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Regulating precipitate orientation in Mg-Al alloys by coupling twinning, aging and detwinning processes

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ABSTRACT

The orientation of basal precipitates in AZ80 Mg alloy is altered by coupling twinning, aging and detwinning processes. This gives the prismatic precipitates with their broad plane parallel to one of the $\{10\bar{1}0\}_\alpha$. Such prismatic precipitates significantly improve the compressive and tensile strength of AZ80 Mg alloy compared to the basal precipitates. This paper provides a new way to regulate precipitate orientation and hence its hardening response in Mg alloys.

One major limitation of commercial Mg alloys in automotive application is their low strength. Precipitation hardening is one of the most efficient ways to improve strength [1,2]. To enhance aging hardening response in Mg alloys, extensive studies have been carried out, aiming to increase the volume, reduce the size and optimize the distribution of precipitates [3–7]. Despite these great efforts, the hardening response in many economic Mg alloys such as Mg-Al serial is still unsatisfied. The major strengthening in Mg-Al alloys is the continuous precipitation of $Mg_{17}Al_{12}$ phase, which is plate-like, formed on the basal plane of Mg matrix (hereafter named basal plates) [8,9]. These basal plates generally give poor strengthening compared to the prismatic plates formed in Mg-Y alloys [10,11]. Attempts to promote prismatic plates have been made by two-steps aging [12] or microalloying additions [13]. But such methods are either inefficient or confined in certain alloy systems.

Twinning is an important deformation mode for Mg alloys. Profuse twinning can be generated by loading along certain directions for strongly textured Mg alloys [14]. Since twinning can induce drastic change of *c*-axis, it has been widely used to tailor the texture of Mg alloys [15]. When a twinned structure is further strained in the reverse direction, detwinning may occur with the *c*-axis rotating back to the original direction [16]. Previous work indicates that the precipitates in Mg alloys may increase the stress for twin growth or detwinning but do not prohibit them [17–19]. Twinning generally engulfs precipitates in Mg alloys and induces only a small rotation of the precipitates [20]. Therefore, if aging treatment is conducted before twinning or detwinning, the orientation of precipitates with respect to Mg matrix, i.e. the orientation relationship (OR) could be altered. Moreover, recent work shows that pre-twinning deformation can promote continuous precipitation and inhibit discontinuous precipitation in Mg-Al alloys [21,22]. This is also beneficial to the aging hardening response. The above results and speculation imply that it could be effective to tailor the precipitate orientation in Mg alloys by coupling twinning, aging and detwinning (named TAD) processes. The purpose of this paper therefore, aims to apply such concept to alter the orientation of basal plates in Mg-Al alloys and hence to enhance their precipitation strengthening.

The alloy used here is a 40 mm thick hot rolled AZ80 plate. The plate was solution treated at 420 °C for 24 h, and then quenched into water at room temperature. This solution-treated plate is free of precipitates and has a typical basal texture. The representative EBSD map and pole figure are provided in the supplementary material (see Fig. S1). Cubic block specimens with 11 mm × 35 mm × 13 mm along RD, TD and ND were machined from the as-solution rolled plate and then subjected to TAD processes. Here, RD, TD and ND designate the rolling direction, transverse direction and normal direction of the rolled plate, respectively. As illustrated in Fig. 1, TAD processes consist of four steps and the purpose of each step was briefly described below:

(i) In-plane compression (along TD by 8%): change the lattice orientation by generating a complete twinned microstructure. This also promotes continuous precipitation.
(ii) Aging treatment (at 185 °C for 30 h): introduce vast continuous precipitation.

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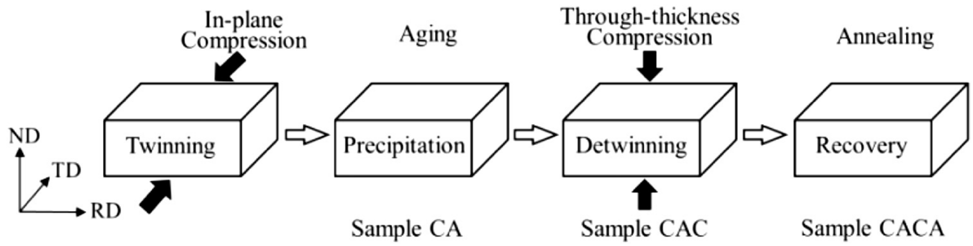

Fig. 1. Schematic diagram of TAD processes and the samples produced in each step.

(iii) Through-thickness compression (along ND by 8%): re-change the lattice orientation by detwinning, and thus alter the OR of precipitates.
(iv) Annealing treatment (at 185 °C for 2 h): eliminate dislocations produced in the previous step, and thus better evaluate the strengthening effect ascribed to the precipitates.

The samples produced in the last three steps are denoted as Sample CA, Sample CAC and Sample CACA, respectively (see Fig. 1). In addition, some solution-treated sample was directly aged at 185 °C for 30 h, and is denoted as Sample A.

The microstructure and texture evolutions of various samples were examined by electron backscatter diffraction (EBSD) analysis using an HKL Channel 5 System equipped in a field emission gun scanning electron microscope (TESCAN MIRA3). Thin foil specimens for transmission electron microscopy (TEM) observations were prepared by punching 3 mm diameter discs and then ion-beam milling using Gatan PIPS 695. Precipitates were examined by a JEOL 2100 TEM operating at 200 kV. Mechanical properties were evaluated by compression and tensile tests using a standard universal testing machine (AG-X) at a strain rate of 1×10^{-3} s^{-1}. The samples for compression test have the dimensions of 11 × 8 × 6 mm (height × width × thickness). The tensile test samples have a gauge length of 8 mm, and the width and thickness are 3 mm and 1.5 mm, respectively. Each mechanical test was repeated three times to get representative results.

The (0002) pole figures of four different samples are shown in Fig. 2. It indicates that Sample A exhibits a typical basal texture with most basal planes parallel to the rolling plane. But the *c*-axis of Sample CA was oriented parallel to TD due to the activation of $\{10\bar{1}2\}$ twinning by compression along TD [23]. The basal poles in Fig. 2b nearly disappeared, indicating most grains are completely twinned. The *c*-axis of most grains in Sample CAC was returned to ND due to the activation of detwinning. Thus, Sample CAC exhibits basal texture again. After annealing, the basal texture was retained in Sample CACA (see Fig. 2d). Compared with Sample A, the texture intensity of Sample CAC decreases slightly. This is because dislocation slip may also occur during the compression deformation. Moreover, a few twinned grains may not be detwinned during compression along ND. Alternatively, secondary twinning may be activated, generating slightly different orientation to

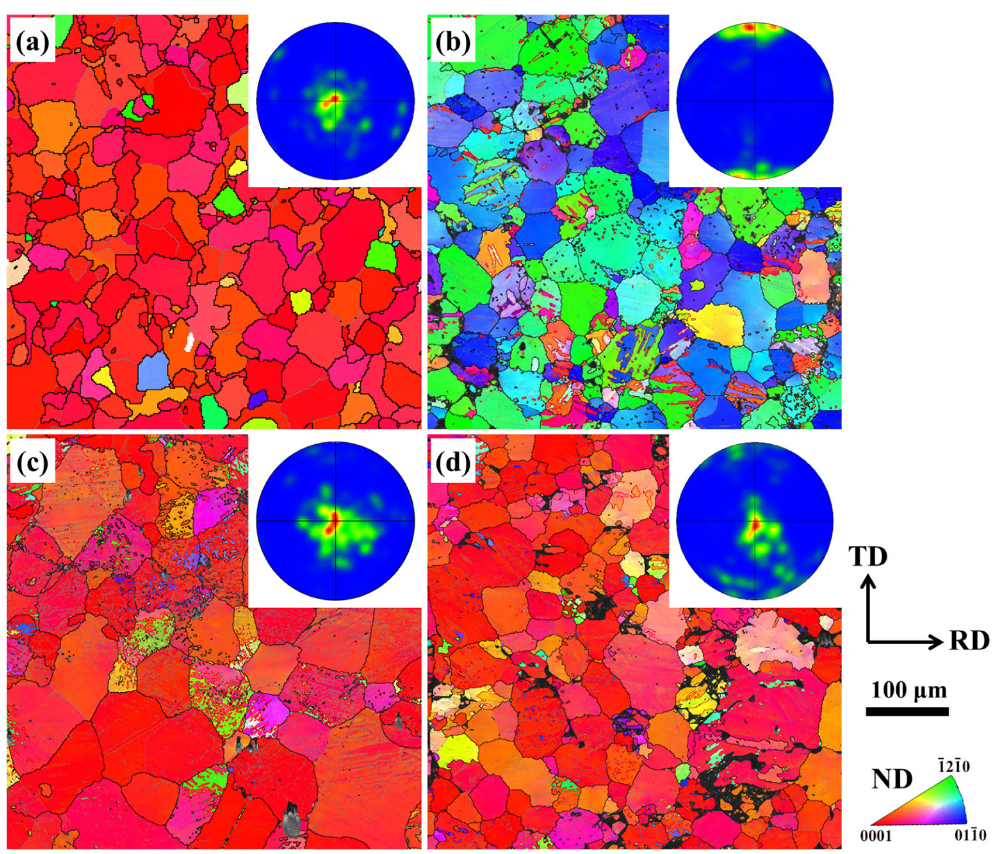

Fig. 2. EBSD IPF maps of (a) Sample A, (b) Sample CA, (c) Sample CAC and (d) Sample CACA. The corresponding (0002) pole figures are presented as the insets. The texture intensities in (a)–(d) are 22.8, 22.5, 14.2 and 15.9, respectively.