Microstructure Evalution of Equal Channel Angular Extrusion In Aluminium 5083 Alloy by Cryogenic Treatment

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***Abstract** - This process is about subjecting the commercially available aluminium magnesium (Al 5083) alloy with equal channel angular extrusion process (ECAP) using route-Bc at room temperature and cryogenic conditions. Initially before the ECAP process the material properties were tabulated. And subsequently the properties of the material after the ECAP process is tabulated against the initial properties of the material, And along with the two readings the properties of material which undergone cryogenic treatment is tabulated. In this study it was clear that the mechanical properties of the material in cryogenic conditions are found to be better than the other two readings. With the increase in pass number the micro hardness and tensile strength of the alloy increases. The tested alloy can be used in various engineering applications requiring high strength.*

Key words: **Equal channel angular extrusion process (ECAP), Scanning electron microscopy, hardness, Aluminium 5083 alloy.**

1. INTRODUCTION

Aluminium and its alloys are being widely used as a predominant material in various engineering applications. More significantly, ultra fine grained (UFG) high strength aluminium 5083 alloy is in great demand to be used in various applications like shipbuilding, vehicle bodies, pressure vessels and armor plates because of its exceptional strength, good weldability and corrosion resistance. Due to this great demand for bulk materials with fine grains and combinational properties, researches are being done on various severe plastic deformation (SPD) methods for producing high strength UFG materials.

Equal Channel Angular Pressing (ECAP) is the most significant and attractive SPD method in which the materials are extruded without any change in the cross section by subjecting to very large shear strain. The processing method of ECAP includes pressing a billet by using a die consisting of two channels of equal cross section intersecting at a specified angle (Φ). A very high shear strain is imposed on the material while it passes through the shear zone of the die [1-3]. As the billet material has nearly the same cross section before and after ECAP, it can be pressed by using the die repeatedly for more passes. The deformation route can be varied between consecutive passes by rotating the billets through 0º (route-A), 90º alternate direction (route-B_A), 90º same direction (route-Bc) and 180º (route-C) [4]. The strain developed and the changes in the microstructure of the material have been controlled by choosing the appropriate channel angle (Φ), deformation route (route-A, route-B_A, route-Bc or route-C) and the number of passes [4- 6]. Extensive research has been done on ECAP for the past two decades for processing materials like aluminium alloys, magnesium, chromium, copper, silver, steel and titanium [7-17, 25]. For the processed material, mechanical and wear properties were found to be high making ECAP an important technique for processing bulk materials [10-14].

In this paper, commercially available aluminium magnesium (Al 5083) alloy has been subjected to ECAP through route-Bc at room temperature and cryogenic conditions, for improving the strength. Investigations have been done on microstructure and mechanical properties of the alloy before and after ECAP with cryogenic treatment.

2. EXPERIMENTAL PROCEDURE

2.1 Sample preparation

Commercial grade aluminium magnesium (Al 5083) alloy has been purchased which was in H34 condition. The samples for ECAP have been prepared by machining the alloy to a diameter of 10 mm and length 120 mm. The chemical composition of the alloy as shown in table.1 has been analyzed by using the ARL spark analyzer. It confirmed that the alloy purchased was an Al 5083 by having a maximum of 4.37% of magnesium.

2.2 Die setup

The ECAP die was made from tool steel consisted of two equal channels of circular cross section 10.1mm in diameter. Channel intersection angle (Φ) of 105º had been selected because it produced strain homogeneity in the billet material and some reduction in the pressing load [18-19]. Outer corner angle (Ψ) of 18º along with a fillet radius of 4 mm have been used to avoid bending like deformation which is more popular with higher outer corner angles [20-21]. As sharp inner corner produced damage in the specimens [22], fillet of radius 1 mm 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 has been used for the easy removal of extruded specimen from the die. A schematic of the ECAP die is shown in fig.1.

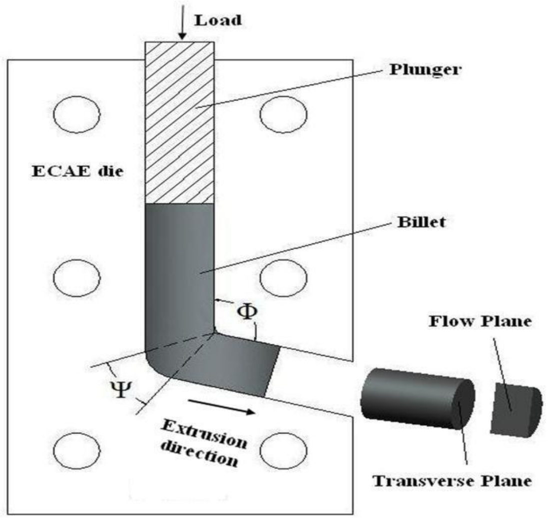


Fig-1: A schematic of ECAP die

The equivalent strain for N passes could be calculated by using equation (1) formulated by Iwahashi et al. [23].

$$\varepsilon = N/\sqrt{3}[2\cot(\Phi/2+\Psi/2)+\Psi \mathrm{cosec}(\Phi/2+\Psi/2)] \quad \text{----} (1)$$

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.

2.3 Processing

The samples prepared had been pressed through the ECAP die at room temperature and cryogenic temperature (-150^{0}C) using a hydraulic press of 100 tons capacity. MoS_2 grease and SAE 68 oil were used as lubricants for reducing the friction between the samples and die surface. The rod which was used in this process was having a diameter of 10 mm and 120 mm in length. After that the rod has been dipped into liquid nitrogen for about 60 seconds. Then, the sample has been produced to the entry channel of ECAP and pressing is done immediately.

The samples were rotated to an angle of 90° (Route-Bc) after each pass. Microstructural investigations of the samples before and after ECAP were conducted using Scanning electron microscope. Microhardness of the samples before and after ECAP with cryogenic treatment without cryogenic treatment was measured along the transverse plane using Vickers microhardness tester by applying a load of 100 grams for 20 seconds. Tensile testing of the samples was done at room temperature using extensometer. The samples for tensile testing were machined along the extrusion direction with 6 mm gauge diameter and 30 mm gauge length.

Table-1: Chemical composition of Al 5083 alloy

Si	Fe	Cu	Mn	Mg	Zn	Ti
0.18 %	0.23 %	0.015 %	0.60 %	4.37 %	0.04 %	0.042 %
Cr	**Ni**	**Pb**	**Sn**	**Na**	**Ca**	**B**
0.07 %	0.001 %	0.002 %	0.002 %	0.00003 %	0.0001 %	0.0007 %
Zr	**V**	**Be**	**Sr**	**Co**	**Cd**	**Sb**
0.004 %	0.0007 %	0.002 %	0.00003 %	0.01 %	0.0003 %	0.005 %
Ga	**P**	**Li**	**Al**			
0.004 %	0.007 %	Nil	94.33 %			

3. RESULTS AND DISCUSSION

3.1 Microstructure

Optical micrographs of the as-cast aluminium 5083 alloy in the transverse and flow direction are shown in fig.2 (a) & 2 (b). The alloy without ECAP is having coarse grain structure. Fig.3 (a) shows the microstructure in the transverse direction of the billet after one pass ECAP. It is evident that the coarse grain structure of the as-cast alloy is broken down when it is pressed by using the die due to the imposed high plastic strain by ECAP. The microstructure along the flow direction of the specimen after one pass is shown in fig.3 (b). It shows that the deformations produced in the material by ECAP.

Most of the coarse grain structure of the unprocessed material has been replaced with fine and homogeneous grain structure after two ECAP passes which is shown in fig.3 (c). The micrograph shown in fig.3 (d) is taken along the flow plane of the specimen processed by two pass ECAP. It reveals that more deformations have been produced in the material after two passes. Thus processing through ECAP refined the microstructure of as-cast aluminium 5083 alloy.

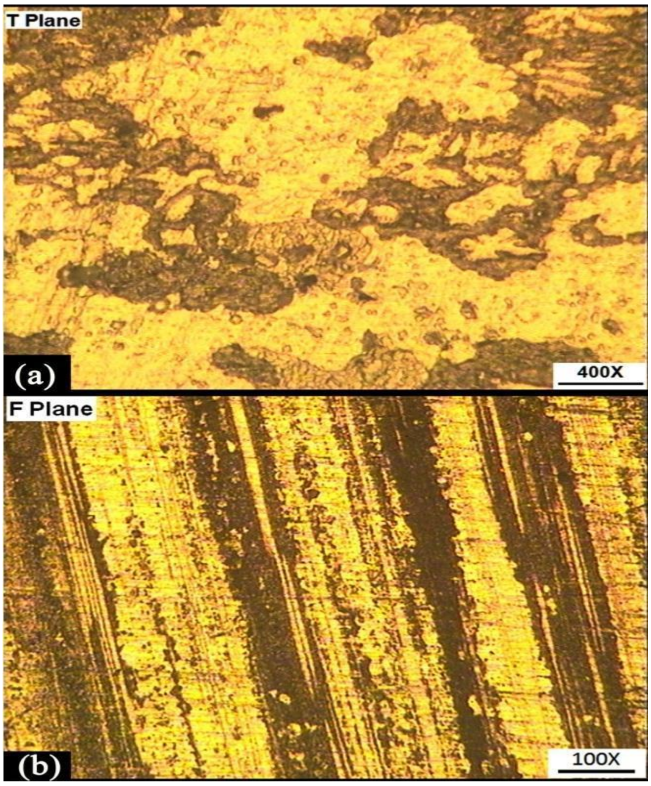
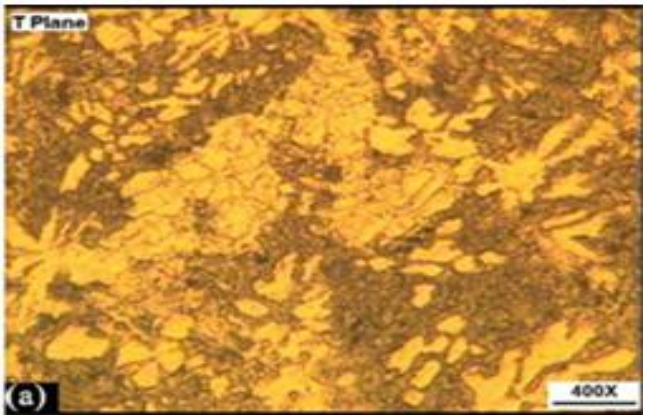


Fig-2: Microstructure of AL 5083 before ECAP



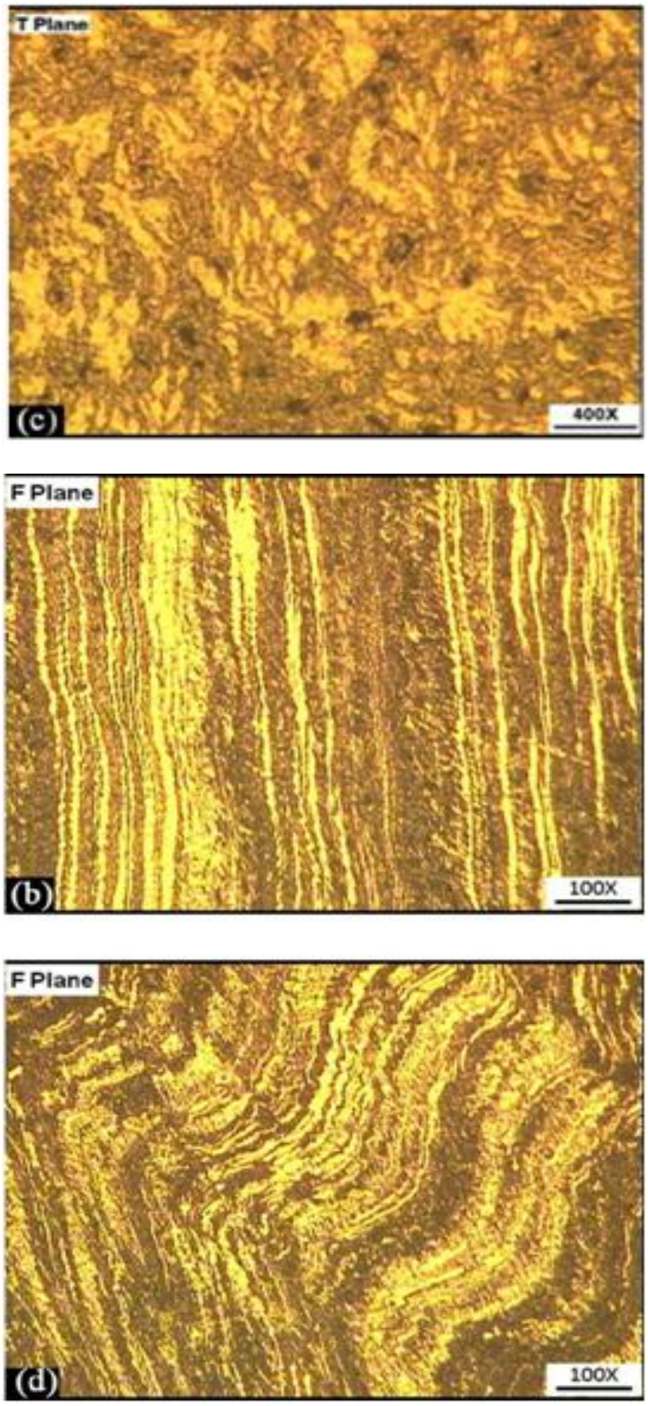


Fig-3: Microstructure of AL 5083 alloy (a) & (b) after ECAP, (c) & (d) ECAP with cryogenic treatment (T- transverse, F- flow)

3.2 Mechanical Properties

3.2.1 Microhardness

Vickers microhardness measurements before and after ECAP using route-Bc at room temperature are shown in fig.4. The microhardness of alloy after cryogenic treatment by using ECAP is higher than that of the unprocessed alloy and it increased with increase of pass number. The hardness of the processed alloy increased suddenly from 105 HV to 142 HV after two passes and which is increased to 151 HV after cryogenic treatment.

The percentage increase of the hardness after one pass is higher when compared to the increase in hardness of two pass ECAP specimen. It is clear that the increase in hardness of the alloy is caused by the homogeneous and highly refined microstructure of the alloy.

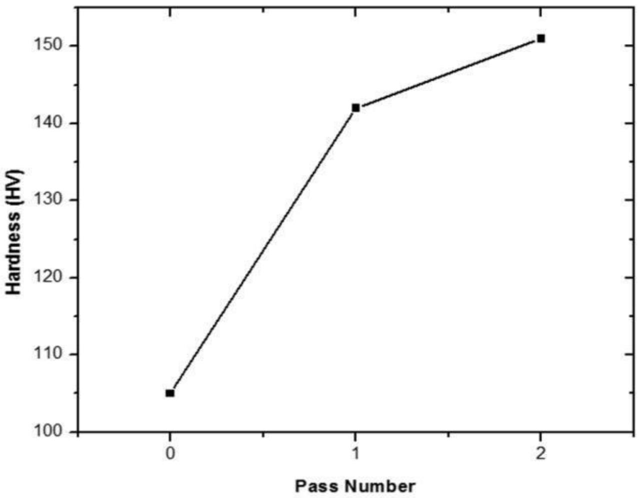


Chart-1: Vickers hardness of Al 5083 before and after ECAP

3.2.2 Tensile Properties

The tensile properties of aluminium 5083 alloy before and after ECAP are shown in Table.2. The yield strength (YS) and ultimate tensile strength (UTS) of the alloy before processing using ECAP was 305 MPa and 340 MPa with an elongation of 24%. After ECAP with one pass, the YS of the alloy increased by 29% to 393 MPa and UTS by 18% to 402 MPa with 15% elongation. With cryogenic treatment using ECAP to two passes, the YS of the alloy increased by 43% to 437 MPa and UTS by 31% to 445 MPa with 14% elongation when compared to unprocessed alloy.

Though the strength of the alloy increased, the ductility was reduced from 24% to 14%. This may caused by the strain hardening of the alloy after cryogenic treatment by ECAP. It is concluded that the increases in strength of the alloy processed cryogenic treatment using ECAP is mainly due to refinement of grains as according to Hall-Petch relation [24].

The specimens after the tensile test are shown in fig.5. It was observed that necking occurs only in the unprocessed alloy near the fracture surface. This shows that the type of fracture was ductile in unprocessed alloy and the same was brittle in processed alloy. The plot of engineering stress versus engineering strain of the alloy before and after ECAP is shown in fig.6. The curve exactly denotes that the specimens after ECAP has fractured just after reaching the tensile strength while in the as cast alloy considerable reduction in the stress value is reached which denotes the ductile type of fracture. The brittle fracture of the processed alloy was due to the increase in hardness value and tensile strength of the material.

Table-2: Tensile properties of Al 5083 alloy before, after ECAP and after cryogenic treatment

Process	Tensile Properties		
	YS(MPa)	*UTS(MPa)*	*Elongation to failure (%)*
Before ECAP	305	340	24
After ECAP (room temperature)	393	402	15
After Cryogenic treatment With ECAP	437	445	14

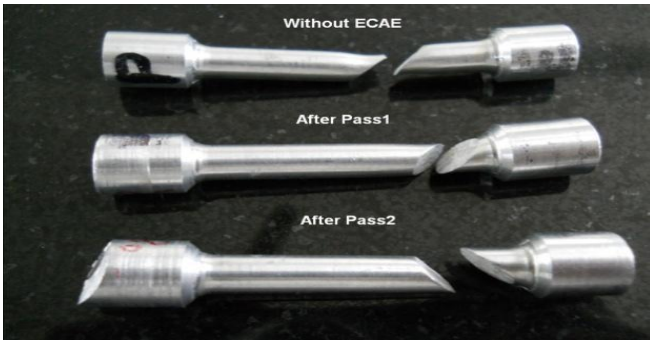


Fig-4: Fractured specimens after tensile test

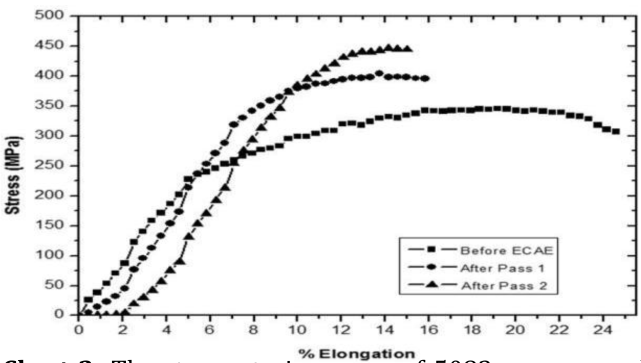


Chart-2: The stress-strain curves of 5083 unprocessed and processed Al alloy

4. CONCLUSIONS

The equal channel angular extrusion have been performed on aluminium 5083 alloy using a suitable die design for enhancing the strength and wear properties of the alloy. The results of this study are as follows. The coarse grain structure of the as-cast alloy has been replaced by highly refined and homogeneous microstructure after processing of cryogenic condition using ECAP till two passes using route-Bc. The microhardness of the alloy have been increased while there was an increase in pass number and reaches a maximum value of 151 HV after cryogenic treatment because of the formation of fine grains. The tensile strength of the alloy also increased with increase in pass number but there is some reduction in ductility due to the hardening of the alloy. It is concluded that processing cryogenic treatment using ECAP increased the mechanical properties of aluminium 5083 alloy. The improvement in the mechanical and wear properties were made it possible for using the alloy in various engineering applications requiring higher strength.

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