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Microstructure and fluidity of sand cast ZRE1 alloy

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Materials

ABSTRACT

Purpose: The automotive use of magnesium is currently restricted to low-temperature structural components. Rare earth additions such as Ce, Nd, La and Pr are known to improve the creep performance. The aim of the research was to determine the effect of pouring temperature on the as-cast microstructure of ZRE1 magnesium alloy.

Design/methodology/approach: The study was conducted on Mg-3Zn-3RE-0.5Zr (ZRE1) alloy after cast in different conditions. 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 composition of these alloys was identified by X-ray diffraction (JDX-75). A program for image analysis Met-ilo was used for determination of area fraction of intermetallic phases.

Findings: The microstructure of ZRE1 alloy consists of α-Mg solid solution with Mg12RE phase. Pouring temperature has an influence on the fluidity and microstructure.

Research limitations/implications: The future research will contain creep tests and microstructural investigations of cast and die-cast alloys using TEM microscopy.

Practical implications: Results of investigation may be useful for preparation of sand casting technology of the Mg-Zn-RE-Zr alloys.

Originality/value: This paper includes the results of microstructural investigations and effects of pouring temperature on the fluidity of ZRE1 magnesium alloy for gravity casting technology.

Keywords: Metallic alloys; Magnesium alloys; Microstructure; Fluidity

1. Introduction

Magnesium alloys are called green-engineering material with great development potential because of its low density, high specific strength and stiffness, superior damping capacity, good electromagnetic shielding characteristics and good machinability. However, the number of commercially available magnesium alloys is still limited especially for application at elevated temperature. The applications of most common magnesium alloys, such as AZ91 and AM50 with outstanding mechanical properties and die castability are limited to temperatures below 120 °C. This limitation is attributed to the low hardness of the intermetallic phase $Mg_{17}Al_{12}$ under high temperature [1-2]. The search for creep-resistant alloys has led to the development of rare earth containing magnesium alloys, for example Mg-Al-RE (AE42, AE44) and magnesium alloys with strontium or calcium. In these alloys, structure is characterized by the second phases from system Al-RE, Al-Sr or Al-Ca at the grain boundaries which are stable line compound with a relatively high melting point. However, at elevated temperatures, disadvantageous $Mg_{17}Al_{12}$ phase will precipitate from solid solution or will form during decomposition of intermetallic phases, e.g. $Al_{11}RE_3$ in AE42 alloy [3-10]. Therefore, magnesium alloys, which does not contain aluminum, has been developed. Among these alloys, important role plays alloy, designated Elektron ZRE1, exhibits superior high temperature creep and resistance to stress relaxation compared to that of benchmark alloy AE42. Elektron ZRE1 is a magnesium based alloy containing zinc, rare earths and zirconium. Zinc is usually used in combination with aluminum, zirconium, rare earths, or thorium to produce precipitation-hardenable magnesium alloys having good strength. Zinc also helps overcome the harmful corrosive effect of iron and nickel impurities that might be present in the magnesium alloy. Rare earth metals are added either as mischmetal to reduce of costs of production. Additions of the rare earths increase the strength at elevated temperatures. They also reduce weld cracking and porosity because they narrow the freezing range of the alloys. Zirconium has a powerful grain-refining effect on magnesium alloys. It is thought that because the lattice parameters of zirconium are very close to those of magnesium, zirconium-rich solid particles produced early in the freezing of the melt may provide sites for the heterogeneous nucleation of magnesium grains during solidification. The Elektron ZRE1 alloy exhibits excellent casting characteristics with components being both pressure tight and weldable. Castings are free from microporosity and the tendency to hot cracking in difficult castings is slow [11-14].

2. Experimental procedures

Sand casts of ZRE1 alloy were investigated. The chemical composition of this alloy is provided in Table 1. The rare earth additions were made as mischmetal with the approximate compositions: 50Ce-25La-20Nd-5Pr.

Table 1.
Chemical composition of the ZRE1 alloy in wt.-%

Zn	RE	Zr	Ni	Si	Cu	Mn	Fe	Mg
2.7	3.18	0.53	<0.001	<0.01	<0.01	0.02	0.002	balance

Fluidity has been investigated by determination of the flow length with a mould featuring a spiral shaped cavity. The shape of fluidity spiral is shown in Fig.1. Casting in sand moulds has been done at different melt temperature (730, 780, 830 °C).

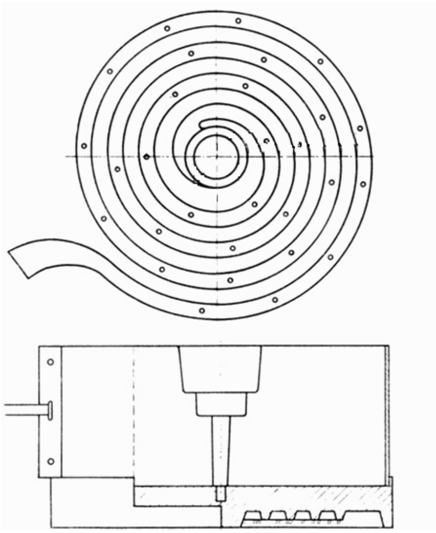


Fig. 1. Drawing of spiral sample to investigate the fluidity

Specimens for microstructural studies were mechanically polished using standard methods and 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 EDS detector (VOYAGER of NORAN INSTRUMENTS). EDS analysis was performed with an accelerating voltage of 15 keV. The phase identification of these alloys was conducted by X-ray diffraction (JDX-75) using Cu Kα radiation. A program for image analysis "Met-ilo" [15] was used for determination of the area fraction of intermetallic phases and grain size.

3. Results and discussion

3.1. Microstructure of sand cast ZRE1 alloy

Optical micrograph taken from as-cast alloy is shown in Fig. 2, from which it can be seen that as-cast microstructure of this alloy consist of α-Mg matrix and second phase crystallize along the grain boundaries. SEM observations of analyzed alloy reveal that the grain boundary second-phase shows a kind of massive morphology with bright contrast (Fig. 3). The results of microanalysis by EDS showed that second phase was composed of magnesium, zinc and rare earth elements (point 1, Tab. 2), however, precisely determined of magnesium content in the second phase is difficult, due to interaction between electron beam and magnesium matrix. The solid solution contains small amount of zinc. The content of rare earth elements in magnesium is below of quantity sensitivity of X-ray energy dispersive spectroscopy analysis (point 2, Tab. 2).

XRD analyses were performed on selected specimens to identify the phases existing in the alloys studied and the results are shown in Fig. 4. It can be seen that the alloy consisted of two phases, the α-Mg matrix and $Mg_{12}Ce$ intermetallic compound. Based results of chemical microanalysis this second phase can be identified as $Mg_{12}Ce$ with some lanthanum and neodymium substituting cerium. Moreover, this intermetallic compound contains zinc, which substitutes part of magnesium due to small differences between atomic radiuses of these elements. Therefore, molecular formula of this phase can be written as $(Mg,Zn)_{12}RE$.

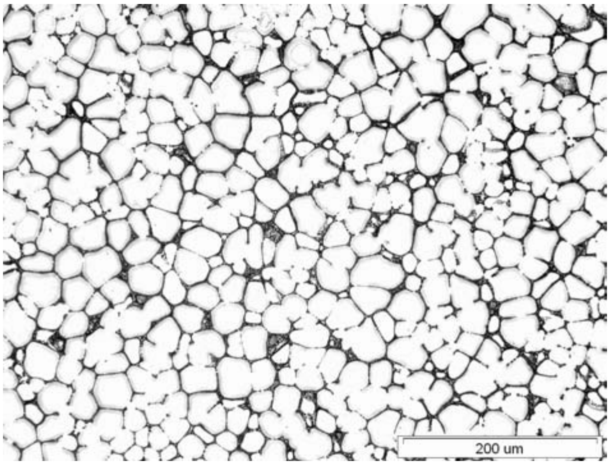


Fig. 2. Optical micrograph of as-cast ZRE1 alloy

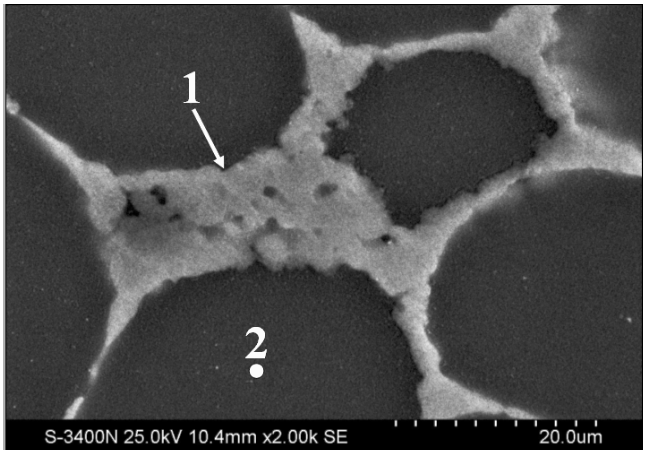


Fig. 3. SEM micrograph of as-cast ZRE1 alloy with marked points of chemical analysis

Table 2
EDS results of ZRE1 alloy for points from Fig. 3

Point	Chemical composition, %at.				
	Mg	Zn	La	Ce	Nd
1	84.0	10.5	1.5	3.1	0.9
2	99.4	0.6	-	-	-

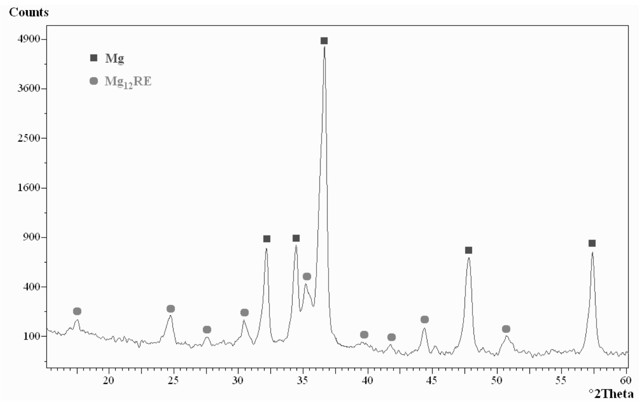


Fig. 4. XRD pattern of sand cast ZRE1 alloy

3.2. Influence od pouring temperature on the fluidity

Figures 5 and 6 show the influence of pouring temperature on the fluidity of ZRE1 alloy. Fluidity can be expressed by the distance that molten metal has flew during filling and solidification. For ZRE1 magnesium alloy, its filling length increases slowly when the pouring temperature increases from 730 to 780°C, but increases rapidly when the pouring temperature increases from 780 to 830°C.

Generally, a better fluidity in higher temperature is connected with the decreasing viscosity and surface tension of molten metal with the increasing of pouring temperature, which leads to the increasing filling speed. At the same time, the heat capacity of molten magnesium alloy rises with increasing temperature of the pouring, what results in the increase of filling time. On the other hand, the oxidation liability of magnesium alloy increases with the increasing of casting temperature, which will increase the viscosity and decrease the filling length. This effect is insignificant within the investigated range of pouring temperature [13].

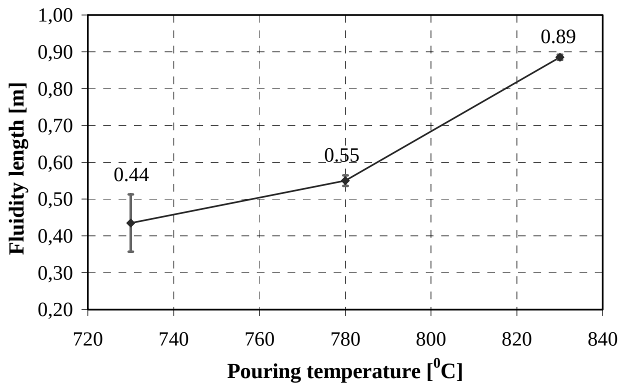


Fig. 5. The influence of casting temperature on the fluidity length

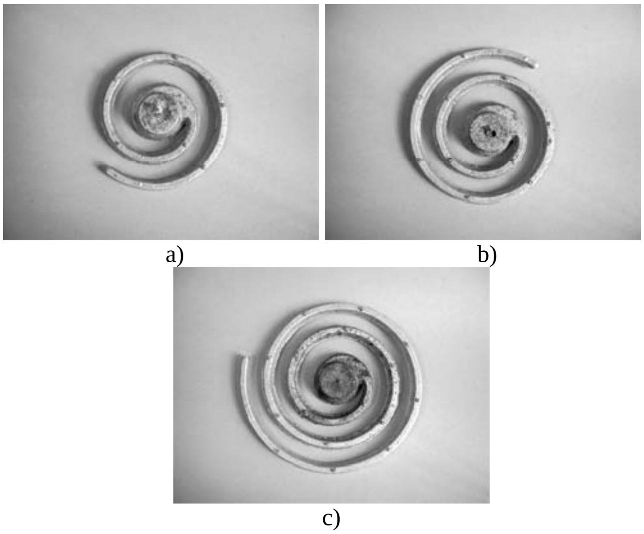
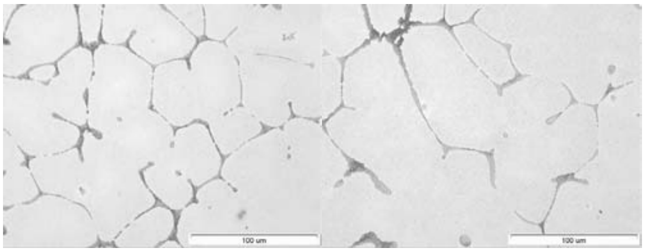


Fig. 6. Spiral cast of ZRE1 alloy poured at the temperature of 730°C (a), 780 (b) and 830°C (c)

3.3. The influence of pouring temperature on the microstructure

Microstructures of ZRE1 alloy after casting at different temperatures are shown in Fig. 7. Generally, pouring temperature does not influence on the phase composition. Tab. 3 shows, the results of quantitative metallography as a function of pouring temperature and associated coefficient of variation. One can see in the Table 3, that the area fraction of $Mg_{12}RE$ phase does not change fundamentally with the increase of the casting temperature within the range studied here. These results are related to very low solubility of rare earth elements in solid solution. The grain size (mean area of plane section) rises with the increasing of the casting temperature due to longer time of self-cooling of casting mould (lower cooling rate).



a) b)

Fig. 7. Microstructure of ZRE1 after casting at 730 °C (a) and at 830 °C (b)

Table 3.
The area fraction of $Mg_{12}RE$ and grain size after casting from different temperatures. In brackets a coefficients of variation are shown

Phase	Unit	Temperature, °C		
		730	780	830
Area fraction of $Mg_{12}RE$	% (%)	7.18 (21)	7.61 (28)	7.29 (23)
mean area of plane section of grain	μm^2 (%)	1302 (156)	1419 (172)	1720 (174)

4. Conclusions

Based on the research results obtained, it has been found that:

- The as-cast microstructure of sand cast ZRE1 alloy is composed of α-Mg matrix and $Mg_{12}RE$ at the grain boundary.
- The increase of pouring temperature results in the increase of the fluidity.
- The decrease of pouring temperature results in the decrease of grain size (mean area of plane section).
- The change of pouring temperature has no influence on the $Mg_{12}RE$ area fraction.

Acknowledgements

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