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Mobility of pinned twin boundaries during mechanical loading of extruded binary Mg-1Zn alloy

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ABSTRACT

The influence of isothermal aging, i.e. solute segregation and precipitation, on the mobility of {10−12} twin boundaries during mechanical loading of a binary Mg-1wt.%Zn alloy was investigated. Segregation along twin boundaries leads to a pinning effect and therefore, twin growth and shrinkage based on twin boundary migration are restricted. The development of microstructure changes, especially the twinning activity, is tracked by using scanning electron microscopy. During reverse loading, a reduction of the twinned volume fraction (detwinning) is realized either by (i) nucleation of new twins inside already existing twin lamellae or by (ii) migration of pinned twin boundaries, similarly to the case, when no heat treatment is applied. No effect of the orientation of the grain with respect to the loading direction during detwinning was observed.

1. Introduction

Wrought Mg alloys are usually characterized by strong textures formed during processing, which leads to an asymmetry of mechanical properties. Pre-deformation can tailor the final texture by creating a new texture component introduced by twins [1]. During further loading, the presence of the texture component composed by twins gives rise for activation of other deformation processes (particularly dislocation slip and detwinning), which are not promoted in the original orientation. Therefore, a presence of twins affects the deformation behavior during tension and compression loading and thus, can help to reduce the tension-compression asymmetry of the mechanical properties, especially the yield strength (YS) asymmetry [2,3]. Moreover, twin lamellae subdivide grains and act as non-dislocation barriers, which can contribute to the hardening of the material.

The most common twin system in Mg alloys is {10–12} ⟨10−11⟩ extension twinning, which reorients the original lattice by 86.3°. It activates during compression perpendicular to the *c*-axis of the *hcp* unit cell and the activation of different variants depends on mutual orientations of the prismatic and/or pyramidal planes and the loading axis [4,5]. During reverse loading, a thickness reduction or complete disappearance of existing twin lamellae, so-called detwinning, can be observed [2,6,7]. During this process, the twin lamellae are rotated back to the original parent (matrix) orientation. Detwinning can be realized either by twin shrinkage, i.e. migration of existing twin boundary to the interior of the twin, or by secondary twinning inside the existing twin. The first way of detwinning is more common in Mg alloys, when no heat treatment (HT) is used [6,8]. Ex-situ and in-situ methods were used for detailled studies of the propagation of twin boundaries during cyclic loading in Mg [8–10].

It has recently been reported that the extension twinning mechanism is characterized by the development of significant residual stresses inside twins as a result of load redistribution between soft and hard grain orientations [11]. In this work annealing at 200 °C for 30–120 min was applied to reduce residual tensile stresses inside the twins without affecting the twin structure. As a result, it was shown that thermal annealing was able to prolong the activity of basal slip and increase the activation stress for detwinning, and therefore, yield strength and elongation have been improved simultaneously. On the other hand, the contribution of twinning to plastic deformation can be also modified by introducing solute segregation and precipitation at the twin boundaries via heat treatment. Precipitates can profoundly affect the amount and size of deformation twins [12]. Therefore, solute segregation and precipitation should significantly affect the propagation

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and nucleation of twins. Cui et al. [13] have investigated the influence of solute elements - Al and Zn - and the therefrom resulting precipitates on detwinning by migration of atoms to the twin boundaries in pure Mg, AZ31 and AZ91. They concluded that the formation of secondary twins inside primary twins during reversed loading is ascribed to the low mobility of the incoherent twin boundaries due to the hindering effect of precipitates. Nie et al. have reported [14] that periodic segregation of solute atoms of Zn and Gd in fully coherent twin boundaries provides a pinning effect for twin boundaries leading to the strengthening of the material. Zeng et al. [15] explain the strengthening of thermo-mechanically treated Mg–0.3Zn–0.1Ca sheets by the pinning of gliding dislocations at GP zones and possible solute atom segregation to the dislocations. Therefore, it has been concluded that the pinning of solute atoms at the twin boundaries results in a different yield behavior during subsequent mechanical loading, which can help to tune mechanical properties. However, it is not completely clear how solute atoms and precipitates interact with twin boundaries and affect their mobility, i.e. growth or shrinkage of twins. The present paper refers to the influence of solute atoms and precipitate segregation to twin boundaries with a potential boundary pinning effect on the ongoing twinning mechanism in a continued compression or reverse tension loading test. This is especially investigated in a simple dilute binary Mg-Zn alloy. The obtained knowledge will be useful for a development of high-performance Mg alloys. A detailed analysis of the microstructure at different stages of the experiment will be provided by using scanning electron microscopy.

2. Experimental Procedure

A binary Mg-1Zn alloy (Mg + 1 wt%Zn) was indirectly extruded at 300 °C to a round bar with an extrusion ratio of 1:30. A homogeneous microstructure with an average grain size of ~50 μm was revealed, Fig.1a. The texture has a typical alignment of basal planes parallel to the extrusion direction (ED), i.e. the *c*-axis of the *hcp* structure is preferentially oriented perpendicular to ED. The main intensities are distributed along the arc between the ⟨10−10⟩- and ⟨11−20⟩-poles, Fig. 1b. For deformation tests, samples with a gauge length of 15 mm, a diameter of 8 mm, and screw heads on both ends were machined from the bar with the loading direction parallel to ED. This sample geometry allowed compression and tension tests in sequences on the same sample to be carried out. All deformation tests were performed at room temperature and a constant cross head speed of $10^{-3}\,s^{-1}$ using a universal testing machine Instron 5882.

For the study of the influence of heat treatment on the mobility of twin boundaries, samples were subjected to the following thermo-mechanical treatment: pre-compression up to 75 MPa (~2.7% of strain) followed by heat treatment at 200 °C for 8 h – hereafter named *TMT condition*. Then such samples were tested in compression and tension – hereafter named *compressed* or *tensile conditions*, respectively.

The microstructure and texture development was investigated by applying scanning electron microscopy on an SEM Zeiss Auriga, particularly using backscattered diffraction techniques (BSE and EBSD imaging). Microstructure characteristics include the homogeneity, twin types, twin boundaries, as well as the texture. EBSD mapping was carried out on longitudinal sections of the samples with a step size of 0.4 μm. Specimens for SEM observations were polished by standard method up to usage of diamond pastes with the particle size of 0.25 μm and subsequently electropolished by means of the Struers AC-2-II electrolyte.

3. Results and Discussion

The stress vs. strain curve for mechanical loading of the original as-extruded state is presented in Fig. 2. The $\sigma_{0.2}$ compressive yield stress (CYS) is 56 ± 1 MPa. The plateau following the macroscopic yield point on the deformation curve for the compression test has been

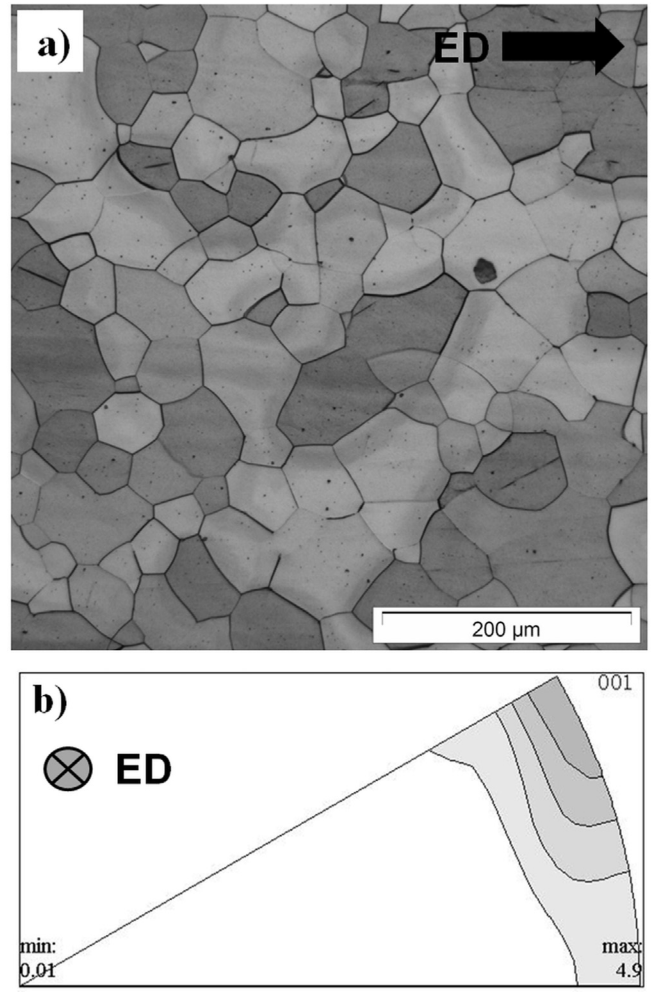

Fig. 1. Microstructure (light microscopy) (a) and texture (b) of extruded Mg-1Zn alloy in initial state.

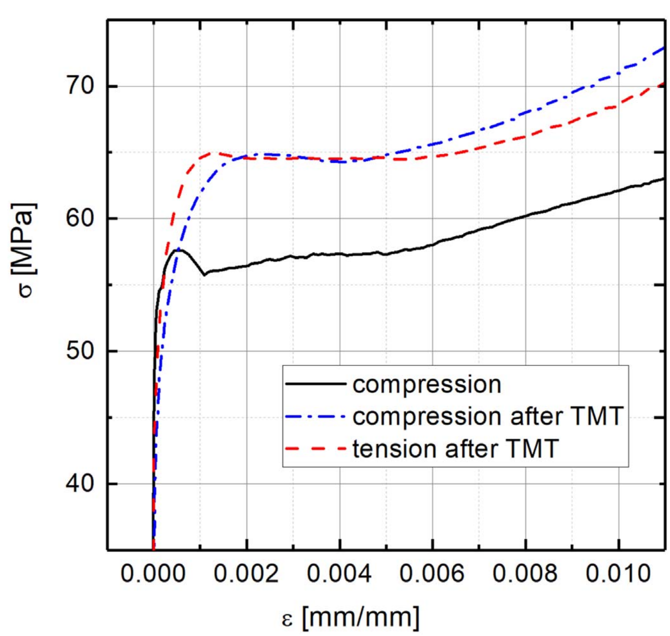

Fig. 2. Stress vs. strain dependences for compression tests of the Mg-1Zn alloy in as-extruded state and after thermo-mechanical treatment (TMT): pre-compression up to 75 MPa (or 2.7% of strain) and annealed at 200 °C for 8 h.