

## Microstructure and mechanical properties of Mg-*x*Li-3Al-1Ce alloys

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**Abstract:** Several Mg-*x*Li-3Al-1Ce alloys were prepared by vacuum induction heating. These alloys are Mg-5Li-3Al-1Ce, Mg-8Li-3Al-1Ce and Mg-14Li-3Al-1Ce, respectively. The microstructure and phase composition of these alloys were analyzed by optical microscopy, scanning electron microscopy, energy dispersive X-ray spectroscopy and X-ray diffractometry. The mechanical properties of these alloys were measured with tensile tester. The results show that, Mg-5Li-3Al-1Ce has a single phase ( $\alpha$ ) structure, Mg-8Li-3Al-1Ce has a double phases ( $\alpha+\beta$ ) structure, Mg-14Li-3Al-1Ce has a single phase ( $\beta$ ) structure. And some compounds distribute in the matrix. After being rolled, the grain size of all the alloys is refined. Under the condition of the same content of other alloying elements, the mechanical properties of Mg-5Li-3Al-1Ce are relatively high. With increasing Li content, the strength of both as-cast and as-rolled alloy decrease. For the as-cast alloys, with increasing Li content, the elongation increases. While for the as-rolled alloys, with increasing Li content, the elongation decreases. Ce has refining effect on these alloys.

**Key words:** Mg-Li alloy; microstructure; mechanical properties

### 1 Introduction

As the lightest structural materials, Mg-Li alloys have many advantages, such as high specific strength, good machinability and formability[1–3]. Therefore, Mg-Li alloys are widely used.

As for Mg-Li binary alloys, according to Mg-Li alloy phase diagram, when Li mass content is lower than 5.7%, the microstructure of alloys is single phase ( $\alpha$ ). When Li mass content is larger than 11%, the microstructure of alloys is single phase ( $\beta$ ). When Li mass content is between 5.7% and 11%, the microstructure of alloys is double phases ( $\alpha+\beta$ )[4–5].

However, due to the severe activity of Li element, Mg-Li binary alloys have some inherent disadvantages: low strength, poor anti-corrosion and poor stability. In order to avoid these disadvantages, some alloying elements should be added into the alloys. Because of its strengthening effect, Al is the most commonly used alloying elements[6–9]. YU et al[10] reported that, with the increase of Al content in Mg-Li alloys, the strength increases accordingly. While when the Al content is too high, the elongation of alloys decreases seriously. The

suitable Al content in Mg-Li alloys is 3% (mass fraction).

To refine the grain size of alloys, Ce is often added in magnesium alloys in previous literatures[11–12]. And the suitable Ce content in Mg-Li alloys is 1% (mass fraction)[12].

There are many researches about Mg-Li alloys added with Al and (or) Ce[6–12]. However, most of these researches focused on just one kind of Mg-Li alloys ( $\alpha$  single phase zone,  $\beta$  single phase zone or  $\alpha+\beta$  double phases zone). The comprehensive research about all the three kinds of alloys containing Al and Ce is not reported in previous literatures.

In order to investigate all the three kinds of alloys ( $\alpha$  single phase zone,  $\beta$  single phase zone or  $\alpha+\beta$  double phases zone) containing Al and Ce, Mg-5Li-3Al-1Ce, Mg-8Li-3Al-1Ce and Mg-14Li-3Al-1Ce alloys were prepared in the present study. And the microstructure and mechanical properties of these alloys were also studied.

### 2 Experimental

The materials used in the experiments were pure magnesium (99.95%), pure lithium (99.90%), pure

aluminum (99.95%) and Mg-26%Ce master alloy. Alloys were prepared under the ambient argon gas in a vacuum induction furnace. The furnace chamber pressure was kept at  $1 \times 10^{-2}$  Pa. Then pure argon was input as protective gas before melting. The melt temperature was about 700 °C. Then the melt was poured into a permanent mould.

Microstructure was measured with optical microscope(OM), as well as with scanning electron microscope(SEM). The samples for OM and SEM were etched by using an etchant consisting of 10 mL  $\text{KNO}_3$  and 90 mL alcohol. Phase analysis was done with X-ray powder diffraction(XRD). The chemical compositions of the analyzed phases of the alloys were analyzed with energy dispersive X-ray spectroscopy(EDS) in the scanning electron microscope. The mechanical properties of these alloys were measured with tensile tester (1 mm/min of the tensile rate).

### 3 Results and discussion

#### 3.1 Microstructure of Mg-5Li-3Al-1Ce

The microstructure of Mg-5Li-3Al-1Ce is shown in Fig.1. In as-cast specimen, the microstructure shows a single phase alloy. And some compounds distribute in the matrix phase. After being rolled, the grain size is reduced obviously and the compounds are crashed. Fig.2 show the SEM image and EDS pattern of Mg-5Li-3Al-1Ce. The EDS result represents the elemental composition of compounds. From the results, the mole ratio of Al/Ce is about 2. Therefore, the compounds in matrix may be

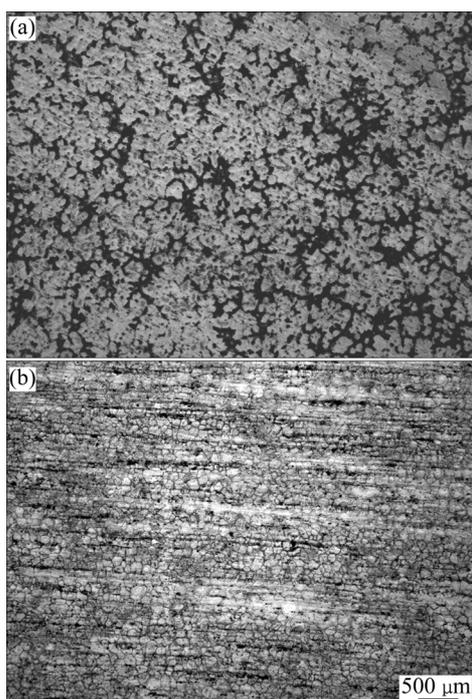


Fig.1 OM photographs of Mg-5Li-3Al-1Ce: (a) As-cast; (b) As-rolled

$\text{Al}_2\text{Ce}$ . This conclusion can be confirmed in Fig.3. From Fig.3, it is known that the alloy is composed of  $\alpha(\text{Mg})$  and  $\text{Al}_2\text{Ce}$ .

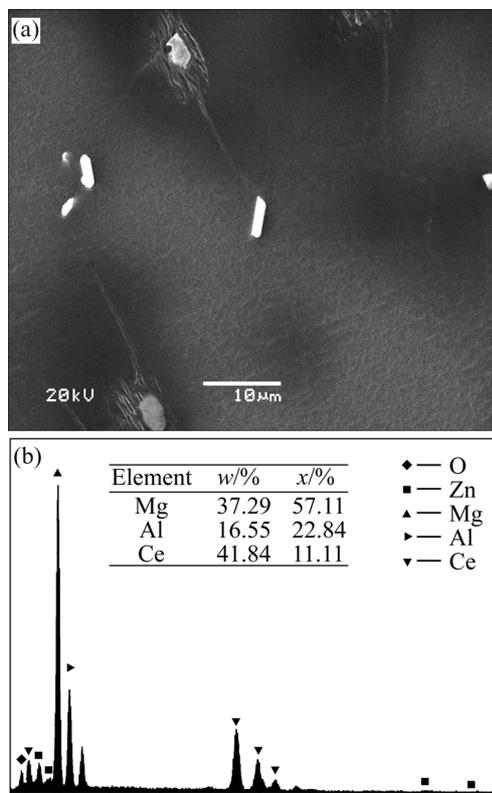


Fig.2 SEM image and EDS pattern of Mg-5Li-3Al-1Ce alloy

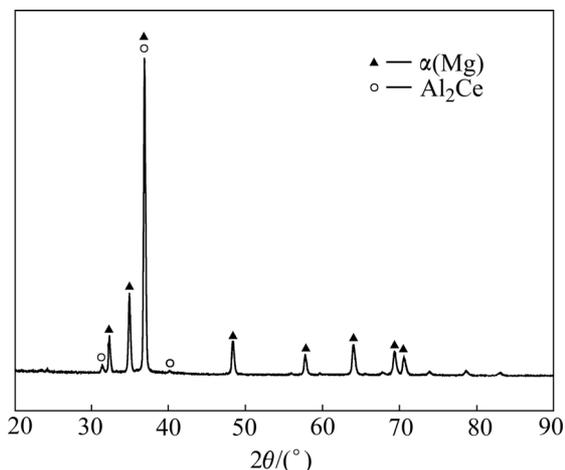


Fig.3 XRD pattern of Mg-5Li-3Al-1Ce alloy

#### 3.2 Microstructure of Mg-8Li-3Al-1Ce

The microstructure of Mg-8Li-3Al-1Ce is shown in Fig.4. For as-cast specimen, it shows double phases microstructure. And some rod-like compounds and granular compounds distribute in the matrix. After being rolled, the grain size is reduced and the compounds are crashed as granular. Fig.5 shows the SEM image and EDS pattern of Mg-8Li-3Al-1Ce. The EDS result represents the elemental composition of rod-like com-

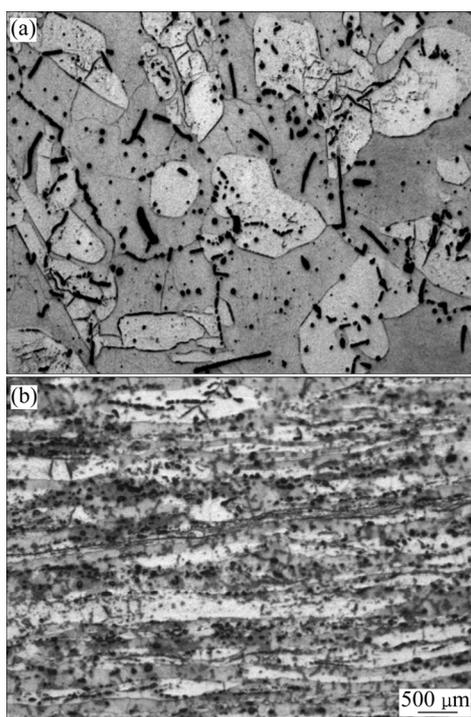


Fig.4 OM photographs of Mg-8Li-3Al-1Ce alloy: (a) As-cast; (b) As-rolled

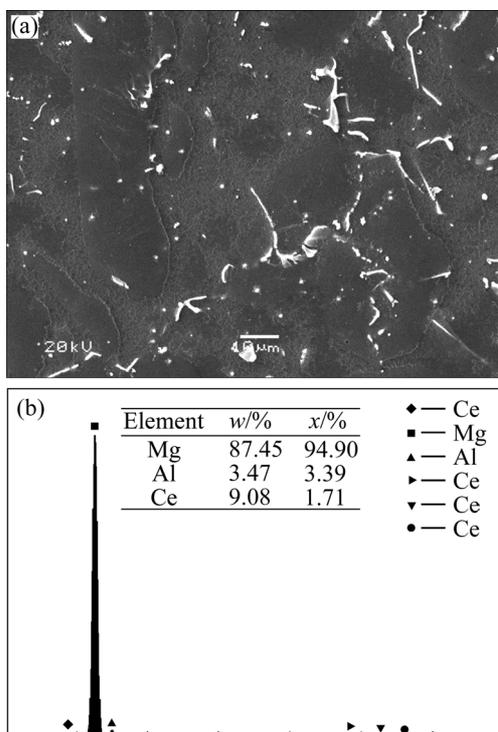


Fig.5 SEM image and EDS pattern of Mg-8Li-3Al-1Ce

pounds. From the results, the molar ratio of Al/Ce is about 2. Therefore, the compounds in the matrix may be  $Al_2Ce$ . In order to confirm this conclusion, the XRD pattern of the specimen was detected (Fig.6). From Fig.6, it is known that the alloy is composed of  $\alpha(Mg)$  and

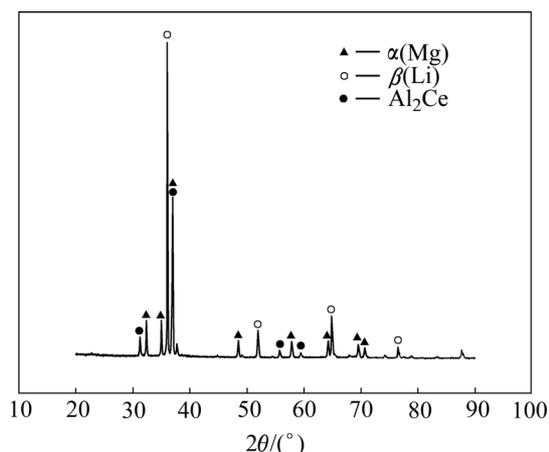


Fig.6 XRD pattern of Mg-8Li-3Al-1Ce alloy

$Mg_{17}Al_{12}$ . There is no  $Al_2Ce$  in XRD result. This is maybe because the amount of  $Al_2Ce$  in specimen is too low to be detected. Considering the EDS and XRD results the granular compounds in Fig.4(a) are confirmed to be  $Mg_{17}Al_{12}$ .

### 3.3 Microstructure of Mg-14Li-3Al-1Ce

The microstructure of Mg-14Li-3Al-1Ce is shown in Fig.7. For as-cast specimen, it shows single phase microstructure. After being rolled, the grain size is reduced seriously. Fig.8 shows the XRD pattern of Mg-14Li-3Al-1Ce. It is known that the alloy is composed of  $\beta(Li)$ ,  $Mg_{17}Al_{12}$ ,  $AlLi$  and  $Al_2Ce$ .

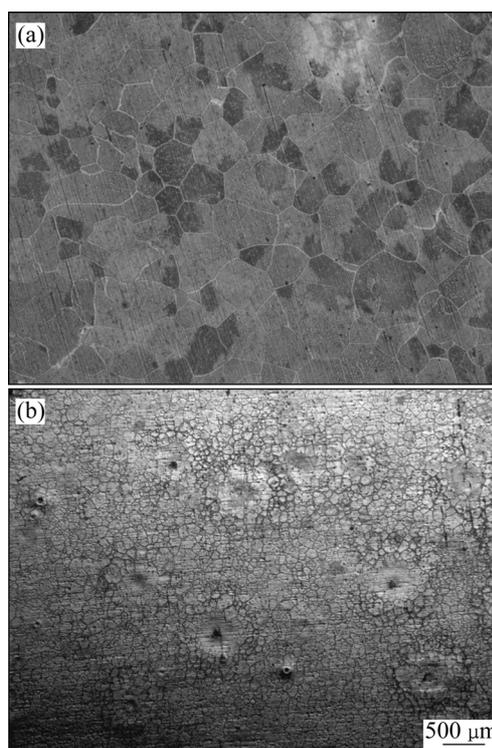


Fig.7 OM photographs of Mg-14Li-3Al-1Ce alloy: (a) As-cast; (b) As-rolled

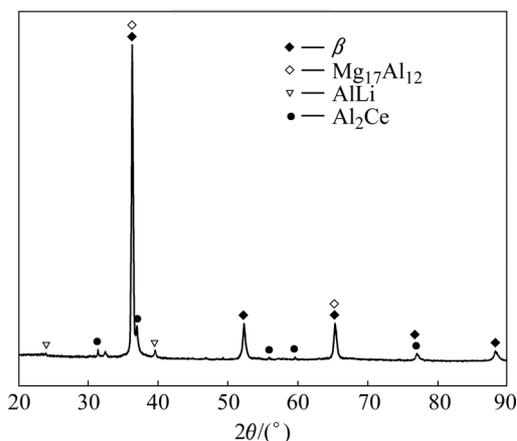


Fig.8 XRD pattern of Mg-14Li-3Al-1Ce alloy

### 3.4 Mechanical properties of alloys

The mechanical properties of alloys mentioned above are shown in Fig.9. For Mg- $x$ Li-3Al-1Ce alloys, the strength of both as-cast and as-rolled decreases with the increase of Li content. As for as-cast alloys, the elongation increases with the increase of Li content. While for as-rolled alloys, it decreases with increasing Li content. The strength of as-rolled Mg-5Li-3Al-1Ce is the largest (285 MPa). And for as-rolled alloys, the

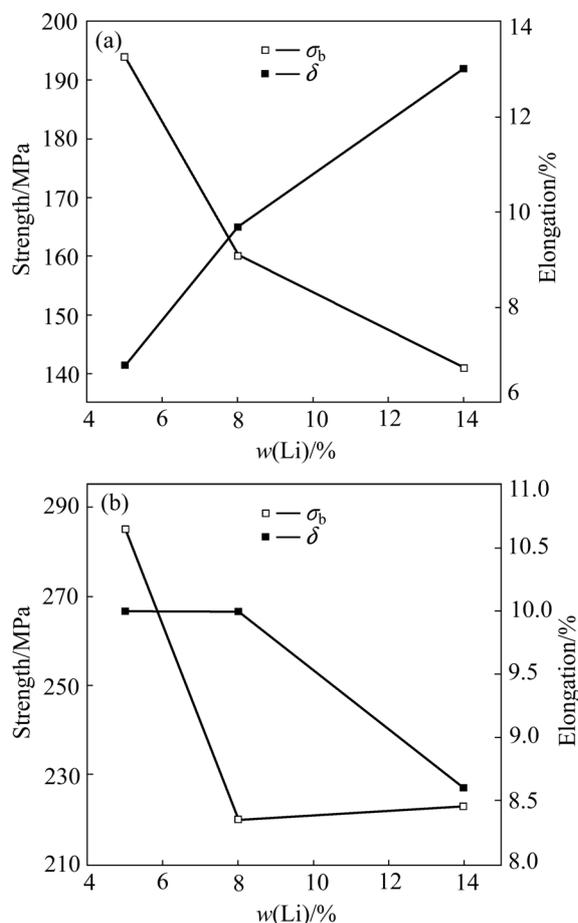


Fig.9 Mechanical properties of Mg- $x$ Li-3Al-1Ce alloys: (a) As-cast; (b) As-rolled

elongation of Mg-5Li-3Al-1Ce alloys is the largest (10%).

## 4 Conclusions

1) Mg-5Li-3Al-1Ce alloy is a single phase ( $\alpha$ ) structure, Mg-8Li-3Al-1Ce is a double phases ( $\alpha+\beta$ ) structure and Mg-14Li-3Al-1Ce is a single phase ( $\beta$ ) structure. Some compounds distribute in the matrix.

2) After being rolled, the grain size of all the alloys is refined.

3) With increasing Li content, the strength of both as-cast and as-rolled alloys decreases. For the as-cast alloys, with increasing Li content, the elongation increases. While for as-rolled alloys, with increasing Li content, the elongation decreases.

4) Among the three alloys (Mg- $x$ Li-3Al-1Ce), Mg-5Li-3Al-1Ce has the maximal strength (285 MPa). And for as-rolled alloys, the elongation of Mg-5Li-3Al-1Ce alloys is the largest (10%).

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