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Microstructure and mechanical properties of Mg–8Li–(0–3)Ce alloys

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Abstract Mg–8Li–(0–3)Ce alloys were prepared with a vacuum melting method. The microstructure and mechanical properties of these alloys were studied. It is found that addition of Ce obviously refines the grain size of the alloy and leads to the formation of intermetallic compound ($Mg_{12}Ce$). Extrusion and rolling processes lead to the improvement of mechanical properties. The alloys after extrusion have better mechanical properties than those after rolling.

Introduction

With the lightest density in structural metallic materials and good formability compared with other magnesium based alloys, Mg–Li based alloys attracts more and more research interests [1–3]. It has been reported that, with the eutectic composition, Mg–Li alloy possesses better comprehensive mechanical properties (a good combination strength and elongation, and good superplasticity) [4, 5]. Therefore, the Mg–Li alloys with eutectic composition have huge potential for application. However, the mechanical properties of binary Mg–Li alloys with eutectic composition are still relatively low for application. For instance, the strength of Mg–8Li alloy is about 100 MPa and the elongation percentage of it is about 30% [6]. To make this kind of alloys become more suitable for application, the strength should be improved [7, 8]. Previous reports show that, as an alloying element, Ce has favorable effects on Mg–Al based alloys [9, 10].

In this paper, the Mg–8.5Li eutectic alloy served as the object of research. To improve the mechanical properties of this alloy, Cerium was added into the alloy as an alloying element and the as-cast alloys were extruded and rolled. The influence of the addition of Ce on the alloy and the effects of deformation processes are studied.

Experimental procedure

The materials used in the experiment were commercial pure magnesium, commercial pure lithium, and Mg–Ce master alloy. The materials were loaded in a graphite crucible which is mounted in a vacuum induction furnace. The pressure of furnace chamber was kept at 1×10^{-2} Pa, then argon gas was inputed as protective gas before melting. After the materials were melted, the melt was poured into a permanent mold. The designed composition of alloys was Mg–8.5Li–(0–3)Ce. Then the as-cast samples were extruded or rolled. At the intervals of the different deformation passes, the samples were annealed at 250 °C for 1 h.

The alloys for microstructure observation were etched by 1 vol.% natal and then were observed with optical microscope (OM) and scanning electron microscope (SEM, JEOL JSM-6480A). The phase analysis was carried with X-ray diffraction (XRD, Rigaku TTR-lll). The microzone elemental content was measured with energy dispersive X-ray spectrometer (EDS). The mechanical properties of alloys were tested with tensile tester under the tensile speed of 2.0 mm/min.

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Results and discussion

Microstructure and phase analysis of as-cast samples

Figure 1 shows the microstructure of as-cast samples. The alloys are mainly composed of α phase (white blocks) and β phase (gray part). With the increase of Ce content, the α phase content decreases and some black particles can be found in β phase. The black particles are $Mg_{12}Ce$ (as shown in Fig. 2). It can be also observed that, Ce has obvious refining effects on microstructure and when Ce content is 2%, the refining effect is the most obvious.

Figure 3 shows the results of SEM image and the microzone elemental content. Because the Li element cannot be measured with EDS, from the relative difference of Mg content (Fig. 3c, d), it can be concluded that "B" point stands for α phase and "C" point stands for β phase.

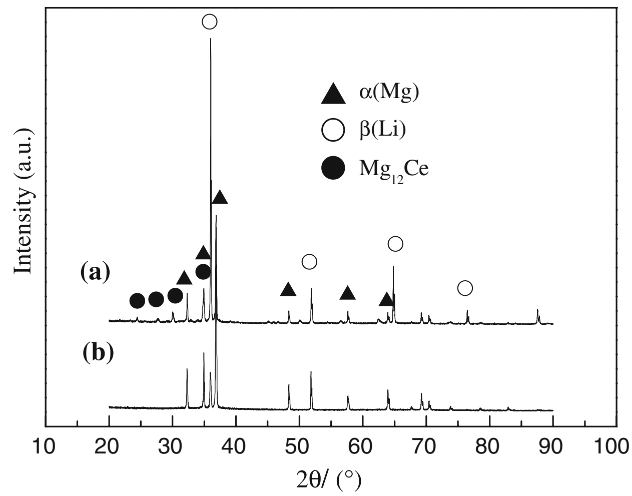

Fig. 2 XRD results of alloys. (a) Mg–8.5Li–3Ce, (b) Mg–8.5Li

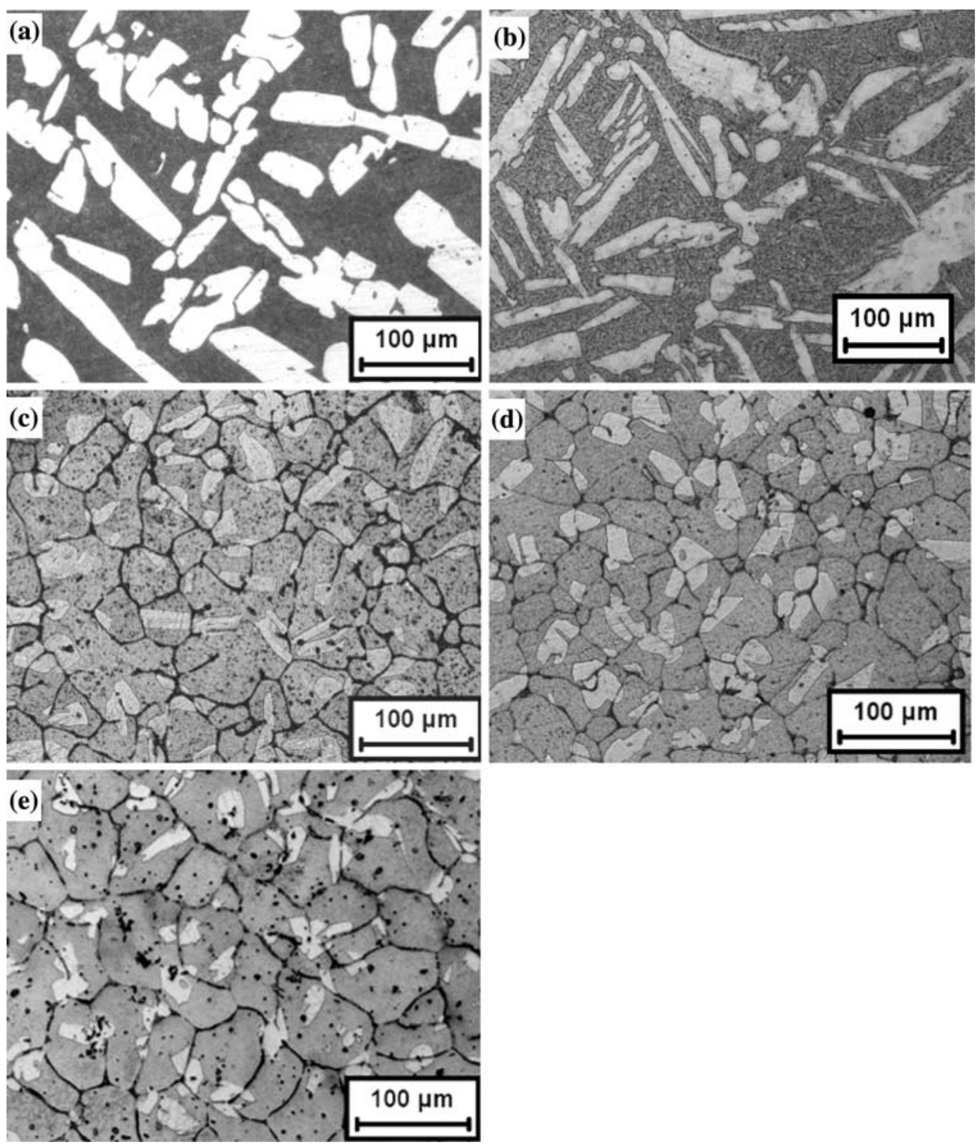

Fig. 1 Microstructure of as-cast alloys. **a** Mg–8.5Li, **b** Mg–8.5Li–0.5Ce, **c** Mg–8.5Li–1Ce, **d** Mg–8.5Li–2Ce, **e** Mg–8.5Li–3Ce

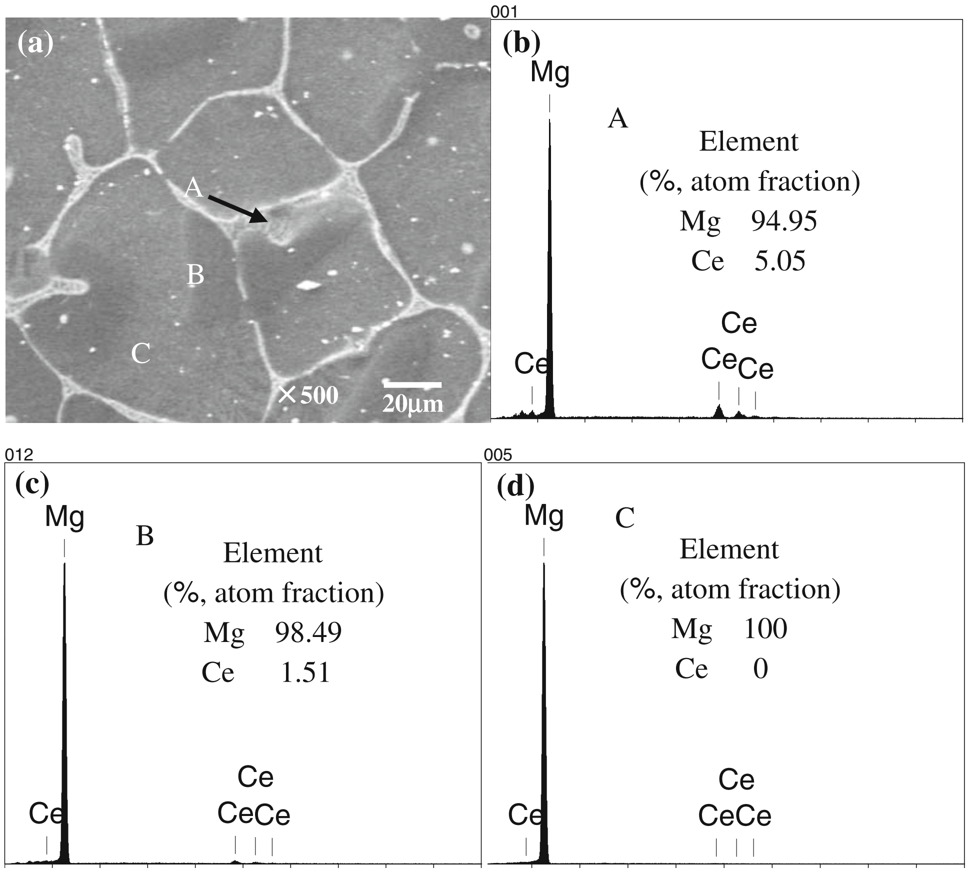

Fig. 3 SEM image and the corresponding microzone elemental content analysis. **a** SEM image, **b** EDS result of "A" point in SEM image, **c** EDS result of "B" point in SEM image, **d** EDS result of "C" point in SEM image

About 1.51 at.% Ce is solid-soluted in α phase and the solid–solution content of Ce in β phase is zero.

The Ce content is largest at "A" point (Fig. 3b). Therefore, combining the result of OM and XRD, it can be concluded that $Mg_{12}Ce$ mainly distributes in β phase and at grain boundary.

The electronegative values of Mg, Li, Ce are, respectively, 1.31, 0.98, 1.12 [11]. The electronegative difference between Mg and Ce is 0.19, which is larger than that between Li and Ce (0.14). Therefore, Mg is more likely to react with Ce than Li. The Mg–Ce compound ($Mg_{12}Ce$) forms in Mg–Li-Ce alloy accordingly.

Perhaps because the activity of Mg in β phase is higher than that in α phase, the Mg in β phase is easier to react with other elements to form compounds than that in α phase. This is possibly the reason that $Mg_{12}Ce$ mainly exists in β phase and at grain boundary.

Mechanical properties of as-cast and as-deformed alloys

Figure 4 shows the mechanical properties of as-cast and as-deformed Mg–8.5Li–(0–3)Ce alloys. In the as-cast, as-rolled, as-extruded samples, the mechanical properties of deformed alloys are better than those of as-cast. And the mechanical properties of as-extruded alloys are better than those of as-rolled.

It is known that, during the deformation process, the defects, such as gas-pore and inclusion, are reduced and the grain size is also refined. The dislocation density of alloys also increased during deformation. Therefore, the mechanical properties of deformed alloys are better than those of as-cast alloys.

During the extrusion process, the three dimensional pressure stresses are applied to alloys. While during rolling process, only two dimensional pressure stresses are applied to alloys. Accordingly, the mechanical properties of alloys after extrusion are better than those of alloys after rolling.

From Fig. 4, it is also known that, when the Ce content is 2%, the ultimate strength of alloy reaches peak value. While as for elongation percentage of alloys, the alloy containing 1% Ce possesses the largest value.

The effects of Ce on the mechanical properties of Mg–Li alloys include two aspects. One is the refining effect. The other is the formation of $Mg_{12}Ce$ compound in alloys. The two aspects are both favorable for strength of alloys. When the Ce content is 2%, the refining effect is most obvious (as shown in Fig. 1). Although further increasing Ce content in alloys can increase the amount of $Mg_{12}Ce$ compound, the strength of alloys will still decrease because

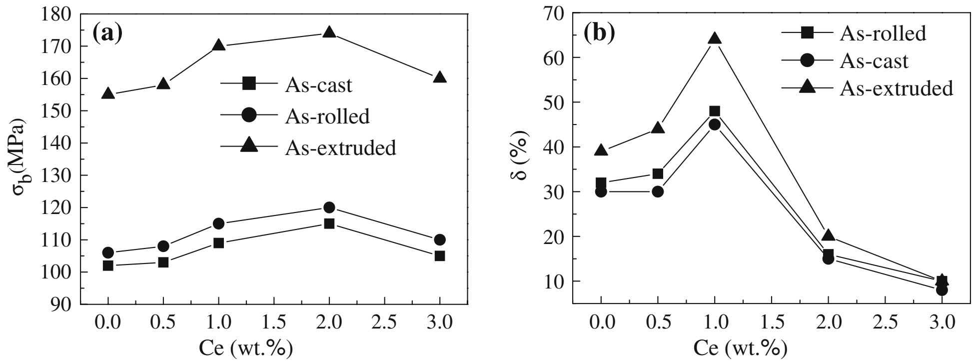

Fig. 4 Mechanical properties of Mg–8.5Li–*x*Ce alloys. **a** Ultimate strength, **b** elongation percentage

of the grain coarsing. As for elongation percentage of alloys, refinement is a favorable factor, while the formation of $Mg_{12}Ce$ compound is an unfavorable factor because $Mg_{12}Ce$ is a hard phase in Mg–Li alloys. Under the combination effects of the two factors, Mg–8.5Li–1Ce alloy possesses the largest elongation percentage. Although the microstructure can be refined further between 1 and 2% Ce content, the elongation of alloys cannot be improved further because of the increase of the amount of $Mg_{12}Ce$ in alloys. What is more is the elongation percentage of alloys decreases when the Ce content is larger than 1%.

Conclusions

The addition of Ce in Mg–8.5Li alloy leads to the decrease of α phase content and the formation of $Mg_{12}Ce$ compound in the microstructure of alloys. Ce also has refining effect on the microstructure of alloys and the refining effect is the most obvious when Ce content is 2%. Besides solid-soluted in α phase, most Ce exists in alloys in the form of $Mg_{12}Ce$. The solid solution content of Ce in β phase is zero. $Mg_{12}Ce$ mainly distributes in β phase and at grain boundary.

In as-cast, as-extruded, as-rolled samples of Mg–8.5Li–(0–3)Ce alloys, the mechanical properties of as-extruded alloys are the best and those of as-cast alloys are the poorest. Ce has two aspects of effects on the mechanical properties of Mg–Li alloys (refinement and formation of $Mg_{12}Ce$). Refinement is favorable for both strength and elongation. Formation of $Mg_{12}Ce$ is favorable for strength and unfavorable for elongation. Mg–8.5Li–2Ce possesses the highest strength and Mg–8.5Li–1Ce possesses the highest elongation percentage.

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References

1. Haferkamp H, Niemeyer M, Boehem R et al (2000) Mater Sci Forum 350/351:31
2. Crawford P, Barrosa R, Mendez J et al (1996) J Mater Process Technol 56:108
3. Aghion E, Bronfin B (2000) Mater Sci Forum 350/351:19
4. Liu T, Zhang W, Wu SD et al (2003) Mater Sci Eng A 360:345
5. Dong SL, Imai T, Lim SW et al (2007) J Mater Sci 42:5296. doi: 10.1007/s10853-007-1709-4
6. Wang T, Zhang ML, Wu RZ (2008) Mater Lett 62:1846
7. Zdenvek D, Zuzanka T, Stanislav K (2004) J Alloys Compd 378:192
8. Sivakesavam O, Prasad Y (2002) Mater Sci Eng A 323:270
9. Zhang JH, Zhang DP, Tian Z et al (2008) Mater Sci Eng A 489:113
10. Xiao WL, Jia SS, Wang J et al (2008) Mater Sci Eng A 474:317
11. Liu B, Zhang ML, Wu RZ (2008) Mater Sci Eng A 487:347