Investigation of mechanical properties of ECAP processed AL7068 aluminium alloy

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Abstract. In this paper, the influence of Equal Channel Angular Pressing (ECAP) on mechanical properties of AL7068 aluminium alloy is investigated. Specimens are subjected to ECAP process by using ECAP split die having an abrupt angle 90° up to 4 ECAP passes using route Bc. The processing temperature was optimized and the ECAP process was conducted at 200°C by route Bc where, the sample is rotated in the same direction between consecutive passes. Unprocessed and ECAP processed samples were subjected to tensile and Vickers microhardness test. ECAP processed samples showed significant improvement in ultimate tensile strength and hardness as compared to unprocessed samples showing improved mechanical properties of the processed aluminium alloy.

Keywords: Equal channel angular pressing, Al7068, Grain refinement, Mechanical properties

1. Introduction

Equal channel angular pressing (ECAP) is one among the important severe plastic deformation (SPD) processes for achieving the mechanical properties of various metals to suit them for different engineering applications by obtaining ultrafine-grained materials. SPD is one of the most promising approach for achieving good mechanical properties by grain refinement and through strain accumulation [1-3]. ECAP process was initially started by Segal with his co-workers during 1970 and 1980 in Minsk in the former Soviet Union [4 and 5]. In ECAP process, the sample is extruded through the sheared formation with dead zone at the outer corner in the die channel [6 and 7].

Z. C. Duan et al. [6], have conducted experiments to assess the capability for producing a high level of homogeneity by ECAP using a split die with a channel angle of 90°. Gopi K. R., et al. [8] worked on magnesium AM90 alloy subjected to ECAP using route Bc. Microstructural characterization revealed the refined grains with an average grain size of 3μm with 4 ECAP passes. Carlo Bruni et al. [9] evaluated the effect of the ECAP on bulk mechanical properties of dual aluminium alloy samples in which one part is cylindrical made of AA6012 aluminium alloy and the other is tubular that is made of AA6026. M. Chegini et al. [10], investigated the impact of grain refinement by ECAP on wear behaviour of Al 7075 material in which, the specimens were processed to four passes using route Bc. Wear resistance of the samples increased substantially because of the development of fine grains by ECAP process. K.R. Cardosoa et al. [11], investigated the effect of ECAP process parameters such as processing route, number of ECAP passes and temperature by pressing AA7050 aluminium alloy through ECAP die. The obtained results revealed that with increase in ECAP passes, refining of microstructure took place by route Bc that achieved more refined microstructure. Cerri E et al. [12] have conducted four ECAP passes via route Bc at room temperature with a die possessing channel of dimension 10 mm in diameter with an internal angle (Φ) of 90° and an outer angle (Ψ) of 35° on Al 6082 alloy. Malek P et al. have conducted experiments to obtain ultra-fine-grained structure in the AA 7075 aluminium alloy through ECAP at pressing temperatures of 120, 170 and 220°C [13]. Zhao X. et al. showed a significant reduction in grain size from 23 μm to 200 nm by pressing the titanium through ECAP die having a channel angle of 120° after 6 or 8 passes at room
temperature [14]. Valiev R. Z et al. examined the improvements by using ECAP towards grain refinement included modified conventional ECAP process to improve the process effectiveness and methods for upgrading the technique and to process hard materials [15].

Literature shows limited work on processing of aluminium 7068 (Al7068) metal matrix composite. To the authors knowledge, no work is reported on ECAP process of Al7068. Therefore further investigation is necessary on the above process to enhance the mechanical properties of the material. By secondary processing like ECAP, we can further improve the material properties and its applications can be extended in different areas of manufacturing.

The present work is an effort towards the enhancement of AA7068 Aluminium Alloy material properties by applying a secondary process called ECAP and hence its applications can be extended in different areas of manufacturing. Al 7068 alloys is a heat treatable wrought alloy possessing good fatigue strength, high thermal conductivity and good anodizing response [16 and 17].

2. Material and Experimentation

The elemental composition of Al7068 is shown in table 1. The cast billets of Al7068 were machined to rod form of dimension 15.8 mm in diameter and 100 mm in length. ECAP die of split type was designed and fabricated by hot die steel (HDS) material. Die was designed with two channels of equal cross section that intersects at an abrupt angle of Φ=90° and corner angle of Ψ = 20°. Die was machined to the required dimension and it was heat treated to strengthen the die for ECAP process. The schematic representation of the ECAE process is shown in figure 1. Heating coils are inserted in the holes fabricated within ECAP die for preheating the samples before ECAP process. Four heating coils are used to achieve the required preheat temperature and temperature is monitored using temperature controller.

| Table 1. Chemical compositions of Al7068 aluminium alloy in wt.% used in the current work. |
|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Elements        | Zn  | Mg  | Cu  | Fe  | Zr  | Si  | Mn  | Ti  | Cr  | Al          |
| Wt.%            | 8.3 | 3   | 2.4 | 0.15| 0.15| 0.12| 0.1 | 0.1 | 0.05| Balance     |

Experimental optimization was conducted and the preheat temperature was set to 200 °C. Samples are positioned in the ECAP die and the sample is allowed to preheat at 200 °C for 15 minutes. Samples were pressed through ECAP split die at a speed of 50 mm per minute with the application of molybdenum disulfide (MoS2) lubricant to avoid friction between die and sample using route Bc. In route Bc, the sample is rotated in the same direction between consecutive passes through an angle of 90° [2]. ECAP process was repeated up to 4 passes. Grain refinement was inspected by SEM (as per ASTM E-112) [6] to evidence the significant grain refinement achieved through ECAP process. Tensile specimens of ASTM-E8 [8] standards of gauge length 16 mm were prepared and inspected on the BISS Tensile Tester with a cross head speed of 0.24 mm per minute.

Micro hardness test was also done to identify the successive improvement in their hardness with respect to number of passes from 1 to 4 through ECAP die by applying a load of 25g for 15s as per ASTM-E384 [4, 9 and 10].
3. Results and Discussion

3.1 Microstructural Analysis

Figure 2 illustrates the SEM images of Aluminium Alloy Al7068 before and after ECAP passes from one pass to four passes. Figure 2(a) shows the microstructure of homogenized Al7068 aluminium alloy. The average grain size of Al7086 homogenised aluminium alloy is 80 μm. SEM image evidences the clear visibility of the grain boundaries, which eases the distinguishing between each grain. Further samples were pressed through ECAP die up to 4 passes.

Figure 2: Microstructures of a) Homogenised b) ECAP 1Pass c) ECAP 2 Pass d) ECAP 3 Pass and e) ECAP 4 Pass samples.

Figure 2(b) shows the ECAP 1 pass specimen where initial coarse grains of 80 μm are broken into an average grain size of 60 μm. Figure 2(c), 2(d) and 2(e) represents the further reduction in grain size of 35, 20 and 8 μm during second, third and fourth ECAP passes respectively. From these
microstructural images, it is visible that the grains obtained through higher passes are of homogeneous, equiaxed and refined grain size with an influence of continuous dynamic recrystallization occurs during ECAP triggers the formation of UFG material structures [8]. From these SEM images, it is also witnessed that the enhancement in mechanical properties as stated above were achieved due to grain refinement as the Al7068 specimens were processed by severe plastic deformation process through ECAP die.

3.2 Mechanical Properties

Tensile test was performed on the universal testing machine (UTM) with a extreme load capability of 50 KN in research laboratory of Vidyavardaka College of Engineering, Mysore. Specimens were prepared to conduct tensile test according to ASTM E8 standards. All the specimens were tested on UTM in laboratory condition at room temperature by maintaining a constant stroke speed of 0.24 mm per minute. The obtained results were plotted as shown in figure 3. The UTS obtained for homogenized sample is 180 MPa and as the ECAP pass increases from 1 pass to 4 pass the UTS increases to 210, 260, 275 and 350 MPa respectively. It is evident from the graph that ECAP processed specimens resulted with increase in its ultimate tensile strength (UTS) with the ECAP passes from 1 pass to 4 passes as compared to unprocessed Al7068. The increase in UTS for ECAP processed samples is because of grain boundary strengthening mechanism due to reduction in grain size which resulted in increased strength based on Hall Petch equation [18].

![Figure 3](image)

Figure 3: Tensile results of a) Homogenized b) ECAP 1Pass c) ECAP 2Pass d) ECAP 3Pass and e) ECAP 4Pass samples.

Homogenized and ECAP processed samples were exposed to hardness test by applying a load of 0.025 kgf with dwell time for 25 seconds. The test was conducted at room temperature on sophisticated Vickers micro hardness tester and the obtained results are shown in figure 4. ECAP processed samples showed a significant improvement in their hardness values due to grain refinement. Increase in hardness with grain refinement occurs because of strain hardening effect. Enhancement in hardness occurs with increase in ECAP passes due to homogeneous microstructure in the material.
Figure 4: Micro hardness results of a) Homogenized b) ECAP 1Pass c) ECAP 2Pass d) ECAP 3Pass and e) ECAP 4Pass samples.

4. Conclusions
ECAP was performed on aluminium alloy Al7068 and its mechanical properties are investigated. Based on the obtained results, the following inferences are made:

- Aluminium alloy Al7068 was comfortably pressed through ECAP die at 200°C up to ECAP 4 passes using route Bc, which resulted with a better grain refinement of average grain size of 8 μm at the end of 4 pass as compared to homogenized condition.
- Increase in UTS for ECAP processed samples are resulted in 112%, 131%, 136% and 183% more as compared with homogenized sample after 1 pass to 4 pass respectively.
- The results obtained from the microhardness test revealed that successive increase in hardness values for ECAP processed samples due to grain refinement occurred within the material.

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