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Short communication

Effect of dislocation-twin boundary interaction on deformation by twin boundary migration

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ABSTRACT

The effect of interaction between $\{10\bar{1}2\}$ twin boundaries (TBs) and ⟨a⟩ dislocations on deformation behavior of TBs migration process was studied. This TB-dislocation interaction greatly enhances activation stress for TB motion and retards TB migration during reloading. Interestingly, a severe TB-dislocation interaction improves strain hardening at the early stage, while reduces the peak hardening rate at the latter stage. High resolution transmission electron microscopy results indicate that severe TB-dislocation interaction greatly damages the coherence of TBs and might induce curving of TBs. Migration of the TBs that intensively interact with dislocations leaves behind low angle boundaries at the initial TBs.

1. Introduction

Twin boundaries (TBs) play an important role in plastic deformation and ultimately in controlling the forming ability and mechanical properties of many engineering materials [1]. Notable examples are the Mg alloys in which twinning constitutes one of the main deformation mode at room temperature. The formability, yield strength and mechanical anisotropy are closely related to twinning [2–4]. $\{10\bar{1}2\}$ TBs have been extensively used to tailor mechanical properties and working ability in recent studies [5–7]. It was found that yield strength of a hot-rolled AZ31 plate can be significantly enhanced without a drop of ductility by introduction of a large number of $\{10\bar{1}2\}$ TBs [8]. The reorientation by $\{10\bar{1}2\}$ twinning can effectively improve hot rolling ability and reduces tension-compression yield asymmetry [8,9]. Recently, Cui et al. reported that Mg alloys with an enhanced damping capacity can be prepared by introducing $\{10\bar{1}2\}$ TBs [6,8,9].

For nano-structured *fcc* or *hcp* metals, dislocations interaction and accumulation at TBs have been reported to significantly affect the strength, ductility and strain hardening. Extensive studies demonstrated that, depending on the characteristics of the dislocations and the driving stress, possible dislocation reactions at TBs included cross-slip into the twinning plane to cause twin growth or detwinning, formation of sessile dislocations at TBs, and transmission across the TBs [10,11]. For metals containing the pre-existing $\{10\bar{1}2\}$ TBs, TBs migration, *i.e.* twin growth or detwinning, is an important (or even the predominant) deformation mode under certain loading conditions. The TBs motion is often accompanied by intensive TB-dislocation interaction during detwinning in nano-structured *fcc* metals [12] or twinning in *hcp* metals [5], or cyclic loading of Mg alloys [13]. Generally, a TBs migration process involves twinning dislocations gliding along coherent TBs and subsequently climbing along facets [14]. It is suspected that the TB-dislocation interaction will affect the motion of twinning dislocations, and ultimately vary mechanical properties and strain hardening. Therefore, understanding how the mechanical behavior is influenced by the TB-dislocation interaction during deformation by TBs motion is of great importance. Although the effect of TB-dislocation interaction on mechanical properties and strain hardening during slip predominant deformations has been extensively studied and well understood, that of the TB-dislocation interaction on mechanical behavior of a TB migration predominant deformation is hardly reported and unclear. In the present study, a twinned Mg AZ31 plate was subjected to a slip predominant deformation to allow an intensive interaction of ⟨a⟩ dislocations with $\{10\bar{1}2\}$ TBs. Then, a TBs migration predominant deformation (detwinning) was initiated by reloading, with the aim to understand the effect of this TB-dislocation interaction on mechanical properties and strain hardening. The corresponding mechanisms were studied and discussed.

2. Experiments and methods

A hot-rolled Mg AZ31 thick plate with fully recrystallized grains and a typical basal texture was used. Blocks of 30 mm (ND) ×

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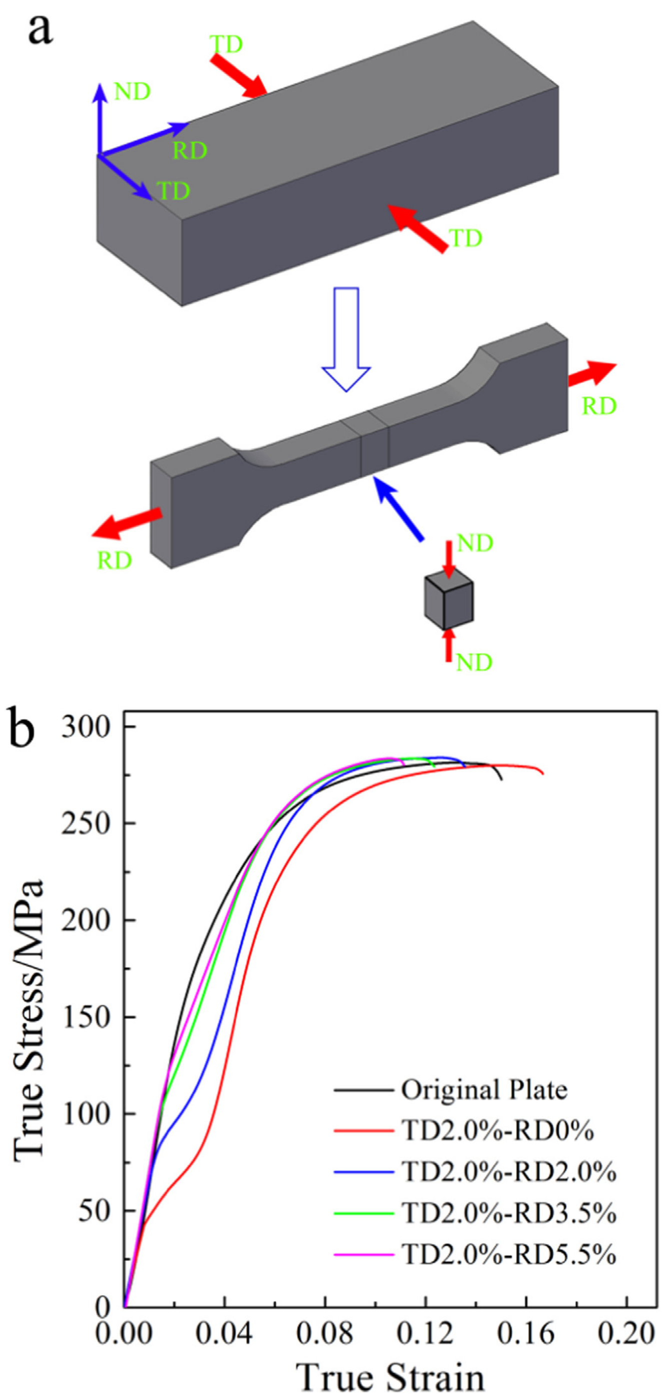

Fig. 1. (a) A schematic diagram showing the pre-straining to generate intensive interaction of {10$\bar{1}$2} TB with ⟨a⟩ dislocation and the preparation of specimen for ND reloading and (b) stress-strain curves under compression along the ND.

35 mm(TD) × 90 mm (RD) were cut and compressed 2.0% along the TD (the designated TD2.0%-RD0%) to generate a large number of {10$\bar{1}$2} TBs. Here, RD, TD and ND represent the rolling direction, the transverse direction and the normal direction of the as-used plate, respectively. As shown in Fig. 1a, the specimens for tension were cut from the center of the twinned blocks and stretched along the RD to 2.0% (the designated TD2.0%-RD2.0%), 3.5% (the designated TD2.0%-RD3.5%) and 5.5% (the designated TD2.0%-RD5.5%), respectively. The RD tension was used to start prismatic slip of ⟨a⟩ dislocations in both the matrix and {10$\bar{1}$2} twins, and, hence, generated an intensive interaction of {10$\bar{1}$2} TBs with ⟨a⟩ dislocations. Afterwards, small blocks of 7 mm (TD) × 7 mm (RD) × 9 mm (ND) were cut for recompression along the ND to initiate detwinning of {10$\bar{1}$2} twins. A strain rate of 10^{-3} s^{-1} was used for all the mechanical tests. Each mechanical test was repeated three times. For comparison, mechanical behavior under compression along the ND of the as-used plate (the designated original plate) and the TD2.0%-RD0% were also measured.

To reveal the deformation behavior during reloading, *in-situ* electron back-scattered diffraction (EBSD) mapping using a step size of 0.5 μm was conducted on a scanning electron microscope (SEM, Zeiss AURIGA) equipped with a HKL-EBSD system. High-angle annular dark-field scanning transmission electron microscopy (HAADF-STEM) and high resolution transmission electron microscopy (HRTEM) conducted on FEI Tecnai G2 F20 TEM were used to further investigate the microstructure of pre-strained samples. For preparation of specimens for TEM examination, the mechanically grinded thin foils were punched into discs of 3 mm in diameter and were subsequently thinned to 50 μm. A twin-jet electro-polishing of the thin foils at −30 °C and 50 V was performed on a Struers Tenupol-5 twin-jet electro-polisher using a solution containing 3 vol% perchloric acid in absolute ethanol. Finally the foils were cleaned for 10 min by a Gatan ion polishing system using an accelerating voltage of 3 kV and at −70 °C.

3. Results and discussion

Fig. 1b shows stress-strain curves of compression along the ND. The curve of TD2.0%-RD0% has a plateau, a typical manifestation of deformation dominated by detwinning of {10$\bar{1}$2} twins. The RD re-tension significantly increases the yield stress and slightly reduces the elongation, though the peak stress being similar. As seen in Table 1, the yield stress increases from 50 MPa to 137 MPa when the RD strain is up to 5.5%. As seen in Fig. 2a, a continuously decreasing strain hardening rate exists during ND compression of the original plate, which is related to a basal slip predominant deformation [8]. Strain hardening curve of the TD2.0%-RD0% is characterized by an obvious peak. When pre-deformation also includes RD tension, a drop of the peak hardening rate is observed; and when the RD strain is up to 5.5%, this peak in the strain hardening curve is not obvious.

In-situ EBSD analyses of the deformation behavior of TD2.0%-RD5.5% before and after 1.5% compression along the ND are shown in Fig. 3. As seen in Fig. 3a, many lamellae (the bands in green or blue) identified as {10$\bar{1}$2} twins exist in the inverse pole figure map before ND compression. A part of {10$\bar{1}$2} twins narrow or disappear after ND compression. It is interesting that many low angle boundaries with misorientations of 3–8° (denoted by the yellow arrows in Fig. 3b) appear just at the sites where the {10$\bar{1}$2} TBs disappear. This can be clearly shown in Fig. 3c. The migration of {10$\bar{1}$2} TBs leaves behind low angle boundaries with a 8° misorientation at the initial TB.

Generally, for a hot-rolled Mg alloy plate with a strong basal texture, compression along the TD is a {10$\bar{1}$2} twinning predominant deformation and basal poles of the {10$\bar{1}$2} twins are close to the compression direction [5]. Therefore, the TD-

Table 1
Yield stress, peak stress and elongation of samples during compression along the ND.

	Yield stress/MPa	Peak stress/MPa	Elongation/%
TD0%-RD0%	166	283	12.3
TD2.0%-RD0%	50	282	10.9
TD2.0%-RD2.0%	89	282	10.5
TD2.0%-RD3.5%	114	285	10.3
TD2.0%-RD5.5%	137	286	9.8