

Compound role of tension twins and compression twins in microstructure and mechanical properties of Mg-Sn-Li rod

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ABSTRACT

This work explores the compound effect of tension twins and compression twins on extruded Mg-5Sn-0.3Li, with an emphasis laid on the microstructure and mechanical properties. To induce both tension twins and compression twins, Mg-5Sn-0.3Li in the cast condition was chosen and subjected to 5% pre-compression. Both the pre-strained sample and unstrained sample were then exposed to extrusion. Our results reveal that pre-strained Mg-5Sn-0.3Li rods exhibit higher overall mechanical properties including yield strength, ultimate strength and elongation to failure in the extrusion condition. The relevant mechanisms were discussed.

1. Introduction

Mg alloys have attracted a great attention with regard to their applications in transportation as the industry seeks to reduce weight and increase fuel efficiency. Although Mg alloys have high strength-to-weight ratio, they often suffer from a low strength and ductility. The low ductility is due to the limited active slip systems at a temperature below 200 °C and the strong texture originated from the fabrication process. Then, in addition to dislocation slip, twinning constitutes an important deformation mechanism at room temperature. For Mg alloy with an *hcp* structure, both contraction twinning (e.g. $\{10\bar{1}1\}$ or $\{10\bar{1}3\}$ twinning) and extension twinning ($\{10\bar{1}2\}$ twinning) mainly exist [1,2]. Extension twinning has a low critical resolved shear stress (CRSS) and is the predominant deformation mode of strongly textured Mg alloys during certain loading conditions. Take, for example, extension twinning is highly activated under compression along the rolling direction or the transverse direction of hot rolled plates or compression along the extrusion direction (ED) of extruded rods [3–7]. On the contrary, contraction twinning is rare to see at low strains and generally grows to a large extent at high strain levels [8]. Deformation twinning could have a large effect on three types of changes in the microstructure, its role comprising boundary spacing reduces, thereby increasing stress (the Hall-Petch effect), reorientation of the twinned regions [9] and relaxing stress concentrations [9,10].

Deformation twins also have been observed to effect dynamic recrystallization (DRX) of Mg alloys, as they can act as preferential sites for DRX. For instance, Park et al. [11] reported that twin-aided DRX occurs at pre-existing twins during hot deformation of a rolled

AZ31 alloy, resulting in a fine and homogeneous microstructure in the deformed material. Similarly, it is observed that when contraction twins (including double twins) were introduced in rolled AZ31 sheet by pre-cold rolling to a thickness reduction of 10%, the stretch formability can be greatly enhanced [12]. It is found that both tension and contraction twins contribute to enhanced mechanical properties of Mg alloys. However, most investigations upon the effect of pre-strain or pre-rolling on microstructure and mechanical properties were conducted using strongly textured Mg alloys. Put this in another way, only tension twins or contraction twins were activated and exerted their effects, respectively. It is therefore lack of studies about the compound effect of tension twins and contraction twins on microstructure and mechanical properties of Mg alloys. It is well accepted that the stored energy is a critical factor to control DRX and there exists a great difference in stored energy between tension twins and contraction twins. As contraction twins have a higher stored energy and often generate inhomogeneous and localized deformation regions, they often serve as effective sites for nucleation [13–15]. However, extension twins are quite resistant to nucleation due to a lower strain accumulation within them [15,16]. The coherent structure of extension twin boundaries leads to a high thermal stability [17–19]. Levinson et al. found that about 67% of $\{10\bar{1}2\}$ twins in a pre-strained Mg alloy AZ31 still exists even after annealing at 275 °C for 16 h [20]. Yang et al. also reported that some $\{10\bar{1}2\}$ twins in a pre-rolled Mg alloy AZ31 cannot be removed even after annealing at 350 °C for 11 h [15]. Therefore, to control the recrystallization behavior of Mg alloy with both tension twins and contraction twins is an important issue. Following this idea, cast Mg-Sn-Li alloy with random texture was chosen and an effective

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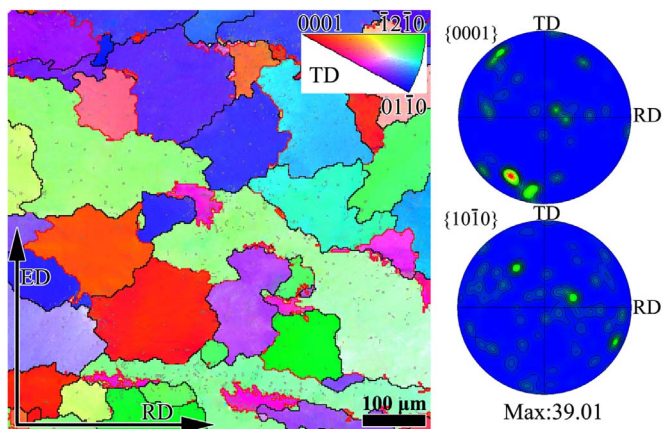


Fig. 1. Inverse pole figure map and relevant pole figures of the AR sample.

pre-compression aim at inducing both tension twins and contraction twins to modify the recrystallization behavior was utilized. We found that pre-compression of a random textured alloys could effectively tailor the microstructure and enhance the mechanical properties. The relevant mechanisms were discussed.

2. Experimental procedure

2.1. Sample preparation and mechanical tests

The analyzed composition of the studied alloy is Mg-4.86 wt% Sn-0.31 wt% Li. The actual chemical compositions were identified by XRF-800 CCDE x-ray fluorescence spectrometer (XRF) and inductively coupled plasma atomic emission spectroscopy (ICP-AES). Details of the casting procedure had been described elsewhere [21], and it was not shown here for brevity. After casting, the alloys were homogenized at 330 °C for 10 h followed by at 440 °C for 12 h. Then the as-homogenized billet was machined into two cylinders with dimensions of 80 mm in diameter and 70 mm in length. In order to generate both tension twins and contraction twins, one cylinder was pre-compressed along the axial direction by a plastic strain of about 5%. Afterwards, both the pre-compressed sample (the designated PC sample) and the one without pre-strain (the designated AR sample) were extruded at 300 °C using an extrusion ratio of 25, along with an extrusion rate of some 4 m/min. Extruded rods with a section diameter of 16 mm were

obtained. Tensile samples with dimension (12 mm gauge length×4 mm gauge width×2.5 mm gauge thickness) and compression specimens with dimension (12 mm gauge length×8 mm gauge width×8 mm gauge thickness) were prepared from the acquired samples. Both the tensile and compressive directions were parallel to the extrusion direction (ED). The mechanical tests were performed at room temperature on a Shimadzu AG-X (50 kN) machine using a strain rate of $5 \times 10^{-4} \text{ s}^{-1}$. An extensometer with a 4 mm gauge length was directly attached to the tensile samples for strain measurement. Each test was repeated three times.

2.2. Microstructure and texture analysis

For the examination of microstructure by scanning electron microscopy (SEM, TESCAN VEGAII scanning electron microscope equipped with an Oxford Instruments INCA Energy 350 energy dispersive X-ray spectrometer (EDS)), the samples were mechanical grinding with a series of SiC papers and chemically etched in an acetic picral solution (2 ml acetic acid+1 g picric acid+2 ml H_2O +16 ml ethanol). The specimens for electron backscatter diffraction (EBSD, FEI Nova 400 FEG-SEM equipped with an HKL channel 5 system and a charge-coupled device camera) mapping were prepared by mechanical polishing to 1200-grit sand paper. The specimens were electro-polished for 90 s at 20 V and 20 °C using the AC2 commercial electrolyte (Struers, Denmark).

3. Results

3.1. Effect of pre-strain on microstructure of random textured alloy

Fig. 1 shows the inverse pole figure map and relevant pole figures of the as-homogenized sample without pre-compression (AR sample). It is obvious that the AR sample is composed of coarse grains with an average grain size over 100 μm, along with a random texture. No twins could be detected. Care should be taken that the strong texture intensity is derived from the mass grains with a large grain size.

The inverse pole figure map, boundary misorientation map and corresponding misorientation angle distribution of sample with pre-compression (PC sample) are revealed in Fig. 2. Noticeably, numerous twins can be clearly seen after pre-compression (Fig. 2a), in comparison with the AR sample (Fig. 1). The twins are identified as both $\{10\bar{1}2\}$ twins and $\{10\bar{1}1\}$ twins (Fig. 2b). Their volume fractions are

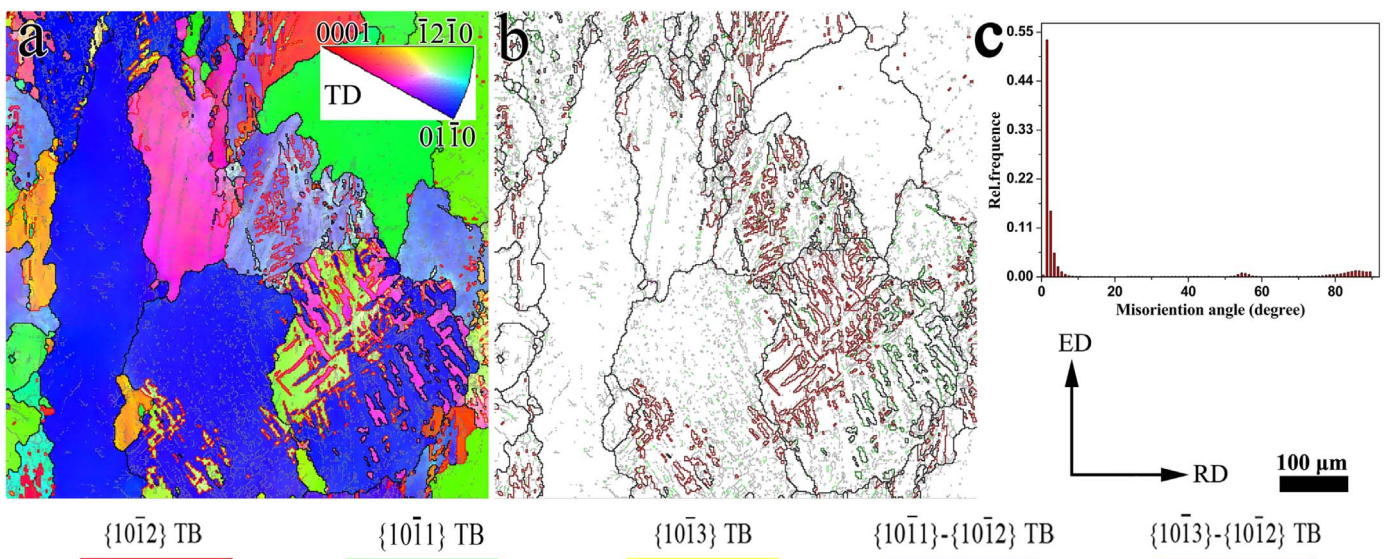


Fig. 2. (a) Inverse pole figure map, (b) corresponding boundary misorientation map and (c) misorientation angle distribution of the PC sample. Note that ED, RD and TD denote the extrusion direction, radial direction and tangential direction respectively.

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