Textures at deformation region of an ECAP processed Mg by synchrotron diffraction

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1 Introduction

Equal channel angular pressing (ECAP) is one of the commonly used severe plastic deformation (SPD) processes which can produce bulk ultra-fine or nano-grained materials [1]. Improved properties of various ECAP processed materials which are mainly attributed to the uniform microstructures, such as refined grains, large fraction of high-angle grain boundaries, unusual textures, etc., have been increasingly investigated [2, 3]. It is known that the principle of plastic straining, which is a direct consequence of simple shear, is the basic process underlying ECAP processing technique [4, 5]. However, resent investigations have demonstrated a combined or complicated deformation model other than a simple shear during ECAP [6, 7]. Moreover, because of the unavoidable friction, especially at the deformation region where two channels meet, there exits an inhomogeneous material flow [8, 9].

Crystallographic texture describes the orientation distribution of the grains constituting a polycrystalline aggregate and records the materials thermal mechanical history. Formation of uniform texture during ECAP is substantial to be related to the plastic anisotropy [1, 10]. Researches indicate many factors that can influence texture evolution during ECAP, such as applied strain path, die geometry, processing conditions, deformation inhomogeneities, accumulated strain, crystal structure, material plastic behavior, initial texture, dynamic recrystallization, deformation twinning, et al. [10, 11]. Unfortunately, systematically studies on these effects are still insufficient.

Magnesium is getting more attractive in the application for light weight constructions and profiles because of its very low density and large amount of available resources [12]. To improve their strength and deformability, ECAP processing of Mg and its alloys has been increasingly investigated [13, 14]. Texture development in Mg is significant because of its strong anisotropic property which comes from its hcp crystallographic structure. Texture analysis will contribute to understand the deformation mechanism during ECAP besides its relation to the following properties.

The evolution of texture gradients during ECAP was primarily investigated by neutron diffraction [15]; due to a relatively low local resolution of neutron diffraction the most interesting near die angle region could not be precise enough. The current paper continues the neutron investigation using high energy synchrotron diffraction to get detailed local information of the region where two channels of the ECAP device meet.

2 Experimental

In this research, a cast commercial pure Mg was first hot quadratic extruded at 340°C to a billet with its cross section area of 10×10 mm^2 and then ECAP processed. The ECAP die which was made of SKD60 contained two separated parts with the 90° vertical channel total in one side. MoS_2 was used as lubricant. During ECAP the pure Mg billet was first inserted into the lubricated die followed by fastening with screws then together heated to 350°C and holding this temperature for 30 min; finally was pressed at a speed of 20 $mm \cdot min^{-1}$ and stopped after 50 % deformation. Thus the ECAP processed pure Mg billet consists of a first part of the ingoing channel, a second part directly of the 90° corner region, and a third part of the outgoing channel after deformation. The macroscopic view of this 50%-ECAP processed billet is shown in Figure 1, in which ED, ND and TD were defined as the extrusion, normal and transverse direction of the billet, respectively.

Texture measurement was performed by high energy synchrotron diffraction at HARWI-W2 (DESY-Hamburg, Germany). A detailed description of texture gradient investigations using synchrotron radiation is given by Brokmeier et al. [16]. Five samples were cut from the deformation region, as shown in Figure 1 by the dashed line. An average two positions of sample 1 to 4 along ND were measured with a beam size of 2 × 2 mm^2 at a wavelength of 0.01523 nm; but three positions for sample 5. Step size in ω was 5° from -90° to 90°. Integral intensities were calculated to obtain a set of five pole figures (10.0), (00.2), (10.1), (10.2) and (11.0). Recalculation of pole figures was performed using Bunge’s system definition of Euler angles by series expansion method with an expansion degree of l_{max}= 22 [16].

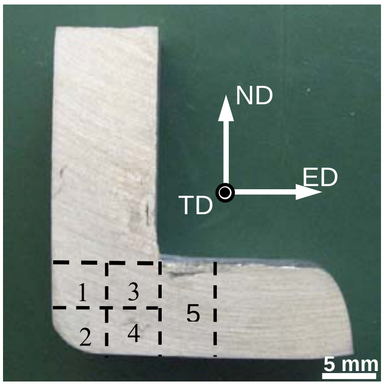

Figure1: Macroscopic view of the ECAP processed billet and the schematic illustration of sample preparing for texture analysis.

3 Results and discussions

Figure 2 shows the (00.2) and (10.0) complete pole figures at position before 90º die angle. It can be seen that the asymmetric deformation has already started at this region. The texture at this region consists of a fiber texture component rotated about 10° from the ED and of a central maximum component visible inside the (00.2) pole figure. Without the rotation this texture is related to the hot quadratic extrusion process before ECAP. Detailed explanation has been discussed in the former paper [15].

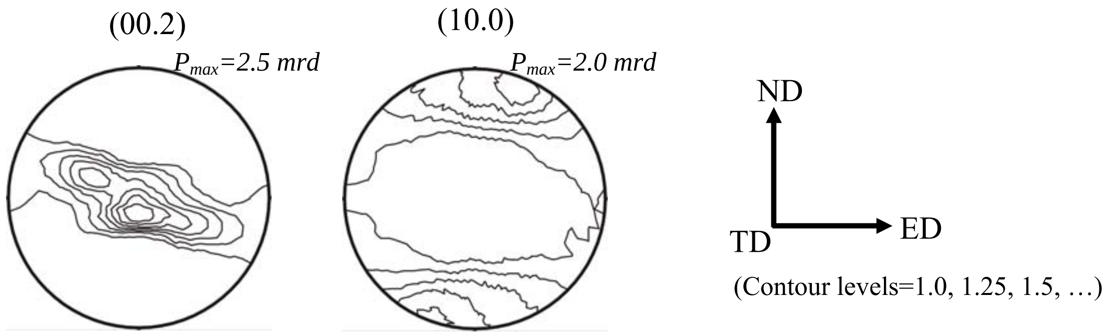

Figure 2: The (00.2) and (10.0) complete pole figures at position before deformation region.

Texture evolution from region 1 to region 5 is illustrated by (00.2) and (10.0) complete pole figures in Figure 3 which represents the top and bottom at region 1, 2, 3 and 4, respectively; and the top, middle, bottom positions at region 5. Looking on deformation region 1 a rotation <00.2> fiber with a central maximum is observed at top part. This <00.2> fiber with its axis orientates at about 30º to the ND and is remained at region 3. Textures at region 3 show relatively homogeneous distribution. While at bottom position of region 1 the <00.2> fiber is re-orientated to be parallel to the ND with the weakening of central maxima. This girdle distribution is similar as those textures in hot rectangular extruded Mg [17]. This indicates that more complex deformation modes other than simple shear occur during ECAP.

Looking on the outer curvature region 2 the <00.2> fiber axis is rotated about 30 º to the ND with the disappearing of central maxima. Interesting is the bottom position at region 2 an ideal 45º shear fiber is formed with a weak pole intensity in centre. When the billet moves to region 4 double fibers are formed, as shown in Figure 3 (d), which is a combination of a rolling type with its central pole maximum intensity of 4.0 mrd (multiples of random distribution) and a weak rotated <00.2> fiber.

From time scale region 5 should record the deformation information of regions 3 and 4 except the temperature effect. A strong <00.2> fiber with its maxima 6.6 mrd around ND is produced at top position which is similar as normal compression type Mg texture. The texture in position 5 should be good correlated to the sample at position 3 and 4. At middle position double components are formed which are similar as at position 3. The asymmetry in (00.2) pole figure at position 4 results also from the shear but is much lower than 45°. A rotation of about 10° around TD between positions 4 and 5 is visible. Due to the inhomogeneous flow field during ECAP this rotation starts already at the beginning and is finished for this experiment after passing the shear zone (sample position 5).

From above texture evolution two important trends can be achieved. One is that current ECAP process shows a combined texture evolution; another is the observation of less shear effect. This evolution of a combined rotated <00.2> fiber, rolling and extrusion type preferred orientation should origin from the complex deformation modes. Modeling of texture evolution in ECAP processing of aluminum using Taylor approach has indicated that a plane strain tension and compression component developed during pressing which led to the rotation of fiber [18]. More important is the twinning which should start since the billet enters the deformation and activation with the rotation of maxima. Twinning can be easily activated in coarse grained Mg. Moreover, friction condition and the processing temperature are also two important factors in current die set-up which affect the deformation modes. Current ECAP die consists two parts with the deformation channel totally in one side. The fasten condition and mismatch friction contribute to the asymmetric <00.2> fiber.

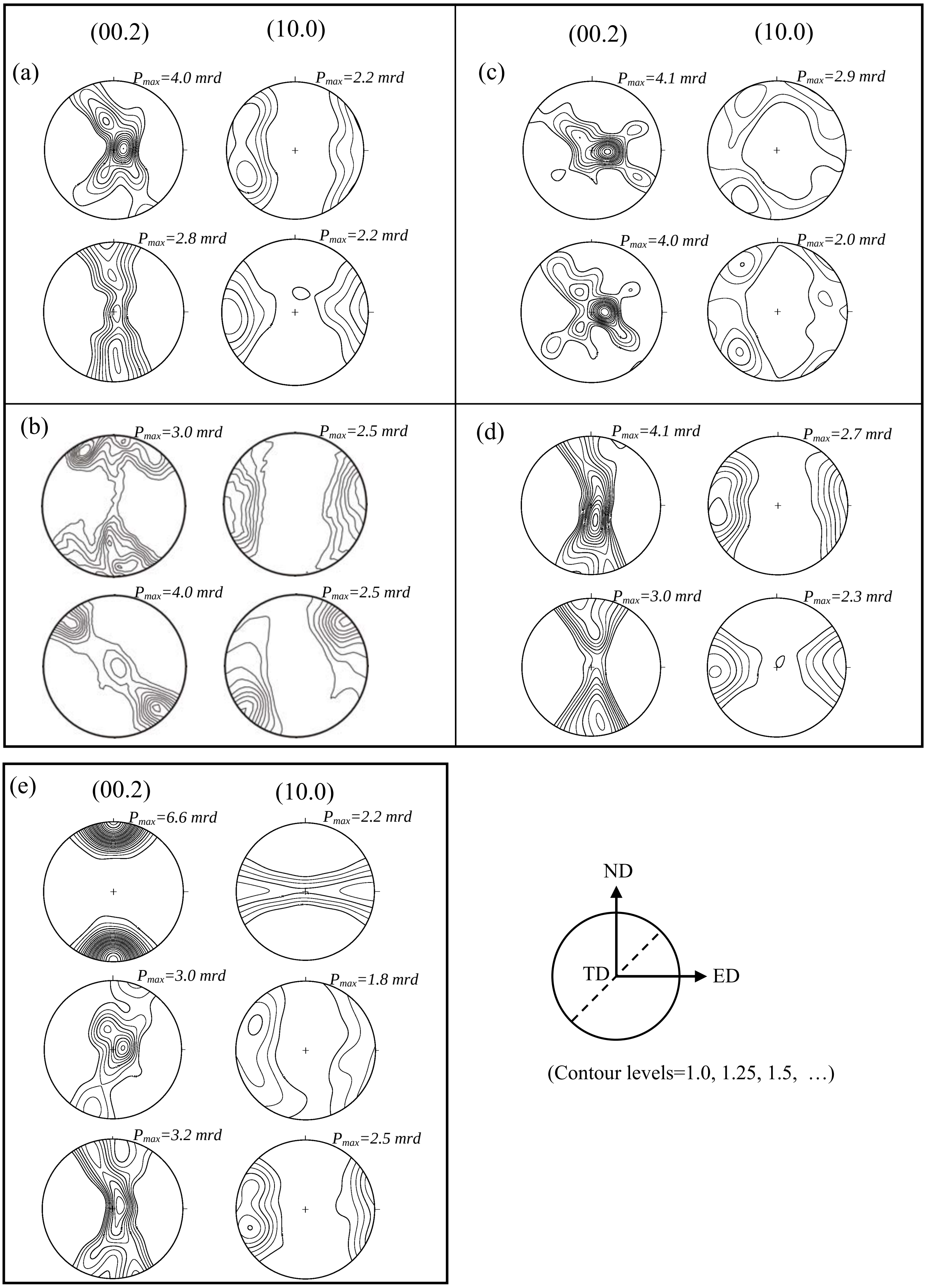

Figure3: Evolution of (00.2) and (10.0) complete pole figures at top and bottom position in region (a) 1, (b) 2, (c) 3, (d) 4; and (e) top, middle and bottom at region 5.

Remarkable is the observation of less shear effect during the whole processing except that an observation of a 45° shear fiber at the region near outer curvature angle. The ideal 45° shear plane is plotted in a dashed in the pole figure, as shown in Figure 3. It should be noted that according to the simulation results the effective strain is higher at the top surface and decreases significantly at the bottom surface which is due to the presence of the out corner angle [19, 20]. Kim has demonstrated that a lesser shear zone (LSZ) in the outer part of work piece occurs when the corner angle of the die is nonzero because of the shorter travel path of outer part within the main deformation zone in that case [21, 22]. However, this is not the case in current research which should be attributed to the increased local flow velocity of the work piece. Variation of this velocity is greatly related to the outer arc curvature angle and the strain hardening behavior of the work piece [22]. The larger the die corner more inhomogeneous strain distribution occurs. Since the outer curvature angle of the present die is 37°, the pronounced inhomogeneous distribution of strain could lead to an intense deformation at position 2. Another important factor is the processing temperature. Recrystallization is prone to happen during hot deformation of Mg which attributes to the strengthening of basal preferred orientation [23]. More or ideal shear effect is expected to be easily detected in ECAP processed Mg at very low or room temperature. But in practical this process is difficult to perform in large grained Mg.

4 Summary

A gradient texture evolution at 90° die region in an ECAP device was characterized by synchrotron diffraction in a 50 % ECAP processed pure Mg. A combined texture evolution was observed which was attributed to the complex deformation modes other than simple shear. During the whole process a continuous rotation of the input texture, a fiber texture from extrusion, was regarded from the ingoing channel over the 90° die region till the first part of the outgoing channel. Remarkable was the obtaining of 45° shear fiber at outer curvature angle. More important is twinning with texture maxima at ND in position 5. But this twinning starts much earlier in the 90° die region and has to follow the rotation by asymmetric flow. Friction and processing temperature both played important roles in current setup for ECAP processing of Mg.

5 Acknowledgements

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