Textures and Microstructures Formed in WE43 and AZ31 Magnesium Alloys during High Speed Rolling and Their Formation Mechanisms

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Abstract. High speed rolling is recognized as the process that can produce sheets of magnesium alloys having RD-split basal texture without or with minimum preheating. However, the mechanism of the texture formation during high speed rolling has not been fully clarified yet. In this study, conventional AZ31 and a rare earth - yttrium added alloy, WE43 were rolled with high rolling speed. The specimens having different textures were prepared by changing the cutting geometry to initially textured sheets. It is seen that the crack, microstructure and texture formations are strongly influenced by the initial textures in AZ31. These features are strongly related to the extension twinning, {10-12}<-1011>. In the case of WE43, cracks are formed more often than in AZ31, despite of the weak initial textures. It is proposed that the activities of the contraction and double twinning systems give more chance of stress concentration, resulting in the narrow shear banding and subsequent cracking. In addition to the experimental analysis, results of the numerical simulation using VPSC model are also used to discuss the texture formation mechanism.

1. Introduction
Magnesium and its alloys have low density and excellent specific strength. From the viewpoint of reducing carbon emission, the application of this light structural material to larger parts is demanded. However, the applications are currently limited to small parts produced by machining or die-casting due to the poor room temperature ductility. High speed rolling is one of the solutions for the above problem. When rolling deformation is conducted with high rolling speed (> 1000 m/min.), the sample is adiabatically heated by surface and internal friction. With the aid of the friction heat, non-basal slip systems are activated and large thickness reduction can be achieved without or with minimum preheating. In addition, the texture formed by high speed rolling is RD-split basal, which has concentrations of (0001) poles ±10~20° inclined from ND toward RD. The frequent existence of the inclined basal planes enhances the workability of the magnesium sheet. The authors have already presented that the formation of the RD-split basal texture in AZ31 (Mg - 3 mass% Al – 1 mass% Zn) alloy is due to the enhanced activation of <c+a> pyramidal slip systems. In a separate paper, we suggest that the strain hardening could promote the activation of the <c+a> slip as well as the thermal assistance. In addition, we showed that the extension twinning, {10-12}<-1011>, strongly affected the texture formation and cracking. In the present paper, additional results of the high speed rolling test of AZ31 are presented and our conclusion is reinforced. In addition, the results of high speed rolling of WE43 are shown.
On the basis of the comparison between these two alloys, mechanisms of high strain rate deformation and texture formation in magnesium alloys are discussed.

2. Experimental Procedures
The tested materials were AZ31 (Mg-3 mass% Al-1 mass% Zn) and WE43 (Mg-4 mass% Y-3 mass% RE-0.4 mass% Zr) hot-rolled sheets provided by Magnesium Elektron. Specimens were cut with different geometry, so that each of them had different initial texture as shown in Figure 1.

Rolling deformation was applied aiming 40% thickness reduction with a rolling speed of 1000 m/min. The rolling was conducted without preheating and with preheating at 473K for both AZ31 and WE43. The deformation with preheating at 573K was conducted only for AZ31. Textures of the samples at the thickness center were measured by X-ray diffractmeter, Bruker D8 Discover, using Cr Kα radiation and the area detection system [4]. Based on the measurement, the ODF was calculated with ADC method [5] by using Resmat TexTools. EBSD measurement was also conducted by using Hitachi SU6600 equipped with Oxford EBSD system. More details of the experiments can be found in our paper [2].

3. Results and Discussion
3.1. High speed rolling of AZ31 with preheating at 573K
Figure 2 shows (0002) pole figures for AZ31 samples rolled with preheating at 573K. All the samples could be rolled without failure up to 40% thickness reduction. The features of the pole figures are similar to what we observed on the samples rolled with preheating at 473K [2]. Samples #1 and #2 have the pole distributions elongated toward TD as well as RD-split component while Sample #3 has only RD-split components. The split angle of the main components is ±20° in all the pole figures, which is the same as the samples preheated at 473K.

The formation of RD-split basal components in Samples #1 and #2 suggests that the extension twinning is an active shear system even at 573K. However, in comparison to the case with preheating at 473K, higher densities are observed along the ND-TD lines and the maxima at RD-split components are lower, which suggests the activation of the slip systems is more enhanced and the twinning is suppressed by increasing the deformation temperature. It should be noted that the extension twinning is not a geometrically preferred shear system in all the samples when compression strain along ND and no strain along TD are assumed.
3.2. WE43

All the samples of WE43 were severely cracked even with preheating at 473K while the AZ31 samples could be rolled without cracking above 473K. Figure 3 is the macroscopic appearance of Sample #1 of WE43 rolled with preheating at 473K. All the samples showed equally spaced cracks parallel to the TD as seen in Figure 3, regardless of the initial texture or preheating temperature. The textures after the deformation with preheating are shown in Figure 4. The distributions of poles are somewhat similar to those in AZ31 (see Figure 2) but the pole densities are lower.

There are a number of studies reporting the formations of weak deformation textures in rare-earth added magnesium alloys [6, 7]. This is usually explained by enhanced activities of non-basal slip systems and dynamic recrystallization [7]. However, we numerically showed the trend of the slip rotation that [0001] moves toward ND and subsequently rotates toward RD-split positions with the activation of \(<c + a>\) slip system [2]. Therefore, it is thought that the formation of the weak texture does not owe to the activation of non-basal slip systems.

The similar cracking was observed in the case of AZ31 samples at room temperature [2]. It was seen that the crack was introduced along the shear band, which was formed by laminated twins. Since the textures shown in Figure 4 have near-basal component, it can be considered that the extension twinning is active also in WE43. This can be confirmed in the result of EBSD measurement shown in Figure 5. In this band contrast map, extension twin boundaries are shown as red lines. In addition, the contraction and double twin boundaries are shown as yellow and blue lines, respectively. The contraction and double twin boundaries were limited in AZ31 but exist considerably in WE43. These twin systems can generate larger shear strain...
than the extension twin [8], resulting in larger local stress concentration. Since the volume fractions of these thin twins are small and the initial texture is nearly random, specific alignment of crystal orientation cannot be achieved by the twinning. In addition, it is thought that the activities of slip systems in the region of stress concentration no longer agree with the macroscopic strain requirement. Therefore, there is no overall trend of crystal rotation to form any deformation texture. It is of interest that the origin of the cracking during high speed rolling is the twinning in both alloys. Regardless of the alloy element or initial texture, twinning plays more important role than non-basal slip systems on the deformation behaviors. It is suggested that if one could develop the alloy which merely activates the twinning systems, it would have excellent ductility.

4. Conclusions
High speed rolling tests of AZ31 and WE43 magnesium alloys were conducted in order to clarify the texture formation and deformation mechanisms. The deformation of AZ31 with preheating at 573K was conducted without cracking with all types of initial textures. The deformation textures showed higher ND-TD pole distribution and lower RD-split peak densities than deformation at lower temperatures. This suggests that the activation of the \( \{a+c\} \) slip system is enhanced and the extension twinning is suppressed with increasing temperature. WE43 showed severe cracks after the rolling with preheating at 473K. The deformed microstructure showed high fractions of extension, contraction and double twin boundaries. It is considered that such inhomogeneous twin deformations generate the shear bands and cracks and result in weak texture, rather than the activation of non-basal slip systems.

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