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Comparative examinations on the activity and variant selection of twinning during tension and compression of magnesium alloys

Dejia Liu [a,c], Renlong Xin [a,b,*], Hongni Yu [a], Zhe Liu [a], Xuan Zheng [a], Qing Liu [a,**]

[a] College of Materials Science and Engineering, Chongqing University, Chongqing, China
[b] State Key Laboratory of Mechanical Transmission, Chongqing University, Chongqing, China
[c] School of Mechatronics Engineering, East China Jiaotong University, Nanchang, China

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ABSTRACT

In the present study, an Mg weld with β-type fiber texture was produced by friction stir welding (FSW) and then was subjected to tension and compression along the transverse direction (TD). The deformed microstructure by 5% strain was examined in various regions of the Mg weld by electron backscatter diffraction (EBSD) technique. It was found that profuse twinning was activated in stir zone (SZ) -side after tension and in SZ-center and crown zone (CZ) -center after compression due to the presence of relatively large Schmid factor (SF). However, a few twins (2–3%) were also observed in SZ-center after tension and in SZ-side after compression. In this case, the twins have very small and even negative SF. For the twins with large SF, they were likely connected at grain boundaries forming twin pairs, while for those with small or negative SF, they were mostly confined within grains. For connected twins, most of the active variants have favorable SF and geometric compatibility factor (m'). However, the distributions of SF and m' are different between the twins formed in compression and tension. For isolated twins, the adjacent grains connected with the twins were generally in favorable orientation for basal slip, and the selection of twin variants was likely affected by m' between the most favorable basal slip and the twins.

1. Introduction

Friction stir welding (FSW) is a solid state joining technique, which has many advantages for welding Mg alloys [1–8]. In general, a very strong and complicated deformation texture is generated in stir zone of Mg alloys, which largely deteriorates the strength of FSW Mg welds [9–15]. In previous studies, post-weld deformation has been applied on FSW Mg welds to optimize the microstructure and strength [16–18]. It was found that the introduction of profuse twinning is a key reason for the enhancement of joint strength [17,18]. Therefore, in order to better optimize joint strength by introducing multiple twins, it is necessary to understand twinning activity and variant selection during plastic deformation of FSW Mg welds.

A statistical study on pure magnesium with basal texture indicated that less than 40% extension twins selected the variant with the first Schmid factor (SF) rank during compression deformation, and even ~37% twins selected the variant with SF rank 3–6 [19]. Here, rank 1 to 6 represents the variant with the first to sixth highest SF value. Although great efforts have been devoted to investigate twinning activity and variant selection in previous studies on Mg alloys [20–31], the underline mechanism for the non-Schmid behavior was still not completely understood. It was considered that the competition between twinning and slip is also important for twinning activity. On one hand, grains well oriented for basal slip are usually unlikely twinned [19]. On the other hand, the pile up of basal slip at grain boundaries (GBs) may stimulate twinning to relieve local stress concentration [23,25]. This issue however has not been well understood so far.

It is expected that the variation in texture and deformation geometry will change SFs for twinning and basal slip, and hence their competition. Therefore, the variant selection of twinning may display different trends for Mg alloys with different texture and under different deformation modes. However, such information was rarely found in literature because most previous studies focused on single deformation mode or simple texture. It is well known that FSW Mg welds generally exhibit a β-type fiber texture, meaning that the *c*-axis of grains varied through the welds along the transverse direction (TD) [9–12]. As a consequence, the competition between twinning and basal slip will be different through the various regions along TD [12–14], which may lead to the different characteristics in twinning activation. In view of the above mentioned facts, a comparative study of twinning activation in

* Corresponding author at: Sha Zheng Jie 174, Sha Ping Ba District, Chongqing, China.
** Corresponding author.
E-mail addresses: rlxin@cqu.edu.cn (R. Xin), qingliu@cqu.edu.cn (Q. Liu).

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FSW Mg welds under both tension and compression will be useful to shed light on the influence of texture and basal slip on variant selection of twinning.

Therefore, in this paper, AZ31 Mg welds with a β-type fiber texture were produced by FSW and were subsequently deformed by tension and compression along TD. The deformed microstructures were examined in various regions by electron backscatter diffraction (EBSD) technique. Statistical analysis on twin variant selection was then performed. By considering Schmid factors and the influence of basal slip, the mechanisms for twinning activation and variant selection were discussed.

2. Experimental procedures

The material examined in this study is an AZ31 FSW joint. The detailed preparation information for the joint was described as follows. Several weld plates with the thickness of 6 mm were cut from a hot-rolled commercial AZ31 Mg alloy sheet (Mg–3%Al–1% Zn). After polished by abrasive paper and cleaned with acetone, they were then subjected to FSW along the rolling direction (RD) of the original sheet, i.e. having welding direction (WD) parallel to RD. A cylindrical screw pin tool with diameter of 5 mm and length of 5.7 mm was used. The diameter of the tool shoulder is 15 mm. The welding speed and rotation rate were 600 mm/min and 1600 rpm, respectively. During FSW process, the pin tool was tilted by 2.5° away from WD and rotated in a counter-clockwise direction.

Dog bone-shaped specimens with nominal gage dimensions of 25 mm (TD) × 5 mm (normal direction, ND) × 4.5 mm (WD) were prepared for tensile tests, and rectangular prism specimens with nominal dimensions of 5 mm (ND) × 5 mm (WD) × 10 mm (TD) were prepared for compressive tests. All the tests were performed at a strain rate of $1\times10^{-3}\ s^{-1}$ at room temperature. Twinning and microstructure evolution in various regions of the FSW samples with 5% tensile or compressive strain was examined by EBSD. The EBSD detector was an HKL Channel 5 Systems equipped in a field-emission scanning electron microscope (FESEM, FEI Nova 400). The samples for EBSD analysis were polished at 20 V in a commercial polishing solution AC2 (Struers) at 20 °C. The EBSD step size was 1 μm. Pole figure was obtained based on an EBSD scan area of approximately 200 × 200 μm.

3. Results and discussion

Fig. 1a presents the stress–strain curves of the FSW Mg joints and base material (BM) under tension and compression, indicating that the tensile property was significantly decreased compared to BM. Although the compressive yield strength of Mg joints was increased, the ultimate strength was decreased compared to BM. The fracture surface of the tensioned and compressed samples are shown in Fig. 1b, which confirms that macroscopic strain localization was occurred in stir zone (SZ), and crack was initiated and propagated within the transition region between BM and SZ. These results and also some previous work [11–16] clearly indicate that it is important to have microstructure control and strength enhancement for FSW Mg joints.

As reported in previous studies [11–13], the FSW joints of Mg alloys can be divided into several regions due to the difference in texture. Particular attention has been paid on a few specific regions such as SZ-side, the region adjacent to SZ-side, SZ-center and crown zone (CZ)-center. The relative positions of these regions in the present weld sample are illustrated in Fig. 2a, and the

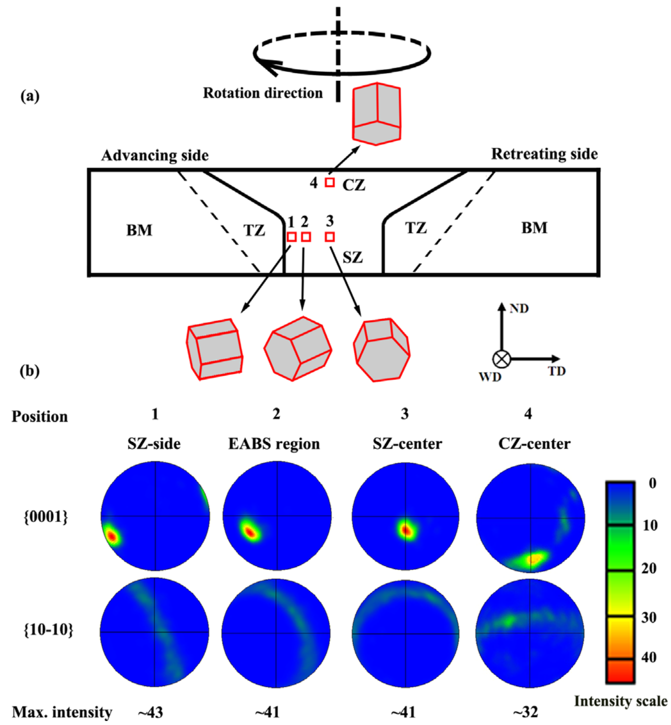

Fig. 2. (a) Schematic of the relative position and grain orientation of various specific regions in a FSW Mg weld, and (b) the corresponding {0001} and $\{10\bar{1}0\}$ pole figures.

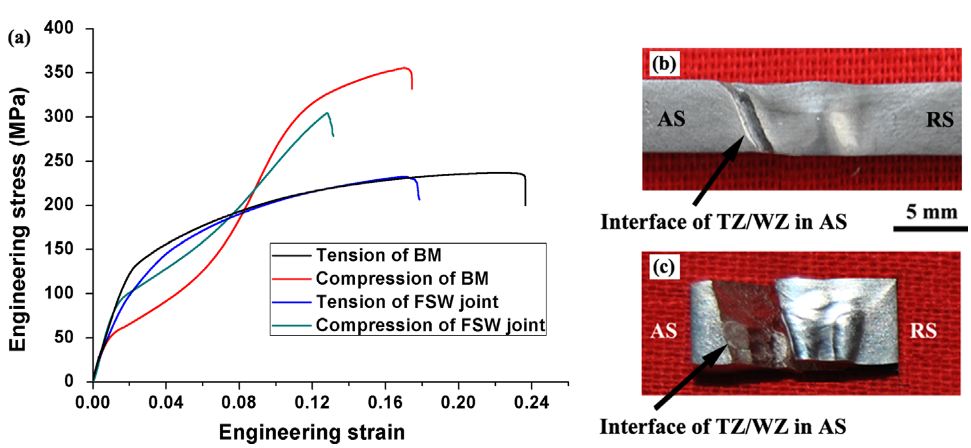

Fig. 1. (a) Stress–strain curves of BM and FSW Mg welds for transverse tension and compression, and fracture morphologies for the (b) tensile and (c) compressive samples. In this paper, AS, RS, TZ and WZ stand for advancing side, retreating side, transition zone and weld zone, respectively.