

Microstructure and mechanical properties of Mg-5.6Li-3.37Al-1.68Zn-1.14Ce alloy

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Abstract: Mg-5.6Li-3.37Al-1.68Zn-1.14Ce alloy was prepared using vacuum induction melting furnace. The microstructure and phases composition of as-cast and as-extruded alloys were investigated by optical microscopy, energy dispersive X-ray spectroscopy, scanning electron microscopy and X-ray diffraction. The mechanical properties of these alloys were measured with tensile tester. The results indicate that the as-cast alloy is composed of α (Mg) phase and rod-like Al_2Ce compound. Al_2Ce has the refining effect on the microstructure of alloy. During the extrusion at 523 K, dynamic recrystallization happens in the alloy. The dynamic recrystallization refines the grain size of alloy obviously. The phases are refined clearly after extrusion deformation, and the strength and ductility of the alloy are increased accordingly.

Key words: Mg-Li alloy; microstructure; extrusion deformation

1 Introduction

Mg-Li alloys are the lightest structural materials with high stiffness ratios, good machining properties, good magnetic screening and shock resistance ability. They are used widely in the fields of electricity, war industry and spaceflight and so on[1–4]. Because of the low strength, poor corrosion resistance and thermal stability of Mg-Li binary alloys, some other alloying elements (such as Al and Zn), are always added into Mg-Li binary alloys. Much previous research has been focused on the Mg-Li-Al and Mg-Li-Zn alloys[5–7]. However, these alloys have the aging softening phenomenon[8].

Mg-Li alloys can be divided as three kinds of phase structures: 1) single-phase (α) structure; 2) double-phase ($\alpha+\beta$) structure and 3) single-phase (β) structure. In previous literatures, most of them focused on the double-phase ($\alpha+\beta$) and single-phase (β) alloys[9–10]. However, these alloys have two shortcomings, namely relatively low strength and relatively poor corrosion resistance. Therefore, it is necessary to research the

single-phase (α) alloys.

Mg-5Li alloy is a single-phase (α) structure alloy and has good plasticity and strength. Aluminum and zinc are the most commonly used alloying elements because of their obvious solution-strengthening effect[11–12]. And cerium is one of the most commonly used alloying elements in Mg alloys. It has obvious refining effects on the grain size of Mg alloys[13–15]. However, few researches have been reported about Mg-Li-Ce alloy[16].

In this work, Mg-5.6Li-3.37Al-1.68Zn-1.14Ce alloy was prepared by the vacuum-melting method in an argon atmosphere. The microstructure and mechanical properties of as-cast and extruded specimens were studied to reveal the effects of Ce on the Mg-5.6Li-3.37Al-1.68Zn alloy.

2 Experimental

The materials used in experiments were taken from pure magnesium ingot, pure lithium ingot, pure aluminum ingot, pure zinc ingot and Mg-Ce master alloy (containing 26% Ce, mass fraction). The materials were melted in vacuum induction furnace under pure argon

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atmosphere. With the materials and melting method, Mg-5.6Li-3.37Al-1.68Zn-1.14Ce alloys were prepared.

The as-cast specimens were then homogenized in vacuum furnace (573 K, 12 h). Finally, the specimens were extruded at 523 K. The diameters of the specimens before and after extrusion were 50 mm and 14 mm respectively.

The specimens for optical micrographs were etched with 1% (volume fraction) nital. The micrographs were observed with LEICA optical microscope and the grain size of the alloy was calculated with Leica Qwin software. The phase analysis was tested with XRD (D/Max2500). The microstructure and element compositions were analyzed using SEM (SM-6360LV) with EDS (FALCON 60S). The composition was analyzed with ICP-Ms and the results show that the alloys prepared is Mg-5.6Li-3.37Al-1.68Zn-1.14Ce. The tensile strength and elongation to rupture were tested with tensile tester at 1 mm/min.

3 Results and discussion

3.1 Phases analysis of alloys

Fig.1 shows the XRD patterns of Mg-5.6Li-3.37Al-1.68Zn-1.14Ce alloy. The alloy is composed of α (Mg) and Al_2Ce phases. The phases of the as-extruded alloy

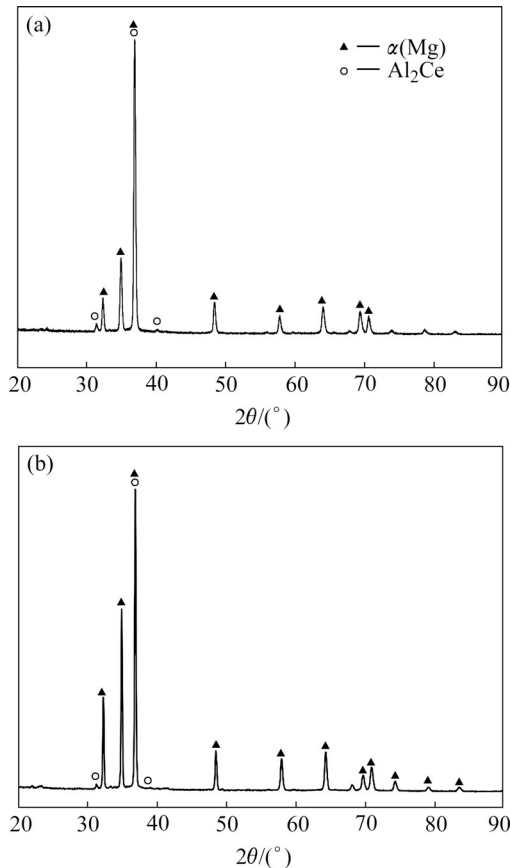


Fig.1 XRD patterns of Mg-5.6Li-3.37Al-1.68Zn-1.14Ce: (a) As-cast; (b) As-extruded

are the same as those of the as-cast alloy. The difference between the as-extruded and as-cast alloys is that the diffraction intensity of α (Mg) phase on all the crystal planes changes after extrusion process.

Some of the Al and Ce elements in the alloy solid-solutes in α (Mg) phase. And the other part forms compounds. The EDS results are shown in Fig.2. The blocky compound at point A is composed of Mg, Al and Ce elements. And the atomic ratio of Al to Ce is about 2. According to the electronegative difference between elements, the formation trend of compounds can be judged. The larger the electronegative difference is, the easier the elements are to form compound. The electronegative differences of Ce/Al, Ce/Mg and Ce/Li are 0.4, 0.1 and 0.3, respectively. Therefore, combined with the XRD patterns, it can be concluded that the blocky compound at point A is Al_2Ce .

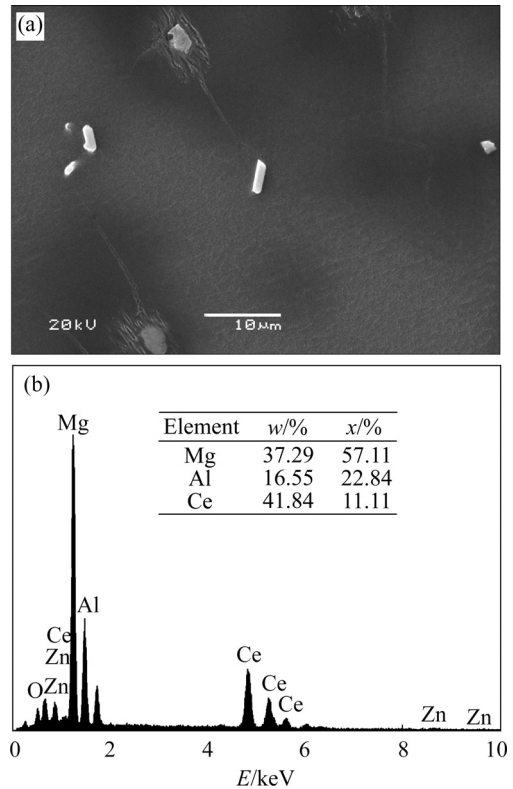


Fig.2 EDS analysis of precipitated compounds in as-cast specimen

The melting point of Al_2Ce is relatively high. During the solidification of melt, Al_2Ce can restrain the growth of grains and refine the grain size accordingly. Therefore, the existence of Al_2Ce improves the strength of the alloy.

3.2 Microstructure of alloys

Fig.3 shows the optical micrographs of Mg-5.6Li-3.37Al-1.68Zn-1.14Ce alloy. In the as-cast alloy, obvious dendritic microstructure can be seen. After extrusion, the microstructure of alloy is composed of fine

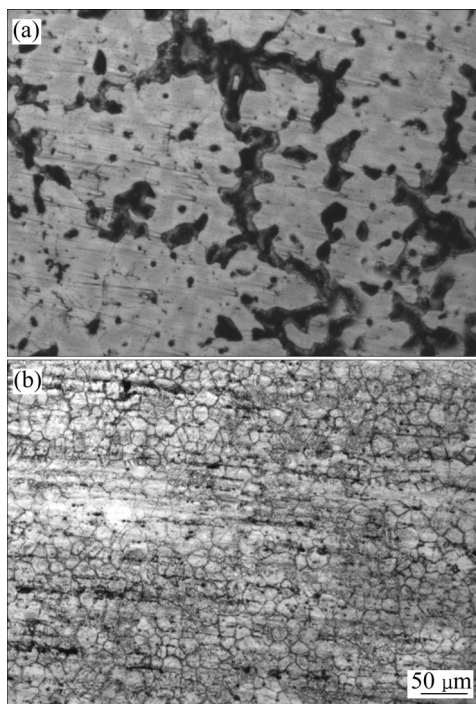


Fig.3 Microstructure of Mg-5.6Li-3.37Al-1.68Zn-1.14Ce alloys: (a) As-cast; (b) As-extruded (parallel to extruding direction)

equiaxed grains. The average grain size is 15 μm . From the micrographs, it is known that the microstructure of the alloy is refined obviously through extrusion.

The lithium in alloy can make the crystal axial ratio (c/a) of magnesium decrease. This improves the symmetry of alloy crystal lattice and makes the nonbasal slip systems ($\{10\bar{1}0\}$ $\langle 11\bar{2}0 \rangle$ and $\{11\bar{2}2\}$ $\langle 11\bar{2}3 \rangle$) be activated at a relatively low temperature. Accordingly, the plasticity of the magnesium alloys is improved. The melting point of Mg-5.6Li alloy is about 870 K and its recrystallization temperature ($0.4T_m$) is 348 K. During the extrusion at 523 K, several slip systems of Mg-5.6Li-3.37Al-1.68Zn-1.14Ce alloy are activated. Dislocations move along multiple slip and cross slip. They tangle or pile up to form dislocation walls. Then the dislocation walls become sub-boundaries. The slipping and climbing of dislocations make the merge of subgrains become easy. With the growth of subgrains, large angle boundaries will form and then the recrystallization nuclei forms. Finally, the new crystal grains form and the whole recrystallization process finishes. The recrystallization process is the key cause of the refinement of Mg-5.6Li-3.37Al-1.68Zn-1.14Ce alloy during extrusion.

3.3 Mechanical properties and fractural micro-structure

The mechanical properties of alloy before and after extrusion are listed in Table 1. After extrusion, the mechanical properties of the Mg-5.6Li-3.37Al-1.68Zn-

Table 1 Mechanical properties of as-cast and as-extruded alloys

Condition	Fracture strength/MPa	Yield strength/MPa	Elongation/%
As-cast	240	235	8
As-extruded	286	270	10

1.14Ce alloy are improved.

The improvement of strength can be attributed to two aspects. One is that the casting defects, such as shrinkage porosity and gas porosity, can be decreased in extrusion process. The other aspect is the refining effect of extrusion. According to Hall-Petch theory, the refinement increases the amount of grain boundaries. This makes the motion of dislocations become more difficult and the strength of alloy is improved accordingly.

The refinement is also favorable for elongation improvement of the alloy. In the alloy with fine grains, it is difficult for cracks to form. Even when the cracks form in alloy, they are not easy to spread. The spread of cracks in fine grain alloy needs to change spreading direction for many times. This will consume much energy. Therefore, fine grain microstructure of alloy can improve the elongation of alloy.

Fig.4 shows the fractural microstructure of the alloy. The fracture mechanism of the as-cast alloy is cleavage fracture mode. In the fractural microstructure of as-extrusion alloy, there exist even fine fractural dimples which demonstrate the fracture mechanism is microvoid coalescence fracture mode.

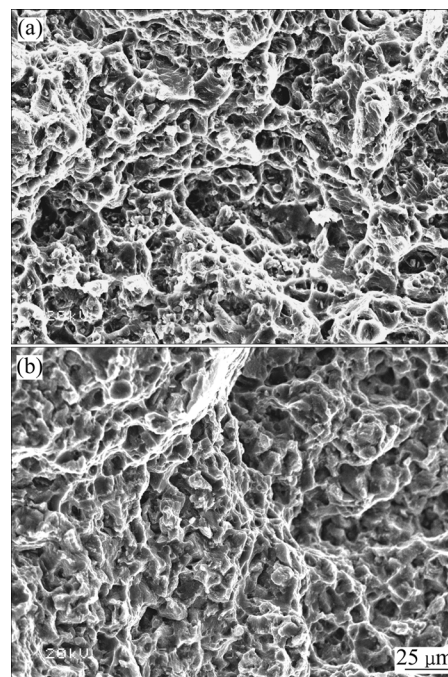


Fig. 4 Fracture micrographs of as-cast and extruded specimens: (a) As-cast specimen; (b) As-extruded specimen

4 Conclusions

1) The Mg-5.6Li-3.37Al-1.68Zn-1.14Ce alloy is composed of α (Mg) and Al₂Ce phases. Al₂Ce has the refining effect on microstructure of the alloy.

2) During the extrusion at 523 K, dynamic recrystallization happens in the alloy. The dynamic recrystallization refines the grain size of the alloy obviously.

3) After extrusion, the average grain size of the alloy is 15 μ m. The mechanical properties of the alloy after extrusion are improved accordingly.

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