MICROSTRUCTURAL ANALYSIS OF AM50+3%RE MAGNESIUM ALLOY IN THE AS-CAST CONDITION AND AFTER HEAT TREATMENT

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Abstract
The experimental AM50+3%RE (Mg-5Al-0.4Mn-3RE, wt.%) alloy was prepared by metal mould casting method. The microstructure of the as-cast and heat-treated alloy was investigated by light microscopy and X-ray diffraction (XRD). The results show that the phase compositions of the as-cast alloy are α-Mg matrix, eutectic α + γ (where γ is Mg\textsubscript{17}Al\textsubscript{12}), Al\textsubscript{10}RE\textsubscript{2}Mn\textsubscript{7} phase and needle shape precipitates of Al\textsubscript{11}RE\textsubscript{3} compound, which is the dominant intermetallic phase in the alloy. During long term annealing at 473K for 1000h Al\textsubscript{11}RE\textsubscript{3} phase is still thermally stable, even after compression with a 330 MPa stress.

Keywords:
Mg-Al-Mn-RE alloy, Microstructure, Heat treatment

1. INTRODUCTION
Magnesium alloys are characterized by low density (1.5 – 1.8 g/cm\textsuperscript{3}) and high strength in relation to their weight but also good corrosion resistance and low heat of fusion. Magnesium alloys as the lightest structural materials, are very suitable for the applications in the automotive sector where vehicle weight reduction, CO\textsubscript{2} emission and fuel economy are becoming world focus. Reducing car weight by 100 kg makes it possible to save 0.5 l of petrol per 100 km [1, 2].

Nowadays, most commercial magnesium alloys are based on the magnesium - aluminium system. The Mg-Al alloys, in comparison with other magnesium alloys available, are relatively cheap. They exhibit excellent castability, corrosion resistance and strength at room temperature. Even though magnesium alloys with aluminium possess good mechanical properties, ternary systems with zinc or manganese are used for further properties improvement. Zinc (AZ type alloys) is introduced to improve fluidity, while manganese (AM type alloys) is added to control corrosion behaviour. Among the alloys used, AZ91 and AM50 dominate [3, 4].

The microstructure of as-cast magnesium – aluminium alloys generally consists of: a solid solution of aluminium in magnesium (α – Mg phase) and α + γ eutectic (where γ is an intermetallic compound Mg\textsubscript{17}Al\textsubscript{12}). Additionally the presence of manganese causes the formation of aluminium – manganese compounds Al\textsubscript{4}Mn, Al\textsubscript{6}Mn or Al\textsubscript{8}Mn\textsubscript{5} [5, 6]. Mg\textsubscript{17}Al\textsubscript{12} is incoherent with the magnesium matrix and it exists in a wide composition range of Al. What is more, this intermetallic has a low melting point (458°C). That is why γ – phase has poor metallurgical stability and may contribute to the poor properties of the alloy at high temperature [7].

The group of alloys which has been developed for improved elevated – temperature performance is based on Mg-Al-RE system. This alloy system contains at least one and, in general, a mixture of RE elements (RE – rare earth). Mg-Al-RE type alloys exhibit a major improvement in high temperature properties by replacing Mg\textsubscript{17}Al\textsubscript{12} phase with thermally stable Al-RE-containing compounds [8]. However, above 150°C the properties of Mg-Al-RE alloys deteriorate. It has been reported that at elevated temperature Al\textsubscript{11}RE\textsubscript{3} phase is unstable and decomposes to the Al\textsubscript{2}RE phase releasing Al atoms which form Mg\textsubscript{17}Al\textsubscript{12} phase, leading to the deterioration in properties [9 - 11].
In order to investigate the microstructure and phases existing in the experimental AM50+3wt.%RE alloy fundamental research of as-cast and annealed specimens was carried out in the present paper. Special attention was paid to the type, morphology and thermal stability of Al-RE phase.

2. EXPERIMENTAL PROCEDURES

2.1. Material and processing
AM50 magnesium alloy with a composition listed in Table 1, was melted at 700°C in an electric resistance furnace using a steel crucible. The 3 wt.% addition of rare earth elements was done in the form of cerium rich mish metal, with the composition according to attestation listed in Table 2.

| Table 1 Chemical composition of AM50 alloy according to ASTM B93-94 |
|------------------------|--------|--------|--------|--------|--------|--------|
| Alloy      | Al     | Mn     | Zn     | Si     | Fe     | Cu     |
| AM50       | 4.50-5.30 | 0.28-0.50 | max 0.02 | max 0.05 | max 0.004 | max 0.008 |
| * Mg rest  |

The melt was held at 700°C for 10 minutes and mechanically stirred using a stainless steel rod to ensure a homogenous composition. Then, it was cast into a permanent mould (made from steel).

| Table 2 Chemical composition of mish metal |
|------------------------|--------|--------|--------|--------|--------|
| Chemical composition [wt.%] |
| Ce     | La     | Nd     | Pr     | Fe     | Mg     |
| mish metal | 54.80 | 23.80 | 16.00 | 5.40 | 0.16 | 0.19 |

2.2. Microstructural characterization
In order to study the thermal stability of the alloy, two samples were annealed at 200°C for 1000h: before and after compression with a stress 330 MPa than cooled in the air. Microstructure of the alloy in as-cast and annealed condition was studied by light microscopy (LM) using Axiovert 25, Carl Zieiss Jena microscope. A standard metallographic technique was used for sample preparation which included wet prepolishing and polishing with different diamond pastes.

X-ray diffraction (XRD) using a Brucker D8 Advance diffractometer operating at 40 kV and 40 mA was carried out to identify the existing phases. In these tests, samples were exposed to Cu Kα radiation (λ = 1.54056 Å) using step scanning 2θ from 10 to 120° with a step size of 0.02°.

3. RESULTS AND DISCUSSION
In Fig. 1, the microstructure of the as-cast AM50+3wt.%RE alloy is shown. It can be seen that the microstructure of this alloy consists of solid solution α – Mg (point 1, Fig. 1.), small amount of binary eutectic α + γ (point 2, Fig.1.) and intermetallic phases in the interdendritic regions. The intermetallic phases can be classified into two types, one with a polygonal shape (point 3, Fig.1) and the other with a needle-like morphology (point 4, Fig.1).
The microstructure of AM50+3%RE alloy annealed at 200°C for 1000h before and after compession with a stress 330 MPa is shown in Fig. 2a and 2b. No distinct changes in size or shape of intermetallic phases with rare earth elements were observed. On the other hand, cooling in the air caused the formation of fine, plate-like, discontinuous γ phase precipitates (point 5 in Fig.2a and 2b).

To identify the existing phases in the alloy, XRD analysis was performed. X-ray diffraction patterns of heated samples in comparison with as-cast are shown in Fig.3. The diffraction patterns were indexed as four different phases, α-Mg (space group P63/mmc, a = 0.3202 nm, c = 0.5199 nm ICDD PDF 04-003-5619), γ-Mg17Al12 (space group I-43m, a = 0.9131 nm ICDD PDF 04-007-1274), Al11Ce3 (space group Immm, a = 0.4395 nm, b = 1.0092 nm, c = 1.3025 nm ICDD PDF 04-001-1534) and Al10Ce2Mn7 (space group R-3m, a = 0.9040 nm, c = 1.3170 nm ICDD PDF 04-009-8811). Because of the fact that rare earth elements in mish metal are isostructural [12], they can be referred to collectively as RE (Al11RE3 and Al10RE2Mn7). All diffraction lines found in the as-cast state were also present in annealed samples. These results suggest that intermetallic phases in the investigated alloy are stable and during long term annealing there is no phase transformation.
Fig. 3 X-ray diffraction patterns of AM50+3%RE alloy a) in as-cast condition, b) annealed at 200°C for 1000h, c) annealed at 200°C for 1000h after compression with a 330 MPa stress

4. SUMMARY
The microstructure of AM50+3% RE in the as-cast condition and after heat treatment has been investigated. Based on the obtained results, it has been found that:

(1) The as-cast microstructure of AM50+3%RE alloy is mainly composed of α – Mg matrix and small amount of α + γ (Mg17Al12) eutectic. Additionally the presence of Al11RE3 and Al10RE2Mn7 was found.

(2) Annealing at 200°C for 1000h has no influence on the Al11RE3 and Al10RE2Mn7 size or shape and does not result in the formation of any new phases. The microstructure of Al11RE3 phase is highly stable at 200°C even after compression with a 330MPa stress.

(3) After heat treatment with cooling in the air discontinuous precipitates of Mg17Al12 phase was observed.

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LITERATURE


