Materials and Design 63 (2014) 177–184

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

The effect of twinning and detwinning on the mechanical property of AZ31 extruded magnesium alloy during strain-path changes

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ARTICLE INFO

Article history:
Received 7 April 2014
Accepted 27 May 2014
Available online 18 June 2014

Keywords:
Pre-compression
Pre-stretch
Strain-path changes
Twinning–detwinning

ABSTRACT

In order to investigate the effect of twinning–detwinning on the mechanical properties of AZ31 extruded magnesium alloy pre-compression and pre-stretch deformation were conducted along extrusion direction (ED) at 1%, 3%, 5% strain levels. After pre-strain, the strain-path was inverted by performing tensile or compressive tests at room temperature. Results showed that the detwinning behavior occurred during the inverse tension after the pre-compression. Although due to the aforementioned effect the tensile yield strength decreased, by increasing the pre-compressive levels both fracture elongation and peak strength improved. In the inverse compressive tests after pre-stretch the $\{10\bar{1}2\}$ twinning was restrained and the volume fraction of twins decreased, leading to the improvement of yield strength by increasing in pre-stretching levels.

1. Introduction

Magnesium and its alloys have been attracted by large number of industrial sectors due to their low density, high specific strength, high stiffness and good machinability [1,2]. However, owing to the hexagonal close packed (HCP) crystal structure, it exhibits a poor formability at room temperature. That is, there are limited numbers of available slip systems at low temperatures so as the only activated are two basal planes which cannot meet the Mises Criterion addressing which requires 5 independent slip systems [3,4]. As well known, twinning plays an important role at low temperatures for coordinating the deformation along prismatic directions [5]. Moreover, it is well accepted that the $\{10\bar{1}2\}$ extension twins could be only generated by loading along the special directions (compression perpendicular to *c*-axis or tension parallel to *c*-axis) [6,7]. Improving the properties of magnesium through exploiting twinning has been widely investigated and a pre-strain has been recognized. Song et al. [8] reported a marked enhancement in tensile and compressive properties of AZ31 plates by pre-rolling along TD whereby grains were divided by the $\{10\bar{1}2\}$ twinning lamellae. Xin et al. [9] also reported that the grains could be refined by $\{10\bar{1}2\}$ twins generated by pre-compression along the rolling direction, giving rise to improvement of yield and ultimate tensile strength along the transverse direction. Zhang et al. [10] reported that the formability was improved by pre-stretch and annealing through the weakening of basal texture. Besides, detwinning behavior through pre-strain has been also researched aimed at improving the mechanical properties of magnesium alloys. Wang et al. [11] indicated that the yield strength decreased when inverse tension after pre-compression was applied on AZ31 magnesium alloy due to the twinning–detwinning. He et al. [12] also reported that the yield asymmetry of AZ31 magnesium alloy could be effectively controlled by appropriate pre-compression.

Recently, the effect of pre-strain on properties of magnesium alloys has been explored by several researchers [8–12]. However, the inverse deformation after pre-strain, especially pre-stretch, has rarely been considered. In addition, although several researches have concerned the twinning–detwinning effects from fatigue point of view, the aforementioned phenomenon has not been individually addressed. Accordingly, the present study aims the effect of twinning and detwinning during strain-path changes on the mechanical properties of AZ31 magnesium alloy.

2. Experimental procedure

The material used in this work was a commercial AZ31 (Mg–3 wt.%Al–1 wt.%Zn) magnesium alloy in the form of extruded

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http://dx.doi.org/10.1016/j.matdes.2014.05.056
0261-3069/

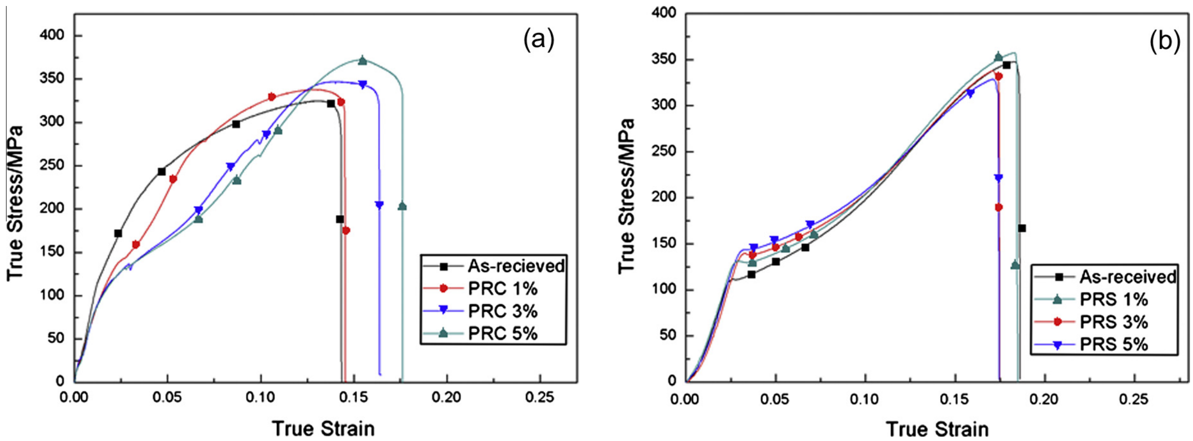

Fig. 1. Stress vs. strain curves: (a) inverse tension after pre-compression and (b) inverse compression after pre-stretch.

bars with a diameter of 16 mm. The AZ31 bars were first annealed at 673 K for 4 h. In order to achieve a microstructure with {10−12} extension twins, some of the bars were pre-compressed along extrusion direction (ED). The levels of the pre-compression were 1%, 3% and 5%, followed by an annealing at 473 K for 2 h aiming at removing excess dislocations and keeping twinning variants. Song et al. [8] reported that the twinning variants were kept in the microstructure even after annealing at 473 K. According to General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (AQSIQ) Standard GB/T 2 28-2002 [13], as-received and pre-compressed bars were cut into dumbbell-shaped tension specimens with nominal gage dimensions of 6 mm × 36 mm. The inverse tension tests were conducted on a CMT6305-300 KN electro-mechanical universal testing machine at room temperature. The strain rate was set at 10^{-3} s^{-1}. Each test was repeated three times.

Another set of bars were pre-stretched along ED at different deformation degrees of 1%, 3% and 5%. Afterwards, annealing at 473 K for 2 h was applied to remove the excess dislocations. Based on General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (AQSIQ) Standard GB/T 7314-2005[14], the pre-stretched bars with height and diameter of 15 mm and 10 mm were cut for compression tests with height and diameter of 15 mm and 10 mm, respectively. Inverse compressive tests were conducted with a strain rate of 10^{-3} s^{-1} at room temperature. Each test was repeated three times.

The microstructure of the alloy before and after the deformation was characterized by optical microscopy and electron backscatter diffraction (EBSD). The microstructure was observed by standard metallographic technique while samples for EBSD observations were prepared by mechanical grinding followed by polishing down to colloidal silica naps. Then electro-polishing was performed using a solution of 20% nitric acid and 80% methanol with a voltage of 20 V for 120 s at temperature −30 °C. Finally, EBSD measurements were performed on a Zeiss EVO 50 SEM. The EBSD data were processed by an INCA OXFORD crystal software.

3. Results and discussions

3.1. Mechanical properties of pre-stretched and pre-compressed samples

True stress–strain curves of inverse tensile tests on pre-compressed specimens and inverse compressive tests on pre-stretched specimens at room temperature are given in Fig. 1. The tensile curves of pre-compressed samples exhibit a concave shape, which

Table 1
Yield strength (YS), Peak strength (PS), fracture elongation (FE) of various samples along the ED.

		YS/MPa	PS/MPa	FE/%
Pre-compression then tension	As-received	132 ± 4	323 ± 3	12.7 ± 0.2
	PRC 1%	100 ± 2	333 ± 2	12.9 ± 0.3
	PRC 3%	97 ± 3	345 ± 4	14.6 ± 0.3
	PRC 5%	94 ± 2	370 ± 3	16.1 ± 0.2
Pre-stretch then compression	As-received	108 ± 4	349 ± 3	18.6 ± 0.4
	PRS 1%	128 ± 3	347 ± 2	18.2 ± 0.3
	PRS 3%	137 ± 3	337 ± 4	17.4 ± 0.2
	PRS 5%	148 ± 2	325 ± 3	17.2 ± 0.3

is different from the as-received one, suggesting a different deformation mechanism during inverse tension. Mechanical properties derived from the curves in Fig. 1(a and b) are also listed in Table 1, as shown, the yield strength of the as-received alloy was 132 MPa and it decreased to 100, 97 and 94 MPa for PRC 1%, PRC 3% and PRC 5% samples, respectively. The peak strength (PS) values of the PRC samples seemed to be much higher than samples without PRC. Moreover, fracture elongations of all PRC samples were also slightly higher than that of the as-received one.

Fig. 1(b) represents the mechanical response under inverse compression along ED in pre-stretched samples. As seen, the samples without pre-stretch (as received alloy) showed a clear yield plateau, typical feature of {10−12} extension twinning [15,16]. Similar yield plateaus also appeared in all the curves of the pre-stretched (PRS) samples, implying that the dominant deformation mechanism during inverse compression along ED was still twinning and no changes arose from PRS. Compared with samples without PRS, the yield stress increased significantly in PRS samples. The gain was about 20, 29 and 40 MPa in PRS 1%, PRS 3% and PRS 5%, respectively. Concurrently, the peak strength was slightly reduced after the different PRS degree.

3.2. Microstructure of pre-compressed samples

The microstructure and pole figures of as-received, PRC specimens as well as the schematic view of the orientation of grains after PRC are shown in Fig. 2. The as received sample revealed a nearly equiaxial microstructure exhibiting ⟨0001⟩ fiber texture, with a grain size of about 15.5 μm (Fig. 2a). However, as PRC proceeded, large amount of twins progressively were introduced in the samples' microstructures. According to the EBSD map, the boundaries of twinning lamella were {10−12} extension twinning boundaries. Due to the {10−12} extension twins, the grains