

Multiple twinning modes in rolled Mg–3Al–1Zn alloy and their selection mechanism

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ABSTRACT

Rolled Mg–3Al–1Zn alloy subjected to consecutive in-plane compressions along two orthogonal directions exhibited multiple twinning modes: {10–12} twinning in residual parent grain, {10–12}–{10–12} double twinning in twin band, and {10–12} detwinning in twin band. A combined examination of the in situ electron backscatter diffraction technique and Schmid factor (SF) analysis revealed that the selection mechanism of each type of twinning mode is governed by the combined effect of the SF and grain size, and this controls the texture evolution developed.

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1. Introduction

It is well known that the specific texture of wrought magnesium (Mg) alloys, developed during manufacturing process, with most basal planes aligned parallel to the process direction is susceptible to the {10–12} twinning, as compressive load is applied along the process direction (i.e., compression perpendicular to the *c*-axis of the hexagonal close-packed (hcp) lattice) [1–10]. The {10–12} twinning introduces a crystallographic lattice rotation of 86.3° [7,8]. Moreover, the loading condition of compression perpendicular to the *c*-axis activates just one twin variant pair adjacent to the loading direction and this causes the *c*-axis in twin regions to be arranged along the specific direction (i.e., twin texture) [9,10]. This fact indicates that two types of textures can coexist in the material being compressed along the process direction; initial and twin textures with the *c*-axis aligned almost perpendicular and parallel to the loading axis, respectively. If compressive load is further applied to this deformed material along the different direction in the process plane (i.e., multiple compressive loadings), different types of twinning modes can be possible, depending on the angle relationship between two compressive loading directions applied; for example, as subsequent compressive load is applied along the direction perpendicular to the initial compressive loading, both

residual parent grains and twin bands are subjected to the loading condition of compression perpendicular to the *c*-axis, indicating that, theoretically, the {10–12} twinning can occur in both of them. In practice, such a multiple compressive loading condition can easily occur from the manufacture of wrought materials (rolling, levelling, coiling, etc.), handling process, production of final products (typically sheet forming involving both bending and stretching), etc.

It has been recently reported that the {10–12} twinning plays an important role in the deformation of wrought Mg alloys [4,10]: (1) accommodation of plastic strain, causing a low flow stress and strain hardening rate; (2) Hall–Petch hardening by twinning-induced grain size change; (3) twin texture induced change in activities of slip systems. These facts suggest that a change in twinning characteristics, caused by multiple compressive loadings, would have a significant effect on the deformation behavior of wrought materials and the production process of final products, and thus a detailed study on this topic is required.

In this study, therefore, twinning behavior of rolled Mg alloy subjected to consecutive in-plane compressions along two orthogonal directions was investigated using the in situ electron backscatter diffraction (EBSD) technique in combination with the SF analysis.

2. Experimental details

The material used in this study was a commercial hot-rolled AZ31 Mg alloy (Mg–3.6Al–1.0Zn–0.5Mn) plate of 50 mm thickness, which was homogenized at 400 °C for 4 h; an average linear

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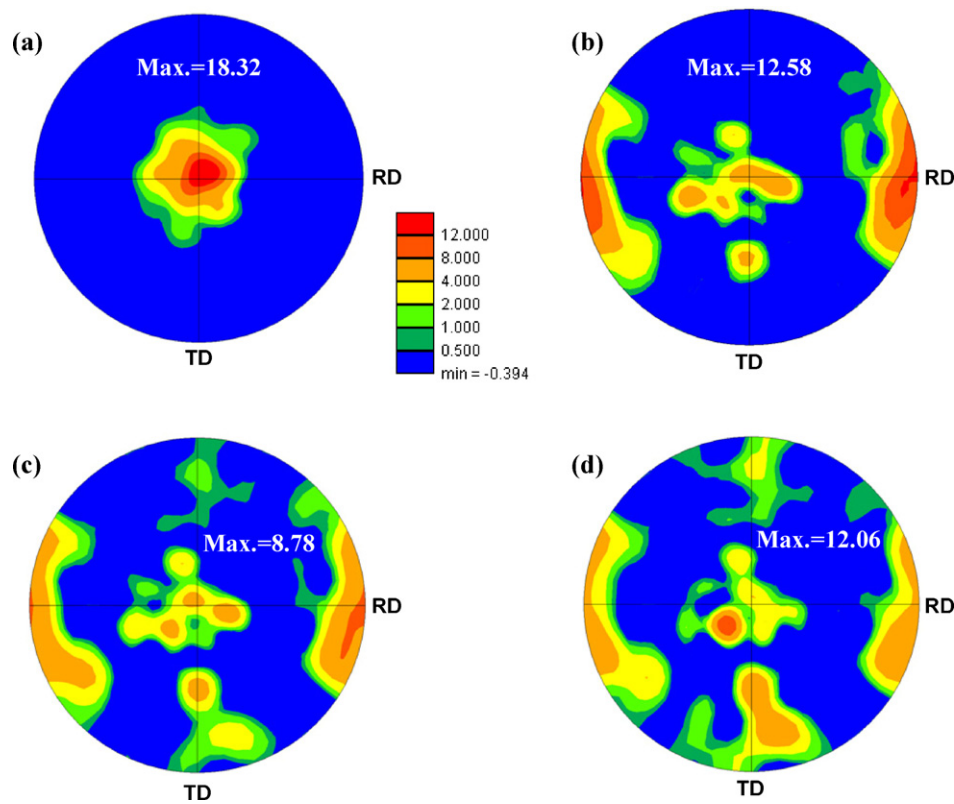


Fig. 1. (0002) pole figures: (a) the as-rolled material, (b) the material compressed to 6% along the RD, (c) the material compressed to 6% along the RD and subsequently compressed to 3% along the TD, and (d) the material compressed to 6% along the RD and subsequently compressed to 6% along the TD.

intercept grain size was $\sim 30 \mu\text{m}$. The material exhibited a twin-free equiaxial grain structure, and an intense basal texture with a *c*-axis aligned parallel to the normal direction (ND) to the rolling plane (i.e., RD–TD plane) and a randomly oriented *a*-axis in the RD–TD plane (Fig. 1a); RD and TD represent the rolling and transverse directions, respectively.

Test specimens of rectangular plate shape with a dimension of $10 \text{ mm} \times 10 \text{ mm} \times 5 \text{ mm}$ (length $\times$ width $\times$ thickness) were machined from the homogenized plate; the length and width directions correspond to the RD and TD, respectively. For EBSD examination, the specimen surface was ground on 2400 grit silicon carbide papers and polished using $1 \mu\text{m}$ diamond paste, followed by a final polish with colloidal silica.

The specimen was compressed to 6% along the RD and unloaded. Then, it was further compressed to 3 and 6% along the TD. All tests were conducted using an INSTRON 8801 testing machine at room temperature and a strain rate of 10^{-3} s^{-1} . For EBSD examination, after compressing the specimen to each strain level required, it was

unloaded. Then, this unloaded specimen was examined with EBSD installed in a field emission scanning electron microscope. Analysis of the EBSD data was accomplished with TSL OIM analysis software and the data with a confidence index of >0.1 were used for twin variant and texture analysis.

To examine the Hall–Petch effect on the $\{10\text{--}12\}$ twinning, which requires the control of grain size, the as-rolled material was further processed by combining the annealing and additional rolling processes. The as-rolled material of 50 mm thickness plate was rolled to 10 mm thickness sheet at 350°C with an 8% thickness reduction per pass (total ten passes were applied). Then, the additionally rolled material as well as the as-rolled material was annealed at 350 and 500°C . The detailed conditions of annealing process and the resultant grain size are given in Table 1. It is noted that the texture of the materials remained almost unchanged (i.e., intense basal texture) despite of the additional rolling and annealing processes. Compression tests were conducted on these grain size controlled materials; testing details were the same as above.

Table 1
Grain size control via additional rolling and annealing processes.

Material	Annealing	Grain size (μm)	Yield strength (MPa)	Texture
As-rolled material	–	30	66	Basal texture (18 ^b)
	500°C , 1 h	39	58	Basal texture (18)
	500°C , 48 h	82	48	Basal texture (20)
Additionally rolled material ^a	350°C , 1 h	7	95	Basal texture (18)
	500°C , 0.5 h	10	83	Basal texture (14)
	500°C , 1 h	11	79	Basal texture (15)
	500°C , 6 h	25	62	Basal texture (17)
	500°C , 48 h	23	63	Basal texture (13)

^a The as-rolled material of 50 mm thickness plate was rolled to 10 mm thickness sheet at 350°C with an 8% thickness reduction per pass (total ten passes were applied).

^b The number in parenthesis indicates the maximum pole intensity in the basal pole figure, taken by EBSD.

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