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Dynamic recrystallization behavior and microstructural evolution of Mg alloy AZ31 through high-speed rolling

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ABSTRACT

High-speed rolling (HSR) is known to improve the workability of Mg alloys significantly, which makes it possible to impose a large reduction in a single pass without fracture. In the present study, dynamic recrystallization (DRX) behavior and microstructural and textural variations of Mg alloy AZ31 during a HSR process were investigated by conducting rolling with different imposed reductions in the range of 20%–80% at a high rolling speed of 470 m/min and 400 °C. High-strain-rate deformation during HSR suppresses dislocation slips but promotes twinning, which results in the formation of numerous twins of several types, i.e., {10–12} extension twins, {10–11} and {10–13} contraction twins, and {10–11}–{10–12} double twins. After twinning, high strain energy is accumulated in twin bands because their crystallographic orientations are favorable for basal slips, leading to subsequent DRX at the twin bands. Accordingly, twinning activation and twinning-induced DRX behavior play crucial roles in accommodating plastic deformation during HSR and in varying microstructure and texture of the high-speed-rolled (HSRed) sheets. Area fraction of fine DRXed grains formed at the twin bands increases with increasing rolling reduction, which is attributed to the combined effects of increased strain, strain rate, and deformation temperature and a decreased critical strain for DRX. Size, internal strain, and texture intensity of the DRXed grains are smaller than those of unDRXed grains. Therefore, as rolling reduction increases, average grain size, stored internal energy, microstructural inhomogeneity, and basal texture intensity of the HSRed sheets gradually decrease owing to an increase in the area fraction of the DRXed grains.

1. Introduction

With the tightening of international regulations on carbon dioxide emissions and fuel efficiency of vehicles, Mg alloys have attracted considerable attention in view of their density being lower than that of other metallic materials such as Al alloys and steels. In particular, rolled Mg alloys have superior mechanical properties (e.g., strength [1–4], ductility [3,5,6], fatigue resistance [6], and fracture toughness [7]) to cast Mg alloys, and therefore, extensive efforts have been made toward the application of rolled Mg alloys in various modes of transportation, such as automobiles, high-speed trains, and aircraft. However, conventional rolling processes are generally performed by imposing relatively small reductions per pass (10%–30%) at high temperatures (>350 °C). In this case, since the strain applied during one rolling pass is small, a number of rolling passes are required to obtain thin Mg sheets and intermediate annealing between rolling passes is necessary to compensate for the temperature drop during rolling [8–12]. This time- and energy-consuming rolling process causes a drop in productivity, which consequently leads to an increase in the price of the fabricated products. In view of this problem, there is a pressing need to simplify the conventional rolling processes via a reduction in the number of cycles of hot rolling and annealing in order to lower the processing cost and to expand the application range of rolled Mg alloys.

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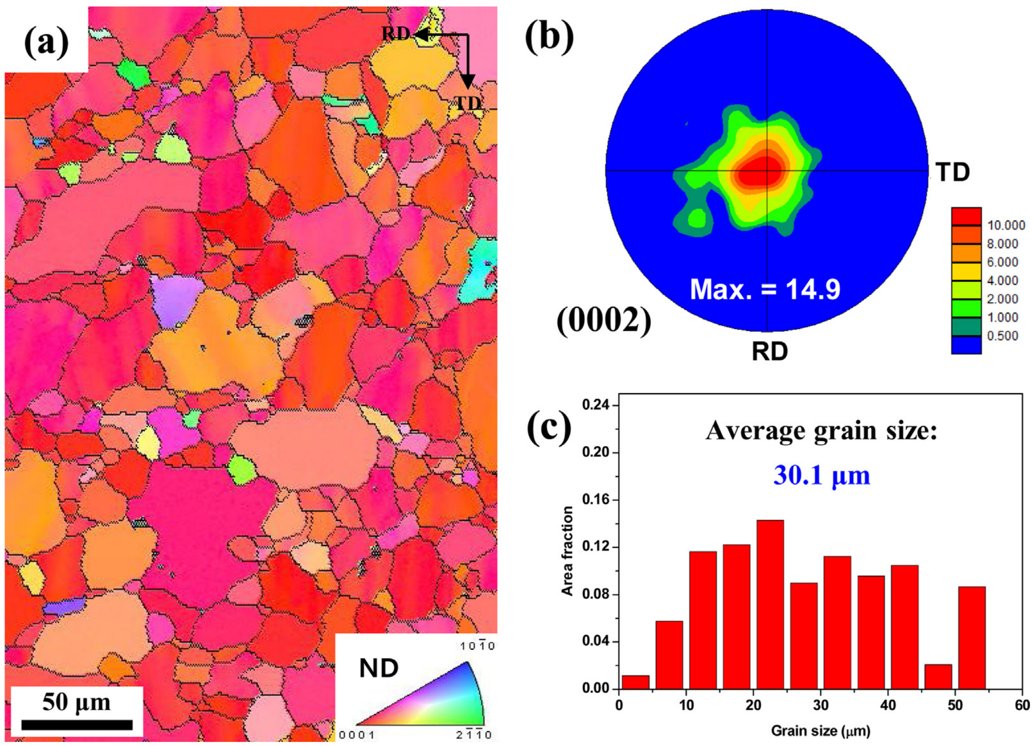

Fig. 1. Microstructural characteristics of initial material: (a) inverse pole figure map, (b) (0002) pole figure, and (c) grain size distribution.

Table 1
Process parameters of high-speed rolling and microstructural characteristics of high-speed-rolled (HSRed) samples with different reductions.

Rolling reduction	Processing parameters		Microstructural characteristics					
	Strain	Strain rate (s^{-1})	f_{DRX} (%)	d_{avr} (µm)	d_{DRX} (µm)	d_{unDRX} (µm)	I_{max}
20%	0.22	91	16.1	20.9 (14.2)	5.0 (2.4)	23.9 (13.5)	14.0
40%	0.51	128	50.2	11.6 (12.9)	4.3 (2.1)	18.9 (14.9)	13.3
60%	0.92	157	63.8	6.7 (6.4)	3.9 (2.0)	11.4 (8.3)	12.1
80%	1.61	181	95.2	3.4 (1.5)	3.3 (1.3)	5.0 (2.1)	11.3

f_{DRX} denotes the area fraction of recrystallized grains.
d_{avr}, d_{DRX}, and d_{unDRX} denote the average grain sizes of total, recrystallized, and unrecrystallized regions, respectively.
I_{max} denotes the maximum intensity of (0002) pole figure.
The values in parentheses denote the standard deviation.

Recently, it has been reported that the workability of Mg alloys improves remarkably via rolling at high speeds (>~200 m/min). As a result, large reductions (50%–80%) can be imposed in a single pass and the rolling can be successfully performed without fracture at low temperatures (<200 °C), even at room temperature. For instance, Zhu et al. [13] showed that a cast billet of ZK60 alloy could be rolled down to 80% reduction in one pass with a high strain rate of 9.1 s^{-1} at 200 °C. Su et al. [14] reported that an AZ31 alloy sheet could be rolled to 72% reduction by a single pass at a rolling speed of 1000 m/min at 100 °C. Koh et al. [15] and Li et al. [16] demonstrated that even at room temperature, 60% reduction could be achieved in an AZ31 alloy sheet at a rolling speed of 2000 m/min. This outstanding workability achieved by the high-speed rolling (HSR) process is known to be attributable to several factors: preferred initiation of twinning and subsequent dynamic recrystallization (DRX) [17], homogeneous distribution of shear bands [18,19], activation of <*c* + *a*> slip systems [16,20,21], and high deformation heating [15,16,22].

When Mg alloys are hot-rolled to a large reduction in a single pass through HSR, high-speed-rolled (HSRed) alloys generally have an almost fully recrystallized microstructure owing to the high applied strain and strain rate. To identify metallurgical phenomena and microstructural evolutions that occur during HSR process, it is necessary to perform detailed analysis of rolled Mg alloys subjected to HSR with various reductions ranging from a small reduction to a large one. Studies have extensively been conducted on the effects of rolling speed and sample temperature in HSR process on microstructure and texture of rolled Mg alloys [13,14,23,24]. However, few in-depth studies have been conducted for examining the influence of rolling reduction on microstructural characteristics of HSRed Mg alloys and for establishing dominant deformation mechanisms during HSR at 400 °C, which lies within the temperature range adopted in conventional rolling processes. The present study therefore investigated variations in hot deformation behavior and resultant microstructure with imposed reduction in the HSR processes. To accomplish this purpose, Mg alloy AZ31 was subjected to HSR with various reductions ranging from 20% to 80% at a high rolling speed of 470 m/min and 400 °C, and then, twinning activation, DRX behavior, grain structure, internal strain, and developed texture of the HSRed alloy were systematically analyzed.

2. Experimental procedure

A commercial hot-rolled Mg alloy AZ31 (Mg-3.6Al-1.0Zn-0.3Mn, wt.%) plate with a thickness of 50 mm was used as an initial material in this study. It was homogenized at 400 °C for 24 h