



PRIVREDNA  
KOMORA  
SRBIJE



Република Србија  
МИНИСТАРСТВО НАУКЕ,  
ТЕХНОЛОШКОГ РАЗВОЈА И ИНОВАЦИЈА

# 11<sup>th</sup> International Conference on Renewable Electrical Power Sources



# PROCEEDINGS

Editor Dr Milica Vlahović

Belgrade, November 02-03, 2023



# PROCEEDINGS

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## 11th International Conference on Renewable Electrical Power Sources



2023

**PROCEEDINGS**  
**11th International Conference**  
**on Renewable Electrical Power Sources**

Chamber of Commerce and Industry of Serbia,  
Belgrade, November 2 and 3, 2023

**Publisher**

Union of Mechanical and  
Electrotechnical Engineers and  
Technicians of Serbia (SMEITS)  
Society for Renewable Electrical  
Power Sources  
Kneza Miloša str. 7a/II,  
11000 Beograd

**President to the Society**  
**for Renewable Electrical**  
**Power Sources**  
**within the SMEITS**

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Tiraž  
50 primeraka

CD umnožava  
MT-KOMEX doo, Beograd

**ISBN**  
978-86-85535-16-1

CIP - Каталогизacija u publikaciji - Narodna biblioteka Srbije, Beograd

MEĐUNARODNA konferencija o obnovljivim izvorima električne energije (11 ; 2023 ; Beograd)

Zbornik radova pisanih za 11. Međunarodnu konferenciju o obnovljivim izvorima električne energije [Elektronski izvor]: [Beograd, 2. i 3. novembar 2023.] / [urednik Milica Vlahović] = Proceedings / 11th International Conference on Renewable Electrical Power Sources : [Belgrade, October 2 and 3, 2023] ; [editor Milica Vlahović]. - Beograd : Savez mašinskih i elektrotehničkih inženjera i tehničara Srbije SMEITS, Društvo za obnovljive izvore električne energije = Union of Mechanical and Electrotechnical Engineers and Technicians of Serbia (SMEITS), Society for Renewable Electrical Power Sources, 2023.

Sistemska zahtevi: Nisu navedeni. - Nasl. sa naslovne strane dokumenta. - Tiraž 50. - Bibliografija uz svaki rad.

ISBN 978-86-85535-16-1

a) Энергетски извори - Одрживи развој - Зборници

COBISS.SR-

## Organizer

Savez mašinskih i elektrotehničkih  
inženjera i tehničara Srbije (SMEITS),  
**Društvo za obnovljive izvore  
električne energije**

## Co-organizer

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## Sponsors

Interplast, Greece



MS Kablovi, Paraćin



## Endorsement

MT-KOMEX, Beograd



Održavanje 11. MKOIEE finansijski je pomoglo  
Ministarstvo nauke, tehnološkog razvoja i inovacija  
Republike Srbije



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## FOREWORD

*The conditions created by the development of technologies in which modern man lives have led to a complex and paradoxical effect: that by removing obstacles on the way to a more comfortable, simpler, faster and more efficient life and way of working, man also generates numerous misfortunes, attracting dark clouds of threats to the survival of the planet and humanity. The question that concerns and affects all of us - all people, all living beings, systems in which life takes place, large and small, strong and weak - boils down to the problem of the negative impact of man on the environment; this issue invites us to an urgent solution by looking at the causes, proposing solutions, evaluating them, changing approaches and ways of thinking, as well as drawing correct conclusions. Simply put, by adapting nature to one's own needs, man threatens and damages it. That is why, with the joint efforts of all of us, individuals, organizations and states, it is necessary to take all possible measures to immediately prevent the negative effects that are ahead of us.*

*The importance of renewable sources of electricity, which this international conference focuses on, is noticeable from two angles: the first - it is certain that fossil fuels as a resource will disappear and it is necessary to find alternative sources, the second - the use of renewable energy sources by its essence implies "clean" technology that significantly contributes to reducing CO<sub>2</sub> emissions and thus mitigating climate change and reducing pollution, while encouraging social and economic development in all spheres of life.*

*The 11th International Conference on Renewable Electrical Power Sources is organized by the Society for Renewable Electrical Power Sources (DOIEE) at SMEITS, with co-organizers: The Institute of Architecture and Urban & Spatial Planning of Serbia (IAUS) and the Chamber of Commerce and Industry of Serbia, with the support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia.*

*The registered participants designed their papers according to the given conference topics:*

- Energy sources and energy storage;*
- Energy efficiency in the context of use of renewable energy sources (RES);*
- Environment, sustainability and policy;*
- Applications and services.*

*Eminent authors - scientists, teachers, experts in this field from fifteen different countries: Algeria, Belgium, Bosnia and Herzegovina, China, Croatia, Greece, Hungary, India, Portugal, Saudi Arabia, Serbia, Slovenia, Spain, the United Arab Emirates, and Ukraine, contributed to the conference through sixty-nine papers that were reviewed by the Scientific Committee of the Conference, and after the review process were accepted for presentation at the conference and for publication in the proceedings.*

*At the end of this short message and at the beginning of the proceedings I believe that it can be proudly said that scientists, researchers, policy makers and industry experts gathered in one place, in order to exchange experiences and knowledge with the aim of promoting scientific and professional ideas and results of research, technology improvement for the use of RES, promoting the rational use of electricity, affirming and proposing inventive solutions in the field of sustainable sources of electricity.*

*Belgrade,  
November 2023*

*Milica Vlahović*

# SADRŽAJ / CONTENTS

## Plenarna predavanja:

1. **IZAZOVI U ELEKTROHEMIJSKOM SKLADIŠTENJU**  
ENERGIJE CHALLENGES IN THE ELECTROCHEMICAL ENERGY STORAGE  
Branimir N. GRGUR..... 1
2. **POLIANILIN: PROVODNI POLIMER U UREĐAJIMA ZA SKLADIŠTENJE ENERGIJE**  
POLYANILINE: CONDUCTIVE POLYMER IN ENERGY STORAGE SYSTEMS  
Aleksandra JANOSEVIC LEZAIC ..... 11
3. **ISPITIVANJE KVALITETA EKSPLOZIVNO ZAVARENOG SPOJA RAZNORODNIH METALA ZA POTENCIJALNU PRIMENU U OBNOVLJIVIM IZVORIMA ENERGIJE**  
TESTING THE QUALITY OF EXPLOSIVELY WELDED JOINTS OF DISSIMILAR METALS POTENTIALLY APPLICABLE IN RENEWABLE ENERGY SOURCES  
Ana ALIL, Milos LAZAREVIC, Danica BAJIC, Nada ILIC, Tihomir KOVACEVIC, Bogdan NEDIC..... 23
4. **METODE BEZ RAZARANJA I UNAPREĐENJE POUZDANOSTI RADA KULE ZA HLAĐENJE, KAO ASPEKT TEMATIZACIJE OBNOVLJIVIH IZVORA ENERGIJE**  
NON-DESTRUCTIVE METHODS AND IMPROVEMENT OF THE COOLING TOWER OPERATION RELIABILITY, AS AN ASPECT OF RENEWABLE ENERGY SOURCES THEMATIZATION  
Marko JARIC, Sanja PETRONIC, Nikola BUDIMIR, Zoran STEVIC, Suzana POLIC..... 35

## Energetski izvori i skladištenje energije:

1. **ELEKTRIČNA SVOJSTVA TANKIH FILMOVA GO I GO/WPA NA INTERDIGITALNIM ELEKTRODAMA**  
ELECTRICAL PROPERTIES OF GO AND GO/WPA THIN FILMS ON INTERDIGITAL ELECTRODES  
Zeljko MRAVIK, Milica PEJCIC, Sonja JOVANOVIC, Darija PETKOVIC, Misa STEVIC, Zoran STEVIC, Zoran JOVANOVIC..... 45
2. **MODELOVANJE I SIMULACIJA UREĐAJA ZA NAVODNJAVANJE KAP-PO-KAP**  
MODELING AND SIMULATION OF A DEVICE APPLIED FOR LOW-FLOW DRIP IRRIGATION  
Nouredine BENSEDIRA, Abdessmad MILLES, Mohammed-Salah AGGOUNE ..... 53
3. **UTICAJ SENKE USLED DENIVELACIJE KROVA NA PROIZVODNJU KROVNE SOLARNE ELEKTRANE IZLAZNE SNAGE 400KW**  
THE INFLUENCE OF THE SHADOW CAUSED BY THE SLOPE OF THE ROOF ON THE PRODUCTION OF A ROOF-TOP SOLAR POWER PLANT WITH AN OUTPUT POWER OF 400KW  
Marko S. DJUROVIC, Zeljko V. DESPOTOVIC ..... 61

<b>4. PROJEKTOVANJE I IZVOĐENJE SOLARNE ELEKTRANE IZLAZNE SNAGE 400KW NA KROVU FABRIČKE HALE "EP BELT"-LOZNICA</b>	
DESIGN AND REALISATION PV ROOF-TOP POWER PLANT 400KW IN THE FACTORY "EP BELT"-LOZNICA	
Zeljko V. DESPOTOVIC, Marko S. DJUROVIC .....	<b>67</b>
<b>5. PRENAMENA NAPUŠTENIH ILI STARIH NAFTNIH POLJA ZA IZGRADNJU GEOTERMALNIH ELEKTRANA</b>	
THE CONVERSION OF ABANDONED OR MATURE OIL FIELDS INTO GEOTHERMAL POWER PLANT LOCATIONS	
Ivan RAJSL, Sara RAOS .....	<b>79</b>
<b>6. POBOLJŠANJE SPOSOBNOSTI SAMOIZLEČIVANJA I ŽILAVOSTI MIKROKAPSULA SA TUNG ULJEM DODATKOM GRAFENSKIH NANOPLOCICA I NJIHOVA PRIMENA U EPOKSI SISTEMU</b>	
THE IMPROVEMENT OF SELF-HEALING CAPABILITY AND TOUGHNESS OF MICROCAPSULES WITH TUNG OIL BY THE ADDITION OF GRAPHENE NANOPATELETS AND THEIR APPLICATIONS IN EPOXY SYSTEM	
Natasa TOMIC, Abdullah MUSTAPHA, Maitha ALMHEIRI, Mohamed Nasr SALEH .....	<b>87</b>
<b>7. MODEL SOLARNOG PANELA SA SOLARNIM TRAGAČEM, UPRAVLJAN POMOĆU ARDUINO UNO MODULA</b>	
MODEL OF THE SOLAR PANEL WITH SOLAR TRACKER CONTROLLED BY THE ARDUINO UNO BOARD	
Ivan TODORIC, Djordje DIHOVICNI, Dragan KRECULJ, Sanja JEVTIC, Nada RATKOVIC KOVACEVIC .....	<b>93</b>
<b>8. TERMoeLEKTRIČNI EFEKAT KAO IZVOR ENERGIJE U PRUŽNIM ŽELEZNIČKIM APLIKACIJAMA</b>	
THERMOELECTRIC EFFECT AS A SOURCE OF ENERGY IN RAILWAY TRACKSIDE APPLICATIONS	
Sanja JEVTIC, Milesa SREČKOVIĆ, Dragan KRECULJ, Nada RATKOVIĆ KOVACEVIC.....	<b>101</b>
<b>9. POREĐENJE RAZNOVRSNIH TIPOVA ENERGIJE OD POKRETNIH VODA</b>	
COMPARISON OF VARIOUS TYPES OF ENERGY FROM MOVING WATERS	
Djordje DIHOVICNI, Dragan KRECULJ, Olga JAKSIC, Nada RATKOVIC KOVACEVIC .....	<b>107</b>
<b>10. ISPITIVANJE LIF/B SISTEMA KORIŠĆENJEM NEGATIVNOG MODA LDI MS: MOGUĆI SISTEM ZA SKLADIŠTENJE VODONIKA</b>	
INVESTIGATION OF LIF/B SYSTEM USING THE NEGATIVE MODE LDI MS: A POSSIBLE HYDROGEN STORAGE SYSTEM	
Filip VELJKOVIC, Bojan JANKOVIC, Ivana STAJCIC, Milovan STOJILJKOVIC, Marija JANKOVIC, Djordje KAPURAN, Suzana VELICKOVIC .....	<b>115</b>
<b>11. UŠTEDA ENERGIJE PRILIKOM ELEKTROLITIČKOG DOBIJANJA VODONIKA-POREĐENJE DVOKOMPONENTNIH I TROKOMPONENTNIH JONSKIH AKTIVATORA</b>	
ENERGY SAVINGS IN ELECTROLYTIC HYDROGEN PRODUCTION – COMPARISON OF BINARY AND TERNARY ACTIVATORS	
Sladjana MASLOVARA, Dragana VASIC ANICIJEVIC, Snezana BRKOVIC, Vladimir NIKOLIC, Milica MARCETA.....	<b>119</b>

<b>12. KINETIKA TERMALNE DEGRADACIJE LIGNOCELULOZNOG OTPADA NA BAZI KOŠTICA BRESKVE</b> THERMAL DEGRADATION KINETICS OF LIGNOCELLULOSIC PEACH STONE WASTE Zorica LOPIČIĆ, Anja ANTANASKOVIĆ, Slobodan CVETKOVIC, Vladimir ADAMOVIĆ, Tatjana SOSTARIC, Jelena AVDALOVIC, Mirjana KIJEVCANIN .....	<b>125</b>
<b>13. THERMAL PROPERTIES OF RAPIDLY SOLIDIFIED Cu-Al-Ni-Mn SHAPE MEMORY ALLOY</b> <b>Borut KOSEC</b> , Milan BIZJAK, Mirko GOJIC, Ales NAGODE, Ivana IVANIC, Blaž KARPE .....	<b>133</b>
<b>14. PROCENA POTENCIJALA POLJOPRIVREDNO-FOTONAPONSKIH SISTEMA U SRBIJI</b> ASSESSMENT OF THE AGRIVOLTAIC POTENTIAL IN SERBIA Aleksandar IVANCIC, Melita ROGELJ, Bora OBRADOVIC, Slaviša JELISIC.....	<b>139</b>

### Energetska efikasnost u kontekstu primene RES:

<b>1. ULOGA KUPCA-PROIZVOĐAČA (PROZJUMERA) U PRIMENI OIEE</b> <b>U SRBIJI: PRE-PREKE I MOGUĆNOSTI</b> THE ROLE OF THE BUYER-PRODUCER (PROSUMER) IN THE IMPLEMENTATION OF RES IN SERBIA: OBSTACLES AND OPPORTUNITIES Marina NENKOVIC-RIZNIC, Borjan BRANKOV, Mila PUCAR, Ana STANOJEVIC.....	<b>147</b>
<b>2. PRIMENA SERIJSKE VEZE KOMPONENTI FREKVENTNO ZAVISNIH KOMPONENTI ISTOG</b> <b>TIPA U SISTEMIMA SA OBNOVLJIVIM IZVORIMA ENERGIJE</b> APPLICATION OF A SERIES CONNECTION OF THE SAME TYPE BANDPASS FREQUENCY DEPENDENT COMPONENTS IN SYSTEMS WITH RENEWABLE ENERGY SOURCES Tykhon SYTNIKOV, Igor PEREKRESTOV, Andrey CHMELECKSKY, Pavlo STUPEN, Valerii SYTNIKOV.....	<b>159</b>
<b>3. SMANJENJE GUBITAKA U DISTRIBUTIVNOJ MREŽI UVAŽAVAJUĆI NESIGURNOST</b> <b>SNAGE OPTEREĆENJA I DISTRIBUIRANE PROIZVODNJE IZ OBNOVLJIVIH IZVORA</b> REDUCTION OF LOSSES IN THE DISTRIBUTION NETWORK CONSIDERING THE UNCERTAINTY OF LOAD AND RENEWABLE DISTRIBUTED GENERATION POWER Nikola KRSTIC, Dragan TASIC, Teodora DENIC.....	<b>165</b>
<b>4. TEHNOLOGIJE ZA PRAĆENJE POLJOPRIVREDNIH ZASADA POMOĆU BESPILOTNIH LETILICA</b> TECHNOLOGIES FOR MONITORING AGRICULTURAL CROPS USING UAV Njegos DRAGOVIC, Milovan VUKOVIC, Snezana UROSEVIC .....	<b>173</b>
<b>5. MIKRO STEP ELEKTROMOTORNI POGON KONTROLISAN MIKROKONTROLEROM</b> MICRO STEP ELECTRIC DRIVE CONTROLLED BY MICROCONTROLLER Misa STEVIC, Zoran STEVIC, Predrag STOLIC, Ilija RADOVANOVIC, Dejan ILIC, Zoran JOVANOVIĆ.....	<b>181</b>
<b>6. SMART MATERIJALI I SAVREMENI KONTEKST ZA FUNKCIONALIZACIJU OBNOVLJIVIH</b> <b>IZVORA ENERGIJE U GALERIJSKOM PROSTORU</b> SMART MATERIALS AND CONTEMPORARY CONTEXT FOR THE FUNCTIONALIZATION OF RENEWABLE ENERGY SOURCES IN THE GALLERY SPACE Suzana POLIC, Sanja PETRONIC, Marko JARIC.....	<b>185</b>

<b>7. BLOCKCHAIN I RANE VIZUELIZACIJE KORIŠĆENJA ENERGIJE VETRA U MUZEJSKIM KOLEKCIJAMA</b>	
BLOCKCHAIN AND EARLY VISUALIZATION OF THE USE OF WIND ENERGY IN MUSEUMS COLLECTIONS	
Suzana POLIC .....	<b>195</b>
<b>8. ENERGETSKA EFIKASNOST U ELEKTRIČNIM VOZILIMA – PREGLED</b>	
ENERGY EFFICIENCY IN ELECTRIC VEHICLES – AN OVERVIEW	
Zoran STEVIC, Ilija RADOVANOVIĆ, Predrag STOLIC, Sanja PETRONIC, Marko JARIC, Misa STEVIC, Dejan ILIC.....	<b>203</b>
<b>9. TOPOLOGIJE NEIZOLOVANIH DC-DC KONVERTORA SA POBOLJŠANIM KARAKTERISTIKAMA</b>	
NON-ISOLATED DC-DC CONVERTERS TOPOLOGIES WITH IMPROVED CHARACTERISTICS	
Oleksii YAMA, Zoran STEVIC, Oleksandr BONDARENKO .....	<b>209</b>
<b>10. MOGUĆNOST PRIMENE ULTRAZVUČNE KAVITACIJE U PROCESU PRERADE INDUSTRIJSKIH OTPADNIH VODA</b>	
POSSIBILITY OF USING ULTRASONIC CAVITATION IN THE PROCESS OF INDUSTRIAL WASTEWATER TREATMENT	
Sladjana JEZDIMIROVIC, Marina DOJCINOVIC .....	<b>219</b>
<b>11. ZNAČAJ DISTRIBUCIJE TOPLOTE U SAVREMENIM ENERGETSKI EFIKASNIM ELEKTRIČNIM VOZILIMA</b>	
IMPORTANCE OF HEAT DISTRIBUTION IN MODERN ENERGY EFFICIENT ELECTRICAL VEHICLES	
Zoran STEVIC, Borivoje BEGENISIC, Dušan MURGASKI, Luka STAJIC, Sanja PETRONIC, Ilija RADOVANOVIĆ, Suzana POLIC .....	<b>227</b>
<b>12. PRIMERI PRIMENE VIŠEKRITERIJUMSKOG ODLUČIVANJA U OBLASTI OBNOVLJIVIH IZVORA ENERGIJE</b>	
EXAMPLES OF THE APPLICATION OF MULTI-CRITERIA DECISION-MAKING IN THE FIELD OF RENEWABLE ENERGY SOURCES	
Zoran STIRBANOVIC, Dragiša STANUJKIC, Jovica SOKOLOVIC.....	<b>233</b>

### **Životna sredina, održivost i politika:**

<b>1. RAZMATRANJE PRISUSTVA FENANTRENA U OPŠTINI BOR NA BAZI NJEGOVOG SADRŽAJA U LIŠĆU I STABLJKAMA HEDERA HELIX L.</b>	
A CONSIDERATION OF PHENANTHRENE PRESENCE IN BOR'S MUNICIPALITY BASED ON ITS CONTENT IN LEAVES AND STEMS OF HEDERA HELIX L.	
Aleksandra D. PAPLUDIS, Slađana C. ALAGIC, Snezana M. MILIC, Jelena S. NIKOLIC, Dragana V. MEDIĆ, Zoran M. STEVIC, Vesna P. STANKOV JOVANOVIĆ.....	<b>239</b>
<b>2. PERSPEKTIVE GRADSKOG VAZDUŠNOG SAOBRAĆAJA U BEOGRADU, SRBIJA</b>	
PROSPECTS OF URBAN AIR MOBILITY IN BELGRADE, SERBIA	
Jelena SVORCAN, Djordje CANTRAK, Jelena ANDRIC, Andrea IANIRO.....	<b>245</b>

<b>3. ULOGA SINERGIJE RUDARSKIH I RAČUNARSKIH TEHNOLOGIJA U PROCESU TRANZICIJE KA OBNOVLJIVIM IZVORIMA ELEKTRIČNE ENERGIJE</b>	
THE ROLE OF THE SYNERGY OF MINING AND COMPUTER TECHNOLOGIES IN THE PROCESS OF TRANSITION TO RENEWABLE ELECTRICAL POWER SOURCES	
Predrag STOLIC, Ilija RADOVANOVIĆ, Zoran STEVIĆ, Dejan PETROVIĆ.....	<b>253</b>
<b>4. ODRŽIVOST REŠENJA ZASNOVANIH NA OBNOVLJIVIM IZVORIMA ELEKTRIČNE ENERGIJE – INFORMATIČKI PRISTUP</b>	
SUSTAINABILITY OF SOLUTIONS BASED ON RENEWABLE SOURCES OF ELECTRICITY - ICT APPROACH	
Predrag STOLIC, Ilija RADOVANOVIĆ, Zoran STEVIĆ .....	<b>261</b>
<b>5. CHATGPT, MATERIJALI I OBNOVLJIVI IZVORI ENERGIJE: JEDAN NEELABORIRANI PROSTOR</b>	
CHATGPT, MATERIALS AND RENEWABLE ENERGY SOURCES: ONE UNREALIZED SPACE	
Suzana POLIĆ, Sanja PETRONIĆ, Marko JARIĆ.....	<b>269</b>
<b>6. ANALIZA STRUKTURE OŠTEĆENJA GRAĐEVINSKIH KONSTRUKCIJA NA OSNOVU ODREĐIVANJA FRAKCIONOG SASTAVA OSTATAKA</b>	
ANALYSIS OF THE STRUCTURE OF BUILDING STRUCTURE FAILURES BASED ON THE DETERMINATION OF THE FRACTIONAL COMPOSITION OF DEBRIS	
Valeriia CHORNA, Elena PONOMARYOVA, Sergey SHATOV, Liliia DRUZHININA.....	<b>279</b>
<b>7. UTICAJ EFEKTA STAKLENE BAŠTE NA KLIMATSKE PROMENE</b>	
THE INFLUENCE OF THE GLASS GARDEN EFFECT ON CLIMATE CHANGES	
Sladjana JEZDIMIROVIĆ, Marina DOJCINOVIĆ .....	<b>287</b>
<b>8. PRIMENA TEHNOLOGIJE 3D ŠTAMPE BETONA U REPUBLICI SRBIJI</b>	
APPLICATION OF 3D CONCRETE PRINTING TECHNOLOGY IN SERBIA	
Stefan Z. MITROVIĆ, Ivan IGNJATOVIĆ.....	<b>295</b>
<b>9. ULOGA VODOPROPUSNIH PROIZVODA U POPLOČAVANJU URBANIH SREDINA U SVETLU ODRŽIVOG KORIŠĆENJA RESURSA</b>	
THE ROLE OF PERMEABLE PRODUCTS IN THE PAVING OF URBAN ENVIRONMENT IN THE LIGHT OF SUSTAINABLE USE OF RESOURCES	
Marina ASKRABIĆ, Aleksandar RADEVIĆ, Aleksandar SAVIĆ .....	<b>301</b>
<b>10. OTPADNO STAKLO KATODNIH CEVI U PRIPREMI BETONA – POVEĆAVANJE ODRŽIVOSTI</b>	
CATHODE RAY TUBE WASTE GLASS IN CONCRETE PREPARATION – INCREASING SUSTAINABILITY	
Ivana JELIĆ, Aleksandar SAVIĆ, Tatjana MILJOJČIĆ, Marija SLJIVIĆ-IVANOVIĆ, Marija JANKOVIĆ, Slavko DIMOVIĆ, Dimitrije ZAKIĆ, Dragi ANTONIJEVIĆ .....	<b>309</b>
<b>11. DOPRINOS STUDIJI VEGETACIJSKOG POKRIVAČA: STUDIJA SLUČAJA ZELENIH POVRŠINA U GRADU HRAOUA (ALŽIR)</b>	
CONTRIBUTION TO THE STUDY OF VEGETATION COVER: A CASE STUDY OF GREEN SPACES IN THE CITY OF HRAOUA (ALGERIA)	
Mostafia BOUGHALEM .....	<b>317</b>

<b>12. TRANZICIJA KA OBNOVLJIVIM IZVORIMA ENERGIJE, DEKARBONIZACIJA I PROMENE U ENERGETSKOM SEKTORU KOJE UTIČU NA RADNIKE U TRADICIONALNIM INDUSTRIJAMA</b> TRANSITION TO RENEWABLE ENERGY SOURCES, DECARBONIZATION, AND CHANGES IN THE ENERGY SECTOR AFFECTING WORKERS IN TRADITIONAL INDUSTRIES Miloš CURCIC .....	<b>323</b>
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### **Aplikacije:**

<b>1. IMPLEMENTACIJA SOLARNE ELEKTRANE SNAGE 200 KWP NA RAVNOM KROVU U PARAĆINU</b> IMPLEMENTATION OF 200 KWP SOLAR POWER PLANT ON A FLAT ROOF IN PARAĆIN Bosko IVANKOVIC, Zoran LAZAREVIC, Ilija RADOVANOVIC, Misa STEVIC, Predrag STOLIC, Dejan ILIĆ, Zoran STEVIC .....	<b>329</b>
<b>2. FIZIČKO-HEMIJSKA KARAKTERIZACIJA ŠTAMPANIH PLOČA</b> PHYSICO-CHEMICAL CHARACTERIZATION OF PCBs Silvana B. DIMITRIJEVIC, Aleksandra T. IVANOVIC, Srdjana MAGDALINOVIC, Stefan S. DJORDIJEVSKI, Stevan P. DIMITRIJEVIC .....	<b>333</b>
<b>3. DEALLOYING PDNI5 LEGURE U 0.5M SULFATNOJ KISELINI</b> DEALLOYING OF PDNI5 ALLOY IN 0.5M SULFURIC ACID Stevan P. DIMITRIJEVIC, Silvana B. DIMITRIJEVIC, Aleksandra T. IVANOVIC, Renata KOVACEVIC .....	<b>341</b>
<b>4. SAGOREVANJE OTPADNOG TERMOBARIČNOG EKSPLOZIVA POD KONTROLISANIM USLOVIMA KAO IZVOR ENERGIJE</b> COMBUSTION OF WASTE THERMOBARIC EXPLOSIVE UNDER CONTROLLED CONDITIONS AS A SOURCE OF ENERGY Danica BAJIC, Mirjana KRSTOVIC, Mladen TIMOTIJEVIC, Bojana FIDANOVSKI .....	<b>351</b>
<b>5. INTERAKCIJE LASERA OD INTERESA ZA MATERIJALE U SISTEMIMA I KOMPONENTAMA U TRANSFORMACIJI ENERGIJE U LINEARNOM I NELINEARNOM OPSEGU</b> LASER INTERACTION OF INTEREST FOR MATERIALS IN SYSTEMS AND COMPONENTS IN ENERGY TRANSFORMATION IN LINEAR AND NONLINEAR RANGES Milesa SRECKOVIC, Aleksandar BUGARINOVIC, Milanka PECANAC, Zoran KARASTOJKOVIC, Milovan JANIĆIJEVIC, Aleksander KOVACEVIC, Stanko OSTOJIC, Nenad IVANOVIC .....	<b>359</b>
<b>6. DETEKCIJA MELASE LAŽNIH DATULA INFRACRVENOM SPEKTROKOPIJOM PRIMENOM HIJERARHIJSKE KLASIFIKACIJE</b> DETECTION OF DATE MOLASSES ADULTERATED BY INFRARED SPECTROSCOPY USING ASCENDING HIERARCHICAL CLASSIFICATION Samir CHERIGUI, Ilyes CHIKHI, Hadj FAYÇAL DERGAL, Ferial CHELLALI, Hanane CHAKER .....	<b>369</b>
<b>7. DETEKCIJA FALSIFIKOVANJA MELASE GROŽĐA FIZIKO-HEMIJSKIM PARAMETRIMA</b> DETECTION OF ADULTERATION OF GRAPE MOLASSES BY PHYSICO-CHEMICAL PARAMETERS Samir CHERIGUI, Ilyes CHIKHI, Hadj FAYÇAL DERGAL, Ferial CHELLALI, Hanane CHAKER .....	<b>373</b>

<b>8. SENZOR SALINITETA ZASNOVAN NA HEKSAGONALNOM FOTONOM KRISTALNOM VLAKNU</b> SALINITY SENSOR BASED ON A HEXAGONAL PHOTONIC CRYSTAL FIBER Ilhem MIREL, Hicham CHIKH-BLED.....	<b>377</b>
<b>9. NAPREDAK U FOTONSKIM KRISTALNIM VLAKNAMA: METODE PROIZVODNJE I PRIMENA ŠIROKOG SPEKTRA</b> ADVANCEMENTS IN PHOTONIC CRYSTAL FIBER: FABRICATION METHODS AND BROAD-SPECTRUM APPLICATIONS Mohammed DEBBAL, Hicham CHIKH-BLED, Mouweffeq BOUREGAA, Mohammed CHAMSE EDDINE OUADAH .....	<b>385</b>
<b>10. ENERGETSKA EFIKASNOST PREDIZOLOVANIH PLASTICNIH CEVI</b> ENERGY EFFICIENCIES OF PRE-INSULATING PLASTIC PIPES Vasilis ZOIDIS.....	<b>393</b>
<b>11. STATISTIČKO MODELOVANJE NEKIH EKOLOŠKI PRIHVATLJIVIH LEGURA NA BAZI BAKRA</b> STATISTICAL MODELING OF SOME ENVIRONMENTALLY-FRIENDLY COPPER-BASED ALLOYS Aleksandra T. IVANOVIC, Silvana B. DIMITRIJEVIC, Stevan P. DIMITRIJEVIC, Branka B. PETKOVIC.....	<b>403</b>
<b>12. SPEKTROSKOPSKA ANALIZA NATRIJUM KARBONATA</b> SPECTROSCOPY ANALYSIS OF ACTIVATED SODIUM CARBONATE Natasa DJORDJEVIC, Milica VLAHOVIC, Slavica MIHAJLOVIC, Nenad VUSOVIC, Srdjan MATIJASEVIC .....	<b>409</b>
<b>13. ANALIZA PERFORMANSI KRUŽNOG FOTONSKOG KRISTALNOG VLAKNA ZA TERAHERC APLIKACIJE</b> PERFORMANCE ANALYSIS OF CIRCULAR PHOTONIC CRYSTAL FIBER FOR TERAHERTZ APPLICATIONS Mohammed CHAMSE EDDINE OUADAH, Mohammed DEBBAL, Assia AHLEM HARRAT, Hicham CHIKH-BLED, Mouweffeq BOUREGAA .....	<b>415</b>
<b>14. POSTUPAK IZRADE POLIMERNOG KALUPA ZA ISPITIVANJE NA ISTEZANJE BIOKOMPOZITNIH MATERIJALA</b> POLYMER MOULD MANUFACTURING FOR TENSILE TESTING OF BIOCOMPOSITE MATERIALS Marija BALTIC, Milica IVANOVIC, Igor STAMENKOVIC, Miloš VORKAPIC, Aleksandar SIMONOVIC .....	<b>421</b>
<b>15. HABANJE Ti-6Al-4V NANOKOMPOZITA SA DISPERGOVANIM ZrO<sub>2</sub> DOBIJENOG MEHANIČKIM LEGIRANJEM I SPARK PLAZMA SINTEROVANJEM</b> WEAR BEHAVIOR OF ZrO <sub>2</sub> DISPERSED Ti-6Al-4V ALLOY NANOCOMPOSITES PREPARED BY MECHANICAL ALLOYING AND SPARK PLASMA SINTERING R. KARUNANITHI, M. PRASHANTH, M. KAMARAJ, S. SIVASANKARAN .....	<b>427</b>
<b>16. PROIZVODNJA NISKOLEGIRANOG Cr-Mo-Ni ČELIKA U ELEKTROLUČNOJ PEĆI</b> PRODUCTION OF LOW ALLOY Cr-Mo-Ni STEEL IN ELECTRIC ARC FURNACE M. GOJIC, M. DUNDJER, S. KOZUH, I. IVANIC, D. DUMENCIC .....	<b>435</b>
<b>17. NUMERIČKA SIMULACIJA I DIZAJN SPOJNICA OD FOTONSKIH KRISTALNIH VLAKNA ZA SEPARACIJU TALASNIH DUŽINA</b> NUMERICAL SIMULATION AND DESIGN OF A PHOTONIC CRYSTAL FIBER COUPLER	

FOR WAVELENGTH SEPARATION Assia AHLEM HARRAT, Mohammed CHAMSE EDDINE OUADAH, Mohammed DEBBAL.....	445
<b>18. FOTOKATALITIČKA DEGRADACIJA KONGO CRVENE BOJE KORIŠĆENJEM KOMPOZITA UIO-66 METALO-ORGANSKIH MREŽNIH STRUKTURA I METALNIH OKSIDA</b> PHOTOCATALYTIC DEGRADATION OF CONGO RED DYE USING UIO-66 MOF-METAL OXIDES COMPOSITES Dimitrije PETROVIC, Marija EGERIC, Radojka VUJASIN, Yi-nan WU, Fengting LI, Ljiljana MATOVIC, Aleksandar DEVECERSKI .....	451
<b>19. EKSPERIMENTALNA OPTIČKA ANALIZA OTPORNOSTI NA LOM NERĐAJUĆEG ČELIKA</b> EXPERIMENTAL OPTICAL ANALYSIS OF STAINLESS STEEL FRACTURE BEHAVIOUR Katarina COLIC .....	461
<b>20. OPTIMIZOVANI PRORAČUN ČELIČNIH HALA NA DEJSTVO POŽARA</b> OPTIMIZED FIRE DESIGN FOR STEEL PORTA-FRAMED SHEDS Filip LJUBINKOVIĆ, Luís LAÍM, Aldina SANTIAGO .....	469
<b>21. HIDROFOBIZACIJA KALCITA STEARINSKOM KISELINOM MOKRIM POSTUPKOM</b> HYDROPHOBIZATION OF CALCITE BY WET METHOD USING STEARIC ACID Slavica MIHAJLOVIC, Nataša DJORDJEVIC, Vladan KASIC, Srdjan MATIJASEVIC.....	479
<b>22. INDEX ZA PROCENU STRUKTURALNE EFIKASNOSTI ČELIČNIH RAMOVA</b> INDEX FOR THE ASSESSMENT OF STRUCTURAL EFFICIENCY OF STEEL PORTAL FRAMES Filip LJUBINKOVIC, Luís Simões da SILVA .....	485
<b>23. RAZVOJ APARATURE ZA IN SITU ISPITIVANJE ANKERA NOSACA SOLARNIH PANELE</b> DEVELOPMENT OF THE APPARATUS FOR IN SITU TESTING OF SOLAR PANEL RACKING ANCHORS Gordana BROČETA, Aleksandar SAVIC, Milica VLAHOVIC, Sanja MARTINOVIC, Tatjana VOLKOV HUSOVIC.....	495
<b>24. POVEĆANJE EFIKASNOSTI DOBIJANJA BIOGASA I NJEGOVOG KORIŠĆENJA U POSTROJENJU ZA TRETMAN KOMUNALNIH OTPADNIH VODA</b> INCREASING THE EFFICIENCY OF BIOGAS PRODUCING AND ITS UTILIZATION IN THE MUNICIPAL WASTEWATER TREATMENT PLANT Darja ZARKOVIC, Milica VLAHOVIC, Bilyana ISZITY.....	503
<b>25. ISPITIVANJE MORFOLOGIJE SUMPOR-POLIMERNOG KOMPOZITA MORPHOLOGY</b> INVESTIGATION OF SULFUR-POLYMER COMPOSITE Milica VLAHOVIC, Kong FAH TEE, Aleksandar SAVIC, Nataša DJORDJEVIC, Slavica MIHAJLOVIC, Tatjana VOLKOV HUSOVIC, Nenad VUSOVIC .....	513
<b>26. PRIMENA VARENJA, TVRDOG I MEKOG LEMLJENJA U IZRADI SOLARNIH SISTEMA</b> APPLICATION OF WELDING, BRAZING AND SOLDERING IN SOLAR SYSTEMS MANUFACTURING Zoran KARASTOJKOVIC, Milesa SRECKOVIC, Misa STEVIC .....	521
<b>27. ŠTETNI EFEKTI LEGURA ZA LEMLJENJE IZ ŠTAMPANIH KOLA PRILIKOM ZAJEDNIČKOG TOPLJENJA SA GVOZDENIM I ČELIČNIM DELOVIMA</b> HARMFULL EFFECTS OF SOLDERING ALLOYS FROM PRINTED CIRCUITS WHEN MELTED TOGETHER WITH IRON&STEEL COMPONENTS Zoran KARASTOJKOVIC, Ognjen RISTIC, Misa STEVIC .....	529

# ISPITIVANJE MORFOLOGIJE SUMPOR-POLIMERNOG KOMPOZITA

## MORPHOLOGY INVESTIGATION OF SULFUR-POLYMER COMPOSITE

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### *Abstract*

*This research evaluates the effects of the acid environment on sulfur-polymer composite. For this purpose, a morphology investigation consisting of mathematical morphology analysis and SEM analysis was performed. Based on the obtained results, insignificant changes in the pore system of sulfur-polymer composite in terms of deterioration, pore distribution, and homogeneity were observed. Namely, no signs of severe damage were detected at the surface and inside the samples. With increasing the acid exposure time, the material exhibited further changes in the direction of homogenization and drowning of the aggregate in the sulfur binder compared with the starting structure. These facts indicate that sulfur-polymer composite can be effectively used as a construction material in an acid environment.*

**Key words:** sulfur-polymer composite; mathematical morphological analysis; SEM

### *Apstrakt*

*U ovom istraživanju procenjuju se efekti kisele sredine na sumpor-polimerni kompozit. U tu svrhu izvršeno je morfološko ispitivanje koje se sastojalo od matematičke morfološke analize i SEM analize. Na osnovu dobijenih rezultata, uočene su neznatne promene u sistemu pora kompozita sumpor-polimer u pogledu propadanja, raspodele pora i homogenosti. Naime, na površini i unutar uzoraka nisu otkriveni znaci ozbiljnih oštećenja. Sa povećanjem vremena izlaganja kiselini, materijal se dalje menjao u smislu homogenizacije i utapanja agregata u sumporno vezivo u poređenju sa početnom strukturom. Ove činjenice ukazuju da se sumpor-polimer kompozit može efikasno koristiti kao građevinski materijal u kiseljoj sredini.*

**Ključne reči:** sumpor-polimerni kompozit; matematička morfološka analiza; SEM

## 1 Introduction

Sulfur- polymer matrix composites are high performance environmentally sustainable and durable thermoplastic materials made of mineral aggregates, filler and modified sulfur binder which replaces cement and water in conventional Portland cement composite at temperatures above the hardening point of sulfur (120 °C) [1]. Using sulfur to make modified sulfur binder is based on its physico-chemical characteristics. Different types of modified sulfur have been created in order to prevent failure of composite material with elemental sulfur as a binder. For this purpose, various chemical modifiers were used to polymerize sulfur and one of them is dicyclopentadiene which reacts with elemental sulfur to form long-chain polymeric polysulfides [2]. Unlike conventional Portland cement- based composites, sulfur- polymer composites are produced without water and achieve final strength in a few days. In spite of durability and sustainability of sulfur- polymer matrix composites, their wide use is limited due to the high price of chemical modifiers.

According to our own terminology, the term *modified sulfur binder* means a mixture of elemental sulfur and modified sulfur-sulfur polymer [3]. Recent experience all over the world shows that composite materials produced with modified sulfur binder instead of cement and water have significant chemical and physico-mechanical advantages comparing with Portland cement composites.

Since all materials during their service life are exposed to different external impacts that cause certain kind of reaction, the idea of this research was to examine the quality of sulfur- polymer composite in extreme conditions, during the accelerated destruction testing in hydrochloric acid solution.

Image analysis of microphotographs taken through a microscope was applied as a conventional way of these examinations, whereby the samples were cut and changes of the obtained slices were quantified. The question of the resolution necessary for observing the surface or the interior of the samples in this case was solved by using two types of microscopes, optical and scanning electron microscope (SEM).

## 2 Materials and Methods

### 2.1 Samples preparation

Sulfur-polymer composite samples were fabricated according to the manufacturing technological procedure described in [1,4]. The process included mixing both melted sulfur and modified sulfur into heated and homogenized dry mixture of aggregate and filler at sulfur melting temperature, 132–141 °C. After homogenization and mixing, sulfur-polymer composite mixture was casted into molds preheated at 120 °C and vibrated for 10 s on a vibrating table. The surface of each sample was finished and left to harden inside the molds, at room temperature. The samples were removed from the mold after 3 h and cured at room temperature for 24 h.

### 2.2 Accelerated destruction

In order to evaluate quality of sulfur- polymer composite, cube samples were tested under immersion in 10 % HCl solution for 7, 14, 21, 60 and 180 days.

### 2.3 Morphology investigation

The resulting damage of sulfur-polymer composite was assessed by monitoring and analyzing morphology changes.

Microstructure changes of sulfur-polymer composite samples during the accelerated destruction agent influence were observed using optical and scanning electron microscope (SEM).

Slices, that is cross-sections of the samples, were taken by the optical stereomicroscope with CCD (Charge Coupled Device) camera, LEICA DC 150 in order to analyze the volume changes. The samples of sulfur-polymer matrix composite were cut into four slices by diamond cutting blade that is used for the preparation of mineralogical specimens. Software Image Pro Plus, version 6.2, with the appropriate programming procedure was used and mathematical morphological analysis was performed for the analysis of the obtained images [5].

In order to analyze the morphological and structural changes, sulfur-polymer composite samples were taken by scanning electron microscope JEOL JSM 5800, Vega Tescan TS 5130MM.

## 3 RESULTS AND DISCUSSION

### 3.1 Mathematical Morphological Analysis

Set of selected morphological parameters served for the quantification of changes in the analyzed samples. Cumulative analysis of the measured parameters changes enabled the quantification of the accelerated destruction agent effect on the material quality, that is, on the structure properties.

The surfaces of the slices obtained by cutting samples of sulfur- polymer composite are taken by a stereomicroscope, and typical images are shown in Figure 1.

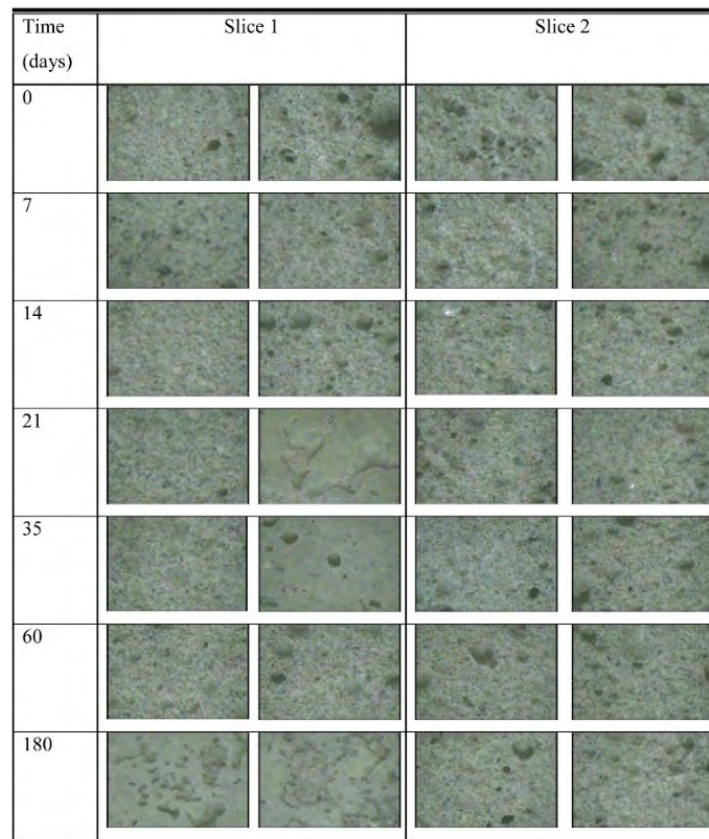


Figure 1. The stereomicroscope images of sulfur- polymer matrix composite samples during accelerated destruction testing.

After data reduction, extensive mathematical analysis using statistical procedures was performed for each sulfur- polymer composite sample as well as time analysis of all measured

parameters. Statistical analysis was performed to define the homogeneity of the sample. It was important that the values of measured parameters on the slices of a certain sample do not vary significantly. It means that the inhomogeneity shows whether a sample is not affected by the influence of the agent of accelerated destruction throughout the volume, or does not respond.

Mean values of measured parameters during the treatment time, Figure 2, indicate that there is a homogeneity change, meaning that more significant interactions took place than in the first 21 days. In this way, the impact of sulfur on the material behavior in terms of inhibition of the observed changes in the structure can be discussed.

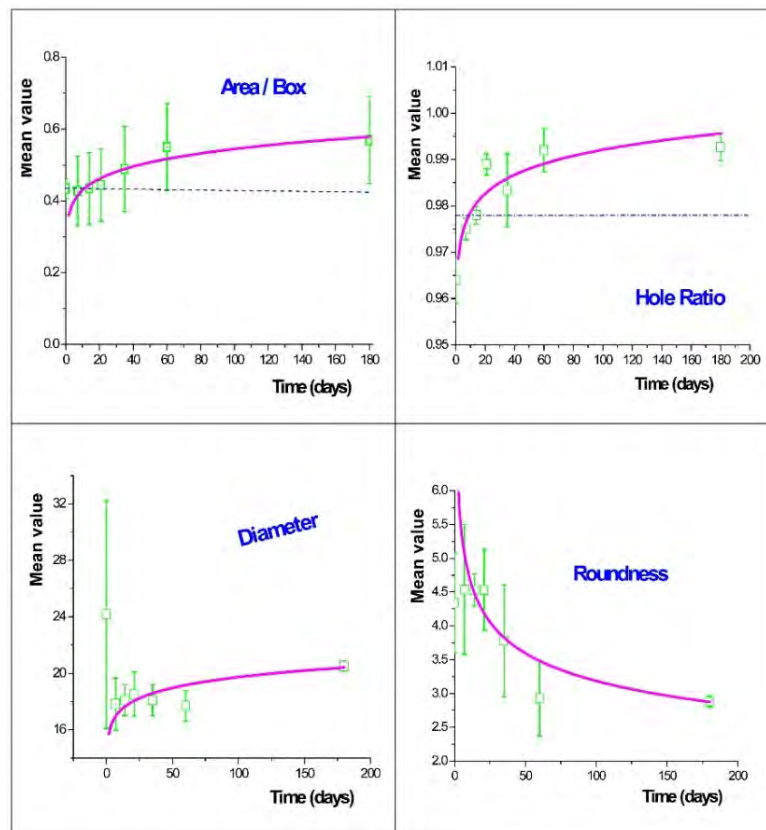


Figure 2. Mean values of measured parameters- homogeneity change of sulfur- polymer composite during accelerated destruction testing.

Based on the given analysis, it may be concluded that the greatest homogeneity increase takes place at 21<sup>st</sup> day of treatment. The morphological analysis is interesting after 21 days of treatment because of evident greater volume changes of certain parameters which positively or negatively affect the homogeneity achieved at approximately 21<sup>st</sup> day of accelerated destruction agent influence. However, regardless the effect, the action of the accelerated destruction agent was towards rearranging sulfur, which was the main moderator of homogeneity changes.

Further analysis was the analysis of time changes in cumulative parameters for each sample.

Figure 3 shows the graphs for four measured parameters through the volume of sulfur- polymer composite sample during the treatment time from 0 to 180 days.

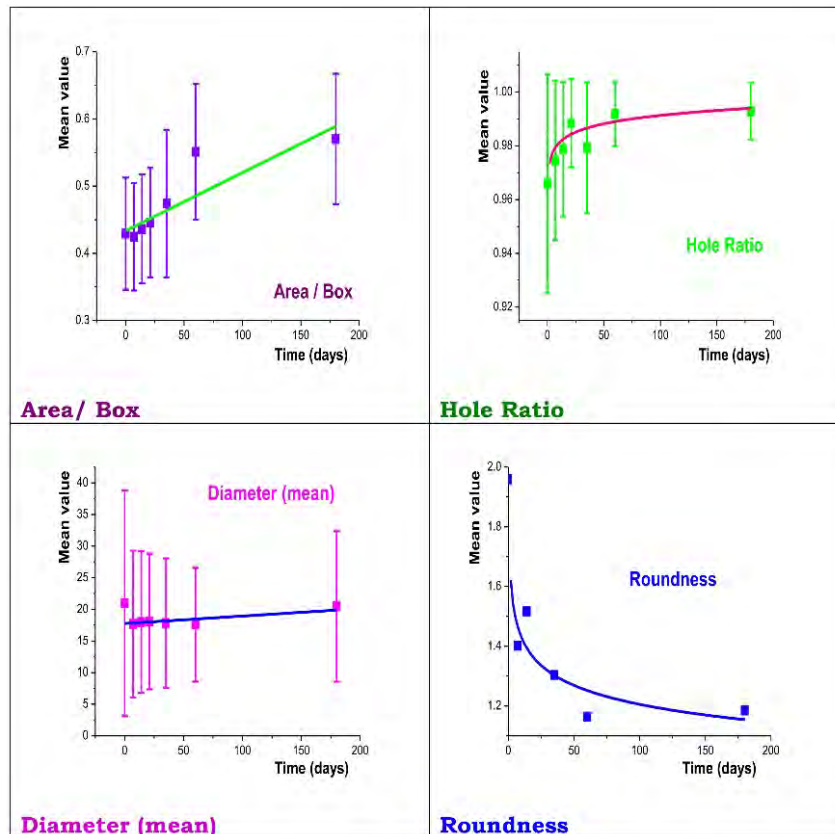


Figure 3. Change of measured parameters through the volume of sulfur- polymer matrix composite samples during accelerated destruction testing from 0 to 180 days.

As it can be seen from the graph shown in Figure 3, the time change kept the same form- power function. Compared with the surface analysis, a lower correlation degree is present here. This is entirely in accordance with the supposed model, since, unlike surface changes, bulk changes are cumulative changes of higher interaction material- agent, which results in a lower correlation degree between the examined parameters.

### 3.2 Morphological Analysis by SEM

The testing methodology included monitoring the structure changes of sulfur- polymer composite before the treatment and up to six months of the accelerated destruction agent action.

Microphotographs generated by the SE detector were analyzed in order to determine the morphological structure of the samples. To determine the final distribution of sulfur in the structure, element mapping, which means observing a sample in the energy range of the selected element, was applied.

SE microphotographs of sulfur- polymer composite samples are presented in Figure 4.

As seen on SE microphotographs, the existing binding phase, sulfur, and separated aggregate grains can be distinguished.

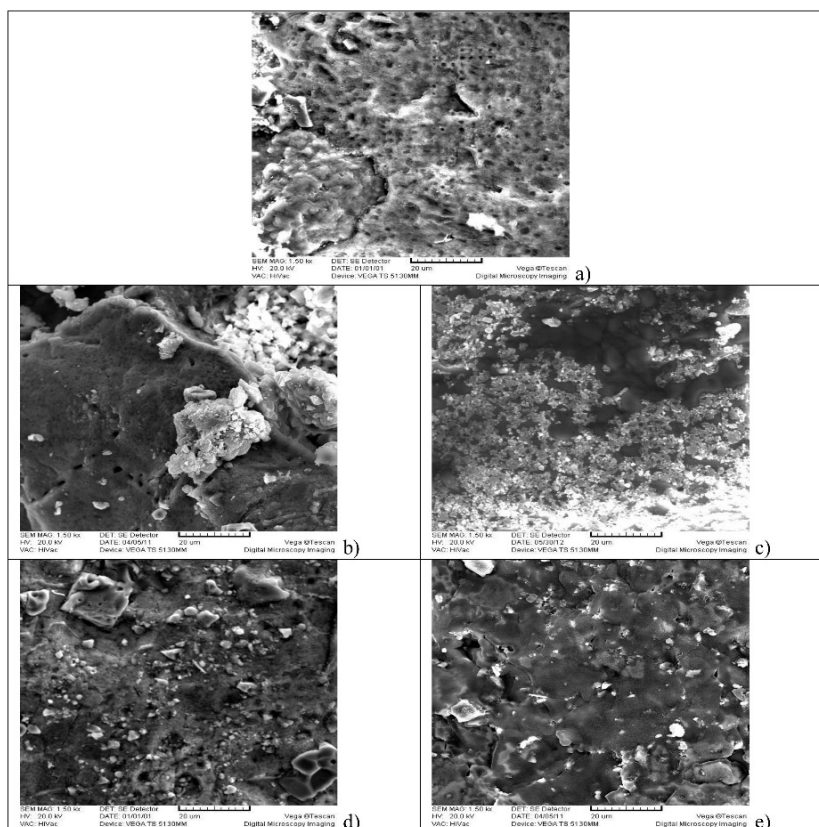


Figure 4. SE microphotographs of sulfur- polymer matrix composite samples during accelerated destruction testing: a) 0 days, b) 14 days, c) 21 days, d) 60 days, and e) 180 days.

Clearly defined aggregate and sulfur binder that looks like a monolithic integral part of the system can be noticed in the structure of the untreated sulfur- polymer composite sample, Figure 4 a).

Sulfur- polymer composite samples exposed to accelerated destruction show more pronounced monolithic structure. Also, “drowning” of the aggregate into the binder phase- sulfur, homogenization, can be observed. With increasing the treatment time, the structure exhibits further changes in the direction of homogenization and drowning of the aggregate in the sulfur binder compared with the initial structure, Figure 4 b), c), d). Based on the analysis of the structural changes, secondary homogenization of sulfur- polymer composite treated by acid, with clearly visible secondary binding of the aggregate and primary binder phase, expressed after 180 days, is evident, Figure 4 e).

#### 4 Conclusion

According to the trends of selected parameters variations throughout the samples volume, it was concluded that a homogenization of sulfur-polymer composite sample occurred during the time of accelerated destruction. The greatest homogeneity increase happened at 21<sup>st</sup> day of treatment. The influence of the accelerated destruction agent was towards rearranging sulfur, which was the main factor of homogeneity changes.

It was possible to show sulfur- polymer composite structure rearranging by observing the material structure with higher resolution and by choosing another method that would indicate the volume changes. The scanning electron microscopy was applied as a highly resolution method. This method clearly identified changes- rearrangement of the structure during the time.

According to the presented research, it can be concluded the accelerated destruction can be used to provoke changes in the structure of materials and thus properties changes. The used methods adequately demonstrate the possibility of detecting destruction influence on the sulfur- polymer composite structures.

## 5 Acknowledgments

This work was financially supported by the Ministry of Science and Technological Development and Innovation of the Republic of Serbia (Contract Nos. 451-03-47/2023-01/200026, 451-03-47/2023-01/200023 and 451-03-47/2023-01/200135).

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