Materials Letters 178 (2016) 208–212

Contents lists available at ScienceDirect

Materials Letters

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

Effect of slip on detwinning behavior during multi-direction compression of a wrought magnesium alloy

Hongtao Huang [a,b,*], Andy Godfrey [a], Wei Liu [a], Jian Ping Zheng [b]

[a] Laboratory of Advanced Materials (MOE), School of Materials Science and Engineering, Tsinghua University, Beijing 100084, China
[b] Department of Reactor Engineering Research and Design, China Institute of Atomic Energy, Beijing 102413, China

A R T I C L E I N F O

Article history:
Received 2 December 2015
Received in revised form
15 March 2016
Accepted 30 April 2016
Available online 2 May 2016

Keywords:
Deformation and fracture
Metals and alloys
Mg alloy
Micro-grid method
Twinning
Detwinning
Basal slip

A B S T R A C T

The effect of slip on detwinning behavior of a wrought Mg alloy has been investigated, using a micro-grid method to measure the local strain. Two compression paths were designed. In one case compression was applied first along a direction promoting twinning, and then along a perpendicular direction promoting detwinning. In the second an intermediate deformation along a direction midway between these two directions was applied to promote basal slip. It is shown that a smaller strain is required for detwinning than for the initial twinning. Moreover, the interaction between basal ⟨a⟩ slip and twinning accelerates the detwinning behavior.

1. Introduction

Twinning plays an important role in plastic deformation of magnesium alloy. Three types of twins are frequently reported in magnesium alloys [1–4], namely $\{10\overline{12}2\}$ $\langle 10\bar{1}1\rangle$ extension twinning, $\{10\bar{1}1\}$ $\langle 10\bar{1}2\rangle$ contraction twinning and $\{10\bar{1}1\}$–$\{10\bar{1}2\}$ double twinning. Among all the possible twinning modes in Mg alloys $\{10\bar{1}2\}$ $\langle 10\bar{1}1\rangle$ extension twinning is considered to be the most important twinning mode. However, it must be recognized that twinning is a polar mechanism. A state of stress which causes an extension along the *c*-axis or a contraction perpendicular to the *c*-axis will favor the activation of $\{10\bar{1}2\}$ extension twinning [5]. In addition, detwinning will occur in a twinned region under reversed loading or multi-axis loading. Wang et al. [5] observed that detwinning dominates the subsequent tensile reloading deformation following pre-compressive deformation and results in a significant drop in tensile yield strength. Additionally it was reported by Lou et al. [6] that the activation stress for detwinning is lower than that for twinning because twin nucleation is not required. Similarly, an investigation of cyclic deformation of ZK60 magnesium alloy was carried out by Wu et al. [7], showing that the activation stress for detwinning is 9 MPa lower than that for twinning. In a study of strain-path change compression by Proust et al. [8], it has been found that as the amount of pre-strain increases, the activation stress for detwinning increases.

All of these studies, however, focus on the effect of detwinning on yield strength. Less attention has been given to the effect of dislocation slip on detwinning behavior during multi-direction compression of wrought magnesium alloys such as AZ31. Therefore, in this study we have designed two multi-direction compression paths designed to isolate and shed light on the effect of slip on detwinning.

2. Experimental procedures

The received AZ31 sheet was hot rolled from 161 mm to 30 mm, followed by a further annealing at 400 °C resulting in a sheet with a strong basal texture. Eight-sided prism samples were cut from this sheet for compression, with edges parallel to both the transverse direction (TD) and normal direction (ND) of the original rolled sheet (Fig. 1a). For these samples compression along TD is expected to promote twinning, and compression along ND to promote detwinning. Two kinds of multi-direction compression path were used in this work. In path A, the samples were pre-compressed along TD up to a nominal strain of 6%, and then compressed along ND up to nominal strains of either 2%, 4%, or 6%. Path B was similar, but with an additional compression in the 45° direction to a nominal strain of 4% applied between the TD and ND

* Corresponding author at: Laboratory of Advanced Materials (MOE), School of Materials Science and Engineering, Tsinghua University, Beijing 100084, China.
E-mail address: huanghongtao401@163.com (H. Huang).

http://dx.doi.org/10.1016/j.matlet.2016.04.213
0167-577X/

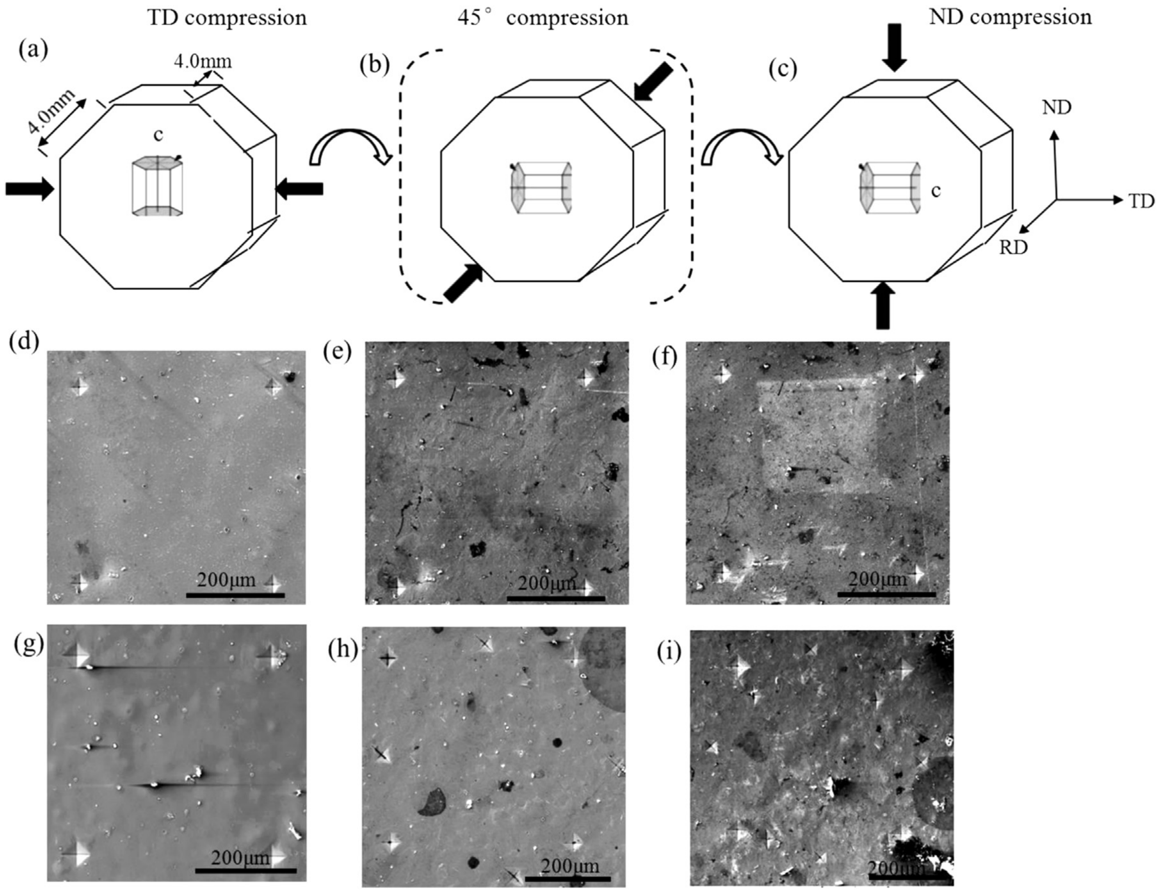

Fig. 1. Schematic illustration of the sample geometry and compression paths (a, b, c) and the corresponding microgrids used (d, e, f) in each step in path A and (g, h, i) in each step in path B(TD, RD and ND show transverse direction, rolling direction and normal direction of the sheet respectively).

compression steps (Fig. 1a–c). All the compression tests were performed at room temperature at a strain rate of 0.01 s^{-1}.

For measurement of local strains one of the sample base-planes was first electro-polished, then grids of size 400 μm × 400 μm were marked at the center of the electro-polished sample surface using a micro-indenter with 50 g load (Fig. 1d). These were used to calculate the local strains on the sample surface after the first deformation step in the area of interest (Fig. 1d–i). A number of other workers have used a similar technique to measure local strains [9–11]. To further improve the accuracy of the local strain measurements new 400 μm × 400 μm indent marker grids were applied after each deformation step in path B, always ensuring the indents were sufficiently far away from the area where the twinned fraction was finally measured (Fig. 1h–i). Before and after each deformation step the exact positions of the hardness indents were measured in a scanning electron microscope, and then used to calculate the average displacement gradient tensor (and hence local plastic strain) in the area to be examined. The principle and accuracy of the micro-grids method to calculate local strain are reported elsewhere [12]. The maximum relative error in strain measurement with this method is estimated at only approximately 5% (and in most cases considerably better than this). After each final ND compression step, the sample surface was once again electro-polished and the microstructure in a 200 μm × 200 μm area inside the micro-indents characterized by EBSD (Fig. 1d). In this way we can correlate the local strain with the local twinning behavior.

3. Results and discussion

The material deforms primarily by $\{10\bar{1}2\}$extension twinning during pre-compression along TD up to a strain of 6%because the *c*-axis of most grains are almost perpendicular to the compression direction. Since $\{10\bar{1}2\}$ twinning leads to a reorientation of 86° of the crystal lattice, the *c*-axis of most grains lie nearly parallel to TD after the 6%pre-compressionstep (Fig. 1b). This lattice reorientation favors detwinning in the twinned grains during subsequent compression along ND (Fig. 1c) since the *c*-axis of most grains are almost perpendicular to the compression direction. More detailed information about this deformation behavior is reported elsewhere [13]. During the 45°compression step, basal slip is the dominant deformation mechanism, because the angle between the compression direction and the *c*-axis of most grains is about 45° (Fig. 1b). As a result of the small amount of applied deformation the grains only rotate by a small amount during this 45° step (see later for details) and hence the deformation is still largely accommodated by detwinning during the following ND compression in path B since the *c*-axis of most grains are almost perpendicular to the compression direction.

It should be noted that as a result of the spread in the initial texture of the sample, some grains may in fact also deform by twinning during the 45° compression step. Additionally some grains may become well-aligned for twinning only in the final ND compression step. To eliminate any errors in the final measured twin area fraction due to such grains we only determine therefore the twinned area fraction in grains where: i) the maximum Schmid factor of the six $\{10\bar{1}2\}$ twin variants is larger than 0.3 during TD compression; ii) the maximum Schmid factor of the six $\{10\bar{1}2\}$ twin variants is smaller than 0.3 during 45° compression both in the twin and untwinned matrix; and iii) the maximum Schmid factor of the six $\{10\bar{1}2\}$ twin variants is smaller than 0.3 in the untwined matrix, while that in the twin is larger than 0.3,