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Non-Schmid-based {10-12} twinning behavior in polycrystalline magnesium alloy

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ABSTRACT

In this study, the hot-rolled AZ31 Mg alloy sheet was subjected to dynamic plastic deformation (DPD) with the compression axis taken at different angles to the sheet normal direction (ND). {10-12} twin variant selected is not always the primary one with the highest Schmid factor (SF). For some twinned grains in which the orientations have a deviation of about 10°–40° from the ideal orientation (i.e. rolling direction) favoring {10-12} twinning under compression loading to the DPD direction, the nucleated twin variants have the highest SFs; with higher deviation of 30°–60°, the first twins to form are low-SF variants in the twinned grains. This non-Schmid effect is probably associated with the local-stress fluctuation near grain boundary due to strain accommodation between grains. And the deviation angle that ranged from 30° to 40° is considered to be a transition of variant selection toward the non-Schmid behavior.

1. Introduction

Due to the characteristic of the hexagonal close packed (HCP) structure, magnesium alloys have a very limited number of slip systems, which results in the poor room-temperature formability and limits its potential application in the automotive industry. Therefore, deformation twinning becomes an important mode of strain accommodation to satisfy the requirement for five independent deformation systems in HCP metals. It is well known that deformation twinning, especially {10-12} twinning, plays an important role in plastic deformation of polycrystalline magnesium alloys [1–3]. Theoretically, {10-12} twinning is possible on six equivalent {10–12} twinning planes with a specific shear direction of <10-11> (i.e., six equivalent twin variants): (10-12)[-1011], (-1012)[10-11], (01-12)[0-111], (0-112)[01-11], (-1102)[1-101] and (1-102)[-1101]. And twin variant selection depends on whether the accumulated local stress reaches its critical resolved shear stress (CRSS). It has been widely reported that the Schmid factor (SF) law is applicable to analyze {10-12} twinning nucleation when compression deformation is perpendicular to the c-axis of HCP lattice or tension is parallel to the c-axis, i.e. the theoretical {10-12} twin variant with the maximum SF value could be generated in grain during deformation [4–7]. But due to the plastic deformation affected by several internal and/or external factors, multiple twin variants are usually activated in one grain. For example, when the tensile loading is parallel to the c-axis of magnesium single crystal, all six theoretical {10-12} twin variants have an equal SF value [5,7], implying that, based on the SF law, six variants could be simultaneously generated; for the compression along the rolling direction (RD) of the as-rolled Mg alloy sheet, the {10-12} twin variant pair with the maximum SF is generated at the early stage of deformation. With further strain, the new variants with the low SF could also be activated as long as the local stress reaches its CRSS value [4].

The above results indicate that the selection of {10-12} twin variant is a complex process and would be affected by several factors, such as strain accommodation between grains, strain path and strain parameter. However, the first twins activated are always primary variants with the highest SF during tension or compression loading of single crystals and polycrystals, as in the previous studies [4–7]. In this work, it was found that the initial {10–12} twinning behavior does not comply with the SF criterion in AZ31 Mg alloy under the specific loading conditions. Twin-variant selection has a significant effect on the microstructure and mechanical properties of Mg alloy. For example, the nucleation of multiple twin variants would change the internal stress state in grain. Twin–twin boundaries of misorientation relationships of 60° <10-10> and 60.4° <8-1-70>, which are produced from the interaction between different {10-12} variants, could retard the twin growth and promote twinning nucleation [8]. Therefore, understanding the select rule of {10-12} twin variants under different loading conditions is an important requirement for improving the mechanical property of Mg alloy.

2. Material and experimental methods

The hot-rolled AZ31 Mg alloy sheet (Mg–3%Al–1%Zn) has twin-free equiaxed grain structure and an average grain size of ~34 μm (Fig. 1a). This investigated material was industrially cast and processed. After semi-continuous casting, Mg alloy sheet was homogenized in a reheating

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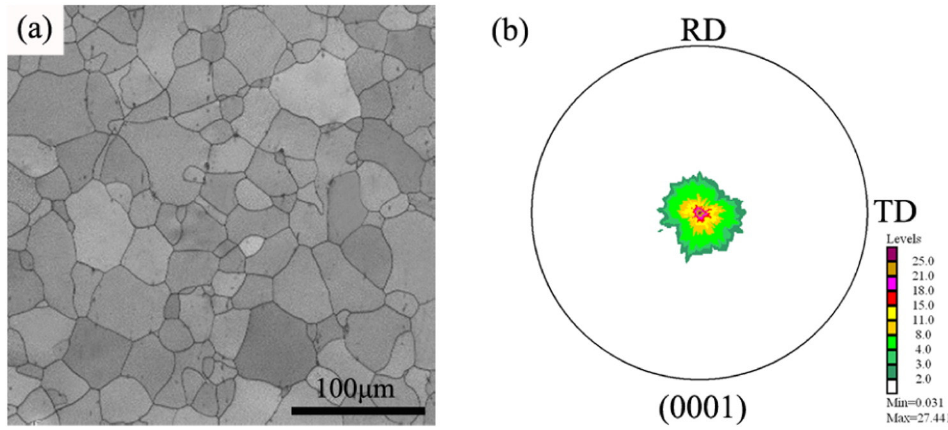

Fig. 1. (a) Microstructure characteristics and (b) (0001) pole figures of the as-rolled material. RD and TD represent the rolling direction and the transverse direction respectively.

furnace at 400 °C for 2 h. This sheet was subsequently hot rolled to a thickness of 30 mm using an industrial hot rolling mill, and was annealed at ~400 °C to diminish the effect of mechanical processing. As generally observed in the as-rolled AZ31 sheet, the basal {0001} planes of this sheet were aligned almost parallel to the rolling plane, as shown in Fig. 1b.

Cylinders (8 mm in diameter and 12 mm at height) were cut from this sheet with axis either at 0°, 30°, 60° and 90° to the normal direction (ND) in the as-rolled sheet, producing a set of samples with different initial textures, as shown in Fig. 2.

Dynamic plastic deformation (DPD) is a processing technique based on plastic deformation at high strain rates above 10^1/s [9]. A cylinder sample placed on a lower anvil was compressed by an upper impact anvil at high loading rate. The deformation process is controlled automatically by a computer. A disk mold is used to limit the final thickness of the deformed samples. Dynamic rate is thought to facilitate {10-12} twin nucleation and propagation [10]. All samples were subjected to DPD just once with Instron Dynatup 8120 testing machine at room temperature and tests were interrupted at true strain of 6%. The strain rate applied in each impact was estimated to be about 10^3/s.

The initial macrotexture was measured by X-ray diffraction on a Rigaku D/max-2500PC diffractometer. Scanning electron microscopy–electron back-scattered diffraction (SEM–EBSD) was utilized to analyze twinning orientations and samples texture after deformation. EBSD scans were performed by FEI Nova 400 FEG-SEM on an area of 300 × 300 with a step size of 1 μm for each sample.

3. Experimental results

3.1. Microstructural evolution

The EBSD maps of DPD samples observed in the longitudinal section are presented in Fig. 3. Generally, {10-12} twinning is activated by compression perpendicular to the c-axis of HCP lattice or tension parallel to

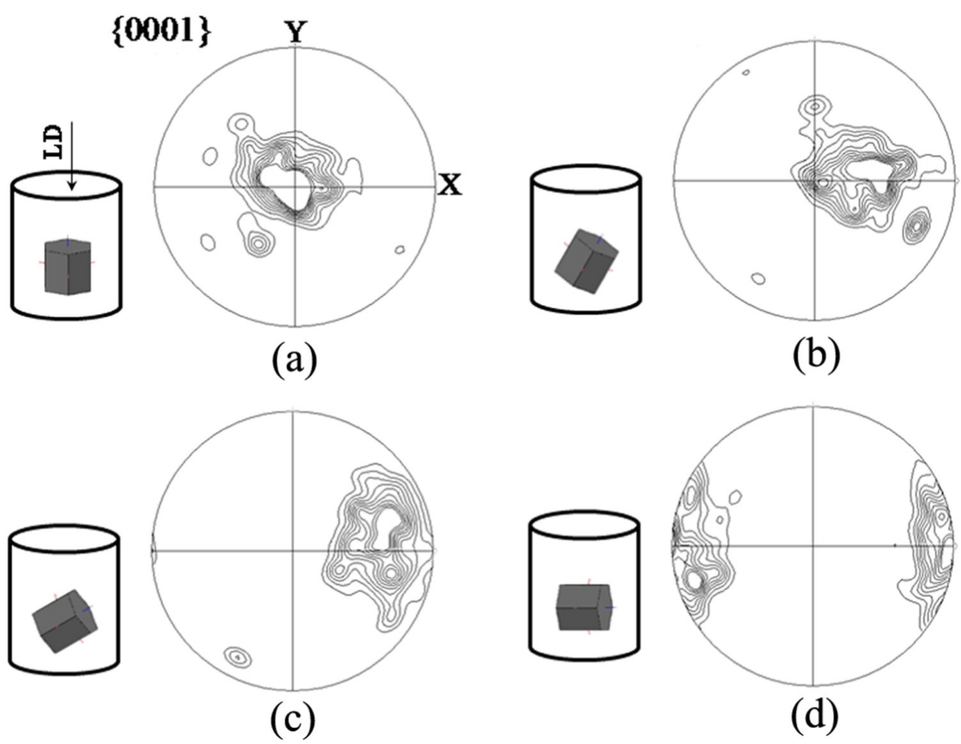

Fig. 2. (0001) pole figures of four sample orientations used for DPD testing: (a) 0°; (b) 30°; (c) 60°; (d) 90°. LD is the loading direction.