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Effect of Rolling Deformation on Microstructure of AZ31 Magnesium Alloy

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Abstract. The AZ31 Mg alloy thin sheets were hot-rolled by using a small-sized rolling mill. The thickness was successfully reduced to 0.6 mm without surface crack in 150mm×50 mm area. The effect of rolling deformation on microstructure of the thin sheets was investigated. The basic α-Mg phase preferred on (0001) plane and had equiaxed grains with an average grain size of about 20 μm. All cross sections parallel to the rolling direction showed a streamline-like microstructure due to the strong working strain during hot rolling. The precipitates were remarkably refined to less than 5 μm.

Introduction

Magnesium alloy has been considered as advanced materials for many applications, especially in automotive, railway and aerospace industry, since they have low density (1.74 g/cm^3), good machinability, excellent damping capacity, high specific strength and other good mechanical, thermal and electromagnetic properties [1-3]. However, it is commonly recognized that magnesium possesses poor formability at room temperature due to its hexagonal closed packed structure. The insufficient formability makes processing steps like rolling, extrusion etc difficult, thus limiting the use for rolled or wrought parts. Magnesium alloys for numerous structural applications were mostly made by casting, die-casting as well as thixotropic molding process. Recently, there is a great demand for the thin Mg alloy plates since applications in automobile, bicycle and electronic field have rapidly extended [4,5]. In this study, the effect of rolling deformation on microstructure of AZ31 Mg alloy which is the most popular alloy among Mg alloy systems such as AZ (Mg-Al-Zn), AM (Mg-Al-Mn) and ZK (Mg-Zn-Zr) was investigated.

Experimental Procedures

The raw ingot was AZ31 as-cast Mg alloy shaped as a column with ϕ78 mm in diameter and 42 mm in height, in which the chemical compositions were listed in Table 1. After being heated at 300°C for 10 min in air, the as-cast ingot was pressed by die-press (200T Press) until to form a cake-like disk with 13 mm in thickness and about 126 mm in diameter. The disk was then cut to a plate with 3 mm in width and used for subsequent rolling experiments. This plate was heated up to 350°C and kept at this temperature for 5 min, followed by rolling with a small-sized rolling mill. The multiple rolling passes and re-heating were performed for several times by controlling the compressive deformation ratio in thickness near 10~15% for each rolling. The plates without cracks were successfully produced below 1 mm in thickness by hot rolling combined with heat treatment. The thickness and distortion ratio of AZ31 Mg alloy samples were listed in Table 2.

Table 1 Chemical compositions of AZ31 Mg alloy

Element	Al	Zn	Si	Cu	Mn	Ni	Fe
Wt %	2.51	1.03	0.017	0.0036	0.2	0.0003	0.0045

Table 2. Thickness and deformation ratio of AZ31 Mg alloy after hot rolling

Sample No	Condition	Thickness t , [mm]	Deformation ratio $(t_0-t)/t_0$, %
Raw ingot	As-cast	42	
Starting sample	As-pressed	13	69.0%
1	As-rolled	10.6	74.8%
2	As-rolled	2.12	95.0%
3	As-rolled	1.16	97.2%
4	As-rolled	0.6	98.6%

As-rolled sheets used for metallurgical analysis were cut into a square with a dimension of 10mm×10 mm, as shown in Fig. 1. The observed positions are on the longitudinal and rolling sections, abbreviated as L and R sections, respectively. L and R sections were parallel to the rolling direction, while former is a surface and latter cross section. Samples were grinded with SiC papers and then were polished with diamond paste of 1μm. All samples were kept in ethanol between the different polishing steps to avoid rapid oxidation. Etching was performed at room temperature for 10-40 s in a mixed solution of ethylene glycol, acetic acid and nitric acid. Metallurgical structures were observed by using an Olympus PME-3 optical microscopy. The precipitates were analyzed using scanning electron microscopy (SEM, Philips EM400T) equipped with an energy dispersive X-ray (EDX) spectrometer.

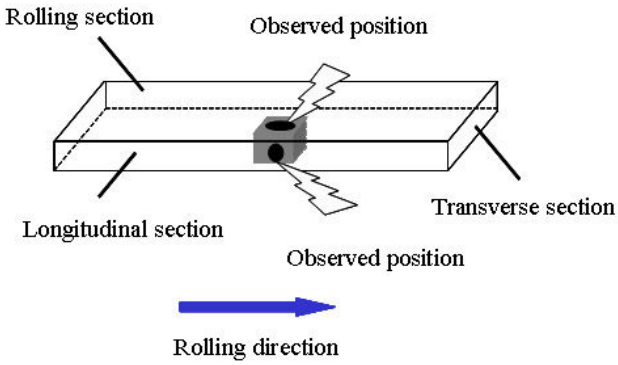

Fig. 1. Schematic illustration of as-rolled sheet for metallurgical analysis.

Results and Discussion

X-ray diffraction. Figure 2 shows the XRD patterns of the as-pressed sample with 13mm in thickness and the as-rolled sample with 0.6mm in thickness. All diffraction lines in Fig. 2 coincide with those of α-Mg (PDF#35-0821), suggesting that the basic phase of AZ31 Mg alloy is α-Mg. The crystal orientation changed obviously after rolling with large amount of deformation. The relative diffraction intensity of (0001) peak increased, while the relative diffraction intensities of $(10\bar{1}0)$ and $(10\bar{1}1)$ peaks decreased. The formation of the (0001) preferred orientation for the rolled plate was attributed to the easily sliding of the (0001) basal plane parallel to rolling plane for the AZ31 hexagonal crystal structure [6].

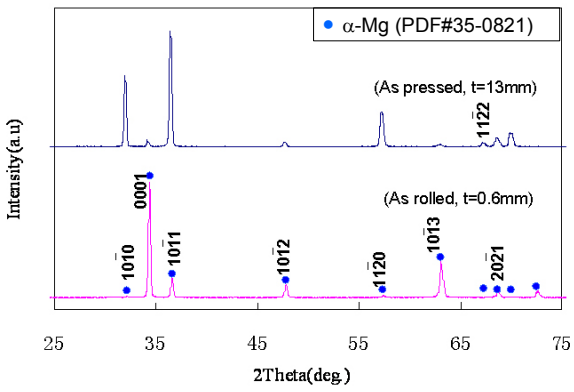

Fig. 2. X-ray diffraction patterns of as-pressed and as-rolled samples.

Microstructure. Figures 3a and 3b show the optical micrographs of AZ31 Mg alloy after hot

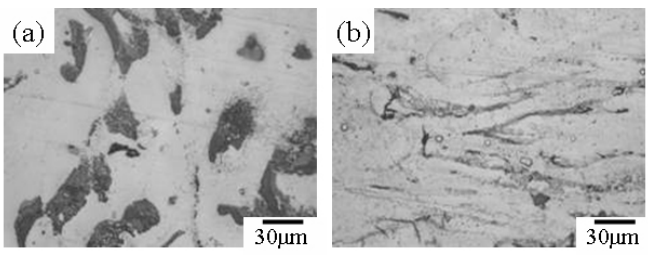

Fig. 3. Optical micrographs of as-pressed AZ31 Mg alloy observed for surface (a) and cross section (b).

press observed from surface (R section) and cross section (L section). AZ31 as-cast Mg alloy shows a typical non-equilibrium cast structure mainly consisting of α-Mg matrix with the size of about 50μm and its eutectic with β-$Mg_{17}Al_{12}$ [7]. The pressed sample shows a similar microstructure to those of the as-cast alloy. A lot of β-$Mg_{17}Al_{12}$ phase is remained with a size of about 200 μm as shown in Fig. 3a. However, the uniform network structure observed in the as-cast material was partly destroyed, eutectic precipitates (black parts) distributed discontinuously on the α-Mg grain boundaries. As more clearly shown in Fig. 3b, the eutectic phase distributed along the grain boundary when the big grains staved, curved and broken during the press process [8].

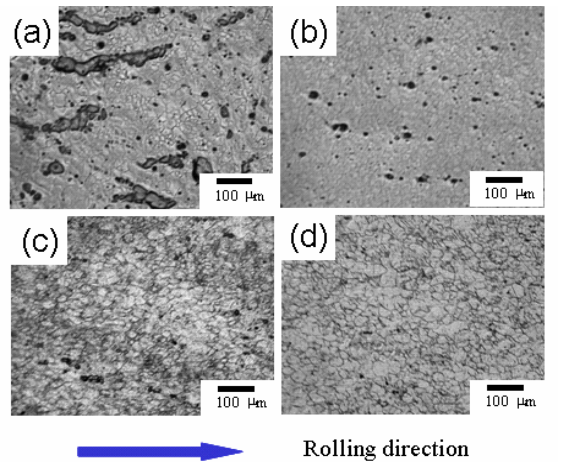

Fig. 4. Optical micrographs of as-rolled AZ31 Mg alloy observed for rolling section with 10.6mm (a), 2.12mm (b), 1.16mm (c), 0.6mm (d) in thickness.

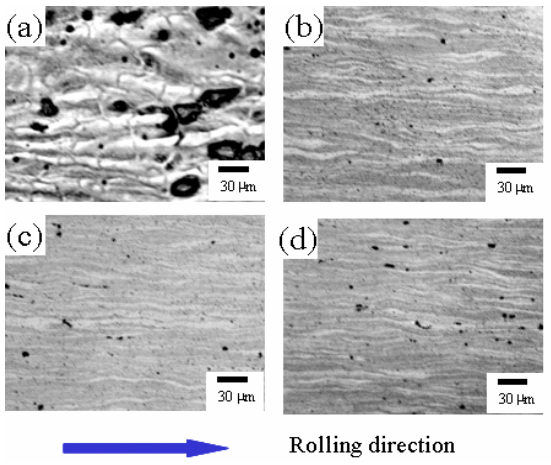

Fig. 5. Optical micrographs of a-rolled AZ31 Mg alloy observed for longitudinal section with 10.6mm (a), 2.12mm (b), 1.16mm (c), 0.6mm (d) in thickness.

Figure 4 shows the optical micrographs of AZ31 Mg alloy sheets with different thickness observed from R section. The α-Mg phase shows an equiaxed grain with an average grain size of about 20 μm for the rolled sample with 10.6mm in thickness (Fig. 4a). The grain size decreased slightly with increasing the deformation ratio. When the thickness became too thin, the grain size tended to increase slightly and to wiredraw along rolling direction as shown in Figs. 4c and 4d, in which the ratio of grain size between parallel and perpendicular rolling direction is about 25 to 20 μm. Meanwhile, the eutectic precipitates changed gradually from lamellas to small particles with increasing the deformation ratio. There were a lot of residual precipitates at the grain boundaries for the rolled sample with 10.6 mm in thickness (Fig. 4a), even though the deformation ratio was raised up to 74.8%. When the deformation ratio increased up to 93.5%, the precipitates were remarkably refined with the size less than 10μm (Fig. 4b). They distribute uniformly on the α-Mg matrix with the size less than 5 μm as the deformation ratio increased more than 97%, as shown in Figs. 4c and 4d.

Figure 5 shows the optical micrographs of AZ31 Mg alloy sheets with different thickness observed from L section. The same tendency was observed, in which the α-Mg grains were wiredrew obviously and a lot of precipitates distributed over the section. As shown in Fig. 5a, no obvious change on the distribution and the size of the precipitates (dark points) is observed when the deformation ratio is higher than 95% (Figs.

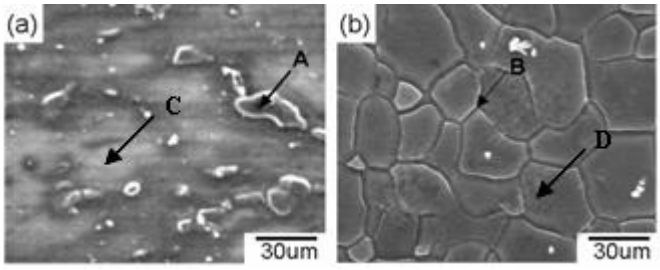

Fig. 6. SEM imaged of the as-rolled samples with 10.6mm (a) and 0.6mm (b) in thickness.

5b and 5d). All as-rolled samples show a streamline-like microstructure that is parallel to the rolling direction since the samples experienced strong working strain during the hot rolling. With increasing the deformation ratio, the streaks increases and the layers become thinner and longer.

Figure 6 shows the SEM images of the as-rolled samples with 10.6 mm and 0.6 mm in thickness, respectively. As shown in Fig. 6a, the precipitates enrich around the grain boundary, while no precipitate almost presents near the grain boundary when the sheet is too thin (Fig. 6b). There are obvious differences of the concentrations of Mn and Al between position A and B (Table 3). The results of the α-Mg matrix (position C and D) are also listed in the Table 3 for comparison. The grain boundary phases such as eutectic β-$Mg_{17}Al_{12}$ changed with increasing the deformation ratio. The precipitates gradually broke and slipped away from the gain boundary into the α-Mg matrix by large deformation and heat treatment during the rolling process. The decomposition of precipitates is also supported by the increase in the composition of Al and Mn in the α-Mg matrix as shown in Table 3. Those results well correspond to the results of the metallographic observation.

Table 3. Chemical composition analyzed by EDX (at %)

Sample	Thickness	Position shown in Fig. 6	Mg	Al	Si	Mn	Zn
As-pressed	10.6mm	A	29.0678	28.8188	0.3734	41.6070	0.1330
As-rolled	0.6mm	B	99.1643	0.3437	0.0000	0.1920	0.0000
As-pressed	10.6mm	C	98.7863	0.8877	0.3260	0.0000	0.0000
As-rolled	0.6mm	D	97.1178	0.3351	0.0000	2.5471	0.0000

Summary

The AZ31 Mg alloy thin sheet was hot-rolled by using a small-sized rolling mill. The thickness was successfully reduced to 0.6 mm without crack in 150mm×50mm area. The as-pressed and as-rolled alloys mainly consisted of α-Mg phase. The as-rolled sheet showed a preferred orientation of (0001) plane. Although a lot of β-$Mg_{12}Al_{17}$ type precipitate remained at the grain boundaries at the first rolling process, they were refined with less than 5 μm in size and distributed uniformly in the α-Mg matrix by further rolling. The α-Mg phase had equiaxed grains with an average grain size of about 20 μm. All cross sections parallel to the rolling direction showed a streamline-like microstructure due to strong working strain during hot rolling.

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