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The activation of twinning and texture evolution during bending of friction stir welded magnesium alloys

Dejia Liu [a,b], Renlong Xin [a,c,*], Zeyao Li [a], Zhe Liu [a], Xuan Zheng [a], Qing Liu [a]

[a] College of Materials Science and Engineering, Chongqing University, Sha Zheng Street 174, Sha Ping Ba District, Chongqing, China
[b] School of Mechatronics Engineering, East China Jiaotong University, Nanchang, China
[c] State Key Laboratory of Mechanical Transmission, Chongqing University, Chongqing, China

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A B S T R A C T

The present study aims to investigate the twinning behavior and texture evolution during bending of a friction stir welded (FSW) AZ31 Mg alloy. Two kinds of three-point bending tests (designated as Surface test and Base test) were applied at room temperature. Strong texture-dependent twinning characteristics were revealed after bending. The largest numbers of extension twins were observed in SZ-side after Surface test and in SZ-center after Base test. The texture-dependent twinning activity was well explained by the calculated Schmid factor based on a speculated local stress state. Some extension twins were likely connected with each other and formed twin chain or twin band, and most of the neighboring twins present a high geometrical compatibility factor (larger than 0.8), implying that the local strain compatibility played an important role in the formation of connected twins.

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1. Introduction

Friction stir welding (FSW) is a solid-state joining technique [1,2], which can avoid surface distortion and grain coarsening, and is especially suitable for the welding of light metals such as Al and Mg [3–7]. The successful application of FSW in Mg alloys is expected to compensate their low formability and to expand their use as structural materials [8–10]. It is known that the grains in stir zone (SZ) can be significantly refined after FSW [10–14], which is beneficial for mechanical properties. However, strong deformation texture is usually formed in weld zone, and varies in different positions [6,15–19], which largely complicates the deformation behavior and leads to severe strain localization [20–22]. Previous studies found that strain localization is one important factor determining the joint strength and fracture position of Mg welds [20,21]. Therefore, it is important to understand the deformation mechanism of Mg welds with such complicated texture and strain localization behavior.

It is known that $\{10\bar{1}2\}\langle 10\bar{1}1\rangle$ extension twinning is one important deformation mechanism for Mg alloys especially at room temperature, and the activity of extension twinning is highly dependent on grain orientation with respect to loading direction [23–25]. Therefore, for Mg welds with complicated texture, the propensity of twinning might be largely different at various positions [26–28]. Moreover, the stress and strain state for bending is also different between the inner and outer surfaces, which may also lead to largely different twinning behavior. However, to the authors' knowledge, these issues have not yet been reported before. Therefore, the present work aims to examine the twinning behavior in various regions of FSW Mg alloys during two types of bending tests, and to answer whether the activation and propensity of twinning can be evaluated by Schmid law in terms of the assumed stress state for bending.

2. Experimental procedures

Hot-rolled commercial AZ31 Mg alloy (Mg–3%Al–1%Zn) plates with 6 mm thickness were used as base material (BM) in the present work. Prior to FSW the surface oxides were removed with abrasive paper and cleaned with acetone. Butt welding along the rolling direction (RD) of the Mg alloy plates was conducted using a cylindrical thread pin (5.7 mm in length and 5 mm in diameter) at a rotation rate of 1600 rpm and a welding speed of 600 mm/min. The welded work-pieces were sectioned perpendicular to welding direction (WD) for microscopic examinations.

Microstructure evolution was examined in various regions of the joint by electron backscattered diffraction (EBSD) techniques. The EBSD detector (HKL Channel 5 System) equipped in a field-emission gun scanning electron microscope (FEI Nova 400 SEM) was used. The samples for EBSD analysis were polished in a

* Corresponding author at: College of Materials Science and Engineering, Chongqing University, Sha Zheng Street 174, Sha Ping Ba District, Chongqing, China. Fax: +86 2365102179.
E-mail address: rlxin@cqu.edu.cn (R. Xin).

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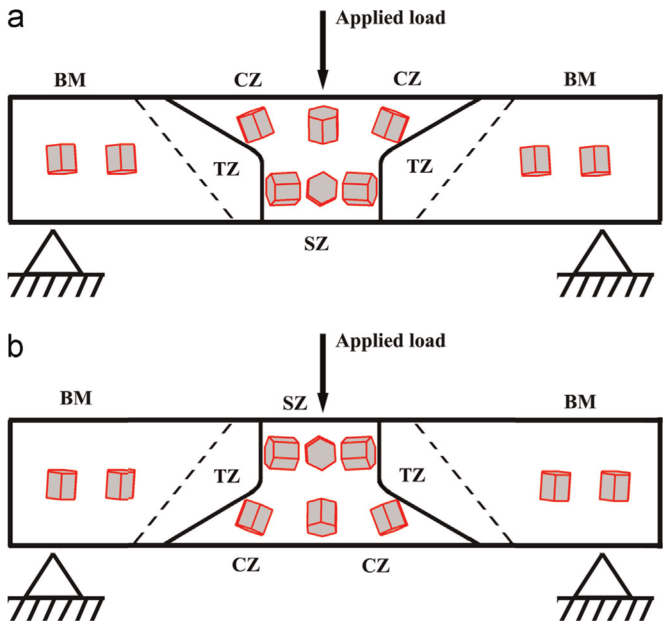

Fig. 1. Schematic illustration of three-point bending tests for FSW Mg alloys: (a) Surface test and (b) Base test.

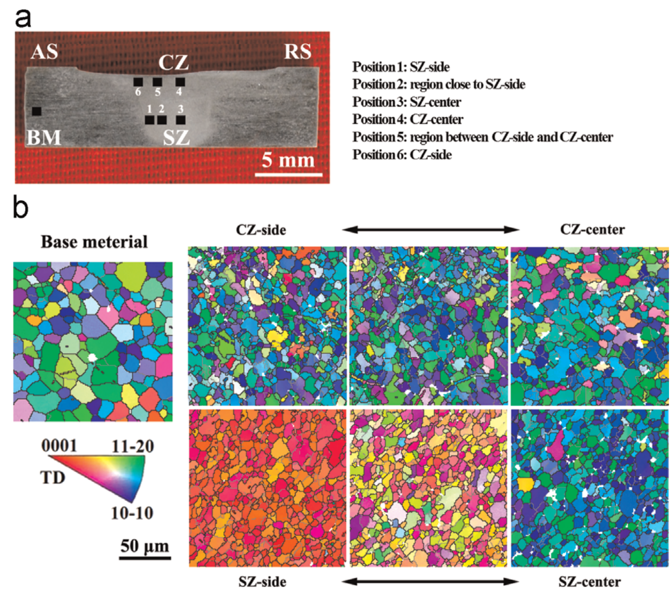

Fig. 2. the cross-section of the FSW Mg joint: (a) macrograph showing the positions of six regions, (b) initial microstructure of base material and the six regions indicated in the macrograph. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

commercial polishing solution (AC2) at 20 V and 20 °C. The step size for EBSD scan was 1 μm. The pole figures presented in this paper were obtained based on an EBSD scan area of approximately 200 × 200 μm^2.

Rectangular shaped specimens with dimensions of 84 mm (transverse direction, TD) × 10 mm (WD) × 4.5 mm (normal direction, ND) were prepared for three-point bending tests. The beam span for the bending tests is 50 mm. The bending specimens were cut with ~0.7 mm away from bottom surface of the FSW plates. The bending tests were performed at a cross-head speed of 2 mm/min and were interrupted at 5% strain of outer surface to examine twinning and microstructure evolution. As shown in Fig. 1, two kinds of deformation geometry were used for bending tests, with the load applied on surface and base of the welds, and were designated as Surface test and Base test, respectively. For a three-point bending sample with triangular shape, the flexural strain ε of the outer surface is evaluated as $\varepsilon = \frac{6*d*h}{L^2}$, where d is the deflection of beam center, L is the beam span, and h is the sample thickness [29].

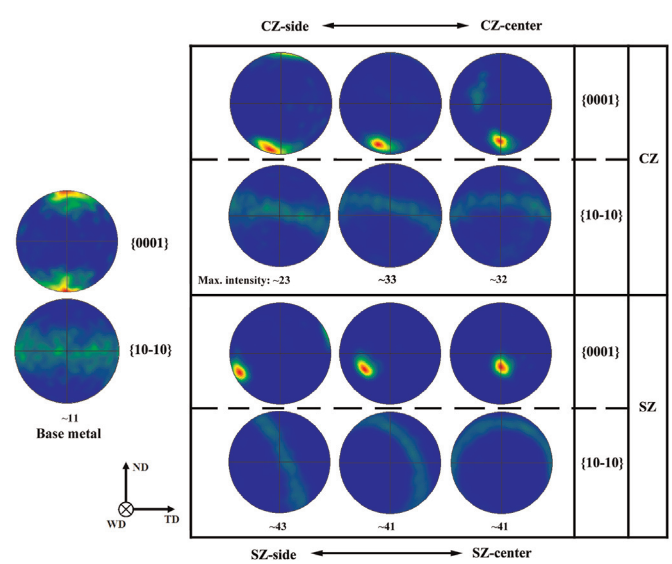

Fig. 3. Texture distributions of the various regions in the FSW AZ31 alloy.

3. Results

3.1. Initial microstructure

Fig. 2a shows the macrograph of the cross-section of the FSW sample. It indicates that the SZ and crown zone (CZ) have shiny contrast and can be clearly distinguished from BM. No crack and pores are observed at the interface between the SZ/CZ and BM. To examine the evolution of microstructure and texture, a series of positions on the cross-section of SZ and CZ are chosen for EBSD analysis, as indicated by squares in Fig. 2a. The corresponding EBSD maps and pole figures are presented in Figs. 2b and 3, respectively. It reveals that the microstructure is significantly refined in SZ and CZ after the severe friction stir deformation. By a linear intercept method, the average grain size was measured to be ~28 μm, ~7.8 μm and ~10 μm in BM, SZ and CZ-center, respectively. According to previous studies [1,11,15,16], the significant grain refinement was achieved by dynamic recrystallization during the severe plastic deformation of FSW.

As shown in Fig. 3, BM has a typical basal texture with the c-axis parallel to ND and the {1012}⟨1011⟩ pole distributed nearly at random. After FSW, strong basal texture was formed in SZ with the intensity about 40 times of random distribution. Being consistent with previous studies [16,18,30], the {0001} pole is oriented in different direction at the various positions. It tends to tilt from TD to WD with the position moving from SZ-side to SZ-center. However, in all the SZ, it is away from the ND plane, and is inclined about 25° to TD in SZ-side. The texture is also strong in CZ (20–30 times random) compared with BM (~11 times random). But the (0001) pole is tilted away from ND. It is ~17° away from ND in CZ-side and 30° away in CZ-center. The texture in SZ is primarily due to the shear stress by stir pin, and in CZ due to the stress by tool shoulder [6,16].

3.2. Microstructure evolution during bending

The macrographs of the FSW and as-received samples after 5%

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