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Journal of Magnesium and Alloys 2 (2014) 159−164
www.elsevier.com/journals/journal-of-magnesium-and-alloys/2213-9567

Full length article

Influence of Route-R on wrought magnesium AZ61 alloy mechanical properties through equal channel angular pressing

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Received 13 March 2014; accepted 14 April 2014
Available online 15 June 2014

Abstract

A new fundamental route entitled ‘Route-R’ is introduced to refine the grains in the material through Equal Channel Angular Pressing (ECAP) process. In route R, specimen is inverted to the original position in each ECAP pass. In the present work, AZ61 alloy is processed using ECAP process for three different fundamental routes mainly route A, route Bc, and route R. ECAP experiment is carried out on AZ61 alloy at lower temperature of 483 K up to two passes. Microstructural characterization is evaluated on unECAPed and ECAPed specimens for three routes. Average grain size of the alloy is to be reduced from 66 μm to 16 μm, 14.1 μm and 10 μm for route A routes Bc, and route R respectively. Vickers microhardness of the alloy is found to be 60 HV for as received material. This microhardness of the alloy is increased to 71 HV, 72 HV, and 74 HV for route A, route Bc, and route R respectively. Mechanical properties of the AZ61 alloy are observed to be route R is providing maximum YS, UTS, and percentage elongation than other route A and route Bc. Tensile fracture topography of the specimen is analyzed using three different routes for two passes.

Keywords: ECAP; Routes; AZ61 alloy; Microstructure; Properties

1. Introduction

AZ wrought magnesium alloys have been used as structural material in many applications due to their precise properties [1]. However, AZ wrought magnesium alloys retain limited ductility and poor formability at a room temperature recognized their hexagonal closed pack (hcp) structure [2]. Grain refinement is the process to improve their properties of AZ wrought magnesium alloys. In the present work, AZ61 alloys have been used as a material and is processed through Equal channel angular pressing. In ECAP, there are four basic fundamental routes are available to deform the material with different directions [3]. These are route A, route Ba, route Bc, and route C. In route A the specimen is not rotated in any direction; in route Ba the specimen is rotated by 90° in an alternative direction between repeated passes. In route Bc the specimen is rotated 90° counter clock wise direction and in route C the specimen rotated by 180° between each passes.

AZ61 and AZ31 alloys were deformed under ECAP process to develop their mechanical properties using route Bc [4]. AZ31 alloy processed through ECAP process to enhance the mechanical properties with different temperatures using route Bc [5]. ECAP process was carried out on Al−Cu alloy to improve the mechanical properties for route A, Ba, Bc, and C up to 5 passes [6]. Tubular aluminum products were produced using ECAP process for route A, route Ba, route Bc, and route

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Peer review under responsibility of National Engineering Research Center for Magnesium Alloys of China, Chongqing University

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jma.2014.04.002.

C up to 3 passes [7]. Maximum grain refinement and strain of material can be obtained through processing routes and its following directions between each consecutive passes in the ECAP die channel [8]. However, the maximum strain induced in the top of the specimen and mid portion of the specimen. This has been investigated clearly the strain distribution and deformation mechanism of ECAP using FEM analysis [9].

In the present work, a new fundamental route namely ‘Route-R’ introduced to induce the large strain in the entire material, which distribute the equal strain top to bottom and start to end point of the specimen. In route R the specimen is inverted/reverse to the original position in each ECAP pass. Mainly, the cost and time of the experiment can reduce with this route. In this work, AZ61 alloy is used as a material and ECAP experiment has been carried out to enhance the mechanical properties using route R. Microstructural characterization and mechanical properties of AZ61 alloy are obtained for route R at a lower temperature of 483 K up to two passes. Again these results are compared with other main fundamental route A and route Bc for the same temperature and ECAP passes. Tensile fracture topography of the AZ61 alloy is analyzed using scanning electron microscopy to get the material behavior.

2. Experimental work

Fig. 1 represents the ECAP setup with the die and plunger. In the experimental work, equal channel angular pressing consists a die angle of 120^0 and corner angle was 30 having a strain around 0.7 in each pass. A commercial AZ61 alloy was machined into desired shape to the diameter of 16 mm and a length of 80 mm. AZ61 alloy rods were homogenized for 24 h at a temperature of 673 K to bring all constituents into a single phase before ECAP process. The ECAP experiment was carried out by route A, route Bc, and route R up to 2 passes at a temperature of 483 K. 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. 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 to observe the microstructure [10]. Microstructure study was carried out by linear interception method to know the grain size of AZ61 alloy using an image analyzer (BIOVIS Software). Hardness test was done using Vickers microhardness test rig by applying load of 100 g with a significant time 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.

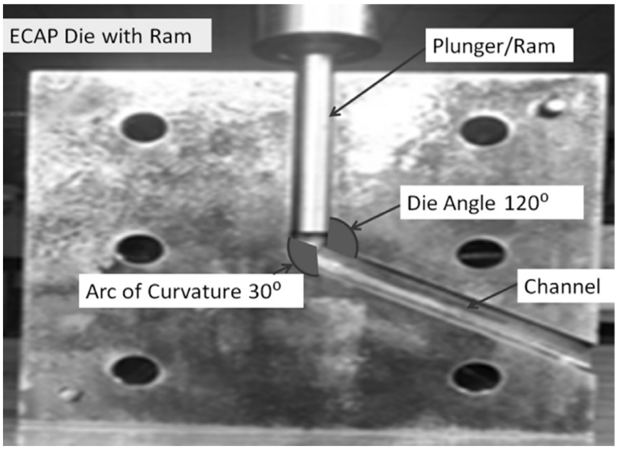


Fig. 1. ECAP die with Ram/Plunger.

3. Results and discussion

3.1. Microstructure variation with three different processing routes

Fig. 2 illustrate the distribution of average grain size of AZ61 alloy for as received specimen, Zero pass specimen, and for three processing route A, Bc, and R. Initial average grain size of the AZ61 alloy was found to be 66 μm using linear interpolation method as shown in Fig. 3. At zero pass all specimens are homogenized at a temperature of 673 K for 24 h and the average grain size is found to be 56 μm. Here, the processing temperature used for three routes is 483 K up to two ECAP pass. The average grain size of the processing route A, route Bc and route R was reduced to 15.9 μm, 14.1 μm and 10 μm respectively as shown in Table 1. It can be observed from Table 1 that the obtained results are effective in route R when compared to route A and route Bc. Generally, sub grain formation after shear deformation occurred in ECAP due to the mechanism of dynamic recrystallization [11]. However, route Bc results have been reported and proved that the

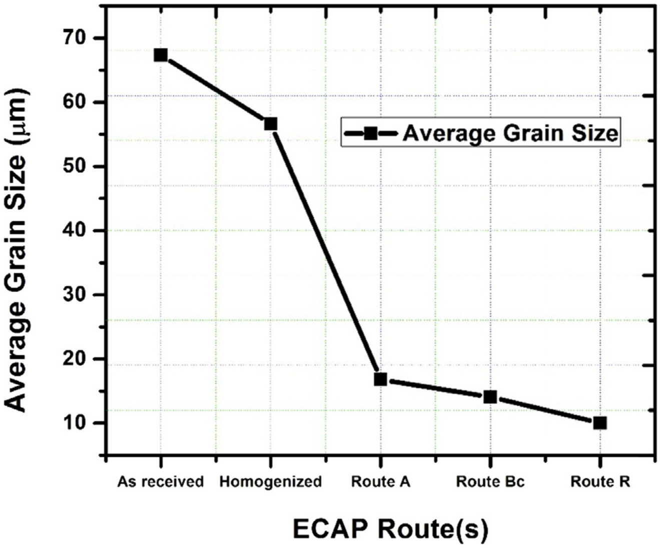
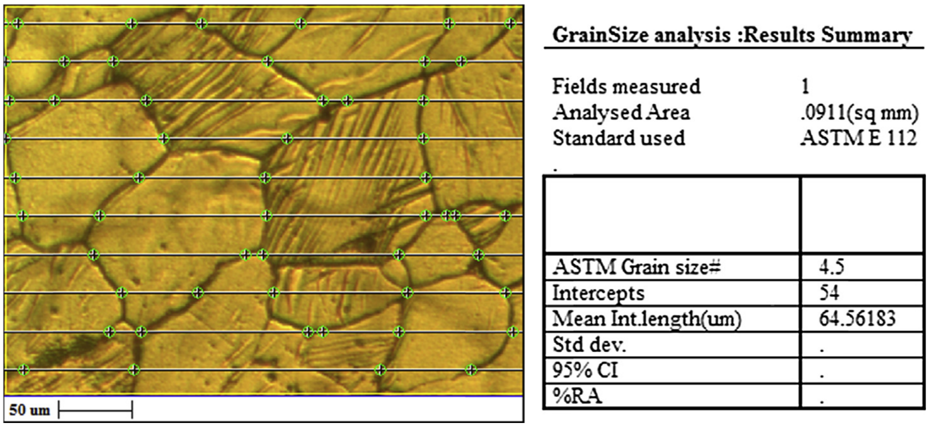


Fig. 2. Average grain size with different routes.



GrainSize analysis :Results Summary

Fields measured	1
Analysed Area	.0911(sq mm)
Standard used	ASTM E 112

ASTM Grain size#	4.5
Intercepts	54
Mean Int.length(um)	64.56183
Std dev.	.
95% CI	.
%RA	.

Fig. 3. Grain size analysis: results summary.

material deformation is more in route Bc [12]. Meanwhile, microstructure analysis was done using both Optical Microscopy (OM) and Scanning Electron Microscopy (SEM) to understand the variation of average grain size of three processing routes which are shown in Figs. 4 and 5 respectively.

Fig. 4 represents the optical microstructures of AZ61 alloy for unECAPed and ECAPed specimen. The microstructure of the as received sample is shown in Fig. 4(a). The average grain size in the as received sample is 66 µm. Twins are observed on the grains and these are probaly to increase the twining stress on the grain boundaries resulting plastic deformation occurs in the alloy. Inhomogeneous grain distribution is observed in the specimen after regulating at a temperature of 673 K for 24 h as shown in Fig. 4(b). The obtained average grain size is found to be 56 µm. Decrease in average grain size than as received material shows that the grain growth is followed at higher temperatures [13].

In route A, where the alloy orientation is kept constant in each ECAP pass, repetitive shear arises on the same shear plane and the deformation leads to the formation of bimodal structure as shown in Fig. 4(c). The combination of equiaxed and maximum sub grains are observed in route Bc, where the alloy is rotated by 90° counterclockwise after first ECAP pass which is shown in Fig. 4(d). Effective strain path can be obtained by varying the fundamental routes to which AZ61 alloy is subjected to deformation. Evidently, in route Bc, different shear planes have deformed effectively during ECAP process and as a result better grain refinement is enhanced in the material [14]. In this work, route R is introduced and related deformed microstructure reveals the maximum grain refinement is as shown in Fig. 4(e). The average grain size in the route R is obtained to 14 µm. Hence, changing the orientation of the alloy from one pass to next pass leads to different combinations of grain shapes and grain sizes which is evident from the microstructures as shown in Fig. 4(c)–(e). Fig. 5(a)–(e) shows the SEM images of unECAPed and ECAPed specimens of AZ61 alloy. In route R grains are clearly distributed uniformly and equiaxed grain are observed than route A and route Bc. This uniform distribution of grain in the specimen would be increases with increase in number of ECAP passes than route Bc and route A.

Table 1
Room temperature mechanical properties of the AZ61 alloy.

	YS (MPa)	UTS (MPa)	Elongation (%)	Hardness (HV)	Average grain size (µm)
As received AZ61 alloy	178	234	15.87	60	67.3
0P AZ61 alloy	199	268	14.80	61	56.6
Route A at 483 K	195	232	15.20	70	16.8
Route Bc at 483 K	213	275	15.68	71	14.1
Route R at 483 K	220	280	14.83	74	10

3.2. Vickers microhardness with different processing routes

Fig. 6 shows the variation of the Vicker's microhardness of the AZ61 alloy against unECAPed and ECAP processed specimens for different three routes. Initially the average microhardness of the as received material is obtained to be 60 HV. Further AZ61 alloy microhardness is increased to 64 HV after conducting homogeneous at a temperature of 673 K for 24 h. whereas, at route A, route Bc, and route R, the microhardness of the AZ61 alloy is increased to 71 HV, 72 HV, and 74 HV respectively as shown in Table 1. After two ECAP pass the microhardness is increased drastically for route A, route Bc, and route R at a processing temperature of 483 K. There is an improvement in microhardness of the material because of work hardening occurred during ECAP process [15]. The work hardening would be increases with increase in number of ECAP passes. The hardness of the AZ61 alloy increases with decrease in grain diameter of the material because of the strength is accommodated to the material by refining the grains of the material. Hence, microhardness of the material would be more in route R than route A and route Bc after 2 ECAP passes at a temperature of 483 K. Overall, the deformation direction route R in the ECAP process would be influenced greatly to the AZ61 alloy.

3.3. Tensile properties with different processing routes

Engineering stress curves of the AZ61 alloy have been plotted against the engineering strain as shown in Fig. 7. These

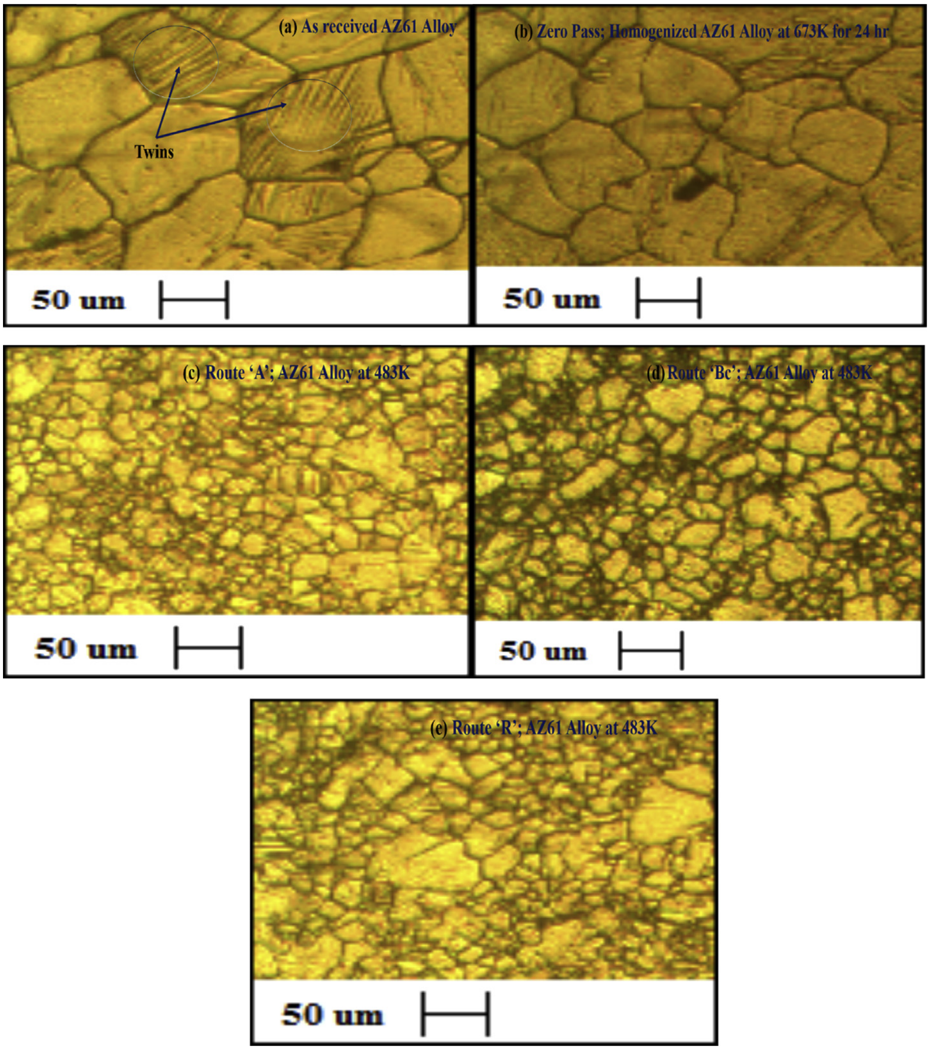


Fig. 4. OM images of AZ61 alloy at (a) as received (b) homogenized; after two ECAP passes at 483 K for (c) route A (d) route Bc and (e) route R.

curves are belonging to the as received material, zero pass, and different three processing routes including route R. Yield strength (YS) and Ultimate tensile strength (UTS) of the as received material is found to be 178 MPa and 234 MPa respectively. Generally, after homogenization/heat treatment the material properties would be vary with changing the time and temperature [16]. On the contrary, after homogenization at 673 K for 24 h, the material tensile strength is increased to 268 MPa. After 2 ECAP passes, tensile strength of the AZ61 alloy have been increased greatly and found to be increased and tabulated in Table 1. Increase in strength with increase in number of ECAP passes for three processing routes would be the cause of strengthening mechanism [17]. Here the strength of the material can be increases with decrease in grain diameter is explained by following Hall–Petch equation (1) [18].

$$\sigma_0 = \sigma i + kD^{-1/2} \tag{1}$$

where, σ_0 = yield strength (MPa); σ_i = friction strength (MPa); k = parameter constant; D = grain size (μm).

Percentage elongation of as received AZ61 alloy is found to be 15.87%. After homogeneous the percentage elongation decreased to be 7% though the strength of the specimen increases [19]. In this paper, the percentage elongation is decreased for route A and route R when compared to route Bc. However the strength of the route R is higher to route Bc. Hence, the main advantage of the equal channel angular pressing is develop the strength with narrow loss of percentage elongation. Hence, in the present work after overall observations processing route R would be the prime important processing route than route A and route Bc.

3.4. Fracture topography

Fig. 8 shows the scanning electron microscopy fractured surfaces of AZ61 alloy (a) as received, (b) homogenized at 673 K specimen for 24 h. After two ECAP pass at a temperature of 483 K for (c) route A, (d) route Bc, and (e) route R. Fig. 8(a) shows the fractured surface of as received sample. The surface reveals the few dimples of variable size resulting

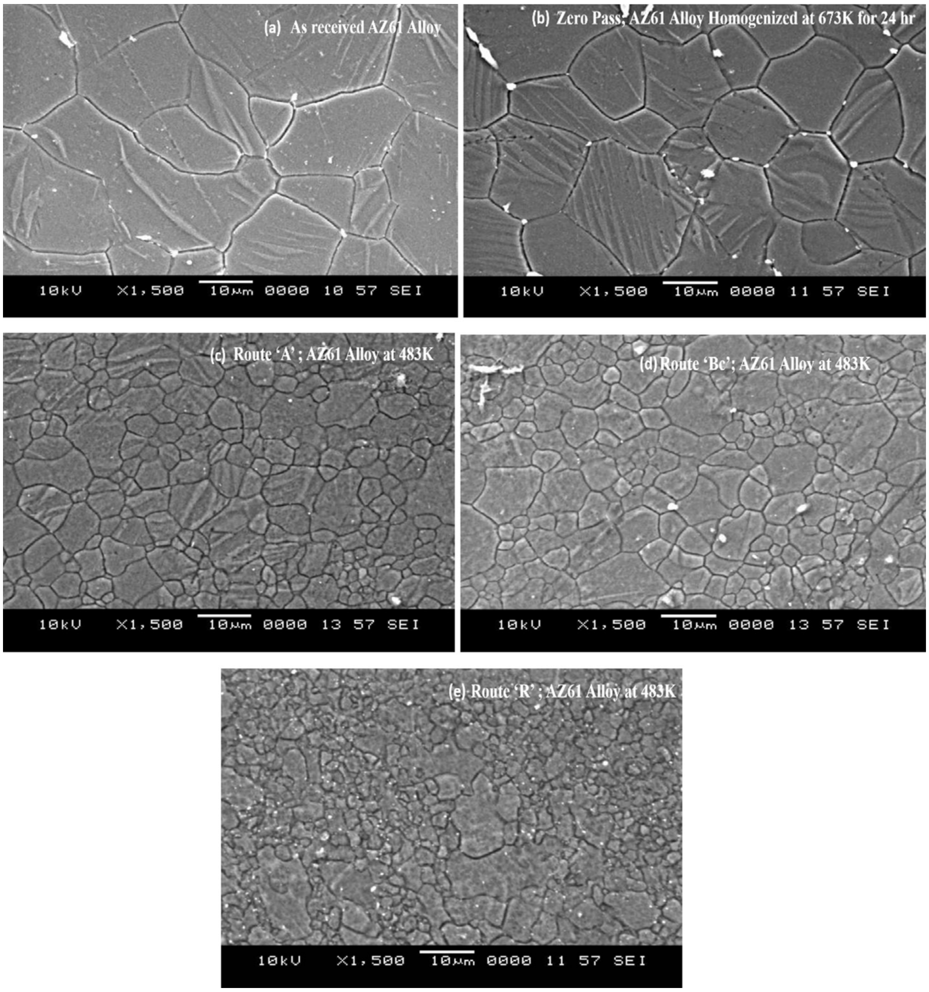


Fig. 5. SEM images of AZ61 alloy at (a) as received (b) homogenized; after two ECAP passes at 483 K for (c) route A (d) route Bc and (e) route R.

that there is an inhomogeneous grain size distribution. Also it can be seen from Fig. 8(a) that there are ripping ridges on the surface and few quasi-cleavage fractures [20]. It can be seen Fig. 8(b) that before deformation the samples are homogenized resulting shallow dimples are observed in different size. Grain orientation of the material has been improved after homogenization at 673 K for 24 h. Fig. 8(c)–(e) shows that the material became more

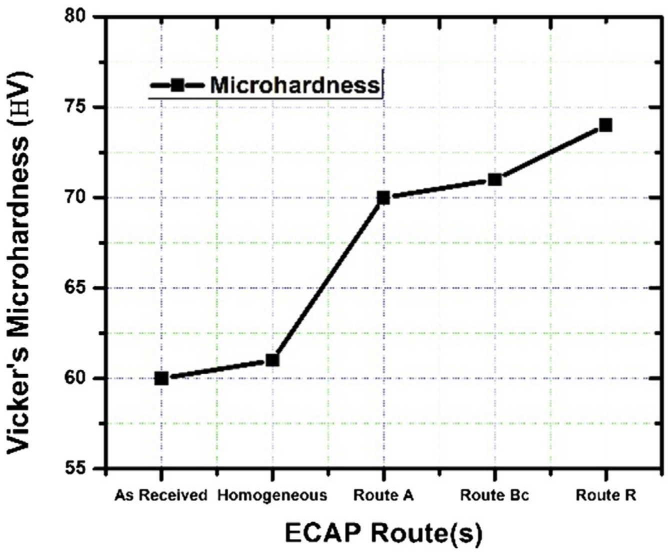


Fig. 6. Variation of microhardness with processing routes.

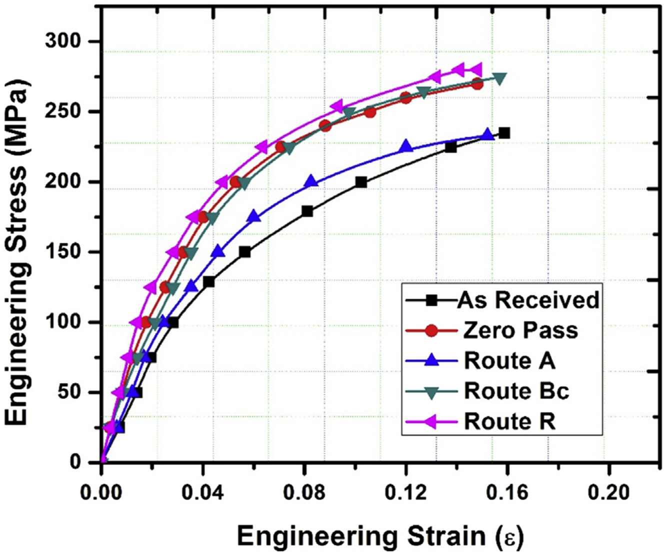


Fig. 7. Engineering stress vs. elongation (%) curves for different processing routes.

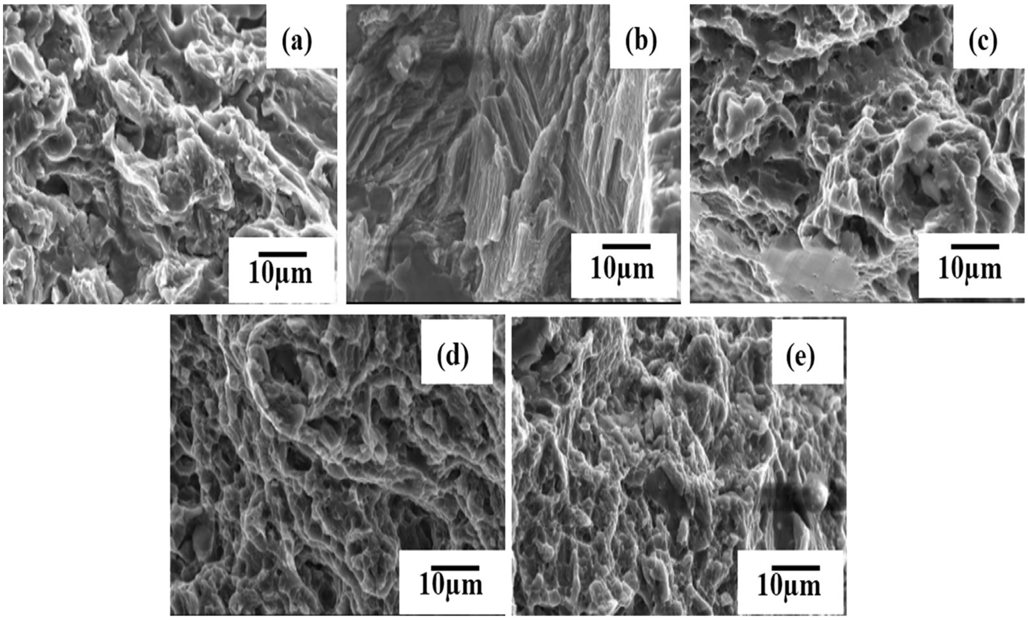


Fig. 8. SEM tensile fractured specimen images of AZ61 alloy at (a) as received (b) homogenized; after two ECAP passes at 483 K for (c) route A (d) route Bc and (e) route R.

homogeneous and many small dimples are formed. It representing that the material is deformed uniformly with reduced grain boundaries. Hence, higher percentage elongation observed after ECAP processed samples at 483 K.

4. Conclusions

In the present work, ECAP experiment is processed on AZ61 alloy to evaluating the influence of route R with comparison of route A and route Bc at a temperature of 483 K for two passes. The following conclusions are drawn.

- Microstructural homogeneity is improved with increase in number of passes for route R. During route R in ECAP process for AZ61 alloy at 483 K, the grain refinement is more because of dynamic recrystallization and strain path variation is influenced effectively in refining the grain size in the material.
- Route R can reduces the number of ECAP passes by deforming the AZ61 alloy and hardness of the AZ61 material increases rapidly in route R because of strain hardening when compared to route A and route Bc for two passes.
- YS increases with decrease in grain size of the AZ61 alloy. Hence, from reasonable considerations route R would be preferable to deform the material in all planes in ECAP processes.
- SEM fractured surfaces in all the three routes at a temperature of 483 K reveals various small size dimples which indicates the ductile brittle fracture.

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