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Study of deformation texture in an AZ31 magnesium alloy rolled at wide range of rolling speed and reductions

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Abstract. The plasticity of Mg is restricted at low temperatures because: (a) only a small number of deformation mechanisms can be activated, and (b) a preferred crystallographic orientation (texture) develops in wrought alloys, especially in flat-rolled sheets. This causes problems in thin sheet processing as well as component manufacturing from the sheet. In this study, different rolling speeds from 15 to 1000 m/min were employed to warm-roll AZ31B magnesium alloy to different reductions. The results show that AZ31B sheets rolled at 15 m/min and 100 °C has fractured for reductions of more than 30% per pass. However, by increasing the rolling speed to 1000 m/min the rollability was improved significantly and the material can be rolled to reductions of more than 70% per pass. The results show that with increasing strain rate at 100°C, the splitting of basal poles was observed, indicating the activation of more contraction twins and secondary twins.

Keywords: Magnesium alloys, Texture evolution, High speed rolling, VPSC

1. Introduction

Having the lowest density among all structural metals, magnesium has opened new horizons for developing commercial alloys with successful use in a wide variety of applications [1-2].

However, the plasticity of Mg is restricted at low temperatures because: (a) only a small number of deformation mechanisms can be activated [3-4], and (b) a preferred crystallographic orientation (texture) develops in wrought alloys, especially in flat-rolled sheets [5-7]. Therefore, manufacturing processes such as rolling and stamping should be performed at elevated temperatures [1, 8]. These barriers to the manufacturing process increase the price of magnesium wrought alloy products and limits the use of Mg to castings [9-10]. As a result, many studies have been conducted to improve formability by investigating the effect of manufacturing process.

Therefore the current sheet production techniques, based on DC casting and hot rolling, are basically slow because the demand is easily met [11]. Twin roll casting followed by hot rolling appears to be processing route which can fulfill high volumes and reduced costs.

The present authors succeeded in single-pass large draught rolling of various magnesium alloy sheets at low temperature (<473K) by high speed rolling [12]. Based on the data available in those works [13-17], the sheet obtained by high-speed rolling exhibited a fine-grained microstructure (mean grain size of 2-3 μm), with good mechanical properties. For these advantages, the high speed rolling is a promising process to produce high-quality rolled magnesium alloy sheets at a low cost.

For these advantages, the HSR is a promising process to produce high-quality rolled magnesium alloy sheets at a low cost. The goal of this research is thus to investigate the mechanisms responsible for the much higher rollability and the grain refinement after HSR. To do that, in this study, different rolling speeds from 15 to 1000 m/min were employed to twin rolled cast AZ31B magnesium alloy and different reductions.

2. Experimental procedure

The material used in the present study was commercial AZ31B (Mg-3.2%Al-0.77%Zn-0.34%Mn) rolled sheets with the thickness of 3.0mm. The rolling experiments were conducted through two different rolling mills. The high speed rolling of 1000m/min was performed in a high-speed, two-high mill



with ϕ 530 mm rolls. A specimen was rolled at different reduction of 20-70% in a single pass and rolling temperature was varied from room temperature to 100 °C. The specimen was water-quenched immediately after rolling. The rolls were not heated. The low speed rolling of 15m/min was performed in a low-speed, two-high mill with ϕ 380 mm rolls. The specimens were processed in a single pass at the reduction of 30-60% and constant temperature of 100 °C. The rolls were neither heated nor lubricated.

The characterization has been done by optical microscopy , SEM with EBSD and XRD (Bruker X8) to observe the microstructures and analyze micro and macro texture of the sheets during rolling and annealing. The samples used for EBSD analysis were prepared by electro-polishing with a 10% Nital solution with a voltage of 20V at -20°C.

3. Results and discussion

3.1. Appearance of edge cracks

Fig. 1 shows the effect of rolling speed on the rollability of AZ31 alloys at different reductions and rolling temperature of 100 °C. As can be seen in this figure, the edge cracks can be classified into three main types: (a) minor edge cracks, (b) regular edge cracks, and (c) zigzag edge cracks. As can be seen in Fig.1, a heavy reduction of 70% with small zigzag edge cracking was attained for AZ31 in single pass by high-speed rolling at 100°C; however, at the lower speed of 15 m/min, cracks initiated at edges propagated to longitudinal fracture at the centre to form so-called “scissors cracks”. The maximum reduction can be attained at low speed rolling is 30% although with “scissors cracks”. Similar scissors cracks, although less intense, were observed in high speed rolling of 1000 m/min. By increasing the rolling speed to 1000 m/min and reduction of 70%, the sheets were produced without any edge cracks.

R %	15 m/min	100 m/min	1000 m/min	
8%	⊙	⊙	⊙	
15%	⊙	NA	⊙	
23%	○	○	○	
30%	△	○	○	
37%	X	○	○	
51%		△	△	
62%		△	△	
71%		▲	▲	

Figure 1 –Appearance of AZ31B specimen rolled at 100 °C at different rolling speed and reduction.

3.2. Texture evolution

To study the effect of rolling speed and reduction on the texture evolution, the pole figures of the samples deformed at 100°C and different rolling speed were analyzed (Fig. 3). According to these results, at all strains, the bulk texture of the deformed samples showed the typical basal texture of compressed Mg alloys, with the majority of c-axes of the grains aligned with the compression direction. At the early stage of deformation (reduction of 8% , $\epsilon=0.08$), the rate of texture evolution is higher in the samples deformed with lower strain rate and the maximum intensity are 4.9 for the samples deformed at 15 m/min, in compare with the samples deformed at 1000 m/min with the maximum intensity of 4.2. By increasing the reduction to 16%, the maximum intensity increased to 4.8 and 4.5 for rolling speed of 15 and 1000 m/min; respectively. At rolling speed of 1000 m/min, by increasing the reduction from 23% to 30%, the maximum intensity does not change significantly and is slightly increased from 4.9 to 5.0. On the other hand in the case of 15 m/min, the maximum intensity increased from 5.8 to 6.5.

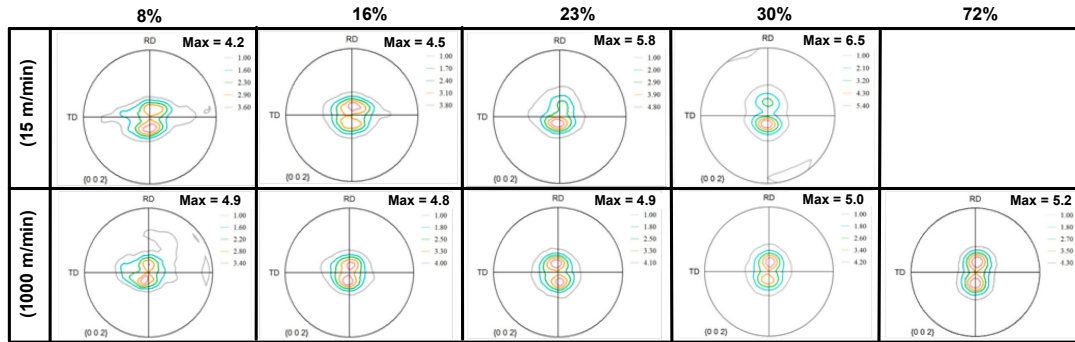


Figure 3 – $\{0002\}$ pole figure of the finish rolled samples AZ31B specimen rolled at 100 °C at different rolling speed and reduction

It is worth noting that by forming C-twins the basal planes are reoriented by 56° around an $\langle 2\bar{1}10 \rangle$ axis. This orientation change facilitates glide on the basal planes [18]. However; the activity of T-twinning is much higher than the C-twinning particularly at the early stage of deformation [19]. It was reported that the T-twinning would be activated in the grains tilted $45\text{--}90^\circ$ away from the compression direction [20]. On the other hand, Yi et. al [20] reported that C-twins can be activated just in grains with c -axes is tilted less than 30° away from the normal direction (ND) of the sheet in their rolling experiments. However as shown in Figure 5 (microstructure of the partially rolled and EBSD was performed of the entry to the exit of the deformed zone) by increasing the strain, the volume fraction of both type of C-twins increases especially in the samples deformed at high speed rolling of 1000 m/min. It has been hypothesized that potential mechanism for basal poles splitting toward the RD during the rolling can be promotion of S-twinning [21] and/or $\langle c+a \rangle$ slip system [3]. The Critical Resolved Shear Stress (CRSS) of $\langle c+a \rangle$ slip system is very high at 100°C , leading to very low contribution of this type of slip system [22]. It was also reported that under dynamic conditions, the CRSS of non-basal slip systems remains higher than that of twinning [23].

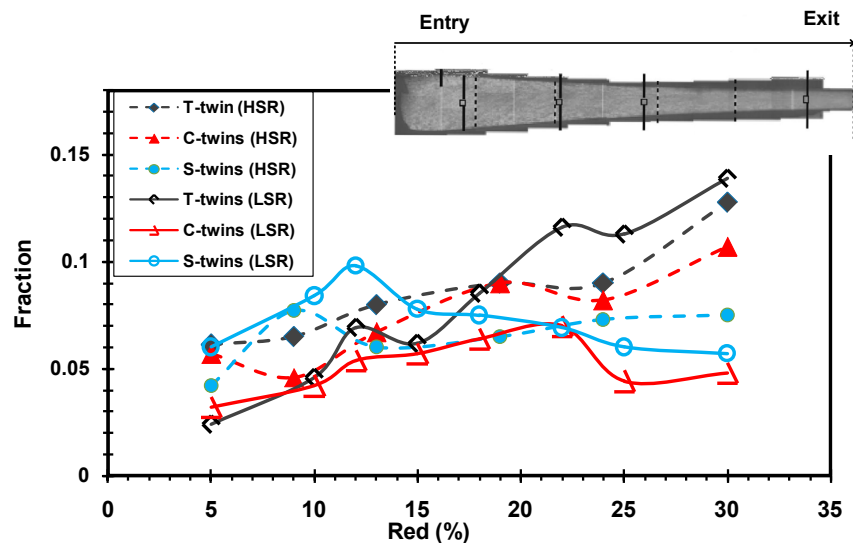


Figure 4 – The twin fraction at different reduction of the sheet produced by interrupted rolling, the microstructure of the partially rolled and EBSD was performed of the entry to the exit of the deformed zone.

3.3. Effect of rolling speed, annealing time and temperature on macro-texture

Texture evolution (the figure shown maximum intensity of basal texture at 200°C , 350°C and 500°C with increasing annealing time and $\{0002\}$ plane pole figures at lowest value of basal texture and the longest annealing time at each temperature) of high speed rolled specimens during annealing are shown in Fig. 5. the basal texture of as rolled specimen at high speed is lower than that of low speed rolled one. And this tendency kept all the way along the annealing time at both 200°C and 350°C . Therefore the texture is more sensitive to annealing temperature, but less sensitive to rolling speed prior to annealing.

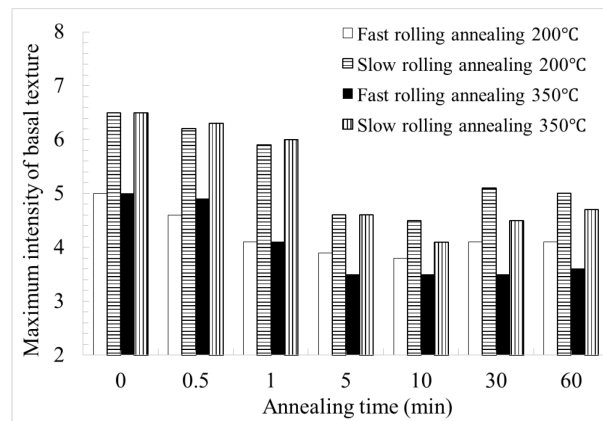


Fig. 5 The comparison of the maximum intensity of basal texture of high and low speed rolled specimens during annealing at temperatures of 200°C and 350°C and time range from 30s to 1h

4. Conclusion

AZ31B sheets are rolled in a wide range of rolling speed and reduction. The remarks obtained are listed as follows:

1. By increasing the rolling speed rollability of the samples are increasing.
2. The morphologies of edge cracks are classified into (a) minor edge cracks, (b) regular edge cracks and (c) zigzag edge cracks.
3. At the rolling speed of 1000 m/min and 1000 m/min, by increasing the rolling reduction to 60% and higher, recrystallized grains can be observed in the microstructure.
4. Texture weakening occurred during annealing and reached a steady state at 200°C and 350°C while abnormal grain growth happened at 500°C which sharply strengthened the texture. With increasing annealing temperature, the maximum intensity of basal texture decreased.

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