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The influence of wall thickness on the microstructure of HPDC AE44 alloy

T. Rzychoń *, A. Kiełbus
Department of Material Science, Silesian University of Technology,
ul. Krasińskiego 8, 40-019 Katowice, Poland
* Corresponding author: E-mail address: tomasz.rzychon@polsl.pl

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ABSTRACT

Purpose: The main objective of this study was determination of influence of wall thickness on the microstructure of die-cast magnesium alloy containing aluminum and rare earth elements.

Design/methodology/approach: The study was conducted on die-cast magnesium alloy containing 4% wt. aluminum and 4 % wt. mixture of rare earth elements (mischmetal) in the die-cast condition. The mischmetal includes cerium, lanthanum, neodymium and praseodymium. The microstructure was characterized by optical microscopy (Olympus GX-70) and a scanning electron microscopy (Hitachi S3400) equipped with an X-radiation detector EDS (VOYAGER of NORAN INSTRUMENTS). The phase identification of these alloys was identified by X-ray diffraction (JDX-75). Quantitative examination was conducted using the "MET-ILO" automatic image analysis programme.

Findings: The decreasing of wall thickness of die-cast AE44 leads to grain size decrease and emergence new intermetallic phases in microstructure of this alloy. With increasing thickness higher porosity was observed in alloy.

Research limitations/implications: Future researches should contain investigations of the influence of die-cast parameters on microstructure and porosity.

Practical implications: AE44 magnesium alloy is used in automotive industry. Moreover, this alloy has a new potential application and results of investigations may be useful for preparing optimal technology of die casting and designing parts of car engine.

Originality/value: The results of the researches make up a basis for the next investigations of magnesium alloys with addition of aluminum and rare earth elements designed to exploitation at temperature to 200°C.

Keywords: Metallic alloys; Magnesium alloys; Microstructure; Die-casting

MATERIALS

1. Introduction

The development of magnesium applications for the automotive industry has received significant attention due to its light weight and consequent potential to reduce both fuel consumption and green house effect [1-7]. AZ91D alloy has been used to fabricate a variety of automobile parts, such as cam covers, baffles, oil adapters, clutch housings, steering wheels, and so on; AM60 and AM50 alloys are frequently employed to manufacture instrument panels, steering wheel armatures and seat risers, with a view to its good toughness. However, their applications are restricted when the temperature surpasses 120°C, due to instability of $Mg_{17}Al_{12}$ phase. Rare earth elements are added to magnesium alloys, in order to improve their elevated temperature property. AE42 shows improved creep resistance, but it exhibits unbalanced strength at room temperature [8-13]. Also, the decomposition of $Al_{11}RE_3$ phase in AE42 alloy at high temperatures had been reported [8], this leads to the emergence of $Mg_{17}Al_{12}$ phase to the deterioration of creep resistance. Another access to promoted creep resistance property is to reduce the Al content under its solid solubility limitation, in attempt to avoid the precipitation of $Mg_{17}Al_{12}$ phase [9-13]. Recently, Hydro Magnesium developed a new high-pressure die-casting alloy, AE44, which has attractive high temperature mechanical properties, as well diecastability, and corrosion resistance [11]. The contains 4% Al and 4% RE. AE44 also has good fracture sensitive mechanical properties such as ductility and strength. High-pressure die-casting is the preffered manufacturing process for cast Mg-alloy components. Consequently, AE44 alloy is being considered for structural components such as automotive front engine cradle [11-14]. The aim of the present study is evaluation of effect of wall thickness on the microstructure and porosity of AE44 alloy.

2. Experimental

Chemical composition of AE44 alloy is presented in Table 1. The rare earth additions (RE) were made as mischmetal with the approximate compositions: 50Ce-26La-15Nd-3Pr. The samples were obtained using hot chamber die casting machine. The melt and die temperatures for investigated alloy were 680 °C and 150 °C, respectively. The plunger velocity in the second phase was 350 cm/s. Structural investigations were carried out on plate specimen as shown in Fig. 1.

Table 1.
Chemical composition (wt. %) of experimental alloy

Alloy	Composition, wt.%				
	Mg	Al	Mn	Si	RE
AE44	Bulk	4.15	0.39	0.03	4.01

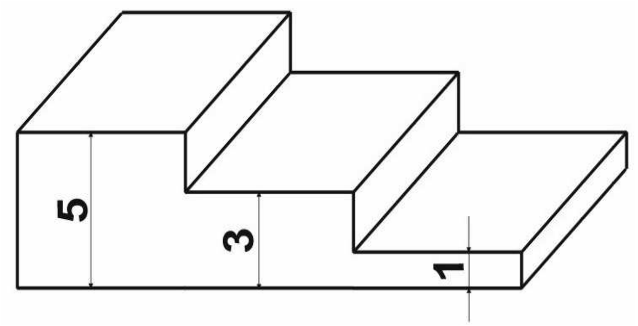


Fig. 1. Dimensions in mm and shape of investigated specimen

Specimens for microstructure studies were mechanically polished using standard methods, etched with 5% acetic acid. The microstructure was characterized by optical microscopy (Olympus GX-70) and a scanning electron microscopy (Hitachi S3400) equipped with an X-radiation detector EDS (VOYAGER of NORAN INSTRUMENTS). X-ray diffraction patterns were collected using X-Pert Philips diffractometer equipped with curved graphite monochromator on diffracted beam and with the following slits (in the sequence form Cu tube counter. Quantitative metallography was performed using Metilo software.

3. Results and discussion

3.1. Phase compositions

X-ray diffraction patterns of die-cast AE44 alloy with varying thickness of plate are shown in Fig. 2. For all specimens the α-Mg peaks are observed with a slight shift toward higher angles, resulting from the formation of aluminum in magnesium solid solution. Distinctions between analyzed diffractograms were observed. Only two intermetallic phases were identified in the 5 mm thick sample, e.g. main compound $Al_{11}RE_3$ and Al_2RE, however the diffraction lines of Al_2RE are very weak. In samples with lower thickness, peaks of Al_2RE are clear and additionally $Al_{2.12}RE_{0.88}$ hexagonal phase was identified. The clear peaks of $Al_{2.12}RE_{0.88}$ are observed in the thinnest specimen. The peak positions for all intermetallic phases are shifted, a shift that can be consistent with substitution of rare earth atoms in crystal lattice of identified compounds.

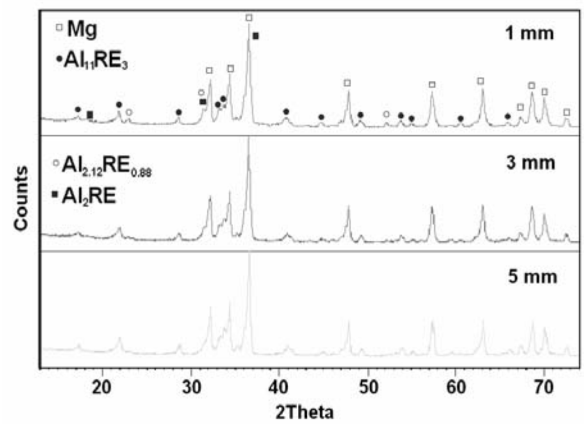


Fig. 2. XRD patterns of specimen with different thickness

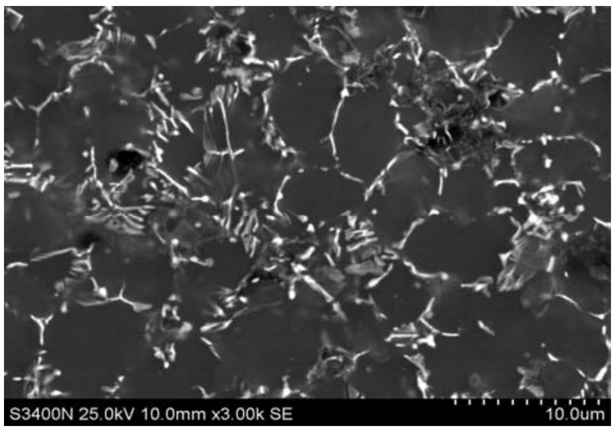


Fig. 3. SEM image of die-cast AE44 alloy

With a decreasing thickness of plate reflections of $Al_{2.12}RE_{0.88}$ are more visible and it indicates that of increasing of cooling rate favors emergence of this phase from liquid in grain boundaries solidifies as eutectic reaction.

SEM investigations indicate the presence lamellar eutectic and globular phase in the interdendritic regions (Fig. 3). For all specimens the same morphology was observed. The ratio of Al:RE for lamellar precipitates close to 3.8 and it is consistent with the $Al_{11}RE_3$. In globular precipitates, ratio of Al:RE is close to 2.5 (Tab. 2). It is good agreement with compound of $Al_{2.12}RE_{0.88}$, however globular precipitates was present in the thickest sample, which not contained of this phase. We assume that globular morphology is the same for precipitates of $Al_{2.12}RE_{0.88}$ and Al_2RE.

Table 2.
Chemical composition (at. %) of precipitates in AE44 alloy

Phase	Mg	Al	La	Ce	Nd	Al/RE
Lamellar	80.3	15.7	1.9	2.1	-	3.9
Globular	82.7	12.4	1.8	2.8	0.3	2.5
Matrix	97.9	2.1	-	-	-	-

3.2. Grain size of solid solution

Specimens taken from the thinnest plate (Fig. 4) have finer grain structure as compared to samples taken from thicker plates (Fig. 5 and 6). A different grain size in analyzed samples was observed. In plate with thickness 1 mm the surface area of grain varied from 15 to 100 μm^2 over the whole cross-section with an average of 41 μm^2. The grain size of samples machined from plate with thickness 3mm varied from 15 to 105 μm^2 with an average of 50 μm^2. The highest grain size was observed in the thickest cross section where average surface area of flat section grain was 67 μm^2 (Fig. 7). The increasing of grain size with the increasing of thickness is consistent with lower a cooling speed of larger sections of diecasting components. Due to smaller grain size in thinner section can be expected higher yield strength.

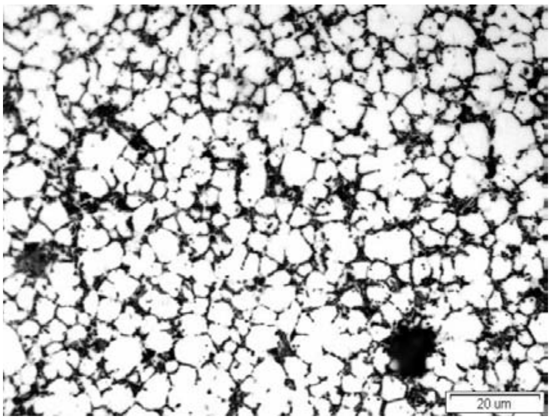


Fig. 4. Microstructure of 1 mm thick plate

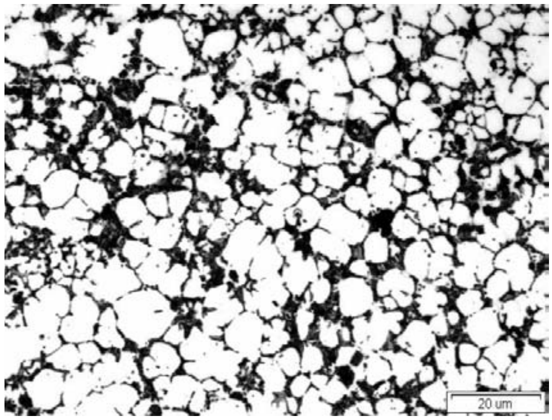


Fig. 5. Microstructure of 3 mm thick plate

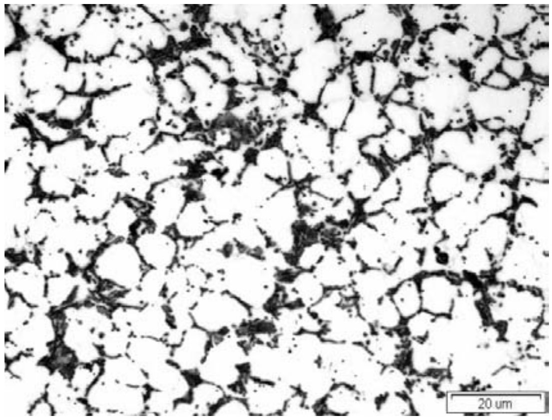


Fig. 6. Microstructure of 5 mm thick plate

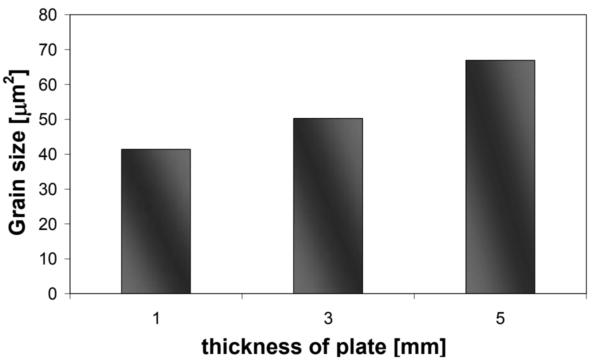
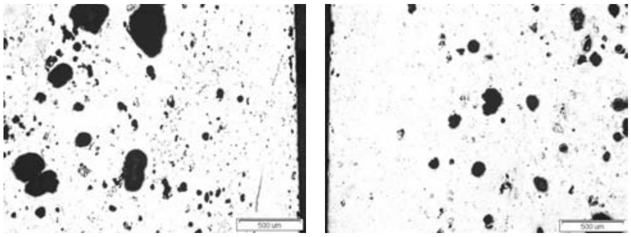


Fig. 7. The influence of wall thickness on the grain size of AE44 alloy

3.3. Porosity

Figure 8 shows examples of porosity observed in the polished cross sections of the specimens. The effect of wall thickness on porosity is shown in Fig. 9. In general, it was evident that increased wall thickness resulted in reduced porosity. This can mainly be explained by the fact that die casting of thin walled specimens encounters high turbulent flow of the molten metal, during the first phase of die casting, inducing volume porosity. The volume porosity in this case can be identified as micro-cavity porosity that is obtained from the combination of gas porosity and shrinkage. The gas porosity is due to the entrapped air in the mold cavity as well as due to hydrogen and other gases dissolved in the liquid alloy.



1 mm 5 mm

Fig. 8. Polished sections normal to the filling direction

High porosity level, which was observed for all specimen, is consistent with high plunger velocity in the second phase (350 cm/s). The high velocity of the cast metal causes porosity, due to spray effect and the tendency to get a jet flow instead of a smooth fill from the gate a jet flow instead of a smooth fill from the gate to the end of the die cavity [15].

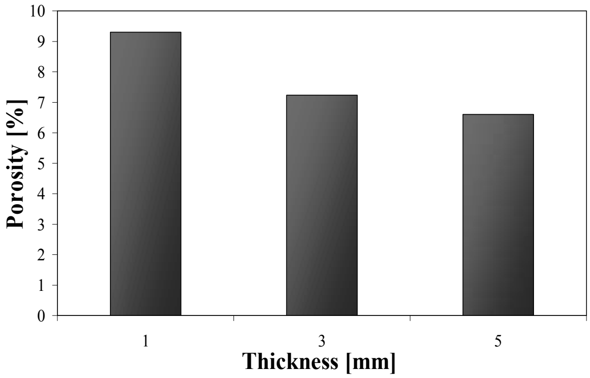


Fig. 9. Porosity percentages according to specimen wall thickness

4. Conclusions

(1) The microstructure of investigated alloy in the thickest section contains cored fine α-Mg dendrites that are surrounded grain boundary region containing eutectic phases consisting of intermetallic phases $Al_{11}RE_3$ and Al_2RE. The decreasing of wall thickness of die-cast AE44 leads to precipitation of $Al_{2.12}RE_{0.88}$ in microstructure.
(2) The increasing wall thickness of die cast AE44 alloy leads to decreasing of grain size.
(3) The increasing wall thickness results in reduced gas porosity.

Acknowledgements

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