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Controlling the microstructure of magnesium alloy sheet during rolling

Se-Jong Kim*, Chang Dong Yim, Young-Seon Lee, Jong-Hun Yoon, Jung Hwan Lee

Korea Institute of Material Science, 66 Sangnam-dong, Changwon-si, Gyeongnam 641-831, South Korea

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ABSTRACT

A hot rolled magnesium alloy sheet embedded in a steel block was rolled together with 3% thickness reduction at room temperature, 373 K, and 673 K. Tensile twins were observed after the rolling, which could not be found when the magnesium alloy sheet was rolled without the steel block. The twin fraction was the highest at 373 K because of thermal expansion and activating non-basal slip systems at high temperature. Electron back-scattered diffraction analysis and finite element simulations confirmed that the steel block with higher strength played an important role in generating compressive stress along the transverse direction in the magnesium alloy sheet. The compressive stress could increase owing to suppression of thermal expansion in the magnesium alloy sheet at 373 K. The yield stress and the tensile stress became higher in the rolled specimen with the steel block at 373 K than in the specimen without it owing to grain refinement caused by tensile twins.

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1. Introduction

Magnesium alloys, which have high specific strength and low density, have recently attracted much research interest because of their potential applications in lightweight structural components [1,2]. Their applications are restricted, however, because of their poor formability at low temperature owing to the limited number of easily activated slip systems and the specific texture, which are formed during the manufacturing process [3–5]. Therefore, the {10–12}s tensile twin plays an important role in the deformation of Mg alloys at low temperature by helping the material satisfy the von Mises criterion [4]. The {10–12} tensile twin, which can occur when a tensile load is applied along the *c*-axis (i.e. compressive load perpendicular to the *c*-axis), induces a crystallographic lattice rotation of 86.3° in twinned regions. This leads to accommodation of plastic strain causing a low flow stress and strain hardening rate, grain refinement resulting in the Hall–Petch hardening and change in activities of slip systems [6,7]. Much research has been conducted to improve the mechanical properties of magnesium alloys using tensile twinning.

Song et al. [8] pre-rolled the AZ31 magnesium alloy plate along the transverse direction (TD) with a small thickness reduction ($<5\%$) to generate the {10–12}tensile twin; the resulting level of tension-compression asymmetry was significantly reduced, and the strength of AZ31 plates along the rolling direction (RD) was enhanced.

Xing et al. [9] reported that the {10–12}tensile twin, generated by pre-rolling along the TD at room temperature (RT), could improve the rolling capability of a magnesium alloy plate at high temperature by rotating the basal plane to a favorable direction for activating the ⟨a⟩ type non-basal slip system.

Park et al. [10] indicated that a pre-existing {10–12}tensile twin, produced by forging a casting billet along the longitudinal at RT, could improve the mechanical properties of the extruded magnesium alloy by increasing dynamically recrystallized (DRX) grain fraction since the {10–12}tensile twin boundary provides a nucleation site for the DRX grains during extrusion.

The aforementioned methods, however, are only applicable to a thick magnesium alloy plate or an extruded magnesium alloy. In the case of the rolled magnesium alloy sheet, it is difficult to apply favorable loading condition for initiation of the {10–12} tensile twin.

In this study, we present a new method of rolling a magnesium sheet embedded in a steel block with higher strength for the development of the {10–12} tensile twin in the magnesium alloy sheet. The effect of the steel block on the microstructure of the rolled specimen was investigated as a function of the rolling temperature, and the results were compared to those in the rolled specimen without the steel block. Electron back-scattered diffraction (EBSD) analysis and finite-element (FE) simulations were also carried out to reveal the mechanism behind the process.

2. Experimental procedures

The material used in this study was a commercial hot-rolled AZ31B (Mg–3 Al–1 Zn–0.3 Mn in wt%) plate. The material has polygonal grains and a strong basal texture, which is the typical rolling texture for magnesium alloys. The initial microstructure

* Corresponding author. Tel.: +82 55 280 3829; fax: +82 55 280 3849.
E-mail address: ksj1009@kims.re.kr (S.-J. Kim).

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and texture are shown in Fig. 1a and b. The as-received material was machined into pieces with dimensions of 90 mm × 12 mm × 1.2 mm along the RD, TD, and normal direction (ND), respectively. The machined magnesium sheet was embedded in the steel block (Fe–0.12C–0.20 Si–0.87 Mn in wt%) with dimensions of 90 mm × 12 mm × 2.4 mm along the RD, TD and ND whose strength was higher than that of the magnesium alloy sheet. Fig. 1c shows an illustration of a specimen. The specimens were rolled using a rolling mill with a diameter of 250 mm at RT, 373 K, and 673 K with the thickness reduced by 3%. The rolling speed was fixed at 2 rpm. The specimens were homogenized at the nominal rolling temperature for 20 min and then rolled immediately. Before and after rolling, the specimens were observed under an optical microscope at three different points in the mid RD plane, which correspond to the edge, quarter and center regions along the TD. Texture analysis using EBSD and a tensile test were subsequently carried out for the specimens rolled at 373 K. The results were compared to those for the rolled magnesium alloy sheet without the steel block at the same temperature to identify the effect of the steel block on change in the microstructure of the magnesium alloy sheet during rolling. The EBSD analysis was carried out at the edge region on the RD plane after 3% reduction using a Hitachi SU-6600 field emission scanning electron microscope equipped with a TSL OIM™ EBSD system. The sample preparation was carried out following a previously reported method [11]. The accelerating voltage was kept constant at 15 kV. The spatial resolution (i.e., step size) between two adjacent pixels was 0.5 μm. The scanned area in the specimen was 190 μm × 300 μm. The tensile specimens with a gage length of 25 mm were machined along the RD from the rolled specimens with and without the steel block and their tensile properties were measured at RT with a strain rate of 1.0×10^{-3}.

3. Results and discussion

Fig. 2a–c shows the microstructures in the edge, quarter and center regions along the TD on the RD plane after homogenizing at nominal rolling temperatures of RT, 373 K and 673 K for 20 min. A significant number of lenticular twins were found in the microstructure homogenized at 373 K, and their volume fractions were similar regardless of the observation position in the three regions. The coefficient of thermal expansion (*CTE*) was higher in the magnesium alloy sheet (26.4 μm/mK) than in the steel block (11.5 μm/mK) [12,13]. Therefore, the thermal expansion along the TD of the magnesium alloy could be prevented by the contiguous steel block with lower CTE during homogenization. This could induce compressive stress along the TD in the magnesium alloy sheet, which was a favorable stress state for the initiation of tensile twinning in grains with a basal texture [14]. It could be expected that the twin volume fraction would be highest at 673 K, where the compressive stress in the magnesium alloy sheet would be the highest. However, the expected maximum was not observed in the experimental result, which could be explained by activation of non-basal slip systems at high temperature. This will be discussed in more detail in a later section of this paper.

After rolling with the steel block, significant change in the microstructure was observed. Compared to the microstructures before rolling, the twin volume fractions distinctively increased after rolling with the steel block. The twin volume fraction was the highest in the rolled specimen with the steel block at 373 K (Fig. 3b), but the twins could hardly be found in the rolled specimen without the steel block at the same temperature (Fig. 3d). It could be deduced that the compressive stress along the TD was developed in the magnesium alloy sheet during the rolling owing to the difference in mechanical properties between

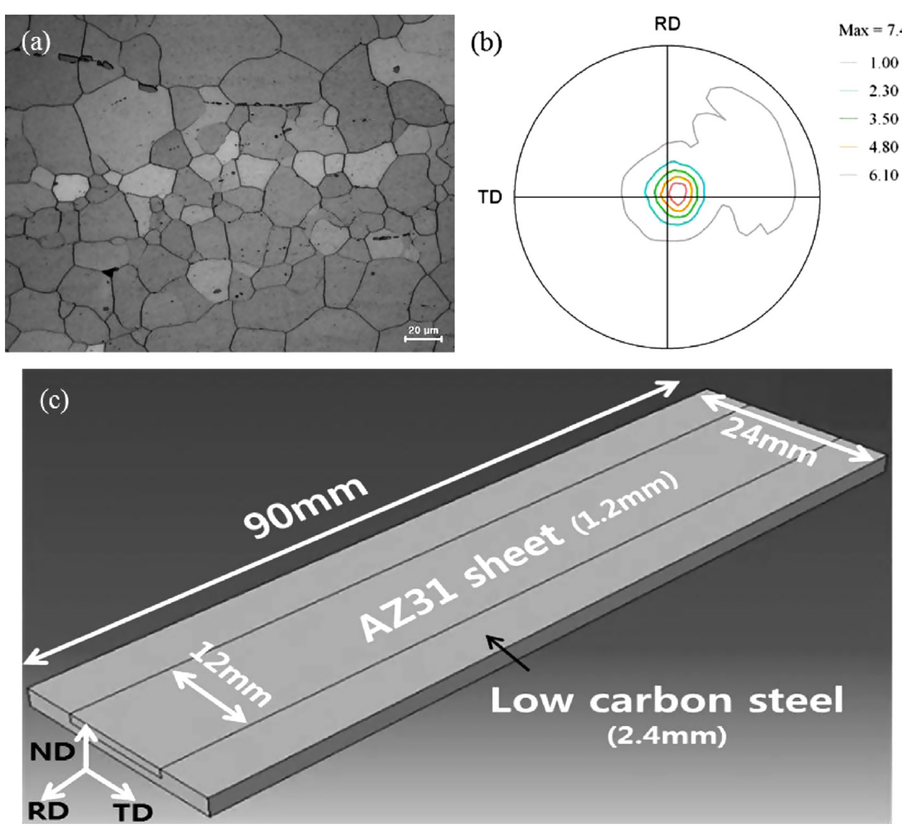

Fig. 1. (a) Microstructure and (b) (0 0 0 1) pole figure of the as-received specimen obtained by optical microscopy and X-ray diffraction, respectively. (c) Schematic diagram showing the specimen dimensions.

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