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Influence of rolling ways on microstructure and anisotropy of AZ31 alloy sheet

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Abstract: Two rolling ways, unidirectional rolling and cross rolling, were carried out on twin roll cast AZ31 alloy sheet to study the influence of strain path change on the evolution of the rolling microstructure and texture as well as the anisotropic properties of AZ31 alloy sheet with microscopy, X-ray diffraction technique and tensile tests. It is found that cross rolling gives rise to more uniform microstructure and stronger texture intensities compared with unidirectional rolling. The differences in the microstructure and texture intensities are reflected in the anisotropy characterized by the difference in the yield stress and the fracture elongation that were measured along directions in the rolling plane at angles of 0˚, 45˚ and 90˚ from the rolling direction.

Key words: AZ31 alloy sheet; cross rolling; microstructure; texture; anisotropy

1 Introduction

In recent years, magnesium alloys have attracted an increasing interest from the automobile industry because of their excellent properties such as low density and high specific strength[1−4]. However, AZ31 magnesium sheet displays stronger levels of anisotropy considerably than aluminium[5−7]. This phenomenon is related to the fact that magnesium has a hexagonally close-packed (HCP) structure and texture shape of the basal plane [1, 8−10]. Such a texture places most grains in an orientation (hard orientation) difficult to deform since the resolved shear stress in the basal plane is essentially zero. The insufficient room temperature formability of wrought magnesium alloys is commonly ascribed to their anisotropic plastic behavior[6−7, 11−12].

It was reported that cross rolling (CR) is an effective method to prevent the development of the basal texture during rolling[13], which differs from the standard unidirectional rolling (UR) by having two rolling directions, i.e. after each rolling the rolling direction is changed by rotating the specimen by 90˚ along the normal direction. SINGH and SCHWARZER[14] found that (0002) texture intensity of the rolled pure Mg could be reduced by cross rolling. Some investigators[13, 15] showed that the texture intensities were decreased due to cross rolling of the AZ31 alloys. However, the deformation behavior of the AZ31 Mg alloy sheet during rolling is still not clear[16−17]. Little attention was paid to the effect of cross rolling on the AZ31 magnesium sheets, in particular when the sheets have strong initial basal texture.

In the present work, crossing rolling is carried out on AZ31 alloy sheets with strong initial basal texture. We aim to characterize the influence of rolling ways on the microstructure and anisotropy of AZ31 magnesium sheet.

2 Experimental

The material investigated was twin roll cast magnesium AZ31 (nominally 3%Al, 1%Zn, balance Mg, mass fraction) alloy sheets with thickness of 5.6 mm. The sheets were heated at 460 ℃ for 1 h, and then rolled to 3.8 mm in thickness. After that, the sheets were heated at 450 ℃ for 1 h and rolled by two different rolling ways. Route A is the unidirectional rolling where the rolling direction (RD) is always the same. Route B is a special crossing rolling where the rolling direction changes by 90˚ every five passes, as shown in Fig.1. Here RD1 is the initial rolling direction of the as-received AZ31 sheet; RD2 is changed by rotating the specimen by 90˚ along the normal direction (ND). These treatments were

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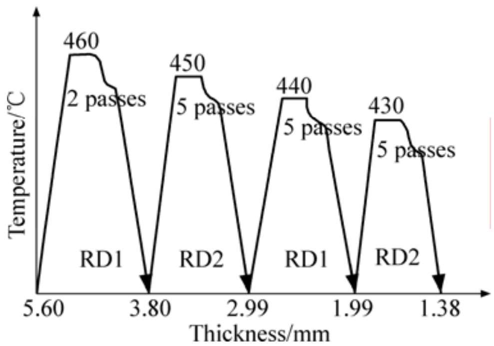

Fig.1 Schematic illustration of cross rolling schedule (RD1—Initial rolling direction; RD2—Rotating by 90° about normal direction)

repeated twenty times, after each pass the rolled specimens were returned back to the furnace and reheated for 5 min to regain the rolling temperature. Finally, the sheets were rolled to 1.38 mm in thickness.

Microstructure of the rolled magnesium alloy sheet was investigated by the optical microscopy. The longitudinal sections were polished, and the metallography was performed with an acetic-picral etching. The texture measurements were done on the centre of the sheet prepared by mechanical grinding. The (0002) and $(10\bar{1}0)$ pole figures of the rolled Mg alloys were investigated using the Rigaku D/max-2500PC X-ray diffractometer in reflection geometry.

Tensile specimens are sub-sized dog-bone shaped specimens with a gage length of 8 mm, width of 3 mm, and the same thickness of the sheet (1.38 mm). The tensile axes were determined for three types against the rolling direction for the anisotropy of mechanical properties of the specimens, and those machined parallel to the RD, transverse direction (TD), and an intermediate (45°) orientation. An extensometer with 4 mm in gage length was used, and the tensile tests at room temperature were conducted on a Shimadzu AG-X10kN universal testing machine with a constant strain rate of 5×10^{-3} s^{-1}.

3 Results and discussion

3.1 Microstructures

Microstructural evolution of the as-rolled AZ31 sheets during two rolling ways is shown in Fig.2. The

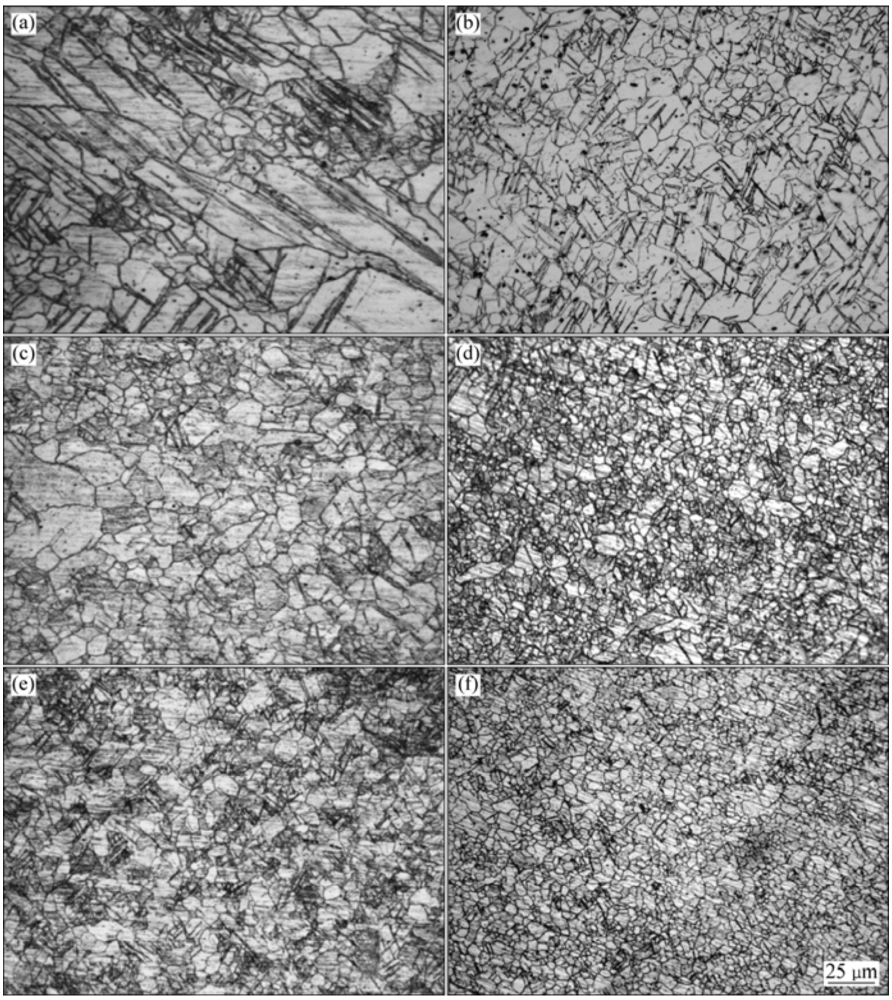

Fig.2 Microstructural evolution during route A and route B process: (a) UR, 2.99 mm, (b) CR, 2.99 mm, (c) UR, 1.99 mm, (d) CR, 1.99 mm, (e) UR, 1.38 mm; (f) CR, 1.38 mm

microstructures on RD−TD planes of the sheets were examined. For the 2.99 mm-thick AZ31 sheets, both the route A and route B samples show a severely deformed microstructure, having some original grains remained and recrystallized small grains along boundaries and in most twinned regions. Nevertheless, it should be pointed out that the grain size distribution of the route A sample becomes more homogeneous than that in route B with increasing the thickness reduction, the grain size in route A sample is obviously smaller compared with route B, and full recrystallization is achieved in the route A sample of 1.38 mm. On the contrary, there are some twins present in the route B sample of 1.38 mm. This indicates that the microstructure is hardly affected by the change of the rolling ways.

3.2 Texture evolution

Fig.3 shows the (0002) and $(10\bar{1}0)$ pole figures for the 3.8 mm-thick AZ31 sheet. It is clearly seen that the dominant feature of this texture is the alignment of the basal poles with the normal direction of the sheet. The texture exhibits near radial symmetry, i.e., the intensity in the $(10\bar{1}0)$ pole figures is essentially uniform around their perimeter. However, close examination of the (0002) pole figure, in particular, shows a slight off-basal character of the primarily basal texture. The peaks in the basal pole figures are not collinear with the ND; they are tilted towards the RD by approximately 10˚. The above results indicate that a very strong basal texture is generated by rolling the sheet to 3.8 mm in thickness.

In order to investigate the effects of different rolling ways on the texture of the AZ31 sheets, the 3.8 mm-thick sheets were rolled by two routes. Fig.4 illustrates the evolution of crystallographic texture during unidirectional rolling and cross rolling process. It can be seen in Fig.4 that the (0002) basal pole figure exhibits a strong basal texture, with the majority of *c*-axes aligned in the sheet normal direction for both routes A and B. Furthermore, the intensities of the basal textures for both routes A and B are increased compared with 3.8 mm-thick sheet (Fig.3). However, it should be noted that the (0002) basal plane texture intensities of the cross-rolled sheets become stronger than those in the unidirectional rolled sheets.

On the other hand, it is interesting to observe that the distribution of the (0002) basal texture for both routes is dramatically different due to the change of the strain path. For the cross-rolled sheet, the basal pole moves to the normal direction of the sheet, and the distribution of the texture profile becomes more symmetric (Figs.4 (b) and (d)). As a consequence of cross rolling deformation, the (0002) texture component is strengthened. By comparison of Fig.4(b) and (d), it is readily seen that the maximum intensity of the (0002) pole figure slightly decreases. The weakening of the strong basal texture in the 1.38 mm-thick sheet compared with 2.99 mm is owing to the fully dynamic recrystallization occurring during the cross rolling process (Fig. 4 (d)). While for the unidirectional rolled sheet, there is little change in the basal texture, the spread-peak in the basal pole figure is replaced by a single fiber, and there is still greater angular spread in the pole density toward the RD than towards the TD (Figs.4(a) and (c)).

It is well known that the microstructure of a specimen undergoing plastic deformation is defined by the strain path[15]. In the case of rolling deformation, each rolling step creates a grain microstructure that tends to be elongated toward the rolling direction. The change of the basal plane distribution and the strengthening of the texture for cross-rolled specimens imply that the basal texture of the AZ31 sheet is very stable.

3.3 Mechanical properties

Fig.5 shows the tensile properties as a function of the sheet orientation for the unidirectional rolling and cross-rolling sheet of 1.38 mm, whereby 0˚ means rolling direction and 90˚ indicates transverse direction. It is clearly observed in Fig.5(a) that the yield and tensile

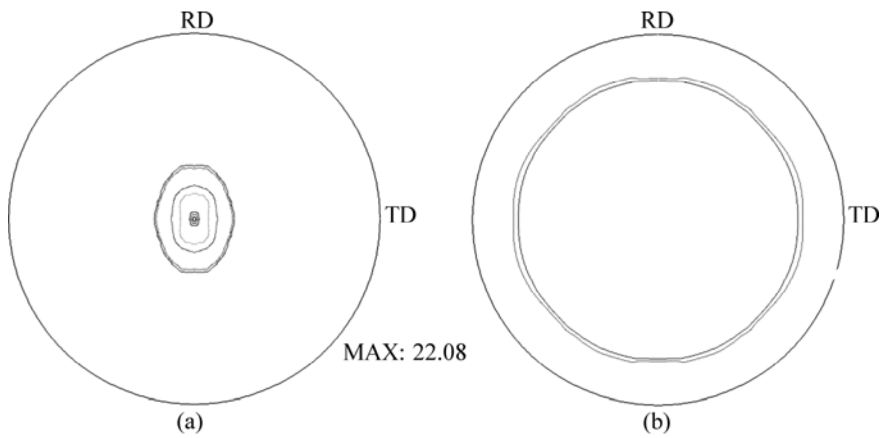

Fig.3 (0002) (a) and $(10\bar{1}0)$ (b) pole figures of 3.8 mm-thick AZ31 sheet

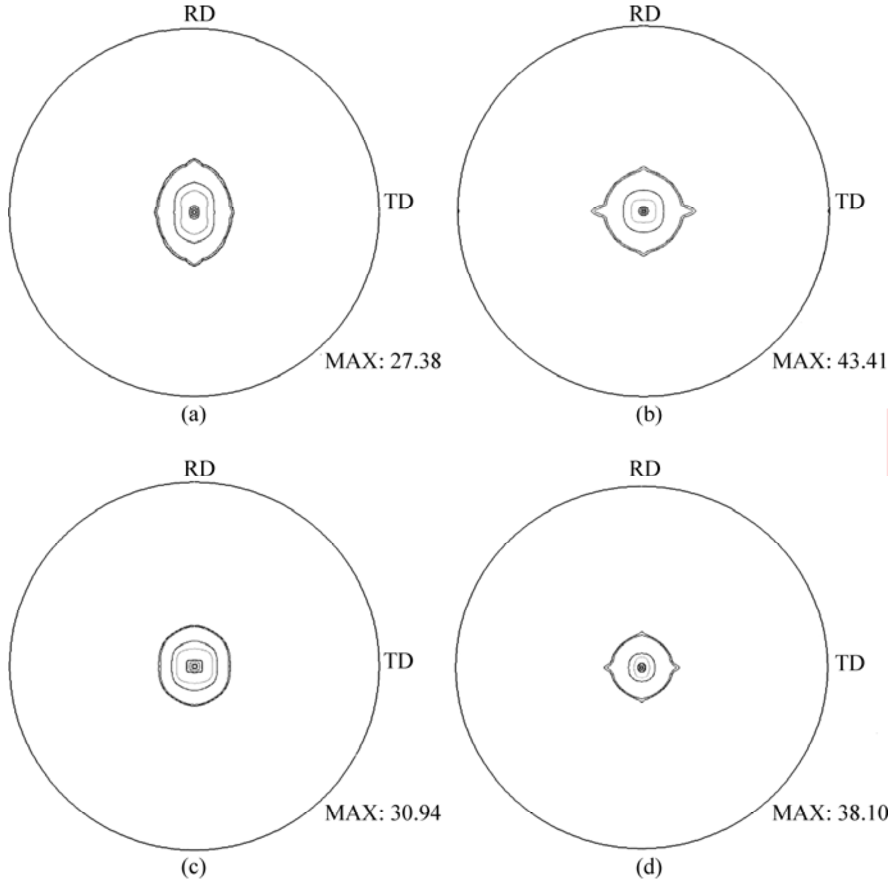

Fig.4 (0002) pole figures of rolled AZ31 sheet: (a) UR, 2.99 mm, (b) CR, 2.99 mm, (c) UR, 1.38 mm, (d) CR, 1.38 mm

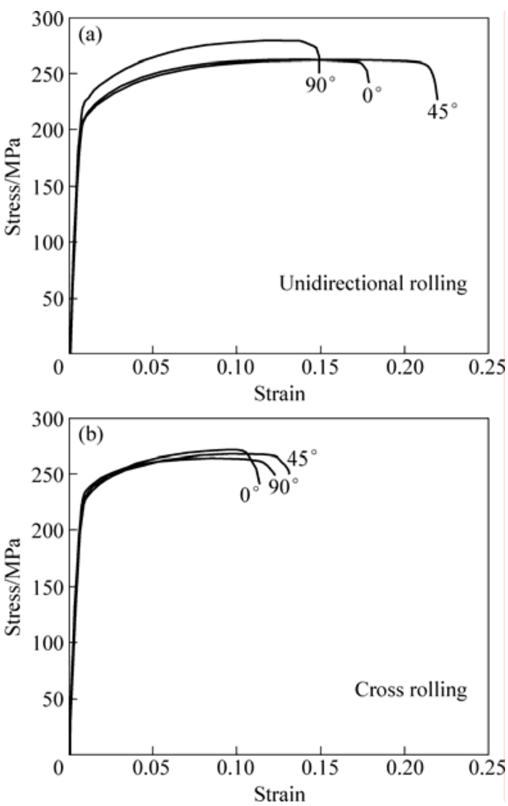

Fig.5 Stress−strain curves of unidirectionally rolled (a) and cross rolled (b) AZ31 sheets at room temperature with a strain rate of 5×10^{-3} s^{-1}

strengths in the unidirectionally rolled sheet strongly depends on the tensile direction. The yielding difference between rolling direction and transverse direction is 23 MPa, which is roughly 10% of maximum value at 90°. In addition, the fracture elongation for three orientations is very different. On the contrary, cross rolled AZ31 sheet exhibits a higher strength and a more uniform elongation compared with unidirectionally rolled sheet (Fig.5(b)), which suggests that cross rolling is more effective to decrease the anisotropy of AZ31 sheet than unidirectional rolling.

The tensile properties of AZ31 sheets with different orientations are summarized in Table 1. By contrast, the unidirectionally rolled sheet exhibits less strength and much elongation. However, the strength and strain anisotropy is very obvious. The anisotropic behavior of the unidirectionally rolled AZ31 sheet is mainly a result of the texture. It was reported that the distribution of the (0002) basal plane has a significant influence on the planar anisotropy of the sheet [11]. For the unidirectionally rolled 1.38 mm-thick sheet, where texture exhibits greater spreading of the basal poles towards the RD than the TD (Fig. 4c), whereby activation of the basal slip in the sheet rolling direction is preferred to the transverse direction. This would result in lower stresses necessary for the 90° orientation, hence decreasing the yield strength.

Table 1 Tensile properties of AZ31 sheets with different rolling ways

Specimen orientation	Yield stress/MPa		Elongation/%	
	UR	CR	UR	CR
0°	200	225	16.8	10.3
45°	199	222	20.8	11.0
90°	223	226	14.0	11.9

On the other hand, cross rolling creates more fine and homogeneous microstructure than unidirectional rolling. In addition, cross-rolling gives rise to stronger basal texture, which results in higher yield strength. However, the cross rolling decreases the strength anisotropy, the difference of the yield strength between the RD and TD becomes very smaller, and there is almost no difference anymore in the strain anisotropy.

4 Conclusions

1) Cross rolling is an effective way in improving microstructure and anisotropy of mechanical properties of AZ31 sheet with strong initial basal texture.

2) Microstructures following multi-step cross rolling are more uniform than those by unidirectional rolling.

3) Cross rolling results in more symmetric and strengthened basal texture, which results in higher yield strength and lower elongation.

4) Cross rolling decreases both the strength anisotropy and the strain anisotropy.

References

[1] ROBERTS C S. Magnesium and its alloys [D]. Wiley, New York/London, 1960.

[2] BETTLES C J, GIBSON M A. Current wrought magnesium alloys: Strengths and weaknesses [J]. JOM, 2005, 57(5): 46−49.

[3] LIAO J, HOTTA M, KANEKO K, KONDOH K. Enhanced impact toughness of magnesium alloy by grain refinement [J]. Scripta Materialia, 2009, 61(2): 208−211.

[4] LIANG S, SUN H, LIU Z, WANG E. Mechanical properties and texture evolution during rolling process of an AZ31 Mg alloy [J]. Journal of Alloys and Compounds, 2009, 472(1/2): 127−132.

[5] KOIKE J. Enhanced deformation mechanisms by anisotropic plasticity in polycrystalline Mg alloys at room temperature [J]. Metall Mater Trans A, 2005, 36A(7): 1689−1696.

[6] del VALLE J A, RUANO O A. Effect of annealing treatments on the anisotropy of a magnesium alloy sheet processed by severe rolling [J]. Materials Letters, 2009, 63(17): 1551−1554.

[7] AGNEW S R. Plastic anisotropy and the role of non-basal slip in magnesium alloy AZ31B [J]. Int J Plasticity, 2005, 21: 1161−1193.

[8] STYCZYNSKI A, HARTIG C, BOHLEN J, LETZIG D. Cold rolling textures in AZ31 wrought magnesium alloy [J]. Scripta Mater, 2004, 50: 943−947.

[9] YUKUTAKE E, KANEKO J, SUGAMATA M. Anisotropy and non-uniformity in plastic behavior of AZ31 magnesium alloy plates [J]. Mater Trans, 2003, 44(4): 452−457.

[10] PHILLIPE M J. Texture formation in hexagonal metals [J]. Mater Sci Forum, 1994, 157/162: 1337−1350.

[11] KAISER F, LETZIG D, BOHLEN J, STYCZYNSKI A, HARTIG C H, KAINER K U. Anisotropy properties of magnesium sheet AZ31 [J]. Mater Sci Forum, 2003, 419/422: 315−320.

[12] HOSFORD W F. Reflections on the dependence of plastic anisotropy on texture [J]. Mater Sci Eng A, 1998, 257: 1−8.

[13] AL-SAMMAN T, GOTTSTEIN G. Influence of strain path change on the rolling behavior of twin roll cast magnesium alloy [J]. Scripta Mater, 2008, 59: 760−763.

[14] SINGH A K, SCHWARZER R A. Evolution of texture in pure magnesium during rolling [J]. Z Met Kd, 2005, 96(4): 345−351.

[15] CHINO Y, LEE J S, SASSA K, KAMIYA A, MABUCHI M. Press formability of a rolled AZ31 Mg alloy sheet with controlled texture [J]. Mater Lett, 2006, 60: 173−176.

[16] CHANG L L, SHANG E F, WANG Y N, ZHAO X, QI M. Texture and microstructure evolution in cold rolled AZ31 magnesium alloy [J]. Materials Characterization, 2009, 60(6): 487−491.

[17] LEE J B, KONNO T J, JEONG H G. Grain refinement and texture evolution in AZ31 Mg alloys sheet processed by differential speed rolling [J]. Materials Science and Engineering B, 2009, 161(1/3): 166−169.

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