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ARCHIVES of FOUNDRY ENGINEERING

DOI: 10.1515/afe-2016-0037

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

DE GRUYTER OPEN

ISSN (2299-2944)
Volume 16
Issue 2/2016

115– 118

Microstructure of Mg–Al–RE-type Experimental Magnesium Alloy Gravity Cast into Sand Mould

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Received 30.03.2016; accepted in revised form 05.05.2016

Abstract

Magnesium alloy with 5 wt% Al, 0.35 wt% Mn and 5 wt% rare earth elements (RE) was prepared and gravity cast into a sand mould. Microstructure investigations were conducted. Analyses of the Mg-Al-RE alloy microstructure were carried out by light microscopy, scanning electron microscopy and the XRD technique. In the as-cast condition, the alloy was composed of α-Mg, $Al_{11}RE_3$ and $Al_{10}RE_2Mn_7$ intermetallic phases. Additionally, due to non-equilibrium solidification conditions, an Al_2RE intermetallic phase was revealed.

Key words: Magnesium alloy, Aluminium, Rare earth elements, As-cast conditions, Microstructure

1. Introduction

Mg-Al alloys such as AZ91 or AM50 are the most widely used magnesium alloys [1, 2]. The microstructure of cast Mg-Al alloys is characterized by heavy segregation of the alloying elements and consists mainly of a solid solution of aluminium in magnesium (α phase) with a different composition of alloying elements due to the solidification rate and α + γ eutectic (where γ is the intermetallic compound $Mg_{17}Al_{12}$). However, the applications of these alloys are limited to the temperature of about 120°C, above which the mechanical properties degrade sharply [3-6].

The poor elevated temperature properties of Mg-Al alloys are related to the occurrence of the low-melting γ - $Mg_{17}Al_{12}$ phase [7-10]. The most common way of improving the elevated temperature properties is the formation of thermally stable precipitates along the grain boundaries to resist deformation by grain boundary sliding. Rare earth elements added to the Mg-Al alloys caused the preferential formation of Al-RE phases and suppressed γ – phase precipitation by decreasing the aluminium content in the matrix [11-17]. In the presented work, the microstructure of an experimental alloy from the Mg-Al-RE system cast into a sand mould was presented.

2. Experimental procedures

The experimental alloy AE55x with the nominal chemical composition of 5 wt% Al, 0.35 wt% Mn, 5 wt% RE was prepared. The investigated material was cast into sand moulds (rod samples 25 mm diameter). Derivative thermal analysis (DTA) was carried out using a Crystaldigraph PC computer recorder. The DTA curves were collected from a NiCr-NiAl thermocouple with a 1.5 mm diameter, located directly in mould. The specimens for microstructure investigations were prepared by standard metallographic procedures. The microstructures were observed with an Axiovert 25 (Carl-Zeiss Jena) light microscope and a JSM-6610LV scanning electron microscope. The phase composition of the investigated alloy was analyzed by X-ray diffraction (XRD) using a Brucker D8 Abvence diffractometer. $Cu_{K\alpha}$ X-ray radiation was used.

3. Results and discussion

Fig. 1 shows a fragment of the pseudo-binary Mg(5 wt% Al) – Ce system calculated by using Thermo-Calc Software. According to this system, the microstructure of the investigated alloy should consist of an α (Mg) solid solution, $Al_{11}RE_3$ intermetallic phase and γ phase in the form of secondary precipitation (occurring below the solvus curve). Fig. 2 presents the DTA curves obtained for AE55x magnesium alloy solidified in sand moulds. In a sand mould, the investigated alloy solidified in about 70 seconds. Fig. 3 shows a representative microstructure of the as-cast experimental alloy.

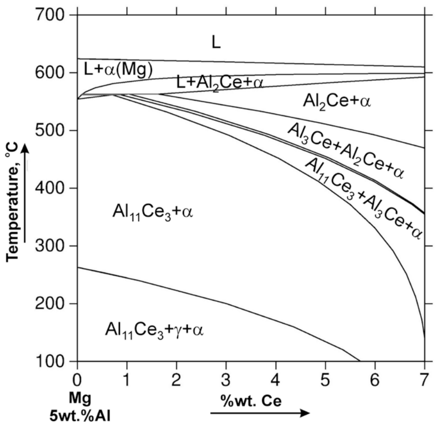


Fig. 1. Fragment of pseudo-binary Mg(5 wt.% Al) – Ce system (calculated in ThermoCalc)

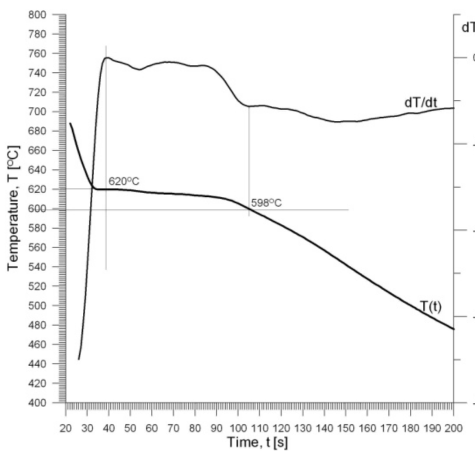


Fig. 2. T(t) and dT/dt curves of AE55x alloy (sand mould)

The microstructure (Fig. 3) of the investigated alloy has a dendritic morphology with strong segregation of the alloying elements, which is typical for a large majority of magnesium alloys. Non-equilibrium solidification conditions caused the formation of large α-Mg phase crystals (depleted especially in Al in ratio to equilibrium conditions) and pushed the alloying elements into the interdendritic regions.

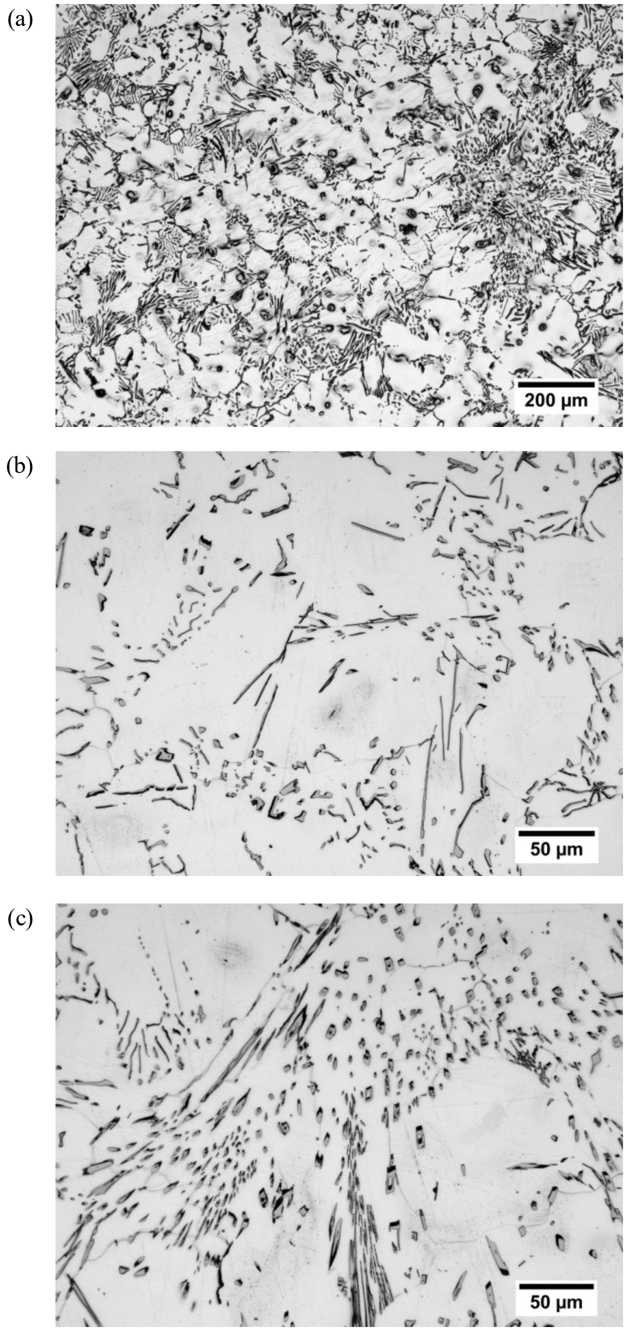


Fig. 3. Microstructure of AE55x magnesium alloy, sand mould

During solidification of the alloy, the aluminium and rare earth elements were consumed in the first sequence of the formation of the $Al_{10}RE_2Mn_7$, $Al_{11}RE_3$ and Al_2RE phases. Due to the low weight percentage of manganese in the alloy chemical compositions, an $Al_{10}RE_2Mn_7$ ternary intermetallic phase was created under a limited volume fraction. Although the $Al_{11}RE_3$ phase was one of the main structural constituents for both experimental alloys, some volume fraction of an Al_2RE phase was also revealed. Fig. 4 presents an image of the investigated alloy microstructure at high magnification. Detailed distribution of the alloying elements in particular structure constituents were analysed by using an SEM+EDS instrument. Figs. 5-7 show the results obtained from those investigations. The phase with acicular (or rhombus at the different surfaces) morphology corresponds to the $Al_{11}RE_3$ phase composition (Figs. 5-6). The chemical composition of the fine monolithic phase shown in Fig. 7 corresponds to the Al_2RE intermetallic compound. On the other hand, the structural constituent with blocky morphology consisting of manganese and rare earth elements indicates the Al-RE-Mn-type phase (Fig. 8).

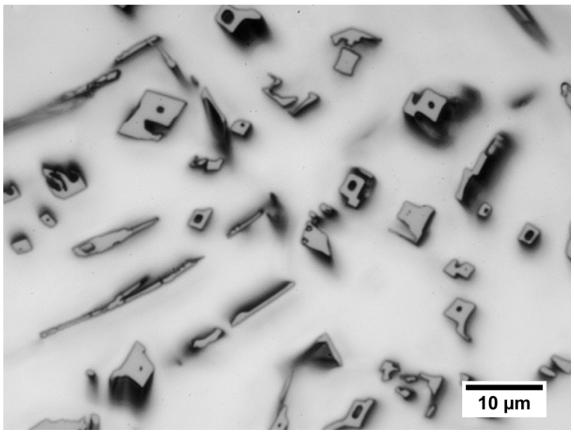
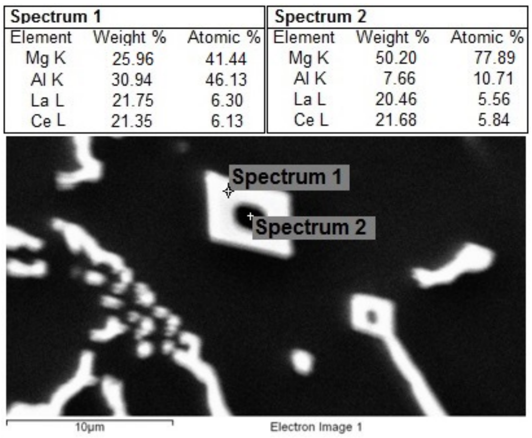
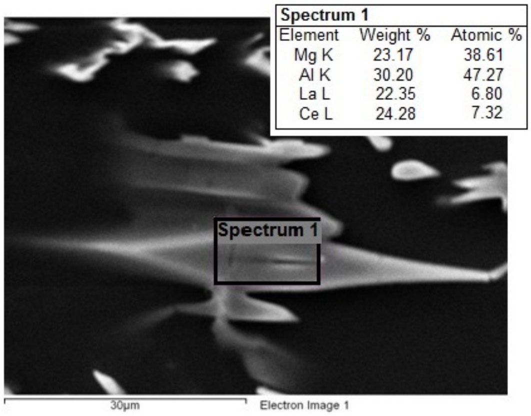


Fig. 4. Microstructure of AE55x magnesium alloy, sand mould



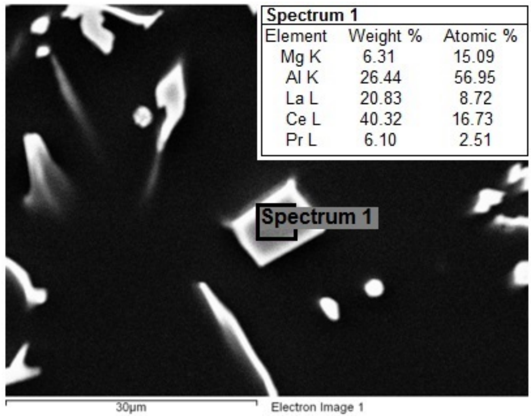
Spectrum 1			Spectrum 2		
Element	Weight %	Atomic %	Element	Weight %	Atomic %
Mg K	25.96	41.44	Mg K	50.20	77.89
Al K	30.94	46.13	Al K	7.66	10.71
La L	21.75	6.30	La L	20.46	5.56
Ce L	21.35	6.13	Ce L	21.68	5.84

Fig. 5. Microstructure of AE55x magnesium alloy, sand mould; SEM+EDS



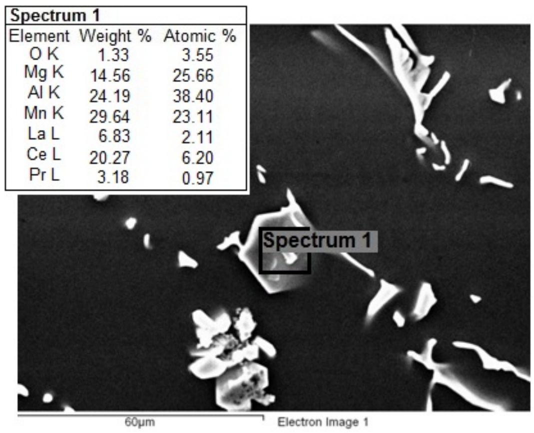
Spectrum 1		
Element	Weight %	Atomic %
Mg K	23.17	38.61
Al K	30.20	47.27
La L	22.35	6.80
Ce L	24.28	7.32

Fig. 6. Microstructure of AE55x magnesium alloy, sand mould; SEM+EDS



Spectrum 1		
Element	Weight %	Atomic %
Mg K	6.31	15.09
Al K	26.44	56.95
La L	20.83	8.72
Ce L	40.32	16.73
Pr L	6.10	2.51

Fig. 7. Microstructure of AE55x magnesium alloy, sand mould; SEM+EDS



Spectrum 1		
Element	Weight %	Atomic %
O K	1.33	3.55
Mg K	14.56	25.66
Al K	24.19	38.40
Mn K	29.64	23.11
La L	6.83	2.11
Ce L	20.27	6.20
Pr L	3.18	0.97

Fig. 8. Microstructure of AE55x magnesium alloy, sand mould; SEM+EDS

The X-ray diffraction micrograph for the as-cast experimental alloy is presented in Fig. 9. It confirmed that the alloy is mainly composed of an α-Mg, $Al_{11}RE_3$ phase and $Al_{10}RE_2Mn_7$

intermetallic phase. The $Al_{11}RE_3$ phase was identified on the basis of the $Al_{11}Ce_3$ phase (Immm space group, a = 0.4389 nm, b = 1.0072 nm, c = 1.3011 nm), whereas the $Al_{10}RE_2Mn_7$ intermetallic compound was identified on the basis of the $Al_{10}Ce_2Mn_7$ phase (R-3m space group, a = b = 0.9040 nm, c = 1.3170 nm). X-ray analysis of the AME505 experimental alloy also revealed a significant presence of the Al_2RE intermetallic compound (identified on the basis of the Al_2Ce phase; Fd-3m space group, a = b = c = 0.8015 nm).

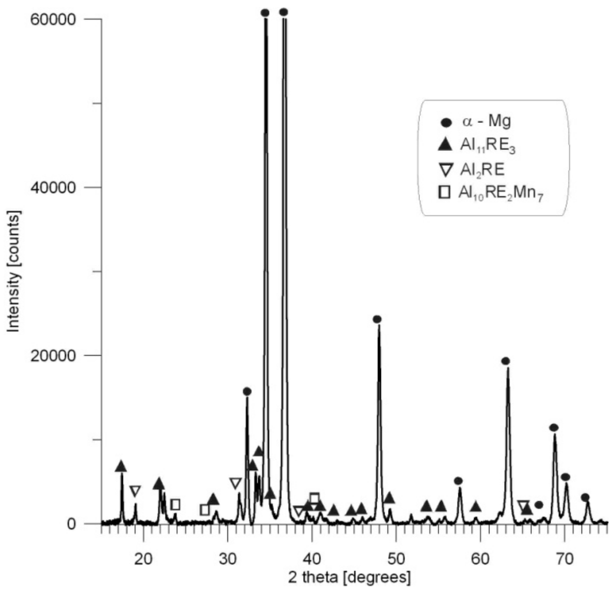


Fig. 9. X-ray diffraction pattern of AE55x alloy solidified in sand moulds

4. Conclusions

The microstructure analysis of the AE55x experimental alloy was presented. The results revealed that the microstructure of the alloy cast into sand mould consists of α-(Mg) solid solution, $Al_{11}RE_3$ and Al_2RE intermetallic phases. Additionally, the presence of a small amount of manganese in the alloy composition caused the formation of an intermetallic compound expressed as $Al_{10}RE_2Mn_7$.

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