "waddling" in fashion can lead to tokenism or the appropriation of cultural symbols and dilute the impact of genuine activism

and activism in the fashion world. Consumers are becoming more aware of these practices and demanding greater accountability and transparency from fashion brands in their actions, not just words [19].

Several fashion companies aim to be environmentally conscious, "eco-conscious," or "sustainable." Some examples include:

- Patagonia (Patagonia) [20]: Known for its commitment to environmental activism and sustainability, Patagonia uses environmentally friendly materials and manufacturing processes and supports ecological causes through its activism program and grants.

- Everlane (Everlane) [21]: This brand is focused on transparency and sustainability, using sustainable materials such as organic cotton and Tencel lyocell and disclosing their carbon footprint and factory location.

Stella McCartney (Stella McCartney) [22]: Stella McCartney is a pioneer in sustainable fashion, using innovative materials such as vegan leather, organic cotton, and recycled polyester. It also promotes environmentally responsible practices in its supply chain.

- Allbirds (Allbirds) [23]: Allbirds use environmentally friendly materials, such as recycled plastic bottles and eucalyptus trees.

These are just a few examples of the many companies in the fashion industry making efforts to be environmentally conscious. Consumers can support these companies by choosing to buy from them and seeking information about the environmental and social practices of the brands they buy from.

4. EXAMPLES OF GREENWASHING IN FASHION, CASE STUDY H&M

Fast fashion brands H&M, Zara, and Uniqlo are among the companies that have been linked to greenwashing over the years. [24] These fashion brands contribute to huge amounts of textile waste caused by clothing. According to fashion nonprofit ReMake, 80% of discarded textiles globally are incinerated or landfilled, and only 20% are reused or recycled [25].

Fast fashion brands also habitually tout their green initiatives widely despite it being a small part of their business. For example, in 2019, H&M launched its eco-friendly clothing line called "Conscious." The company claims to use organic cotton and recycled polyester. However, this line is a marketing tactic to make themselves appear more environmentally friendly. When looking at H&M's "Conscious" line, its mission statement says: "Shop our selection of sustainable fashion pieces that make you both look and feel good" [25]. However, there is no single legal definition for marketing words such as "sustainable," "green," or "environmentally friendly." H&M was then criticized by the Norwegian Consumer Authority for misleading marketing of their Conscious Collection because "the information provided regarding sustainability was not sufficient, especially considering that the Conscious Collection is advertised as a collection with environmental benefits" [25].



Figure 2: Conscious Collection, a fake environmentally conscious collection of the fashion house H&M [30]

The greenwashing lawsuit against H&M highlights how the brand misled the public with false sustainability marketing. This investigation was conducted by the news outlet Quartz regarding its sustainable practices [26].

An investigation by the news outlet "Quartz" [28] revealed the company's untrue claims that most of its clothes are better for the environment, thanks to sustainable practices. This world-leading clothing company produces around five billion garments annually. According to the fashion label, its products are made from 50% or more sustainable materials [27].

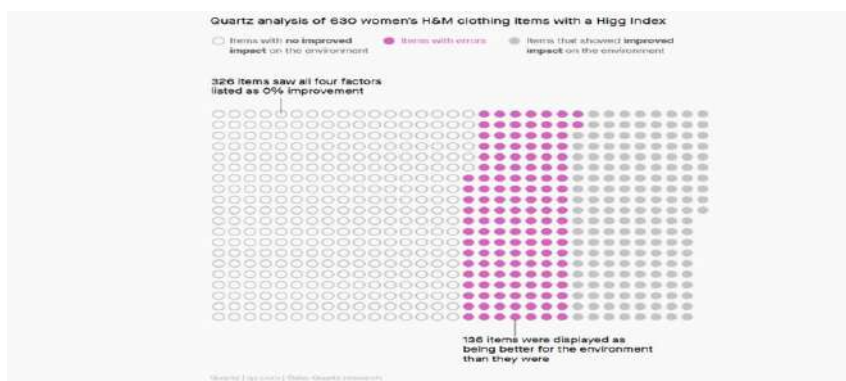


Figure 3: The Higue Index is a tool designed to assess the environmental impact of a product throughout its life cycle, from design to disposal. A Quartz investigation found that H&M's self-reported Higg Index scores were often inaccurate [28]

The greenwashing lawsuit cites examples of H&M misleading customers with false advertising. For instance, one sustainability profile sold by H&M "claims the dress is made with 20% less water on average," when an independent investigation by news outlet Quartz found that the dress "was made with 20% more water [27]. The plaintiff claims that the

Swedish company failed to comply with environmental standards and that its products were more environmentally harmful than others.

It is further said that the fashion house tapped into the sentiment of environmentally conscious customers willing to pay more for sustainable products.

The H&M lawsuit also reveals that the company blatantly lied about its Conscious Choice label, which is said to contain "at least 50% sustainable materials, such as organic cotton and recycled polyester" [29]. In reality, the products consist of undeniably unsustainable materials, such as polyester, which are not sustainable because polyester does not decompose, sheds toxic microfibers, and cannot be recycled [30].



Figure 4: the label of the company H&M, through which an eco-friendly product is suggested to consumers. Conscious Choice [30]

Similar practices of deceiving customers through greenwashing have been discovered by other global fashion brands, such as Zara and Adidas [31], according to the environmental organization Earth.Org. Also, green brand initiatives are increasingly the focus of marketing campaigns. They advertise a lot, but it is only a small part of their business, which is irrelevant to the nature around us. Fortunately, customers are undoubtedly becoming more aware of the negative environmental impacts of the clothing industry and are opting for sustainable brands and products. Thus, more and more customers are discovering the dubious motives behind sustainable marketing.

Platforms that address the problem of greenwashing in Serbia and beyond can be found most easily on Instagram. Those are platforms for discussing sustainability, "The FFM platform," "re. Gekko," which encourages discussion about the consequences of the textile industry, or "Mašina," which deals with social criticism and discusses the position of textile workers and the harmful effects of fashion on the environment.

5. CONCLUSION

After all, greenwashing is a marketing strategy that can significantly affect both customers and the environment. On the one hand, it can lead customers to believe they are making environmentally conscious choices when, in fact, they are not. This can result in a lack of



trust in companies and confusion among consumers about which products are truly environmentally friendly. On the other hand, these eco-manipulations can also have negative effects on the environment itself because they can encourage the production and consumption of products that are not sustainable.

Overall, companies must be transparent and honest in their environmental claims to build trust with customers and ensure that their products positively impact the environment [32]. In addition, consumers can take steps to educate themselves about eco-washing and seek certifications and verifications from reputable organizations to ensure that the products they are purchasing are truly eco-friendly. By working together, we can fight greenwashing and make informed decisions that benefit us and the environment.

However, there are steps consumers, organizations, and governments can take to combat greenwashing and promote sustainable and responsible practices. Consumers can learn about the environmental impact of the products they buy and support companies that have demonstrated a commitment to sustainability and ethical practices. Organizations can work to develop and implement standards and certifications that ensure environmental claims are credible and transparent. Governments can strengthen environmental regulations and enforcement and provide consumers with access to reliable information about the environmental impact of products [33].

By taking these steps, we can help reduce the prevalence of greenwashing and create a more sustainable and just world for current and future generations. We must be informed, vigilant, and persistent in our efforts to combat greenwashing and promote sustainability to create a world that is not only greener but fairer for all.

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ENVIRONMENTAL ISSUE OF SUSTAINABLE TEXTILE INDUSTRY – EXAMPLES OF GOOD MANUFACTURING PRACTICES

Professional paper
DOI: 10.5937/CT_ITI24060Z

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ABSTRACT: Growing impact on the environment and the rising demand for water, energy and raw materials that has resulted from the worldwide expansion of industry, put the principles of sustainability and cleaner production in a front line, as emergent activity. The textile industry consumes a high amount of energy and generates an enormous quantity of wastewater - worldwide, it generates 20 % of industrial wastewater and 8 % of greenhouse gas (GHG), while cotton production uses large amounts of pesticides, water and fertilizers. Many aspects of sustainable textile industry are not related only to production process itself (product quality and its market price, production process, supply of raw materials and its costs), but also to nus products, energy and water consumption, equipment service time, occupational health, and environmental issue. Thus, successful companies in textile production are driven by the basic principles of sustainable development and implementation of good manufacturing practice and cleaner production principles. This paper presents main principles of environmental protection in textile industry to be adopted toward sustainable production; these principles consider minimization of water, energy, virgin raw materials and chemicals usage, which results in reduction of the CO₂ emissions, toward climate neutral production and business. Described company increases the share of sustainable/renewable materials and recycled materials, by accomplishing its own sustainability goals concerning environmental issue.

Keywords: Textile industry, sustainability, CO₂ emission reduction, renewable materials, circularity, waste minimization.

EKOLOŠKI ASPEKT ODRŽIVOSTI U TEKSTILNOJ INDUSTRIJI – PRIMERI DOBRE PROIZVOĐAČKE PRAKSE



APSTRAKT: Sve veći uticaj na životnu sredinu i rastuće potrebe za vodom, energijom i sirovinama, koje su posledica rasta industrijske proizvodnje na globalnom nivou, stavljaju principe održivosti i čistije proizvodnje u prvi plan, kao aktivnosti od izuzetnog značaja. Tekstilna industrija troši veliku količinu energije i stvara ogromnu količinu otpadnih voda – procenjuje se da na globalnom nivou proizvodi 20 % industrijskih otpadnih voda i 8 % gasova staklene bašte (GHG), a proizvodnja pamuka je značajan potrošač pesticide, vode i đubriva. Mnogi aspekti održive tekstilne industrije nisu vezani isključivo za sam proizvodni proces (kvalitet proizvoda i njegova tržišna cena, proizvodni proces, nabavka sirovina i troškovi proizvodnje), već i za nus proizvode, potrošnju energije i vode, servisiranje opreme, zaštitu na radu i pitanje očuvanja životne sredine. Uspešna preduzeća u tekstilnoj industriji su vođena osnovnim principima održivog razvoja i implementacijom dobre proizvođačke prakse i principa čistije proizvodnje. Ovaj rad predstavlja glavne principe zaštite životne sredine u tekstilnoj industriji koje treba usvojiti u pravcu održive proizvodnje; ovi principi razmatraju minimiziranje upotrebe vode, energije, sirovina i hemikalija, što rezultira smanjenjem emisije CO₂, prema klimatski neutralnoj proizvodnji i poslovanju. Opisana tekstilna kompanija povećava udeo održivih/obnovljivih i recikliranih materijala, ostvarivanjem sopstvenih ciljeva održivosti koji se tiču pitanja životne sredine.

Ključne reči: Tekstilna industrija, održivost, smanjenje emisije CO₂, obnovljivi materijali, cirkularnost, minimizacija otpada.

1. INTRODUCTION

One of the most used definitions of sustainable production is the one that defines it as a production of goods and services in a manner that is socially beneficial, economically viable and environmentally benign over whole life cycle [1]. In entrepreneurial points of view, environmental sustainability is a business strategy for using processes without generating harmful effects to the environment and natural resources throughout the life cycle (e.g., consisting of collection, processing, application, replenishment, consumption, and disposal) of natural resources [2-4]. Besides the high quality of final product and its competitiveness at market, the aim of sustainable textile production is also to ensure conservation of resources and preserve the regenerative capacity of the environment, as well as to obtain social benefits for employees and associated companies [5]. In practice, sustainable production is based on optimized balance between inputs (raw materials, water, energy, human resources etc.) and production outputs (main products, nus-products, and effluents) [5]. Sustainable production integrates ecological, social, and economic aspects, leading management to invest in cleaner production, human well-being, and effective resource usage. This approach presents a long-term profitable strategy that saves resources, reduces production costs, and lowers the final product's price, all without compromising quality.

This paper presents one successful international fashion/textile company, as an example of good manufacturing practice, especially concerning environmental issue of sustainable textile production – minimization of emissions to water, air and soil, economic usage of



resources, waste management (3R principle), energy efficiency, and all of them in accordance with local legal regulations. The special part in sustainable production of textile garments presents the evaluation of positive impact of sustainability goals and the circular economy principles – recycling textile material and waste reuse, as well as minimizing generation of solid waste and its characterization if needed. This company promotes new and efficient technologies for waste recycling and decarbonization - reduction of greenhouse gasses (GHGs) emissions.

2. ENVIRONMENTAL ISSUE OF SUSTAINABILITY IN THE TEXTILE INDUSTRY

The textile industry uses a large amount of energy and generates a huge quantity of waste water. Worldwide, it is estimated to produce 8% of GHG emissions and 20% of industrial wastewater. Additionally, cotton production demands great amounts of pesticides, water and fertilizers. Microfibers released from synthetic textiles during production, use, and disposal enter surface water, further polluting already heavily stressed ecosystems. The textile industry is also intensive user of chemicals (it is estimated that 1 kg of textiles requires almost half a kilogram of chemicals on average), which presents another environmental time bomb, because a large part of these chemicals ends up in the effluent of the processing plants. The impact of textile industry on the environment can be eliminated or strongly reduced by [6]:

- decreasing the amount of chemicals used (e.g. by getting a higher percentage of a dye to stay on the fabric);
- substituting hazardous chemicals by less harmful and
- using better abatement techniques (e.g. water treatment facilities).

The environmental impact of the textile industry extends beyond hazardous chemicals to include chemicals widely used in the industry that are not classified as hazardous to humans. For example, starch, one of the highest volume chemicals used in the textile industry, is not hazardous but can cause environmental harm if released untreated into surface water bodies (rivers, lakes, etc.). In such cases, algae thrive while most other aquatic life suffers from oxygen depletion. Emissions to air and energy consumption are also significant concerns. The textile industry uses stenters – long ovens where surface treatments are cured and solvents are driven out – primarily powered by natural gas. These stenters emit common air pollutants from combustion, such as NO_x, along with other chemicals used in the process [6].

2.1. Best available techniques (BAT) in textile industry

In the global manufacturing industry, the textile production is one of the longest and most complex industrial production/supply chains; it is a fragmented and heterogeneous sector dominated by a majority of small and medium-sized enterprises, as well as multinational companies, which demand is mostly driven by three main end uses: clothing, home furnishing and industrial use. The entire manufacturing cycle in textile and clothing production chain consists of a wide range of subsectors: from the production of raw

materials (man-made fibers) to semi-processed materials (yarns, woven and knitted fabrics with their finishing process) and final/consumer products (carpets, home textiles, clothing and industrial textiles). Best available techniques (BAT) are advanced, state-of-the-art processes, *techniques*, facilities or methods of operation that are developed at a scale that enables implementation of a particular measure for limiting discharges to the environment, under economically and technically viable conditions. BAT are proven techniques for preventing and controlling industrial emissions and the wider environmental impact caused by industrial installations. The BAT concept has evolved as a key element for setting emission limit values and other permit conditions in environmental permits for these installations. The range of emission levels obtained under normal operating conditions using BAT (or a combination of BAT), as described in BAT conclusions [7] and expressed as an average over a given period of time under specified reference conditions, presents Associated Emission Level (BAT-AELs). In the textile industry, BAT-AELs are defined for emissions to air and water. Other environmental performance levels (so-called indicative levels) include specific energy consumption, specific water consumption, specific wool grease recovery level, and caustic soda recovery level. BAT Reference Document (BREF) for the Textiles Industry is part of a series of documents presenting the results of an exchange of information between EU Member States, the industries concerned, non-governmental organizations promoting environmental protection, and the Commission. This exchange aims to draw up, review, and update BREF as required by Directive 2010/75/EU on Industrial Emissions [8].

2.2. Life cycle assessment (LCA)

Life cycle assessment (LCA) is a scientific method or technique to identify, quantify and evaluate the environmental impacts (inputs and outputs) of a product, service or activity, from cradle to grave stages [9]. It can be used to quantify the environmental impact of processes and has many variants. It is highly useful for assessing the environmental impacts of a product from the beginning (raw material extraction stage or cradle) to the end (disposal or end of life, also called the grave stage) [2]. The life cycle of a typical textile product comprises the five stages as depicted in Fig. 1.

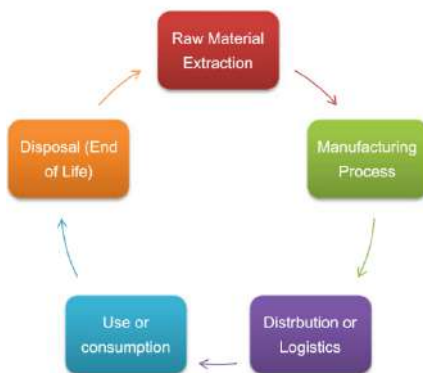


Figure 1: Life cycle stages of a typical textile product [2]

3. GOOD MANUFACTURING PRAXIS IN TEXTILE INDUSTRY

In textile production, the usage of energy, chemicals, and water are major environmental impact generators throughout the life cycle of products [2]. To ensure environmental sustainability, apparel designers should create products based on environmentally and socially responsible design approaches and trends; the supply chain must consider its impacts on society, economy, and environment for their business practices [2,3,10]. The example of good manufacturing praxis concerning environmental issue of sustainability is one successful international fashion/textile company, founded in 1954. in Alingsås, with Head office in Gothenburg, Sweden (part of the Stockmann Group) [11]. The Company employs about 4,300 people and operates around 440 stores in 18 markets, nine of which are franchises. Online shopping is available in 34 markets. Their main advertisement is pointed at the Company's web site saying that 42 % of their assortment has at least 15 % recycled content and 78 % of their assortment is made from more sustainable materials. The Company does not own any factories; instead, it works with selected independent suppliers in close, long-term collaborations, enabling mutual commitment to support, investment, and improvement projects. They have five production offices in Bangladesh, China, Hong Kong, India and Turkey. Their production offices work in close collaboration with their design and buying department in the development and production of the collections. They also work closely together with suppliers to make sure that the styles that end up in store and online meet the standards when it comes to quality, fit and sustainability [11]. As the fashion industry heavily depends on and consumes natural resources, this Company believes the only sustainable path forward is through a circular transformation of its business. This transformation aims to decrease its climate impact, minimize natural resource use, and influence consumer behavior to reduce overconsumption.

3.1. Achieving sustainability goals

Described Company has a responsibility to contribute to the UN Sustainable Development Goals, for their customers, for society and for their business today and tomorrow. Main goals concern climate, circularity and natural resources. To reduce climate impact in line with scientific recommendations throughout their entire value chain, the company defined two main goals [12]:

- By 2023, they plan to become climate neutral in their own operations;
- By 2030, they aim to reduce CO₂ emissions in their entire value chain by 50% compared to the 2017 baseline.

In the field of minimizing natural resource use and impacting consumer behavior to reduce overconsumption, the company defined several goals, including two main ones:

- By 2025, 100% of their materials will be recycled or sustainably sourced;
- By 2025, their entire assortment will be designed for longevity and/or circularity [13].

The Company's main goals for minimizing their impact on ecosystems and biodiversity with a responsible and regenerative approach to natural resources are:



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19-20th September, 2024, Belgrade, Serbia

- By 2025, all their business partners with water-intensive operations will be required to measure their water use, set reduction goals, and incorporate reduction, reuse, and recycling of wastewater into their environmental management systems;
- By 2025, the company will eliminate the release of all hazardous and toxic substances from their supply chain and promote transparency and more sustainable chemistry.

The Company continuously develops its sustainability goals, ambitions and strategies within its own promise to the customers and business partners; update on their progress is described in their annual sustainability report [12]. The last sustainability report (for 2023) shows significant improvements in several fields concerning „respect the planet”, as shown in Table 1.

Table 1: The Company's progress of environmental goals in 2023 (2017 baseline year) [12]

TOPIC	GOAL	PROGRESS in 2023	NOTES
Climate	By 2023, operations are climate neutral	Emissions decreased by 50%	Initially included offsetting that is no longer in the strategy.
	By 2030, the Company achieves 50% reduction of CO ₂ emissions	Emissions decreased by 42%	Excludes customer use phase, including laundry, care, and transportation to and from stores.
Circularity	By 2026, all Company's materials are recycled or sustainably sourced	78%	A garment counts towards their 100% goal if it contains at least 50% "more sustainable materials," meaning renewable or recyclable raw materials produced with less environmental impact.
	By 2026, 70% of products include a minimum of 15% recycled content	42%	They now have a goal specific to recycled fibers uptake compared to previous in 2025.
	By 2025, the entire assortment is designed for longevity and/or circularity		Going forward, this goal aligns with the emerging EU regulations on eco-design.
	By 2025, all Company's stores have functioning collection and recycling systems for paper and plastic	96%	-
	By 2025, paper and plastic packaging follows the Company's circular materials strategy	98% of all plastic packaging has 100% recycled content	This includes their transport business packaging, e-com consumer packaging, plastic bags and sales packaging

Natural resources	By 2025, its business partners measure their water use, set reduction goals and RRR of wastewater in the EMSs	72%	Progress in 2022 was 79 % for both goals (more than in 2023), but scoring methodology is changing. Currently this score is a higher-level environmental score encompassing all areas.
	By 2025, no hazardous substances will be released from its supply chain, promoting transparency and sustainable chemistry.	72%	

RRR- reduction, reuse and recycling; EMS- environmental management system

3.1.1. Sustainable/renewable materials and recycled materials

All raw materials used by the Company require natural resources, but it is possible to choose materials with minimal impact on people and the environment. The Company designates these materials as "more sustainable", meaning the raw material comes from a renewable or recyclable source and the fiber is cultivated or produced using methods that have less negative impact on people, animals, and the planet compared to conventional alternatives. Using recycled materials is part of the Company's 2030 circularity strategy, which aims to eliminate all waste. Utilizing recycled synthetic materials wherever possible significantly reduces the footprint of their produced synthetic fibers, such as polyester and polyamide, thereby reducing pressure on natural resources and climate impact. With new partnerships and a focus on mechanically recycled content, they have made great progress in recycling viscose and cotton materials. Figure 2 shows the Company's trends in switching to more sustainable raw materials and the share of products with more than 15% recyclable content.

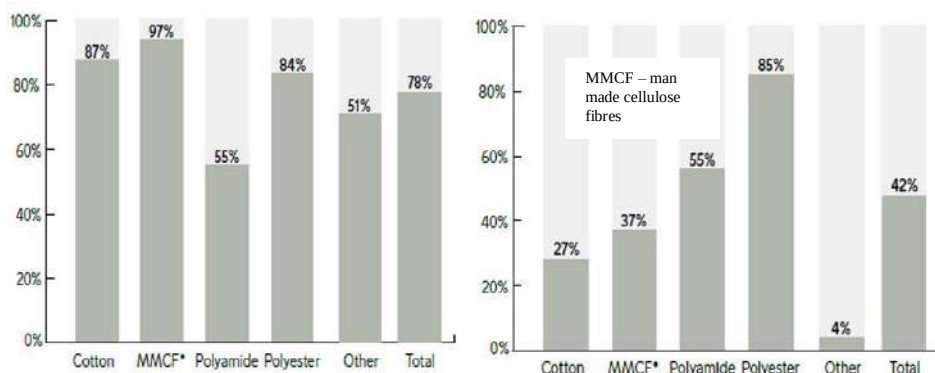


Figure 3: The Company's achievements in switching to more sustainable materials in production (left: sustainable share per fiber type; right: share of products with at least 15 % recycled content) [12]



3. CONCLUSION

The environmental challenges of sustainable textile production have prompted management to invest in cleaner production and efficient resource usage. This approach presents a long-term profitable strategy, saving resources, reducing production costs, and lowering the price of the final product without compromising quality. Given the fashion industry's heavy reliance on natural resources, textile companies are increasingly embracing circular business models to reduce their climate impact, minimize resource use, and influence consumer behavior to curb overconsumption. As an exemplary case of manufacturing best practices, the described textile company has made significant strategic decisions and investments towards environmental sustainability in recent years. For instance, 42% of their product assortment contains at least 15% recycled content, and 78% is made from more sustainable materials. By 2023, they achieved a 42% reduction in CO₂ emissions across their entire value chain compared to a 2017 baseline. Additionally, 96% of their own stores have operational collection and recycling systems for paper and plastic waste streams. Despite these achievements, the Company maintains ambitious sustainability goals, particularly in climate action, circularity, and natural resource management. Over the next few years, they plan to achieve climate neutrality in their operations and reduce CO₂ emissions across their value chain by 50% from 2017 levels. They also aim for all materials to be recycled or sustainably sourced, with the entire product range designed for longevity and circularity. Moreover, they require all business partners with water-intensive operations to measure, set goals for, and manage water use, including reduction, reuse, and recycling of wastewater in environmental management systems. Furthermore, the Company is committed to eliminating the release of hazardous and toxic substances from their supply chain while promoting transparency and adopting more sustainable chemistry practices.

ACKNOWLEDGMENTS

This research has been financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract No: 451-03-66/2024-03/200026).

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LIFE CYCLE AND RECYCLING OF CLOTHING

Professional paper
DOI: 10.5937/CT_ITI24061P

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ABSTRACT: The paper emphasizes that the life cycle and production process of an article of clothing includes a large number of stages such as: production of raw materials and fibers; production of fabrics, knitwear, non-woven textiles, etc.; design; tailoring, sewing and finishing of clothes; distribution; retail; phase of use and disposal of clothing - recycling or disposal. All this leads to the textile industry creating tens of millions of tons of textile waste annually on a global scale. Therefore, the need to find a solution to the complex production process of clothes in order to reduce the negative impact of the fashion industry on the environment is becoming more and more important. Various strategies for solving the problem of textile waste are also described. In the end, the conclusion is drawn that fashion companies pay more and more attention to the improvement of the products themselves as well as to the extension of the lifespan of the products themselves. For a typical textile product, 7 characteristic life stages through which it passes are described: concept and design stages, engineering stages, production stages, distribution and application stages, use and service activities (dry cleaning and washing), second life cycle stages (reuse) and end-of-cycle stages (recycling or disposal).

Keywords: clothing, life cycle, textile waste, recycling.

ŽIVOTNI CIKLUS I RECIKLAŽA ODEĆE

APSTRAKT: U radu se naglašava da životni ciklus i proces proizvodnje jednog odevnog predmeta podrazumeva veliki broj faza kao što su: proizvodnja sirovina i vlakana; proizvodnja tkanina, pletenina, netkanih tekstilija i sl.; dizajn; krojenje, šivenje i dorada odeće; distribucija; maloprodaja; faza korišćenja i odlaganje odeće – reciklaža ili nošenje

Union of engineers and textile technicians of Serbia



na otpad. Sve to dovodi da tekstilna industrija stvara desetine miliona tona tekstilnog otpada godišnje na globalnom nivou. Stoga se sve više nameće potreba za iznalaženje rešenja kompleksnog proizvodnog procesa odeća u cilju smanjenja negativnih uticaja modne industrije na životnu sredinu. Opisane su i različite strategije za rešavanje problema tekstilnog otpada. Na kraju se izvodi zključak da modne kompanije sve više obraćaju pažnju na poboljšanje samih proizvoda kao i na produžavanje životnog veka samih proizvoda. Za tipičan tekstilni proizvod, opisano je 7 karakterističnih životnih faza kroz koje on prolazi: faze izrade koncepta i dizajna, inženjerske faze, faze proizvodnje, faze distribucije i primene, faze upotrebe i uslužne delatnosti (hemijsko čišćenje i pranje), faze drugog životnog ciklusa (ponovna upotreba) i faze kraja ciklusa (recikliranje ili odlaganje).

Ključne reči: odeća, životni ciklus, tekstilni otpad, reciklaža.

1. INTRODUCTION

The life cycle and production process of a garment includes a large number of stages such as: production of raw materials and fibers; production of fabrics, knitwear, non-woven textiles, etc.; design; tailoring, sewing and finishing of clothes; distribution; retail; phase of use and disposal of clothing - recycling or disposal. All this shows that the technological process of making clothes is complex and that it requires the consumption of a large amount of different resources and thus causes the appearance of a large amount of waste [1].

With the advent of fast fashion, it is increasingly being talked about that the fashion industry has a huge negative impact on the environment. Namely, some of the production stages of textiles and clothing have become very unfavorable for the environment, considering the amount of clothing that is produced today [2]. It is usually cited as an example that there used to be two clothing collections per year - spring-summer and autumn-winter. However, today fashion companies launch 12 or more clothing collections per year.

All this leads to the textile industry creating tens of millions of tons of textile waste annually on a global scale. In addition, the technological process of textile production consumes huge amounts of water, land and raw materials. Therefore, serious efforts are being made to move from the linear economy in the textile sector to a greater degree of closed-loop recycling. In this direction, special emphasis is placed on high-quality recycling, which would ensure to a greater extent that recycled raw materials reduce the share of primary raw materials. In this way, disposed waste is reduced as well as the production of primary raw materials, which has a negative impact on the environment to a large extent [3].

In all of this, the reliance of the textile industry on synthetic fibers contributes to the unfavorable impact on the environment. The raw material base for the production of these fibers is fossil fuels. This includes polyester, which is one of the most common textile fibers in the textile industry today. Therefore, the textile industry must develop quality

closed-loop recycling systems for its materials [4]. In this direction, the Action Plan for the circular economy was adopted in the EU countries. This plan aims to ensure the application of circular economy principles to textile production, products, consumption and waste management. Several European countries have already implemented extended producer responsibility schemes, making brands and retailers responsible for post-consumer waste and requiring financial contributions from producers to collect, recycle and reuse products.

2. LIFE CYCLE OF FASHION PRODUCTS

The life cycle of fashion products starts from its conceptual solution in technical preparation, then through production to retail sale, i.e. its disposal. Therefore, today, more and more attention is paid to the design of fashion products, because design can significantly influence the duration of the product's life cycle. In addition to design, attention is also paid to other levels of the product life cycle, all with the aim of directing the fashion sector towards a socially and environmentally responsible industry. Many authors discuss the opportunities and obstacles for the implementation of a sustainable life cycle of fashion products in an effort to reduce the negative impact of fast fashion by using the opportunities offered by sustainable design. Thus, the authors in their work [5] provide an assessment of the life cycle of clothing by showing it in Figure 1.

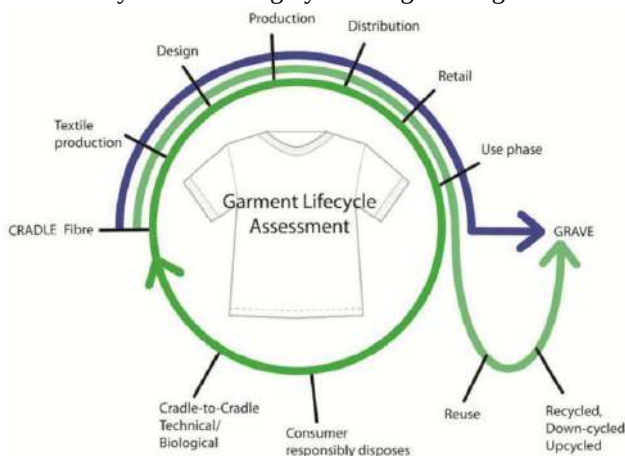


Figure 1: Assessment of the life cycle of clothing

According to these researches, the life cycle of a garment begins with the selection of fibers for the textile material from which the garment will be made. Then it goes through the production of fabrics and knitwear, the manufacture of the garment, its distribution, retailing, the stages of use and disposal of the garment. At all these stages, designers are in a good position to plan the impact of various parameters on the properties and lifespan of the clothing products they are designing [5].

3. NEGATIVE INFLUENCE OF THE FASHION INDUSTRY ON THE ENVIRONMENT

The textile sector was the third largest source of water and land use degradation in 2020. Therefore, there is an increasing need to find solutions to the complex production process of clothing in order to reduce the negative impact of the fashion industry on the environment. The production of raw materials is responsible for a large part of the environmental impact of the textile and clothing industry. This applies not only to the production of chemical fibers but also to the cultivation of natural fibers. For example, cotton, which accounts for more than 43% of all fibers used to make clothes on the EU market, is considered particularly problematic because it requires huge amounts of land, water, fertilizers and pesticides. This is attempted to be solved by using acceptable ecological cotton, whose negative impact on the environment is drastically less compared to conventional cotton. Like cotton and silk, it has a particularly harmful effect on the depletion of natural resources. However, natural fibers used less frequently today, such as hemp and flax, require less water, fertilizers and pesticides.

Polyester, according to its raw material composition, is a product of fossil fuels. It is therefore not biodegradable. Today, it is represented by about 16% in the total mass of all fibers used in the production of clothing. Its main advantages are that it consumes less water, can be washed at lower temperatures, dries quickly, and almost does not require ironing. [6] Clothes made of synthetic materials, which are washed in washing machines, are responsible for 35% of primary microplastics released into the environment. A single wash of PES clothing in washing machines can release 700,000 microfibers that can end up in the human food chain. Most microplastics from textiles are released during the first few washes, and fast fashion, due to its mass production, low prices and high volume sales, is responsible for many first washes [3]. Table 1 shows the positive and negative properties of the most commonly used fibers [2].

Table 1: Positive and negative properties of the most commonly used fibers

Fiber	Advantages	Disadvantages
Cotton	Natural fiber, easy to find and cheap	A large amount of pesticides are used for the production of cotton, also, cotton requires a lot of water
Wool	Natural fiber, no pesticides needed	Possible water pollution from manure
Linen	Natural fiber, processed using relatively little energy, good material for warm weather, requires less water and chemicals than cotton, longer life material	Pesticides, it's a bit more expensive, it's not practical at lower temperatures, it's not available in the quantities that other fibers are

Acrylic	It remains in its shape, can be very elastic and is suitable for sportswear	Acrylic is used in the production of plastics so the question is how easily it actually breaks down
Nylon	A strong yet lightweight fiber, cheap and widely available	It is not biodegradable, it creates a greenhouse effect 310 times stronger than carbon dioxide. Too many disadvantages outweigh the advantages of using this fiber
Polyester	Durable, cheap, widely used not only for clothing but also in the furniture industry, for insulation, etc.	It is not biodegradable, it pollutes water and air. Although it is practical to use, it has serious environmental consequences
Rayon	It's easy to produce, it's comfortable, it's cheap	Contributes to deforestation and chemical processes of water and air pollution. It ranks low on the list of "friends" of the environment

Also, the production of all types of fibers has been constantly increasing for many years. That trend will continue in the future, as can be seen from Figure 2 [7].

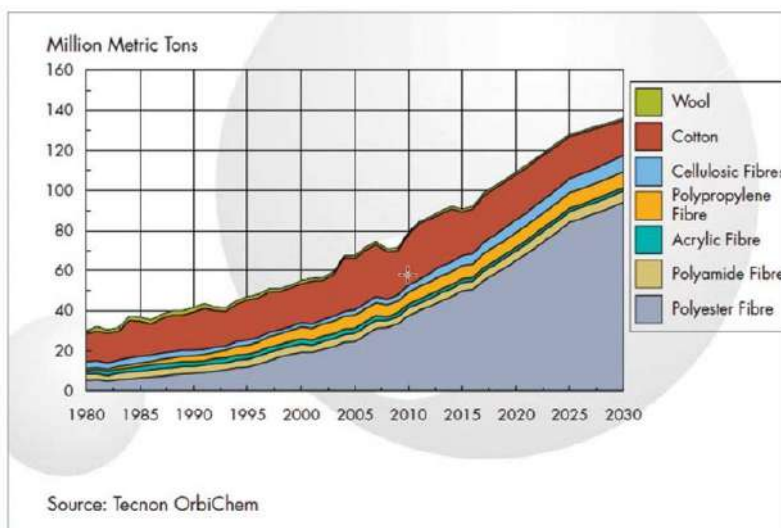


Figure 2: World fiber production 1980-2030. [7]

It is estimated that textile finishing processes, mainly dyeing and finishing in production, are responsible for 20% of global water pollution.



Figure 3: Industrial dyeing of textile materials [8]

In the textile industry, large amounts of water are used for various processes and stages. Therefore, we should expect different amounts and types of waste water, which become an important and significant burdening factor of negative impact on the environment.

4. SUGGESTIONS FOR SOLVING THE PROBLEM

The textile industry is increasing its production to a large extent, and thus creating large amounts of waste that have a negative impact on the environment. To solve these problems, new ways are recommended to reduce the impact on the environment in the processing and production phase, including reducing the consumption of chemicals, replacing them with enzymes, using color controllers and dyeing machines that require less water, and water recycling. Others are experimenting with different material savings in tailoring, new cuts, computer-controlled pattern making tools to reduce fabric consumption, and the like [9].

We are also working on finding new raw materials. Emphasis is placed on organic cotton because it uses less water and pollutes less. Some proposals also go in the direction of biobased polyester (also known as biosynthetics). It is partly made from renewable resources such as starch and lipids from corn, sugar cane, beet or vegetable oils. Further development is lyocell fiber made from eucalyptus pulp, which grows quickly and requires no irrigation or pesticides.

One of the innovative processes was developed by the Technical Research Center of Finland and the Infinite Fiber Company. The environmental advantages compared to viscose production are: 98% less water is used and harmful chemicals such as carbon disulphide can be avoided [10].



The Textile and Clothing Research Institute from Hong Kong is working on solutions for textile recycling from fiber mixtures of different raw material compositions into new fibers and yarns through the hydrothermal process and biological methods [11].

Different strategies for solving the problem of textile waste mainly include the following [3]:

- ❖ development of new technologies for making clothes with less waste in production,
- ❖ designing products in a way to facilitate reuse and recycling (circular way),
- ❖ persuading consumers to buy less clothing of better quality (slow fashion),
- ❖ constant direction of consumer behavior towards more sustainable options i
- ❖ development of new business models for clothing rental.

4.1. Industry 4.0 solutions - the development of new clothing manufacturing technologies with less waste in production

The development of new technologies for making clothes with less waste in production is based mainly on Industry 4.0 solutions. One of the essential characteristics of Industry 4.0 is flexibility and production according to the requirements of each individual customer. That is why a direct connection with the customer via the product (IoT) is extremely important for sales and marketing. For the realization of that goal, modern equipment is used today that is integrated with IT systems, and for it the common name cyber-physical systems (Cyber-Physical Systems - CPS) is used. These systems integrate computer technology, data transmission and processing, as well as modern mechanical systems [12]. The smart factory provides new possibilities for designing and producing fashion clothing collections [13].

5. LIFE CYCLE MANAGEMENT CONCEPT CLOTHING PRODUCTS

Fashion companies are paying more and more attention to improving the products themselves as well as extending the lifespan of the products themselves. For a typical textile product, there are 7 life stages that it goes through: [2]

- ❖ stages of concept and design development: quality parameters of raw materials, parameters of use and maintenance of the final product, prediction and simulation of its possibilities, comfort and satisfaction of standards and legal provisions,
- ❖ engineering phases: include innovative tools for optimizing quality and ecology in production, distribution, application, use, service activities, recycling or disposal, and prototyping. This phase is based on the experiences of using existing products,
- ❖ production phases: include specification of materials in production, quality management, system management of errors / damage to materials, self-optimization of production systems, on-line control of quality and environmental parameters,
- ❖ distribution and application phases: envisage improvement in product quality standardization and quality data management,
- ❖ phases of use and service activities (dry cleaning and washing): foresee the development of methods and processes for retaining and restoring the functional properties of textile material, the durability of properties during the phase of use, the

development of new products that affect the improvement of product quality during the phase of use and care, instructions and training for the correct global use and care of the product, analysis of problems arising during application and complaints, methods of more precise determination of possible errors, development of non-destructive methods for quality assessment, modeling / simulating the aging process in various conditions of use or care,

- ❖ phases of the second life cycle (reuse): envisage the development of new procedures by which existing textiles could be reused,
- ❖ end-of-cycle phases (recycling or disposal): envisage end-of-cycle research that must focus on the development of new recycling procedures.

6. CONCLUSION

The paper emphasizes that the life cycle and production process of an item of clothing includes a large number of stages such as: production of raw materials and fibers; production of fabrics, knitwear, non-woven textiles, etc.; design; tailoring, sewing and finishing of clothes; distribution; retail; phase of use and disposal of clothing - recycling or disposal. All this leads to the textile industry creating tens of millions of tons of textile waste annually on a global scale. Therefore, there is an increasing need to find solutions to the complex production process of clothing in order to reduce the negative impact of the fashion industry on the environment. In this direction, we are also working on finding new raw materials. Emphasis is placed on organic cotton because it uses less water and pollutes less. Some proposals also go in the direction of biobased polyester (also known as biosynthetics). It is partly made from renewable resources such as starch and lipids from corn, sugar cane, beet or vegetable oils. Further development is lyocell fiber made from eucalyptus pulp, which grows quickly and requires no irrigation or pesticides.

In the end, the conclusion is drawn that fashion companies pay more and more attention to the improvement of the products themselves as well as to the extension of the lifespan of the products themselves. For a typical textile product, 7 characteristic life stages through which it passes are described: concept and design stages, engineering stages, production stages, distribution and application stages, use and service activities (dry cleaning and washing), second life cycle stages (reuse) and end-of-cycle stages (recycling or disposal).

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IMPACT OF THE TEXTILE INDUSTRY ON THE ENVIRONMENT

Professional paper
DOI: 10.5937/CT_ITI24062J

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ABSTRACT: The topicality of the topic of this research work lies in the growing interest in environmental protection in the context of the textile industry. The textile industry has become one of the key actors in the discussions on environmental protection, given its complexity and significant impact on the ecological balance. This paper investigates the specific challenges and problems that the textile industry presents to the environment, analyzes various aspects of its impact, and presents possible strategies and solutions to reduce negative effects. Through a detailed analysis of current events, trends, and needs in society, the research focuses on identifying key points for intervention and improving the sustainability of the textile industry. This paper aims to contribute to the understanding of the complex problems arising from the impact of the textile industry on the environment, as well as to offer practical guidelines for addressing these challenges at the current time. The results of this research can serve as a basis for further discussions and decision-making to preserve the environment and promote the sustainability of the textile industry.

Keywords: textile industry, environment, sustainability, environmental impact, environmental awareness, challenges, strategies.

UTICAJ TEKSTILNE INDUSTRIJE NA ŽIVOTNU SREDINU

APSTRAKT: Aktuelnost teme ovog istraživačkog rada leži u sve većem interesu za očuvanje životne sredine u kontekstu tekstilne industrije. Tekstilna industrija je postala jedan od ključnih aktera u raspravama o zaštiti životne sredine, s obzirom na njenu kompleksnost i značajan uticaj na ekološki bilans. Ovaj rad istražuje konkretne izazove i probleme koje tekstilna industrija predstavlja za životnu sredinu, analizira različite aspekte njenog uticaja i predstavlja moguće strategije i rešenja za smanjenje negativnih efekata. Kroz detaljnu analizu aktuelnih događaja, trendova i potreba u društvu, istraživanje se fokusira na identifikaciju ključnih tačaka za intervenisanje i unapređenje održivosti tekstilne industrije. Cilj ovog rada je da pruži doprinos razumevanju složenih



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„Contemporary trends and innovations in the textile industry“

19-20th September, 2024, Belgrade, Serbia

problema koji proističu iz delovanja tekstilne industrije na životnu sredinu, kao i da ponudi praktične smernice za adresiranje tih izazova u trenutnom vremenskom periodu. Rezultati ovog istraživanja mogu poslužiti kao osnova za dalje diskusije i donošenje odluka u cilju očuvanja životne sredine i promocije održivosti tekstilne industrije.

Ključne reči: *tekstilna industrija, životna sredina, održivost, ekološki uticaj, ekološka svest, izazovi, strategije.*

1. INTRODUCTION

The textile industry ranks among the activities that have an extremely large negative impact on the environment. The products of the textile industry are among the products that make significant negative contributions to the environment at all stages of their life cycle. The factors that most influence the unsustainability of textiles and clothing include the use of chemicals that harm the environment during the production of these products, high consumption of water and energy, long transport distances, the generation of large amounts of solid waste and the use of non-biodegradable packaging.

The specificity of the textile industry and the products that are created in it is reflected in the existence of significant sources of negative impact on the environment in all stages of their production and use, starting from the production of raw materials, until the end of the use of these products. It is this specificity that imposes the need to use an approach based on the evaluation of the entire life cycle when assessing the impact of the textile industry on the environment. The Life cycle assessment is a scientifically based and systematic approach that analyzes the environmental impacts that occur during the entire life cycle of textile products.

2. NEGATIVE EFFECTS OF FAST FASHION ON THE ENVIRONMENT

The negative impacts of the textile industry on the environment have, during the past two decades, increased to an extremely large extent due to the development of fast fashion.[1] Fast fashion is based on the constant creation of new styles and clothing based on them, which is sold at very low prices. It is based on cheap products, usually of low quality, which are intended for use during one or at most two seasons, after which they are thrown away. Fast fashion products are based on trends, which is why their use usually stops after they stop being trendy, not because of their damage or loss of functionality. The development of fast fashion has led to an enormous increase in the amount of clothing being thrown away, even though it is still completely usable.[2] In this way, large amounts of waste are created, which, in most cases, are difficult to recycle, which is why they are disposed of in landfills.

Fast fashion is a consequence of the desire of companies that produce clothes, shoes, and accessories to maximize the market on which they can sell their products. It is one of the most drastic examples of ignoring care for the environment and socially responsible business for the sake of making a profit. Numerous researches that have had the impact of the textile industry on the environment as a subject point to the conclusion that fast fashion



and the concept on which it is based are the generators of most of the damage that the textile industry causes to the environment.[3] Awareness of the negative effects of fast fashion on the environment has resulted in increasingly intensive activities aimed at extending the life of clothes and shoes, to reduce the amount of textile waste generated and the negative effects on the environment that occur during the first few washes.

3. OVERUSE OF NATURAL RESOURCES

The textile industry is based on the use of extremely large amounts of resources that are required to produce products. The largest number of textile products still contain significant proportions of cotton, the use of which in the production of fashion products is associated with extremely high use of various resources, many of which are non-renewable. The production of textile products requires large amounts of water and land to grow cotton or produce other fibers from which they are made. As much as 2,700 liters of fresh water are needed to produce one short-sleeved cotton T-shirt.[4] This amount of water is sufficient to meet the drinking water needs of an average person for a period of 2.5 years.

During 2020, the textile sector was the third largest source of land use and water degradation. In 2020, an average of 9,000 liters of water, 400 square meters of land, and 391 kilograms of raw materials were used to produce clothes and shoes for every citizen of the European Union.[4] The production of the amount of clothing and footwear that the average citizen of the European Union needs annually leads to the creation of about 270 kilograms of carbon dioxide, which is equivalent to the emissions that passenger cars with Euro 6 emission standards generate when traveling 2,500 kilometers.

The textile industry is one of the segments of modern society whose impact on the use of resources is often ignored or poorly understood. A factor that additionally affects the negative effects that arise as a result of the production of textile products is reflected in the fact that this industry is characterized by a high level of use of non-renewable resources. Excessive use of resources is largely a consequence of insufficient attention to business sustainability in the textile industry.[1] This industry is characterized by emphasizing the lowest possible production costs and motivating consumers to constantly buy new clothes, which are in line with current trends that last very short. The characteristics of the textile industry and the sources of competition in the textile products market greatly influence companies to ignore the efficiency of using natural resources and the negative effects on the environment that arise as a consequence of their operations.

4. THE MOST SIGNIFICANT NEGATIVE IMPACTS OF THE TEXTILE INDUSTRY ON THE ENVIRONMENT

The textile industry creates a large number of different negative impacts on the environment. Some of these impacts are very large and can significantly affect the occurrence of pollution and irreparable damage to the environment. The most significant negative impacts on the environment, that arise as a result of the activities carried out in the textile industry, can be singled out:



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- water pollution,
 - air pollution and gas emissions that lead to the creation of the greenhouse effect,
 - soil pollution and occupation of arable land, and
 - generation of large amounts of waste.

4.1. Water pollution

The production of textiles is classified among the activities that have an extremely large negative impact on the environment through water pollution that occurs in the various stages of the production of textile and fashion products. It is estimated that textile production is responsible for about 20% of the total global clean water pollution.[4] These pollutions mostly occur as a result of the processing, and dyeing of textile materials and the use of textile products. During one wash of textile products made of polyester fibers in a washing machine, around 700,000 microplastic fibers are produced. Most of these fibers end up in water, with a significant part of these harmful materials also reaching various segments of the food production process.

It is estimated that in 2017, the textile industry generated about 20.6 million tons of various types of hazardous waste that were released into the water.[5] Most of this pollution occurs during the release of dyes during the dyeing and final processing of clothing. An additional negative impact of the production of textile products on water is reflected in the consumption of large amounts of water, which is used during the removal of excess pigments and chemicals so that only the amount that was fixed on the products remains on them. The dyeing of fibers, materials, and products is one of the most important elements that influence the occurrence of pollution and negative environmental impacts [6].

The textile industry uses a large number of processes that involve the dyeing of fibers, materials, or products. In addition, treatments that require large amounts of water and whose aim is to improve the quality, appearance, or functionality of the product are often used. Dyes used in the textile industry are mostly made of synthetic materials.[7] The wide application of synthetic dyes is due to their ability to stay on clothes much longer than dyes made from natural materials. After the processing process, the textile materials must be rinsed and washed, in order to remove the unused dye that is excess. During this process, large amounts of water are used, which after its completion contain significant amounts of paint residues. A factor that has an additional negative impact on the environment is the fact that the dyes used in the textile industry are made of chemical components that can be very harmful to people and the environment. Another factor that negatively affects the environment is the fact that the dissolution period of the materials from which the paints are made is very long [6].

The development of fast fashion has greatly increased the negative effects on water that arise as a result of the use of fashion products. Most of the harmful microparticles are released from textile products after the first few washes. The short lifespan of fast fashion products results in frequent purchases of new fashion products and their first washes. The concept on which fast fashion is based promotes a large number of first washes and consumer behaviors that are very harmful to the environment. The washing of synthetic products results in the collection of more than half a million tons of microplastics on the ocean floor each year.

Microfibers that arise as a result of the use of synthetic materials during the production of clothing lead to water pollution, which is not given enough attention.[8] The results of numerous researches point to the conclusion that the synthetic microfibers used in the production of textiles are too small to be filtered, which is why they create pollution that ends up in water and has significant negative impacts on animals and the environment.[9] Water pollution that occurs as a result of the work of the textile industry is an ecological problem that is not given enough attention. This pollution is particularly dangerous in the vicinity of factories where various activities related to the production of textile products are carried out.

4.2. Air pollution and gas emissions that lead to the creation of the greenhouse effect

Air pollution resulting from activities carried out in the textile industry can manifest itself in several different ways. The textile industry has a significant share in the total global air pollution, which is largely a consequence of the processes that take place during the production of fibers, materials, and finished products. Most often, air pollution in the textile industry is generated in the form of emissions of carbon dioxide, carbon monoxide, sulfur dioxide, and nitrogen gases [10].

The textile industry is among the industries that have a significant participation in the generation of carbon dioxide and other gases that lead to the creation of the greenhouse effect. The negative impact of the textile industry on the creation of the greenhouse effect is best illustrated by the fact that in 2020 it contributed 10% to the total global carbon dioxide emissions. Aviation and maritime transport together contribute less to global carbon dioxide emissions than the textile industry [4]. Textile products consumed in the European Union resulted in the emission of gases that led to the creation of the greenhouse effect in the amount of 121 million tons, which is only one-third less than the total amount of these gases emitted by passenger cars in the European Union.

The largest part of emissions of harmful gases in the textile industry occurs during the production process of fashion products. Numerous stages in the production of textile products require high temperatures, which results in the consumption of large amounts of energy and the emissions of harmful gases associated with it.[11]. The negative impacts of the textile industry in the form of air pollution and emissions of harmful gases that lead to the creation of the greenhouse effect are additionally increased due to the characteristics of the production processes that take place in it. These processes most often lead to the creation of a combination of several harmful gases, the negative effect of which is greater than the sum of the individual negative effects of each of these gases.

The textile industry is classified as one of the activities in which human labor has a large share in the total costs. Fast fashion and the emphasis on low production costs have placed the imperative of minimizing all segments of production costs before companies engage in the production of fashion products [3]. Most fast fashion products are produced in countries with low labor costs (most often in Southeast Asia), which are located a long distance from the largest markets. The large distances over which raw materials and fashion products are transported due to savings in human labor costs increase the negative impact of the textile



industry on the environment, primarily through the emission of carbon dioxide that occurs during transportation.

4.3. Soil pollution and occupation of arable land

Every year, textile factories globally generate about 280,000 tons of industrial wastewater, which has significant negative effects on the soil [12]. There are a large number of factors associated with the textile industry that lead to soil pollution, the most significant of which are the synthetic dyes used, heavy metals, and organic compounds. The greatest negative effects of the textile industry through soil pollution are realized due to the use of synthetic dyes, the release of which after the production process results in the contamination of the soil near the factories and along the waterways through which these dyes pass [13]. Some of these dyes can be carcinogenic if they are not treated appropriately after the end of the textile production process [13]. A frequent source of soil pollution is the biotransformation of bacteria used in paints.

Large amounts of soil pollution generated by the textile industry also occur as a consequence of its contamination, which is a consequence of the use of heavy metals. Production processes in the textile industry require the use of large amounts of heavy metals, which, in addition to negative effects on water and air quality, can also lead to soil contamination [14]. The high concentration of organic compounds produced during the production of textile products harms the health of the soil, thereby endangering the lives of plants, animals, and people.[14] The results of numerous studies point to the conclusion that organic compounds from the textile industry can contribute to the emergence of a large number of soil problems, which are especially pronounced in urban areas [15].

The cultivation of cotton and other natural materials used in the textile industry requires large amounts of arable land, on which raw materials from which fibers and materials are obtained are produced. Despite the development of a large number of modern, synthetic materials, cotton still plays a large role as a raw material from which fashion products are produced, even in the fast fashion industry [12]. The production of cotton requires large areas of arable land, which is in short supply in most of the countries where it is grown, which is why it is often cited as one of the factors influencing the increase in hunger.

4.4. Generation of large amounts of waste

The generation of large amounts of waste is a factor that significantly increases the negative impact of the textile industry on the environment. An additional problem with this type of negative impact is the constant increase in the amount of clothing that is thrown away, which is largely a consequence of the development of fast fashion, in which the emphasis is placed on shortening the lifespan of products and replacing them with new ones as often as possible. In addition to the extremely large amounts of clothes that end up being used, the generation of large amounts of textile waste is also influenced by changes in the way consumers relate to the clothes they no longer want to wear. Instead of donating old clothes, which were popular in the past, consumers increasingly decide to throw them away, considering that they no longer have a functional value.

In European Union countries, less than half of end-of-life clothing is collected for reuse and recycling, with only 1% of used clothing being converted into new clothing [4]. The



low percentage of recycling is largely due to the fact that the technologies that enable the recycling of clothing into fibers that can be used to make new ones are still in the early stages of development. As one of the solutions to the problem of generating large amounts of textile waste, donating clothes to less developed countries and exporting them in the form of used products is increasingly being used. In this way, short-term solutions are created, which reduce the amount of textile waste in developed countries and increase this problem in less rich countries, which take upon themselves the storage of clothing after its use has ceased [3].

The negative impact of fast fashion on the environment and the increase in the amount of waste it leads to, represent an increasing threat to the environment and modern society. Large amounts of waste generated in the textile industry threaten the environment and require large areas of land where textile products that are no longer used can be disposed of. The European Union and a large number of other countries place increasing emphasis on extending the life of clothing, through the introduction of rules and various measures aimed at disincentivizing the discontinuance of clothing that is still functional and has useful value.

The extent of the negative impact of textile waste on the environment can best be seen based on the data that the citizens of the European Union use about 26 kilograms of clothing on average per year and that they throw away about 11 kilograms every year.[4] Used clothing, due to the impossibility of its recycling, can be exported to countries outside the European Union, where about 87% of discarded textile products are burned or disposed of in landfills.[4] Reducing the amount of fully functional textile products that are discarded is one of the basic and most important tasks that must be accomplished to reduce the negative impacts of the textile industry on the environment.

5. CONCLUSION

The textile industry has extremely large negative impacts on the environment, which are accompanied by very low levels of business sustainability. The negative impacts of the textile industry on the environment and sustainability are largely the result of the development of the concept of fast fashion, in which the emphasis is placed on maximizing sales and profits, while much less attention is paid to environmental protection and business sustainability. The development of fast fashion had a key impact on the increase in the consumption of clothing and footwear, which also had numerous negative effects on the environment. The development of fast fashion was largely influenced by social media and the fashion industry, which used them to present fashion trends to a larger number of customers, with the dynamics of changing these trends significantly faster than in the past. Activities that should ensure the reduction of negative impacts of the textile industry on the environment must be directed towards reducing the consumption of textile products and finding efficient ways for recycling. Significant savings could also be achieved by bringing the places of production of textile products closer to the places of their consumption, which would significantly reduce emissions of harmful gases that occur during transport. Reducing the negative impacts of the textile industry on the environment



can be achieved by creating new strategies, such as the development of a business model for renting clothes, designing products in a way that allows for a greater number of their use, and simpler recycling (circular fashion), persuading customers to buy clothes of better quality that will last longer instead of fast fashion products (slow fashion) and direct customers to direct their behaviors towards ensuring sustainable consumption of textile products.

ACKNOWLEDGMENT

The research presented in this paper was carried out with the financial support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, as part of the funding of scientific research work at the University of Belgrade, Technical Faculty in Bor, according to the contract with number 451-03-65/2024-03 /200131.

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DETERMINATION OF ATMOSPHERIC MICROPLASTIC LEVELS IN A TEXTILE INDUSTRY INTENSIVE REGION

Original scientific paper
DOI: 10.5937/CT_ITI24063H

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ABSTRACT: Microplastics (MPs) are synthetic plastic particles ranging in size from 1.000-5.000 μm , which can be found in regular, irregular, fiber, and foam shapes. Due to their environmental ubiquity and potential toxicological effects, they have become one of the most concerning pollutants worldwide in recent years. It is known that MPs are present in water, soil, and air environments, and their atmospheric concentrations in the air, as a result of their wide distribution, are considered a potential source of exposure through respiration and ingestion. The main sources of MPs are considered to be synthetic textile fibers, cosmetics, detergents, plastic wastes, abrasion from car tires, and the gradual breakdown of plastic materials. Synthetic textiles and urban dust are thought to be the most important sources of microplastics. In this study, the concentration levels of atmospheric MPs were determined in Çorlu and its surroundings, an industrial zone located in the province of Tekirdağ-Turkey, which hosts many textile facilities and is exposed to intensive industrialization. For this purpose, atmospheric deposition and street dust samples were collected from three locations: a central area with dense urban settlement, an industrial zone with concentrated textile activities, and a clean downwind coastal area. The samples were collected in three periods: December 2023, February 2024, March 2024. According to the results obtained, total MP values in atmospheric deposition samples were determined to be in the range of 131-1.397 units/ m^2/day , and in street dust samples, they were determined to be in the range of 9.810-213.485 units/kg. When the sampling points were compared, it was determined that the highest levels were found in the industrial zone and urban area.

Keywords: Microplastics, textile industries, atmospheric deposition, street dust, Çorlu.

ODREĐIVANJE NIVOA ATMOSFERSKIH MIKROPLASTIČNIH
ČESTICA U REGIONU INTENZIVNE TEKSTILNE INDUSTRIJE

Union of engineers and textile technicians of Serbia



APSTRAKT: Mikroplastika (MP) su sintetičke plastične čestice veličine od 1.000-5.000 mm, koje se mogu naći u pravilnim, nepravilnim, vlaknastim i penastim oblicima. Zbog njihove sveprisutnosti u životnoj sredini i potencijalnih toksikoloških efekata, poslednjih godina su postali jedan od najvećih zagađivača širom sveta. Poznato je da su MP prisutni u vodenj, zemljišnoj i vazdušnoj sredini, a njihove atmosferske koncentracije u vazduhu, kao rezultat njihove široke distribucije, smatraju se potencijalnim izvorom izloženosti disanjem i gutanjem. Glavnim izvorima MP se smatraju sintetička tekstilna vlakna, kozmetika, deterdženti, plastični otpad, habanje od automobilskih guma i postepeno razlaganje plastičnih materijala. Smatra se da su sintetički tekstil i urbana prašina najvažniji izvori mikroplastike.

U ovoj studiji, nivoi koncentracije atmosferskih MP su utvrđeni u Corlu i njegovoj okolini, industrijskoj zoni koja se nalazi u provinciji Tekirdag-Turska, u kojoj se nalaze brojni tekstilni objekti i koja je izložena intenzivnoj industrijalizaciji. U tu svrhu, uzorci atmosferskih taloženja i ulične prašine prikupljeni su sa tri lokacije: centralno područje sa gustim urbanim naseljem, industrijska zona sa koncentrisanim tekstilnim aktivnostima i čista priobalna oblast koja pada niz vetar. Uzorci su prikupljeni u tri perioda: decembar 2023, februar 2024, mart 2024. Prema dobijenim rezultatima, ukupne vrednosti MP u uzorcima atmosferskih taloženja utvrđene su u rasponu od 131-1397 jedinica/m²/dan. uzoraka prašine, utvrđeno je da su u rasponu od 9.810-213.485 jedinica/kg. Kada su upoređene tačke uzorkovanja, utvrđeno je da su najviši nivoi pronađeni u industrijskoj zoni i urbanom području.

Ključne reči: Mikroplastika, tekstilna industrija, atmosfersko taloženje, ulična prašina, Corlu.

1. INTRODUCTION

The production and use of plastics have been continuously increasing due to their benefits, such as the ability to form various shapes, being cheap, lightweight, and durable. While plastic production was 2 million tons in 1950, it reached 390.7 million tons in 2021 [1]. On the other hand, only 10% of plastic waste can be recycled [2]. More than 40% of plastic products are produced for single-use applications such as plastic bags, cutlery, straws, cups, and food packaging. These short-lived applications rapidly lead to large amounts of persistent plastic waste. Most of this plastic waste reaches the oceans as the final recipient environment from terrestrial sources, coasts, or rivers [3].

Microplastics (MP) are synthetic materials of 1-5 mm in size that can be found in regular (granular), irregular (fragment or film), fiber, and foam shapes. MPs, identified as a problem since the 1970s, are found in every region of the world. MPs are classified as primary or secondary based on their formation pathways. Primary MPs are plastic particles produced for industrial use that can be released into the environment both indirectly and directly [4]. Secondary MPs are substances formed from larger plastic pieces through mechanical, photochemical, biological degradation, etc. [5]. They result from the degradation of larger plastic items such as plastic bags, crates, bottles, and ropes. MPs that



originate from particles formed during the use of products, such as tire wear or clothing fibers, are also included in this category [6].

The durability and long-range transport capabilities of plastics result in these wastes being transported from their sources to ecosystems where they are not produced [7]. MPs have been found in surface water systems, especially in seas and oceans, soil, and within the bodies of fish and other organisms. There are three main pathways through which MPs can enter the human body: inhalation, ingestion, and skin contact [2]. The hazardous properties of plastics are increased as they contain numerous dangerous chemicals, such as those that provide flexibility, flame retardant properties, and various dyes and pigments.

When examining studies related to MPs, it has been observed that over the past 20 years, most research has focused on the concentrations of MPs in water systems, freshwater surface water sources such as lakes and rivers, and especially in seas. Initially, MPs were generally considered a problem in marine ecosystems, but nowadays, they are recognized as particulate contaminants that can be found in terrestrial and atmospheric environments. In recent years, studies on the atmospheric accumulation and transport of MPs have increased in the global lit Due to their small size and low density, MPs can remain suspended in the air for a sufficient duration and be transported to various locations by the wind [8]. Among the sources of atmospheric MPs, the most important include synthetic fabric clothing, road dust, vehicle tires, macroplastic waste, household applications, industrial processes, and 3D printing. Industrial sectors with high MP emissions include those where polymeric materials are produced and processed, as well as textile businesses where synthetic yarn and/or fabric production takes place.

Dris et al. (2016) [9] are almost the first researchers to investigate atmospheric MP deposition. In the study, atmospheric deposition samples were collected in a 20 L glass bottle on the roof of the University of Paris-Est Créteil, located in a dense urban environment, for 3 months. MPs were observed in atmospheric compounds for the first time in the study. According to the results of the study, MPs were detected at 53 ± 38 particles/m².day in urban areas and 365 particles/m².day in mountainous areas. In another study where atmospheric deposition sampling was performed, atmospheric deposition was sampled on the roof of a tall building in London, England, and the deposition rate was 712-162/m²-day, and microfibers were detected as the dominant species [10]. In a study conducted in Beijing, China, atmospheric deposition was sampled at 1,5 and 18 m above the ground and $16,7 \times 10^{-3}$ and $14,1 \times 10^{-3}$ fiber/ml were found [11].

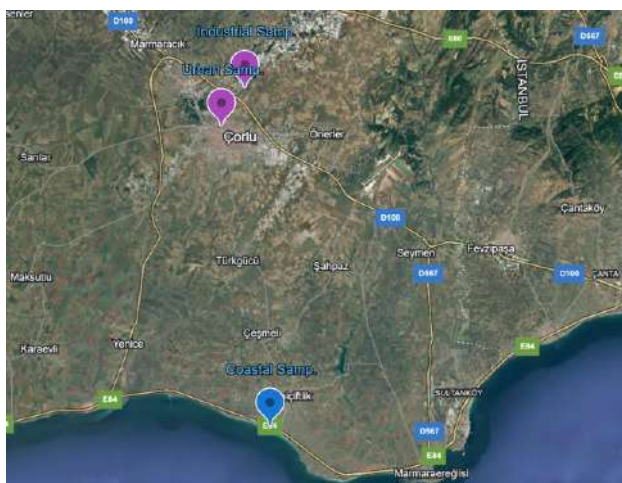
Patchaiyappan et al., 2021 [12] sampled road dust in India and found the MP concentration range to be 227.94-91.4 particles/100 g dust. In another study conducted in Victoria, Australia, road dust sampling revealed the amount of MP to be 21-529 particles/kg [13].

Within the scope of the study, atmospheric MP concentration levels and types in Çorlu district and its surroundings, which is one of the regions where industry and especially textile and recycling sectors are most dense in Turkey, were determined for the first time. Within the scope of the thesis, MP amounts were determined in atmospheric accumulation and street dust samples in 3 different periods at 3 sampling points in Çorlu and its surroundings, namely the industrial region where textile and recycling sectors are dominant, the residential region where urban settlement is dominant and the coastal region with a coastline in the lee of the region, and the obtained results were evaluated.

2. MATERIAL AND METHOD

The population of Çorlu district of Tekirdağ province, which is the study area, is 294,020 people. It is the second largest settlement in Turkish Thrace after Istanbul. The leather and textile sectors are quite active in Çorlu and its surroundings. The number of organized industrial zones in the province is 14. Especially in the Çorlu-Çerkezköy-Muratlı-Lüleburgaz line, there are approximately 3,000 industrial facilities/enterprises operating in the sectors of textile, leather, paper, chemistry, food, etc. [14].

Within the scope of the study, 3 sampling points were selected in the area covering Çorlu district and its surroundings. Atmospheric samples and street dust samples were collected simultaneously from the determined points.



specially designed 60-65 cm diameter stainless steel funnel was used as the sampling apparatus. The design and an image of the sampling equipment are given in Figure 2.

Total atmospheric deposition sampling was carried out from 3 sampling sites for 7 days in each period. Each time atmospheric deposition samples were collected, the funnel was rinsed 3 times with 1 L of distilled water to recover all particles adhering to the funnel. After the rinsing step, the samples were capped and transported to the laboratory to prevent any contamination.

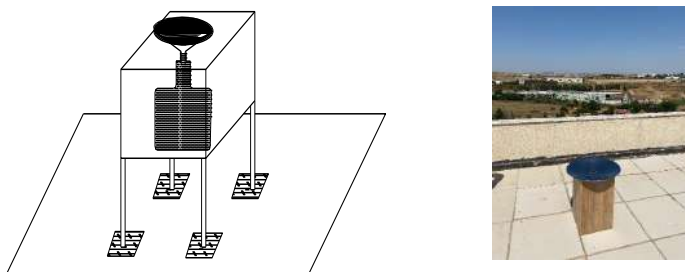


Figure 2: Atmospheric Total Deposition Sampler

Street dust samples were collected from 3 sampling points at the end of each atmospheric deposition sampling period. Samples were collected from a location close to the area where atmospheric deposition samples were collected, from an area of approximately 1 square meter, by sweeping the ground with a small brush and metal shovel near the pavement and placed in glass bottles. Sampling was done on rainless days.

Sampling was carried out at 3 points in December 2023, February 2024 and March 2024.

2.1. Sampling Analysis

The method followed in the study is the procedure applied by Dris et al., 2016; Dris et al., 2017; Prata et al., 2020 [9, 16, 17]. Atmospheric deposition samplers are placed at the sampling points (3 points) and kept for 7 days simultaneously. At the end of the sampling period, the particles retained on the surface of the sampling funnel are washed and taken into a glass bottle. The samples are brought to the laboratory. The amount of precipitation is measured. The sample is taken into a suitable glass container and left to dry. After drying, 40 ml of H_2O_2 is added to the samples taken from the oven and kept for 7 days. At the end of the waiting period, 6 g of NaCl is added to the sample and kept for 1 day. In this way, MPs are allowed to rise to the upper phase by density separation. At the end of the waiting period, the fraction separated in the upper phase is extracted with the help of a pipette and filtered. The dried filter paper is placed under the microscope and imaging and counting are performed.

Street dust samples collected from sampling points are brought to the laboratory in glass containers. Large pieces of grass, stones, etc. are removed from the collected sample. The remaining amount is weighed and the path followed in atmospheric deposition samples is followed.

In the study, MPs of different sizes and colors were counted under a stereoscopic microscope. Criteria previously used in various studies were employed to identify MPs [16, 17]. Some of these criteria are:

- Fibers must be of equal thickness throughout their entire length.
- Fibers should not be completely straight, as this indicates a biological origin.
- A fiber must show no visible cellular or organic structures.
- The same filter was estimated by comparing counts from two different observers. An average difference of 5% in the total number of fibers was observed.

3. RESULTS

3.1. Results of Atmospheric Deposition Samples

The MP count results obtained from the sampling points during each of the 3 periods are presented in Table 1. In atmospheric deposition samples, the total MP values ranged from 384 to 1.397 in the industrial area, 869 to 1.284 in the residential area, and 131 to 857 particles/m²/day in the coastal area. The highest counts of points (black and colored), pieces (black and colored), and black spirals were observed in the residential area. Generally, colored spirals were most frequently observed in the industrial area. The most detected type of MP was the black point, which constituted 83.6% of the total detected MPs.

Figure 1 shows the total MP values detected in the collected atmospheric deposition samples. Accordingly, the highest values were observed in the residential area during the 1st period and in the industrial area during the 2nd period. The highest values among all samplings were found in the atmospheric deposition samples collected from the industrial area in February 2024. The coastal area had the lowest MP values across all periods.

Table 1: Results of Atmospheric Deposition Samples (particles/m²/day)

Sampling Area	Sampling Period	MP types						Total
		Black point	Colored point	Black piece	Colored piece	Black spiral	Colored spiral	
Industrial Area	1 st Period	302,9	1,9	48,6	1,0	23,3	6,7	384,3
	2 nd Period	1133,3	1,4	235,2	0,5	24,8	1,9	1.397,1
	3 rd Period	824,3	5,7	155,2	2,9	26,2	0,0	1.014,3
Residential Area	1 st Period	725,7	2,4	106,2	3,3	30,0	1,4	869,0
	2 nd Period	882,9	0,5	113,3	1,0	43,8	1,4	1.042,9
	3 rd Period	1130,0	1,0	129,0	0,5	22,9	1,0	1.284,3
Coastal Area	1 st Period	94,8	1,4	8,6	0,0	26,2	0,5	131,4
	2 nd Period	123,3	1,0	13,8	0,0	8,1	1,0	147,1
	3 rd Period	743,3	0,5	90,5	0,5	21,9	0,0	856,7

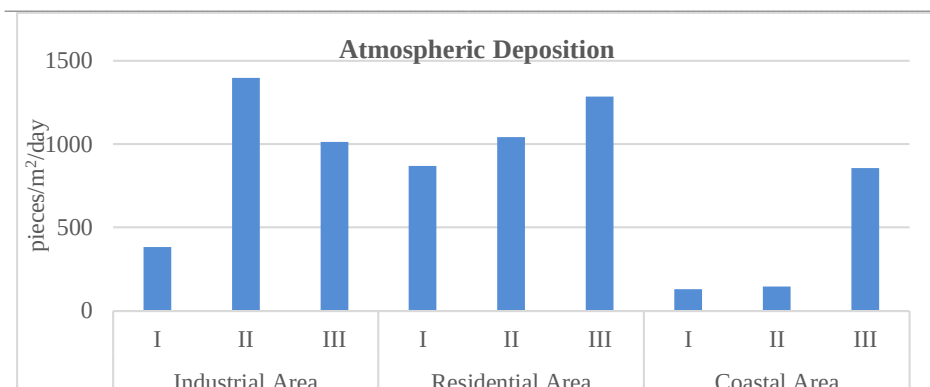


Figure 3: Total MP values in atmospheric deposition samples

3.2 Results of Street Dust Samples

According to the MP results in street dust samples, the MP count values ranged from 35.080-141.454 in the industrial area, 9.810-213.485 in the residential area, and 12.133-46.780 items/kg in the coastal area. Among the types of MPs, black pieces were the most frequently detected. Black points, black pieces, and black spirals were found in street dust samples collected from the industrial area. Colored points, colored pieces, and colored spirals were most frequently found in samples collected from the residential area. In street dust samples, the most frequently encountered MP type was the black point, constituting 81.8% of the total detected MPs.

Figure 2 shows the total MP values detected in the collected street dust samples. According to this figure, the highest values were observed in the industrial area during the 1st and 2nd periods and in the residential area during the 3rd period. The coastal area had the lowest MP values across all periods.

Table 2: Results of Street Dust Samples (particles/kg)

Sampling Area	Sampling Period	MP types						Total
		Black point	Colored point	Black piece	Colored piece	Black spiral	Colored spiral	
Industrial Area	1 st Period	29.385,1	129,4	3.883,5	129,4	1.553,4	0,0	35.080,8
	2 nd Period	58.665,5	173,3	25.649,9	-	5.286,0	173,3	89.948,0
	3 rd Period	127.636,4	272,7	12.090,9	181,8	1.181,8	90,9	141.454,5
Residential Area	1 st Period	6.603,8	377,4	566,0	119,1	1.905,9	238,2	9.810,4
	2 nd Period	44.211,5	273,5	19.598,9	91,2	1.732,0	1.002,7	66.909,8
	3 rd Period	192.775,3	719,4	15.859,0	264,3	3.507,2	359,7	213.484,9
Coastal Area	1 st Period	11.911,9	-	1.905,9	-	691,8	62,9	14.572,5
	2 nd Period	10.900,5	94,8	-	-	1.137,4	-	12.132,7
	3 rd Period	33.363,3	704,8	9.712,2	179,9	2.731,3	88,1	46.779,6

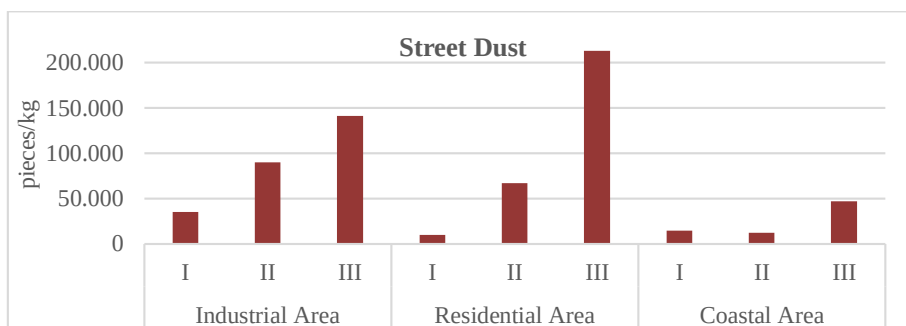


Figure 4: Street Dust

4. CONCLUSION

In this study, atmospheric deposition and street dust samples were collected at three different points in Çorlu and its surroundings—an area characterized by heavy industry and dense residential population. Samples were taken from two points with high industrial activity and dense residential population, as well as from a coastal area with no pollution sources. MP detection was conducted on atmospheric deposition and street dust samples collected over three separate periods. After pre-processing the samples, the quantities of MPs were determined by counting based on specific criteria, categorizing them by number, shape, and color. Overall, higher concentrations were found in industrial and residential areas, with the lowest values measured in samples collected from the coastal area. The highest values by shape and color across all sampling points were black points and black pieces. As observed in this and similar studies, MP pollution is a significant issue in urban areas. Particularly in industrial zones like Çorlu, which have both high urban density and industrial activities such as textile and plastic recycling, MPs need to be continuously monitored and included in measurement plans. This study serves as an initial study for the region, indicating the necessity for more frequent sampling from different matrices and conducting advanced chemical analyses to determine polymer types. The information obtained will help reveal the interaction between MP pollution and public health in the region and identify the measures needed to reduce MP pollution.

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ADSORPTION OF METHYLENE BLUE FROM TEXTILE WASTEWATER WITH PYROLYZED WALNUT SHELL

Scientific paper,
DOI: 10.5937/CT_ITI24064K

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ABSTRACT: Discharge of colored wastewater, especially textile applications, into receiving environments can cause serious environmental problems. Conventional methods are not preferred because they are not successful in the treatment of colored wastewater or are not economical. Among different techniques, adsorption is gaining importance in pollutant removal from wastewater due to its low operating cost and ease of use. The use of agricultural wastes as low-cost adsorbents in the removal of dyestuffs from wastewater after applying various activation processes is of interest.

The aim of this study is to evaluate the adsorption performance of methylene blue (MB) dye, which is used in textile, from aqueous solutions with walnut shell (WAC), an agricultural waste that has been pyrolyzed and activated with phosphoric acid. In the study, in batch experiments were carried out at fixed adsorbent dose (0.1 g/200 mL), constant temperature (20 °C), different pH values (4, 6, 7, 9, 11), different contact times (0, 5, 15, 30, 60, 90 and 120 minutes), different initial dyestuff amounts (2, 4, 6, 8 and 10 mg/L) and at different adsorbent doses (0.05, 0.1, 0.2, 0.5 and 1 g/ 200 mL) was carried out. Moreover; the effect of ionic strength on the color removal efficiency from the dye solution was evaluated by adding different salt doses (500, 1000, 1500, 2000 and 2500 mg/L NaCl). By increasing the pH value of the dye solution from 4 to 11, the color removal efficiency by WAC was determined as 65% at 90 minutes for pH:9, 4 mg/L MB concentration and 0.1 g/200 mL adsorbent dose. Optimum pH values were determined as 9 for WAC. In all experiments, adsorption increased with increasing contact time, and removal efficiency decreased with the increase in dye concentration. The color removal efficiency increased slightly with increasing ionic strength. While 38% removal efficiency was achieved with 2000 mg/L NaCl application in 90 minutes, the removal efficiency decreased to 30% with 2500 mg/L NaCl application.

Keywords: Textile wastewater, methylene blue, color removal, walnut, adsorption, activated carbon.



ADSORPCIJA METILENSKE PLAVOSTI IZ TEKSTILNIH OTPADNIH VODA SA PIROLIZOVANOM LJUSKOM ORAHA

APSTRAKT: *Ispuštanje obojene otpadne vode, posebno tekstilnih aplikacija, u prijemno okruženje može izazvati ozbiljne probleme životne sredine. Konvencionalne metode nisu poželjne jer nisu uspešne u tretmanu obojenih otpadnih voda ili nisu ekonomične. Među različitim tehnikama, adsorpcija dobija na značaju u uklanjanju zagađivača iz otpadnih voda zbog niskih operativnih troškova i lakoće upotrebe. Interesantna je upotreba poljoprivrednog otpada kao jeftinih adsorbenata u uklanjanju boja iz otpadnih voda nakon primene različitih procesa aktivacije.*

Cilj ovog istraživanja je da se proceni sposobnost adsorpcije boje metilen plavo (MB), koja se koristi u tekstilu, iz vodenih rastvora sa ljuskom oraha (VAC), poljoprivrednog otpada koji je pirolizovan i aktiviran fosforom kiselinom. U studiji su serijski eksperimenti izvođeni pri fiksnoj dozi adsorbenta (0,1 g/200 mL), konstantnoj temperaturi (20 °C), različitim pH vrednostima (4, 6, 7, 9, 11), različitim kontaktnim vremenima (0, 5, 15, 30, 60, 90 i 120 minuta), različite početne količine boje (2, 4, 6, 8 i 10 mg/L) i različite doze adsorbenta (0,05, 0,1, 0,2, 0,5 i 1 g / 200 mL). Štaviše; Efekat jonske snage na efikasnost uklanjanja boje iz rastvora boje je procenjen dodavanjem različitih doza soli (500, 1000, 1500, 2000 i 2500 mg/L NaCl). Povećanjem pH vrednosti rastvora boje sa 4 na 11, efikasnost uklanjanja boje pomoću VAC-a je određena kao 65% na 90 minuta za pH:9, 4 mg/L MB koncentracije i 0,1 g/200 mL doze adsorbenta. Optimalne pH vrednosti su određene kao 9 za VAC. U svim eksperimentima, adsorpcija se povećava sa povećanjem vremena kontakta, a efikasnost uklanjanja opada sa povećanjem koncentracije boje. Efikasnost uklanjanja boje blago se povećala sa povećanjem jonske snage. Dok je efikasnost uklanjanja od 38% postignuta primenom 2000 mg/L NaCl za 90 minuta, efikasnost uklanjanja je smanjena na 30% sa primenom 2500 mg/L NaCl.

Ključne reči: *Tekstilna otpadna voda, metilen plavo, uklanjanje boje, orah, adsorpcija, aktivni ugalj*

1. INTRODUCTION

Textile wastewater is intensely colored and direct discharge of this wastewater into the receiving environment can cause many environmental problems such as decreased light transmittance, aesthetic deterioration, and negative effects of life in the aquatic environment. Traditional methods for treating textile wastewater mostly rely on organic carbon removal. Traditional treatment methods used to treat wastewater of industries that produce colored wastewater, such as the textile industry; coagulation flocculation, biological treatment, oxidation etc. However, activated sludge systems are mostly preferred. However, these treatment systems are not effective in removing color from wastewater containing dyestuffs that resist biological parasites and oxidation. Coagulation-flocculation, advanced oxidation processes (as $H_2O_2 + Fe^{+2}$), membrane processes and

electrochemical methods are effective in color removal. However, these methods have disadvantages such as high cost and high amount of sludge formation [1].

The most preferred method for color removal is adsorption, and activated carbon in granular or powder form is generally used as an adsorbent. However, commercial activated carbon costs are also quite high. For this reason, research is being carried out on the production of adsorbents with high adsorption capacity using materials such as different agricultural wastes (walnut shells, almond shells, olive seeds, rice husks, etc.) as an alternative to commercial activated carbon [2]. Active carbon from agricultural wastes is used. The most important reason for choosing carbon production is that it provides both environmental and economic benefits. Generally, for the production of activated carbon, the carbonization and activation process of the material is applied by oxygen-free combustion with inert gas flow (such as N_2) in an oxygen-free environment below 800 °C. During the carbonization process, non-carbonic elements turn into volatile gases and are removed. The structure formed by the remaining carbon atoms is disordered. In this way, gaps are created between them. Thanks to these gaps, it can show good adsorbent properties. The quality parameters that show the effect of the carbonized material on the adsorption efficiency are affected by the heating rate in the pyrolysis application, the final temperature, the holding time at the final temperature, and the structure and physical properties of the raw material [3].

In this study, the use of walnut shells, which are produced in large quantities around the world due to their easy adaptation to different climates, as an adsorbent in color removal was investigated. For this purpose, the biochar obtained from pyrolyzed walnut shell was activated using phosphoric acid and Methylene Blue (MB) adsorption was evaluated by taking into account the effect of pH, contact time, initial concentration and ionic strength.

2. MATERIAL AND METHOD

2.1. Preparation of adsorbent

In this study, walnut shells used as feed for the pyrolysis unit were obtained from local markets. Walnut shells were chopped into pieces with a diameter of 2-3 cm and subjected to pyrolysis with nitrogen gas at 600 °C for 2 hours. The pyrolysis process was carried out in a down-flow, fixed bed and throatless type pyrolysis unit. The pyrolysis unit was operated at a speed of 200 kg/m²h. The resulting biochar was sieved to be smaller than 1 mm. Biochar obtained from walnut shells was activated with phosphoric acid. For this, biochar with H_3PO_4 (85 %) at a ratio of 1:3 (w:w) in an oven at 105 °C for 12 h. The resulting activated adsorbent was washed with distilled water and dried in an oven at 105 °C and labeled as WAC [4].

2.2. Analytics

The dye concentration in the samples collected after the adsorption process was measured at a wavelength corresponding to the maximum absorbance (λ_{max} 670 nm) using a Thermospectronic AquaMate brand spectrometer. Accordingly, as a result of



measurements made at different wavelengths (400 nm–700 nm), 670 nm was the wavelength that gave the highest adsorbance.

2.3. Dye adsorption

Methylene blue (MB) is a cationic dye and has numerous uses in the textile and paper industry. MB used as adsorbate was supplied as Merck brand. A 20 mg/L stock solution was prepared and used in dilutions (2-10 mg/L) for adsorption studies. In the study, in batch experiments, fixed adsorbent dose ($m=0.1$ g/200 mL), constant temperature (20°C), different pH (4, 6, 7, 9, 11), different contact time (0, 5, 15, 30, 60, 90 and 120 minutes), at different initial dyestuff amounts ($C_0=2, 4, 6, 8$ and 10 mg/L) and at different adsorbent doses ($m=0.05, 0.1, 0.2, 0.5$ and 1 g/200 mL) was carried out. Moreover; The effect of ionic strength on the color removal efficiency from the dye solution was evaluated by adding different doses of salt (500, 1000, 1500, 2000 and 2500 mg NaCl/L). The collected samples were centrifuged at 3500 rpm for 5 minutes, and then color measurement will be carried out in a spectrophotometer.

3. RESULTS AND DISCUSSION

3.1. Effect of pH

The pH value of the solution significantly affects the adsorption of the dye molecule. The reason for this is that it affects the binding units on the surface of the dye molecule and the adsorbent. Since the chemistry of the dye molecule and adsorbent in aqueous solutions is affected by the pH value of the solution, the effect of pH was first examined in studies on the removal of MB from aqueous media with WAC. It has been evaluated at different pH values such as pH 4, 6, 7, 9 and 11.

pHpzc is an important parameter to explain the adsorption mechanism and determine the optimum pH value. The pHpzc value for WAC was determined as 5.8 ± 0.2 . If the pH value of the adsorbent is above the pHpzc value, the adsorbent becomes negatively charged. Therefore, when the adsorbent surface is negatively charged, the cation adsorption ability will increase due to the effect of electrostatic attraction. At pH values below this value, the pH of the solution tends to increase. Color removal efficiencies for WAC depending on pH change are shown in Figure 1.

The pH effect on MB adsorption with WAC was evaluated for 4, 6 (original pH), 7, 9 and 11 ($C_0 = 4$ mg/L and $m=0.1$ g/200mL adsorbent dose). An increase in removal efficiency was determined with an increase in the pH value of the solution. While the removal efficiency was 27% at pH:4, the removal efficiency reached 65% at pH:9. In case of pH: 11, the removal efficiency (61%) tended to decrease. Since MB is a cationic dye, it can be stated that electrostatic attraction and ion exchange may be effective in the adsorption mechanism. The maximum removal efficiency was obtained at pH:9. In subsequent evaluations, pH 9 value was taken as a referenc

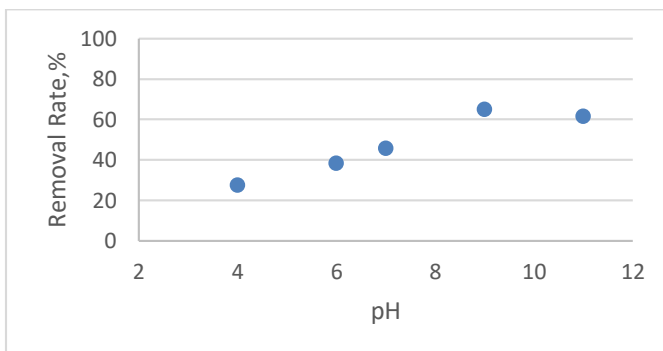


Figure 1: Effect of pH on removal rate ($t=90$ min, $C_o=4$ mg/L, $m=0.1$ g/200mL)

3.2. Effect of initial dye concentration

Removal efficiencies in MB adsorption with WAC at different initial dye concentrations, 0.1 g/200 mL adsorbent dose and constant pH (pH:9) conditions at a contact time of 90 minutes are shown in Figure 2. Removal efficiencies decreased due to increasing MB concentration. At the end of 90 min, the removal efficiency obtained for 2 mg/L MB was 67%, while the removal efficiency was determined as 13% at 10 mg/L MB concentration.

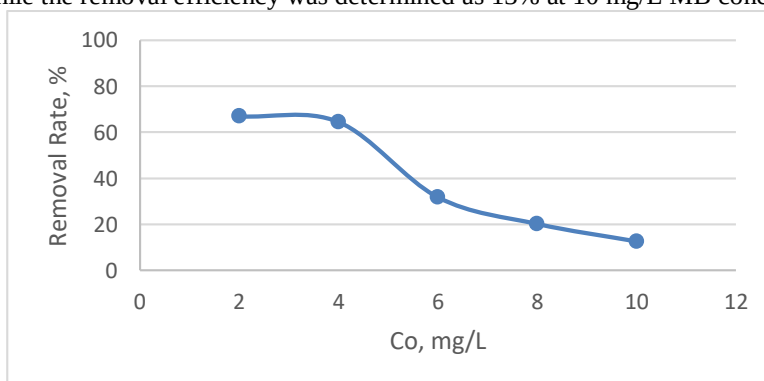


Figure 2: Effect of initial dye concentration ($t=90$ min, $m=0.1$ g/200mL, pH:9)

Removal efficiencies decreased with the increase in initial MB concentration. This can be expressed as the required driving force above the mass transfer resistance of MB being provided by the initial MB concentration [5]. With the increase in C_o , the removal efficiency decreased as the binding areas on the WAC surface were filled by MB. At low C_o values, MB could bind to effective sites on the WAC surface, and a high adsorption rate could be achieved. With the increase in MB concentration, the areas that can be adsorbed on the WAC surface decrease [6].

3.3. Effect of Contact Time

The change in removal efficiency depending on contact time in MB adsorption experiments with WAC within 4 mg/L initial dye concentration, 0.1 g/200 mL adsorbent dose, 120 min contact time is shown in Figure 3. According to Figure 3, adsorption was rapid and removal efficiency increased with the increase in contact time. It was assumed that the equilibrium state was reached in 90 min. The optimum contact time was accepted as 90 min.

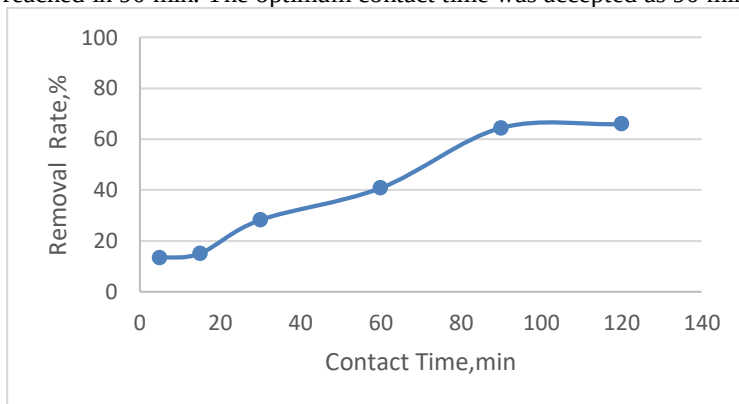


Figure 3: Effect of contact time ($m=0.1$ g/ 200mL, $pH:9$, $Co=4$ mg/L)

3.4. Effect of adsorbent dosage

Adsorbent dose is also an important parameter in determining adsorption efficiency in adsorption applications. The change in removal efficiencies depending on different adsorbent doses in case of $Co=4$ mg/L, $pH:9$ and 90 min contact time is shown in Figure 4. As seen in Figure 4, dye removal efficiencies increased from 26% to 92% by increasing the adsorbent dose from 0.05 g/200 mL to 1 g/200 mL. This situation can be explained by the increase in dye-binding areas on the adsorbent surface

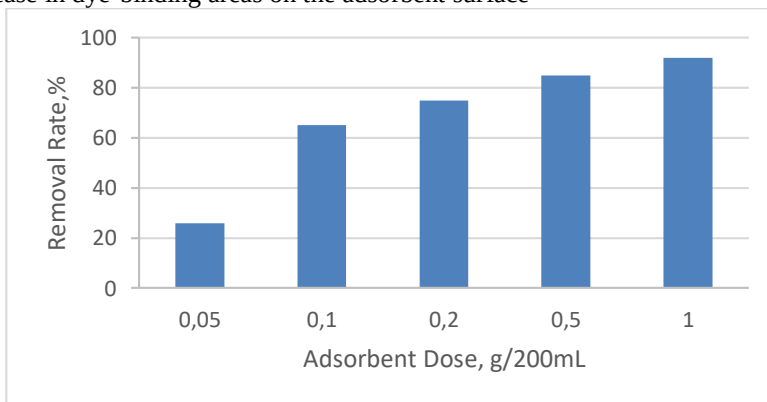


Figure 4: Effect of adsorbent dose ($t= 90$ min, $Co= 4$ mg/L, $pH:9$)

3.5. Effect of ionic strength

The effect of ionic strength on dyestuff adsorption with WAC was realized by adding 500, 1000, 1500, 2000 and 2500 mg/L NaCl into the dyestuff solution. The removal efficiencies obtained for different NaCl concentrations in the case of pH: 9, 0.1 g/ 200 mL adsorbent dose and $C_0=4$ mg/L are shown in Figure 5. While the removal efficiency was 65% in the absence of NaCl, the removal efficiency decreased to 18% in the presence of 500 mg/L NaCl. Accordingly, an increase in MB removal efficiency was observed with the increase in ionic strength.

A removal efficiency of 38% was achieved with the application of 2000 mg/L NaCl, but the maximum removal efficiency decreased slightly (30%) with the application of 2500 mg/L NaCl. Industrial wastewater may contain high concentrations of salt as well as dyestuffs, and salt concentration may affect adsorption. In typical dyeing processes, salt can accelerate or slow down dye adsorption. Various studies have evaluated the effect of salt concentration during dye adsorption [7-8]. In general, a decrease in adsorption capacity is observed with an increase in ionic strength. The reason for this is the electrostatic interaction between the adsorbent surface and the adsorbed substance [7]. The change in ionic strength with the addition of electrolyte can affect the potential interfaces on the adsorption surface of the electrolyte ions and compete for the sorption areas between the electrolyte ions and the adsorbed ions.

In this study, a decrease in removal efficiency was determined by increasing the ionic strength in the solution. However, with the increase in NaCl concentration, removal efficiencies tended to increase. The presence of NaCl in solution can cause two opposite effects. One of these is that it can shield the electrostatic interaction between dye molecules and adsorbent. MB adsorption capacity may decrease with the increase in NaCl concentration. Another is that salt positively affects adsorption by facilitating the dissociation of dye molecules into their protons.

According to the results obtained, the dye removal efficiency increased until 2000 mg/L NaCl, but the removal efficiency tended to decrease again when it was 2500 mg/L NaCl. It can be said that this situation arises from the decomposition of the dyestuff under the influence of salt. Similar results were obtained in some studies evaluating the effect of NaCl on the adsorption of various dyestuffs [8-9].

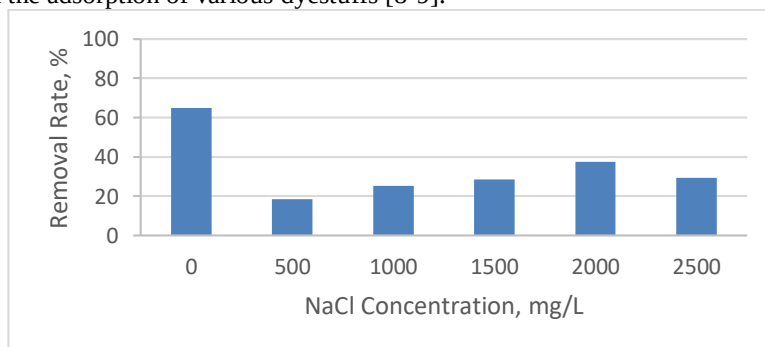


Figure 5: Effect of ionic strength ($t=90$ min, $C_0=4$ mg/L, pH:9, $m=0.1$ g/200mL)



4. CONCLUSION

In this study, activated carbon (WAC), obtained by activating the biochar obtained as a result of applying pyrolysis to walnut shells, which is an agricultural waste, with phosphoric acid, was used to remove MB by adsorption. The results of the study are summarized as follows;

- The maximum removal efficiency with WAC was determined as 65% ($t=90$ min, $pH:9$, $Co=4$ mg/L MB and $m=0.1$ g/200 mL adsorbent dose)
- Optimum pH values are 9 for WAC.
- In all experiments, adsorption increased with increasing contact time, and removal efficiency decreased with the increase in dye concentration.
- While the removal efficiency was 65% in the absence of NaCl, the removal efficiency decreased to 18% in the presence of 500 mg/L NaCl. The dye removal efficiency increased until 2000 mg/L NaCl, but at 2500 mg/L NaCl, the removal efficiency tended to decrease again. It can be stated that the salt concentration affects both the shielding of the electrostatic interaction between the dye molecules and the adsorbent and the fact that the salt facilitates the dissociation of the dye molecules into protons.

As a result, the use of WAC in the removal of MB dyestuff, which is widely used in the textile industry, by adsorption process has been evaluated, and kinetics and isotherm calculations continue in the other part of the study. Additionally, the physical and chemical properties of the adsorbent used will also be determined. The fact that WAC, which will be used instead of commercial activated carbon in color removal from textile industry wastewater, is produced from waste material, makes it economically and ecologically advantageous.

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ALBANIAN GARMENT AND LEATHER FOOTWEAR INDUSTRY; CHALLENGES FOR SUSTAINABILITY AND GREEN DEVELOPMENT

Professional paper
DOI: 10.5937/CT_ITI24065L

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ABSTRACT: Albanian Garment and Leather Footwear Industry, remain one of the most advanced among the other Balkan regions regarding operational environment, due this to the implementation of digital reforms from the government. Although this is an advantage, many companies are facing challenges due to external and internal factors. This is due to many factors such as the COVID–19 pandemic, internalization, technology innovation, decrease of primary resources, customer demand customized at the lowest price, etc. Albania cannot be called a free labor force, on the other hand, the devaluation of the euro, technological transformations, and the implementation of EU legislation to protect primary resources, by leading them through sustainability and green production. This sector nowadays needs to change the concept of production by investing in advanced technology, if they want to survive in the local and EU market.

Keywords: Garment and leather footwear, green development, sustainability, advanced technology.

ALBANSKA INDUSTRIJA ODEĆE I KOŽNE OBUĆE; IZAZOVI ZA ODRŽIVOST I ZELENİ RAZVOJ

APSTRAKT: Albanska industrija konfekcije i kožne obuće ostaje jedna od najnaprednijih regiona na Balkanu u pogledu operativnog okruženja, zahvaljujući implementaciji digitalnih reformi od strane vlade. Iako je ovo prednost, mnoge kompanije se suočavaju sa izazovima zbog spoljašnjih i unutrašnjih faktora. To je zbog mnogih faktora kao što su pandemija COVID-19, internalizacija, tehnološke inovacije, smanjenje primarnih resursa, potražnja kupaca prilagođena po najnižoj ceni, itd. Albanija se ne može nazvati slobodnom radnom snagom, s druge strane, devalvacija evra, tehnološke transformacije i implementaciju zakonodavstva EU za zaštitu primarnih resursa, vodeći ih kroz održivost i



zelenu proizvodnju. Ovaj sektor danas treba da promeni koncept proizvodnje ulaganjem u naprednu tehnologiju, ako želi da opstane na lokalnom i tržištu EU.

Ključne reči: Konfekcija i kožna obuća, zeleni razvoj, održivost, napredna tehnologija.

1. INTRODUCTION

Albania's Garment and leather footwear industry has a significant potential. This sector created around 30,000 employment opportunities in the clothing industry and 40,000 in the leather footwear industry. It encompasses 802 small and medium-sized enterprises (SMEs) operating in the country. About 95% of companies are oriented towards CM and CMT production, with customers ordering from EU countries. About 5% of companies operate with their brands for the local and foreign markets [2].

In 2022, this industry accounted for approximately 38% of the country's total exports [1]. Despite efforts by Garment and leather footwear companies in Albania over the past two decades, to invest in updated technology, the existing technology and human resource investments still do not meet the need for high competitiveness in European and global markets [2].

Although Garment and Leather Footwear companies operating in this sector have made efforts to invest in updated technology, the current technology in use and human resource investments still need to meet the requirements for high competitiveness in European and global markets [2].

Achieving sustainability in this sector requires the adoption and investment in new technologies and considerable efforts to integrate existing policies, laws, and stakeholders' diverse interests into a unified framework.

2. SECTOR ANALYZE EXPORTS AND IMPORTS OF GARMENT AND LEATHER FOOTWEAR

Albania's garment and leather footwear industry has encountered difficulties and challenges since 2020 [2].

The challenges faced by the garment and leather footwear industry in Albania include:

- Competition and globalization.
- Technological upgrades.
- Human resources.
- Supply chain disruptions.
- Sustainability and ethics.
- Market trends.
- Regulations and compliance.

These challenges have negatively impacted the industry, leading them to the closure of 100 companies and an increase in unemployment [2].

This sector in 2023 had a Total annual turnover (garment and footwear) of 1000 million Euro and 41% export contribution of all industries, according to Instat [1].



During the month of December 2023, this industry had a negative impact on the annual decrease in exports with a value of - 4.1 percentage points and -1.0 points percentage for imports [Instant]; this is related to some of the factors mentioned above [1].

This negative impact was caused by many internal and external factors, one of which was the euro devaluation, product diversification, lack of client orders, and EU regulation for Green products.

In 2023, exports decreased by 7%, and imports decreased by 8% compared to 2022 [2].

Table 1: Exports/Imports of Textile and Leather; Footwear Foreign trade according to the products, 2019-2023/ *million ALL*

Exports / Imports of textile and Leather Footwear (Mill AL)					
Textile and footwear; Foreign trade according to the products, 2019-2023/ <i>million ALL</i>	2019	2020	2021	2022	2023
Exports of textile and leather					
Textile & textile materials	61,235,760,695	56,679,554,613	61,292,341,209	69781820112	70,127,952,775
Leather footwear	56,965,779,270	45,664,926,626	51,162,755,258	65440203344	56,179,808,567
Exports of textile and leather footwear (Mill AL)	118,201,539,965	102,344,481,239	112,455,096,467	135,222,023,456	126,307,761,342
Imports of textile and leather					
Textile & textile materials	71,073,141,113	63,272,740,756	76,217,550,198	84,614,515,730	79,879,959,872
Leather footwear	16,129,723,827	12,184,034,004	14,613,078,109	17,173,683,613	14,310,607,785
Imports of textile and leather footwear (Mill AL)	87,202,864,940	75,456,774,760	90,830,628,307	101,788,199,343	94,190,567,657

Overall, the Albanian garment and leather footwear industry faces challenges that necessitate the adoption of advanced technology and sustainable practices based on EU regulation for Green Products, to ensure its survival and competitiveness in both local and EU markets.

3. DENIM FACTORY: AN ECO-FRIENDLY AND SUSTAINABLE ENTERPRISE - CASE STUDY

The origin of jeans dates back to the 16th century. Denim is a valuable and comfortable material for clothing that has gained popularity for many decades, and still does.

Jeans, a global staple in the fashion industry, are among the most sold and used garments worldwide. However, the chemical colors and laundry processes used in their production have a significant negative impact on the environment.

In the denim washing industry, significant advancements are being made to reduce environmental impact. Innovative approaches such as laser technologies, ozone-washing methods, water-free technology, and sustainable dyeing techniques are transforming traditional practices. Some Albanian denim companies, such as Krienko Jeans Blue Sky and Denim Factory Group, have adopted eco-friendly practices and transparent supply chains, contributing to a cleaner future.

Denim Factory Group produces for Italian and EU suppliers. With an experience of over 20 years, the company has been cooperating and still cooperates with important clients such as SCOUT, PINKO, TRUSSARDI, JAQUMUS, JECKERSON, RELISH, GAS, DIXIE, ROY ROGERS, DIESEL.

The production lines produce approximately 2500/3000 pieces per day.

The Laundry / Denim Dyeing in Denim Factory Group is extensive and is divided respectively into: Laundry Department, Dyeing Department, Jeans Collection and Dyeing Sample Department, Laser Department

The company fulfills different requests by using new technologies and the latest machines for printing, laser, and embroidery.

3.1. Dyeng process

In the dyeing laboratory for white textiles, the process begins with a thorough examination of the sample sheet. This involves assessing the color, conducting tests such as colorfastness and dye penetration, and sending the sample to the customer for approval.

Based on the comments that are brought to the company, they proceed further with the production with the color that the customer has approved

Before sending campions to the customer, two or three tests are done to achieve the color requested by the customer; the coloring powder is weighed based on the weight of the sample, and the weight of the colorant is calculated. More than three color mixtures can be made to achieve a single color, then the mass of powder prepared with hot water is mixed and the solution is put in the washing machine, for the dyeing process.



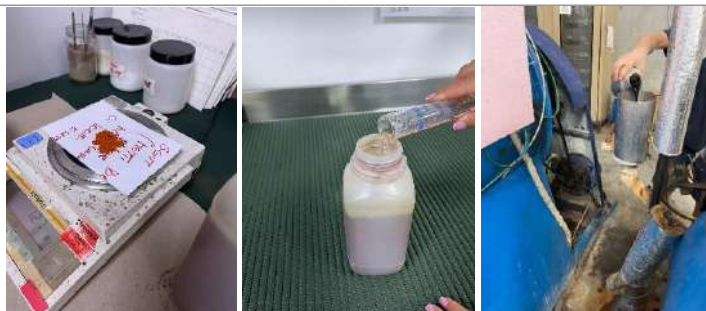


Figure 1: Laboratory of dyeing equipments

The Laundry Department has a production capacity of about 4,000 items per day. The use of ozone-flow technology, which significantly reduces water waste, is another investment of the company. The company produces certified eco-sustainable products for environmental protection.

The company produces certified eco-sustainable products for environmental protection. In collaboration with many clients, they are developing projects with eco-sustainable products, creating certified washes and fabrics, which are enjoying tremendous success in sales.



Figure 2: Laundry Machines

3.1.2 Jeanologia laser technology

The company have invest in Jeanologia laser equipment. It works as a thermal source, eliminates the indigo dye of denim fabric by sublimation through heat.

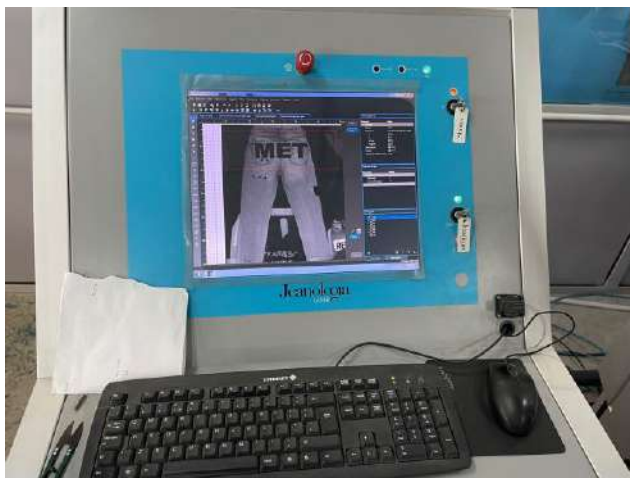


Figure 3: Jeanologia Laser Machine

By using this laser, the company gives the fabric a faded or patterned look based on the client's orders.



Figure 3 a: Faded Denim product designed in Jeanologia Laser

Depending on the client's request, the company also uses the laser for logo brand design as it is shown in the figure 4.



Figure 4: Logo Denim product designed in Jeanologia Laser

This innovative method not only minimizes water usage, replace chemical hazard, reduces time and costs, protect environment based on EU legislation, but also plays a crucial role in protecting workers from harmful processes. That means that the company will have high-quality production and productivity improvement.

3.2. Minimizing water consumption

The company have invest in technology and equipments to minimize water consumption by filtering and reusing water.

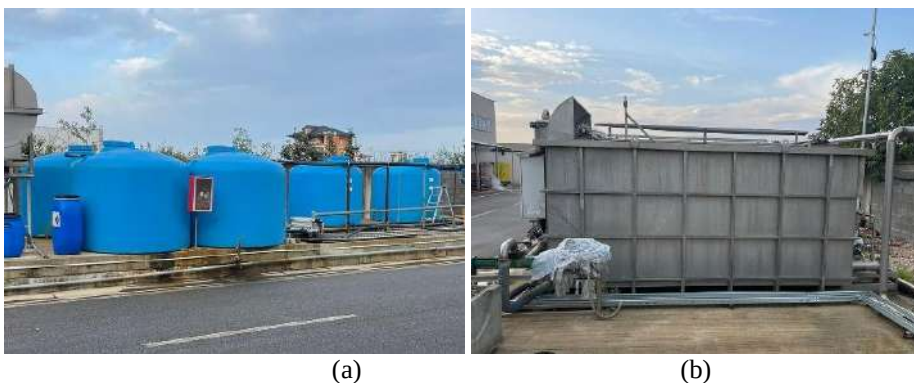


Figure 5: Water reservoirs (a); Water filtration (b)



Figure 5 (c): Water Draining from the laundry

4. CONCLUSION

Innovations for Sustainability (Water-Free Lasers) in Denim Group Factory have a positive impact on environmental protection and in minimization of low primary resources (water, energy, chemical reduction of carbon footprint).

This laser offer several benefits in denim washing, making them an eco-friendly and efficient choice:

- **Conservation of Water:** As the name suggests, water-free lasers eliminate the need for excessive water during the fading process. Traditional wet processes consume large amounts of water, contributing to environmental strain.
- **Precision and Customization:** Water-free lasers offer a level of precision and customization that is unmatched in the denim industry. They allow for the precise fading and distressing of denim, enabling designers to create intricate patterns, whickering, and worn effects with unparalleled accuracy. This level of customization enhances the uniqueness of each pair of jeans, appealing to consumers who value quality and individuality.
- **Reduced Chemical Usage:** Unlike chemical-based techniques, water-free lasers don't require bleaching agents or dyes. This significant reduction in chemical usage not only minimizes chemical pollution but also ensures a safer working environment for workers, providing reassurance about the safety of the process.
- **Energy Efficiency:** Water-free laser machines are designed to consume less energy than traditional washing methods. This high level of efficiency not only contributes to a greener production process but also instills optimism about its Sustainability.



- **Speed and Productivity:** Lasers work swiftly, reducing production time. Faster processing means quicker turnaround for denim manufacturers.
- **Worker protection.**

The company has also invested in equipment for water filtration and its discharge, as well as in energy with solar panels and LED lights.

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LIMIT VALUES OF WASTEWATER EMISSIONS OF THE TEXTILE INDUSTRY AND THEIR INFLUENCE ON THE SUSTAINABLE MANAGEMENT OF WATER RESOURCES

Original scientific paper
DOI: 10.5937/CT_ITI24066S

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ABSTRACT: The textile and clothing sector has been changing rapidly over the past years as a result of technological development and changes in economic conditions, as well as increasing competitive pressure, which also caused the restructuring of companies, modernization of production and adaptation to technological changes. As a consequence of this very development of technology and industrialization, major problems have arisen regarding the pollution of natural waters with various contaminants that are discharged from the technological processes of the textile industry into the recipients. Compliance with the legal regulations regarding the limit values of emission of polluting substances that are released into recipients is of exceptional importance in the preservation and sustainable management of water resources. In this regard, the aim of the work is to point out significant mechanisms and instruments for managing harmful substances present in the production processes of the textile industry, which are needed to ensure the sustainable management of water resources and indicate protective measures in this important segment of the environment. The obtained results indicate that this research can be successfully used as a model in the management of the quality of the working and living environment.

Keywords: chemical hazards, health of employees, working environment, textile industry.

GRANIČNE VREDNOSTI EMISIJE OTPADNIH VODA TEKSTILNE INDUSTRIJE I NJIHOV UTICAJ NA ODRŽIVO UPRAVLJANJE VODNIM RESURSIMA

Savez inženjera i tehničara tekstilaca Srbije



APSTRACT: Sektor tekstila i odeće tokom proteklih godina menjao se ubrzano kao rezultat tehnološkog razvoja i promena ekonomskih uslova, kao i sve većeg konkurentskog pritiska što je uslovalo i prestrukturiranje preduzeća, osavremenjivanje proizvodnje i prilagođavanje tehnološkim promenama. Kao posledica upravo tog razvoja tehnologije i industrijalizacije, javili su se i veliki problema oko zagađenja prirodnih voda najrazličitijim kontaminantima koji se ispuštaju iz tehnoloških procesa tekstilne industrije u recipijente. Karakteristike otpadnih voda koje u recipijente dospevaju iz proizvodnih procesa tekstilne industrije variraju u zavisnosti od izvora zagađenja, te poštovanje zakonske regulative u pogledu graničnih vrednosti emisije zagađujućih materija ima izuzetan značaj u očuvanju i održivom upravljanju vodnim resursima. S tim u vezi cilj rada je da ukaže na značajne mehanizme i instrumente upravljanja štetnostima prisutnim u proizvodnim procesima tekstilne industrije kako bi se osiguralo održivo upravljanje vodnim resursima i ukazalo na mere zaštite od zagađenja ovog važnog segmenta životne sredine. Dobijeni rezultati rada ukazuju, da se ovo istraživanje može uspešno koristiti kao model u upravljanju kvalitetom radne i životne sredine.

Ključne reči: zagađujuće materije, otpadne vode, granične vrednosti emisije, tekstilna industrija.

1. INTRODUCTION

The relationship between human and nature has changed significantly throughout history. The increase in the number of population, as well as the accelerated technological development at the global level, has significantly affected the quality of water, soil and air. Apart from the negative impact on the environment brought about by the modern way of life, the need for resources has also increased. In this regard, the global need for water of acceptable quality for the population and the economy has placed demands on society to analyze this problem and explore possibilities for its sustainable use [1]. It is a well-known fact today that both natural and anthropogenic sources of pollution have the greatest influence on water pollution. Natural sources of pollution largely depend on geographical location, climatic characteristics, etc., while anthropogenic sources of pollution come from the industry [2] whereas the textile industry occupies a special place.

The sector of the textile industry is one of the most complex production sectors of the industry. It is accompanied by a long tradition and rich historical development. More than 2.5 million workers are employed in over 100 countries where textile production is developed. The sector of this industry is composed of a large number of sub-sectors, starting from the production of raw materials, through semi-finished and finished products. Due to the differences in the production processes of such a branched industry, there is a realistic need to use a large number of chemical substances. Unfortunately, that trend is constantly growing, as a result of the increased demand and consumption of textile products that belong to the group of consumables, and are causally related to the increase in the number of inhabitants with a high standard of living [3].



The wide use of chemicals in the textile industry can be the cause of numerous side effects during the production itself, use and after-use of the product, i.e. during the entire life cycle of textile products. In order to establish a safe way of using chemicals in the textile industry, it is necessary to harmonize standards, make a systemic effort in innovation and ensure complete safe treatment of chemicals and waste water from production processes [4].

Considering the extent of use of chemicals, defining the limit values of the concentrations of chemicals that are released from the production processes of the textile industry is extremely important, first of all, in order to protect the environment, but also the health and safety of people [5].

Due to all of the above, in this paper, an analysis of the regulations related to the treatment of waste water was carried out, with a special emphasis on the limit values of the emission of polluting substances into water from the production processes of the textile industry.

2. TEXTILE INDUSTRY

2.1. Waste water from the production processes

The status of the textile industry from the aspect of sustainable development is not favorable. Globally, this branch of industry is still considered one of the biggest polluters of the environment, while textile waste is becoming an increasing environmental problem. Based on the conducted research, it was determined that more than 8,000 chemical substances are used in the technological processes of the textile industry, which means that there is literally no textile product that has not been chemically treated, i.e. it is not "chemical-free". The wide range of chemicals used in the textile industry can cause an unwanted impact on humans and the environment during the entire life cycle of textile products. Chemical substances from textile products can be emitted in several ways - migration, leaching, evaporation and emission [6]. Emissions from textile products depend on factors such as the physico-chemical properties of the substances, the integration of the substances into the materials, the nature of the fibers and the way the textile is handled. For most of these chemical substances, there are no reliable data on whether and to what extent they negatively affect the health of employees who are in direct contact with it in the production process, as well as the users. The currently available data show that the impact of these components on the environment is extremely large. Wastewater from production processes can be loaded with numerous chemical substances that are reliably known to be difficult to remove from water and require complex technological processing.

In regards to the above, a research was carried out on the legal regulations in the field of waste water in Serbia, with a special emphasis on the limit values of the emission of polluting substances in the waste water of the textile industry, the results of which are presented in this paper.

2.2. Legislative framework

EU directives on integrated pollution prevention and control (*Directive Concerning Integrated Pollution Prevention and Control, IPPC*) [7] and industrial emissions (*Directive on industrial emissions*) [7], and regarding the Water Framework Directive (*Water*



Framework Directive EU/WFD-2000 /60/EC) [7] laid the foundations of legal frameworks in the field of sustainable management of water resources and effluent parameters after the treatment.

The selected parameters set requirements for the implementation of various measures, especially with regard to water protection. The legislative framework on the protection of the environment and natural resources in the Republic of Serbia follows the current legislation of the European Union. The most important strategic document that determines the long-term directions in water management on the territory of Serbia is certainly the Water Management Strategy [8], and all the necessary reforms of the water sector with the aim of reaching standards are carried out on the basis of the Strategy as well as the Law on Water [9]. The Law on Water is the umbrella law of our legal system of water protection, and there is a whole set of laws and by-laws that deal with these issues. The Regulation on limit values of emission of polluting substances into water and deadlines for their achievement [10] is of particular importance in the segment of emission of polluting substances from industrial production facilities. The emission values for certain groups or categories are included in the annex to this Regulation, and within the framework of industrial waste water, the Regulation also includes waste water from the textile industry.

2.3. Limit values of waste water emissions from textile processing and production

In view of the above, and bearing in mind the complexity of the production process of textile product treatment, the emission of waste water from the plant must be at the lowest level of polluting substances. This can only be achieved if water is treated and reused, while the use of synthetic products, organic-complex compounds and surfactants and other similar materials is limited. Accordingly, it is necessary to carry out regular monitoring of waste water before mixing it with other waste water. The frequency and the methods applied in the purification or pretreatment process determine the frequency of examination of the composition, quantity and quality of wastewater. In accordance with the legal regulations, the limit values of the emission of chemical substances from the production processes of the textile industry at the point of discharge into surface water are determined, as shown in Table 1.

Table 1. Emission limit values at the point of discharge into surface waters [10]

Parameter	Unit	Emission limit value ^(II)
Temperature	°C	30
pH		6.5-9
Suspended matter	mg/l	80
Biochemical oxygen consumption (BOD5)	mgO ₂ /l	30
Chemical Oxygen Demand (COD)	mgO ₂ /l	200 ^(III)
Total Organic Carbon (TOC)	mg/l	60 ^(IV)
Mineral oils	mg/l	10
Adsorbing Organic Halides (AOH)	mgCl/l	0.5



Volatile chlorinated hydrocarbons (VOX)	mg/l	0.1
Phenols	mg/l	0.1
The sum of anionic and nonionic degenerates	mg/l	1.0
Aluminum	mg/l	3.0
Copper	mg/l	0.5
Zinc	mg/l	2.0
Cadmium	mg/l	0.1
Cobalt	mg/l	0.5
Tin	mg/l	2.0
Chrome total	mg/l	0.5
Chrome VI	mg/l	0.1
Nickel	mg/l	0.5
Lead	mg/l	0.5
Active chlorine	mg/l	0.3
Total chlorine	mg/l	0.5
Ammonia (as NH ₄ -N)	mg/l	20 ^(V)
Total inorganic nitrogen (NH ₄ -N, NO ₃ -N, NO ₂ -N)	mg/l	20 ^(V)
Total phosphorus	mg/l	1.0 ^(VI)
Sulfates	mg/l	1000
Sulfides	mg/l	1
Sulfites	mg/l	1.0
Toxicity to fish (TF)		2

According to the reports available to the Serbian Environmental Protection Agency, textile industry production plants most often enter the recipients of waste water that is burdened with increased concentrations of oils and fats and increased PH values, as a result of the presence of alkali and azo-dyes. The presence of chemical substances in wastewater certainly depends on the way these waters are treated, as well as on the specifics of the production processes, which can be complex and demanding, especially in dyeing, but also in the fine processing of textiles, which requires the use of phosphonates, polyacrylates and maleic acid copolymers [10]. Tables 2 and 3 show the measured values of wastewater emissions from the production processes of the textile industry at the point of discharge, respectively. The tests were carried out during 2023, and the data refer to waste water from the production process of the textile industry, which is discharged into recipients on the territory of the Jablanica administrative district.



Table 2. Measured values of wastewater emissions from production processes of the textile industry at the point of discharge into surface waters [11]

Sample name	Waste water - Textile industry			
Field test data				
Parameter	Unit	Determined value	Permissible value	Test method
Air temperature	°C	20.2	ND	US EPA 170.1:1974
Water temperature	°C	26.4	40.0	SRPS H.Z1.106:1970
pH value	-	11.65	6.50-9.00	SRPS EN ISO 10523:2016
Electrical conductivity	μS/cm	6870	ND	SRPS EN 27888:2009
Oil and fat content	mg/l	56.80	40	EPA 1664 revision A, 1999
Ammonia content (NH3)	mgN/l	<5	10	SMEWW 4500 NH3 C 24th edition, 2022
Chromium VI content (Cr6+)	mg/l	<0.05	0.5	ISO 11083:1994
Content of anionic detergents	mg/l	0.17	10	SMEWW 5540 C 24th edition, 2022

Table 3. Measured values of metal emissions at the point of discharge into surface waters [11]

Parameter	Unit	Determined value	Emission limit value	Test method
Iron (Fe)	mg/l	<0.1	5	DM 107
Manganese (Mn)	mg/l	0.15	3	DM 107
Lead (Pb)	mg/l	<0.1	0.0012	DM 107
Copper (Cu)	mg/l	<0.1	1	DM 107
Zinc (Zn)	mg/l	0.05	2	DM 107
Cadmium (Cd)	mg/l	<0.02	0.00015	DM 107
Nickel (Ni)	mg/l	0.18	0.034	DM 107
Chromium (Cr)	mg/l	<0.1	1	DM 107



3. WASTEWATER OF THE TEXTILE INDUSTRY AND SUSTAINABLE MANAGEMENT

Water pollution, resulting from the discharge of industrial wastewater, is a current worrisome phenomenon due to its increasing impact on the health and safety of the environment [12]. Textile waste water produced in different stages of textile processing without appropriate treatment [13] usually contains huge amounts of azo dyes [14], the presence of sulfur, naphthol, sulfuric acid, soap, chromium compounds, heavy metals and certain chemicals that together make the effluent very toxic. Effluents are often of high temperature and pH, both of which are extremely harmful [15] and represent an eco-toxic hazard. In order to protect the environment and sustainably manage water resources, there are restrictions on the amount and type of chemical substances, some of which are even prohibited. To this end, numerous methods of waste water treatment are in use today in the production processes of the textile industry aimed at obtaining water of acceptable quality before mixing it with other waters. Table 4 shows existing and alternative methods of textile industry wastewater treatment [16].

Table 4. The existing and the alternative methods of textile industry wastewater treatment

Existing methods	Alternative methods
Deemulsification (1. flocculation, 2. coagulation)	Filters under pressure
Gravity settling/separation	Adsorption with activated carbon
Removal from the surface of wastewater	Ion exchange
Tubular separation	Air-stripping (separation of components from the liquid phase with the help of the gaseous phase)
Flotation (with dissolved air)	Activated sludge
Chromium reduction	Biofilm
Decomposition of cyanide	Membrane bioreactor
Chemical deposition	Electrodialysis
Filtration	Ultrafiltration
Sand filtration	Reverse osmosis

In practice, the current water management is still incomplete, primarily due to the lack of resources at all levels, and consequently, the degradation of the already existing, weak management system, and the waste water of the textile industry still represents a serious problem of water pollution.

Considering the sensitivity and essential importance of this sector of the environment, only with a responsible approach and effective implementation of the adopted plans and



measures it is possible to timely implement reforms in every sector of industry, in order to reach the required standards in water management.

4. CONCLUSION

Issues of environmental pollution with wastewater originating from the production processes of the textile industry due to a wide range of environmental and toxicological impacts have become increasingly significant in recent years. The adverse impact of wastewater on aquatic ecosystems is determined by its composition, quality and quantity. The most negative impact is certainly industrial waste water. Therefore, adequate waste water management of the textile industry implies continuous serious, conscientious and professional work, which, in addition to compliance with legal regulations, also implies constant monitoring and implementation of modern technical and technological solutions, as well as the production flow of textile industry facilities, with the reduction of water consumption and the introduction of new technologies and wastewater treatment plants in terms of compliance with local requirements and environmental quality standards. In this regard, it is necessary to continuously harmonize the legislation with European and world legislation in this area.

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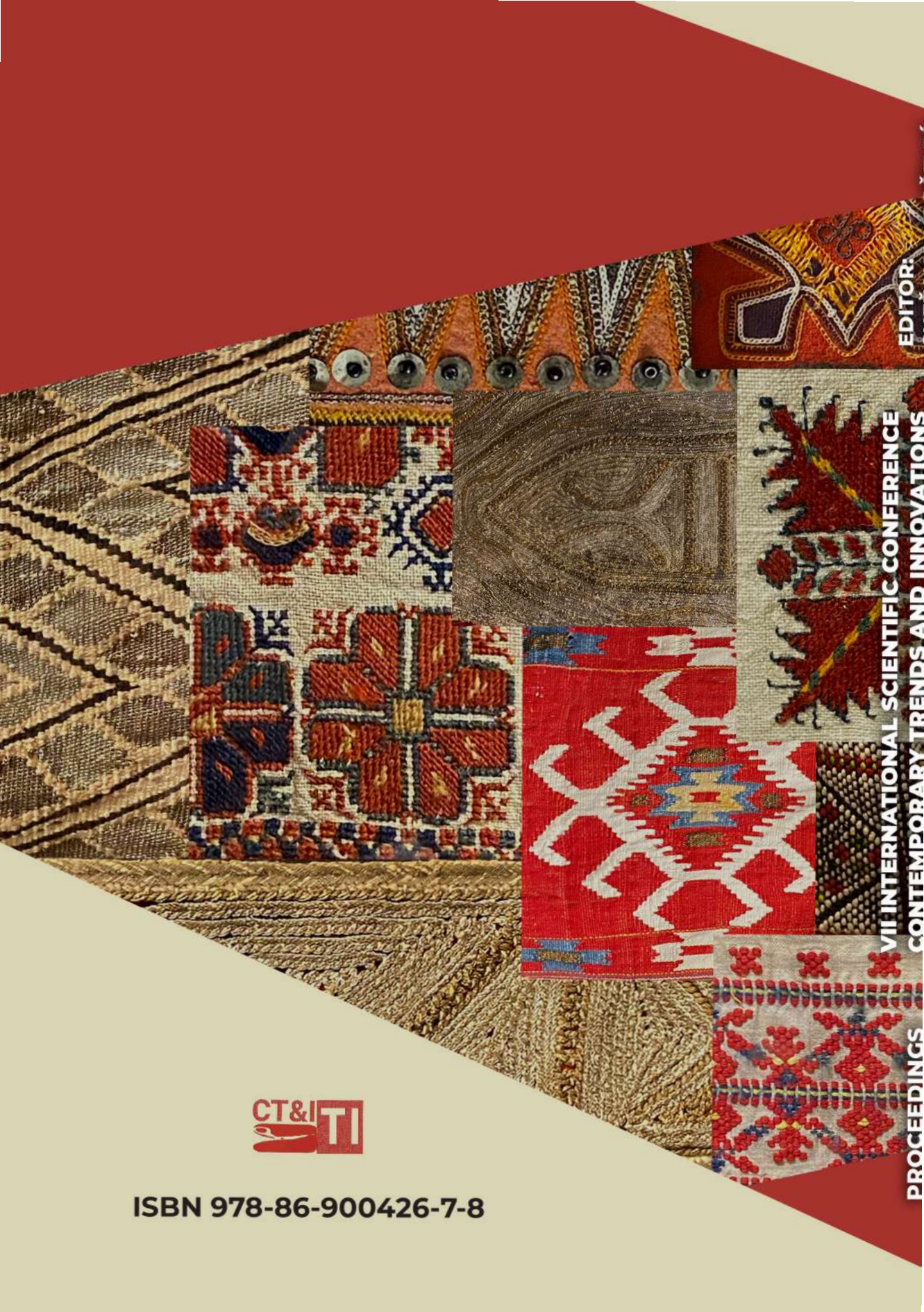
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ISBN 978-86-900426-7-8