NATIONAL INSTITUTE OF TECHNOLOGY
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Mini Project

Effect of ECAP on Microstructure and Mechanical Properties on 6061-T6 Aluminum Alloy

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Guide

Introduction:

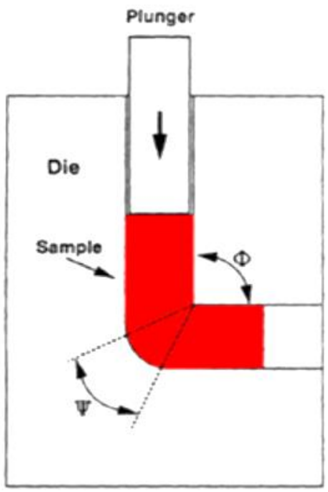
Aluminum is one of the most critical metals in human life. The properties of Aluminum are thoroughly explored by humankind by various processes. Aluminum can also be recycled very effectively and represents a relevant engineering material also for the future. The effort of increasing the mechanical properties of engineering materials led in the last two decades to the development of the so-called severe plastic deformation (SPD) processes, resulting in fine-grained structures that exhibit improved mechanical properties.

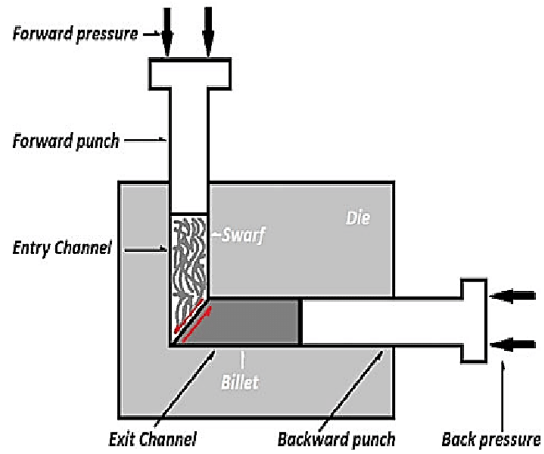
This work briefly summarizes the mechanical behavior of ultrafine grained (UFG) Aluminum prepared by one of the SPD methods, namely by Equal Channel Angular Pressing (ECAP). The Equal Channel Angular Pressing is a hardening treatment with which ductile metals can be processed to refine their grain and sub-grain structure. This process enhances the mechanical strength of metals in terms of tensile strength, hardness, etc.

This method enables the production of Ultra Fine Grain Aluminum, which is favorable from the industrial point of view. The work emphasizes comparing the Tensile properties and Hardness of Aluminum produced without ECAP and ECAP (with backpressure and without back pressure) individually.

Equal Channel Angular Pressing (ECAP):

Equal Channel Angular Pressing is the most popular severe plastic deformation (SPD) technique. The fundamentals of this procedure, the details of the process and conditions of material flow during pressing can be found in many technical papers. The principle of the method is simple. It consists of pressing a rod-shaped billet through a die with an angular channel having an angle Φ (which depends on the material). When a plunger presses the billet through the channel's knee, the billet's material is severely shear strained. Since the billet's cross-sectional dimensions remain constant after passing the channel, the procedure can be repeated. The final result is the imposition of a very high plastic strain to the processed material. As this process is feasible with small billets, it is used in the laboratory environment to form Ultrafine grains at room temperature without any heat-treatment process. It is easy to study microstructures.





ECAP with only main pressure

ECAP with main pressure & back pressure

Duties Performed:

At room temperature, aluminum samples were processed by Equal Channel Angular Pressing (ECAP) in the present work. The Aluminum samples were ECAP for one pass through 90° die-channel. The microstructures were observed through an optical microscope. The actual results are that tensile, hardness, and ductility of the so obtained refined structure are improved to the original coarse-grained metal.

Material:

In this work, the materials are three samples of Commercially available 6061-T6 an aluminum alloy of length 50 mm and a diameter of 12 mm each.

Composition:

The composition of 6061-T6 Aluminum alloy is given below.

Element	Composition (wt.%)
Aluminum	95.9 - 98.6
Magnesium	0.8 - 1.2
Silicon	0.4 - 0.8
Iron	0 - 0.7
Copper	0.15 - 0.4
Chromium	0.040 - 0.35
Zinc	0 - 0.25
Manganese	0 - 0.15
Titanium	0 - 0.15
Residuals	0 - 0.15

T6 tamper condition indicates that the alloy is solution treated at high temperatures and then artificially aged at a certain temperature.

Method:

Initially, two samples of Aluminum are at room temperature. The ECAP was done at room temperature for one aluminum sample with an angle between channels as 90°. MoS_2 grease was used for lubrication. ECAP was performed via route A that means no rotation of billet between passes) with only 1 pass.

The same procedure was repeated for another sample, but backpressure (10-15% of the main load) is applied.

S. No	Specimen (Al Rod)	ECAP	Length of the sample (mm)	Main pressure (Mpa)	Backpressure (Mpa)	Length of the sample after ECAP (mm)
1.	As received	No	**-**	-	-	-
2.	Sample without back pressure	Yes	50	3.7	0	45
3.	Sample with backpressure	Yes	50	5.6	0.3	43

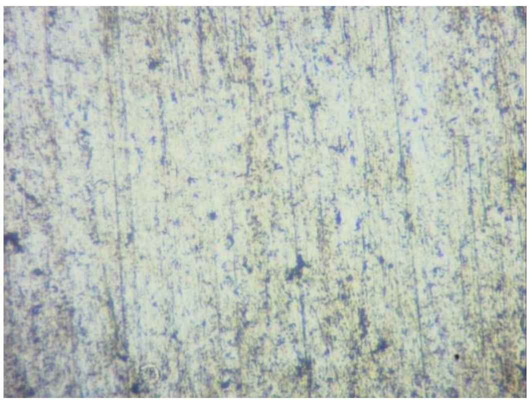
Microstructures:

The microstructure of three samples, i.e., as-received sample, ECAP (without backpressure sample), and ECAP (with backpressure) Aluminum samples, are viewed in Binocular Inverted Optical Microscope combined with an Image Analyzer.

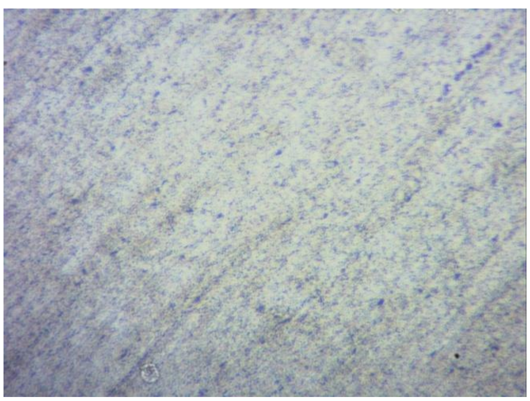
Etchant:

Distilled Water 190ml + Nitric Acid 5ml + Hydrochloric Acid 3ml + Hydrofluoric acid 2ml (Etch Time: 5-10 seconds)

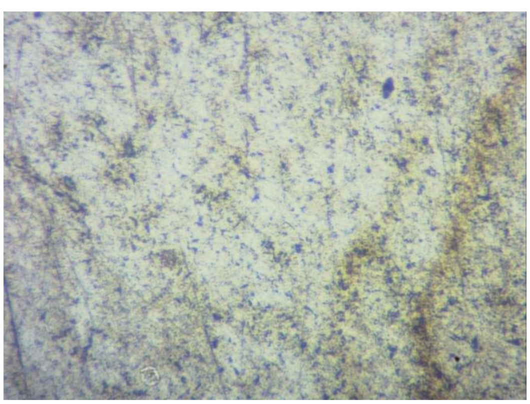
Microstructures of Al (at 100X):



a) As received sample.

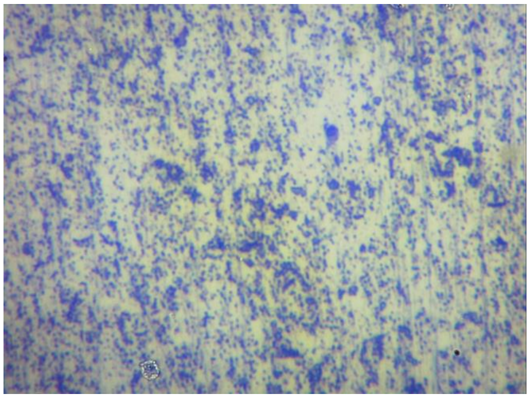


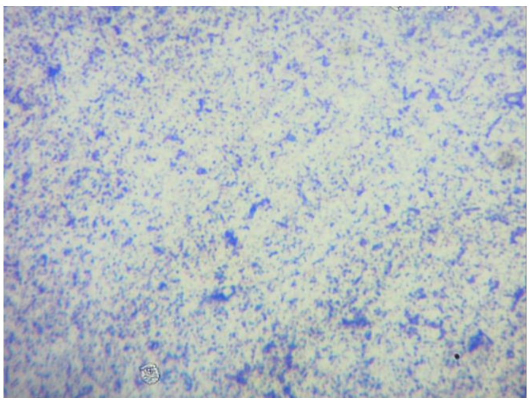
b) ECAP (without backpressure).

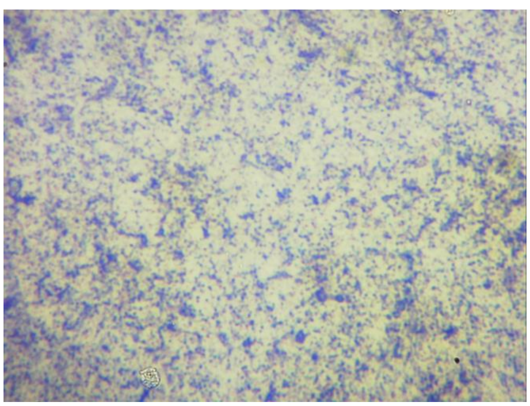


c) ECAP (with backpressure)

Microstructures of Al (at 400X):

a)  As received sample.

b)  ECAP (without backpressure).

c)  ECAP (with backpressure).

Tensile Properties and Hardness:

Tensile Properties:

The stress-strain Curve of the as-received, ECAP (without back pressure), and ECAP (with backpressure) aluminum rods are plotted across various values of Stress and Strain. The tensile test is Performed in a Digital Tensometer, and the shape of the specimen is according to ASTM E8 standards with a Gauge diameter of 4.0 ± 0.1mm. Tensile Strength and Elongation are noted for each rod.

S.No	Specimen (Al Rod)	Load (N)		Area (sq.mm)	Length (mm)		UTS (MPa)
		Peak load	Break load		Peak load	Break load	
1.	As received	2462	677	12.93	1.4	3.6	190
2.	Sample without back pressure	2648	1294	10.69	0.2	1.6	239
3.	Sample with back pressure	3138	2049	12.82	0.5	2.1	251

Rockwell Hardness:

The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload. Here a ball-indenter of 1/16th mm dia. is used. The applied load is 100Kgf. The resultant hardness values have been mentioned in the above table.

S.No	Specimen (Al Rod)	Rockwell Hardness (HRB)
1.	As received	37
2.	Sample without back pressure	40
3.	Sample with back pressure	42

Rockwell Hardness Tester

Result and Analysis:

In this method, three Aluminum rods are taken, and one of them is taken to perform ECAP by Servo Hydraulic Press at room temperature with an extrusion angle of 90°. A similar process is repeated for another Aluminum rod, but back pressure is applied to the sample. ECAP is performed here by Process A for only 1 pass for each sample. However, after ECAP, Microstructural analysis, Tensile test, and Rockwell Hardness Test are conducted for all the samples.

In this review, the effects of ECAP on the microstructure and mechanical properties studied and observed that the

1. ECAP refines the microstructure of the materials by inducing SPD (Severe Plastic
   Deformation) in the material.
2. Grains are either elongated or made finer along the direction of the ECAP.
3. UTS values for samples are in the order of
   No ECAP (190MPa) < ECAP without backpressure (239MPa) < ECAP with backpressure (251MPa).

4. Rockwell Hardness values for samples are in the order of
   No ECAP (37 HRB) < ECAP without backpressure (40 HRB) < ECAP without backpressure (42 HRB).

By the process of ECAP, we got finer grains. According to the Hall-Petch relation, mechanical properties like tensile strength and hardness of the alloy have been improved.

$$\sigma_y = \sigma_0 + \frac{k_y}{\sqrt{d}}$$

References:

1. https://en.wikipedia.org/wiki/Severe_plastic_deformation
2. "Consolidation of Al-5083 Alloy Powders by Equal Channel Angular Pressing" International Journal of Materials and Product Technology.
3. "Effect of Microstructure and Mechanical Properties of Al-Mg Alloy processed by ECAP at Room Temperature and Cryo Temperature" Transactions of Indian Institute of Metals, vol. 70 (3) (2017) pp 639-648.