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AlMg5 Alloy Behaviour under Different Solidification Conditions

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Abstract
Various solidification conditions of processing alloys have a strong influence on microstructure development, often leading to extended solid-state solubility. In this study, the solubility of Mg in the α-Al solid solution was investigated by varying the solidification conditions of the AlMg5 alloy. Two different casting methods were employed: a conventional technique (gravity casting) and a non-conventional one (melt-spinning), using a self-design device. The variations in Mg solubility were assessed by EDS analysis, revealing a value of 5.20wt% for the sample obtained through gravity casting into a metallic die, and complete solubility of all alloying elements in the sample produced by melt-spinning. Although the XRD patterns confirmed the formation of a fully supersaturated solid solution after rapid solidification, the hardness of the material did not exhibit a significant increase, with values around 90 HV. These findings suggest that while melt-spinning enhances solubility at the microstructural level, additional mechanisms may be required to achieve substantial improvements in mechanical properties.

Keywords
AlMg5, melt-spinning technique, extended solid-state solubility

1. Introduction

Al-Mg alloys are widely used as structural materials, in automotive, transportation and aerospace industry. In addition to being shaped into complex geometries by pouring techniques, these materials can be processed into rods, wires, and profiles through mechanical deformation, or into powders. As a result, they find applications in fields such as the chemical and defence industries, as well as in food packaging. [1, 6, 7]

The quality and final properties of casting components are significantly influenced by microstructural evolution during the solidification of the molten alloy. A comprehensive understanding of phase formation mechanisms during the pouring processes is essential for customizing material properties to meet specific performance requirements [1, 3]. Extended solubility and supersaturated solid solution (SSS) can be obtained by increasing the cooling rates from liquid state [3, 4]. The cooling rate can be increased so dramatically that the atomic mobility becomes insufficient for the formation of an ordered crystalline lattice, resulting in the formation of amorphous alloys. These materials are characterized by enhanced mechanical strength, improved corrosion resistance, and unique magnetic or electrical properties, depending on their composition [5].

According to Al-Mg phase diagram indicated in Figure 1, solubility of Mg exhibit limited solubility in the aluminium-based matrix that decreases with decreasing temperature. In Table 1 are listed the Mg solubility variation in α-Al solid solution as a function of temperature, for equilibrium condition [8]. Since, in practical applications, the processing conditions deviate from equilibrium, these values may increase considerably.

Table 1. Mg solubility in α-Al collected from the phase diagram

Temperature [°C]	450	400	350	300	250	200	150	100	20
Mg [wt.%]	18.6	13.5	9.9	6.7	4.4	3.1	2.3	1.9	0.8

The present study is focused on the Mg solubility in the α-Al solid solution and hardness evolution of one of the industrial Al-Mg alloy suitable for castings. By applying two casting technologies that ensure different cooling rates from the liquid state, it was possible to observe the variation in the solubility of alloying elements in the α-Al solid solution.

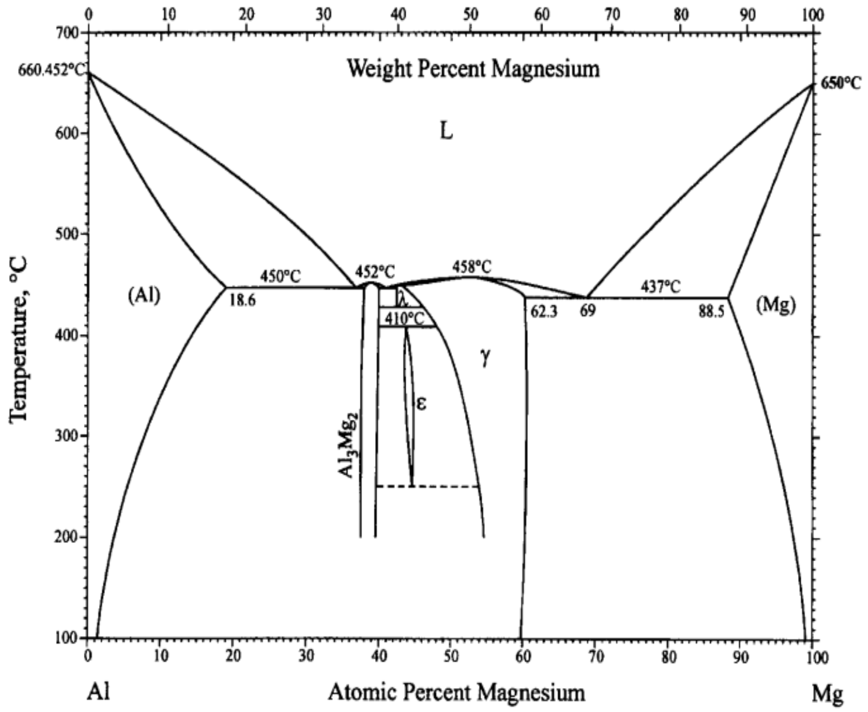


Fig. 1. The Al-Mg phase diagram [8]

2. Material and Methods

In this study, samples of EN AC-51300 (AlMg5) with chemical composition shown in Table 2 were obtained by gravity casting in metallic die and by melt-spinning technique. Chemical composition of the studied alloy is according to industrial specification of EN 1706: 2020 Aluminium and aluminium alloys. Castings. Chemical composition and mechanical properties [9].

Table 2. Chemical composition of EN AC-51300 alloy (wt. %)

Mg	**Si**	**Fe**	**Mn**	**Zn**	**Ti**	**Other**	**Al**
6.22	0.15	0.32	0.05	0.01	0.02	0.04	remain

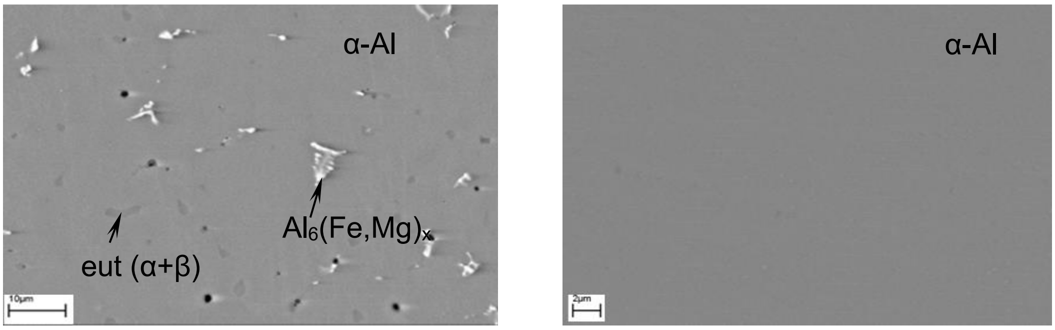
Different solidification conditions were obtained by practicing two types of pouring methods, namely gravity casting and melt-spinning technique, using a self-design device described in [2]. Gravity casting specimens were cut from a master sample of 14 X 80 X 160 mm and metallographic prepared as well as samples collected from the second pouring technique. As-ribbon samples obtained by melt-spinning have a thickness of 30-50 μm and a width of 4-5 mm. For the following material characterisation one sample of each technique were investigated.

Structural and morphological characterizations were performed using a Scanning Electron Microscopy (LEO 1450VP). Vickers hardness measurements were performed using an AHOTEC FM-700 device and 30 measurements were performed for each sample using a loading force of 0.98 mN for 15s. XRD technique was employed by using Brucker diffractometer with a scanning rate of 1°/min and 2θ of 20°-90° using a Co anode with a wavelength λ = 0.1789 nm.

3. Results and Discussion

In order to investigate the influence of different solidification conditions, samples obtained by one conventional and other non-conventional technique were microstructurally analysed (Figure 2).

The microstructure of AlMg5 alloy revealed in Figure 2a, for the sample obtained through gravity casting into a metallic die, it can be indicated specific alloy phases as: solid solution, eutectic, intermetallic compounds. Microstructural analyses performed on the as-ribbon sample of AlMg5 revealed qualitative changes by the presence of a single α-Al phase (Figure 2b).



a) b)

Fig. 2. SEM images of AlMg5 alloy: a) as-cast in metallic die, b) as-ribbon by melt-spinning

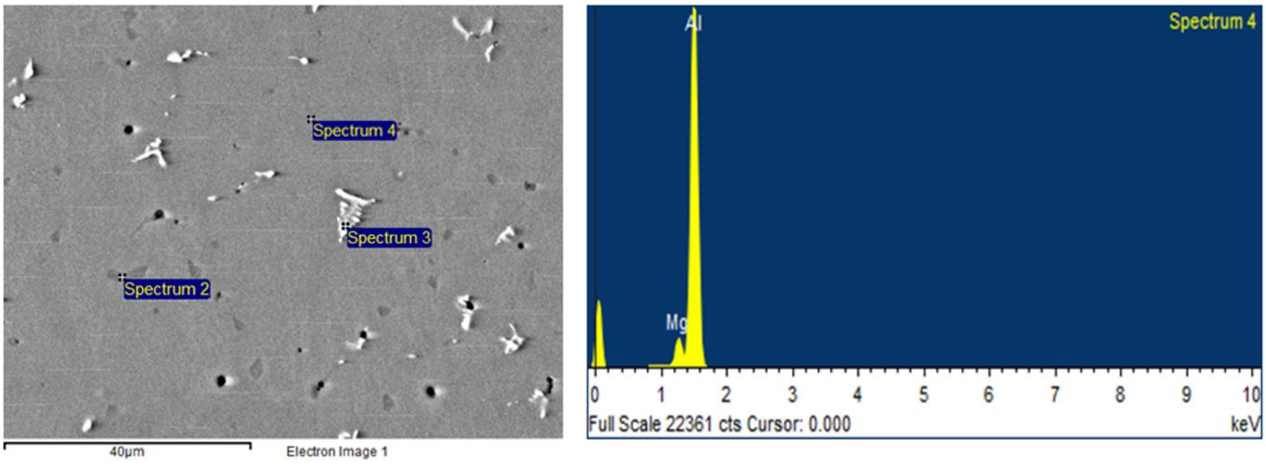


Fig. 3. SEM image and EDS spectra for AlMg5 alloy obtained by gravity casting in metallic die

Energy-dispersive X-ray spectroscopy was implicated in order to evaluate the chemical composition of the indicated phases. Thus, in Figure 3 are indicated the evaluated area and EDS spectra for α-Al solid solution for the sample obtained by gravity casting. In Table 3 it can be found the chemical composition for the analysed areas with indication of structure phases.

Table 3. Chemical composition by EDS of analysed spectra of AlMg5

Areas from Fig.2	**wt.%**				**Structure phases**
	Al	**Mg**	**Fe**	**O**	
spectrum 2	87.25	12.53	-	0.22	Eutectic (α-Al + β-Al_3Mg_2)
spectrum 3	91.11	6.16	1.38	1.35	Intermetalic compound $Al_6(Fe, Mg)_x$
spectrum 4	84.80	5.20	-	-	Solid Solution α-Al

According to phase diagram and information related with EDS spectra, in compacted grey small areas it can de identify also β- Al_3Mg_2 phase, as part of the eutectic morphology along the α-Al phase. Due to the fact that the investegated alloy is an industrial-grade, it contains a relatively high amount of Fe, leading to the formation of intermetallic compounds that decrease mechanical properties and can promote failure propagation.

According to the thermal equilibrium diagram, the maximum solubility limit of Mg in α-Al is 18.6wt%. Thus, even at a cooling rate provided by gravity casting in metallic die, it can be observed that the α-Al solid solution is supersaturated in Mg. Following the EDS analysis performed on the α-Al solid solution in the gravity cast alloy (spectrum 4) and the value recorded for the Mg content in the base matrix from Table 3, it is observed that almost the entire amount of Mg in the alloy is dissolved in α-Al (5.20wt%). Increasing the cooling rate from the liquid state Al dissolved the entire amount of Mg, the value obtained from the microhardness determination confirms this observation. Ribbons obtained from this alloy contains 1.2wt% more Mg than the bulk sample in the Al base matrix.

In order to confirm the complete solubility of all alloying elements in the samples obtained by melt-spinning, X-ray diffraction (XRD) analysis was performed. Figure 4 shows the XRD results, where only crystallographic orientations specific to aluminum are present.

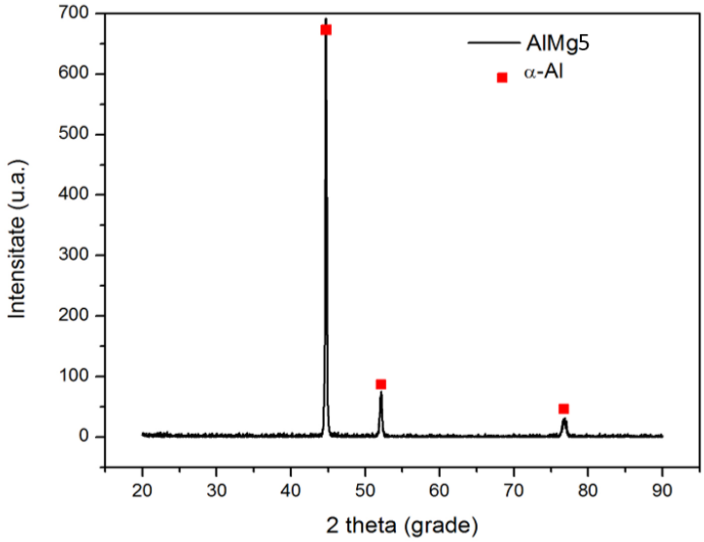


Fig. 4. XRD profile for AlMg5 obtained by melt-spinning technique

Vickers hardness measurements were performed to evaluate the influence of the different solubility levels in α-Al. The average values obtained were 80 HV for the as-cast sample and 92 HV for the melt-spun ribbon. To achieve a substantial improvement in hardness, a higher amount of Mg must be dissolved in the solid solution.

4. Conclusions

For both pouring technologies an α-Al solid solution with extended solubility was obtained. Furthermore, by melt-spinning technique knew as quenching from liquid state, the entire amount of Mg was dissolved in α-Al, avoiding the formation of intermetallic compounds.

Ribbons obtained from this alloy contains 1.2 wt% more Mg than the bulk sample in the Al base matrice, which leads to an insignificant increase in microhardness.

The increased cooling rate during melt-spinning enables a higher degree of Mg solubility in the α-Al matrix, as confirmed by EDS and XRD analysis.

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