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Effect of equal channel angular pressing on AZ31 wrought magnesium alloys

Avvari Muralidhar*, S. Narendranath, H. Shivananda Nayaka

Mechanical Engineering Department, National Institute of Technology Karnataka (NITK), Surathkal, Srinivasanagar, Mangalore 575025, Karnataka, India

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Abstract

AZ31 wrought magnesium alloys are light weight materials which play an important role in order to reduces the environmental burdens in modern society because of its high strength to weight ratio, corrosion resistance, and stiffness and machinability. Applications of this material are mainly in structural component i.e., in constructions, automobile, aerospace, electronics and marine industries. In the present work, the microstructure characterization of the AZ31 alloys up to four ECAP passes at temperature of 573 K was observed for route Bc. Average grain size of the material was reduced from 31.8 μm to 8 μm after four ECAP passes. Mechanical properties of the alloy improved with increase in number of ECAP passes. Moreover, X-ray diffraction analysis was carried out for as received and ECAP processed material.

Keywords: ECAP; AZ31 alloy; Grain refinement; Microstructure; Mechanical properties; XRD

1. Introduction

Severe Plastic Deformation (SPD) is a material forming technique used to refine the grain size of various materials to improve material properties [1]. Among all SPD techniques, equal channel angular pressing is one of the simpler and most effective procedures to improve quality of the products [2–4]. It has been proved that, ECAP is a good refining technique to improve various material properties like magnesium alloy [5], aluminum alloy [2] and other materials such as Cu, Fe and Ti [6]. Literally, wide research has been accomplished by changing die layout angles from 60° to 150° to improve properties of material [6]. In comparison with above materials reported in the literature, magnesium and its alloys have many advantages mainly in terms of high strength to weight ratio and ductility [7–10]. Hence, these materials are being used as structural material in automotive, aerospace, electronic devices and nuclear industries [11,12]. Magnesium and its alloys have HCP structure and the slip systems activation at room temperature is insufficient to accommodate uniform plastic deformation, which can be considered as a major limitation [13]. However, research papers have been published related to mechanical properties by controlling the slip systems and twins of the magnesium material through ECAP at different die angles. C.F. Gu et al., developed ECAP with back pressure to refine the magnesium alloy Mg–3Al–1Zn (wt.%) at room temperature for improving the mechanical properties [14]. Majid Al-Maharbi et al., observed the results on microstructure and texture evolution for magnesium alloy using equal channel angular extrusion processing. Here, the AZ31 Mg alloy billets

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* Corresponding author. Tel.: +91 9448793833; fax: +91 0824 2474033.
E-mail addresses: seemurali@gmail.com, muralidharavvari@gmail.com (A. Muralidhar), snnath.nitk@gmail.com (S. Narendranath), shivananda@rediffmail.com (H. Shivananda Nayaka).

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were processed with an extrusion rate of 0.075 mm/s at 473°K in the presence of 30 MPa back pressure [4]. James valder et al., improved the mechanical properties of the tubular aluminum products using ECAP process with an angle of 423°K for route A, route Ba, route Bc, and route C up to three number of pressings [2].

Thus a scope always exist for enhancing the mechanical properties by refining the grain size of magnesium and its alloys using ECAP at elevated temperatures. In the ongoing study, the main aim is to evaluate the grain size of wrought AZ31 alloy through ECAP process using die angle of 120° and an arc of curvature of 30°. The process has been carried out up to four passes at a temperature of 573 K for route Bc. Microstructure examination has been done to know the grain refinement of AZ31 alloy using an optical microscope and scanning electron microscopy. Mechanical properties of the material were observed at room temperature before and after ECAP passes. The various influencing factors on grain refinement were studied to understand the mechanical behavior of AZ31 alloy.

2. Experimental procedure

The layout of the ECAP was designed with two equal channels, intersecting at particular angle called die angle (ϕ) and arc length (ψ) subtended at channel intersection as shown in Fig. 1. In the present work, ECAP die is designed with an angle of 120° and arc of curvature of 30° to reduce the dead zone of material [15]. Theoretically, total strain of the present die was calculated and found to be 0.6 in each pass. A commercial AZ31 alloy sheet thickness of 22 mm was machined into rods having a diameter of 16 mm and a length of 80 mm. Magnesium rods were homogenized at 673 K for 24 h to dissolve the intermetallics that were present in the alloy. Experiments were carried out up to four passes at a temperature of 573 K for route Bc. For each ECAP pass, heating plates were arranged around the die to provide designated temperature. Specimen was held in the channel for the same temperature in order to reach stabilization between the die and specimen. Graphite was used as a lubricant to reduce the friction between die and specimen. After ECAP process the samples were cooled down to the room temperature in the air. Further, ECAP processed samples were machined using CNC lathe machine for tensile test and middle part of the specimen was used to characterization. The preparation of sample for testing involves mechanical polishing using different SiC papers in addition; the colloidal Al_2O_3 and diamond paste were used to achieve mirror surface finish. Picral reagent was used to etch the polished surface of the sample for microstructure observation [16]. Microstructure study was carried out by linear interception method to know the grain size of AZ31 alloy using an image analyzer (BIOVIS Software). Hardness test was done using Vickers microhardness test rig by applying load of 100 g over a time period of 13 s. Tensile test specimen was prepared as per ASTM E-8 standard following the gauge length of 15 mm and a diameter of 5 mm. The test was carried out using Hounsfield Tensometer to analyze the tensile properties.

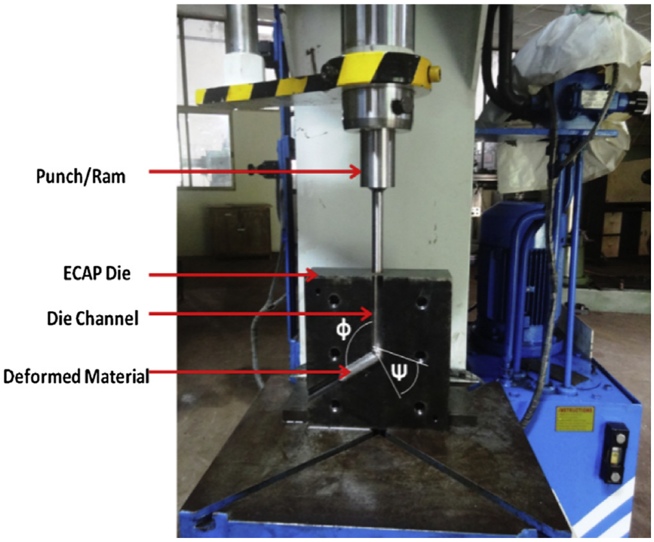

Fig. 1. Equal channel angular pressing (ECAP) setup.

3. Results & discussion

3.1. Effect of ECAP on microstructure

Fig. 2 shows the optical images of the as received material and extruded AZ31 alloy in the cross sections perpendicular to extrusion direction. Initial average grain size of the as received material was found to be 31.8 μm. After homogenization, the average grain size of the material was reduced to 26.7 μm. Later with number of increased ECAP passes, the average grain size of the material again reduced to 13.3 μm, 11.2 μm, 9.4 μm and 8 μm up to four pass. Fig. 2(a) represents the large number of coarse grains with formation of twins in the as received material. This would be the cause of specimen being prepared from rolled sheet with the presence of yield asymmetry. In addition, the shear deformation occurs in only one direction during experimentation. Yin et al., observed the similar results during use of ECAP process for AZ31 alloy [17]. After homogenization at 673 K, the average grain size of the material was found to be reduced and distributed uniformly when compared with the as received material because of recrystallization [18]. Elongated grains along with few coarse grains were observed after one pass which is parallel to the extrusion direction. But in second pass, the grains were deformed and distributed heterogeneously [19]. In third pass, grains were distributed more homogenously with fine average grain size of 9.4 μm. Further, the fine grains were refined greatly and distributed uniformly because of dynamic recrystallization taking place in the material after four ECAP passes. Similar detailed observations were made for AZ31B alloy by Majid Al-Maharbi et al. [4].

Fig. 3 shows the scanning electron microscope microstructures of (a) as received and (b) four passed ECAP specimen at temperature of 573 K for route Bc. The observations were made from the microstructures reveals, the as received material consisting equiaxed grains and twins appearing on the

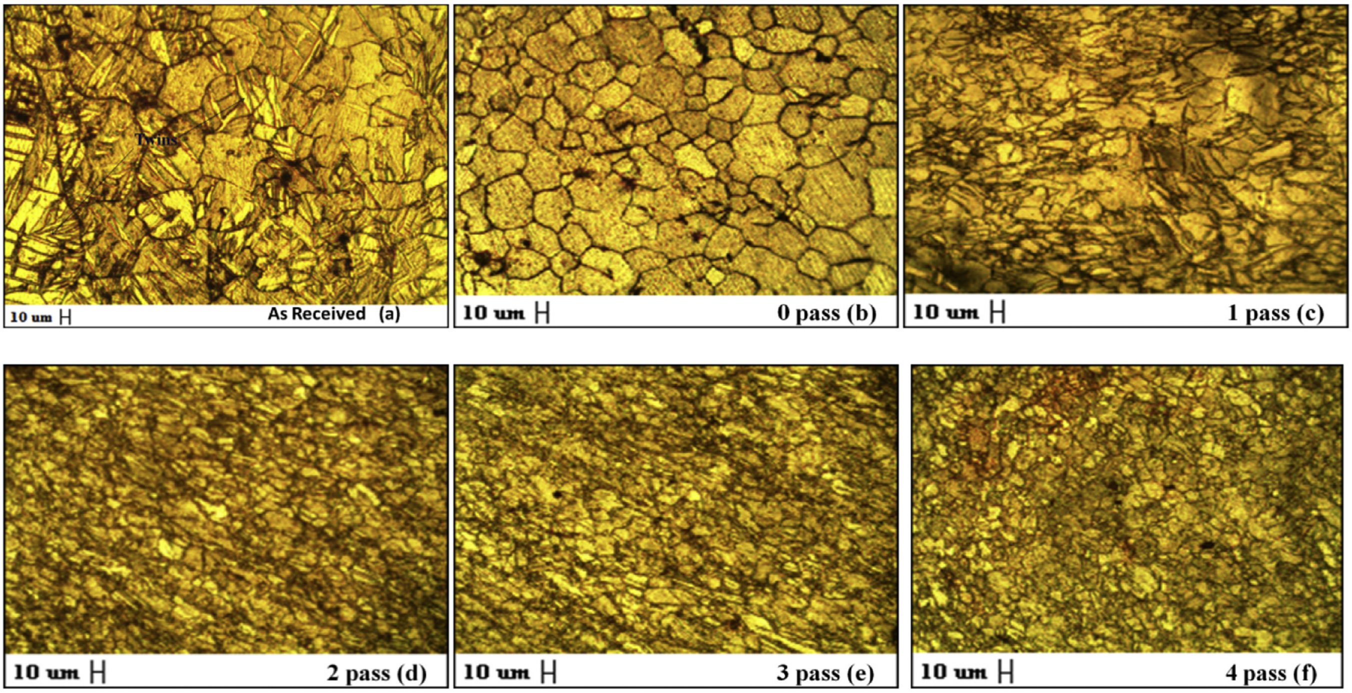

Fig. 2. OM microstructures of AZ31 alloy at (a) as received (b) 0 pass and after ECAP at 573 K (c) 1 pass (d) 2 pass (e) 3 pass (f) 4 pass.

surface. The grain size decreased having few twins to the scope of improving the material properties after four passed ECAP process as similarly illustrated through the Hall–Petch equation [20]. As explained in this paper dynamic recrystallization is the cause of grain size refinement and also ECAP passes could refine the grain size of the material. It implies that the homogeneity of the material improved in ECAP process at higher processing temperature.

3.2. Effect of ECAP on mechanical properties

Fig. 4 represents the values of Vicker's microhardness against the number of ECAP passes. Initially, the average microhardness of as received material was found to be 51 HV. After homogenization, the hardness of the material was observed to have increased to 53 HV. Further, the hardness of the material increased to 60 HV and 69 HV for first and second passes respectively. But, it was reduced to 66 HV and 64 HV after third and fourth passes respectively. Generally, hardness depends upon the strength, plasticity, elasticity and ductility of the material. Accordingly, the hardness was observed to be decreased after second pass with respect to the ductility and tensile strength of the material for same passes. Hence, the hardness of the material after second pass became more softened than previous number passes.

Fig. 5 shows the engineering stress (MPa) vs. engineering strain (E) curves of AZ31 alloy up to four ECAP passes. There were some important observations made: First, the tensile strength of the material decreased with increase in number of passes. Second, the ductility of the material increased up to two ECAP passes and then slightly decreased for third and fourth ECAP passes. The decrease in tensile strength decreases the average grain size of the material after ECAP passes because of the changes occurring in the texture of the material [17]. Because, non basal planes were varied to ECAP processed samples which were observed clearly in the

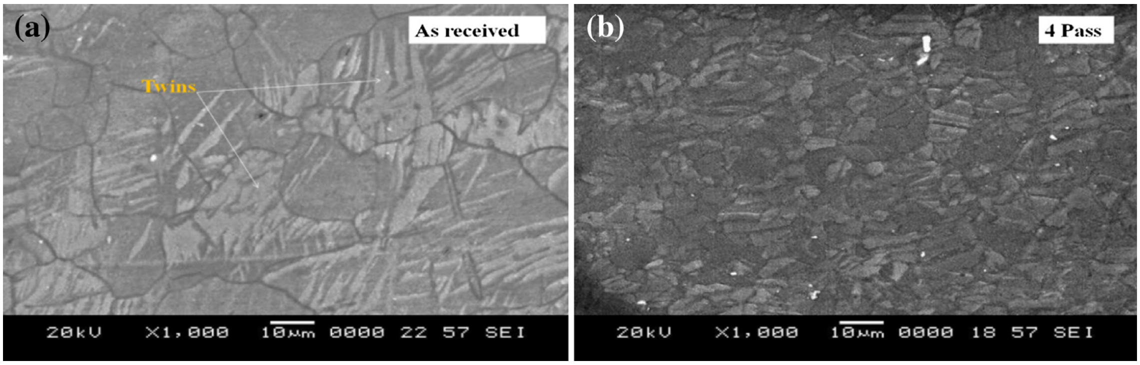

Fig. 3. SEM images of AZ31 alloy at (a) as received and (b) four ECAP pass at 573 K.

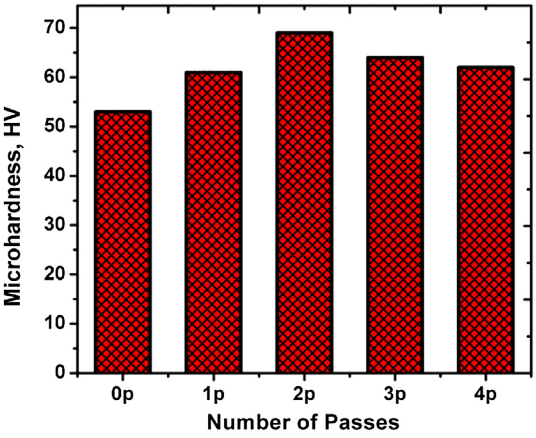

Fig. 4. Microhardness versus number of passes.

XRD patterns. Planes $(10\bar{1}1)$ and $(10\bar{1}2)$ are having a relation with the twin planes in HCP structured materials [21]. Hence, the intensity of the two planes increased along planes perpendicular to the extrusion direction. All together, dislocation density of the material increases with increase in number of ECAP passes [22]. Percentage elongation of the AZ31 material has been increased up to second ECAP passes. This is because of the strain hardening occurred in the material with increased number of passes [23]. Further, elongation was slightly reduced but it was found to be of higher value than the as received material. Hence, the mechanical properties of material might have been influenced by the grain refinement, distribution of residual stresses, processing temperature, number of passes, texture modification with slip systems and dislocation density of the material.

3.3. X-ray diffraction analysis

Fig. 6 shows the X-ray diffraction (XRD) patterns of as received, homogenized and fourth ECAP passed AZ31 alloy at 573 K. It was noticed that the planes $(10\bar{1}0)$ for the as received material and homogenized show a strong intensity to be positioned perpendicular to the channel direction while no such tendency occurs after four ECAP pass at 573 K for route Bc. Basal slip system $\{0002\} < 11\bar{2}0 >$ of the material is operated after ECAP. Intensity of planes $\{10\bar{1}1\}$ and $\{10\bar{1}2\}$ were observed to be increased after four passes. By contrast, the intensity of planes $\{10\bar{1}0\}$ decreased significantly at 573 K. Similar results have been observed using ECAP by Feng Xiao-ming et al. [24]. In general, low symmetry HCP structured materials change their texture while being processed through ECAP process. Hence, the shear deformation of the material in ECAP was increased with increase in number of passes.

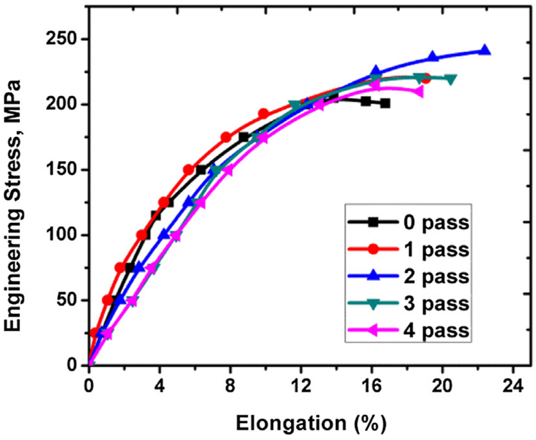

Fig. 5. Engineering stress versus percentage elongation of AZ31 alloy.

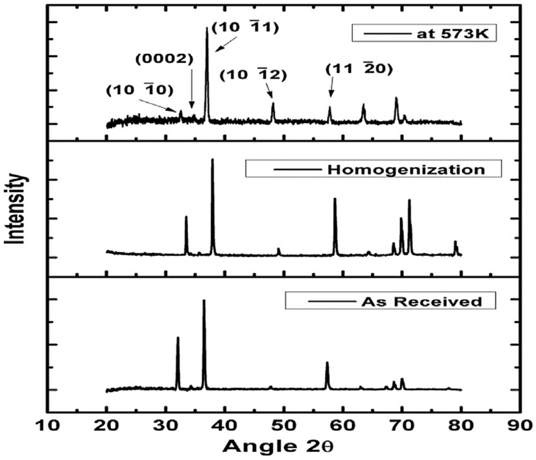

Fig. 6. XRD patterns of AZ31 alloy before and after 4 ECAP process at 573 K.

4. Conclusions

Equal channel angular pressing has been carried out on wrought AZ31 alloy up to four passes at a temperature of 573 K for route Bc. The following main observations are made from this study.

- The average grain size of AZ31 alloy was reduced after ECAP process with increase in number of passes; hence the dislocation density increased with disappeared twins.
- Dead zone was reduced with increased corner angle or arc of curvature and the material flowed easily during ECAP process due to reduction in friction between the die channel and the material.
- Hardness of the material was increased after second pass and further reduced with increase in number of passes.
- Percentage elongation and hardness of the material found to have good relation between each other with increase in number of ECAP pressings.

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