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Improvement of magnesium alloy edge cracks by multi-cross rolling

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ABSTRACT

In order for the edge cracks during the AZ31 Mg alloy rolling to be reduced, the hot-rolling microstructure and texture were modified through multi-cross rolling (MCR) during the deformation. The AZ31B magnesium alloy sheets were hot rolled at a temperature ranging from 250 °C to 400 °C and at a rolling speed of 0.5 m/s. Four different multi-cross rolling (MCR) routes were selected in the test. The macroscopic morphology, microstructure and texture of the as-rolled AZ31B sheets were characterized to investigate the edge-crack behavior during the rolling with various rolling routes and temperatures. Through the various rolling routes comparison, the grain size, the texture and the twins were the main factors that affected the cracks. It was demonstrated that the grain refinement and weak basal textures obtained by RII where the rolling direction was changed by 90° between two adjacent passes, could significantly reduce the edge cracks during the rolling at an elevated temperature. When rolling with RII at 400 °C, no apparent edge cracks appear on the sheet rolled with four passes. The propagation mechanism of the crack tips was studied in details at the temperature of 350 °C, whereas the results demonstrated that a high-sized area of grain boundaries in-between the finer grains could increase the crack propagation resistance.

1. Introduction

The magnesium alloys have become certain promising lightest metal structural materials, with a high potential for automotive and electronic industry applications, due to the corresponding high specific strength, excellent electro-magnetic shielding characteristics and good mechanical properties. In contrast, the lack of operative slip systems at room temperature and the sharp textures in the rolled products lead to a poor working ability and a higher occurrence of edge cracks in rolling, which have highly limited the magnesium utilization in the industry (Hamad and Ko, 2016). The edge cracking is a commonly observed phenomenon during the magnesium alloys sheet rolling, which might cause the sheet crevices and the product quality and productivity reduction, as presented in Fig. 1.

Over the recent decades, significant efforts have been devoted to the microstructural evolution and the texture changes during the magnesium alloy deformation at an elevated temperature. Several new rolling techniques were reported to improve the mechanical properties of Mg alloys, such as the differential speed rolling (DSR) (Xia et al., 2009), the cross-roll rolling (Kim et al., 2012), the equal channel angular pressing (ECAP) (Ding et al. 2008), the accumulative roll-bonding (ARB) (Zhan et al., 2007) and the high pressure torsion (HPT) (Stráská et al., 2015). Xin et al., (2011) modified the basal texture by twinning deformation. Hamad and Ko, (2016) utilized the cross-shear deformation, where the sheets were rotated 180° around the corresponding longitudinal axis between the adjacent passes of differential speed rolling, successfully obtaining a uniform fine microstructure with the weak basal textures. Ma et al., (2015) also demonstrated that the asymmetric reduction rolling could promote the occurrence of dynamic recrystallization, resulting in a homogeneous microstructure with significantly finer grains and a weakened basal texture.

These results were mainly focused on the microstructure refinement and the strong basal texture weakening for an advance on the mechanical properties of the Mg alloys sheets to be acquired. An area not significantly discussed is the edge cracks reduction by the differential rolling technology. Zhang et al., (2011) predicted the edge cracks of Mg alloy sheets in rolling by the thermal-mechanical damage combined with the elements model. Ding et al., (2013) succeeded in the edge cracks reduction by the rolling route increase from 2 passes to 4 passes. Xie et al., (2011) proposed that the contact pressure increase around the strip edge would accelerate the edge crack propagation. Huang et al., (2017) inhibited the edge crack of rolled AZ31 magnesium alloy sheet by a prefabricated crown.

In the authors' previous study, the edge crack damage and the temperature distribution of the finite element numerical simulation results were analyzed, whereas the AZ31 mathematical model of the

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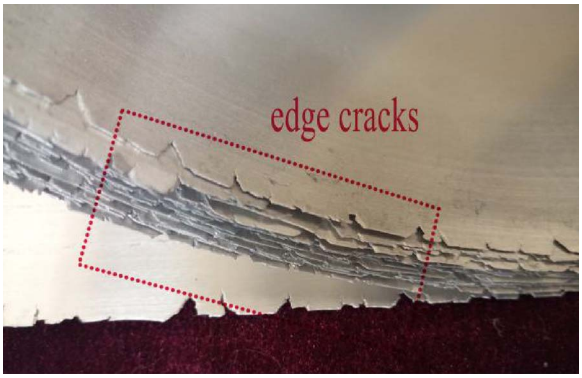

Fig. 1. Edge cracks on rolled magnesium alloy sheet.

surface temperature gradient was established. In the corresponding rolling control research, it was reported that the long strip twins' quantities and the brittle phase were certain key factors regarding the edge cracks control (Ma et al., 2014a,b). Therefore, the microstructure, the texture and the crack morphology of the edge cracks in the AZ31 rolled sheets by differential multi-cross rolling (MCR) was analyzed in this paper.

2. Materials and methods

In the present study, the original material was the cast-rolled sheet produced by the magnesium alloy casting mill of the Chinalco Luoyang Copper Company. The production line of the magnesium alloy casting mill had the advantages of short process, low cost and high efficiency for the magnesium alloy sheet production.

The Cast rolled sheet had a typical equiaxed crystal structure. It could be observed from Fig. 2, that the recrystallized grains with the size of 31 μm accounted for 57.3% of the total area, whereas the recrystallized grains encircled the high-sized grains in the form of a necklace. Certain grains in this structural organization were in a long strip distribution, of 5–20 μm in width, of 50 μm–150 μm in the length range, which constituted one of the most typical features of casting formations in the cast rolling sheet.

The cast-rolled AZ31 magnesium alloy (Mg-3.37%Al-0.86Zn) sheets with the initial size of 90 mm × 90 mm × 7 mm (length, width and thickness) were rolled by the two-high rolling mill. The cast-rolled sheets were pre-heated at the temperatures of 250 °C, 300 °C, 350 °C and 400 °C for various processes. During each process, the roller was retained under the temperature of 150 °C and the rolling speed of 0.5 m/s.

Four rolling routes were designed for the rolling experiments by rotating the rolling direction, as shown in Fig. 3. The four reductions in each pass were 30%, 25%, 20% and 15%, respectively. Following, the RD, the TD and the ND represented the rolling direction, the transverse direction and the normal direction of the rolling sheets, respectively. In addition, every rolling route is defined by the schematic diagram in Fig. 3.

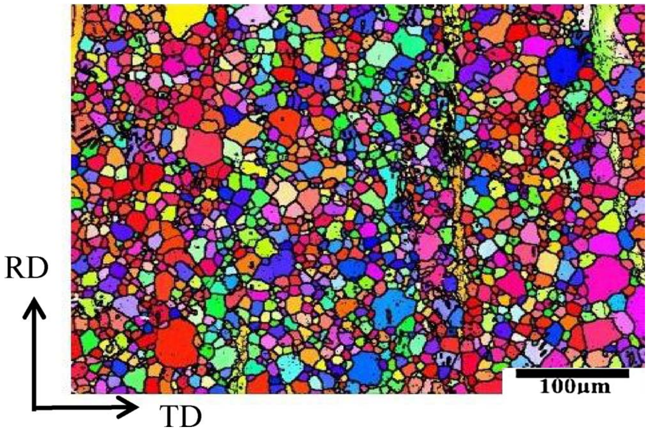

Fig. 2. Microstructure of cast-rolled AZ31B magnesium alloy.

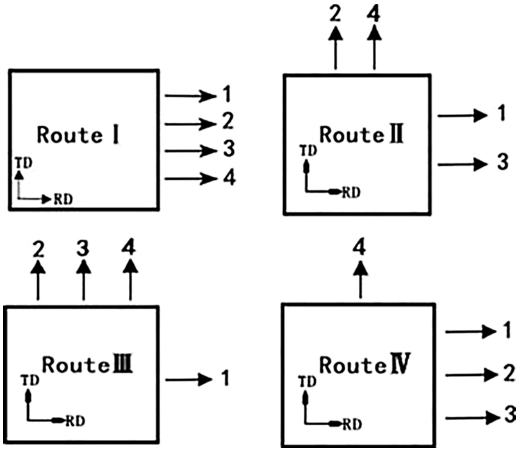

Fig. 3. Schematic diagram of rolling routes.

Subsequently to each rolling pass, the hot-rolled samples were reheated for 15 min to regain the initial rolling temperature in the furnace, where an infrared thermometer was utilized for the temperature measurement, whereas the initial rolling temperature error was retained within ± 5 °C. Before the next rolling, sheet were refreshed with sandpapers to form cleaned metal surfaces, so that the surface state can be approximately consistent.

The edge cracks microstructures were characterized by a ZEISS scanning electron microscope (SEM) on the RD-TD and the RD-ND cross section respectively, as the sampling locations 1 and 3 indicated in Fig. 4. The specimens were observed following being polished with a solution consisting of picric acid (4.2 g), acetic acid (10 ml), distilled water (10 ml) and ethanol (70 ml). The microtexture was monitored by the electron back scattered diffraction (EBSD) method on the RD-TD plane of the sheets, as the sampling location 2 demonstrates in Fig. 4. The EBSD samples were prepared by electrochemical polishing with a solution of ACII, at a voltage of 20 V and a temperature of 248 K for 45–50 s. Besides, the maximum crack depth was defined as the maximum length of the edge cracks in the direction along the TD. The crack quality was characterized by an average number of cracks, every 100 mm. In addition, the grain size was measured by the line intersection method. Fig. 5 demonstrates the rolled sheets with different rolling paths and various rolling temperatures.

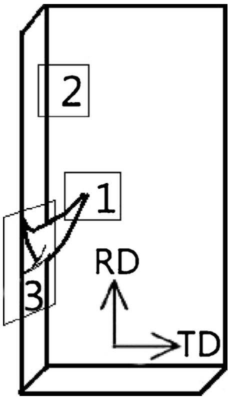

Fig. 4. Schematic drawing of acquired sample position in rolled AZ31 magnesium alloy sheets.

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