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Influence of finish rolling temperature on the microstructure and mechanical properties of Mg-8.5Al-0.5Zn-0.2Mn-0.15Ag alloy sheets

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ABSTRACT

Mg-8.5Al-0.5Zn-0.2Mn-0.15Ag (wt%) magnesium sheets were produced with various final rolling temperatures, and their microstructures and mechanical properties were characterized. It was found that low final rolling temperature (LT) resulted in stronger heterogeneity, stronger basal texture and higher strength compared with the high final rolling temperature (HT). Considerable shear zones were observed within both the LT and HT sheets, even though their microstructures, formation mechanisms and mechanical properties were different. Preliminary analysis suggests that the shear zones exert great influence on the mechanical anisotropy of whole sheets.

1. Introduction

Magnesium alloys have been attracting attentions from many researchers in recent years, and have become one of the most promising metallic structural materials, especially in the automotive and aerospace industry owing to their low density, high specific strength, high dimensional stability, high damping capacity and recyclability [1–3]. Magnesium alloys have a hexagonal close-packed (HCP) crystal structure with limited number of operative slip systems near room temperature, and the HCP structure also contributes to their poor formability [4,5]. Therefore, plastic processing of magnesium alloys is usually conducted at elevated temperatures, at which additional slip systems become available [6,7]. Hot rolling is a high-efficiency way to produce magnesium alloy sheets, and considerable efforts have been made to investigate the microstructure and mechanical properties of magnesium alloy sheets rolled under various conditions [8–10].

Texture and grain size, which are dependent on rolling temperature, have great impacts on the mechanical properties of magnesium sheets [10–13]. It has been reported that, with decreasing deformation temperature, both basal pole intensity became stronger [10,12] and the split texture peak with a large inclination returned to a single peak [10]. According to the Zener-Hollomon parameter formula, the DRX grain size is reduced with decreasing temperature. And the DRX mechanisms connection with the operated deformation modes are also influenced by temperature [7]. Gledhill [7] systematically investigated the temperature dependence of the operated deformation mode, it was found that the operated deformation mode evolve from twinning, ⟨a⟩ basal slip and ⟨a + c⟩ dislocation glide at LT, to extensive cross-slip at intermediate temperature, and then to dislocation climb at HT. To conclude, the rolling temperature is a critical parameter for the microstructure and mechanical properties of magnesium alloy.

Although numerous studies have been conducted to figure out the relationship between rolling temperature, microstructure and mechanical properties during the rolling process [7,12,14,15], little information about the effect of lowering finish rolling temperature is available, especially in thick plate processing. Combination of hot rolling and warm finish rolling will produce alloy sheets with favorable formability, fine grain size, strong texture and high strain hardening effect. Moreover, the LT finish rolling can be realized using existing facilities, which could reduce production costs. The aim of this study is to understand the relationship between finish rolling temperature and microstructure and mechanical properties by combination of hot rolling and warm rolling, so as to provide a guidance for industrial production.

2. Experimental Procedures

2.1. Materials Preparation

High quality Mg-8.5Al-0.5Zn-0.2Mn-0.15Ag (wt%) ingot with 450 mm in diameter was produced by semi-continuous casting method. The solution treatment was performed at 415 °C for 20 h to dissolve the $Mg_{17}Al_{12}$ phase [16]. Then, the ingot was forged to a true strain of 0.6 at 400 °C to eliminate the cast defects and enhancing the formability of the block in the following rolling process. Blanks with a dimension of

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Table 1
Sample designations corresponding to different rolling procedures.

Designation	Rolling procedure
AR	Rolled by 6 passes at 400 °C
RH	Finish rolled at 350 °C
RL	Finish rolled at 250 °C

40 mm × 80 mm × 180 mm were cut from the forged billet for subsequent rolling.

The hot rolling was conducted on a double roll mill, with a diameter of 460 mm and rolling speed of 0.36 m/s, and the thickness reduction is 14% per rolling pass. The samples were held at 400 °C for 2 h in a resistance furnace, and the roller were preheated to 150 °C prior to rolling. The temperature of samples decreases by ~20 °C per pass. To maintain the processing temperature and make the samples deformed uniformly, the samples were reheated in the resistance furnace for 4 min and reversed after every two passes (i.e. the total thickness reduction between every two successive reheating treatments was ~25%). The samples were air-cooled after 6 passes rolling (designated as AR sheets) to 350 °C or 250 °C within 4 min. Thereafter, finish rolling was conducted with the same thickness reduction. The rolled samples were quenched into water at room temperature immediately after the final pass to preserve the rolling microstructure for further characterization. For convenience, the samples that are finish rolled at 350 °C and 250 °C are denoted as RH and RL, respectively.

2.2. Microstructure Characterization

Samples for microstructure and texture analysis were machined from the middle region along the sheet thickness. Leica optical microscope (OM) and FEI Helios Nanolab 600i scanning electron microscope (SEM) equipped with electron backscatter diffraction (EBSD) detector were utilized to investigate the microstructure of the samples. EBSD results were analyzed using HKL Channel 5 software, and the data cleanup procedures including extrapolates zero solution (in moderate degree for once) and extrapolate wild spikes (once). FEI Quanta-200 SEM equipped with an Oxford energy dispersive X-ray spectrometer (EDS) was applied to study the secondary phase in the alloy. The sample for macro-texture analysis was machined from the middle layer of the sheets, and the test was conducted on Bruker D8 Discover X-ray diffractometer (XRD).

2.3. Mechanical Tests

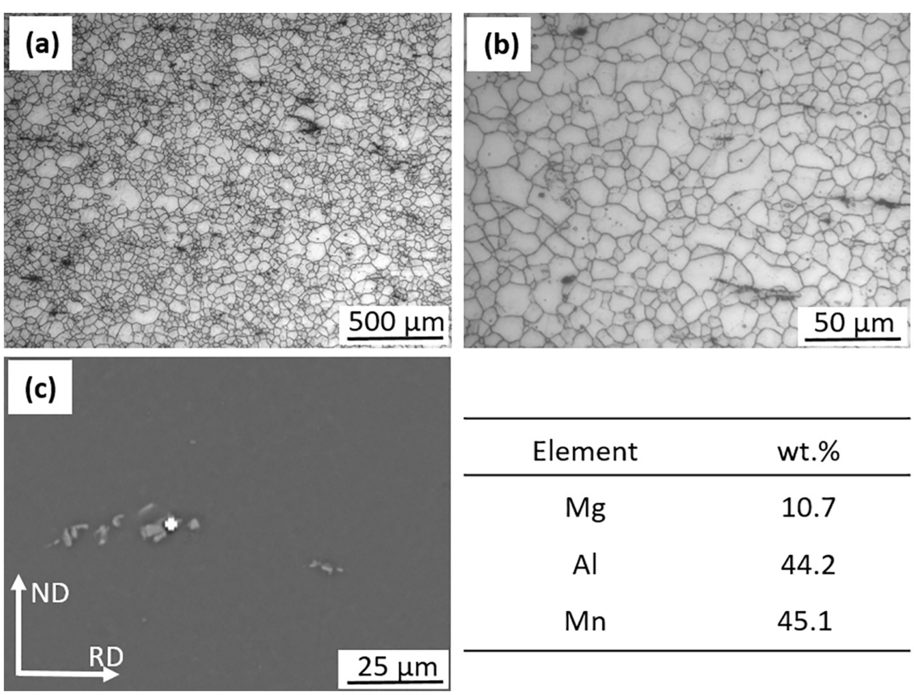
For mechanical properties test, dog-bone tensile samples along rolling direction (RD) and transverse direction (TD) with a gauge length of 15 mm, cross-sectional area of 6 mm × 2 mm were cut from the sheets by electric spark wire-cutting. Tensile tests were carried out using an Instron 3369 testing machine at ambient temperature at a cross head speed of 1 mm/min. Triple tests were conducted for each sample and the averaged values were adopted as the mechanical properties. Vickers hardness tests were conducted with a load of 4.9 N and dwelling time of 15 s. 10 indentations were measured for each hardness test and their average was reported here to assure the reliability (Table 1).

3. Results

3.1. Microstructure

Fig. 1a and b give the optical microstructure of sample AR. The microstructure is relatively homogeneous, which consists of coarse deformed grains and fine DRX-ed grains in bimodal distribution. In addition, a small amount of AlMn particles with stable refractory phase are randomly distributed in the matrix, which were identified by the EDS analysis, as shown in Fig. 1c and d.

The low magnification metallographs of sample RH and RL are exhibited in Fig. 2. It is apparent that microstructure of sample AR changes greatly after the LT finish rolling. Specifically, both samples exhibit striking inhomogeneous deformation microstructure, in which numerous parallel shear zones (along the dashed lines in Fig. 2) distributed symmetrically with respect to the middle plane, and the



Element	wt.%
Mg	10.7
Al	44.2
Mn	45.1

Fig. 1. Optical microstructure of sample AR with different magnification (a) (b), back scattered-electron based SEM micrographs of sample AR (c), and EDS analysis results of the white point in (c) are presented in the table in (d).