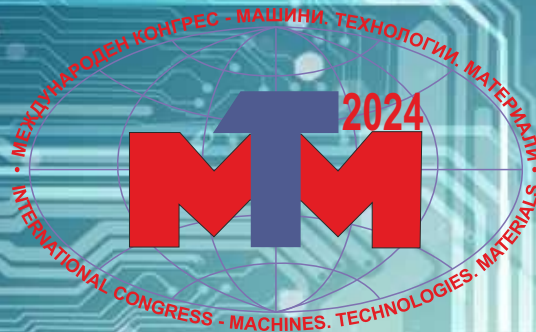


XXI INTERNATIONAL SCIENTIFIC CONGRESS

WINTER SESSION

06 - 09.03.2024, BOROVELS, BULGARIA



MACHINES.
TECHNOLOGIES.
MATERIALS 2024
PROCEEDINGS

ISSN 2535-0021 (PRINT)

ISSN 2535-003X (ONLINE)

**SCIENTIFIC-TECHNICAL UNION OF MECHANICAL ENGINEERING - INDUSTRY 4.0
BULGARIA**

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PROCEEDINGS

YEAR VII, ISSUE 1 (28), BOROEVETS, BULGARIA 2024

VOLUME I
MACHINES. TECHNOLOGIES. MATERIALS.

ISSN 2535-0021 (PRINT)
ISSN 2535-003X (ONLINE)

ALL ARTICLES ARE PUBLISHED AFTER PEER REVIEW BY TWO INDEPENDENT REVIEWERS.

PUBLISHER:

**SCIENTIFIC TECHNICAL UNION OF MECHANICAL
ENGINEERING
INDUSTRY-4.0**

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The influence of aging parameters on thermal, mechanical and structural properties of the EN AW-6060 aluminum alloy

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Abstract: This paper investigates the influence of aging parameters (temperature and time) on thermal, mechanical and structural properties of the EN AW-6060 aluminum alloy. Thermal diffusivity and hardness were measured after applied heat treatments followed by investigation on scanning electron and transmission electron microscopes. Heat treatments included: solutionizing at 550°C for 1 hour followed by quenching in ice water; after quenching samples were aged at two separate temperatures of 180°C and 200°C for 1-8 hours. The results show that hardness gradually increases with aging time achieving peak value of 95 HV₁₀ after aging at 180°C for 5 hours. Thermal diffusivity also increases with both aging time and temperature achieving peak values after aging at 200°C for 4 hours. SEM/EDS analysis show the existence of finely distributed precipitates containing Mg, Si and Fe. TEM investigation confirms the existence of rod-shaped precipitates several nanometers in length.

Keywords: EN AW-6060, AGING, HARDNESS, THERMAL DIFFUSIVITY, MICROSTRUCTURE

1. Introduction

The EN AW-6060 aluminum alloy belongs to the Al-Mg-Si alloy system. Alloys from this system are of particular interest to the researchers due to their technological importance and exceptional increase in hardness due to precipitation hardening [1-3]. Besides mechanical properties, other properties like electrical conductivity, thermal diffusivity, and thermal conductivity can also be improved by aging [4]. The change in mechanical, thermal, and structural properties is due to the precipitation of different metastable phases, but primarily by the precipitation of β'' precipitates (Mg₅Si₆) [5]. Formed precipitates cause severe lattice distortion due to incoherency with the matrix, which in turn leads to inhibition of dislocation movement and an increase in the alloy's hardness [6].

The alloys from this system are usually aged for a very long time at temperatures below 200°C in order to achieve the desired hardening. Many authors investigated this type of aging parameter on mechanical, structural, and other properties [1, 3, 5-9]. The EN AW-6060 aluminum alloy is a great candidate for the production of thermal components that require, besides satisfactory values of hardness, high thermal diffusivity. Because of that, some researchers investigated the influence of precipitation on the thermal properties of the Al-Mg-Si system [4, 10-14]. The authors showed that the thermal properties of Al-Mg-Si alloys are highly influenced and can be enhanced by different aging parameters.

Based on the reviewed literature, it can be concluded that there is a great influence of aging parameters on thermal and mechanical properties; therefore, it is very important that research in this area continues. Accordingly, our interests were focused on investigating the aging parameters, which included one conventional aging temperature (180°C) and one aging temperature that was higher than the conventional ones (200°C). At both aging temperatures, the aging time was from one to eight hours, after which thermal diffusivity, hardness, and microstructure were investigated.

2. Experimental procedure

For this investigation an EN AW-6060 alloy was chosen. The alloy was delivered in aged condition in the form of the extruded rectangular bars. The chemical composition was determined by optical emission spectrometer "Belec Compact Port". Results of the chemical analysis are given in Table 1.

Table 1: Chemical composition of the investigated alloy (mass %)

Si	Mg	Fe	Cu	Mn	Cr	Zn	Ni
0.49	0.594	0.182	0.012	0.006	<0.003	0.01	0.028
Ti	Pb	V	Co	Sn	Zr	Al	
0.005	<0.003	0.014	<0.003	<0.003	<0.003	98.62	

In order to remove the as-received condition, all samples were annealed at 550 °C for 6 h in the electric resistance furnace Heraeus K-1150/2, and cooled in air. To prepare the samples for the aging treatment, samples were heated again at 550°C for one hour and quenched in ice water in order to obtain a supersaturated solid solution (α_{SSS}). After quenching, samples were isothermally aged at 180°C and 200°C for 1–8 hours. Properties of the aged samples were compared to the as-quenched sample for comparison (annotated as quenched state in the presented figure). After the heat treatment, samples were subjected to different characterizations. Hardness was measured on the VEB Leipzig Vickers hardness tester with a 10 kg load and a 15 s dwelling time, according to the ASTM E384 standard [15].

On the TA Instruments DXF 500 thermal conductivity meter, the xenon flash method was applied to determine the thermal diffusivity of the investigated samples after different heat treatments by irradiating the disc-shaped specimens with a diameter of 12.7 mm with the xenon lamp in a nitrogen atmosphere. The thermal conductivity as a function of temperature was calculated according to the equation:

$$\lambda(T) = \rho(T) \times c_p(T) \times \alpha(T) \quad (1)$$

where, λ - thermal conductivity; (W/m·K), ρ - density; (kg/m³), c_p - specific heat capacity; (J/kg·K), α - thermal diffusivity; (mm²/s), T - temperature; (°C).

For thermal diffusivity measurements, four different samples were chosen based on the hardness measurements: underaged samples (aged for 1 hour at 180°C and 200°C) as well as peak aged samples (aged for 4 or 5 hours at 180°C and 200°C) were chosen for the investigation. The aging condition was determined by hardness measurements. These samples were investigated at four different temperatures (25°C, 75°C, 150°C, and 250°C).

The TESCAN Vega 3 LMU scanning electron microscope equipped with an EDS X-act detector by Oxford Instruments was used for metallographic investigation of the samples. The preparation of the samples included wet grinding on a series of SiC papers and polishing with alumina suspension with two different granulations of Al₂O₃: particle sizes of 0.3 μm and 0.05 μm. Dix-Keller solution was used for the etching of the samples by immersion to reveal the microstructure.

Transmission electron microscopy was used to analyze the microstructure at the nanolevel. For this analysis, the sample with the highest hardness was chosen (aged at 180°C for 5 hours). In order to obtain transparent TEM foils, "Gatan PIPS 691" was used for sample preparation. TEM analysis was performed on a "Jeol JEM 2010F" transmission electron microscope.

3. Results and discussion

Figure 1 shows the change in hardness values as a function of time during isothermal aging of EN AW-6060. Looking at the graphs shown in Figure 1, it can be concluded that the aging time has a great influence on the hardness values. With the increase in aging time, the hardness of the aged samples gradually reaches its maximum value and then decreases. The maximum hardness value was reached after aging at 180°C for 5 hours. The obtained value was 95 HV₁₀, which was 69.6% higher than the hardness value of the quenched sample (56 HV₁₀). It can be assumed that, in the first four hours of aging, the precipitation of the pre-β" metastable phase occurs. After quenching, a large number of vacancies were created, promoting the nucleation of the pre-β" phase. During aging, Mg and Si atoms diffuse from the solid solution and move towards the pre-β" phase, exchanging places with Al atoms. As a result, there is a growth of precipitates and a gradual loss of coherence with the Al lattice. With the increase in aging time, the exchange of atoms of alloying elements with Al atoms increases, so the phase transformations continue according to the precipitation sequence [5]. The hardness maximum shown in Fig. 1 is obtained due to the formation of the β" metastable phase (Mg₅Si₆). This has been confirmed by many authors [1-3, 5, 7-9, 16]. According to Marioara et al. [1], although the precipitate density during the precipitation of the β" phase is low, the hardness reaches a maximum because the incoherency with the lattice increases. After aging for 6–8 h, precipitates of the β" phase grow and coagulate, which leads to a decrease in the hardness values.

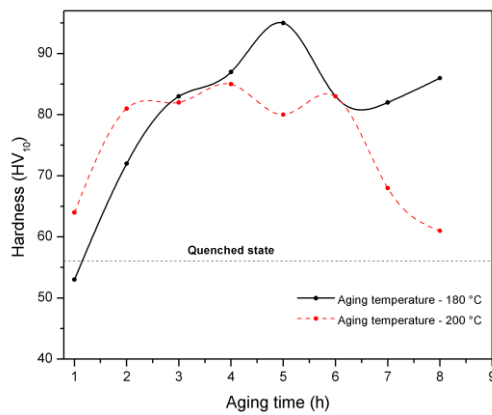


Fig. 1 Change in hardness values as a function of aging time at two different temperatures

From the further analysis of the graphs in Fig. 1, it can be concluded that aging at higher temperatures leads to faster attainment of maximal hardness values. However, the maximum values of hardness achieved after aging at a higher temperature are lower than those obtained after aging at lower temperatures. In the first 2 hours of aging, the achieved hardness values are higher during isothermal aging at 200°C compared to 180°C. This is explained by the fact that with an increase in the aging temperature, there is also an increase in the diffusion rate, so the precipitation of the pre-β" phase and the loss of coherence occur faster. Nevertheless, in order to achieve a true peak aged state, a lower aging temperature with longer aging times must be used.

Thermal diffusivity of the aged samples was investigated at four different temperatures as shown in tables 2 and 3.

Table 2: Change in thermal diffusivity after aging at 180°C for different times at different measuring temperatures

Temperature (°C)	Thermal diffusivity (mm ² /s)	
	After aging at 180°C for 1 hour	After aging at 180°C for 5 hours
25	78.51	87.38
75	77.07	85.94
150	76.88	84.45
250	78.5	83.25

Table 3: Change in thermal diffusivity after aging at 200°C for different times at different measuring temperatures

Temperature (°C)	Thermal diffusivity (mm ² /s)	
	After aging at 200°C for 1 hour	After aging at 200°C for 4 hours
25	81.75	96.53
75	81.49	96.55
150	80.75	93.76
250	81.01	90.6

* Thermal diffusivity of the quenched sample = 85 mm²/s

These temperatures were chosen to represent two different stages in the precipitation process. Samples aged for one hour represent the underaged samples and, samples aged for 4 or 5 hours represent the peak aged state, according to the hardness graph given in Fig. 1. By reviewing the results given in Tables 2 and 3, it can be concluded that the thermal diffusivity of underaged samples is lower, while the thermal diffusivity of peak aged samples is higher than those obtained for the quenched sample. Peak aging had a positive effect on thermal diffusivity values. The maximum value of thermal diffusivity was obtained after aging at 200°C for 4 h, and it is 13.6% higher in comparison to the quenched sample. When aging for 1 hour, the thermal diffusivity values are lower than those obtained for the quenched sample. At these aging parameters, the pre-β" phase (GP-zones) is formed. This type of precipitate has the effect of scattering electrons, which leads to a decrease in thermal diffusivity. With an increase in aging time (4 or 5 hours), the amount of precipitate increases due to the reduction of alloying elements in the solid solution; consequently, the thermal diffusivity increases [4, 10].

Thermal diffusivity is highest when the saturation of the solid solution is lowest, and in this case, that was achieved by the precipitation of the β" phase. Also, by comparing the results in Tables 2 and 3, it can be concluded that at higher aging temperatures, diffusion is accelerated, so the precipitation intensifies, which leads to a faster reduction of alloying elements in the solid solution, leading to an increase in thermal diffusivity. By increasing the measurement temperature (represented by the rows in the tables), the thermal diffusivity decreases due to thermal vibrations in the lattice. This was confirmed in peak aged samples. In underaged samples, this phenomenon is not observed. In these samples, a sudden increase in thermal diffusivity values can be observed at 250°C. This increase can be attributed to additional aging. Given that these samples are underaged, reheating the samples at higher temperatures, at which precipitation takes place according to the precipitation sequence, can result in additional aging. Additional aging causes a new amount of precipitates to be formed, which leads to the reduction of alloying elements in the solid solution, leading to an easier flow of electrons.

For a deeper analysis, the sample with the highest value of hardness (aged for 5 hours at 180°C) was investigated on TEM. Additionally, SEM-EDS analysis was performed on samples underaged and peak aged at 200°C that were subjected to thermal diffusivity analysis.

Fig. 2a-b show the SEM-EDS analysis of the on samples underaged and peak aged at 200°C, respectively. By analyzing figures 2a–b, it can be assumed that the microstructure of the peak aged sample is covered with finely distributed precipitates of the metastable β" phase, which is shown by spectrum 3 in Figure 2b. This can also be stated for the sample that was underaged because this is a possibility due to the high aging temperature combined with the short aging time (Fig. 2a). Analysis of spectrum 1 (Fig. 2a) shows precipitates containing Mg and Si. Also, an AlFeSi phase appears in both analyzed samples, represented by spectrum 3 in Fig. 2a and spectrum 4 in Fig. 2b. Also, somewhat larger particles containing silicon with and without magnesium were analyzed in the microstructures. Those particles are represented by spectrums 2 and 4 in Fig. 2a and spectrums 1 and 2 in Fig. 2b.

The additional analysis was performed using a transmission electron microscope on the samples aged for 5 hours at 180°C.

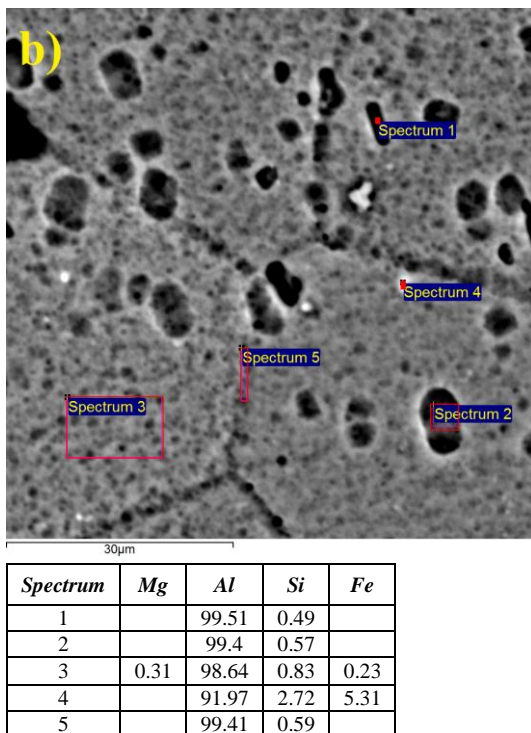
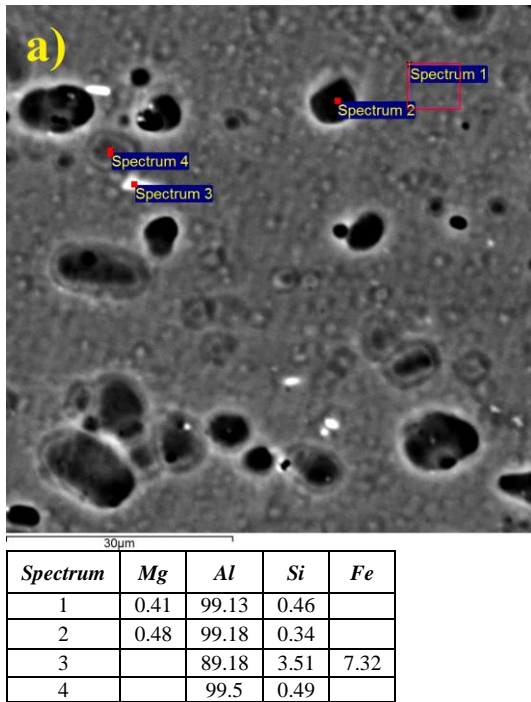


Fig. 2 SEM-EDS analysis of the samples underaged and peak aged at 200°C for 1 and 4 hours, respectively

The peak aged sample was subjected to TEM analysis. The TEM microphotograph (Figure 3) shows the precipitation in the peak aged sample. The SAED (selected area of electron diffraction) image (Figure 4) shows the orientation of the precipitates in the crystal lattice. TEM micrograph was imaged in the [0 0 1] zone axis of Al in order to visualize the precipitates. Looking at Figs. 3 and 4, it can be concluded that small needle-shaped precipitates with a size of several tens of nanometers are visible. The density of the precipitates is high, and they are distributed quite evenly throughout the microstructure of the investigated sample [1, 5, 6, 8].

The presented microstructures in figures 2-4 are in agreement with the results given for hardness and thermal diffusivity measurements.

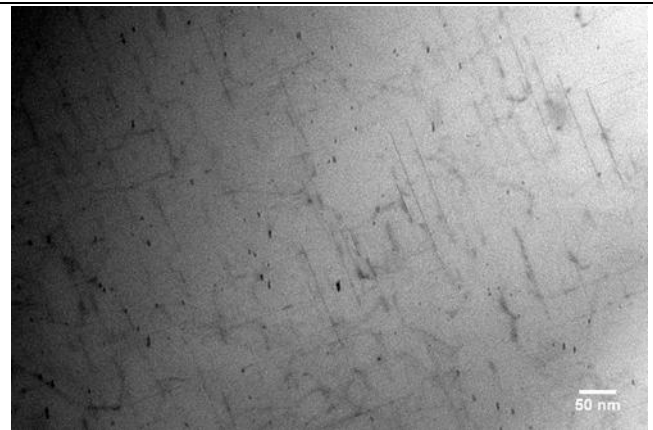


Fig. 3 TEM microphotograph of the sample peak aged at 180°C for 5 hours

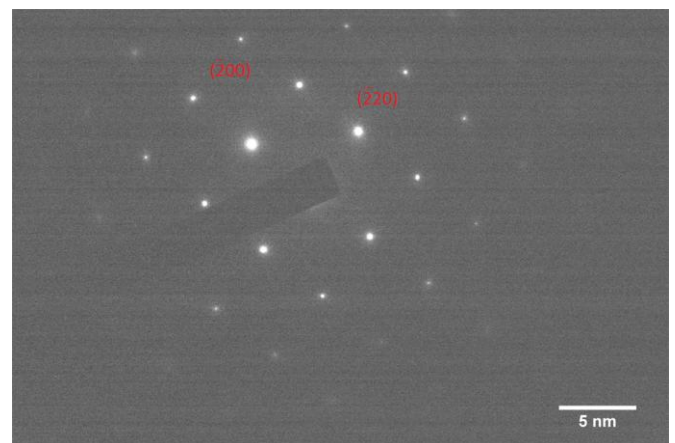


Fig. 4 SAED diffraction pattern of the sample peak aged at 180°C for 5 hours

4. Conclusions

Based on the results obtained during the investigation of the influence of aging on the thermal, mechanical, and structural properties of the EN AW-6060 aluminum alloy, the following conclusions were drawn:

- Isothermal aging caused significant increase in mechanical and thermal properties. The highest improvement in hardness values was obtained after aging at 180 °C for 5 hours. It can be assumed that hardening effect was caused by the precipitation of metastable β'' phase.
- Thermal diffusivity was measured in four different samples that represent underaged and peak aged states. The underaged samples showed lower values of thermal diffusivity in comparison to the quenched sample due to precipitation of electron scattering phases. The highest values of thermal diffusivity were obtained after aging at 200°C for 4 hours, when the highest degree of precipitation from the solid solution was caused.
- Microstructural investigation confirmed the existence of finely dispersed metastable phases which caused the enhancement of thermal and mechanical properties. The responsible phase is believed to be the β'' phase.

5. Acknowledgments

The research presented in this paper was done with the financial support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, within the funding of the scientific research work at the University of Belgrade, Technical Faculty in Bor, according to the contract with registration number 451-03-47/2023-01/200131.

6. References

1. Marioara C.D., S.J. Andersen, J. Jansen, H.W. Zandbergen, The influence of temperature and storage time at RT on nucleation of the β'' phase in a 6082 Al–Mg–Si alloy, *Acta Materialia*, 51 (2003) 789–796.
2. Tan C.F., M.R. Said, Effect of Hardness Test on Precipitation Hardening Aluminium Alloy 6061-T6, *Chiang Mai Journal of Science*, 36 (3) (2009) 276-286.
3. Abid T., A. Boubertakh, S. Hamamda, Effect of pre-aging and maturing on the precipitation hardening of an Al–Mg–Si alloy, *Journal of Alloys and Compounds*, 490(2010) 166–169.
4. Choi S.W., Y.M. Kim, Y.C. Kim, Influence of precipitation on thermal diffusivity of Al-6Si-0.4Mg-0.9Cu-(Ti) alloys, *Journal of Alloys and Compounds*, 775 (2019) 132-137.
5. Gupta A.K., D.J. Lloyd, S.A. Court, Precipitation hardening in Al–Mg–Si alloys with and without excess Si, *Materials Science and Engineering A*, 316 (2001) 11-17.
6. Zheng Y.Y., B-H. Luo, W. Xie, W. Li, Microstructure evolution and precipitation behavior of Al-Mg-Si alloy during initial aging, *China Foundry*, 20 (2023) 57–62.
7. Birol Y., The effect of processing and Mn content on the T5 and T6 properties of AA6082 profiles, *Journal of Materials Processing Technology*, 173 (2006) 84-91.
8. Chang C.S.T., I. Wieler, N. Wanderka, J. Banhart, Positive effect of natural pre-ageing on precipitation hardening in Al–0.44 at% Mg–0.38 at% Si alloy, *Ultramicroscopy*, 109 (2009) 585–592.
9. Marioara C.D., S.J. Andersen, J. Jansen, H.W. Zandbergen, Atomic Model for GP-Zones in a 6082 Al–Mg–Si system, *Acta Materialia*, 49 (2001) 321–328.
10. Kim Y.M., S.W. Choi, Y.C. Kim, C.S. Kang, S.K. Hong, Influence of the Precipitation of Secondary Phase on the Thermal Diffusivity Change of Al-Mg₂Si Alloys, *Applied Sciences*, 8 (11) (2018) 2039-.
11. Choi S.W., Y.M. Kim, K.M. Lee, H.S. Cho, S.K. Hong, Y.C. Kim, C.S. Kang, S. Kumai, The effects of cooling rate and heat treatment on mechanical and thermal characteristics of Al–Si–Cu–Mg foundry alloys, *Journal of Alloys and Compounds*, 617 (2014) 654-659.
12. Zhang C., Y. Du, S. Liu, Y. Liu, B. Sundman, Thermal conductivity of Al–Cu–Mg–Si alloys: Experimental measurement and CALPHAD modeling, *Thermochimica Acta*, 635 (2016) 8-16.
13. Vishwakarma D.K., N. Kumar, A. Kumar Padap, Modelling and optimization of aging parameters for thermal properties of Al 6082 alloy using response surface methodology, *Materials Research Express*, 4 (2017) 046502.
14. Choi S.W., H.S. Cho, C.S. Kang, S. Kumai, Precipitation dependence of thermal properties for Al-Si-Mg-Cu-(Ti) alloy with various heat treatment, *Journal of Alloys and Compounds*, 647 (2015) 1091-1097.
15. <https://www.astm.org/Standards/E384.htm>
16. Masoud I.M., T. Abu Mansour, J.A. Al-Jarrah, Effect of Heat Treatment on the Microstructure and Hardening Properties of 6061 Aluminum Alloy, *Journal of Applied Sciences Research*, 8 (10) (2012) 5106-5113.