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PREFACE

The 31st international conference Ecological Truth & Environmental Research – EcoTER'24 focuses on showing the latest research findings and innovations in the field of ecology, environmental protection and sustainable development. The conference will be held in Sokobanja (Serbia) in hotel Sunce in the period of 18–21 June 2024.

The aim of the conference is to connect the experts in various fields in order to transform attitudes and behaviors in everyday practices, as well as in the industry and economy sector which is essential for achieving the desired changes that our society must undergo.

The 31st international conference Ecological Truth & Environmental Research – EcoTER'24 is organized by the University of Belgrade, Technical Faculty in Bor, and co-organized by the University of Banja Luka, Faculty of Technology; the University of Montenegro, Faculty of Metallurgy and Technology – Podgorica; the University of Zagreb, Faculty of Metallurgy – Sisak; the University of Pristina, Faculty of Technical Sciences – Kosovska Mitrovica and the Society of Young Researchers – Bor.

These Proceedings encompass 119 papers from the authors coming from the universities, research institutes and industries in 15 countries: Brazil, Norway, USA, Spain, Austria, Libya, Italy, Israel, Slovenia, Croatia, Romania, Bulgaria, Montenegro, Bosnia and Herzegovina, North Macedonia, and Serbia. It is a great honor and pleasure to cordially wish a warm welcome to all the participants of the conference.

As a part of this year's conference, the 6th Student Section – EcoTERS'24 will be held. We appreciate the contribution of the students and their mentors who have also participated in the conference and hope that students will continue to explore and to be curious, since education is a never-ending process, and knowledge is continuously growing.

The organization of the EcoTER'24 conference has been financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia.

The support of the Donors and their willingness and ability to cooperate has been of great importance for the success of the EcoTER'24 conference. The organizing committee would like to extend their appreciation and gratitude to the Platinum donors of the conference – Serbia ZiJin Copper doo Bor and HBIS SERBIA, to the Gold donor of the conference – Elixir Group, as well as to the Silver donor of the conference – Serbian Chamber of Engineers.

We would like to express our sincere appreciation to all the authors who have contributed to the Proceedings. We would also like to express our gratitude to the members of the scientific, organizing and honorary committees, reviewers, speakers, chairpersons and all the conference participants for their support of the EcoTER'24. Sincere thanks go to all the people who have contributed to the successful organization of the EcoTER'24.

Prof. Snežana Šerbula,

President of the scientific and organizing committee

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THE INFLUENCE OF AGEING PARAMETERS ON MICROHARDNESS, ELECTRICAL CONDUCTIVITY AND MICROSTRUCTURE OF SOME Al-Mg-Si ALLOYS

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Abstract

This paper investigates the influence of ageing parameters (temperature and time) on the microhardness, electrical conductivity and structural properties of two Al-Mg-Si aluminium alloys. After the applied heat treatment, both microhardness and electrical conductivity were measured. Optical microscopy was used to investigate the microstructures after ageing. The heat treatment began by solutionizing the samples at 550°C for 1 hour, followed by quenching in ice water. Samples were then aged at two separate temperatures, 180°C and 200°C, for 1–8 hours. The results indicate that with the increase in ageing time, the microhardness gradually increases up to a maximum and then decreases, while the electrical conductivity continuously increases. Analysis on the optical microscope shows that with longer ageing, there is precipitation of a larger amount of the strengthening phases due to more intense diffusion of alloying elements from the solid solution.

Keywords: Al-Mg-Si, microhardness, electrical conductivity, ageing, microstructure.

INTRODUCTION

The EN AW-6082 and EN AW-6060 aluminium alloys are two of the several alloys that make up the Al-Mg-Si alloy system. These alloys have garnered the interest of researchers because of their technical significance and observable increase in hardness as a result of precipitation hardening [1–3]. Ageing (precipitation) can improve mechanical and structural properties as well as properties such as electrical conductivity [4,5]. Samples have to be solutionized, quenched, and then aged in order to cause precipitation hardening. During the ageing process, precipitates form in accordance with the previously established precipitation sequence, which may be written as: α_{ssss} (supersaturated solid solution) → Mg:Si clusters → GP zones (pre-β") → β″ → β′ → β (Mg_2Si) [6–9]. The change in mechanical, electrical, and structural properties is caused by the precipitation of different metastable phases, mainly β" precipitates [9]. Because of their incoherency with the matrix, formed precipitates cause significant lattice deformation, which reduces dislocation mobility and enhances the alloy's hardness [7]. Al-Mg-Si alloys are often aged for an extended period of time at temperatures

below 200°C in order to achieve proper hardening. Numerous investigations focused on the impact of ageing time on mechanical, structural, and other properties, as demonstrated by numerous works [2,3,8–11]. Both investigated alloys can become excellent candidates for the manufacturing of overhead electrical wires that require high strength in addition to good electrical properties. Consequently, several researchers have investigated the impact of precipitation on the electrical properties of the Al-Mg-Si alloys [4,5,12]. It can be inferred from the analyzed literature that electrical and mechanical properties are significantly affected by ageing parameters, which emphasizes the importance of continuing research in this area. Consequently, we concentrated our attention on studying the ageing characteristics, which comprised two ageing temperatures: one conventional (180°C) and one greater than the conventional (200°C). Microhardness, electrical conductivity and microstructure were examined after the samples were aged for one to eight hours at each of the two ageing temperatures.

MATERIALS AND METHODS

The aluminium alloys EN AW-6060 and EN AW-6082 were selected for this study. The alloys were delivered in T6 (aged) condition in the form of extruded rectangular bars. The "Belec Compact Port" optical emission spectrometer was used to determine the chemical composition of the investigated alloys. Table 1 reveals the results of the chemical analysis. All samples were annealed at 550°C for 6 hours in the electric resistance furnace Heraeus K-1150/2 and cooled in air to eliminate the as-received (aged) condition. In order to produce a supersaturated solid solution (α_{ssss}), the samples were heated to 550°C for an hour and then quenched in icy water. This was done in order to prepare the samples for the ageing process. Samples were isothermally aged at 180°C and 200°C for one to eight hours post-quenching.

The properties of the aged samples were compared with those of the as-quenched samples (in the Figures marked as quenched state). Following the heat treatment, the samples underwent several analyses. Vickers microhardness values were measured using a 0.1 kg force and a 15-second dwell duration on a PMT 3 microhardness tester. The Sigmatest type 2.063 conductivity tester was used to measure the electrical conductivity values. Every measurement that is given was done at room temperature. All sample surfaces were ground to eliminate oxides before measurements. The samples have been analysed metallographically using the Carl-Zeiss Jena Epytip 2 optical microscope. The samples were prepared by wet grinding on an assortment of SiC papers and polishing with two different alumina suspensions containing different Al_2O_3 granulations (0.3 μm and 0.05 μm). The samples were etched by immersion in Dix-Keller solution in order to reveal the microstructure.

Table 1 *Chemical compositions of the investigated alloys (wt. %)*

EN AW-6060							**EN AW-6082**						
Si	***Fe***	***Cu***	***Mn***	***Mg***	***Cr***	***Ni***	***Si***	***Fe***	***Cu***	***Mn***	***Mg***	***Cr***	***Ni***
0.49	0.182	0.012	0.06	0.594	<0.03	0.028	0.807	0.354	0.042	0.453	0.696	<0.012	0.012
Zn	***Ti***	***V***	***Co***	***Sn***	***Zr***	***Al***	***Zn***	***Ti***	***V***	***Co***	***Sn***	***Zr***	***Al***
0.01	0.05	0.014	<0.003	<0.003	<0.003	98.62	0.115	0.25	<0.003	0.006	<0.003	<0.003	97.45

RESULTS AND DISCUSSION

The microhardness values of the investigated alloys during isothermal ageing are shown in Figure 1. It is evident from the graphs in Figure 1 that the microhardness values are significantly influenced by ageing. The microhardness of the aged samples gradually increases to a maximum and subsequently decreases with an increase in ageing time. The samples reached maximal microhardness values after ageing for five hours at 180 °C for the EN AW-6060 and for six hours for the EN AW-6082 alloy.

For the EN AW-6060 alloy, the highest obtained microhardness value was 110 $HV_{0.1}$, which is 42.8% higher than the microhardness value of the quenched sample (77 $HV_{0.1}$; α_1 on Figure 1). For the EN AW-6082 alloy, the highest obtained microhardness value was 146 $HV_{0.1}$, which is a 55.3% increase in comparison to the quenched state (94 $HV_{0.1}$; α_2 on Figure 1).

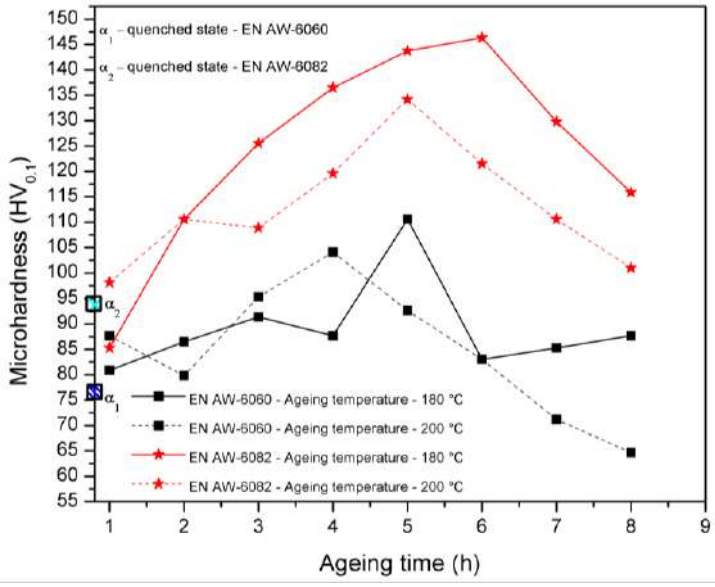

Figure 1 *Change in microhardness values of the investigated alloys as a function of ageing time at two different ageing temperatures*

It is assumed that the formation of multiple vacancies upon quenching, which encourages nucleation of the pre-β" phase, causes this phase to precipitate during the first four hours of ageing. As ageing continues, the Si and Mg atoms migrate from the solid solution and towards the pre-β" phase, trading places with the Al atoms. Precipitates that already exist, transform and grow in numbers overall, which eventually causes coherence with the Al lattice to be reduced. Phase changes proceed in accordance with the precipitation sequence as ageing progresses, together with the exchange of alloying element atoms with Al atoms [9]. Consequently, the maximum microhardness values displayed in Figure 1 are achieved due to the creation of the β" metastable phase and have been observed by multiple investigators [1–3,8–13]. Marioara *et al.* [3] stated that even though the precipitate density is low during the precipitation of the β" phase, there is an increase in incoherency with the lattice, leading to peak hardness values. After ageing for 6–8 hours, precipitates of the β" phase grow and coagulate, causing a decrease in microhardness values. A deeper look at the graphs in

Figure 1 reveals that maximum microhardness values can be obtained faster as a result of higher ageing temperatures. However, after ageing at higher temperatures, the highest microhardness values obtained are not as high as those achieved at lower ageing temperatures. Diffusion rate increases with rising ageing temperature, which leads to faster precipitation of the pre-β" phase and a faster loss of coherency, so the microhardness values are higher after an hour of isothermal ageing at 200°C as opposed to 180°C. However, the use of lower ageing temperatures with longer ageing times is essential for achieving a true peak-aged state.

The change in electrical conductivity values of the investigated alloys as a function of ageing time at two different ageing temperatures can be seen in Figure 2. In age-hardenable alloys, there is a strong relationship between electrical conductivity and precipitation [4]. Analysis of Figure 2 shows that with the increase in ageing time, the electrical conductivity gradually increases, reaching maximum values at the longest ageing times. When ageing for 1 hour, the electrical conductivity values are slightly lower than those obtained for the α_{ssss} (quenched state). At these ageing parameters, the pre-β" phase (GP-zone) is formed. These precipitates have the effect of scattering electrons, which leads to a decrease in electrical conductivity values [5,12,14]. After the initial decrease, there is a gradual increase in electrical conductivity values until the maximum is obtained. As the ageing time increases, an increasing amount of precipitates are formed due to the reduction of alloying elements in the saturated solid solution (α_{ssss} becomes less saturated). As a result of this phenomenon, electrical conductivity increases due to the easier movement of electrons through the matrix. Electrical conductivity is highest when the saturation of the α_{ssss} is the lowest, and in this case, this was achieved first by the precipitation of the pre-β" phase, and with prolonged ageing, by the β" phase [4,5].

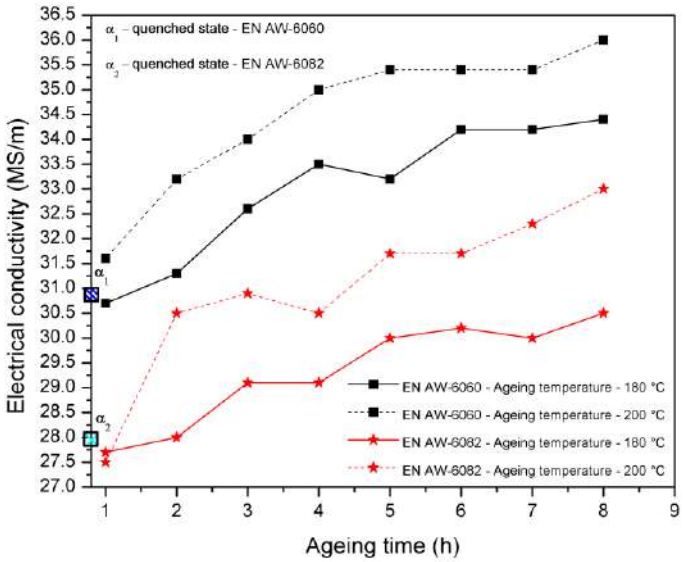

Figure 2 *Change in electrical conductivity values of the investigated alloys as a function of ageing time at two different ageing temperatures*

Unlike mechanical properties, a higher ageing temperature (200°C) leads to higher values of electrical conductivity. At higher ageing temperatures, diffusion is accelerated and

precipitation is intensified, which leads to a faster desaturation of the α_{ssss} with alloying elements, as a result of which the electrical conductivity increases.

The maximum values of electrical conductivity for both alloys were achieved when ageing at 200°C for 8 hours. For the EN AW-6060 alloy, electrical conductivity increased from 30.8 MS/m in the quenched state (α_1 in Fig. 2) to 36 MS/m after isothermal ageing at 200°C for 8 h, so the relative increase in electrical conductivity compared to the quenched state was 16.89%. The relative increase in electrical conductivity for the alloy EN AW-6082 was slightly higher and amounted to 17.86%. For this alloy, electrical conductivity increased from 28 MS/m in the quenched state (α_2 in Fig. 2) to 33 MS/m after isothermal ageing at 200°C for 8 h.

For microstructural analysis, four different samples were chosen based on the microhardness measurements: underaged samples (aged for 1 hour at 180°C) as well as peak aged samples (aged for 5 or 6 hours at 180°C, depending on the alloy).

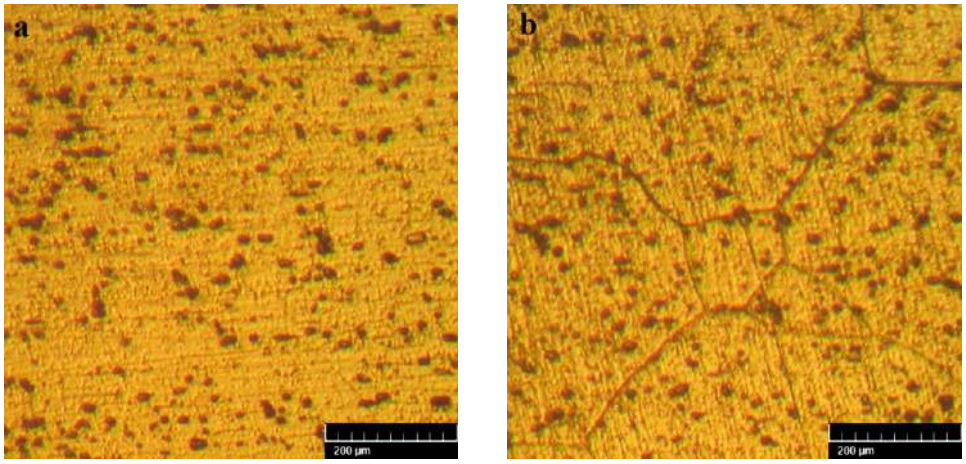

Figure 3 *Influence of ageing temperature on the microstructure of the EN AW-6060 aluminium alloy: a) after ageing for 1 hour at 180°C (underaged sample); b) after ageing for 5 hours at 180°C (peak-aged sample)*

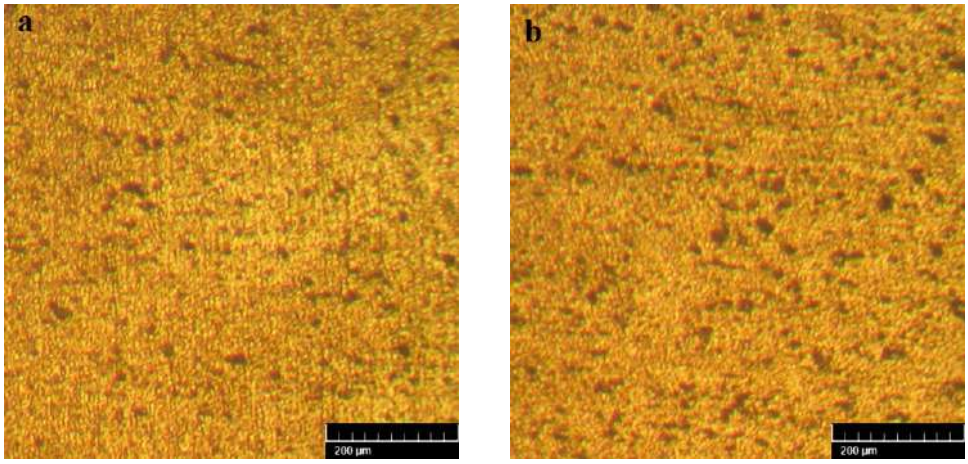

Figure 4 *Influence of ageing temperature on the microstructure of the EN AW-6082 aluminium alloy: a) after ageing for 1 hour at 180°C (underaged sample); b) after ageing for 6 hours at 180°C (peak-aged sample)*

Figures 3(a–b) and 4(a–b) show optical microphotographs of underaged and peak-aged samples of the EN AW-6060 and EN AW-6082 alloys after ageing at 180°C, respectively. From the presented microphotographs, it can be concluded that with longer ageing, there is precipitation of a larger amount of the strengthening phase, which further leads to an increase in the microhardness values, confirming the comments given in regards to the microhardness results [1,13,15].

CONCLUSIONS

Isothermal ageing led to an evident rise in mechanical and electrical properties. After ageing at 180°C for five or six hours, depending on the alloy, the highest values of microhardness were achieved. After ageing for eight hours at 200°C, the electrical conductivity values peaked for both investigated alloys due to the highest level of precipitation from the solid solution. Microstructural analysis showed the presence of finely distributed metastable phases, which caused a change in mechanical and electrical properties. The β" phase is thought to be primarily responsible for this improvement.

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REFERENCES

[1] Tan C.F., Said M.R., Chiang Mai J. Sci. 36 (3) (2009) 276–286.

[2] Abid T., Boubertakh A., Hamamda S., J. Alloys Compd. 490 (2010) 166–169.

[3] Marioara C.D., Andersen S.J., Jansen J., *et al.*, Acta Mater. 51 (2003) 789–796.

[4] Karabay S., Mater. Des. 27 (2006) 821–832.

[5] Cui L., Liu Z., Zhao X., *et al.*, T. Nonferr. Metal. Soc. 24 (2014) 2266–2274.

[6] Birol Y., T. Nonferr. Metal. Soc. 23 (2013) 1875–1881.

[7] Zheng Y.Y., Luo B-H., Xie W., *et al.*, China Foundry 20 (2023) 57–62.

[8] Birol Y., J. Mater. Process. Technol. 173 (2006) 84–91.

[9] Gupta A.K., Lloyd D.J., Court S.A., Mater. Sci. Eng. A 316 (2001) 11–17.

[10] Marioara C.D., Andersen S.J., Jansen J., *et al.*, Acta Mater. 49 (2001) 321–328.

[11] Chang C.S.T., Wieler I., Wanderka N., *et al.*, Ultramicroscopy 109 (2009) 585–592.

[12] Prabhu T.R., Eng. Sci. Technol. an Int. 20 (1) (2017) 133–142.

[13] Masoud I.M., Abu Mansour T., Al-Jarrah J.A., J. Appl. Sci. Res. 8 (10) (2012) 5106–5113.

[14] Edwards G.A., Stiller K., Dunlop G.L., *et al.*, Acta Mater. 46 (11) (1998) 3893–3904.

[15] Mrówka-Nowotnik G., Arch. Mater. Sci. Eng. 46 (2) (2010) 98–107.

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