Effect of element composition on microstructure pattern of Mg-RE alloys

Yongjun Li[a], Xinggang Li[b], Minglong Ma[c], Guoliang Shi[d],
Jiawei Yuan[e],Kui Zhang[f *]

State Key Lab for Processes and Non-ferrous Metals, General Research Institute for Non-ferrous Metals, Beijing, China

[a]lyj@grinm.com, [b]lxg1218@grinm.com, [c]minglongm@grinm.com, [d]shigl@grinm.com
[e]yuanjiawei@grinm.com, [f]zhkui@grinm.com

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Abstract. The microstructure of as cast Mg-RE (Mg-Gd, Mg-Y, Mg-Gd-Y and Mg-Gd-Y-Nd) alloys and that after heat treatment were investigated. The results show that the primary solidified precipitated phases of both Mg-Gd and Mg-Y binary alloy were coarse aberration eutectic microstructure pattern. For Mg-Gd-Y ternary alloy, a small amount of lamellar eutectic microstructure was formed while that mainly was coarse coefficient eutectic microstructure in matrix. In Mg-Gd-Y-Nd quaternary alloy, the as-cast microstructure was composed of α-Mg matrix and α-Mg+Mg_5 (Gd, Y, Nd) phase which had lamellar structure on grain boundaries. Compared with Mg-Gd, Mg-Y, Mg-Gd-Y alloy, the remaining second phase particles in Mg-Gd-Y-Nd alloy was more dispersed after heat treatment.

Introduction

As the lightest metal structure material at present, magnesium alloys have a high ratio of stiffness, strength and elastic modulus that have a wide application prospect in many fields. While for the special application environment that need high performance magnesium alloy materials which the traditional magnesium alloys can not meet these performance requirements. The main reason that restricts the industrial application of magnesium alloys is their low strength at room and elevated temperatures. Compared to Mg-Al and Mg-Zn series conventional magnesium alloys, Mg-RE alloy has higher strength at room temperature and high temperature and become a research hot spot at home and abroad, which has wide application prospect in many fields such as aerospace, automobile, weapon and so on[1-5].

For large size (more than 400mm in diameter) of Mg-RE alloy billets, due to the high melting point of rare earth elements, the melting temperature of the alloy was high that resulted in long solidification time and formed coarse primary solidified precipitated phases at the grain boundaries. The segregation of chemical composition and microstructure formed by these phases were difficult to effectively eliminate even heat treated at high temperature (more than 500˚C) with long time (more than 60 hours). In addition, due to a few slip systems, the deformation processing of magnesium alloy is difficulty. The non-homogeneous of microstructure significantly reduced ductility and forming banded structure in thermal processing that could cause serious internal microcracks in alloys [6-8].

Given the above, on the basis of previous research results, we further investigated the microstructure of Mg-RE alloys and analyzed the evolution law of the alloys, so as to provide experimental basis for improving the structure segregation of Mg-RE alloys.

Experimental Procedure

The pure metals of magnesium, gadolinium, yttrium and neodymium were used as rough materials. The alloy was melted in a mild steel crucible with the protection of home-made flux. When the fused mass temperature reached 750˚C, the pure metals of yttrium, neodymium, and gadolinium were added into the crucible, and then the temperature was raised to 850˚C and kept for 50min. Finally, the molten

metals stirred for about 15 min, and then poured into a steel mold with diameter of 500mm. Microstructures of the as-cast and heat treated samples of different alloys were observed with an optical microscope (OM, Zeiss) and scanning electron microscope (JSM-840) using an accelerating voltage of 25 KV, Phase analyses were performed with a D/max-rA X-ray diffractometer (XRD). The element composition of the alloys was measured via inductively coupled plasma atomic emission spectrometry (ICP-AES) and X-ray photoelectron spectroscopy (XPS).

Tab 1 Chemical composition of the alloys (wt. %)

Alloy	Gd	Y	Nd	Mg
Mg-Gd	7.08	/	/	Bal.
Mg-Y	/	5.16	/	Bal.
Mg-Gd-Y	6.95	4.83	/	Bal.
Mg-Gd-Y-Nd	6.87	4.58	0.92	Bal.

Results and Discussions

Fig.1 was the as-cast microstructure of Mg-Gd, Mg-Y and Mg-Gd-Y rare earth magnesium alloy. It was found that the primary solidification phase was composed of α-Mg matrix and coarse aberration eutectic microstructure Mg_5Gd, $Mg_{24}Y_5$ and Mg_{24} (Gd, Y) $_5$ phases for Mg-Gd, Mg-Y and Mg-Gd-Y alloy especially. There were some second phase particles which were rich of Gd, Y, (Gd, Y) especially in Mg-Gd, Mg-Y and Mg-Gd-Y alloys. As can be seen from Fig.1, the microstructure of both Mg-Gd and Mg-Y binary alloy mainly was aberration eutectic morphology while in the Mg-Gd-Y ternary alloy, a small amount of lamellar eutectic structure was found except coarse aberration eutectic microstructure.

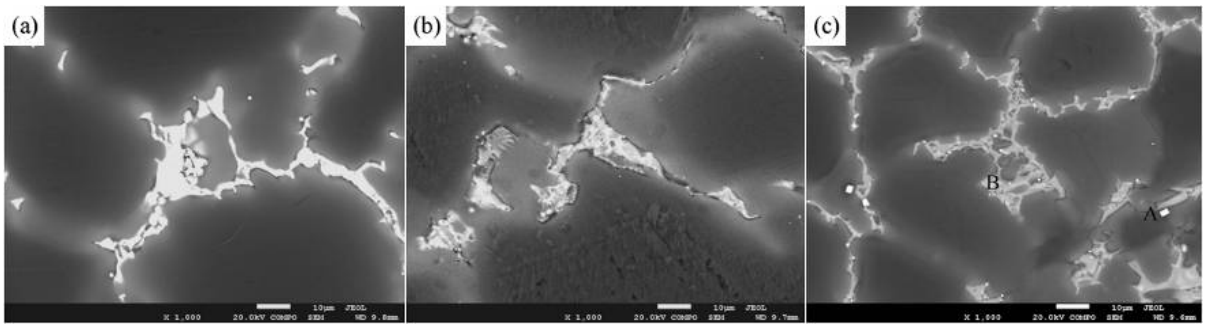

Fig.1 the as-cast microstructure of Mg-RE alloy

(a)Mg-Gd, (b)Mg-Y, (c)Mg-Gd-Y

Fig.2 was the microstructure of Mg-Gd, Mg-Y and Mg-Gd-Y rare earth magnesium alloy after heat treatment (520˚C×12h+535˚C×48h). As shown, after a long process of homogenization of Mg-Gd, Mg-Y and Mg-Gd-Y alloys, there were still a lot of residual second phase particles in the matrix. Due to the contact area of aberration eutectic and matrix was relatively small, in the process of homogenization treatment, Gd and Y atoms were difficult to fully spread. The rest of coagulation precipitates phase segregation at the grain boundaries, which not only easy to become the source of crack, but will be the core of non-uniform recrystallization nucleation along grain boundaries after hot processing. That resulted in serious duplex grain structure, and reduced the stability of the structure and properties of the alloys.

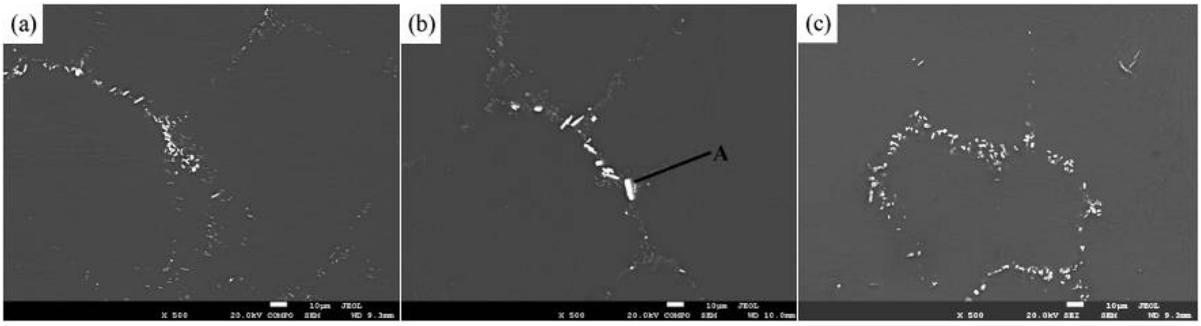

Fig.2 the microstructure of Mg-RE alloy after heat treatment

(a)Mg-Gd, (b)Mg-Y, (c)Mg-Gd-Y

Fig.3 was the microstructure of as-cast Mg-Gd-Y-Nd alloy and that after homogenization treatment. As shown, for addition of fourth element of Nd in Mg-Gd-Y alloy, it was found that the as-cast microstructure of Mg-Gd-Y-Nd alloy mainly was composed of α-Mg matrix and lamellar eutectic structure α-Mg+Mg_5 (Gd, Nd, Y) phases at grain boundaries. After heat treated, the residual second phase particles in the matrix are more dispersed compared with Mg-Gd, Mg-Y and Mg-Gd-Y alloys

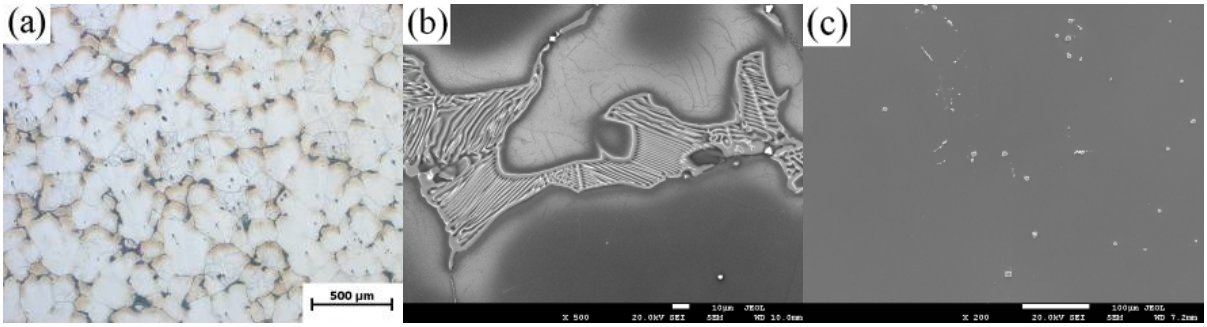

Fig.3 the microstructure of Mg-Gd-Y-Nd alloy

(a) as-cast, (b) lamellar eutectic structure, (c) after heat treatment

Fig.4 was the percent of element dissolved in different Mg-RE alloys after heat treatment. Compared with Mg-Gd, Mg-Y and Mg-Gd-Y alloys, because the contact area between the lamellar eutectic structure and matrix significant increased in Mg-Gd-Y-Nd alloy, the Gd, Y and Nd atoms were more easily diffused into the matrix during the process of homogenization. Thus the dissolve of the primary solidified precipitated phases were effectively promoted, and the strengthening efficiency of the alloy elements was improved.

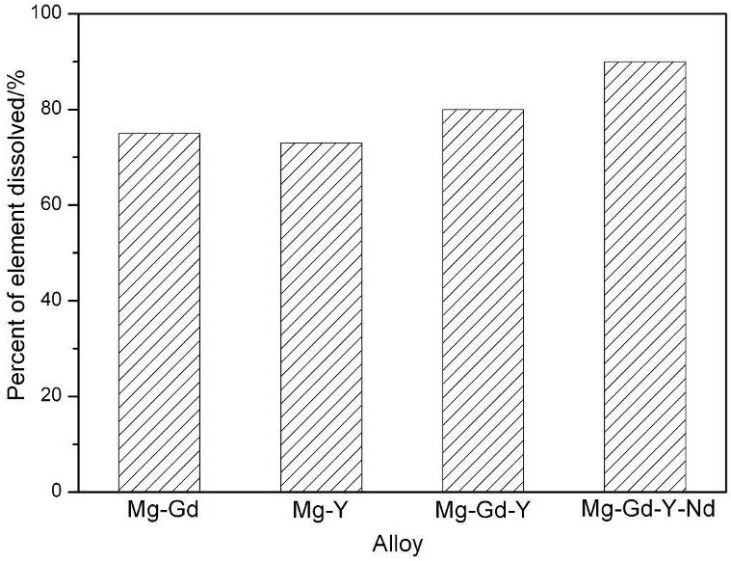

Fig.4 Percent of element dissolved in different Mg-RE alloys after heat treatment

Conclusions

(1) The primary solidified precipitated phases of both Mg-Gd and Mg-Y binary alloy was coarse aberration eutectic microstructure. For Mg-Gd-Y ternary alloy, a small amount of lamellar eutectic structure was formed while that mainly was coarse coefficient eutectic microstructure in matrix.
(2) In the experimental alloys, as the rare earth element composition increases, the microstructure pattern of the as-cast alloy was changed from coarse aberration eutectic structure to lamellar eutectic structure. The contact area between the lamellar eutectic structure and matrix significant increased, that the dissolve of the alloy elements was more fully and the residual second phase particles in the matrix were more dispersed.

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