Materials Science & Engineering A 619 (2014) 328–333

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Enhancing yield strength by suppressing detwinning in a rolled Mg–3Al–1Zn alloy with $\{10\bar{1}2\}$ twins

Jeong Hun Lee [a], Taekyung Lee [b], Seok Weon Song [c], Sung Hyuk Park [d,*], Chong Soo Lee [a,c,**]

[a] Department of Materials Science and Engineering, Pohang University of Science and Technology (POSTECH), Pohang 790-784, Republic of Korea
[b] Center for Advanced Aerospace Materials, Pohang University of Science and Technology (POSTECH), Pohang 790-784, Republic of Korea
[c] Graduate Institute of Ferrous Technology (GIFT), Pohang University of Science and Technology (POSTECH), Pohang 790-784, Republic of Korea
[d] Light Metal Division, Korea Institute of Materials Science (KIMS), Changwon 642-831, Republic of Korea

ARTICLE INFO

Article history:
Received 25 June 2014
Received in revised form
25 September 2014
Accepted 27 September 2014
Available online 5 October 2014

Keywords:
Magnesium alloys
Double twin
Yield strength
Detwinning
Slip

ABSTRACT

A remarkable improvement in the tensile yield strength of rolled Mg–3Al–1Zn alloy with pre-existing $\{10\bar{1}2\}$ twins was achieved by inducing double twinning through compression deformation. The resulting formation of $\{10\bar{1}2\}$–$\{10\bar{1}2\}$ double twins inside pre-existing $\{10\bar{1}2\}$ twin bands effectively suppressed the detwinning of pre-existing twins during subsequent deformation. This in turn led to a change in the dominant deformation mode from detwinning to slip, significantly increasing the yield strength. The mechanisms behind this behavior are considered to be a combination of the redistribution of residual tensile stress within pre-existing twins, refinement of pre-existing twins by double twins, a change in texture due to double twinning and a loss of coherency at twin boundaries.

1. Introduction

The limited number of independent slip systems in Mg alloys makes their primary twin system, $\{10\bar{1}2\}$ twinning, an important mechanism in the early stages of deformation at room temperature [1]. In wrought Mg alloys with a strong basal texture, the polar nature of this $\{10\bar{1}2\}$ twinning produces tension/compression yield asymmetry due to its activation stress being much smaller than that required for slip [2–4]. In addition, regions affected by $\{10\bar{1}2\}$ twinning are reoriented to 86.3°, making them favorably oriented for detwinning during subsequent reversed loading [5]. As the detwinning process does not require the nucleation of new twins [6] and its activation stress is therefore very low, detwinning consequently results in low yield strength under conditions where detwinning is dominant. This combination of low yield strength and the yield asymmetry associated with detwinning greatly restricts the practical application of Mg alloys, especially in structural components that are subjected to tension and compression simultaneously [7].

To reduce the yield asymmetry caused by $\{10\bar{1}2\}$ twinning, extensive research has been carried out into suppressing twinning activity through either refining the grain structure or randomizing the texture using various deformation processes, such as equal channel angular extrusion [8], differential speed rolling [9], caliber rolling [10], and low-temperature, slow-speed extrusion [11]. However, there have been only a limited number of investigations into the suppression of $\{10\bar{1}2\}$ detwinning in wrought Mg alloys with pre-existing $\{10\bar{1}2\}$ twins. Recent reports have suggested that annealing can retard detwinning activity in pre-strained AZ31 alloys with $\{10\bar{1}2\}$ twins during its early stages of deformation by increasing the activation stress for detwinning through the removal of residual tensile stresses developed inside $\{10\bar{1}2\}$ twins [12], or the segregation of solute atoms at $\{10\bar{1}2\}$ twin boundaries [13]. However, despite the apparent effectiveness of annealing in increasing the detwinning stress by 20–30 MPa, the fact that detwinning remains the dominant deformation mode in the early stages of deformation results in a sigmoidal flow curve.

In this study, the tensile yield strength of pre-compressed AZ31 Mg alloy with $\{10\bar{1}2\}$ twins was improved by changing the predominant deformation mechanism from detwinning to slip. This was achieved by forming $\{10\bar{1}2\}$–$\{10\bar{1}2\}$ double twins inside pre-existing $\{10\bar{1}2\}$ twins via compression along the direction most favorably oriented for double twinning, which effectively suppressed the detwinning activity of the pre-existing twins. This suppressed detwinning behavior was then

* Corresponding author. Tel.: +82 55 280 3516; fax: +82 55 280 3299.
** Corresponding author. Tel.: +82 54 279 9001; fax: +82 54 279 9099.
E-mail addresses: shpark@kims.re.kr (S.H. Park), cslee@postech.ac.kr (C.S. Lee).

http://dx.doi.org/10.1016/j.msea.2014.09.097

analyzed in terms of the variation in microstructural characteristics it creates.

2. Experimental procedure

Commercial AZ31 Mg alloy plates hot-rolled to 50 mm in thickness were homogenized at 400 °C for 10 h. To generate $\{10\bar{1}2\}$ twins, rectangular bars were machined from the plate to dimensions of 40 mm × 40 mm × 10 mm in the rolling direction (RD), transverse direction (TD), and normal direction (ND), respectively. These bars were initially compressed to a strain of 2% along the RD at room temperature (RT), with these compressed sample hereafter denoted as "RD2C". Next, some of these RD2C samples were further compressed to a strain of 5% along the TD at RT, being denoted as "RD2C-TD5C". Finally, these RD2C and RD2C-TD5C samples were machined into dogbone-shaped specimens with a rectangular gage section of 10 mm × 5 mm × 3 mm (length × width × thickness) for tension tests, in which the loading axis corresponded to the RD. All tests were conducted using an INSTRON 8801 testing machine at RT and a strain rate of $10^{-3}\ s^{-1}$. To ensure the accuracy of stress–strain curves, tests for each sample were repeated three times to confirm the repeatability and consistency of the results. For the sake of simplicity, however, a representative curve for each test is used in this paper.

To allow analysis by electron backscatter diffraction (EBSD), the surface of the specimens was progressively smoothed using 800–4000-grit silicon carbide paper, then electropolished at 30 V for 10 s. Both as-rolled and deformed specimens were examined with EBSD installed in a field emission scanning electron microscope using TSL data acquisition software. The EBSD data obtained was analyzed using TSL OIM analysis software and data points with a confidence index > 0.1 were used to identify the microstructural characteristics.

3. Results and discussion

Fig. 1 shows the variation in the microstructural characteristics (twin morphology and texture) that is created by consecutive in-plane compression tests. Note that the initial as-rolled material has a twin-free equiaxed grain structure, with an average grain size of ~30 μm and an intense basal texture with a randomly oriented *a*-axis in the rolling plane (Fig. 1a). However, as a compressive load is applied along the RD the material is compressed perpendicular to the *c*-axis, which facilitates $\{10\bar{1}2\}$ twinning and gives rise to a crystallographic lattice rotation of 86.3° in the twinned regions. The RD2C material therefore exhibits numerous $\{10\bar{1}2\}$ twins and a twin texture with a *c*-axis aligned closely to the RD, as shown in Fig. 1b. With the application of further compressive load to this RD2C material along the TD, both parent grains and twins are subjected to compression that is nearly perpendicular to the *c*-axis, and thus $\{10\bar{1}2\}$ twinning and $\{10\bar{1}2\}$–$\{10\bar{1}2\}$ double twinning can occur in residual parent grains and twin bands, respectively. As a result, the RD2C-TD5C material exhibits three types of twins (Table 1): $\{10\bar{1}2\}$ twins generated by RD compression (*i.e.*, RD twins), $\{10\bar{1}2\}$ twins in residual parent grains generated by TD compression (*i.e.*, TD twins), and $\{10\bar{1}2\}$–$\{10\bar{1}2\}$ double twins formed inside RD twins. These twins create a fine and complex microstructure, with the effective size of twinning induced domains, which are surrounded by high-angle grain or twin boundaries, being ~10 μm (Fig. 1c). Given that $\{10\bar{1}2\}$ twinning causes the *c*-axis of the twinned region to align along the loading axis, the initial texture and RD twin texture become weak, and a new texture with a *c*-axis aligned close to the TD is developed with an additional compression along the TD. To provide a clearer explanation of this, the twin structures of both the RD2C and RD2C-TD5C materials are shown schematically in Fig. 2a.

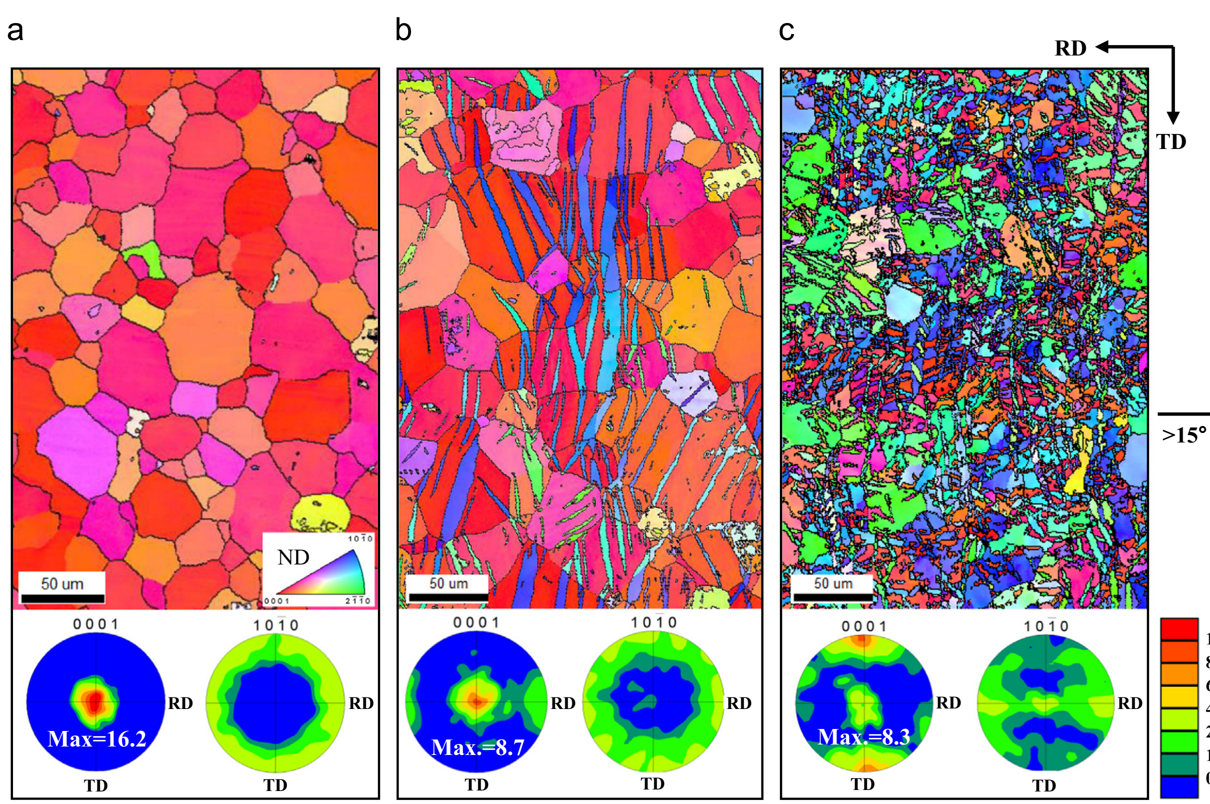

Fig. 1. Inverse pole figure maps and corresponding (0001) and $(10\bar{1}0)$ pole figures for AZ31: (a) as-rolled, (b) compressed to 2% strain along the RD, and (c) compressed to 2% strain along the RD then 5% strain along the TD.