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Influences of 1 wt% La-rich RE addition and deformation processes on the alloy of Mg–6Li–1.5Al

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Abstract 1 wt% La-rich RE was added into the alloy of Mg–6Li–1.5Al. The influence of the RE addition on the microstructure and mechanical properties of the alloy and the deformation behavior of this alloy were investigated. The strengthening mechanisms of the alloy were also studied. Results show that the addition of RE can refine the grain and improve the strength and elongation of the alloy. Extrusion and rolling can improve the strength to a large extent. The strengthening mechanisms for this alloy are mainly the refining strengthening and dispersion strengthening.

Introduction

Magnesium has a crystallization structure of close-packed hexagonal lattice (hcp), which makes the plasticity at room temperature happen only in the slipping systems of $\{0001\}\langle 11\bar{2}0\rangle$ and $\{10\bar{1}2\}\langle 10\bar{1}1\rangle$. Therefore, the plasticity of magnesium is poor. The addition of Li in Mg can improve the plasticity of alloys [1, 2]. When the Li content is between 5.7 and 10.3 wt%, the alloys possess binary phases ($\alpha + \beta$, in which the α and β are Mg-rich solid solution and Li-rich solid solution, respectively). Because of the existence of β phase, the plasticity of the alloy becomes better, but the strength of the alloy becomes somewhat poorer [3, 4]. The magnesium alloy with 6 wt% Li is near the boundary between α single phase zone and $\alpha + \beta$ binary phases zone. In the alloy, the matrix is α phase which is a phase with a somewhat higher hardness, and a small amount of β phase distributes in the matrix. The β phase is somewhat softer phase, which can cooperate the deformation of α phase during the deformation process [5].

Based on Mg–Li binary alloys, some alloying elements are often added into the alloys to improve the strength of them. A small content of Al has a good solution strengthening effect [6]. Different RE elements have some favorable effects on Mg–Li base alloys [7, 8].

In this article, the Mg–6Li–1.5Al and Mg–6Li–1.5Al–1RE (La-rich) were prepared. The effects of RE in the alloy and the strengthening mechanisms of the alloys were investigated.

Experimental procedure

The materials used in the experiments are commercial pure (CP) Mg ingot, CP Li ingot, CP Al ingot, and the master alloy of Mg–15RE (La-rich RE: La 85 wt%, Pr 10 wt%, Ce 5 wt%). The materials were melted at the atmosphere of pure argon in a medium-frequency induction furnace. Then the melt was poured into a permanent mold to obtain as-cast samples. The designed alloys were Mg–6Li–1.5Al (LA6-1.5) and Mg–6Li–1.5Al–1RE (LAE6-1.5-1). The designed compositions and the actual compositions (measured with inductively coupled plasma spectrometer) of the alloys are shown in Table 1.

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Table 1 The designed compositions and the actual compositions of alloys, wt%

Alloys	Li	Al	La	Pr	Ce	Total RE	Bal.
Mg–6Li–1.5Al (LA6-1.5)							
Designed	6.00	1.50					92.50
Actual	6.33	1.49					92.18
Mg–6Li–1.5Al–1RE (LAE6-1.5-1)							
Designed	6.00	1.50	0.85	0.10	0.05	1.00	91.50
Actual	5.81	1.62	0.56	0.09	0.03	0.68	91.89

The as-cast samples were extruded at the temperature of 280 °C. The extrusion ratio is about 13. Finally, the as-extruded samples were rolled at the temperature of 280 °C. The final thickness of the as-rolled samples was 6 mm after five passes.

The phase constitution of alloys was measured by X-ray diffraction (XRD). The morphologies of alloys were observed by optical microscope (OM) and scanning electron microscope (SEM). The micro-zone elemental compositions of alloys were analyzed by energy dispersion X-ray spectroscope (EDS). The strength and elongation of alloys were measured with a tensile tester. The tensile speed is 2 mm/min.

Results

Morphologies of the alloys

The OM microstructures of the alloys of LA6-1.5 and LAE6-1.5-1 are shown in Fig. 1. The as-cast LA6-1.5 is composed of a large amount of α phase and a small amount of β phase. The β phase is mainly located at the grain boundary of α phase as shown in Fig. 1a. Compared with that of LA6-1.5, the microstructure of LAE6-1.5-1 is refined obviously. The β phase distributes more evenly, and some rodlike precipitated phase also can be observed, as shown in Fig. 1b. In the as-extruded LAE6-1.5-1, the twisted microstructure can be observed in the cross section, as shown in Fig. 1c. In the extrusion direction, the α and β phases are both stretched along the extrusion direction, making the β phase exist with the shape of fibrous, as shown in Fig. 1d. In the as-rolled alloys after extrusion, there exist some particles both in the cross section and the rolling section, as shown in Fig. 1e, f. The particles are β phase and precipitated phase.

Identification of the precipitated phase

The SEM and EDS results for the precipitated phase are shown in Fig. 2. EDS results indicate that the rodlike and grainy precipitated phases both contain the elements of Mg, Al, La, Pr, and Ce. The XRD patterns of LA6-1.5 and LAE6-1.5-1 are shown in Fig. 3. Comparing the two patterns with each other, it can be known that the precipitated phase in LAE6-1.5-1 is Al_3La. The Pr and Ce that are detected from the rodlike and grainy precipitated phases in Fig. 2b, d solid solute in the Al_3La phase, the Mg element detected from them maybe come from the matrix.

Tensile properties of the alloys

Table 2 shows the strength and elongation of alloys investigated in this article. With the addition of 1 wt%

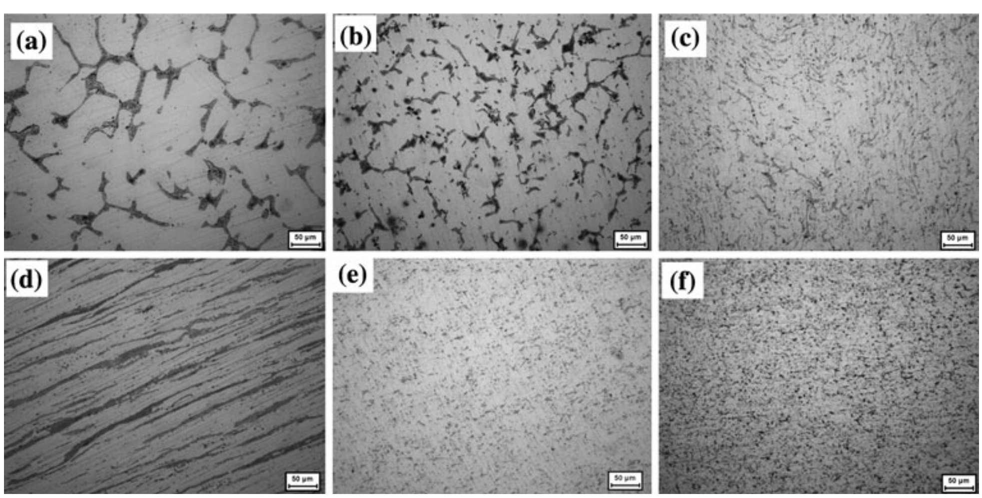

Fig. 1 The OM microstructures of the alloys of LA6-1.5 and LAE6-1.5-1. **a** As-cast LA6-1.5, **b** as-cast LAE6-1.5-1, **c** cross section of as-extruded LAE6-1.5-1, **d** extruding direction of LAE6-1.5-1, **e** rolling section of LAE6-1.5-1, **f** cross section of as-rolled LAE6-1.5-1

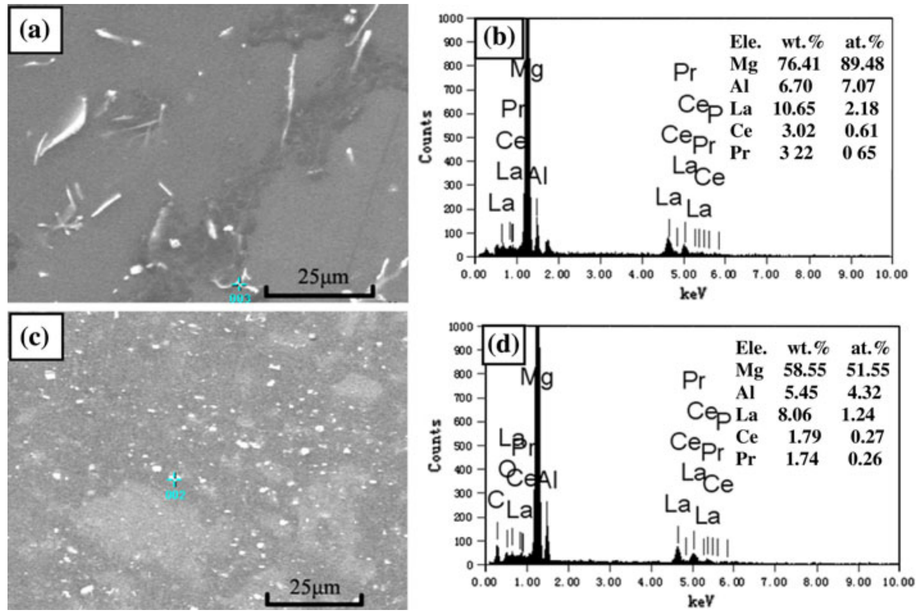

Fig. 2 SEM and EDS results of LAE6-1.5-1. **a** SEM of as-cast LAE6-1.5-1, **b** EDS result of the point "003" in SEM, **c** SEM of as-rolled LAE6-1.5-1, **d** EDS result of the point "002" in SEM

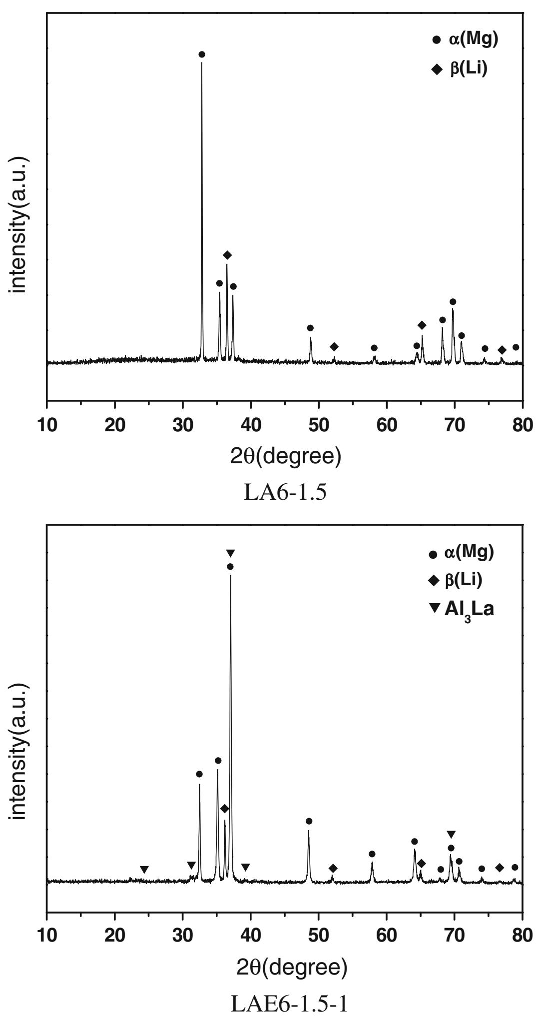

Fig. 3 XRD patterns of LA6-1.5 and LAE6-1.5-1

Table 2 Strength and elongation of alloys

Alloys	States	Ultimate strength (MPa)	Elongation (%)
LA6-1.5	As-cast	162.3	9.8
LAE6-1.5-1	As-cast	172.3	12.3
	As-extruded	244.3	14.1
	As-rolled after extrusion	292.5	17.1

La-rich RE, the strength and elongation of the alloy are both increased. The deformations of extrusion and the rolling can increase the strength and elongation further. The as-rolled alloys possess the highest strength and elongation.

Discussion

Precipitated phase

In La-rich RE, La is the main element. The electronegativity difference between La and Mg is 0.21, that between La and Al is 0.51, and that between La and Li is 0.12. Comparing the three values, the electronegativity difference between La and Al is the highest. Accordingly, among the three elements (Al, Mg, and Li), Al can react with La most easily. Therefore, when 1 wt% La-rich RE is added into the alloy of LA6-1.5, the precipitated phase is Al_3La.

The Al_3La in as-cast alloy is rodlike shape. After the extrusion and rolling, the rodlike Al_3La is crashed, making it become grainy particles.

Tensile properties

The 1 wt% RE addition makes the α and β phases be refined. At the meantime, rodlike Al_3La forms in the alloy. The refining effect is favorable for both strength and elongation, and the secondary phase (Al_3La) is favorable for strength of the alloy. Therefore, the strength and elongation of LAE6-1.5-1 are both higher than those of LA6-1.5.

The extrusion and rolling processes also affect the strength and elongation. Through the extrusion, the microstructure of the alloy is refined. After the rolling, the microstructure is refined further.

Deformation for the alloy also makes the distortion of the microstructure become larger, and makes the dislocation density become larger. Therefore, the strength of the alloy increases [9, 10].

In addition, through the deformation, the casting defects, such as gas pores, are removed [11, 12]. This also improves the strength and elongation of the alloy.

Conclusions

The addition of 1 wt% La-rich RE in LA6-1.5 refines the microstructure and causes the formation of rodlike Al_3La precipitated phase. The addition of RE also makes the strength and elongation increase.

The deformation of the alloy of LAE6-1.5-1 refines the microstructure obviously and makes the shape of Al_3La change from rodlike to grainy particle. The refinement, the increase of dislocation density and the removal of casting defects make the strength and elongation of the alloy increase sequentially from as-cast, as-extruded to as-rolled.

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