Processing & characterization of Al alloy by Equal Channel Angular Pressing (ECAP)

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Abstract— It is an innovative process capable of producing relatively uniform intensive plastic deformation in a variety of material systems, without causing substantial change in geometric shape or cross section. Multiple extrusions of billets by ECAE permit severe plastic deformation in bulk materials. 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 article Al alloy samples were severely deformed by equal channel angular pressing (ECAP) up to two passes at room temperature. The effects of severe plastic deformation on the microstructure, mechanical properties of the Al alloy were investigated.

Key words: ECAP, SPD

I. INTRODUCTION

It is an innovative process capable of producing relatively uniform intensive plastic deformation in a variety of material systems, without causing substantial change in geometric shape or cross section. Multiple extrusions of billets by ECAE permit severe plastic deformation in bulk materials [1].

Equal-channel angular (ECA) pressing is a processing procedure in which a material is subjected to an intense plastic strain through simple shear. This procedure has received considerable attention recently because it has the capability of introducing an ultra-fine grain size, in the sub micrometer or nanometer range, into large-grained polycrystalline materials. In ECA pressing, a sample is pressed through a die in which two channels of equal cross-section intersect at an angle of Φ and an additional angle of Ψ defines the arc of curvature at the outer point of intersection of the two channels [2]. Between each adjacent two passes, it is possible to rotate the billet around its longitudinal axis, creating different ECAP routes. The processing route significantly affects the grain refinement and grain shape. It is of interest to find an ECAP route that most efficiently refines the grain size [3]. The main function of Equal Channel Angular Pressing is to refine grain structure and enhance mechanical properties of material like hardness of material. Main components to perform ECAP process are

- Hydraulic press
- Die
- Punch
- Billet

In ECAP process billets were pressed using different four routes. These routes were classified according to rotation of the billets after each press. Following are four processing routes which used in ECAP operation [4].

- Route A = the billet is not rotated
- Route BC= the billet is rotated 90° clockwise
- Route BA= the billet is rotated 90° clockwise and counterclockwise alternatively
- Route C = the billet is rotated 180°.

During the pressing, high plastic strain is achieved in billet because of accumulative shear strain at each pass. The value of shear strain after one pass ECAP in the frictionless condition is calculated with equation given below [5]

$$\varepsilon = N/\sqrt{3}[2\cot(\frac{\varphi+\Psi}{2}) + \Psi\csc(\frac{\phi+\Psi}{2})]$$

Where ε is the equivalent plastic strain, N is the no of passes, Φ is the channel intersection angle and Ψ is the outer corner angle.

II. EXPERIMENTATION

A. *Sample Preparation:*

A commercial grade aluminum magnesium (Al 6063) alloy was used as billet material. The sample for ECAE was prepared by machining the alloy to a square of 12mm and length 60mm. The chemical composition of the alloy as shown in table.1

Element	Weight (%)
Silicon	0.6
Iron	0.35
Copper	0.10
Magnesium	0.9
Chromium	0.10
Zinc	0.10

Table 1: Chemical composition of 6063 Al alloy

B. *Die Setup:*

The ECAE die was made from High carbon high chromium die steel consisted of two equal channels of square cross section 12.5mm in square. Channel intersection angle (Φ) of 120º was selected because it produced strain homogeneity in the billet material and some reduction in the pressing load. Outer corner angle (Ψ) of 40º along with a fillet radius of 13mm was used. As sharp inner corner produced damage in the specimens, fillet of radius 9mm was made in the inner corner of the two intersecting channels to avoid the cracks and damage in the top surface of the samples. A split type die design was used for the easy removal of extruded specimen from the die. ECAP die is shown in fig.1.

Fig. 1: ECAP Die

C. Processing:

The samples prepared were pressed through the ECAE die at room temperature using a hydraulic press of 200 tons capacity up to two passes. Solid oil was used as lubricants to reduce the friction between the samples and die surface. The samples were through die by four processing routes. The plastic deformation behavior during pressing is governed mainly by [5]

– Die geometry
– Process variable

1	Channel sizes	12.5 mm
2	Channel angle (Φ)	120°
3	Corner angle (Ψ)	40°
4	Outer radius (R)	13 mm
5	Inner radius (r)	9 mm

Table 2: Die Geometry

Temperature	Room Temperature
Lubrication	Solidified oil
Deformation speed	10 m/s

Table 3: Process variable

Samples after ECAP process is shown in following figure for different processing routes

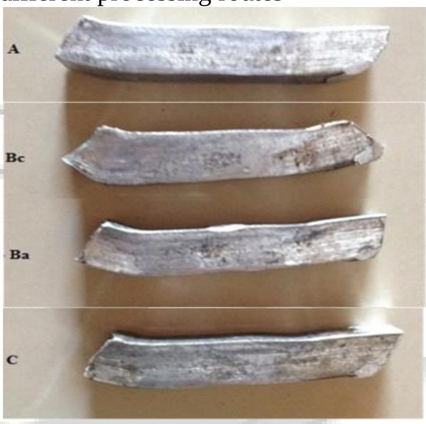

Fig. 2: Samples after ECAP

III. RESULT & DISCUSSION

A. Microstructure Evaluation:

Microstructural investigations of the samples before and after ECAE were conducted using optical microscope. The extruded samples were cut along the flow and transverse plane for microstructural investigations and ground manually using 240, 320, 400, 600, 800, 1000, 1200 grit silicon carbide abrasive sheets. We used 0.5% HF etchant for microstructure examination, observation done using 500 × magnification. Microstructural examination was carried out on Al alloy using test method ASTM E-407, ASTM E3. We used optical microscope OLYMPUS-GX41 in our study, figure 3 shows optical microscope.


Fig. 3: Optical microscope

Microstructure shows globular morphology Si & Al3Mg2 precipitates in Al rich matrix. From microstructure images of two Al alloy before and after equal channel angular pressing, we can see that after process, the grain were elongate in the direction of the extrusion and form lamellar texture [6] [7].

From microstructure of 6063 Al for die of channel angle Φ = 120° we conclude that in route A texture is align in opposite direction of the shear plane, in route Bc align in shear direction and refinement of grain was also done. In route Ba grain refinement is more and we get homogeneous structure compare to other processing routes. The Texture is aligned across the direction of the shear plane in route Bc. In route C texture is align in the extrusion direction.

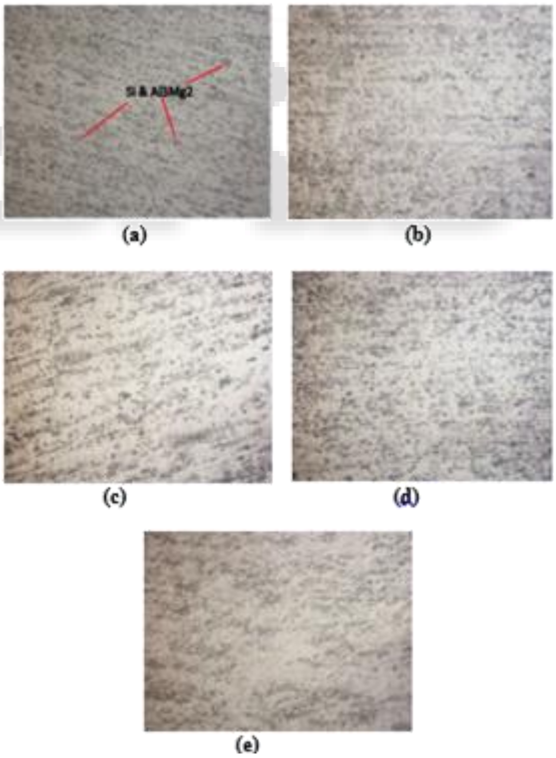

Fig. 4: Microstructure Of (A) Route A (B) Route Ba (C) Route Bc (D) Route C (E) Without ECAP

B. Hardness Evaluation:

Hardness test was carried out on samples using Fie make Vickers hardness tester model VM 50 with maximum capacity of 50 kgf figure 5 shows the Vickers hardness tester used in our study. Test was performed at room temperature using 5 kgf load and loading time was 15 second, Diamond indenter was used in test [8] [9].

Fig. 5: Vickers hardness tester

The hardness of the processed alloy increased suddenly from 51HV to 62HV after two passes. It is clear that the increase in hardness of the alloy is due to the homogeneous and highly refined microstructure of the alloy. Vickers hardness before and after ECAP using four processing route at room temperature are shown in figure 6.

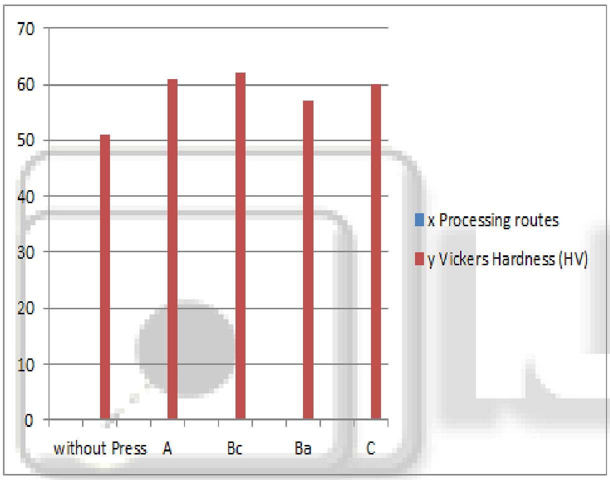

Fig. 6: Vickers Hardness Before & After ECAP For Four Routes

IV. CONCLUSIONS

In our study, Aluminium alloy samples were severely deformed by ECAP for up to two passes for die angle Φ = 120º in room temperature. Afterwards microstructural and mechanical test had been carried out to investigate the effects of ECAP on the grain refinement and hardness measurements of Al alloys were investigated. It was observed that mechanical property of ECAPed sample were enhance in terms of Vickers macro hardness and refinement of grain structure. Microstructure of Al alloy was homogeneous and more refine after ECAP process. Grain refinement and homogeneous texture enhanced more in Al alloy in route Ba.

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