University of Belgrade
Technical Faculty in Bor,
Mining and Metallurgy
Institute Bor

54th International October Conference on Mining and Metallurgy

PROCEEDINGS

IOC 2023
International October Conference

Editors:
Ljubiša Balanović
Dejan Tanikić

18-21 October 2023, Bor Lake, Serbia

PROCEEDINGS,

54th INTERNATIONAL OCTOBER CONFERNCE

on Mining and Metallurgy

Editors:

Prof. dr Ljubiša Balanović

Prof. dr Dejan Tanikić

University of Belgrade, Technical Faculty in Bor

Technical Editor:

M. Sc. Miljan Marković

University of Belgrade, Technical Faculty in Bor

Publisher: University of Belgrade, Technical Faculty in Bor

For the publisher: Dean Prof. dr Dejan Tanikić

Circulation: 200 copies

CIP - Каталогизација у публикацији Народна библиотека Србије, Београд

622(082)(0.034.2)
669(082)(0.034.2)

INTERNATIONAL October Conference on Mining and Metallurgy (54 ; 2023 ; Borsko jezero)
Proceedings [Elektronski izvor] / 54th International October Conference on Mining and Metallurgy - IOC 2023, 18-21 October 2023, Bor Lake, Serbia ; [organized by] University of Belgrade, Technical Faculty in Bor and Mining and Metallurgy Institute Bor ; editors Ljubiša Balanović, Dejan Tanikić. - Bor : University of Belgrade, Technical Faculty, 2023 (Niš : Grafika Galeb). - 1 USB fleš memorija ; 1 x 1 x 5 cm

Sistemski zahtevi: Nisu navedeni. - Nasl. sa naslovne strane dokumenta. - Tiraž 200. - Preface / Ljubiša Balanović. - Bibliografija uz svaki rad.

ISBN 978-86-6305-140-9

a) Рударство -- Зборници b) Металургија -- Зборници

COBISS.SR-ID 126659849

Bor Lake, Serbia, October 18-21, 2023

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

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PREFACE

On behalf of the Organizing Committee, it is a great honor and pleasure to welcome all esteemed participants of the 54th International October Conference on Mining and Metallurgy (IOC 2023), scheduled to take place at the picturesque Bor Lake, Serbia, from October18th to 21st 2023.

The collaborative efforts of the University of Belgrade, the Technical Faculty in Bor, and the Mining and Metallurgy Institute Bor have meticulously organized this year's IOC. Our focus remains unwavering on showcasing the latest research findings and advancements in geology, mining, metallurgy, materials science, technology, environmental protection, and other engineering disciplines. Our primary objective is to foster a dynamic environment where academics, researchers, and industry professionals can come together to share their knowledge, experiences, and innovative ideas while exploring opportunities for collaborative research endeavors.

Our conference agenda is rich and diverse, encompassing plenary sessions, engaging invited lectures, technical presentations, enlightening oral and poster sessions, informative technical tours, a diverse exhibition, and memorable social gatherings. At the heart of this event lies our strong commitment to sustainable development within the mining and metallurgy sector. We are dedicated to exploring ecologically conscious methodologies, responsible resource extraction practices, and cutting-edge technologies that reduce the industry's environmental impact and enhance the well-being of local communities.

The conference proceedings comprise 129 papers authored by individuals from universities, research institutes, and industries in 22 countries. We are proud to welcome participants from Bosnia and Herzegovina, Bulgaria, Canada, China, Croatia, Germany, Greece, India, Iran, Kazakhstan, Libya, North Macedonia, Montenegro, Morocco, Romania, Russia, Slovakia, South Africa, Spain, Turkey, United States, and, of course, Serbia.

We are excited to host the 8th International Student Conference on Technical Sciences (ISC 2023) as part of IOC 2023. This event offers students from Serbia and the wider region a unique chance to showcase their research and discuss the future of their fields with experts.

We sincerely thank the Ministry of Science, Technological Development, and Innovation of the Republic of Serbia for their generous financial support. In addition, we express our profound gratitude to all our sponsors, exhibitors, and friends of the Conference for their contributions and unwavering support for playing a pivotal role in ensuring the success of IOC 2023.

We would like to express our heartfelt thanks to all authors, committees, reviewers, speakers, and chairpersons for their invaluable contributions in shaping IOC 2023.

We look forward to welcoming you to the 55th International October Conference on Mining and Metallurgy (IOC 2024), which will be held in October 2024.

On behalf of the 54th IOC Organizing Committee,

Prof. dr Ljubiša Balanović

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MECHANICAL CHARACTERISTICS OF THE SHAPE MEMORY ALLOY Cu-Zn-Al

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Abstract

Shape memory alloys – SMA are specific alloys which posses unusual characteristic called shape memory effect. This effect enables them to change their own shape and return to some memorized state, according to the environment temperature. The area of usage of shape memory alloys is very large and heterogeneous. There are two main groups of SMAs in commercial usage: Ni-Ti alloys and copper based alloys. This paper will present some of the experimentally obtained mechanical characteristics of the shape memory alloy Cu-Zn-Al.

***Keywords**: SMA, mechanical characteristics, Cu-Zn-Al alloy*

1. INTRODUCTION

The term Shape Memory Alloy (SMA) is used for the group of metallic materials that shows the ability to return to some previously defined shape when subjected to the adequate temperature. For example, these materials can be plastically deformed at some relatively low temperature, and exposure to higher temperature will return their original shape, prior to the deformation.

A wide variety of alloys exhibits the shape memory effect, but only those that can recover substantial amounts of strain or which can generate significant force upon changing shape are of commercial interest. The most common are the nickel-titanium alloys and copper-base alloys, such as Cu-Al-Ni and Cu-Zn-Al. The shape memory effect has been firstly noticed on the copper based alloys (Cu-Zn and Cu-Sn) in 30's years of the past century [1]. Nitinol (alloy on the basis of nickel and titanium), one of the most frequently used shape memory alloy was revealed in the 60's years of the past century in Naval Ordnance Laboratory in USA. This is commonly assigned as the origin of the investigation in the field of shape memory alloys. The first reported and documented large usage of SMA was in 1971 for a coupling which was used to connect titanium hydraulic tubing installations in the Grumman F-14 air-craft [2]. The significant usage of the shape memory alloys for manufacturing the valves for air-condition devices was reported in Japan in the 80's of the past century. Approximately at the same time started the large usage of the shape memory alloys primarily in dental, and after that, for all other medical applications. Among many materials including metals, alloys, ceramics etc. available commercially, only a limited number are currently being used as prostheses or biomaterials in medicine and dentistry. The reason for this is that prostheses need to satisfy two important demands: biofunctionability and biocompatibility [3].

The mechanical properties of shape memory alloys vary greatly over the temperature range spanning their transformation. In this paper, some of the mechanical characteristics of Cu-Zn-Al, one of the mostly commercially used SMA, are presented.

2. THE SHAPE MEMORY EFFECT

The main characteristic of the SMA is their shape transformation, caused by changes in the environment temperature. Depending on the environment temperature and amount of the applied load, shape memory alloys can be present in two different crystal structures, i.e. phases [4]. The low temperature phase is martensite, while the high temperature phase is austenite. Solid state phase transition from martensite to austenite, and vice versa, is a key process which enables shape changing of the SMAs. This effect is called marthensitic thermoelastic transformation [5]. Starting and finishing temperatures of the martensite transformation, as well as starting and finishing temperatures of the austenite transformation depends on the physical and chemical characteristic of the alloy. The copper-aluminium binary alloy (Cu-Zn-Al alloy)displays shape memory effect and has a transformation temperature which is generally too high for practical use. But, the addition of zinc to this system produces a new alloy, Cu-Zn-Al, which is of commercial importance.

The specimens used in this study were made from Cu-Zn-Al alloy, in the form of wire, with diameter of 2.9 mm. Before testing, the specimens were thermally prepared on three different ways: 1. Annealed on 800 °C for 15 minutes, then water cooled; 2. Cold deformed; 3. Thermally processed on the following way: annealed on 450 °C for 15 minutes, then water cooled, after that annealed on 550 °C for 2 hours, then cooled in the furnace to 450 °C and finally cooled on air.

Tensile strength testing: The specimens in the form of wire were used for determination of the tensile strength. The examinations were performed on the Universal Testing Machine, Figure 1. Each specimen was preliminary measured, marked and mounted in the machine. The tensile force is then applied, which causes elastic, then plastic elongation and finally tearing of the wire. The tensile force is then noticed, together with the values of the elongations.

Figure 1 - Universal Testing Machine with specimen.

Three independent tests were performed for each group of thermally prepared specimens. The values of the obtained tensile strengths are:

$$R_{m1} = \frac{445.23 + 427.42 + 440.78}{3} = 437.81[\text{MPa}], \; R_{m2} = \frac{749.48 + 791.03 + 802.91}{3} = 781.14[\text{MPa}]$$

$$\text{and } R_{m3} = \frac{406.65 + 425.94 + 424.46}{3} = 419.02[\text{MPa}] \; .$$

Hardness testing: The hardness of the material was determined by the Vickers hardness test. The specimen was a cylinder made from shape memory alloy, Figure 2, with chemical composition: Cu–68.16%, Zn–27.33%, Al–4.09%. In order to obtain accurate results, one side of the specimen must be flat, so it was machined on the surface grinder. Specimen is then mounted in the Vickers testing machine, Figure 2 and a diamond in the form of a square-based pyramid, with the angle of the opposite sides of 136° is applied. In this particular case injection was performed at 5 different points of the specimen. Injection force was 49.05 [N]. After unloading, area of the square which remains on the specimen surface is calculating by measuring its diagonals.

Figure 2 - Specimen and machine for Vickers hardness testing.

The mean value of the hardness is calculated on the following way:

$$HV_{sr} = \frac{86.7 + 71.6 + 99.7 + 99.7 + 102}{5} = 91.94 \ \left[\mathrm{N/mm^2}\right] \ .$$

Metallographic testing: The preparing phase for the metallographic examinations includes the following operations: 1. Sampling operation – very important step which must provide the real crystal state of the alloy block; 2. Grinding process is the second phase of the specimen preparing. This is necessary operation which is performed on the grinding machine using row and fine grindstones. The final quality of the machined surface is obtained using grinding paper; 3. Polishing is third preparing phase which includes polishing of the specimen with felt panel and polishing pastes which usually contains metal oxide powders; 4. Abrasion is the final phase in the specimen preparing. Abrasion substances are usually acid or salt solutions, with water, alcohol, glycerine or some other solvent. The reagents which are used depend on the material type and the goal is to obtain shineless surfaces. In this case ferric chloride was used (20 g of ferric chloride, 6 cm^3 of hydrochloric acid and 100 cm^3 of water).

Metallographic testing was performed by analysing of the structure of the prepared specimen, using metallographic microscope which operates with reflected light “EPY type 2”, Figure 3. The structures which were obtained by examination with magnifications of 200x and 500x are presented at Figure 3 (a) and (b), respectively.

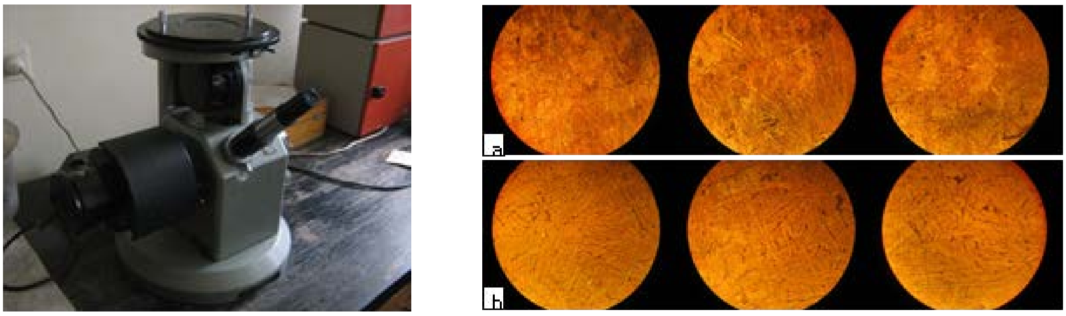

Figure 3 - Microscope “EPY type 2” and
structures obtained by metallographic examinations with magnification of: (a) 200x and (b) 500x.

Microhardness testing: The values of the microhardness were measured on the device for microhardness measuring “PMT-3”, Figure 4(a). The procedure is similar as the procedure for hardness measuring and the main difference is in the amount of the load which is applied. In this case a load of 100 g during 10 s was applied on 5 different points on the specimen.

The mean value of the microhardness obtained by this method is:

$$HV_{\mu sr} = \frac{14.3 + 14.8 + 13.8 + 14 + 12.9}{5} = 13.96 \ \left[\mathrm{kgf/mm^2}\right] = 136.915 \ \left[\mathrm{N/mm^2}\right].$$

Electrical conductivity testing: Electrical conductivity was measured at 5 different points on specimen using the device for electrical conductivity measuring “Sigmatest”, Figure 4(b).

(a) (b)

Figure 4 - (a) Device for microhardness measuring “PMT-3” and (b)Device for electrical conductivity measuring “Sigmatest”.

The mean value of the measured electrical conductivity is:

$$\sigma_{sr} = \frac{10.9 + 10.8 + 10.7 + 10.8 + 10.8}{5} = 10.8 \left[\frac{MS}{m}\right].$$

3. CONCLUSION

Mechanical characteristics of Cu-Zn-Al shape memory alloy are presented in this paper. Some studies have shown that the mechanical properties of SMAs mainly depend on the wire form, or the relationship between the microstructure and thermally induced phase transitions. The investigation shows that thermal treatment of the specimen has a big impact on its mechanical properties. However, SMAs generally have good mechanical and physical characteristics and their ability to remember some previous shape is widely used in almost all fields of science and engineering.

4. ACKNOWLEDGEMENT

The authors are grateful to the Ministry of Education, Science and Technological development of the Republic of Serbia for financial support (451-03-47/2023-01/ 200131).

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ISBN-978-86-6305-140-9

IOC M&M 2023

IOC M&M 2023

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