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THE EFFECT OF HEAT TREATMENT CONDITIONS ON THE STRUCTURE EVOLUTION AND MECHANICAL PROPERTIES OF TWO BINARY Al-Mg ALUMINIUM ALLOYS

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The presented investigation results were carried out on two binary aluminium-magnesium alloys. The article focuses on the influence of heat treatment conditions on the precipitation response of AlMg3 and AlMg5 aluminium alloy, microstructure evolution and strength of the alloys. The microstructure variation was analysed using a scanning electron microscope and an optical microscope in order to characterise the microstructure in a heat treated condition. Tensile tests and hardness measurements were carried out to investigate the effect of heat treatment on the mechanical properties.

Key words: aluminium-magnesium alloy, structure, mechanical properties, heat treatment.

INTRODUCTION

The heat treatment process, in its widest sense, relates to any of the heating and cooling operations that are carried out to increase the mechanical strength, optimise the obtained microstructure, or to remove residual stress in a final metal product. However, when this term refers to aluminium alloys, its use is frequently restricted to the specific operations applied in order to increase mechanical strength and hardness of the precipitation-hardenable cast and wrought Al alloys [1–6].

The mechanical properties of aluminium and its alloys can be increased with the application of a precipitation strengthening heat treatment [7–9].

Alloys of the Al–Mg system have been a recent focus of attention for applications in the automobile industries because they exhibit a combination of high specific strength, relatively good formability, remarkable resistance to corrosion and weldability [7–9]. The precipitation response of Al-Mg alloys has been a subject of many investigations, where the aim is to examine the way that stable and metastable precipitating phases (β’ and β’’) nucleate and are created from a supersaturated solid solution [4–9].

The objective of this investigation is to study the influence of solution treatment and ageing conditions on the evolution of structure and mechanical properties of two binary aluminium-magnesium alloys.

EXPERIMENTAL DETAILS

The chemical composition of the Al-Mg alloys used in this investigation is given in Table 1.

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Table 1 **Chemical composition of Al-Mg alloys / wt. %**

Mg	Fe	Si	Cu	Ti	Al
2,86	0,07	0,07	0,01	0,01	rest
5,55	0,07	0,08	0,01	0,01	rest

The solution treatment (ST) process was conducted using a resistance furnace, and then the samples were quenched in room temperature water. Artificial ageing was performed using a laboratory dryer at 180 °C in different time periods. For a metallographic study, heat treated samples were ground using silicon carbide abrasive papers and polished by standard processes. To reveal the consistent and intermetallic phases of the structure, the samples were etched using Weck’s and Keller’s reagent. The microstructures of the samples were examined with an Axio Observer Image Analyser light microscope using bright field and under polarised light and on the scanning electron microscope ZEISS Supra 35. The chemical composition microanalysis was prepared using Energy-dispersive X-ray spectroscopy (EDS). For the microstructure evaluation, the secondary electron detection method was used, with the accelerating voltage of 20 kV. The X-ray diffraction (XRD) phase analysis was carried out on PANalytical X’Pert Pro diffraction system with a cobalt anode. Hardness measurements were performed on Automatic Rockwell hardness tester ZWICK ZHR 4150 under a load of 60 kg to determine the hardening kinetics of the two investigated aluminium alloys. The tensile tests were conducted at room temperature up to failure with a deformation rate of $6{,}7x10^{-4}s^{-1}$.

RESULTS AND DISCUSSION

The typical microstructure of the Al-Mg alloy in a heat treated condition is shown in Figures 1 and 2. In

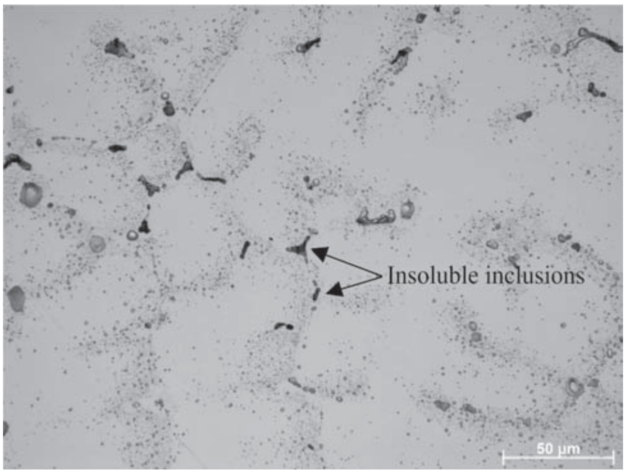

Figure 1 Microstructure of AlMg3 alloy after solution treatment, Keller's reagent

Table 2 **Results of pointwise chemical composition analysis**

Point	Element	Concentration of main elements / %	
		Weight	Atomic
1	Al_K	60,72	76,19
	Fe_K	39,28	23,81
2	Al_K	05,74	05,48
	Mg_K	56,46	59,84
	Si_K	37,81	34,68
3	Al_K	97,48	97,21
	Mg_K	02,52	02,79

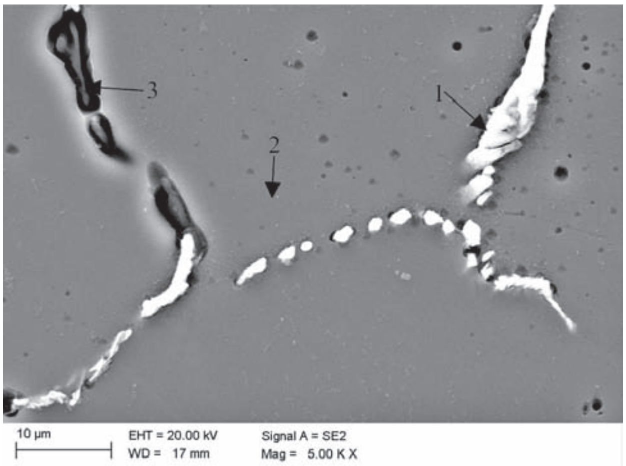

Figure 2 Microstructure of AlMg3 alloy after artificial ageing for 8 hours, Weck's reagent

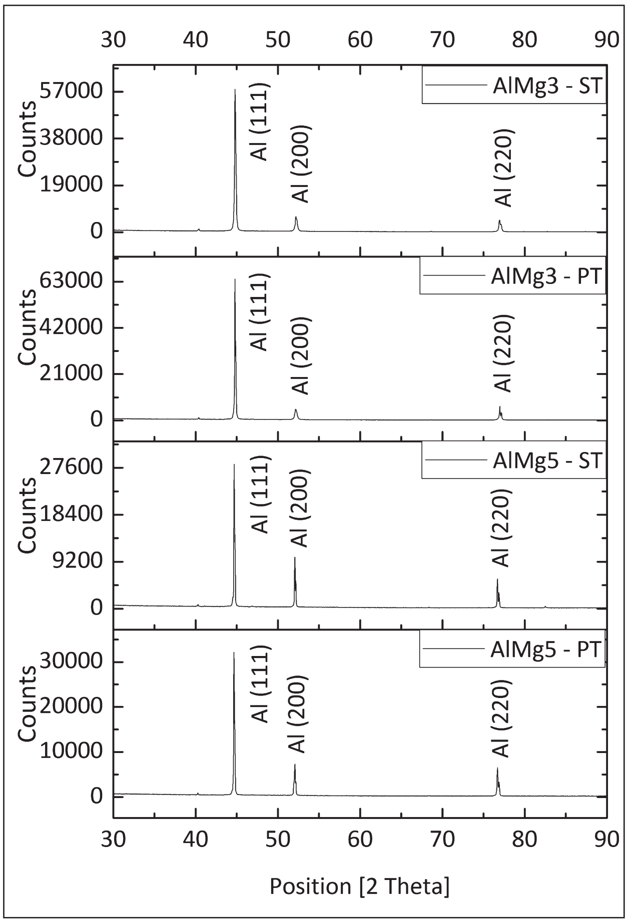

Figure 3 The experimental X-ray diffraction pattern of AlMg3 and AlMg5 aluminium alloys in a heat treated state

the microstructure in a solution-treated state, insoluble inclusions can be observed on the grain boundary. The microstructure after precipitation treatment is complex and consist of a primary α - Al, Al_3Fe, Mg_2Si phase and β - Al_3Mg_2 precipitates responsible for the hardening effect. The EDS technique and X-ray diffraction (XRD) analysis was used in order to investigate and confirm the chemical composition of the intermetallic phases. The results are presented in Table 2.

An EDS analysis confirmed the presence of main alloying elements as well as the presence of phases, which have a stoichiometric composition similar to that of the Mg_2Si and Al_3Fe phase. The Fe - rich phase forms elongated blades or star-shaped clusters. The solubility of Fe in aluminium is very low; therefore, even a small addition of iron is sufficient to create Al_3Fe eutectic forms, which exhibit greater mechanical strength than an aluminium matrix. It is expected that the β - Al_3Mg_2 secondary precipitates that harden the alloy have a size of about > 1µm. Thus, their presence should be confirmed using higher magnification by application of Transmission Electron Microscopy (TEM) [3]. Figure 3 shows the results of X-ray phase analysis (XRD) of the samples in different conditions. Additionally, it can be stated that due to the detection limit of the XRD method, only the presence of a primary aluminium phase can be confirmed. Moreover, the small peak displacement, which can be observed in the Figure 3, may indicate that some internal stresses are present in the heat treated samples.

Hardness measurements were performed in order to investigate the influence of the heat treatment conditions on the mechanical strength and to choose the most beneficial parameters of the precipitation treatment process. The obtained results are summarised and listed in Tables 3 - 4 respectively. The temperature of solution treatment for both investigated alloys was selected by Al-Mg binary diagrams. For each studied material, a solution treatment temperature was just below the solidus temperature to protect the material from partial melting.

Table 3 **Results of mechanical properties measurement of AlMg3 alloy**

T / °C	ST time / h	Artificial ageing time / h at 180 / °C											
		0			4			8			12		
		HRF	R_m / MPa	A_5 / %	HRF	R_m / MPa	A_5 / %	HRF	R_m / MPa	A_5 / %	HRF	R_m / MPa	A_5 / %
580	8	45	198	29	65	222	28	63	236	26	66	232	23
	12	46	197	29	68	234	25	69	238	24	67	225	23

Table 4 **Results of mechanical properties measurement of AlMg5 alloy**

T / °C	ST time / h	Artificial ageing time / h at 180 / °C											
		0			4			8			12		
		HRF	R_m / MPa	A_5 / %	HRF	R_m / MPa	A_5 / %	HRF	R_m / MPa	A_5 / %	HRF	R_m / MPa	A_5 / %
560	8	68	269	28	71	268	30	72	262	27	73	268	28
	12	66	262	27	73	268	33	70	269	32	68	266	29

The temperature of artificial ageing was 180 °C. Rockwell hardness measurements were used as an initial assessment of the influence of the different heat treatments on the mechanical properties. Based on the data listed in Table 2 and 3, it can be concluded that the greatest ageing potential is exhibited by the AlMg3 alloy. A similar effect was observed when the temperature of artificial ageing was 160 °C in a previous study [3]. It can be observed that the highest solution temperature provides the greatest increase in hardness after precipitation treatment and about 50 % in comparison to the solution-treated state. This increase in hardness is caused by the precipitation of the secondary β - Al_3Mg_2 phase from the supersaturated solid solution. The precipitation treatment of the AlMg5 aluminium alloy results in only a small increase in hardness of about 11 % in comparison to the solution treatment condition. This alloy behaviour could be associated with the formation and precipitation of the δ'' phase, which does not contribute to age hardening. However, this statement should be confirmed using a TEM examinations.

Static tensile tests were carried out in order to characterise the strength and ductility of the investigated aluminium alloys before and after heat treatment. These results are presented in Tables 3 - 4. As it was expected, the highest tensile strength is exhibited by the AlMg5 alloy that contains 5 % magnesium; however, the highest ageing potential is presented by the AlMg3 alloy. The increase in tensile strength after eight hours of ageing at 180 °C is approximately 21 % in comparison with a solution-treated specimen. It is also demonstrated that artificial ageing results in only a small decrease in the ductility of the AlMg3 alloy. The heat treatment process of the AlMg5 alloy does not significantly influence the increase in mechanical properties. As it was expected, based on the hardness measurements presented above, this alloy is not age-hardenable. There is only a negligible increase in mechanical properties for the material observed in a sample that was solution treated for 12 h and artificially aged for 8 h. Moreover, the ductility remains the same during the whole heat treatment process, independently from the ageing time.

CONCLUSIONS

- In this work, the evolution of microstructure and mechanical properties was studied as a function of heat treatment. Using a light and scanning electron microscope with the application of energy-dispersive X-ray spectroscopy and X-ray phase analysis, the presence of the main phases was confirmed. It was found that the microstructure consists of a primary α - Al, Al_3Fe, Mg_2Si phase and β - Al_3Mg_2 precipitates responsible for the precipitation strengthening effect.
- It has been proven that heat treatment has a meaningful influence on the hardness and tensile strength of the AlMg3 alloy, but results in a simultaneous decrease in the ductility of the material. Moreover, precipitation treatment of the AlMg5 alloy resulted in only a negligible improvement of the mechanical strength of the alloy.
- The optimum heat treatment conditions were selected based on the mechanical properties investigation results presented above. For the AlMg3 aluminium alloy, the optimum solution treatment temperature and time were 580 °C and 8 h with artificial ageing for 8 h at 180 °C; however, in the case of the AlMg5 alloy, the solution treatment temperature and time were 560 °C and 12 h with ageing treatment for 8 h at 180 °C.

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Note: The responsible translator for English language is Justin Nnorom – native English-speaking translator at Junique, Dąbrówka, Poland