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Microstructures and mechanical properties of cold rolled Mg-8Li and Mg-8Li-2Al-2RE alloys

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Abstract: The microstructures and mechanical properties of Mg-8Li and Mg-8Li-2Al-2RE alloy sheets were evaluated after cold rolling. Both alloys contain *α*-phase and *β*-phase which consists of a solid solution of Mg in BCC Li. The proportion of *β*-phase in both alloys is approximately 60%. The *α*-phase and *β*-phase are elongated approximately parallel to the rolling direction and there is no sign of recrystallization even after being annealed at 200 ℃ for 1 h. The yield strength of Mg-8Li-2Al-2RE sheets is about 165 MPa with elongation of 35% along rolling direction, while the yield strength is about 187 MPa with elongation of 21% along the direction titled 45° to rolling direction. The *α*-phase in both alloys exhibits basal texture, and the intensity of basal texture in Mg-8Li is larger than that in Mg-8Li-2Al-2RE. However, the *β*-phase shows (100) texture, and the intensity of (100) texture in Mg-8Li is twice of that in Mg-8Li-2Al-2RE. It could be attributed to the existence of RE-containing particles in Mg-8Li-2Al-2RE.

Key words: magnesium alloys; lithium; microstructure; texture; Mg-Li alloy

1 Introduction

Magnesium and specially magnesium-lithium alloys are attractive in aerospace and aircraft structures as well as structural components in ultra-light weight communication systems[1]. The influence of Li content on the microstructures and properties of magnesium alloys has been studied[2−4]. With the addition of lithium less than 5.5% (mass fraction), the Mg-Li alloys keep the HCP structure and show a moderate strength and a low ductility. The ductility is much enhanced when the BCC-structured *β* phase is formed with the addition of Li over 5.5%. The binary Mg-Li alloy, such as Mg-8% Li and Mg-9%Li (mass fraction), usually has excellent elongation and could be cold-rolled[5]. Besides, the influence of Li addition on the texture evolution during rolling process is discussed, it is found that the Li additions could random the basal texture of magnesium alloy which is associated with the activation of prismatic slip due to the decrease of *c*/*a*[6]. The weak basal texture is beneficial to improving the room temperature formability of magnesium alloys. However, the strength decreases a lot due to the existence of *β* phase, so aluminum[7−8], zinc[9−10], calcium[11] and rare earths[12−14] are usually added to strengthen Mg-Li alloys. The influence of Li addition over 6% combined with rare earths on the texture in Mg-Li containing *β* phase is seldom discussed. Moreover, the texture of *β* phase is also important to the formability of Mg alloys. Thus, in the present work, Mg-8%Li and Mg-8%Li-2%Al-2%RE alloys are prepared, aimed to study the textures and mechanical properties of cold-rolled sheets.

2 Experimental

The alloys used in this study are Mg-8%Li and Mg-8Li-2Al-2RE (mass fraction, %) alloys. The compositions of the alloys are shown in Table 1. The alloys were prepared by melting high purity Mg, Li, Al and rare earth (mixture RE) in a high frequency induction furnace equipped with vacuum capability and argon gas during the cast. Ingots with dimensions of 150 mm×200 mm×200 mm were prepared by pouring the melt into a preheated steel mold. The ingots were

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homogenized at 350 ℃ for 10 h and then quenched in water, then were machined to slabs with dimensions of 200 mm×100 mm×17 mm. The slabs were rolled to sheets with a final thickness of 3 mm at a reduction of 15%−20% per pass at room temperature. To eliminate the residual stresses of sheets induced by the rolling process and to standardize the microstructures, the sheets were annealed at 350 ℃ for 2 h.

Table 1 Compositions of investigated alloys (mass fraction, %)

Alloy	Li	Al	RE	Mg
Mg-Li	8.81	0	0	Bal.
Mg-Li-Al-RE	8.21	2.02	2.04	Bal.

For microstructure observations, samples were cut from the rolled sheets and etched in acetic picral (25 mL ethanol+2 g picric acid+5 mL acetic acid+5 mL water). The phases were identified by X-ray diffractometry using a monochromatic Cu K_α radiation. The samples were ground to their mid-planes for texture measurements. Three pole figures, {0002}, $\{10\bar{1}0\}$ and $\{10\bar{1}1\}$, were measured up to a tilt angle of 70° using the Schultz reflection method. Defocusing corrections were made using experimentally determined defocusing curves from random powder samples.

Dog-bone specimens with a 6 mm gauge width and a 25 mm gauge length were machined from the sheets in three orientations: rolling direction (RD), 45° to RD and transverse direction (TD). Tensile tests were conducted at room temperature with an initial strain rate of 10^{-3} s^{-1}on a universal testing machine.

3 Results and discussion

3.1 Microstructures

Fig.1 shows the XRD patterns of the as-rolled Mg-8Li and Mg-8Li-2Al-2RE alloys. The results indicate that Mg-8Li is primarily composed of *α*-phase and *β*-phase, and Mg-8Li-2Al-2RE consists of *α*-phase, *β*-phase and $REAl_3$ phase[10].

Fig.2 shows the optical microstructures of two alloys after cold-rolling observed on a plane parallel to the rolling direction. The *α*-phase and *β*-phase are elongated approximately parallel to the rolling direction and exhibit a deformed structure as a result of the severe working, as shown in Figs.2(b) and (d). The proportion

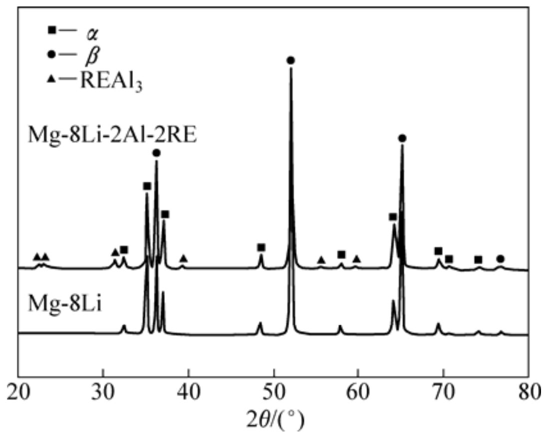

Fig.1 XRD patterns of cold-rolled Mg-8Li and Mg-8Li-2Al-2RE alloys

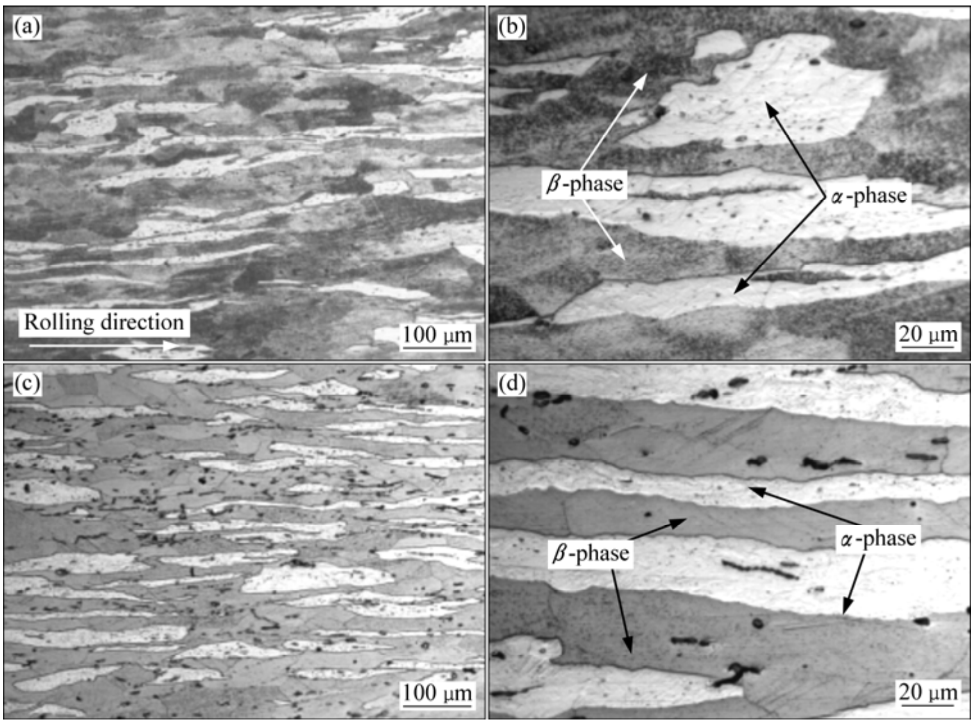

Fig.2 Optical microstructures of cold rolled plates: (a, b) Mg-8Li; (c, d) Mg-8Li-2Al-2RE

of β-phase in both alloys is approximately 65%. The α-phase exhibits discontinuous distribution because of low volume fraction. No obvious dynamic recrystallization occurs during the rolling process because the deformation is taken at room temperature. The rolling process and annealing can only refine the grains of phases but cannot change the dispersion of the phases significantly. In the Mg-8Li-2Al-2RE many precipitates distribute both in the α-phase and β-phase.

Fig.3 shows the SEM microstructures of the two alloys (the vertical is rolling direction). In the Mg-8Li alloy some fine α-phase particles are embedded in the β-phase and the rod-like α-phase particles incline to the rolling direction. However, in the Mg-8Li-2Al-2RE alloy there are no fine α-phase particles embedded in the β-phase besides strings of precipitates containing La and Al, as shown in Fig.3(b). The precipitates also distribute in the elongated α-phase. Rare-earth element and aluminum appear to be concentrated in small and angular structures disperse both in α-phase and β-phase. Assuming that the angular phases contain no lithium, the EDX microanalysis indicates that the compositions correspond to $REAl_3$.

3.2 Textures

Fig.4 shows the texture of α-phase in the cold-rolled Mg-Li alloys. The α-phase presents a double peak basal texture with the basal pole titled $\pm 13^\circ$ and $\pm 18^\circ$ from the normal direction to the rolling direction in Mg-8Li and Mg-8Li-2Al-2RE, respectively. The maximum intensities of basal texture in Mg-8Li and Mg-8Li-2Al-2RE are as low as 3.13 and 2.41 respectively. Usually, the intensity of basal texture in cold-rolled magnesium alloys is much higher. The strong basal texture is attributed to the rotation of plane caused by basal slip and twinning in magnesium alloys without Li additions. With Li addition, prismatic slip and pyramidal slip, which would suppress basal texture formation, become active. Furthermore, slip is much active in BCC structured β-phase and it can accommodate much deformation. Therefore, the strain in α-phase is not as much as that in β-phase. The textures of

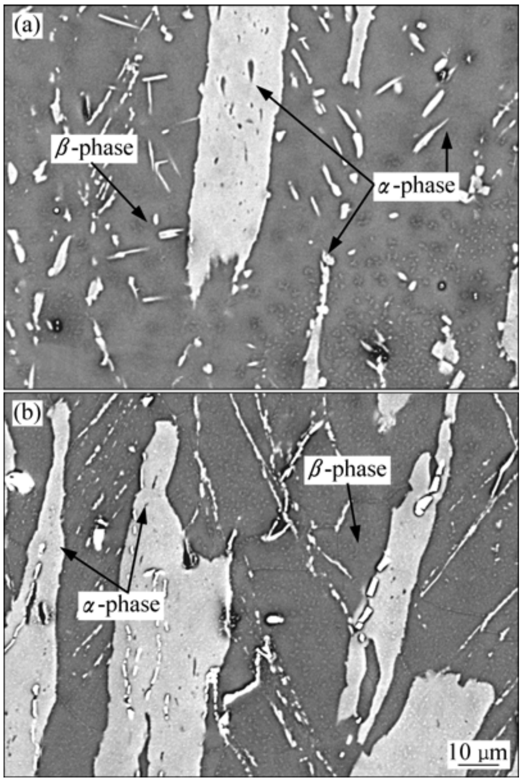

Fig.3 BSE microstructures of cold rolled Mg plates: (a) Mg-8Li; (b) Mg-8Li-2Al-2RE

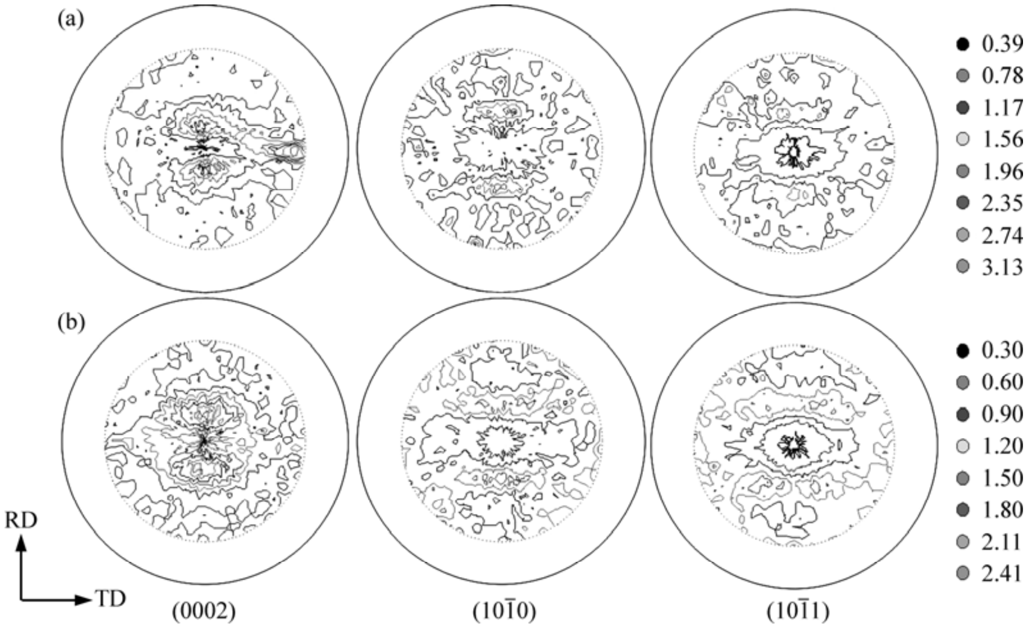

Fig.4 Texture of α-phase in cold rolled Mg plates: (a) Mg-8Li; (b) Mg-8Li-2Al-2RE

α-phase (with Li solution) in this study are similar to textures in Mg-1%Y and Mg-3%Li alloys[15], and the simulation result of textures in the Mg-3%Li alloy show the titling of basal poles toward rolling direction is attributed to the increased activity of the non-basal $\langle c+a\rangle$ slip mode[16].

Fig.5 shows the texture of β-phase in the cold-rolled Mg-Li alloys. The β-phase exhibits (100) texture and the peak intensity is 14.92 in the Mg-8Li alloy. However, the peak intensity of (100) in the Mg-8Li-2Al-2RE is half of that in the Mg-8Li alloy. It could be explained in two aspects. One is that the solution atoms and the precipitates in the β-phase affect the deformation modes and accommodate the deformation. Another is that the α-phase in Mg-8Li-2Al-2RE accommodates much strain due to the addition of Al and RE compared with that in the Mg-8Li. Therefore, the peak intensity decreases a lot due to the released stress and strain.

3.3 Tensile properties

Fig.6 demonstrates the stress—strain curves of the Mg8-Li and Mg-8Li-2Al-2RE alloys obtained from the uniaxial tension tests with an initial strain rate of 10^{-3} s^{-1} at 0˚, 45˚ and 90˚ to the rolling direction. The values of the tensile properties for each direction are given in Tables 2 and 3. It can be seen that the yield strength of Mg-8Li-2Al-2RE is about 2.5 times that of Mg-8Li. The elongation of Mg-8Li-2Al-2RE decreases a little compared with that of Mg-8Li alloy. The strength varies little along different directions in both alloys. The elongation along RD is the highest and it is interesting to note that the elongation in the 45˚ direction is smaller than that in the other directions. It is opposite to result of Mg-6Li-1Zn alloy[17]. The elongation in 45˚ direction is usually between that in the RD and TD in magnesium alloys containing no Li. The strength improvement is evident by the addition of Al and RE. The main strengthening effect of Mg-Li alloys is solid solution hardening.

Table 2 Tensile properties of cold-rolled Mg-8Li sheet at room temperature

Orientation	Tensile strength/MPa	Yield strength/MPa	Elongation/%
RD	127	74	39
45˚	137	80	29
TD	125	76	36

Table 3 Tensile properties of cold-rolled Mg-8Li-2Al-2RE sheet at room temperature

Orientation	Tensile strength/MPa	Yield strength/MPa	Elongation/%
RD	202	170	37
45˚	212	175	21
TD	208	172	32

4 Conclusions

1) The Mg-8Li-2Al-2RE alloy could be rolled at room temperature even with 2% Al and 2% RE additions and the plates show improved strength, which is attributed

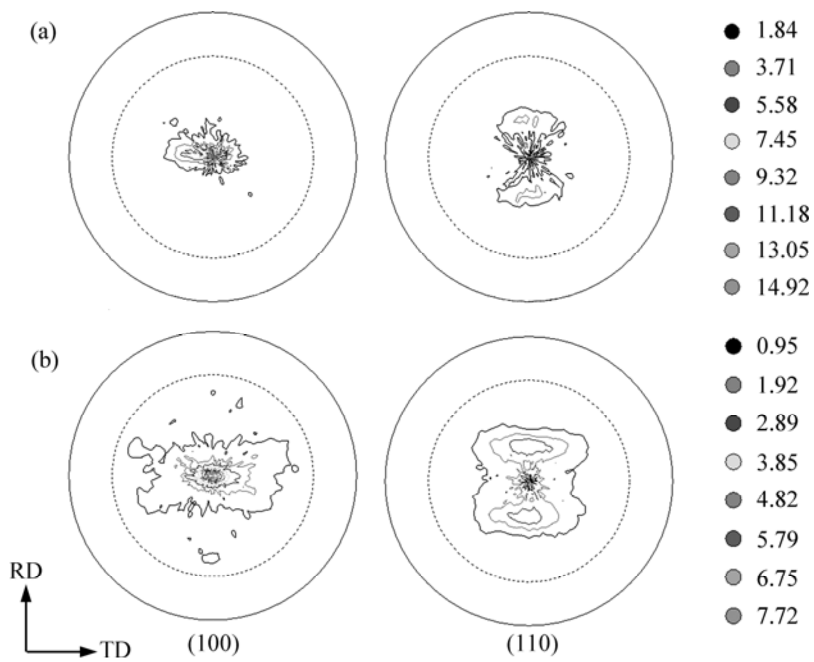

Fig.5 Texture of β-phase in cold rolled Mg plates: (a) Mg-8Li; (b) Mg-8Li-2Al-2RE

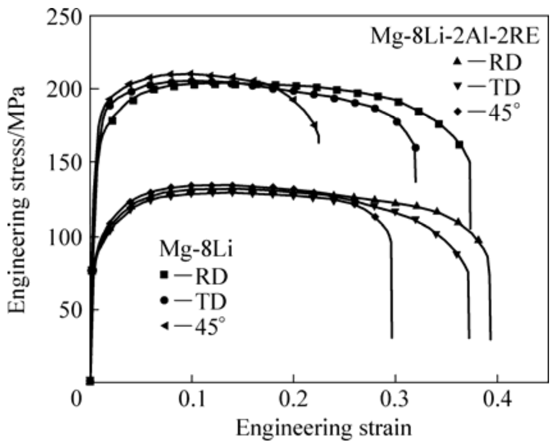

Fig.6 Engineering strain—stress curves of rolled Mg-Li alloys

to the solution strengthening of the *α*-phase and *β*-phase. Al and RE additions produce plenty of precipitates of $REAl_3$ both in *α*-phase and *β*-phase.

2) The peak intensities of texture are decreased due to the precipitates and the solution atoms in Mg-8Li-2Al-2RE alloys, especially in the *β*-phase. The strength of cold-rolled Mg-8Li-2Al-2RE alloy is almost twice that of Mg-8Li, while the elongation is comparable to that of Mg-8Li.

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