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Evolution of microstructure and mechanical properties of a duplex Mg–Li alloy under extrusion with an increasing ratio

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ABSTRACT

Mg–5Li–2Zn dual phase alloy was prepared and extruded with ratios of 10, 25 and 79. Microstructures were acquired, and Vickers hardness was examined as well as tensile and compressive properties. The results showed that the alloy possessed a low fraction of β-Li phase besides α-Mg phase. The increase of the extrusion ratio decreased the widths of both phases and also the grain size of α-Mg phase, while increased the homogeneity of the extruded alloys. The strengths were almost the same after the alloy was extruded with ratios of 10 and 25, and the alloy extruded with the ratio of 79 presented a higher strength and a lower ductility. Serrated flow appeared during the tension of the alloy extruded with the ratio of 10. In both tensile and compressive strain–stress curves, yield plateaus were more and more invisible with the increase of the extrusion ratio. It seemed that the deforming behavior of the duplex Mg–5Li–2Zn alloy is still of the pattern of hexagonal Mg alloy with little effect of β-Li phase because of its low fraction.

1. Introduction

Mg alloys are prevailing in both researching and engineering areas these days. Besides the usages in automobile areas, they are newly used as components, such as framework (covers and roll cages) of laptops, cell phones and digital cameras. Great efforts are still focused on the researches of improving their poor plasticity and limited formability, especially at room temperature [1], arising from their hexagonal close packed (hcp) crystalline lattice [2], since only two slip systems in Mg alloys possess a low critical resolved shear stress (CRSS) and are easy to be activated at room temperature [1,3]. On the other hand, among the slip systems in Mg alloys, the pyramid $\langle c+a \rangle$ slip system, which is the just one to fulfill the requirement of plastic deformation along c-axis, possesses a fairly high CRSS and is ready to glide only when being endowed higher energy via driving forces or elevated temperatures [4–6]. During deforming procedures at room temperature, twins often occur in Mg alloys because of the shortage of usable slip systems [2,7].

Many methods are used to improve the ductility of Mg alloys. The mostly used one is refining the grains to enable Mg alloys to contain more slips [8]. Another is alloying with certain elements, such as Li, to decrease the c/a axis ratio of Mg alloys, which decreases CRSSs of slip systems and make more slip systems ready to be activated at room temperature [8–11]. There exists one more method to achieve Mg alloys with high plasticity, namely introducing a new plastic phase to Mg alloys. It is reported that Mg alloys with a Li content of 5.3–10.7 wt.% possess a ductile β-Li phase [12], which is a lithium based phase with a body centered cubic (bcc) structure. The β-Li phase enables Mg–Li dual phase alloys to be much ductile even superplastic [13–15]. Mg–Li alloys are of the only Mg alloy system lighter than Mg itself, for Li is the lightest metal, and they offer potentials to develop alloys with specific properties higher than Mg. Therefore, the interests of these alloys last to present even in the latest publications [16–20].

Generally, the β-Li phase is soft and it decreases the strength of Mg alloys. Furthermore, the work-hardening of β-Li phase are pretty low [21], while hcp structured Mg alloys present a Hall–Petch coefficient as high as 280–320 MPa $\text{cm}^{0.5}$. Therefore, β-Li phase in Mg alloys is not beneficial to the strength improvement based on work hardening. Until recently, a large amount of researches have focused on mechanical properties of duplex Mg–Li alloys with Li contents among 7–9 wt.% [13,14,21–30]. As the cost of Mg–Li alloys is concerned, it is better to lower the Li content in Mg–Li alloys. To develop Mg–Li dual-phase alloys achieving a good combining the strength of α-Mg phase with the ductility of β-Li phase is a challenge in both academic and engineering areas. This work is based on a duplex Mg–Li alloy with a small fraction of β-Li phase.

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Table 1
Composition of the examined alloy.

Element	Li	Zn	Si	Fe	Cu	Ni	Mg
Content (wt.%)	5.46	1.85	0.011	0.0042	0.0011	<0.0005	Balance

2. Experimental procedures

The raw materials of commercial pure Mg (99.8 wt.%), analytically pure Li (99.9 wt.%) and analytically pure Zn (99.9 wt.%) were used to prepare the alloy. Mg was put into a low carbon steel crucible and heated to 1023 K, under the protection of a mixed gas of CO_2 (99.7 vol.%) and SF_6 (0.3 vol.%). After Zn was added into the melt, the melt was isothermally held for 30 min, and Li was subsequently added by an inverted low carbon steel cup. Then, the melt was isothermally held for another 30 min and cast into a steel mold. After cooled down in air, an ingot of 82 mm in diameter was acquired. The ingot was cut to three sections and each section was machined to 80 mm in diameter. After heated to 573 K and kept for one hour, these sections were extruded at 573 K. The extruded rods were 9 mm, 16 mm and 25 mm in diameter with extrusion ratios of 79, 25 and 10, respectively, and the extruded alloys were accordingly named as EX79, EX25 and EX10 alloys. Dumbbell tensile samples with the gauge size of a diameter of 6 mm and a length of 35 mm, based on ISO 6892-1:2009 [31], and cylindrical compressive samples with a diameter of 8 mm in and a height of 30 mm, according to ASTM: E9, were acquired from these three kinds of extruded rods.

The composition of the studied alloy was determined by inductively coupled plasma-atomic emission spectrometer (ICP-AES) and the results were shown in Table 1. The studied alloy is accordingly designated as Mg–5Li–2Zn (LZ52) alloy. The microstructures were examined by optical microscopy after etched by picronitric solution (5 g picronitric acid, 5 ml acetic acid and 45 ml ethanol) and 2 vol.% nitric acid–ethanol solution. Vickers hardness (HV) was tested with the load of 0.98 N and the dwell time of 15 s, and each HV value was the average value from at least six values. Mechanical tests were performed at room temperature with an initial ratio of $1.67 \times 10^{-3}\ s^{-1}$, and the yield strength was determined by using the 0.002 strain offset method.

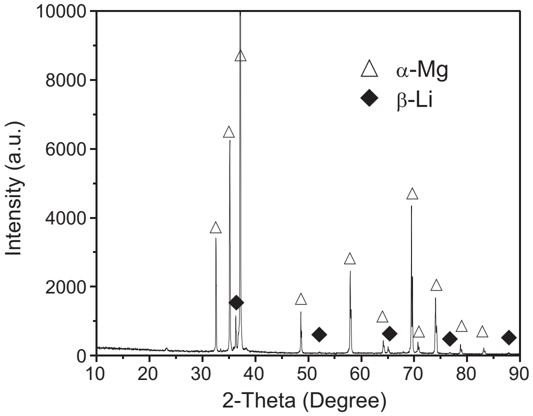

Fig. 2. XRD pattern of the as-cast Mg–5Li–2Zn alloy.

3. Results

3.1. Microstructure

Fig. 1 illustrates optical microstructures of LZ52 alloys extruded with extrusion ratios of 10, 25 and 79. There are two phases, i.e. gray α-Mg phase and dark β-Li phase [32,33], in all three extruded alloys, which is confirmed by the XRD pattern of the as-cast LZ52 alloy shown in Fig. 2. It is obvious in the XRD pattern that besides the hexagonal close packed (hcp) α-Mg phase in common Mg alloys, there also exists body centered cubic (bcc) β-Li phase in LZ52 alloy. This is because that the Li content of 5.46 wt.% in LZ52 alloy is higher than the highest Li capacity of hcp α-Mg phase with the value of ~5.3 wt.% [12]. The abundant Li atoms form the bcc structured β-Li phase and makes LZ52 alloy to be a duplex Mg–Li alloy.

The β-Li phase is in lower amount than the α-Mg phase and is also separated by the α-Mg phase. When increasing the extrusion

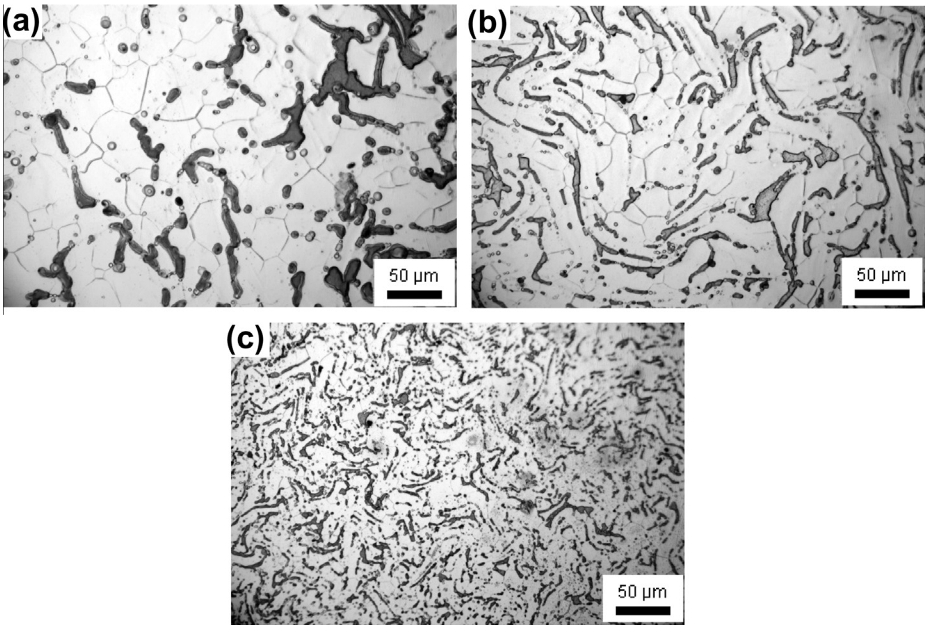

Fig. 1. Optical microstructures of the extruded Mg–5Li–2Zn alloys with extrusion ratios of 10 (a), 25 (b) and 79 (c).