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Stereomicroscopic Analysis of ECAE Processed Mg-Zn-Zr alloy

Lately, a growing volume of research has been conducted on studying the effects of equal channel angular extrusion processing. Equal channel angular extrusion (ECAE) or equal channel angular pressing (ECAP) is a severe plastic deformation (SPD) technique, which presses the test materials through a die with two channels which are equal in cross section and intersecting at a certain angle. After the deformation, the test materials will still retain its original cross-section being able to repeat the process to many cycles. This method improves the mechanical properties of the processed materials because of the ultrafine grained structures resulted. Present paper intends to make a qualitative investigation of the Mg-Zn-Zr samples processed through ECAE.

***Keywords**: severe plastic deformation method, equal channel angular extrusion, magnesium alloys*

1. Introduction

In the last few years there has been a revival in magnesium alloy research driven by increasing global awareness of the link between energy usage and climate change [1]. Because it is the lightest material for manufacturing metal components, magnesium can be used in the fields like automobile and aerospace industry, but also in the military industry [2]. However, the magnesium alloys have mechanical limitations like their limited strength, plasticity and formability [3].

One of the important methods to improve the mechanical properties of magnesium alloys is through grain refinement. Grain refinement can be achieved through a variety of methods, but in recent years, severe plastic deformation (SPD) techniques have been the focus of intense research due to the fact that the structures formed by the SPD are ultra-fine grained structures. The interest in such ultra-fine grained structures is that they can provide an equitable compromise between high strength and satisfactory ductility that is attractive especially for structural applications. The developed and used SPD methods are: severe torsion straining under high pressure, equal channel angular extrusion, accumulative roll bonding, multiple forging, twist extrusion, and repetitive corrugation and straightening [4]. Presently, among the methods of SPD, equal channel angular extrusion (ECAE) is considered as the most promising for industrial applications [5].

2. Mechanism of ECAE

Equal channel angular extrusion or pressing (ECAE) is a novel deformation method resulting in a large grain refinement through severe plastic deformation. In ECAE, deformation is achieved by simple shear when the sample goes through the intersection of the two channels of the die [6-7]. Simple shear can be considered a near ideal deformation method for structure refinement and texture formation in metal working. Large and uniform strain intensity per pass can be reached in material under low pressure and load without a reduction of the initial billet cross-section. The process can be repeated a number of times in the die because the billet cross-section remains constant [8].

The two channels of the die are equal in cross-section and they are intersecting at an internal angle, Φ which can be between 60° and 160° [9].

During ECAE, the processing route is one parameter which can effectively change the strain path of the deformation. A nornenclature has evolved in the literature referring to the major variants as Route A - meaning no rotations between passes, Route B_A - meaning 90º back-and-forth rotations, Route B_C – meaning 90º continuous rotations and Route C meaning 180º rotations [10-11].

The amount of plastic strain introduced in the materials after ECAE processing depends on the die angle and the number of passes.

3. Experimental procedure

The ZK60 magnesium alloy used in this study has the chemical composition (wt.%) given in Table 1.

Table 1.

Chemical composition of the ZK60 magnesium alloy (wt.%)					
Mg	Zn	Zr	Al	Mn	Other elem.
bal	5.49	0.55	0.005	0.025	max 0.3

The as-cast magnesium alloy was machined into ECAE specimens with dimensions of 10 mm x 10 mm x 40 mm. The ECAE process was performed using a die fabricated by tool steel and the internal angle between the two channels has 90°, as can be seen in figure 1.

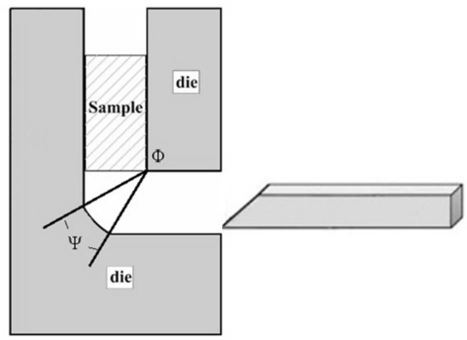

Figure 1. Front view of an ECAE die

Well-lubricated billets were inserted in the die. The ECAE was carried out following route B_A, which involved 90° back-and-forward rotation of the billet between each pass. Prior to each pass, the billets were preheated to the respective temperature of ECAE in the die. The exact temperature of the ECAE was monitored through a thermocouple placed exactly near the plane of intersection of the two channels. The extrusion speed of ECAE tests was 17.30 mm/s.

The first 4 passes were conducted at 250 ± 5 °C. From the 5th pass onward, the temperature of the ECAE was reduced in steps. The 5th pass ECAE was carried at 200 ± 5 °C, the 6th pass at 150 ± 5 °C and the 7th pass at 110 ± 5 °C.

The extruded samples were prepared on Buehler equipment and attacked in order to put in evidence the magnesium compounds.

The results of the equal channel angular extrusion process were analyzed through stereomicroscopy. The equipment used was an Olympus SZX57 microscope, equipped with QuickMicrophoto 2.2 image processing soft.

4. Results and discussion

The material was observed in the extrusion direction in order to reveal any grain elongation. The stereomacrostructural aspect of the ECAE processed ZK60 magnesium alloy is presented in figure 2.

The original macrostructure of the as-cast ingots before equal channel angular extrusion process is shown in figure 2a. Figure 2b shows the macrostructure of an ECAE processed ZK60 magnesium alloy at 250 ± 5 °C after one pass, which consist of fibrous structure of elongated grains, and a relatively low density of shear bands along the extrusion direction. The existence of the shear bands can lead to grain refinement, because they act as new nucleation sites during the static recrystallization. The grains in the cast material were elongated along the extrusion direction. Increasing the number of ECAE passes from 1 (figure 2b) to 3 (figure 2c), then to 5 (figure 2d) and lastly to 7 (figure 2e) clearly produces a microstructure with a fibrous morphology with finer particles, which can be commonly observed in highly deformed metals.

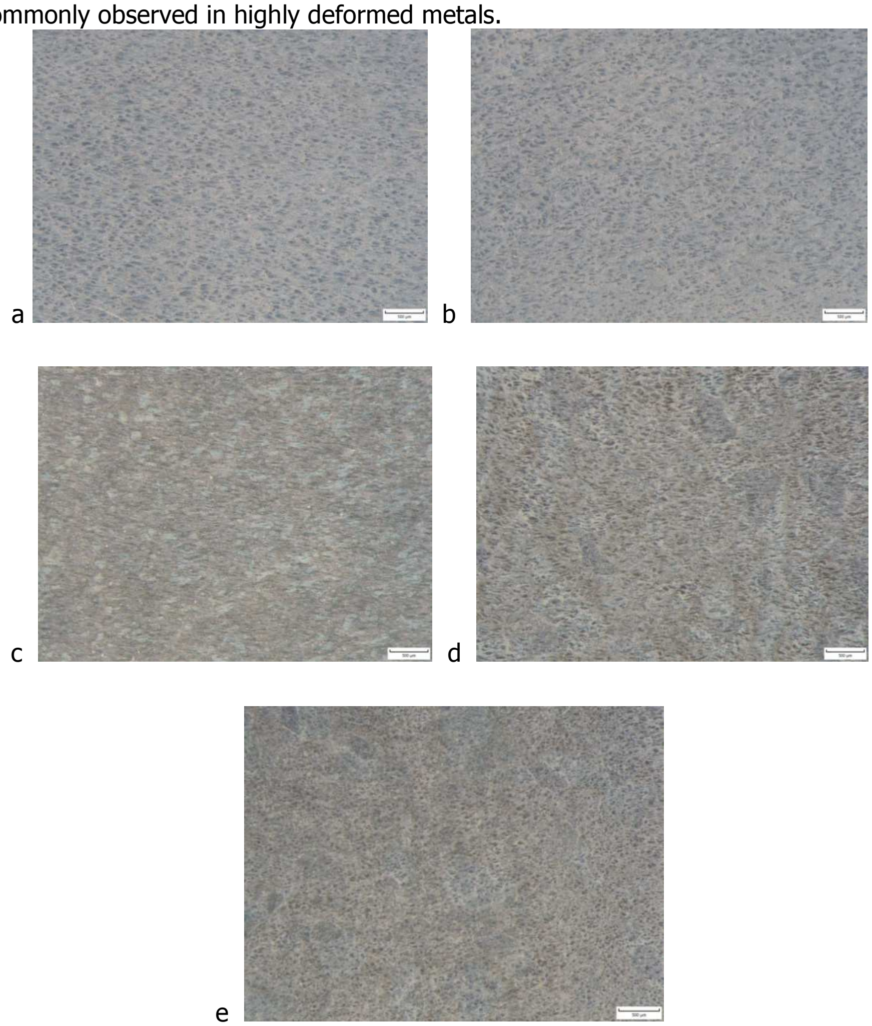

Figure 2. Stereomacrostructural aspect of as-cast ZK60 magnesium alloy (a), after one pass (b), after three passes (c), after five passes (d) and after seven passes (e)

It can be seen that the grains in the longitudinal direction becomes more homogeneous with the increase of passes. After the fourth pass, the grain becomes aproximately equiaxed. Also, the grains are finer in all materials. Thus, compared with the grain size of as-cast ZK60 alloy, the grain size decreases after one pass. With the increase of the number of passes the grain size tends to be more uniform.

5. Conclusion

An ZK60 magnesium alloy was subjected to equal channel angular process at at 250 ± 5 °C for the first 4 passes, at 200 ± 5 °C for the 5th pass, the 6th pass was conducted at 150 ± 5 °C and the 7th pass at 110 ± 5 °C.

After the ECAE process, there can be observed an evolution of the fibrous structures which develop in the ZK60 magnesium alloy with increasing number of passes of the continued shearing route. Thus, the grains of the ZK60 specimens become elongated and aligned along the direction of shearing after processing. The extent of the shear deformation is observed to increase with the number of passes.

Applying a severe plastic deformation technique to a ZK60 magnesium alloy should improve the mechanical properties of the alloy. The improved mechanical properties of the ECAE-ed magnesium alloy will be the subject of our further investigations.

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