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Effect of rolling strain on microstructure and tensile properties of dual-phase Mg–8Li–3Al–2Zn–0.5Y alloy

Wencai Liu^a, Shi Feng^{a,*}, Zhongquan Li^b, Jiong Zhao^a, Guohua Wu^{a,*}, Xianfei Wang^b,
Lv Xiao^b, Wenjiang Ding^a

^a National Engineering Research Center of Light Alloy Net Forming and Key State Laboratory of Metal Matrix Composite, School of Materials Science and Engineering, Shanghai Jiao Tong University, Shanghai 200240, China

^b Shanghai Spaceflight Precision Machinery Institute, Shanghai 201600, China

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ABSTRACT

This study was conducted to discuss the effect of rolling strain on microstructure and tensile properties of dual-phase Mg–8Li–3Al–2Zn–0.5Y (wt%) alloy, which was prepared by casting, and then homogenized and rolled at 200 °C. The rolling process was conducted with 10% reduction per pass and five different accumulated strains, varying from 10% to 70%. The results indicate that the as-cast and as-rolled Mg–8Li–3Al–2Zn–0.5Y alloys are composed of α -Mg, β -Li, AlLi and Al₂Y phases. After rolling process, anisotropic microstructure was observed. α -Mg phase got elongated in both rolling direction and transverse direction with the addition of rolling strain. Consequently, the strength of the alloy in both directions was notably improved whereas the elongation declined, mainly caused by strain hardening and dispersion strengthening. The tensile properties of the as-rolled alloys in the RD, no matter the YS, UTS or the elongation, are higher than those of the TD due to their larger deformation strain and significant anisotropy in the hcp α -Mg phase. In addition, the fracture and strengthening mechanism of the tested alloys were also investigated systematically.

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1. Introduction

Mg–Li alloys have attracted more and more attention for the lowest density as metallic structural materials, which is one of the most required properties in aerospace industry [1]. In addition to that, some other impressive advantages also arouse the interests of researchers all over the world, such as their high stiffness ratio, good machining property, good magnetic screen and shock resistance ability [2,3]. The traditional magnesium alloys generally show unsatisfactory plasticity, because the *c*-axis in hexagonal closed pack (hcp) structure often presents poor ductility. In the Mg–Li alloys, however, the addition of lithium assists to improve the plasticity, achieved by structural transformation from hcp to body centered cubic (bcc); besides, the machining deformation ability also gets improvement owing to more slip systems [4].

NASA developed a series of Mg–Li–Al alloys centered on LA141 for aerospace applications in the 1960s [5]. However, the mechanical properties of LA141 were unsatisfactory because of its low

strength and poor corrosion resistance, which are the usual shortcomings of Mg–Li alloys [6]. Since then, it has attracted great interest to develop high-strength Mg–Li alloys [7–10]. In order to improve the strength of Mg–Li alloys, some alloying elements are frequently used, such as Al, Zn and rare earths (RE) [11–15]. Deformation methods, such as extrusion and rolling are also used to strengthen the Mg–Li alloys [6,9,10,13,15–23].

According to the Mg–Li phase diagram, the alloy is composed of hcp Mg-rich phase and bcc Li-rich phase when the mass fraction of Li is between 5.7% and 10.3%. Mg–8Li alloys possess duplex structure (α -Mg and β -Li), leading to good plasticity and high strength accordingly.

In this study, Mg–8Li–3Al–2Zn–0.5Y (wt%) alloy was chosen as the research subject, because it has been reported that the recently developed Mg–8Li–3Al–2Zn–0.5Y alloy presents satisfactory performance [24–26]. Based on the previous researches, the as-cast Mg–8Li–3Al–2Zn–0.5Y alloy presents good tensile strength of over 200 MPa and elongation of 16%, and the as-extruded alloy presents tensile strength of 240 MPa and elongation of 40%. In order to make further attempts to improve the strength of Mg–8Li–3Al–2Zn–0.5Y alloy, rolling process was conducted with five different accumulated strains, 10%, 30%, 50%, 60% and 70%, respectively. The

* Corresponding authors.

E-mail addresses: fengshi@sjtu.edu.cn (S. Feng), ghwu@sjtu.edu.cn (G. Wu).

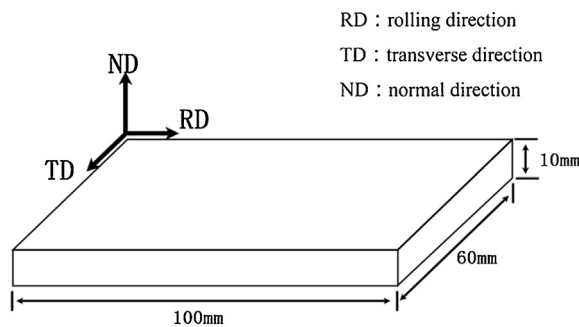


Fig. 1. Size and directions of the sheets for rolling processing.

microstructure and mechanical properties of the as-cast and as-rolled alloys were investigated systematically to evaluate the effect of different rolling strains.

2. Experimental details

Mg–8Li–3Al–2Zn–0.5Y alloy was cast with commercial pure magnesium (99.9 wt%), lithium (99.9 wt%), aluminum (99.9 wt%), zinc (99.9 wt%) and Mg–20 wt%Y master alloy. The materials were melted at 720 °C in a steel crucible under SF₆ and CO₂ gas-protection. The molten metal was covered with mixed flux of LiCl and LiF (with a weight ratio of 3:1). Li bars were inserted under the protection of argon. The liquid metal was then kept at 700 °C for about 10 min and cast into a steel mold preheated to 200 °C.

Then the ingots were cut into sheets with dimensions of 100 mm × 60 mm × 10 mm using numerical controlled line-cutting lathe. The sheets with certain size, as exhibited in Fig. 1, were then homogenized at 200 °C for 1 h. The rolling process was conducted at 200 °C with 1 mm reduction per pass and five different total thickness reduction (1 mm, 3 mm, 5 mm, 6 mm and 7 mm), i.e., the as-rolled sheets got five different rolling strains (10%, 30%, 50%, 60% and 70%). The as-cast and as-rolled sheets were subsequently machined into rectangular bars both in RD and TD for the tensile test.

The chemical composition of the studied alloy was tested by Inductively Coupled Plasma Emission Spectrometer (ICP, Perkin Elmer, Plasma-400), which is displayed in Table 1. After being

Table 1

Chemical composition (wt%) of the studied alloy Mg–8Li–3Al–2Zn–0.5Y.

Li	Al	Zn	Y	Mg
8.11	2.98	2.12	0.44	Bal.

polished and etched with 4% (volume fraction) nital, samples of as-cast and as-rolled specimens were observed with an optical microscope (OM; ZEISS) in three directions (RD, TD and ND). The detailed microstructure was examined by using a scanning electron microscope (SEM; PHENOM) equipped with an energy dispersive spectroscopy (EDS).

Phase analysis was conducted by X-ray diffraction (XRD; Rigaku) with a resource of Cu-K α radiation, at scan rate of 2°/min and step size of 0.02°. Tensile properties at room temperature of the specimens were tested at the initial strain rate of 10^{−3} s^{−1}, with a tensile tester Zwick/Roell Z020. The tensile test of the as-rolled bars was conducted both in two directions, namely the RD and the TD. The fracture surfaces were analyzed with SEM as well.

3. Results

3.1. Microstructure

3-dimensional optical micrographs of the as-cast and as-rolled Mg–8Li–3Al–2Zn–0.5Y alloys are demonstrated in Fig. 2. As can be seen from Fig. 2(a), the microstructure of the as-cast alloy does not display apparent anisotropy in three dimensions. The as-cast alloy is composed of light α -Mg phase, gray β -Li phase, as reported in some previous researches [6,10,12,15,21,24–29]. Continuous β -Li phase fills in the interspace between strip-like α -Mg phases. There also exist some tiny precipitates, most of which are located at the boundary between strip-like α -Mg and continuous β -Li phase.

With the addition of rolling strain, α -Mg phase got elongated and anisotropic microstructure in three dimensions was observed. After one rolling pass with 1 mm reduction, as displayed in Fig. 2(b), α -Mg phase became a little more equiaxial. After three rolling passes with 1 mm reduction per pass, as displayed in Fig. 2(c), α -Mg phase got elongated in RD and TD. After five or more rolling passes, as displayed in Fig. 2(d, e and f), α -Mg phase became obviously elongated while the elongation was more apparent along the RD

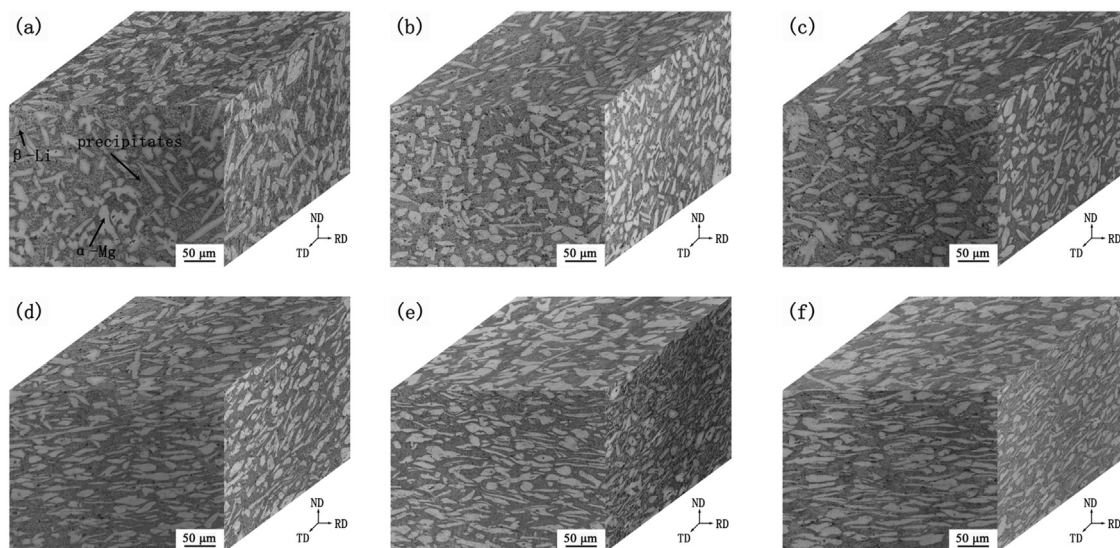


Fig. 2. 3-Dimensional optical micrographs of the as-cast and as-rolled Mg–8Li–3Al–2Zn–0.5Y alloy with different rolling strains: (a) as-cast, (b) 10%, (c) 30%, (d) 50%, (e) 60%, (f) 70%.

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