Materials Science & Engineering A 572 (2013) 98–102

Contents lists available at SciVerse ScienceDirect

Materials Science & Engineering A

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

Pseudoelastic behavior of magnesium alloy during twinning-dominated cyclic deformation

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ARTICLE INFO

Article history:
Received 30 November 2012
Received in revised form
18 January 2013
Accepted 12 February 2013
Available online 18 February 2013

Keywords:
Magnesium
Twinning
Detwinning
Pseudoelasticity
Neutron diffraction

ABSTRACT

In-situ neutron diffraction has been used to examine the pseudoelastic behavior of an extruded Mg–8.5 wt.% Al alloy during twinning-dominated cyclic deformation in both tension and compression. Twinning activity is effectively tracked through the intensity variations of the diffraction peaks for some grain orientations. The results suggest that a fundamental difference in the pseudoelastic behavior between tension and compression cyclic loadings might be due to reversible detwinning–retwinning observed only during cyclic compression.

1. Introduction

Magnesium alloys have recently drawn much attention due to potential applications for lightweight materials in the automotive industry. As compared to the cast alloys, wrought magnesium alloys exhibit superior mechanical properties, e.g. higher tensile strength, yield strength, and fatigue resistance [1,2]. However, the polar nature of {10.2}⟨10.1⟩ extension twinning combined with the typical extruded or rolled textures of wrought magnesium alloys leads to tension–compression yield asymmetry and plastic anisotropy, which restricts their wide application. Thus, many investigators have sought to understand twinning activity by controlling microstructure, temperature, strain rate, grain size, and applied loading direction with respect to crystallographic texture [3–10].

Nonlinear loading–unloading behavior (i.e. pseudoelasticity) under cyclic loading is well-known in magnesium alloys [11–15]. Cáceres et al. [11] observed the development of cyclic loading–unloading hysteresis loops in cast magnesium AZ91 alloy under uniaxial tension and compression; they attributed the hysteresis loops to the partial reversal of {10.2} twins upon unloading, based on *in-situ* optical microscopy of polished surfaces during bending. Mann et al. [12] studied the effects of solute content and grain size on cyclic hysteresis loops in Mg and Mg–Zn alloys. They observed that for a given total strain, the amount of anelastic strain increases with decreasing grain size, and decreases with increasing Zn content. They also reported that elastic {10.2} twins cause anelasticity resulting in the large hysteresis loops, as revealed in *in-situ* three-point bend testing combined with optical microscopy. Zhou et al. [13,14] also observed nonlinear elasticity during cyclic loading–unloading in magnesium and other hexagonal close-packed metals. They ascribed the observed hysteresis to the formation of incipient kink bands, which are fully reversible dislocation loops nucleated on the easy slip planes of plastically anisotropic solids. More recently, Muránsky et al. [15] showed that neutron diffraction enables the investigation of deformation twinning and pseudoelastic-like behavior of extruded AZ31 magnesium alloy. They attributed the observed pseudoelasticity to the reversal of {10.2} twinning during loading–unloading cycles, and suggested that the driving force for the observed detwinning is due to the existence of high tensile stresses in the twinned lattice resulting from load partitioning as a consequence of prior twinning. They also pointed out that the hysteresis effect of tensile cycling was much less pronounced than that of compressive cycling, which was attributed to the lack of twinning activity during tensile loading because of the initial extrusion texture. Most of these previous investigations examined cyclic tension behavior under conditions where deformation is NOT dominated by twinning, as determined by the initial texture.

Neutron diffraction has been used successfully to investigate *in-situ* how stresses distribute among different grain orientations during loading and unloading, and also provides quantitative data

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http://dx.doi.org/10.1016/j.msea.2013.02.021

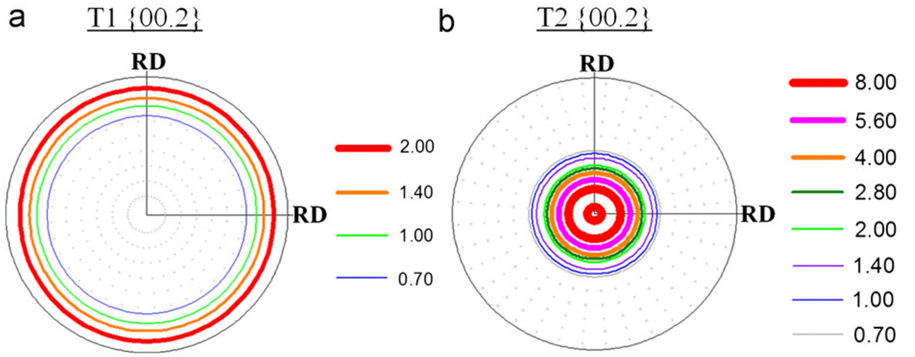

Fig. 1. Initial textures of (a) T1 and (b) T2 samples determined by neutron diffraction. Note that the center of pole figure corresponds to the extrusion direction (ED), and RD is the radial direction of the extruded bar.

on the volume fraction of twinning through measurements of diffraction peak intensity variations [3,6,7,15–19]. In the present work we use neutron diffraction to study the pseudoelastic and plastic deformation behaviors of an extruded Mg–8.5 wt.% Al alloy subjected to twinning-dominated cyclic deformation in both tension and compression, by varying the initial texture.

2. Experimental procedures

An extruded wrought Mg–8.5 wt.% Al alloy was prepared at the Péchiney Research Centre, France. Details of the sample preparation are found elsewhere [3]. The average grain size was 60 μm. The initial extrusion texture was such that the basal pole of most grains was preferentially oriented perpendicular to the extrusion direction (T1, Fig. 1a). Thus, {10.2} extension twinning could be easily activated under compression along the extrusion direction. In order to study the cyclic loading–unloading behavior under twinning-dominated tensile loading, the extrusion texture T1 was modified by compressing the material along the extrusion direction to a strain of ~9%, followed by annealing at a suitable temperature [20]. This yielded a modified texture T2 (Fig. 1b) where the basal pole of most grains is parallel to the extrusion direction, such that {10.2} extension twinning could be easily activated in most grains under tension along the extrusion direction.

In-situ neutron diffraction experiments were carried out on the L3 spectrometer of the Canadian Neutron Beam Centre, Chalk River Laboratories, Canada. T1 and T2 samples were deformed in cyclic compression and cyclic tension, respectively, in order to examine the pseudoelastic behavior under twinning-dominated cyclic deformation. Diffraction peaks for several grain orientations, defined by the indices of the plane normal which was parallel to the stress direction, were monitored *in-situ* during cyclic deformation. This yielded interplanar spacings (*d*-spacings) parallel to the stress axis for each grain family as a function of applied load. The elastic-lattice strains for each orientation were calculated using the following equation:

$$\varepsilon_{hk.l} = (d_{hk.l} - d^0_{hk.l})/d^0_{hk.l} \qquad (1)$$

where $d^0_{hk.l}$ and $d_{hk.l}$ are the *d*-spacings of the {*hk.l*} family of planes in the unloaded and loaded conditions, respectively. A detailed description of the technique is provided elsewhere [3,21,22].

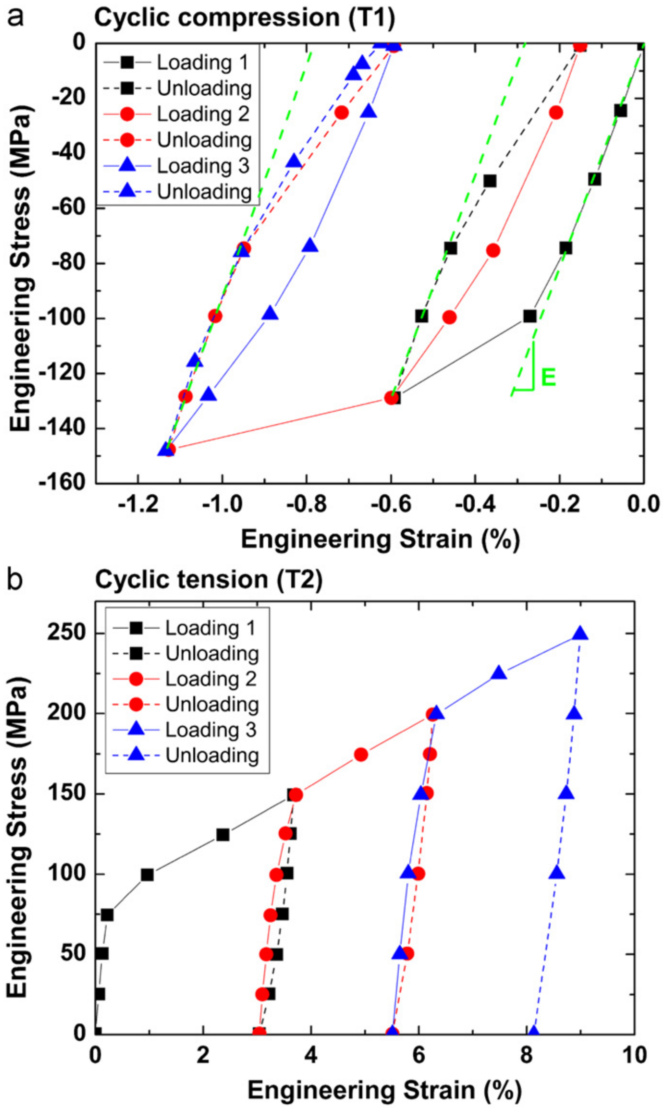

Fig. 2. The macroscopic stress–strain responses of an extruded Mg–8.5 wt.% Al alloy subjected to (a) cyclic compression (T1) and (b) cyclic tension (T2). Symbols correspond to points at which neutron diffraction measurements were made.

3. Results and discussion

Fig. 2 shows the macroscopic stress–stain responses for T1 and T2 samples during cyclic compression (Fig. 2a) and cyclic tension (Fig. 2b), respectively. The symbols show the points on the stress–strain curves at which neutron diffraction data were acquired. The graphs show that cyclic loading was associated with non-linear hysteretic behavior during unloading and reloading.