Grain size and mechanical properties of metals subjected to equal channel angular pressing (ECAP) process

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ABSTRACT – Equal Channel Angular Pressing (ECAP) is one of the most efficient technique in metal forming process which induced severe plastic deformation (SPD) to produce bulk ultrafine-grained metals. This research used Titanium CP Grade 2 and Aluminum Alloy 6061 to investigate the grain size and mechanical properties of both materials after ECAP process. The materials were extruded through die channel angle of 126º internal and 10º external under pressure of 60 bar. The result shows that there is significant increase in grain refinement and hardness after ECAP process for both materials.

1. INTRODUCTION

Equal Channel Angular Pressing (ECAP) has been one of the most popular Severe Plastic Deformation (SPD) techniques for refining grain on metals and composites [1]. The development of this process has been improvised especially by Valiev and Langdon [2] to get better product. ECAP process will produce better grain refinement, with improved strength but retain approximately the same size and shape of the billet before and after the process.

Sanusi et al. [3] stated that SPD technique is a generic term describing a group of metal working techniques that involve using extreme plastic straining to produce materials by imposing very high shear deformation on the materials under superimposed hydrostatic pressure. Several SPD techniques have been developed such as High Pressure Torsion (HPT), Accumulative Roll Bonding (ARB), Accumulative Back Extrusion (ABE) and Equal Channel Angular Pressing (ECAP).

Figure 1 shows that the basic principle of ECAP process which the sample will be extruded through two intersecting channels which have the same cross-section with die internal angle (φ) and die external angle (ψ) by using a plunger as stated by Djavanroodi et al. [4]. The cross-section of the die can either be circular or square. Because ECAP process can be repeated for several times, shear deformation will influence the production of high strength and lightweight materials without compromising their dimension.

In this research, the objective is to conduct ECAP process on Titanium CP Grade 2 (Ti ASTM Grade 2) and Aluminium Alloy 6061 (AA 6061); and to compare the grain size and mechanical properties of both materials before and after ECAP process.

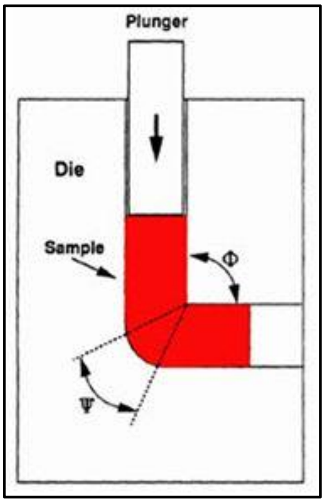

Figure 1 Principle of ECAP process.

2. METHODOLOGY

The ECAP die used for this research was a removable die in circular channel with internal angle of 126º and external angle of 10º as indicated on Figure 2.

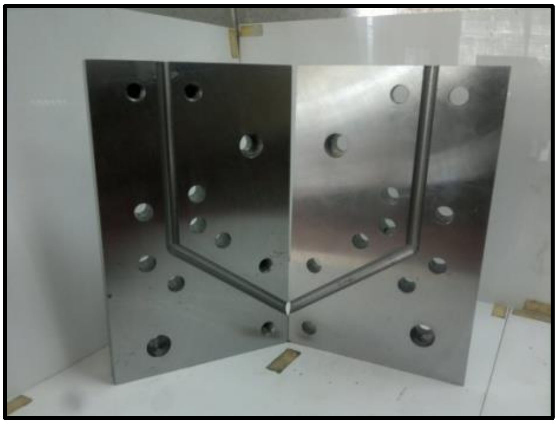

Figure 2 The die used for the experiments.

The removable die consists of two plate bolted together to form the circular channel which then will be locked by die holder. The samples are in the form of cylindrical rod which 10mm in diameter and 100mm in length. The samples were lubricated by using molybdenum disulfide (M_OS_2) lubricant. The samples undergo ECAP process by using Hydraulic Pressure machine under the pressure of 60 bar at room temperature. The ECPD samples hardness was tested using Vickers hardness Matsuzawa hardness machine type MMT-X7 which uses diamond indenter in the shape of pyramid with square base. The result of the sample hardness will be calculated by using the following formula:

$$\text{Vickers Hardness, HV} = 2F\sin\frac{136/2}{D^2} \qquad [1]$$

The microstructure of ECPD samples is analyzed under optical microstructure test by using Wilson Hardness Machine to observe the grain size.

3. RESULTS AND DISCUSSION

The hardness test result across the surface of the samples are shown on Figure 3 and Figure 4. It was clearly shown that there is an increase of hardness value after ECAP process. After ECAP, the average hardness for Ti ASTM Grade 2 is increased for 127% while for AA 6061 is increased for 194%. Based on the calculation of the formula, it showed that as the diagonal length decreases, the value of hardness increase.

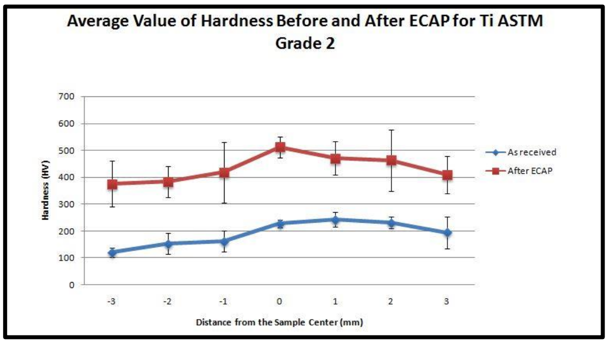

Figure 3 Graph of hardness of Ti ASTM Grade 2.

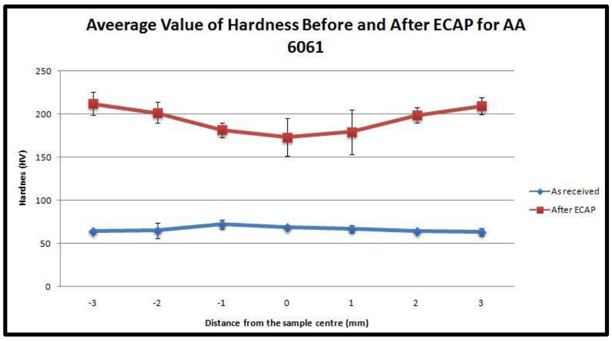

Figure 4 The hardness profile of AA 6061.

The microstructure of the samples after ECAP are in term of grain sizes and shown in the Table 1 and Table 2 for both of materials. The grain sizes of the samples decrease significantly after ECAP process. For Ti ASTM Grade 2, there is approximately 61% decrease in grain size compared to as received condition while for AA 6061, there is approximately 83% decrease in grain size compared to as received condition.

Table 1 Average calculation of grain size of Ti ASTM Grade 2.

Process	Area	Mean	Min	Max	Average grain size (µm)
As-received	29.7	79.08	150.38	55.04	28.69
ECAP	12.2	50.79	99.29	50.79	11.17

Table 2 Average calculation of grain size of AA6061.

Process	Area	Mean	Min	Max	Average grain size (µm)
As-received	10.51	183.86	98.27	253.29	35.49
ECAP	2.06	152.73	81.94	206.09	6.72

4. CONCLUSION

In this research, experiments are conducted to investigate the hardness and the microstructure of Ti ASTM Grade 2 and AA 6061 after ECAP process. The data collected shows that there is significant increase in term of grain refinement and also hardness for both of materials even after single pass.

Based on the results, we can see that ECAP process is indeed proved to be the alternative technique to produce bulk materials under SPD technique which does not sacrifice the dimension of the materials. The material's grain size is indeed will be refined to be more even throughout the workpiece while at the same time increase the hardness value of the workpiece.

5. ACKNOWLEDGEMENT

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