Microstructure of as-cast experimental binary Mg–RE alloys

K.N. Braszczyńska-Malik*
*Częstochowa University of Technology, Institute of Materials Engineering, Al. Armii Krajowej 19, 42-200 Częstochowa, Poland
*Corresponding address: e-mail: kacha@mim.pcz.czest.pl

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Abstract
Microstructure analyses of as-cast experimental Mg–3%RE and Mg–8%RE alloys were carried out. Light microscopy and scanning electron microscopy (SEM+EDX) techniques were used to characterize investigated materials. Results show that the as-cast dendritic microstructure is characterized by lamellar eutectic of primary α phase and interdendritic phase. X-ray phase analyses allowed the identification of the rare earth elements-rich intermetallic compound in the alloys as being Mg12RE.

Key words: Magnesium alloy; Rare earth elements; Microstructure

1. Introduction
Magnesium is useful lightweight structural material because of their low density, good die-castability, weldability, recyclability and abundance. In particular, magnesium alloys have high potential for improving fuel efficiency and reducing CO2 emission due to their high specific strength and stiffness [1, 2]. It is well known that the addition of rare earth (RE) elements is an effective way to improve the mechanical properties of magnesium alloys at elevated temperatures. The addition of rare earth elements is also generally believed to have a beneficial effect on the corrosion resistance of magnesium alloys [3-4].

Rare earth metals are a group of seventeen elements with close chemical characteristics, but with significant differences between them when they are added to magnesium. Very often RE elements are introduced to magnesium in a form of different mish metals compositions. Very popular mish metal added to magnesium has a cerium-rich composition with lanthanum, neodymium and praseodymium. The general view of Mg–Ce phase diagram is characterized of eutectic reaction of α solid solution and intermetallic compound. In the earlier investigations of the Mg–Ce phase diagram the phase established in equilibrium with magnesium solid solution was described by the formula MgCe.

All other investigations rejected this formula because it did not correspond to the phase crystal structure. In the Mg-rich Mg–Ce alloys two phases corresponded to the formulas Mg12Ce and Mg7Ce2 [5-6]. The compound Mg12Ce was determined in the two polymorphic forms with a tetragonal and orthorhombic types. The solubility of Ce in solid magnesium was established from 0.74 wt.% at 580°C to 0.04 wt.% at 200°C. Many Mg–RE phase diagrams are similar to the Mg–Ce system and contain Mg12RE type phase. The most successful magnesium alloys developed have been those based on the Mg–RE system designated as WE43, WE54, QE22, MRI or MEZ [1-7]. In the present paper the microstructure investigations of experimental binary Mg–RE alloys in as-cast form are described.

2. Experimental material and procedures
The experimental Mg–RE magnesium alloys with chemical composition of about 3 and 8 wt.% of rare earth addition were
prepared. Rare earth elements in the form of cerium-rich misch metal with the approximate composition given in Table 1 were used. The experimental alloys were prepared via ordinary ingot metallurgy method and cast into a metal moulds in the form of rods with a diameter of ca. 140 mm.

Table 1. Chemical composition of misch metal

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Ce</th>
<th>La</th>
<th>Nd</th>
<th>Pr</th>
<th>Fe max</th>
<th>Mg max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mish metal</td>
<td>54.8</td>
<td>23.8</td>
<td>16.0</td>
<td>5.4</td>
<td>0.16</td>
<td>0.19</td>
</tr>
</tbody>
</table>

Microstructural analyses were performed by means of light microscopy and scanning electron microscopy. A standard metallographic technique was used for sample preparation including wet prepolishing and polishing with different diamond pastes. Microstructural examination was performed in a Jeol-5400 scanning electron microscope (SEM) operating at 30 kV. Linear analyses of alloying elements distribution were carried out by use of energy-dispersive X-ray spectrometer (EDX) at 20 kV. Phase constitutions of alloys were analyzed by X-ray diffraction (XRD). The Co Kα X-ray radiation was used.

3. Results and discussion

Figs. 1 and 2 show as-cast microstructure of obtained Mg–3%RE and Mg–8%RE alloys, respectively. The microstructure of both alloys has dendritic character with strong segregation of rare earth elements. Magnesium is prone to dendritic solidification in widely range of solidification rate. Due to hexagonal closed packed (hcp) structure of magnesium secondary arms of dendrites grow at about 60° angle (Fig. 3) what is especially visible in Fig. 2. Microstructure of the Mg–3%RE alloy is characterized by more equiaxed dendrites, similar to microstructure of MEZ type alloys [6].

Fig. 1. Microstructure of as-cast Mg–3%RE alloy

Non-equilibrium solidification conditions during gravity cast of investigated alloys caused the formation of primary dendrite of α phase (practically pure magnesium) and binary eutectic α+ intermetallic compound (Figs. 4 and 5). Microstructure observations of interdendritical regions revealed that the increase of rare earth elements caused increase of volume fraction of eutectic. Additionally, eutectic is prone to be more divorced with increase of weight percentage of rare earth elements. Similar microstructure are also reported in as cast Mg–AI and Mg–AI-Zn type hypoeutectic alloys [8]. The divorced structures observed in these alloys have been attributed to the large undercooling of liquid below the eutectic temperature that results in a shift of the composition of liquid away from the coupled zone for eutectic growth.

Fig. 2. Microstructure of as-cast Mg–8%RE alloy

Fig. 3. Scheme of magnesium (hcp) dendrite grow

Fig. 4. Microstructure of as-cast Mg–3%RE alloy, SEM
Analyses of linear distribution of alloying elements in the investigated alloys revealed the presence of rare earth elements in the interdendritic spaces (eutectic regions). Figs. 6 and 7 present secondary electron images with X-ray linear analyses of Mg–3%RE and Mg–8%RE alloys microstructure, respectively.

Fig. 6. Secondary electron image of Mg–3% RE alloy with variation of magnesium and cerium in eutectic regions along the scanning line, SEM+EDX

Fig. 7. Secondary electron image of Mg–8% RE alloy with variations of alloying elements along the scanning line, SEM+EDX
X-ray diffraction patterns obtained from investigated materials are presented in Fig. 8. In both cases, the presence of Mg₁₂RE type intermetallic compound, corresponding to the formula Mg₁₂Ce, was revealed. Additionally, positions of peaks originating from magnesium are exactly corresponded to magnesium standard. It is suggested, that solid solubility of rare earth elements in α phase is practically zero.

4. Summary

The microstructure characteristics of the experimental Mg–3%RE and Mg–8%RE alloys were presented. The investigated alloys had a dendritic microstructure, characterized by dendrite of primary α phase (Mg) and α+intermetallic phase partially divorced eutectic. The intermetallic phase in the eutectic had Mg₁₂RE type.

Literature:


Fig. 8. XRD diffraction patterns of as-cast Mg–3%RE and Mg–8%RE alloy