Equal Channel Angular Pressing of Aluminium Alloy 5083 using different die geometries

Kameswari Bolem[1], Anandababu Varadala[2], Swaminaidu G [3]

[1]M.Tech student, Dept. of Mechanical Engg, Vignan Institute of Engg for Women, Andhra Pradesh, India
[2]Assoc. Professor, Dept. of Mechanical Engg., Vignan Institute of Engg for Women, Andhra Pradesh, India
[3] Professor, Dept. of metallurgical Engineering, UCEV JNTUK, Andhra Pradesh , India

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Abstract - *In the recent years there has been an increasing interest in the production of ultrafine grained material for both commercial as well as research purposes by applying severe plastic deformation (SPD) processes. In this work commercially available AA 5083 as extruded specimens of length 95mm and with cross section of 16 mm × 16 mm were subjected to one of the SPD processes Equal Channel Angular Pressing (ECAP) up to three passes in three different routes, i.e route A, route B_C and route B_A. Experimental study was carried out on samples processed through the three different ECAP dies having channel angles of 105^0, 120^0 and 135^0. The investigation has been carried out to estimate the influence of process parameters namely die channel angle, number of passes, processing routes on microstructure and mechanical properties of AA 5083 samples. Micro-structural analysis has been performed using Optical Microscope to study the initial grain size, grain refinement. Vickers micro-hardness tests were conducted to observe the effect of ultrafine grains formed during ECAP. It is cleared from the results that microstructure and mechanical properties were highly improved after third pass when the billets were pressed in route B_C through the dies having the channel angle of 105^0.*

Key Words: ECAP, hall-petch equation, grain size, Vickers microhardness test, optical microscope.

1. INTRODUCTION

In the recent years a great scientific interest in ultrafine grained materials is due their unusual mechanical properties. Equal channel angular pressing (ECAP), which primarily introduced by Segal is one of the severe plastic deformation methods for developing ultrafine grained materials in metal alloys [1]. This procedure has the advantage of fabricating fully dense materials without the introduction of any contaminants and large enough for real structural applications. Since there is no change in the cross-sectional dimensions of the specimen during the process, it is now accepted as a promising method to enhance the strength of various metallic alloys through the occurrence of grain refinement in severe plastic deformation [2, 3].

The intense plastic strain can be achieved by simple shear by pressing the specimen through a die containing two channels, equal in cross section, intersecting at an angle of ϕ and with a corner angle of ψ, [4, 5]. Earlier studies on ECAP demonstrate that the main experimental factors influence properties and microstructural characteristics of ECAPed samples are processing route (rotation of the billet between successive passes), number of passes (N), die channel angle (Φ), outer corner angle (Ψ) and the temperature of the pressing operation [6–9]. The first few passé of ECAP result in effective grain refinement taking place in successive pressings microstructure tend to be more equiaxed as the number of passes increases [10]. Most of the ECAPed alloys show a common trend that yield stress considerably increases after the first ECAP followed by a slow increase with a further increase in plastic strain by ECAP, while the tensile ductility decreases by large extent after the first pressing and then less sensitively further increase in strain [11].

The relationship between yield stress and grain size can be explained from the Hall-Petch equation [12,13] given by,

$$\sigma_y = \sigma_0 + \frac{k}{\sqrt{d}} \qquad (1)$$

Where σ_y is yield stress, k is the Hall-Petch slope and d is the grian size. From equation 1, yield stress increase as grain size decreases.

In this study, non-heat treatable AA 5083 was chosen for ECAP processing. It is used in development of cheap and high strength constructional materials for applications in automotive and aircraft industries [14]. ECAP process was carried out on three different dies with channels intersecting at 105^0, 120^0, 135^0 following route A, B_A, B_C upto 3 passes. Tensile strength and Vickers hardness studied in ECAPed samples. Evolution of microstructure was studied by means optical microscope (OM) and in order to investigate the strengthening as related to grain size.

2. EXPERIMENTAL PROCEDURE

A commercial grade aluminium magnesium alloy (AA 5083) with chemical composition 4.4 wt% Mg–0.7 wt% Mn–0.15 wt% Cr–Al was used as the processing material in this study. Specimens of length 95mm and cross section 16mm×16mm were sheared from as received rolled plate with dimensions 500mm×500mm×16mm which is in H001 condition. Samples with grain size ---µm were obtained by annealing at 530^0 for 1 hr then processed though a specially designed ECAP dies with varying channel angles (ϕ) 105^0, 120^0 and 135^0 and uniform corner angle (ψ) of 30^0. The three dies were machined from OHNS (Oil Hardened Non Shrinking) material and configurations were showed in fig.1. The whole ECAP processing was done at room temperature using Universal Testing Machine of 400 ton capacity operating at uniform ram speed of 0.02 mm/s. Specimens processed using three different routes namely route A (no rotation of specimen), B_C (rotation of specimen 90^0 in same sense after every pass) and B_A (rotation of specimen 90^0 alternate sense after every pass) up to 3 passes [15]. Specimen surface and die channel were lubricated with MoS_2 and SAE 40 during the process in order to minimize the frictional effects between the contacting surfaces. The schematic representation of ECAP was illustrated in Fig.2.

(a)

(b)

(c)

Fig -1: die geometries with channel angle (a) 105^0 (b) 120^0 and (c) 135^0

During ECAP, the effective strain ε accumulated in the specimen is described in the following equation:

$$\varepsilon = N\left[\frac{2\cot[\phi/2+\psi/2]+\psi cosec[\phi/2+\psi/2]}{\sqrt{3}}\right] \quad (2)$$

Here N is the number of passes a specimen process through die, ϕ is the channel intersection angle and ψ is the outer corner angle.

Equation 1 showed that the effective strain depends upon die channel angle and number of passes and outer corner angle. The effective strains obtained in die of ϕ = 105^0, 120^0 and 135^0 and ψ = 30^0 with max of 3 passes are 2.42, 1.86, 1.37 respectively.

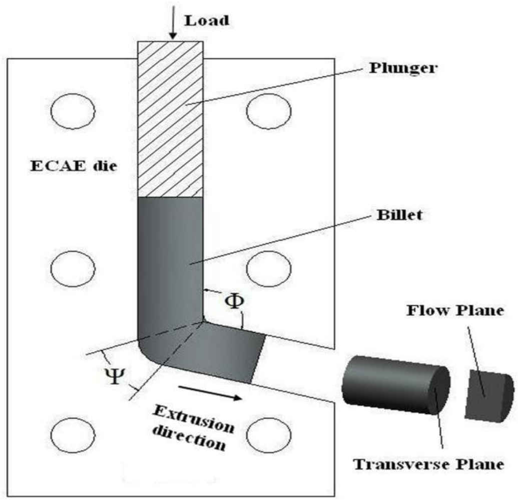

Fig-2: Schematic representation of ECAP

Microstructural characterization of specimen before and after ECAP was performed using Optical Microscope (OM). Specimens for optical microscopy (OM) were obtained by sectioning the processed samples perpendicular to their longitudinal axis i.e. normal direction (ND). The specimens were ground manually using 240, 320, 1/0, 2/0, 3/0 and 4/0 grit silicon carbide abrasive sheets and surfaces were then polished with a alumina powder on a low speed disc polishing machine. The polished surfaces of the specimens were etched by immersing them in kellers's reagent (1 volume part of hydrofluoric acid, 1.5 volume part of hydrochloric acid, 2.5 volume parts of nitric acid and 95 volume parts water) for 15-20 sec.

Vickers microhardness test was performed in order to evaluate the mechanical properties of the ECAPed samples. Prior to microhardness measurement the billets were sectioned along plane perpendicular to the longitudinal axis i.e. normal direction (ND). The specimens were then polished to a mirror like finish using standard polishing techniques. Indentation and micro hardness measurements were undertaken using Vickers micro hardness tester equipped with a Vickers indenter under a load of 200g and 15s dwell time in accordance with ASTM: E92. All microhardness data were at least the average of 3 indentations.

3. RESULTS AND DISCUSSIONS

3.1 Mechanical Properties

3.1.1 Microhardness

In order to observe the improved mechanical properties in ECAP processed samples, Vickers microhardness values were measured for samples before and after ECAP. Charts-1, 2, 3 shows the microhardness values of the unECAPed and ECAPed samples processed in A, B_A and B_C through three die geometries with channel angle 105^0, 120^0, 135^0 respectively.

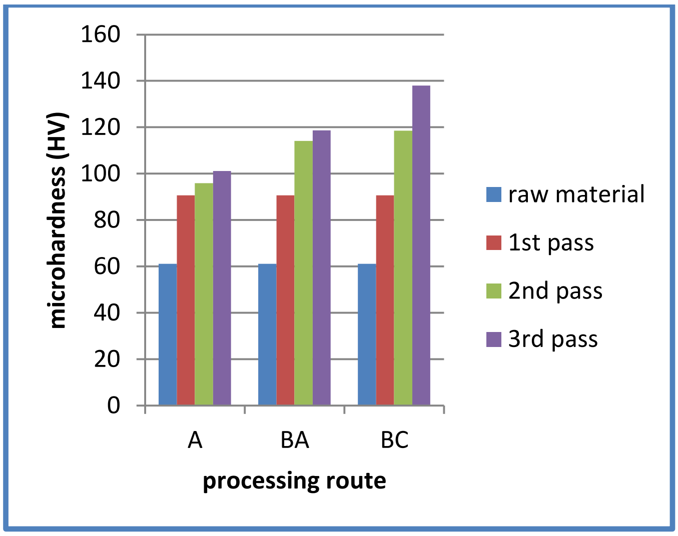

Chart.1: Microhardness values of ECAPed samples processed through die with channel angle 105^0

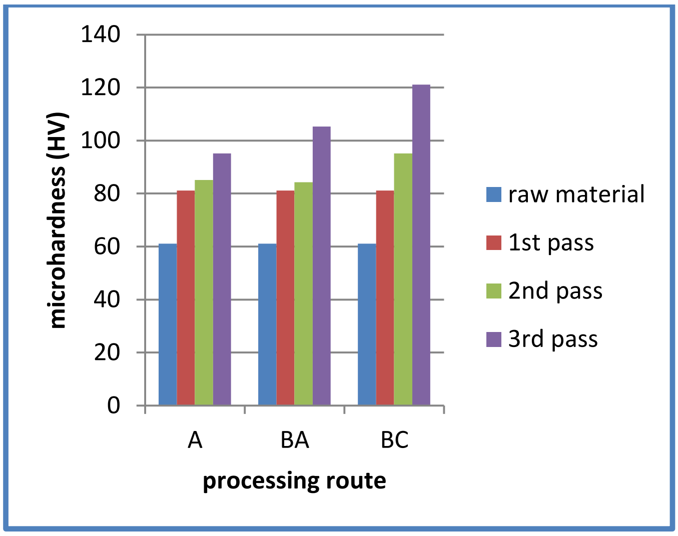

Chart-2: Microhardness values of ECAPed samples processed through die with channel angle 120^0

From the Charts-1, 2, 3 we can conclude that microhardness values were increased with increasing number of passes. After 1st pass, the microhardness of processed alloy increased suddenly from 61.1 HV to 90.6 HV, 81.1 HV and 70.6 HV in dies with channel angle 105^0, 120^0 and 135^0 respectively. Compared to 1st pass and 2nd pass, 3rd pass yields best results. Higher strengths of 138 HV, 121.13 and 115 have been obtained for route B_C, 3rd pass in die with channel angle 105^0, 120^0, 135^0 respectively.

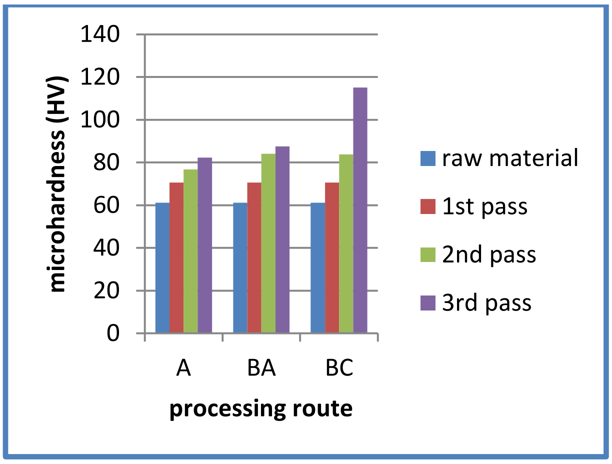

Chart-3: Microhardness values of ECAPed samples processed through die with channel angle 135^0

However there is no significance change as a result of increasing number of passes. This can be compare with the results obtained by Iwahashi *et al.* [16] that the microhardness of pure Al greatly increased from 18 to 36 HV after a single pressing. However after 2 and three repetitive passes microhardness was small and became saturated above 3 pressings.

The drastic increase of microhardness after single pass is due to work hardening that is caused by formation sub grain bands and density increase dislocation occurring with the shear deformation in the initial grain interior. In contrast the reason why the microhardness is constant with the number of pressings is deduced to be due to the dynamic recovery occurring with the rotation of sub grain and rearrangement of dislocation forming grain boundary during the repetitive pressings [17].

Charts-1, 2, 3 also reveal that orientation of the billet between each successive pass i.e. processing routes effect the mechanical properties. Higher values of microhardness 138 HV were obtained for route BC compared to route A and B_A.

Also we can conclude that the microhardness increased with decreasing die channel angle. The microhardness values obtained were very higher for die with channel angle 105^0 compared to 120^0 and 135^0. This is clear from the Iwahashi equation for effective strain which depends upon the channel angle.

3.2 Microstructure

3.2.1 Optical Microscope

Fig.3 shows the appearance of micro structure of unECAPed material in optical microscope after annealing to 530^0 for 1hr. The microstructure consists of large grains with average grain size in the range of 50 μm to 60 μm. The average grain size of initial material was calculated in image analyzer software using line intercept method.

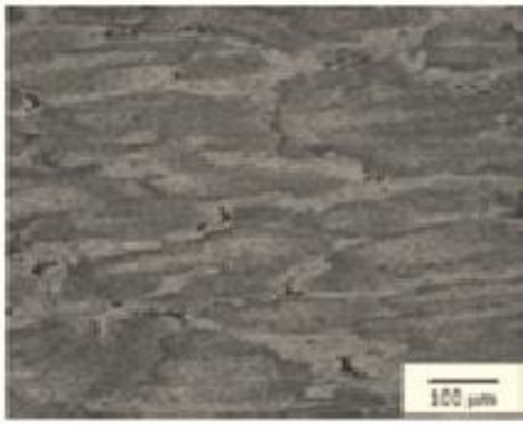

Fig-3: Microstructure of base metal

From fig.4, 5, 6 we can observe coarse grains were refined to finer grains compared to base metal in fig.3. After 1st pass, the average grain size was obtained in the ranges of 0.7-0.9, 1-1.8 and 2.2-2.8 for samples processed through dies of channel angle 105^0, 120^0, 135^0 respectively. It is showing that grains were highly refined in 1st pass. Compared to 120^0 and 135^0, smaller grains were obtained in 105^0.

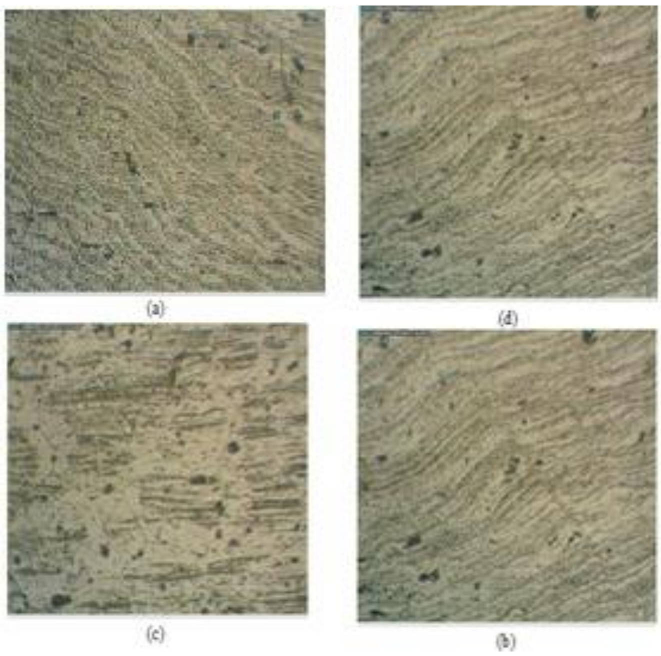

Fig-4: Optical images of UnECAPed and ECAP processed specimens in Die with channel angle 105^0 (a) raw material (b) 1st pass (c) route A, 3rd pass (d) route B_C, 3rd pass

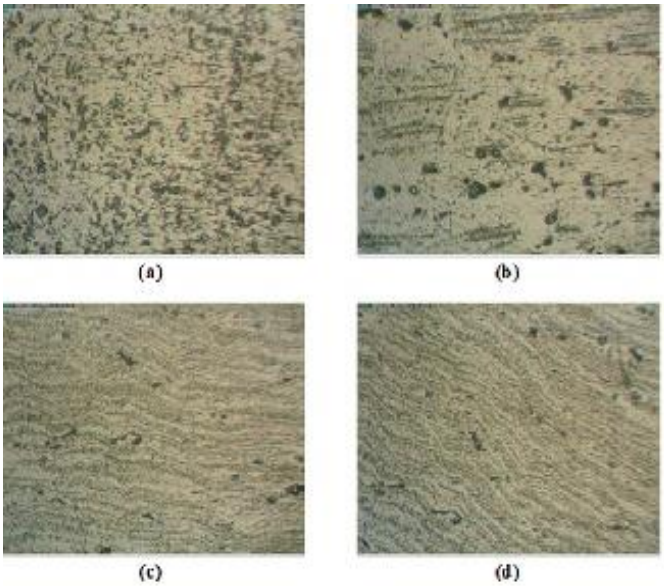

Fig.5: Optical images of ECAP processed specimens in Die with channel angle 120^0 (a) 1^{st} pass (b) route A, 3^{rd} pass (c) route B_A, 3^{rd} pass (d) route B_C, 3^{rd} pass

The microstructure observations of 1^{st} pass ECAPed samples demonstrates that the grains which were initially equiaxed, become considerably elongated along transverse direction relavent to horizontal direction at the point of exit from the ECAP die, and also within these grains, there is much evidence for shearing bands in a direction perpendicular to the horizontal direction.

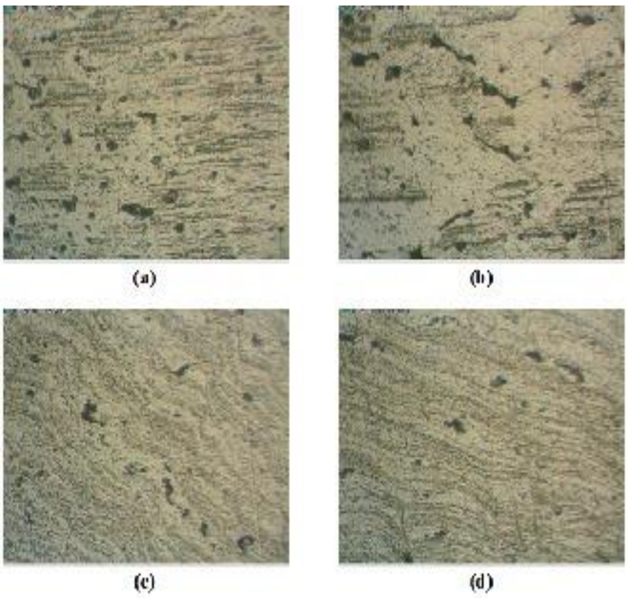

Fig-6: Optical images of ECAP processed specimens in Die with channel angle 120^0 (a) 1^{st} pass (b) route A, 3^{rd} pass (c) route B_A, 3^{rd} pass (d) route B_C, 3^{rd} pass

Lower grain sizes were obtained for route B_C compared to route A and B_A. The lowest average grin sizes in the range of 190nm-250nm, 290nm-377nm and 440nm-600nm were obtained for 3^{rd} pass, route B_C processed in dies of $\phi = 105^0$, 120^0 and 135^0 respectively.

The microstructure observations of 1^{st} pass ECAPed samples demonstrates that the grains which were initially equiaxed, become considerably elongated along transverse direction relavent to horizontal direction at the point of exit from the ECAP die, and also within these grains, there is much evidence for shearing bands in a direction perpendicular to the horizontal direction.

After 3 passes of ECA pressing the amount of deformation bands seems to increase and their distribution becomes more homogeneous, as shown in Fig. (). It is apparent that the microstructure of 3 passes ECAPed specimen is very complex and the grain boundaries are not distinct on the specimen's surface. Grain sizes were highly reduced after passes.

4. CONCLUSIONS

Equal Channel Angular Pressing of AA 5083 was successfully carried out using three suitable different die geometries for enhancing mechanical properties. The coarse grained alloy of grain size in the range of 50-60 µm has been highly refined to 190-250 nm after 3 passes in route BC on ECAP die with channel angle 105^0 compared to 120^0 and 135^0. The microhardness value of unECAPed sample increased with increased number of passes and by decreased channel angle and it reached to a maximum value of 138 HV after three subsequent passes in route B_C and die of 105^0.

Die with lower channel angle of 105^0 yields the higher strength and effective grain refinement compared to other dies i.e. mechanical and micro structural properties were improved with decreased channel angles. It can be concluded that processing by different ECAP dies enhanced the mechanical and microstructural properties of AA5083. The enhancement of these properties has made it possible to use the alloy in various engineering applications requiring high strength.

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