ARCHIVES
Of
FOUNDRY ENGINEERING
Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences
ISSN (1897-3310)
Volume 11
Issue 2/2011
157–160
31/2

Evolution of Mg-5Al-0.4Mn microstructure after rare earth elements addition

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Received 11.04.2011; Approved for print on: 26.04.2011

Abstract

Mg-5Al-0.4Mn-xRE (x = 0, 1, 2, 3 wt.%) magnesium alloys were prepared successfully by casting method. The microstructure was investigated by light microscopy. The influence of rare earth (RE) elements on the area fraction of eutectic was analysed. The obtained results revealed that the as-cast Mg-5Al-0.4Mn alloy consist of α - Mg matrix and eutectic α + γ (where γ is $Mg_{17}Al_{12}$). However, while rare earth elements were added to the Mg-Al type alloy, $Al_{11}RE_3$ precipitates were formed. The amount of the $Al_{11}RE_3$ precipitates increased with increasing addition of RE, but the amount of γ - $Mg_{17}Al_{12}$ decreased.

Key words: Mg-Al-Mn alloy; Rare earth elements; Microstructure

1. Introduction

Magnesium alloys, due to their low density and high specific strength, are promising candidates for applications in the automotive, aerospace and communication industries [1-3].

Currently Mg-Al alloys such as AZ91, AM60 and AM50 are the most economically attractive. The Mg-Al type alloys are prone to segregate due to relatively wide temperature spans between the liquidus and solidus curves. The microstructure of cast Mg-Al alloys is mainly composed of solid solution of aluminium in magnesium (α phase) with a different composition of alloying element according to the solidification rate and α + γ eutectic (where γ is the intermetallic compound $Mg_{17}Al_{12}$). The AM-series alloys, which belong to the Mg-Al system, instead of magnesium and aluminium contain also manganese. Small amount of manganese reduce the harmful effect of iron on corrosion resistance. Manganese in commercial magnesium-aluminium alloys caused the formation of aluminium-manganese compounds such as Al_6Mn, Al_8Mn_5 and AlMn [4,5].

Although, the Mg-Al alloys seem to be the most extensively used magnesium alloys, still the number of commercially available magnesium alloys is limited, especially for application at the temperatures higher than 120°C [6,7]. The poor elevated temperature properties of Mg-Al alloys are related to the occurrence of the intermetallic phase $Mg_{17}Al_{12}$. Recently, considerable efforts have been made to improve the creep resistance of the magnesium-aluminium based alloys via further additions of alloying elements and the formation of thermally stable phases along grain boundaries to resist the deformation by grain boundary sliding. Improvement of the elevated temperature properties is done by the addition of elements like Sb [8,9], Bi [9], Si [8,10], Sr [11] and rare earth (RE) [6,7,10,12,13] for modifying the microstructure of γ, changing the grain size and forming phases which would strengthen grain boundaries. Among them Mg-Al-RE system (with commercial AE42 and AE44 alloys) is a major development in heat-resistant Mg-Al-based alloys. It is thought that rare earth elements added to the Mg-Al alloys caused the preferential formation of Al-RE phases and suppressed the γ – phase precipitation [14]. Earlier studies allowed to introduced successfully rare earth elements (in form of cerium rich mish metal) into AZ91 and AM50 magnesium alloy [13,15]. In the present work, AM50 magnesium alloy was adopted as a based alloy and different RE additions were made but what is more, the influence of RE on the area fraction of eutectic was studied.

2. Experimental material and procedures

AM50 magnesium alloy (the composition of which is listed in Table 1), was chosen as a based alloy. Rare earth elements in the form of cerium rich mish metal, with the composition according to attestation listed in Table 2, were used as an addition. 1, 2 and 3 wt.% of rare earth elements were introduced to the molten AM50 alloy. The experimental alloys were cast into a permanent mould.

Table 1. Chemical composition of AM50 alloy according to ASTM B93-94

Chemical composition [wt.%] [1)]						
Alloy	**Al**	**Mn**	**Zn**	**Si**	**Fe**	**Cu**
AM50	4.5-5.3	0.28-0.5	max 0.02	max 0.05	max 0.004	max 0.008

[1)] Mg rest

Microstructural analyses were performed by means of light microscopy (LM). A standard metallographic technique was used for sample preparation which includes wet prepolishing and polishing with different diamond pastes. Specimens were examined by a Neophot-21, Carl-Zeiss Jena microscope.

Table 2. Chemical composition of mish metal

	Chemical composition [wt.%]					
	Ce	**La**	**Nd**	**Pr**	**Fe**	**Mg**
mish metal	54.8	23.8	16.0	5.4	0.16	0.19

For a quantitative evaluation of the microstructure, stereological parameters describing the size of precipitations were selected. To measure the stereological parameters, a program for image analysis ImageJ was used.

Measurements of area fraction in each alloy were performed on 20 random images. Simple automatic procedure was used to detect investigated phases. However, it should be noted that the precipitations are characterized by a non-homogenous grey level so manual correction should be performed. Additionally, to separate $Al_{11}RE_3$ from eutectic manual method was applied, using the differences in morphology between them.

3. Results and discussion

Fig. 1 shows a typical microstructure of the as-cast Mg–Al–Mn alloy. It indicates that AM50 alloy is mainly composed of the dendrite phase - primary α solid solution of alloying elements in magnesium (point 1 in Fig. 1) and the divorced eutectic in the interdendritical spaces (point 2 in Fig. 1). Strong dendritic segregation of alloying elements is characteristic for majority as-cast magnesium alloys. Moreover, small amount of manganese caused the formation of aluminium-manganese precipitates with polygonal shape.

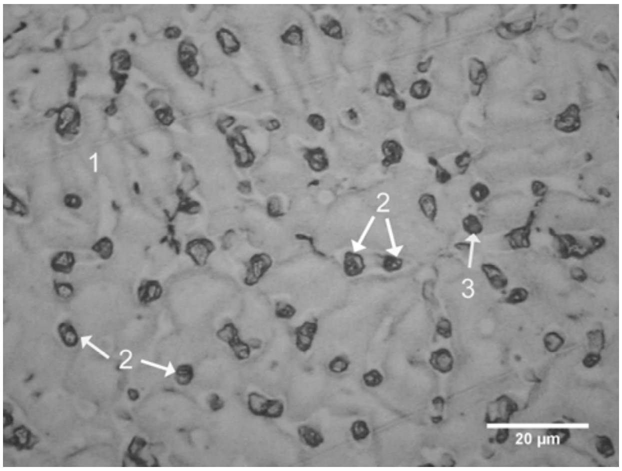

Fig. 1. Microstructure of as-cast AM50 alloy; LM

The microstructure of AM50 with addition of 1, 2 and 3 wt.% is shown in Fig. 2a, 2b and 2c respectively. The α solid solution (marked as 1 in Figs. 2a, 2b and 2c) and binary eutectic α + γ (marked as 2 in Figs. 2a, 2b, 2c) are observed in the experimental alloys, similarly to as-cast AM50 alloy. However, in the microstructure of the experimental AM50+RE alloys needle-like precipitates occurred (point 3 in Figs. 2a, 2b and 2c). The microstructure observations of AM50 with rare earth elements revealed also the occurrence of polygonal precipitates, but in comparison with AM50 these are not aluminium-manganese intermetallic compounds. Rare earth elements addition caused the formation of ternary intermetallic compound (point 4 in Figs. 2a, 2b, 2c). The previous studies indicated that these new phases formed after rare earth elements addition to AM50 alloy are expressed as $Al_{11}RE_3$ – needle-like and $Al_{10}RE_2Mn_7$ – polygonal shape [15].

It should be noted that after RE addition, except from Al-RE and Al-RE-Mn no other phases such as Mg-RE or Mg-Al-RE are detected. The possibility to form metallic compound can be predicted from the electronegativity differences between two elements [16]. The formation of a metallic compound is easier if the electronegativity differences between two elements are bigger and so the bonding force between these elements is stronger. It is commonly noted that the difference in electronegativity between RE (represented by Ce, La, Nd and Pr) and Al is larger than that between RE and Mg. That is why, while rare earth elements are

(a)

(b)

(c)

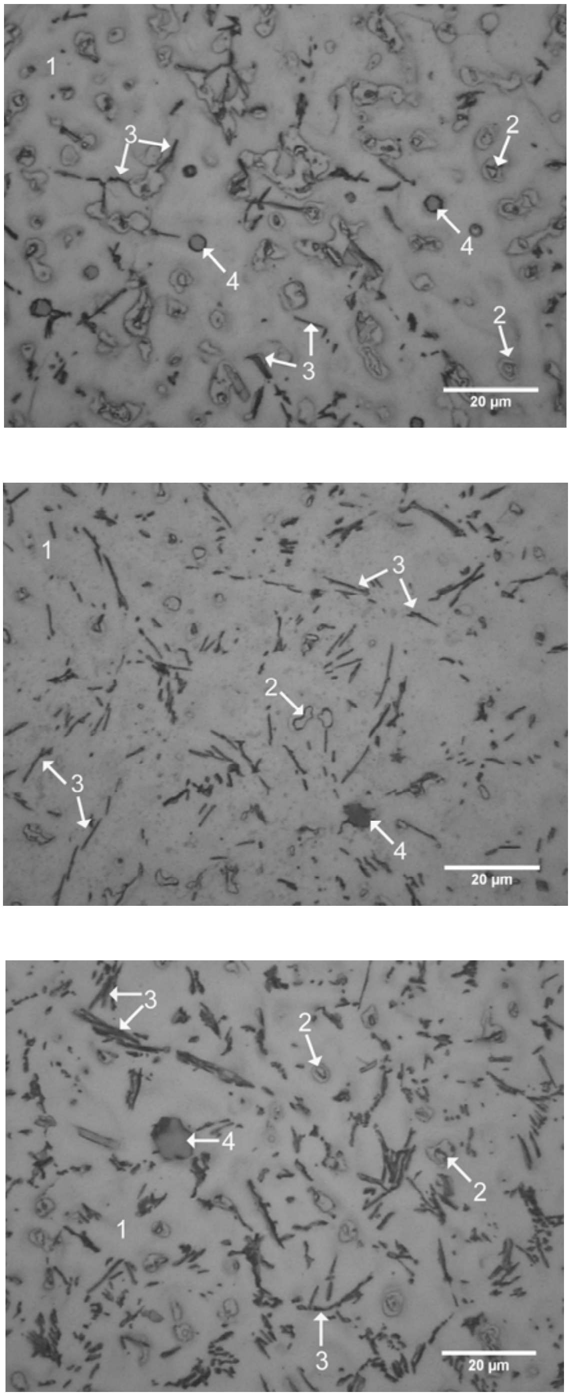

Fig. 2. Microstructure of as-cast a) AM50+1%RE, b) AM50+2%RE, c) AM50+3%RE alloys; LM

added to the Mg-Al type alloy, during solidification they preferentially react with Al to form $Al_{11}RE_3$ compound.

Additionally, it can be seen in Figs. 2a, 2b and 2c that the area fraction of $Al_{11}RE_3$ phase increases with increasing RE content, but that of γ – $Mg_{17}Al_{12}$ phase decrease. In order to study the influence of rare earth elements added to AM50 alloy on the area fraction of the $\alpha + \gamma$ eutectic the statistical analysis was used. The influence of RE addition on the area fraction of eutectic in AM50 alloy was presented in Fig.3.

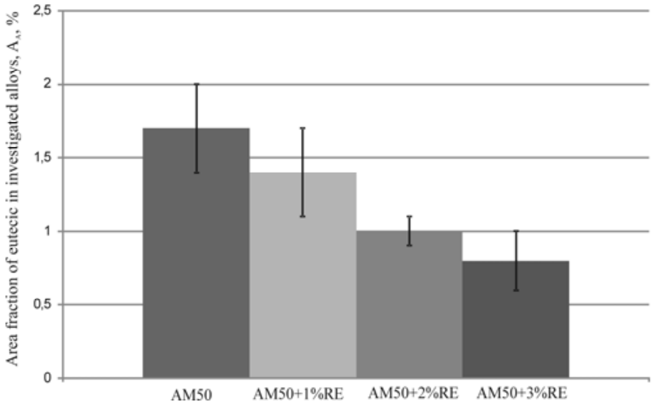

Fig. 3. Influence of RE addition on the area fraction of eutectic in investigated alloys

According to the Mg-Al equilibrium phase diagram, the eutectic phase ($Mg_{17}Al_{12}$) is expected to appear when the aluminium content reaches around 13 wt.%. However, the eutectic phase appears in AM50 alloy containing as little as 5 wt.% Al due to non-equilibrium cooling conditions encountered in the investigated alloys. After rare earth elements addition an enlargement in quantity of $Al_{11}RE_3$ phase was observed. The influence of RE addition on the area fraction of $Al_{11}RE_3$ phase was shown in Fig. 4.

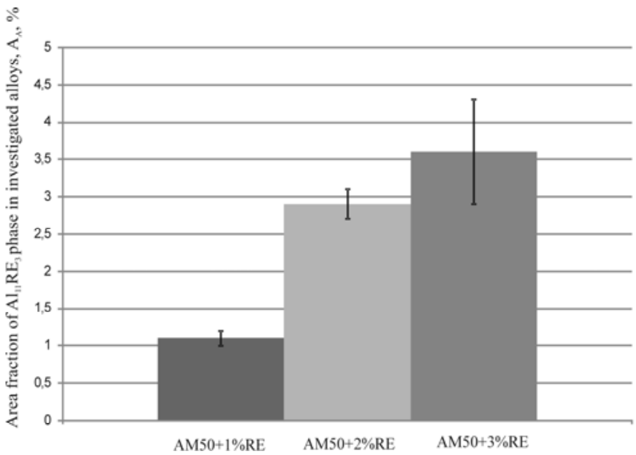

Fig. 4. Influence of RE addition on the area fraction of $Al_{11}RE_3$ phase in investigated alloys

The area fraction of this needle-like phase increased while the area fraction of eutectic decreased with increasing RE content. The formation temperature of the Al-RE phase is much higher than that of $Mg_{17}Al_{12}$, which means the solidification of Al-RE precedes that of γ. Therefore, the formation of the $Al_{11}RE_3$

compound consumes partial Al atoms and reduce the precipitation of γ - $Mg_{17}Al_{12}$.

The results of the λ-Kolmogorov test have confirmed the hypothesis that the area fraction of eutectic and area fraction of $Al_{11}RE_3$ phase can be brought closer by means of normal distribution on the significance level of α=0.05.

4. Summary

The microstructure analyses of the AM50, AM50+1%RE, AM50+2%RE and AM50+3%RE alloys were presented. The results revealed that the microstructure of as-cast AM50 alloy is characterized by the α - Mg matrix and eutectic $\alpha + \gamma$ (where γ is $Mg_{17}Al_{12}$). Addition of rare earth elements to the AM50 alloy caused the formation of $Al_{11}RE_3$ phase with needle-like morphology. With increasing addition of RE the amount of the $Al_{11}RE_3$ precipitates increased, but the amount of γ - $Mg_{17}Al_{12}$ decreased.

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