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Effects of Sm on Microstructure of Mg-12Gd-2Y-0.5Zr Alloy

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Abstract. By alloy melting, microstructure analysis and micro-hardness test, the effects of Sm addition on the microstructure of Mg-12Gd-2Y-0.5Zr alloy with solution treatment and aging treatment were investigated. The results showed that the microstructure of the tested alloy consisted of α-Mg matrix, $Mg_{41}Sm_5$, Mg_5Gdm, $Mg_{24}Y_5$ and β′ phases, and Sm improved the micro-hardness value of α-Mg matrix attributed to its better solid solution strengthening effect in α-Mg. The micro-hardness of the alloy with Sm increases obviously from HV121.4 to HV134.3 when compared with that of Mg-12Gd-2Y-0.5Zr alloy.

1. Introduction

Mg-RE (rare earth elements) alloys are interesting materials since they have excellent mechanical properties at room and high temperature [1]. Among them, Mg-Gd system alloy is one of the most promising candidates due to the remarkable age-hardening response and very good thermal stability of the main strengthening phase till 523K. According to Mg-Gd binary phase diagram, the solubility of Gd is 23.5 wt.% at 821K and 3.8 wt.% at 473K, and the supersaturate solid solution of Gd in α-Mg can be formed after solution treatment. Furthermore. the Mg-Gd based alloy shows significantly age hardening attributes to the finely dispersed precipitation of β' phase even up to 473K. The Mg-Gd-Y alloy possess many excellent properties at peak aged hardness such as high strength and creep-resistance even is superior to that of commercial aluminium alloys, and has the good application prospect in aviation industry [2].

It is reported that [3] the co-addition gadolinium, samarium and yttrium can produce solid solution strengthening and precipitation strengthening, and increase comprehensive mechanical properties of magnesium alloys. The Samarium (Sm) nanoparticles is in orthorhombic structure, and can make an appreciable solid solution strengthening in magnesium alloy for its high solid solubility in α-Mg (5.7wt.% at 813K, and 0.4wt.% at 473K) [3]. In this paper, compared to the Mg-12Gd-2Y-0.5Zr alloy, the microstructure and micro-hardness of Mg-12Gd-2Y-Sm-0.5Zr alloy after heat treatments were investigated at ambient temperature. These results would have profound significance for further developing novel applied Mg-Gd-Y-Sm based alloys.

2. Experimental procedure

The tested alloy was designed as Mg-12Gd-2Y-Sm-0.5Zr (the compared alloy was Mg-12Gd-2Y-0.5Zr). The experimental alloy was prepared by melting pure Mg ingots and Mg-23%Gd, Mg-20%Y, Mg-22%Sm, Mg-28%Zr master alloys in the induction melting furnace. Solution process was 798K and 6 h, then quenched in hot water at 335K. Aging process was 498K and 10h. Microstructure observation is studied by means of Olympus optical microscope (OM), X-ray diffraction meter (XRD), JSM-5610LV scanning electron microscopy (SEM) and its energy dispersive spectroscopy (EDS).

Microstructures of specimen were observed by high resolution transmission electron microscope (HREM). The hardness test was studied with MH-3 Vickers micro-indenter and 20g load. The hardness number of same samples was measured as mean values of three indentations. The grain size measurement was analysed by a mean linear intercept method.

3. Results

The microstructure of aged alloys is shown in Figure 1. It is showed that the microstructure of each experimental alloy contained matrix phase and black particles. According to relative binary phase diagrams, the metallic phase should be α-Mg and Mg-RE compounds respectively. Compared with that of Mg-12Gd-2Y-0.5Zr alloy, the microstructure of Mg-12Gd-2Y-Sm-0.5Zr alloy has two main characteristics: (1) The alloy grain size tend to be uniform and the average size is about 54.4μm; (2) The fine second phases are well distributes in the matrix. The fine grains and dispersed secondary phases are helpful to improving the mechanical properties of experimental alloy.

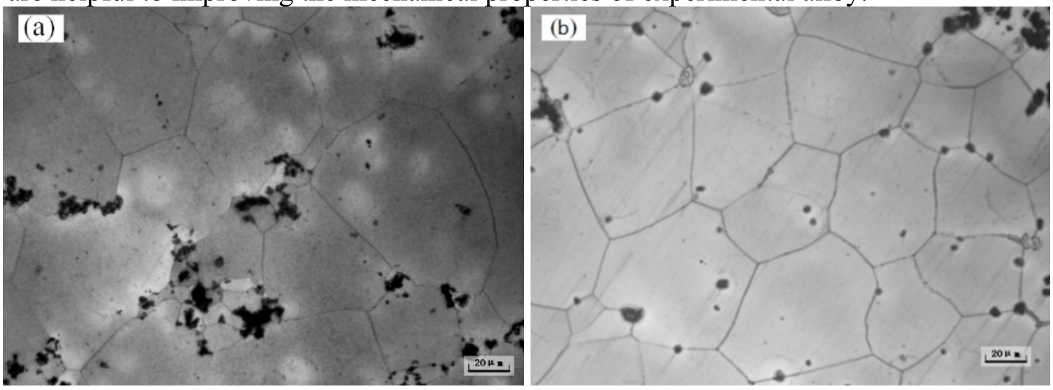

Figure 1. Microstructures of the alloys (a) Mg-12Gd-2Y-0.5Zr; (b) Mg-12Gd-2Y-Sm-0.5Zr

The XRD patterns of the aging hardened samples are shown in Figure 2. It indicates that the newly $Mg_{41}Sm_5$ phase formed in Mg-12Gd-2Y-Sm-0.5Zr alloy besides α-Mg and β′-phase. According to Mg–Gd–Y system phase diagram [4], the equilibrium phases in Mg-12Gd-2Y alloy is Mg, Mg_5Gd and $Mg_{24}Y_5$. In experimental alloy, the Mg_5Gd and $Mg_{24}Y_5$ phases have not been found, and it should be the limitation of examine position.

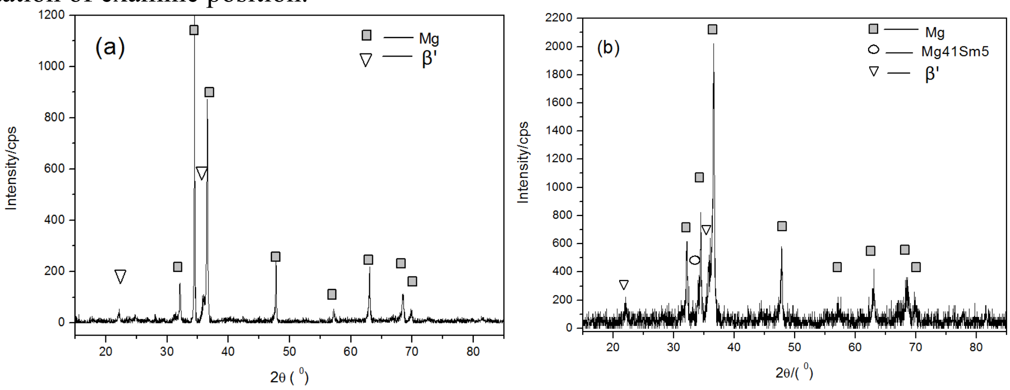

Figure 2. XRD patterns of the alloys (a) Mg-12Gd-2Y-0.5Zr; (b) Mg-12Gd-2Y-Sm-0.5Zr

It has been reported [5] that the β′-phase in Mg-Gd alloy is a metastable phase formed after solid solution treatment and a short time aging at about 523K. The β′-phase has cbco crystalline structure and can strengthen the alloy obviously by precipitation strength, as shown in Figure 3. The calculated results of α-Mg lattice constants in tested alloy are given in Table 1. It can be seen that the lattice constants of α-Mg in Mg-12Gd-2Y-Sm-0.5Zr alloy are higher than those in Mg-12Gd-2Y-0.5Zr alloy. The tested date of α-Mg proved that there was small amount of solution element Sm in α-Mg.

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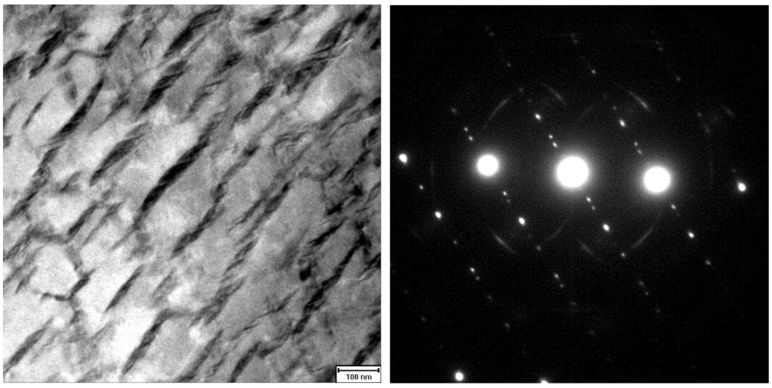

Figure 3. Bright-field TEM images and SAED patterns in aged Mg-12Gd-2Y-Sm-0.5Zr alloy

Table 1. Lattice constants of α-Mg and Mg_5Gd in the alloys

Alloy	Lattice constant of α-Mg [10^{-10}m]	
Mg-12Gd-2Y-0.5Zr	a=3.2052	c=5.2089
Mg-12Gd-2Y-Sm-0.5Zr	a=3.2094	c=5.2097

Figure 4 is SEM image and corresponding EDS analysis results of tested Mg-12Gd-2Y-Sm-0.5Zr alloy. In area A and area B, the analysis showed that the tested alloy contained several phases, including the main super saturated solid solution phase α-Mg which the main solid solution atom is Gd, and rare earth phases that had granular morphology and higher rare earth (Gd +Y+ Sm) content than α-Mg and distributed along the grain boundary. When the XRD pattern and Mg–Gd–Y system phase diagram are taking into account, the composition of these particles was determined to the mixed phases of Mg_5Gd, $Mg_{24}Y_5$ and $Mg_{41}Sm_5$. According to Mg-Gd system phase diagram, the solid solubility limitation of Gd in Mg is less than 3.8 wt% at ambient temperature, which is not in accordance with the EDS analysis in area A. It should be the nano-size β′ precipitates in the alloy that can't be found by EDS detector.

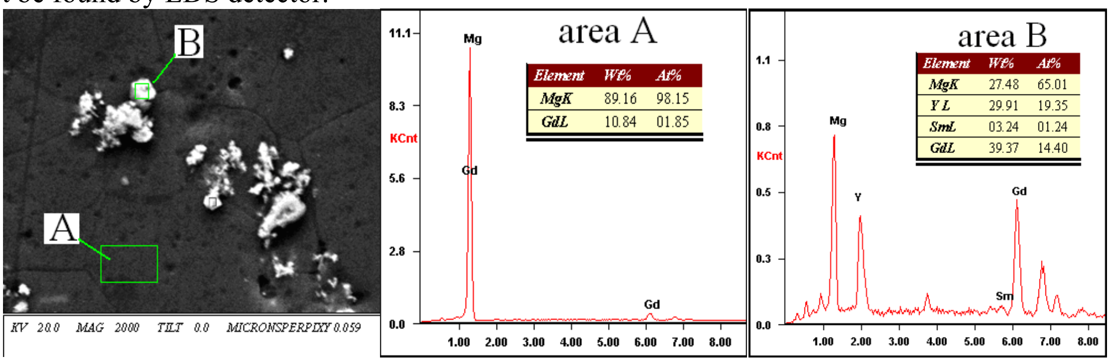

Figure 4. Microstructure and microanalysis of the phases in Mg-12Gd-2Y-Sm-0.5Zr after aging treatment

The research above has shown that Sm refinement effect on Compared alloy Mg-12Gd-2Y-0.5Zr can be summarized as follows: (1) Sm atom was partially dissolved in Mg matrix during the solidification period of tested alloy. It is the necessary condition for grain refining to has effective segregation ability solute and good nucleation substrates. Sm segregation on dendritic solidification fronts during matrix alloy solidification results in composition undercooling, and prevent dendrite growth, and is beneficial for α-Mg nucleation and growth in constitutional undercooled zone. The quantity of effective nuclei is determined by the nucleation capacity of α-Mg in constitutional undercooled zone during the alloy solidification period. According to Mg-Sm binary alloy phase diagram, the Sm solute equilibrium partition coefficient in Mg melt is less than 1 when Sm content is 1.0 wt.%, (where CS is solid phases equilibrium concentration and CL is liquid phases equilibrium concentration), therefore Sm atoms can segregates to the solid-liquid interface during alloy solidification process, which is helpful for alloy to form constitutional undercooled zone and promote forming nucleus of α-Mg, and the magnesium alloy grains can be refined finally. (2) During the solidification process of alloy, high melting point compound $Mg_{41}Sm_5$, Mg-Gd and Mg-Y precipitates can act as a barrier to prevent the growth of α-Mg, and leads to further grain refinement of tested alloy at ambient and elevated temperature.

Table 2 shows the micro-hardness of aged Mg-12Gd-2Y-0.5Zr and Mg-12Gd-2Y-Sm-0.5Zr alloys. It can be seen that the added element Sm has an obvious effect to improve micro-hardness of the experimental alloy. Compared to the micro-hardness value of Mg-12Gd-2Y-0.5Zr alloy is only HV121.4, the average micro-hardness value of tested alloy increases obviously to HV134.3. Based on the analysis above, the solid solution strengthening of Sm is one of the effective strengthening approachs for Mg alloy. In a word, Sm atoms dissolved in α-Mg matrix that strengthened the α-Mg matrix by solid solution effect, and further improved the mechanical properties of Mg-12Gd-2Y-0.5Zr alloy as a whole.

Table 2. Micro-hardnesses of the alloys

Alloy	Hv			
	1	2	3	average
Mg-12Gd-2Y-0.5Zr	120.2	121.3	122.7	121.4
Mg-12Gd-2Y-Sm-0.5Zr	132.9	134.5	135.5	134.3

The better micro-hardness values of tested alloys are mainly attributed to the fine precipitates of β′, solid solution strengthening of Gd +Y+ Sm and grain refinement strengthening of Sm in alloy. The metastable β′ precipitates had the shape of thin slice. It appeared on the prismatic planes of the α-Mg matrix in a dense triangular arrangement. And it was vertical to α-Mg basal plane and had physical stability even up to 523K. Furthermore, the β′ precipitates had semi-coherent interface with α-Mg matrix, and it could efficiently impeded the basal slip of tested alloy [seen in Figure.4] [6]. On the other hand, the existence of stable dispersed Mg_5Gd, $Mg_{24}Y_5$ and $Mg_{41}Sm_5$ phases could effectively hindered basal plane slip because of their high melting point.

The above analysis suggested that samarium (Sm) is one of the effective alloying elements to strengthen the Mg-12Gd-2Y-0.5Zr magnesium alloy.

4. Conclusions

The microstructure of tested Mg-12Gd-2Y-Sm-0.5Zr alloy with solution treatment and aging treatment consists of α-Mg matrix, β', $Mg_{41}Sm_5$ Mg_5Gd and $Mg_{24}Y_5$ phases. Sm dissolved in α-Mg matrix and enhanced the alloy by solid solution and grain refinement effect.

Compared with that of Mg-12Gd-2Y-0.5Zr alloy, the average micro-hardness of Mg-12Gd-2Y-Sm-0.5Zr alloy increases obviously from HV121.4 to HV134.3.

The strengthening mechanisms of tested alloy was mainly attributed to the fine precipitates of β′, solid solution strengthening of Gd +Y+ Sm and grain refinement strengthening of Sm in alloy.

Acknowledgments

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