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Texture evolution of extruded AZ31 magnesium alloy sheets

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Abstract: The evolution of texture during the annealing and hot rolling process of extruded AZ31 magnesium alloy sheets was studied. There are two kinds of texture components in the extruded AZ31 sheets. One is $\{0002\}\langle 10\bar{1}0\rangle$ and the other is $\{10\bar{1}0\}\langle 11\bar{2}0\rangle$. The $\{0002\}\langle 10\bar{1}0\rangle$component predominates. After annealing at 723 K for 3 h, both $\{0002\}\langle 10\bar{1}0\rangle$ and $\{10\bar{1}0\}\langle 11\bar{2}0\rangle$ components are strengthened moderately. This indicates that grains with both two components mentioned above grow faster than those with other orientations. The $\{10\bar{1}0\}\langle 11\bar{2}0\rangle$ component disappears and the intensity of $\{0002\}\langle 10\bar{1}0\rangle$ component decreases significantly after hot rolling with a 30% reduction at 623 K. This is mainly attributed to rotational dynamic recrystallization (RDX) during the hot rolling.

Key words: AZ31 magnesium alloy; texture; extruded sheet; inverse pole figure

1 Introduction

Magnesium alloys, well-known for their lightweight and high specific strength, have been extensively studied recently[1]. The major problem for the application of the magnesium alloys is their poor workability at room temperature due to the insufficient number of slip systems in magnesium crystal[2−3]. Magnesium alloys, especially the wrought products, usually develop sharp crystallographic textures and show a strong anisotropy of properties. It is therefore of great scientific and practical interest to study the formation of texture.

Many studies of magnesium alloys have been concerned on the mechanical properties and the developments of new alloys. There are few studies focused on the texture development during the thermo-mechanical processing and annealing of the wrought magnesium alloys. Especially, the extruded sheets with large deformation degree need more investigation on the texture evolution[4−6]. Therefore, in this work, texture development of extruded AZ31 magnesium alloy sheets under annealing and hot rolling is studied. The relationship between deformation mechanism and the characteristics of the texture is also discussed.

2 Experimental

The direct chill (DC) cast ingots of an AZ31(Mg-3%Al-1%Zn in mass fraction) magnesium alloy with 90 mm in diameter were homogenized at 673 K for 16 h. Then the ingots were extruded at 653 K to sheets with dimensions of 1.5 mm×100 mm on cross section, corresponding to an extrusion ratio of 42.4.

Some studies[7−8] have found that the texture endures small changes during moderate annealing (e.g. at 623 K for 0.5 h) after extrusions of AZ31 alloy. So the annealing treatment was performed at 723 K for 3 h with the aim of studying the texture evolution of AZ31 alloy at a relatively high temperature and a relatively long time. The extruded sheets were hot rolled along extrusion direction with a reduction of 30% at 623 K.

Microstructure observation was carried out by Polyvar-MET optical microscopy. Average grain size was measured by the linear intercept method. X-ray texture analysis was performed in a Rigaku D/max 2 500 VB+ diffractometer. Texture was presented by means of inverse pole figures which were calculated by HARRIS method[9] developed by MORRIS. Specimen for X-ray

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diffraction is a cubic (with dimensions of 15 mm×15 mm×15 mm) with some rectangular plates (with dimensions of 15 mm×15 mm×1.5 mm) that were cut from the extruded or rolled sheets.

3 Results

3.1 Microstructure and texture of extruded AZ31 sheets

The microstructure of the extruded AZ31 sheets is composed of equiaxed, recrystallized grains with a heterogeneous grain size (Fig.1). The measured average grain size is 37 μm.

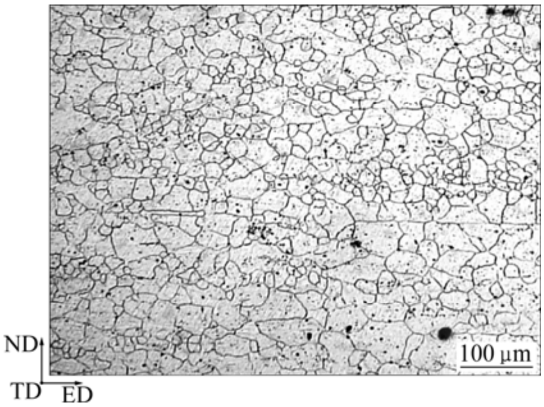

Fig.1 Optical micrograph of extruded AZ31 sheets (ND: Normal direction; TD: Transverse direction; ED: Extrusion direction; grains are observed from ND-ED plane, that is, TD direction)

The texture in the as-extruded condition is illustrated in Fig.2 by means of inverse pole figures. The density of poles in Fig.2(a) indicates that there are grains with basal {0002} and prismatic $\{10\bar{1}0\}$ planes parallel to the sheet plane, called the ND component (grains with their *c*-axis parallel to normal direction of sheet) and TD component (grains with their *c*-axis parallel to transverse direction of sheet). The positions of these two components are illustrated schematically in the sample coordinate system in Fig.3. The ND component predominates, as inferred by examining the intensity contours. Fig.2 reveals that ND component is $\{0002\}\langle 10\bar{1}0\rangle$ and TD component is $\{10\bar{1}0\}\langle 11\bar{2}0\rangle$. The *c*-axis of ND component is titled by about 15° away from the normal direction of the basal plane towards the ED (Fig.2(c)). The *c*-axis of TD component is titled by about 30° away from the normal direction of the basal plane towards the ND (Fig.2(a)).

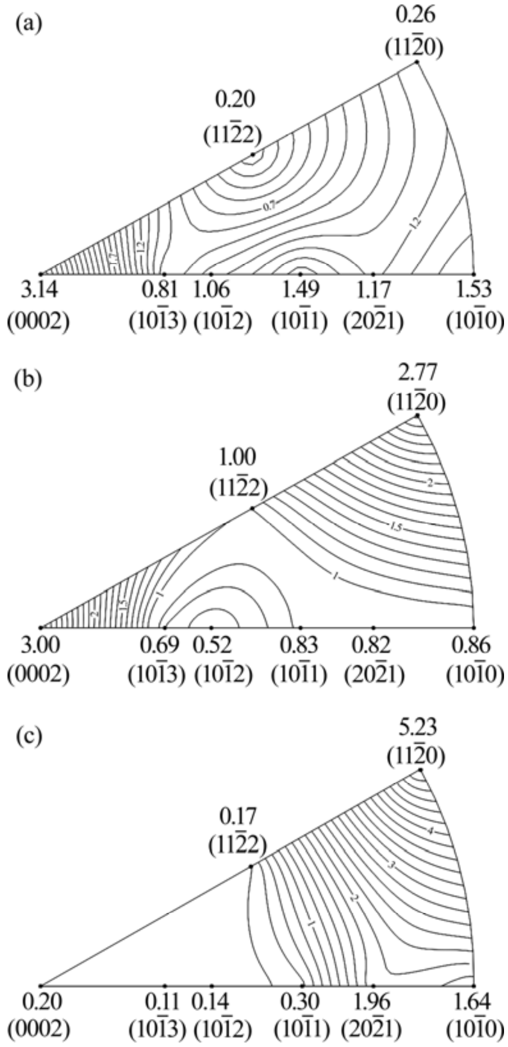

Fig.2 Inverse pole figures of extruded AZ31 sheets: (a) ND; (b) TD; (c) ED

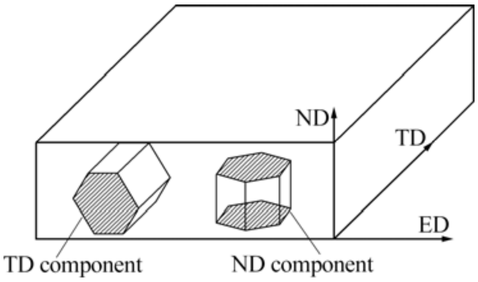

Fig.3 Schematic diagram relating ND and TD components to specimen coordinate system (Basal planes of two components are shown to be shaded)

3.2 Microstructure and texture evolution during annealing and hot rolling after extrusion

The average grain size of the extruded sheet after annealing at 723 K for 3 h is about 42 μm (Fig.4), slightly larger than the grain size of extruded sheet.

Fig.5 shows the texture evolution during annealing under this heat treatment condition. It can be seen from Fig.5(a) that the intensities of {0002} and $\{10\bar{1}0\}$ poles increase compared with Fig.3(a), especially the intensity of {0002} pole increases significantly. This indicates that grains with ND and TD components grow at the expense

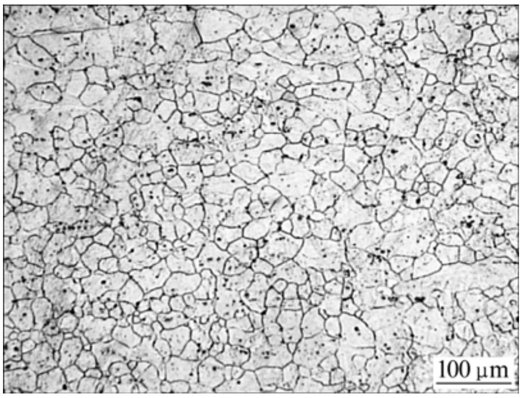

Fig.4 Microstructure of extruded AZ31 sheets annealed at 723 K for 3 h (TD plane)

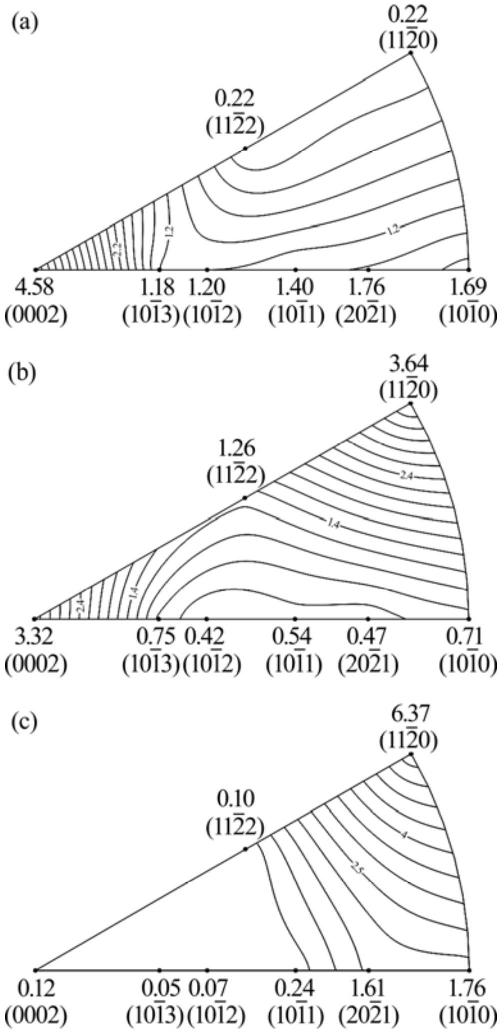

Fig.5 Inverse pole figures of extruded AZ31 sheets annealed at 723 K for 3 h: (a) ND; (b) TD; (c) ED

of grains with other orientations.

After hot rolling at 623 K with 30% reduction, a significant microstructure change is observed (Fig.6). It can be seen that the distribution of grains tends to be rather heterogeneous. Besides the recrystallized grains, there are deformation structure and twins in Fig.6(a). Some grains are elongated, especially some large grains (coarser than 30 μm) are surrounded by smaller recrystallized grains developed during hot rolling (Fig.6(b)). TEM images of the microstructure of the rolled AZ31 is shown in Fig.7. It can be found that there are substructure, twins and sub-grains in the deformation structure. Fig.8 shows the texture evolution of extruded sheets after hot rolling. It can be seen that significant texture changes also take place. The TD component disappears and a decrease of ND component (basal texture) is observed. The spread of {0002} pole can also be observed.

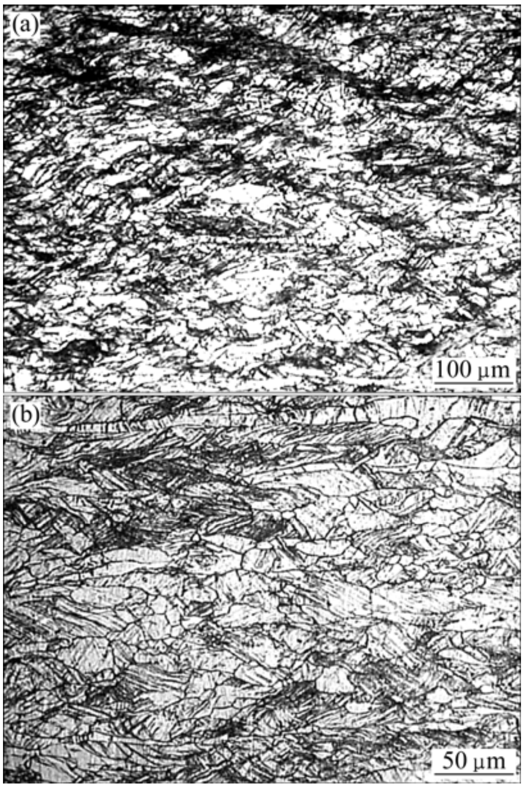

Fig.6 Microstructures of extruded AZ31 sheets after hot rolling with 30% thickness reduction at 623 K (TD plane)

4 Discussion

In magnesium alloys, there are four different slip systems that can operate if their critical resolved shear stress(CRSS) is exceeded[10]. They are 1) basal slip $\{0002\}\langle 11\bar{2}0\rangle$, 2) prismatic slip $\{10\bar{1}0\}\langle 11\bar{2}0\rangle$, 3) first-order pyramidal slip $\{10\bar{1}1\}\langle 11\bar{2}0\rangle$ and $\{10\bar{1}2\}$ $\langle 11\bar{2}0\rangle$, and 4) second-order pyramidal slip $\{11\bar{2}2\}$ $\langle 11\bar{2}3\rangle$. The CRSS for the non-basal systems is much larger than that for basal slip(approximate ratio of 1:38:50:100 at room temperature)[11] and temperature at which they get activated also increases in the above order. However, the

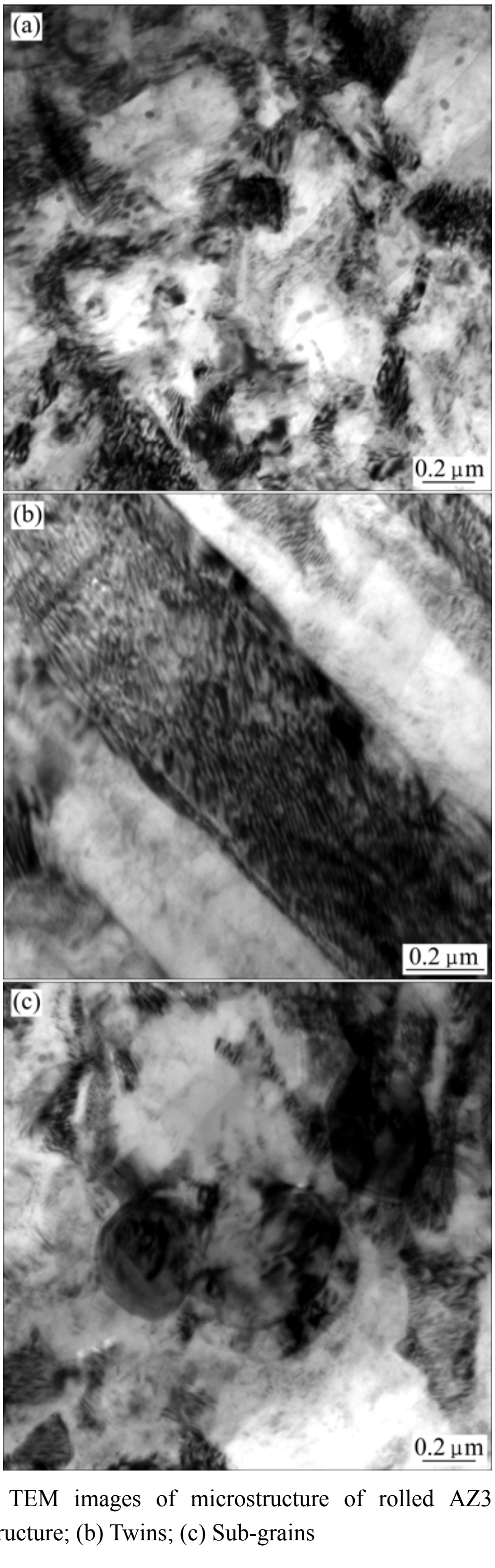

Fig.7 TEM images of microstructure of rolled AZ31: (a) Substructure; (b) Twins; (c) Sub-grains

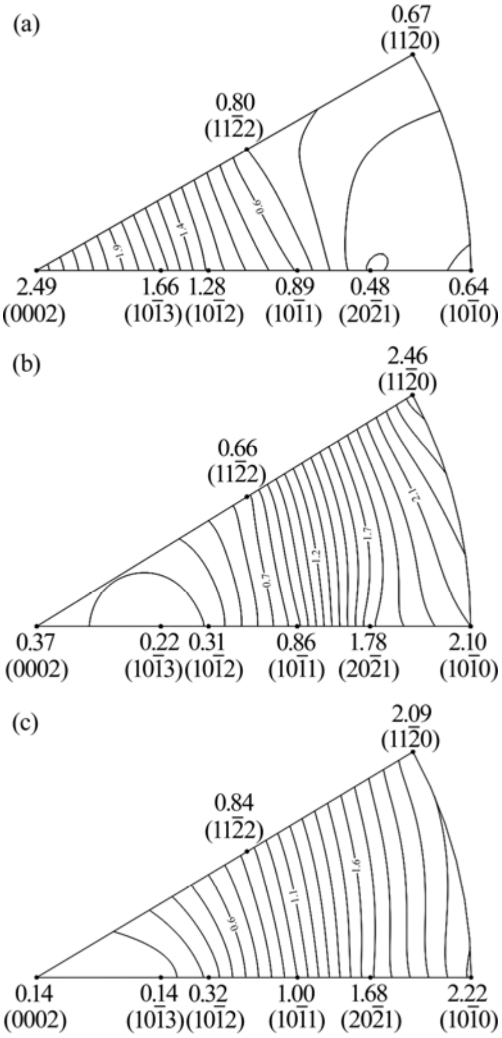

Fig.8 Inverse pole figures of extruded AZ31 sheets hot rolled with 30% reduction at 623 K: (a) ND; (b) TD; (c) ED

CRSS for non-basal slip decreases significantly with an increase in temperature[12]. It is noted that only the second-order pyramidal slip has a slip direction not parallel to the basal plane, also referred to as $\langle c+a\rangle$ Burgers vector. While there are several potential twinning systems, and only the system of $\{10\bar{1}2\}\langle\bar{1}011\rangle$ is observed in most hexagonal metals, particularly in magnesium. This twinning system is so-called “tension twinning” in magnesium[13], since it can only be activated by a tensile stress parallel to the *c*-axis (or a compressive stress perpendicular to the *c*-axis) when the *c*/*a* ratio is less than 1.732(magnesium has a *c*/*a* ratio of 1.624).

Although there are few studies of extruded sheets [4−5], several investigations have described rolling texture for hexagonal metals[14−15]. According to these studies, hot rolling in magnesium alloys gives rise to a basal texture, with {0002} planes parallel to the sheet plane. In order to rationalize the rolling texture of magnesium, the model of CALNAN and CLEWS[16] is used, in which the rolling process can be rationalized as a compression perpendicular to the sheet plane and tension in the rolling direction. This model predicts that the compression will rotate the active slip plane so that its normal direction moves towards the stress axis. An easy slip in Mg occurs on basal planes, and the rolling process will orientate basal planes to be parallel to the sheet plane. Compared with rolling, there is a compression perpendicular to the sheet plane (ND plane) and longitudinal plane (TD plane) during extrusion process for sheets. Therefore, besides ND component (basal texture), TD component appears in extruded sheets. Extruded rods have basal fiber texture (basal plane parallel to extrusion direction with 360° rotation around it) because of compressive stresses distributed symmetrically around extrusion direction during extrusion process.

The extruded sheet has already a predominant basal texture (ND component) as a result of prior processing consisting of extrusion to a 1.5 mm-thick sheet. Grains with ND component of their *c*-axis are parallel to the compression axis during hot rolling, and these grains are unfavorably oriented for both $\{10\bar{1}2\}$ twinning and basal slip. However, grains with TD component of their *c*-axis are perpendicular to the compression axis during hot rolling, and these grains are favorably oriented for $\{10\bar{1}2\}$ twinning. This is expected to occur during the initial stage of hot rolling, as documented by PHILIPPE [14]. After grains with TD component are deformed by $\{10\bar{1}2\}$ twinning, they reorient the basal planes perpendicular to the compression axis, as shown in Fig.9.

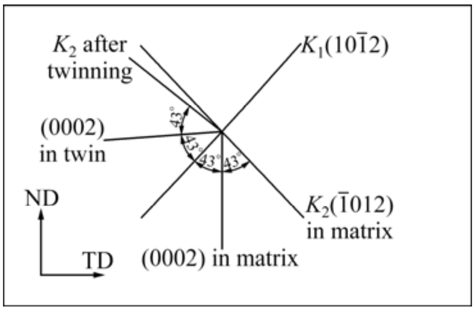

Fig.9 Schematic illustration of $\{10\bar{1}2\}$ twinning orienting basal plane nearly parallel to sheet plane (Plane of this work is perpendicular to K_1 and K_2 planes)

After $\{10\bar{1}2\}$ twinning, most grains with basal texture are unfavorably oriented for basal slip. Especially at high temperature and large deformation degree (30% reduction and the true strain is about 0.36), slip in non-basal systems may operate, thus giving rise to rotated regions and accomodating the imposed external deformation. As the strain increases further, sub-grains form in the vicinity of grain or twin boundary regions by dynamic recovery and ultimately high angle boundaries appear by sub-boundary migration and coalescence. Finally, new small recrystallized grains form at the distorsion region in the vicinity of grain boundaries. This is so called “rotational dynamic recrystallization”(RDX) proposed by ION et al[17]. After RDX, smaller grains appear in the vicinity of original grain boundaries (Fig.6(b)). These grains are rotated away from the original grains, which mostly belong to the {0002} basal texture. Thus, a significant decrease in the intensity of the {0002} pole is observed. It must be noted that $\{10\bar{1}2\}$ twinning is closely related to the dynamic recrystallization during thermo-mechanical processing of magnesium alloys. AL-SAMMAN and GOTTSTEN[18] found that basal texture was weakened by the recrystallized grains in $\{10\bar{1}2\}$ tension twins. The mechanism of RDX and the relationships between RDX and $\{10\bar{1}2\}$ twinning need further investigation.

5 Conclusions

1) There are two main texture components, that is $\{0002\}\langle 10\bar{1}0\rangle$ and $\{10\bar{1}0\}\langle 11\bar{2}0\rangle$, in extruded AZ31 sheets, and the $\{0002\}\langle 10\bar{1}0\rangle$ component predominates.

2) The $\{0002\}\langle 10\bar{1}0\rangle$ and $\{10\bar{1}0\}\langle 11\bar{2}0\rangle$ components are strengthened moderately after annealing at 723 K for 3 h. This indicates that grains with both two components mentioned above grow at the expense of grains with other orientations.

3) After hot rolling with a 30% thickness reduction at 623 K, the $\{10\bar{1}0\}\langle 11\bar{2}0\rangle$ component disappears and the intensity of $\{0002\}\langle 10\bar{1}0\rangle$ component decreases significantly. This is mainly attributed to rotational dynamic recrystallization(RDX) during the hot rolling.

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