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Full length article

The effect of Equal Channel Angular Pressing process on the microstructure of AZ31 Mg alloy strip shaped specimens

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Abstract

Equal Channel Angular Pressing (ECAP) is one of the most applicable Sever Plastic Deformation (SPD) processes which leads to strength and ductility improvement through the grain refining and development of a suitable texture. In this study, after designing and manufacturing a suitable die, 4 pass ECAP process at route C is done on strip shaped specimens of AZ31 magnesium alloy in order to achieve desirable microstructural and mechanical properties. Microstructure then got studied through the optical microscopy. Results show that mean grain size is decreased and grain size distribution got close to normal distribution state by increasing the pass number. However, the grain size is reduced by increasing of ECAP temperature.

Keywords: Equal Channel Angular Pressing (ECAP); AZ31 Mg Alloy; Microstructure

1. Introduction

One of the most effective parameters on physical and mechanical properties of crystalline materials is mean grain size. Based on the Hall−Petch relationship, strength of materials related to their grain size.

$$\sigma_y = \sigma_o + k_y d^{-\frac{1}{2}} \quad (1)$$

Where the σ_o is the friction stress, d average grain size, σ_y yield stress and k_y is the yield constant [1]. In the last two decades, methods of severe plastic deformation (SPD) are developed with the aim of improving the microstructure and consequently the production of metals and alloys with proper microstructure and high strength and ductility [2−4]. Among these methods, the Equal Channel Angular Pressing (ECAP), Cyclic Extrusion Compression (CEC), High Pressure Torsion (HPT) and Friction Stir Processing (FSP) can be mentioned. Among above processes, ECAP has been more used, since it can be applied to high range of materials like composites, precipitation harden able materials and alloys, it can be commercialized because, it can be done in several passes to impose high strains. ECAP process which is also called ECAE is generally conducted using samples in the form of bars or rods having square or circular cross-sections. This leads to need to secondary rolling process in order to make the specimen usable in the industrial forming processes.

One of the newest areas of recent research to solve this problem is ECAP of plate-shaped samples like sheets and billets [5]. In spite of having high ratio of strength to weight and research and applied importance in automotive, aerospace and electrical industry, magnesium alloys have low workability in room temperature that is due to their rare

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appropriate slip system in low temperatures. Because of this, the magnesium alloys are hot or warm formed. Therefore, in order to increase their workability at ambient temperature with the acquisition of appropriate grain structure and texture, ECAP process has been carried out on magnesium alloys.

2. Experimental procedure

In the present study, first a die is designed and made for ECAP of strip shaped samples (Fig. 1). AZ31 magnesium alloy billets with 2.8Al–0.9Zn–0.3Mn chemical composition were hot rolled to dimensions 70 × 30 × 4 mm, then heated to 300 °C and held for 2.5 h to be annealed. Later on, ECAP Process is done at three different temperatures and through the route C (180 rotation about the longitudinal axis between passes) up to 4 passes. To achieve to the same temperature of samples and die, the strips were held for 10 min before being ECAPed. Etching the specimens by a picric acid (4.2 g) – acetic acid (10 ml) – distilled water (10 ml) – ethanol (70 ml) solution was followed by optical microscopy was done. CLEMEX commercial software was used to grain size measurement.

3. Results and discussion

Fig. 2 shows initial and ECAPed specimen microstructure for 1, 2 and 4 passes at 200 °C through the route C. The mean grain size in the initial sample was 38.9 μm. It should be noted that graphical sketches were used in grain size measurement.

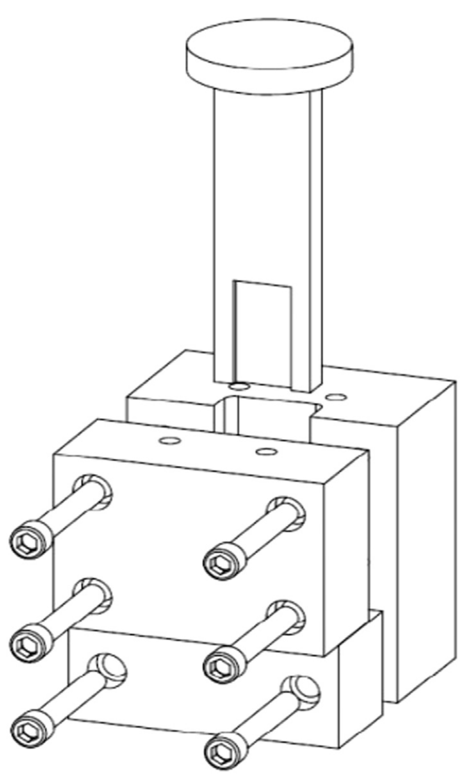

Fig. 1. Schematic of die designed and manufactured for ECAP of strip shaped specimens.

It was seen that after 4 passes ECAP, microstructure is homogenized and also the mean grain size is reduced to 4.7 μm which is in agreement with previous findings [6,7]. Histogram shows the grain size distribution gets close to normal form (Fig. 3). The fine recrystallized grains of the initial pass gets remain unchanged and instead the coarser grains are refined through the further passes. Of course after 4 passes, there are some coarse grains which are surrounded by fine grains. The wide distribution which is illustrated in the histogram also shows this bimodal microstructure. Basically, observation shows that the main part of grain refinement and microstructure homogenization happens during two first passes and then it descends. It can be concluded that by refining the grains in the primary passes, grain boundary sliding mechanism is activated and some portions of strain energy is depreciated by this mechanism. So, the stored strain energy in the grain is reduced. As a result, dynamic recrystallization driving force is diminished and microstructure refining process slows down. On the other hand, grain boundary sliding activation leads to a decrease in stress and strain profile slope in the coarse grains. So the continuous dynamic recrystallization steps down as a result of the rotation of near to grain surface regions [8].

Rotation of the samples between the passes in route C, leads to intensity decrease of the basal planes which are parallel to normal direction (ND). Furthermore, more grain refinement in the route C can be attributed to activation of other deformation systems which themselves are the result of rotation of samples which inturn leads to deformation of inappropriately orientated grains and refinement of grains [9,10].

In comparison with structures including numerous slip systems like FCC, the orientation of the grains in HCP structures plays more important role in the activation of deformation systems in different temperatures. This can also account for the presence of bimodal structure in AZ31. During deformation, some grains have suitable crystallographic orientation and proper Taylor factor which are accompanied with smaller critical resolved shear stress. So the slip is activated in these grains leading to increase in dislocation density by deformation accommodation. Continuing deformation, restoration phenomena like continuous dynamic recovery (CDRV) and continuous dynamic recrystallization (CDRX) cause the refinement of main grains and sub grains. Because of the lack of inadequate slip systems in Mg alloys, continuous dynamic recrystallization occurs so that lots of grain boundary constraints which is present between well orientated and other grains causes the impsing of a lot of rotations on main and sub grains. Rotations of low angle grain boundary lead to increase of their misorientation and change them to high angle grain boundaries.

Finally inappropriately orientated grains will have lower degrees of slip and consequently a bimodal structure including coarse grain surrounded by finer grain will appear (as shown in Fig. 2). As stored strain (pass numbers) increases, regions near to grain boundaries in coarse grains are deformed and because of dynamic recrystallization, the misorientation of sub grain boundaries in these regions is increased. Then they are