

Influence of Ce on microstructure and mechanical properties of LA141 alloys

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Abstract: LA141-(0–1.2)Ce alloys were prepared with vacuum induction melting method. The effects of Ce addition on the microstructure and mechanical properties of LA141 alloys were studied. The microstructure and phases 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 Ce has refining effect on the alloys. In the alloys, some Al_2Ce compounds exist, which make the Al content dissolved in α and β phases decrease and the hard brittle $Mg_{17}Al_{12}$ phase refined. The refining effect improves the mechanical properties of alloys. When Ce content is 0.9%(mass fraction), the tensile strength reaches 206.8 MPa and the elongation is two times as high as that of LA141 alloy. Due to the generation of Al_2Ce , the content of Al solid soluted in β phase decreases resulting in the decrease of alloy hardness with the addition of Ce.

Key words: LA141 alloy; cerium; grain refinement; mechanical property

1 Introduction

Due to the low density and good plasticity capability of Mg-Li alloys, Mg-Li alloys can meet the light-mass demand in the fields of aircraft, aerospace and military, etc. In the middle of 1960s, LA141(Mg-14Li-1Al) alloys were used in manufacture of spacecraft and weapon parts. Several parts on Apollo aerospace plane are also made of LA141 alloy[1–3].

Lithium in Mg-Li alloys is a key factor affecting property and microstructure. When lithium content is larger than 10.3%(mass fraction), the microstructure of alloy will be changed from $\alpha(\text{hcp})+\beta(\text{bcc})$ to $\beta(\text{bcc})$. In the single $\beta(\text{bcc})$ phase zone, with the lithium content increasing, the strength, corrosion resistance capability and high temperature properties will decrease. For instance, the tensile strength, yield strength and elongation percentage of LA141 are respectively 135 MPa, 103 MPa and 13%[3]. And the corrosion resistance is also poor. These shortcomings restrict the application of this kind of alloys to some extent.

Therefore, to obtain high-performance Mg-Li alloys, alloying is always used to improve performance of alloys. Commonly used alloying elements are Al, Zn, Zr, RE, etc. Many researchers have studied Mg-Al, Mg-Zn, Mg-Ca alloys[4–7]. Research results show that, RE in these alloys has many favorable effects, such as melt purification, improving microstructure, grain refinement, and dispersion strengthen. And the strength and high-temperature stability of magnesium alloys are accordingly improved. However, the reports about the effects of RE on Mg-Li alloys are very deficient.

In this paper, Mg-14Li-1Al-(0–1.2)Ce alloys were prepared and characterized. The effects of Ce on the microstructure and mechanical properties of LA141 alloys were studied to obtain high-performance high lithium content Mg-Li alloys.

2 Experimental

The materials used in these experiments were pure magnesium(99.95%), pure aluminum(99.90%), pure lithium(99.90%) and magnesium-cerium master alloy

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(containing Ce 27.5%). The materials were molten in graphite crucible with vacuum induction melting method. Before the heating process, the vacuum furnace was pumped to vacuum and then was charged with pure argon to 0.01 Pa. In the argon ambient, the materials were heated to 690–720 °C and then the melt was poured into permanent mold.

Chemical composition of alloys was measured with inductively-coupled plasma spectrometer. The measure results are listed in Table 1.

The optical microstructure samples were itched with 2%(volume fraction) nital and then were observed and

the grain size was measured with Leica software. The as-cast microstructure, fracture microstructure and micro-zone chemical analysis were also measured with SEM and EDS. Phase analysis was carried out on XRD. Microhardness of samples was measured and the average hardness from five points of every sample was determined. The room-strength was measured with tensile tester. Tensile sample size is $d6 \text{ mm} \times 50 \text{ mm}$. Tensile speed is 1 mm/min.

3 Results and discussion

3.1 Microstructure and phase analysis

Microstructures of alloys are shown in Fig.1. In Fig.1(a), the microstructure of as-cast LA141 alloy is large size equiaxed grains whose average grain size is 209.8 μm . And some bulky $\text{Mg}_{17}\text{Al}_{12}$ compounds exist at the grain boundaries. This result agrees to the previous literature[8]. 0.30% Ce addition makes the grain size and the $\text{Mg}_{17}\text{Al}_{12}$ compounds existing at the grain boundaries be refined. When the Ce addition is 0.90%, the grain size is the finest, being reduced by 68%. If Ce addition is

Table 1 Chemical composition of the alloys (mass fraction, %)

Nominal composition	Actual composition
LA141	Mg-13.91Li-1.05Al
LA141-0.3Ce	Mg-13.82Li-0.95Al-0.28Ce
LA141-0.6Ce	Mg-13.92Li-0.98Al-0.53Ce
LA141-0.9Ce	Mg-13.90Li-0.94Al-0.88Ce
LA141-1.2Ce	Mg-15.10Li-0.93Al-1.10Ce

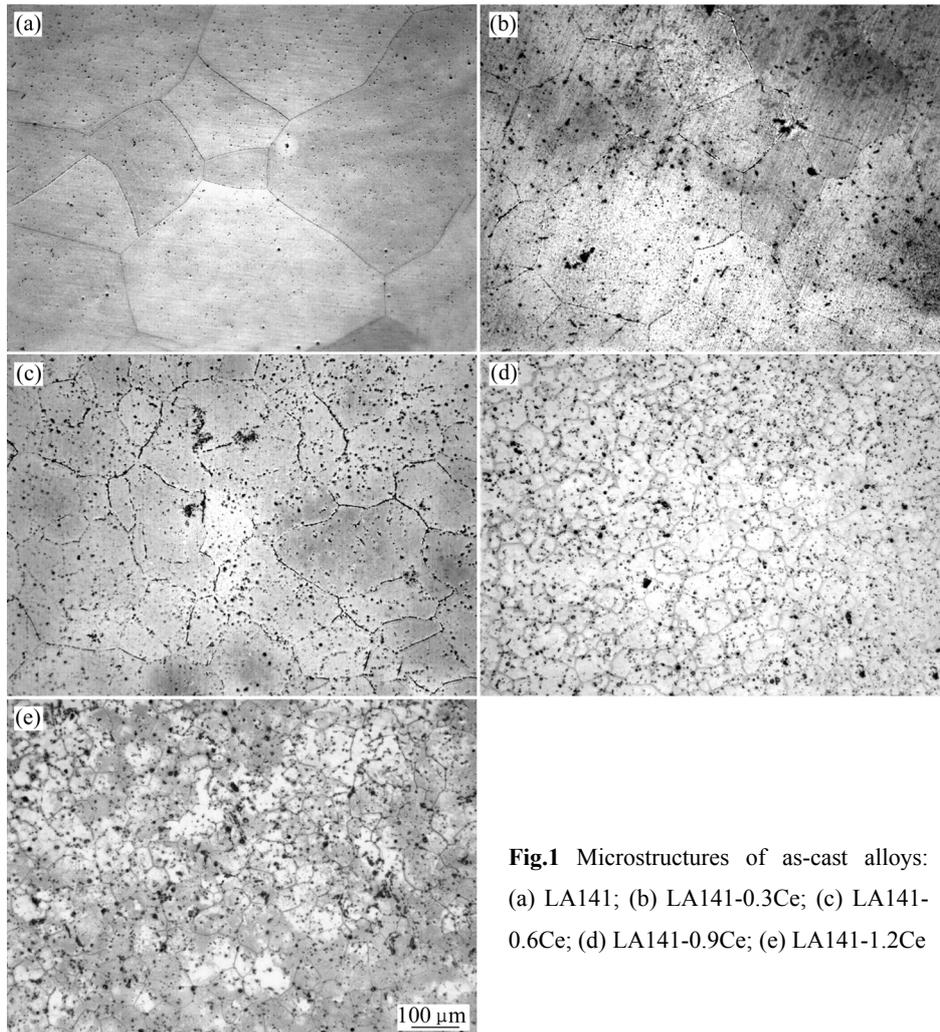


Fig.1 Microstructures of as-cast alloys: (a) LA141; (b) LA141-0.3Ce; (c) LA141-0.6Ce; (d) LA141-0.9Ce; (e) LA141-1.2Ce

increased further, grain size will increase again. The relationship between Ce addition and the grain size is shown in Fig.2. It is known that Ce has obvious refining effect on LA141 alloy.

Figs.3 and 4 are respectively XRD patterns and SEM images of as-cast alloys. The XRD patterns show that LA141 alloy is composed of β , $Mg_{17}Al_{12}$, $AlLi$ and $MgLiAl_2$ phases. While in LA141-1.2Ce alloy, the $AlLi$ and $MgLiAl_2$ phases disappear. This illustrates that Ce has the effect of restraining the formation of these two phases. From Fig. 4, it is known that some rod-shape compounds (as shown "A" in Fig.4(a)) exist near the grain boundary and some blocky compounds (as shown "B" in Fig.4(a)) exist at the grain boundary when Ce addition is 0.60%. With the Ce addition increases, the size of rod-shape compounds becomes larger and the amount of blocky compounds becomes less (as shown in Fig.4(b)). According to electronegativity difference between elements, the trend to form compounds can be valued. The electronegativity difference between Ce and Al is larger than that between Ce and Mg[9]. Accordingly, Al is easier than Mg to react with Ce to form compounds. Table 2 is the EDS results for the rod-shape compound and blocky compound. It can be deduced that the rod-shape compound is Al_2Ce and the blocky compound is $Mg_{17}Al_{12}$.

The solid solubility of Ce in Mg is only 0.09%[10]. Accordingly, most of Ce exists in alloy in the form of compounds. The melting point of Al_2Ce is relatively high. During the solidification process, Al_2Ce solids primarily and is rich at the frontier of solidifying interface. This leads to the constitutional supercooling and makes the rate of grain nucleation increase. Therefore, the addition of Ce has refining effect on alloy. When the Ce addition is too high, the size of Al_2Ce becomes larger and the amount of Al_2Ce does not increase. This makes the refining effect becomes poor.

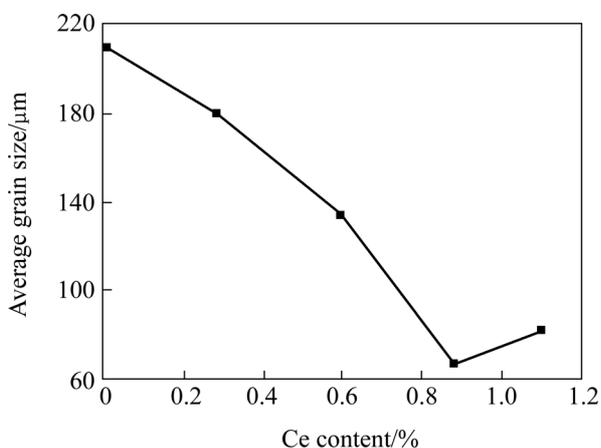


Fig.2 Effect of Ce content on grain size

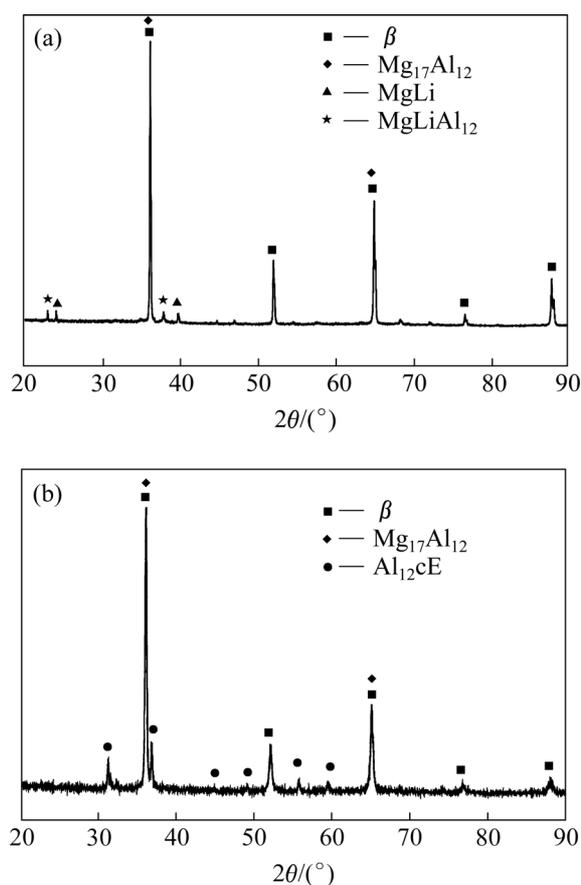


Fig.3 XRD results of investigated as-cast alloys: (a) LA141; (b) LA141+1.2Ce

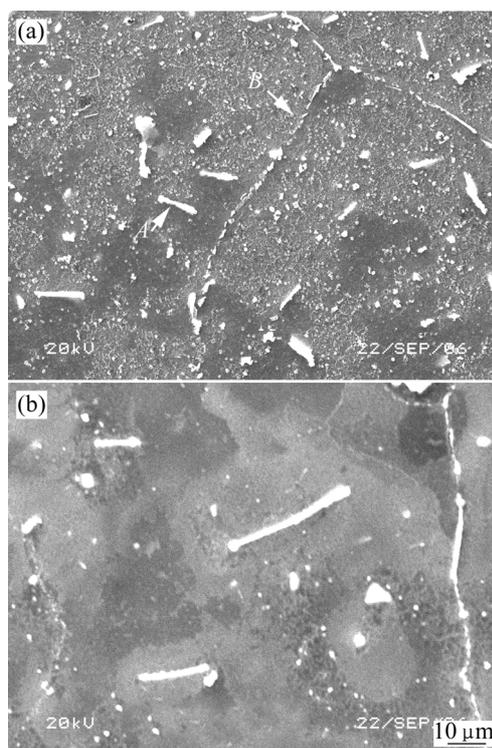


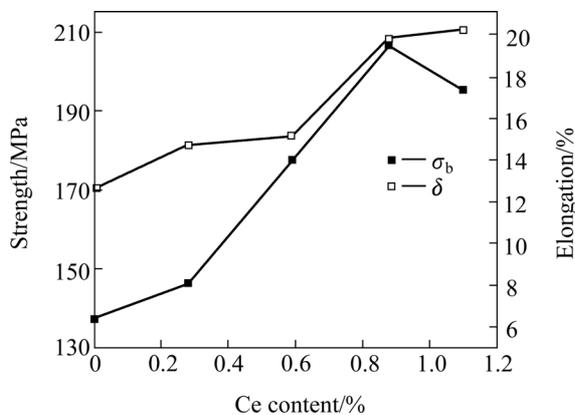
Fig.4 SEM images of as-cast alloys: (a) LA141+0.6Ce; (b) LA141+1.2Ce

Table 2 EDS analysis results of alloy (molar fraction, %)

Dots	Mg	Al	Ce	C	O
A	49.52	15.60	7.21	9.21	18.46
B	50.23	36.71	0	5.37	7.69

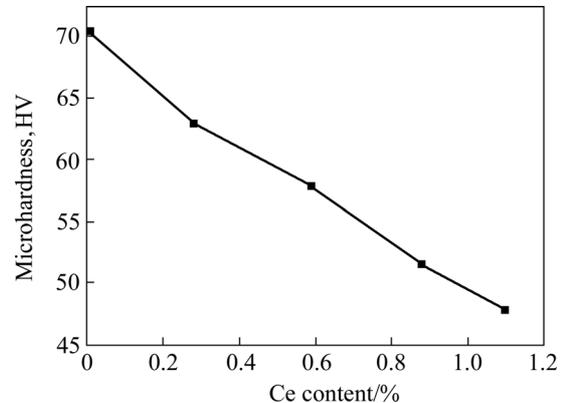
3.2 Mechanical properties

Fig.5 shows the influence of Ce content on the mechanical properties of alloys. With the Ce content increases, the tensile strength and elongation percentage both increase accordingly. When Ce addition is 0.88%, the tensile strength reaches 206.8 MPa, increases by 50% compared with that of LA141 alloy. The strength improvement can be attributed to two aspects. One is the refining effect. According to Hall-Patch theory, the refinement of grains will lead to the strength increasing(refining strengthening). And Ce has the refining effect on $Mg_{17}Al_{12}$ phase existing at grain boundary. This leads to the dispersion strengthening. The other aspect is that the Al_2Ce existing near the grain boundary restrains the grain boundary slip and the spread of cracks. On the other hand, during the tensile testing, the refined grains are easier to slip and rotate. And the refinement of hard brittle $Mg_{17}Al_{12}$ makes the possibility of forming cracks. Therefore, the Ce addition improves the elongation percentage of alloy also.

**Fig.5** Relationship between mechanical properties of alloys and Ce content

The effect of Ce addition on the hardness of alloys is shown in Fig. 6. The hardness of alloys decreases with the increase of Ce content. This result is contrary to Ref.[11]. In LA141 alloy, Al exists in two forms. Some of Al is dissolved in α and β phases. And the other part of Al exists in the compounds of $Mg_{17}Al_{12}$, $MgLiAl_2$ and $AlLi$. The Al dissolved in α and β phases can improve the strength and hardness of alloy. The $Mg_{17}Al_{12}$ and $MgLiAl_2$ are both hard phases. They are also the favorable factors for hardness of alloy. With the addition of Ce, Al_2Ce forms in alloys and leads to the decrease of Al content dissolved in α and β phases. This is the direct

cause of the decrease of hardness. On the other hand, with the formation of Al_2Ce , the amount of $Mg_{17}Al_{12}$ and $MgLiAl_2$ decreases and causes the hardness of alloy to decrease.

**Fig.6** Relationship between microhardness of alloys and Ce content

4 Conclusions

1) With the addition of Ce in LA141 alloy, the grain size of alloy is refined. When the Ce addition is 0.88%, the grain size of alloy is the finest, decreasing by 68%. The formation of Al_2Ce restrains the formation of $AlLi$ and $MgLiAl_2$ phases. And the $Mg_{17}Al_{12}$ phase is also refined.

2) Due to the refining effect of Ce, the tensile strength and elongation percentage of alloys are improved. When the Ce addition is 0.88%, the strength is the highest. The hardness of alloy decreases with the Ce content. The formation of Al_2Ce leads to the decrease of Al content dissolved in α and β phases. This is the cause of the decrease of hardness.

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