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# Experimental Study of Impact Strength of Al-6063 Alloy Processed by Equal Channel Angular Extrusion

S.Sulaiman[1, a] , J.Nemati[1, b], Hani Mizhir Magid [1, c], B.T.H.T. Baharudin [1, d], G.H.Majzoobi[2, e], M.A.Azmah Hanim[1, f]

[1]Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor DarulEhsan, Malaysia

[2]Mechanical Engineering School, Islamic Azad University, Takestan branch, Takestan, Iran
[a]shamsuddin@upm.edu.my, [b]ja_neamati@yahoo.com, [c]hani_magid@yahoo.com, [d]tuah@eng.upm.edu.my, [e]gh_majzoobi@yahoo.co.uk, [f]azmah@eng.upm.edu.my

**Keywords:** Equal Channel Angular Extrusion **(**ECAE), Al-6063, Impact strength, Grain refinement, Split-Hopkinson pressure bar.

**Abstract.** In the present study, the impact strength of annealed Al-6063 alloy developed by equal channel angular extrusion (ECAE), up to 6 passes at a temperature of 200°C following route A with a constant ram speed of 30 mm/min through a die angle of 90° between the die channels was investigated. The impact strength of extruded specimens is evaluated for different passes at a strain rate of 1800 $s^{-1}$ using Split-Hopkinson pressure bar techniques. The results indicate that the major strength improvement occurs in the 5$^{th}$ and 6$^{th}$ passes while in primary passes, the strength improved but at a considerably lower rate. A total increasing in ultimate strength (UTS) and yield strength (YS) are 127% and 65% respectively and observed for the extruded material after 6 passes. Optical microscopic examinations show a grain refinement from 45 μm to 2.8 μm.

## Introduction

Equal channel angle extrusion (ECAE) is known for producing materials with nano-scaled structures. In this method, the material in the form of a billet is extruded through an equal channel angle. The billet undergoes sever plastic deformations when it passes through the channel elbow. The increase of the pass number (up to 7 to 8 times of extrusion) can give more improvement into the mechanical behavior of the billet. One of the advantages of ECAE is that the billet can sustain sever deformations and large strains greater than one without suffering any change of dimensions. Because of these large strains, materials grains get finer. It is shown that the process can lead at the end to a nano-structures material. The microstructure and mechanical aspects of different ultrafine-grained (UFG) metals and alloys are studied by many researchers over the past two decades, but there are limited reports on dynamic behavior in particular, impact response of ECAEed materials. Kim et al. [1] investigated the influences of ECAE process on microstructure and shear strength of commercially pure aluminum (1050 Al alloy). Their results show that a significant improvement in shear yield strength with the first ECAE pass, but the second pass resulted in only a slight increase in strength. Rehbi et al [2] subjected 99.1% aluminum to ECAE process up to 4 passes using routes $B_C$ and C to evaluate the microstructure and change in mechanical properties. Coherency lengths D calculated from X-ray diffraction. Their results indicate that for route $B_C$, it was kept constant when the number of passages N was increased. For route C, an increase of D was observed when increasing N. Dadbakhshi [3] investigated the effect of pre and post different heat treatment on strengthen a commercial 6082 Al alloy processed by ECAE. His results reveal that aging before and after ECAP processing is an effective method for strengthening of the alloy. In this study an increase in both strength and ductility of the ECAPed specimen was reported. Khan and Meredith [4] studied the effect of strain rates and processing temperature on ECAEed Al 6061.It was found that, the ECAP process increases the strength versus the T651 condition. Additionally, the Al 6061 ECAP is not sensitive to strain rate at room and lower temperatures, but the sensitivity increases as the number of passes and/or temperature are increased. Enab [5] reviewed the influence of single pass ECAE process on mechanical properties and microstructure of four important commercial aluminum alloys, 1050, 5083, 6082 and 7010AA. It was found that the hardening rate was high at the early stage of deformation after which the hardening rate was negligible assuming a response close to perfectly plastic behavior moreover; the hardness of 6082 and 5083AA developed almost similar values. Cardoso et al [6] studied the effect of heat-treated condition and processing route on ECAEed Commercial AA7050 aluminum alloy at different temperatures. They observed that in all cases, the microstructure was refined by the formation of deformation bands, with dislocation cells and sub grains inside these bands. Sun et al [7] subjected commercial purity aluminum over a range of grain sizes was tested over quasi-static to dynamic strain rates, at 298 and 77 K in compression. They concluded that the influence of strain rate and temperature is most significant in the smallest grain size specimens. The effect of strain rate on tensile behavior of cryo-rolled ultrafine-grained OFHC CU was investigated in the strain rate range $10^{-5}$ – $10^{-2}$ $S^{-1}$ in the present study by Chinta Babu et al [8]. A significant uniform elongation was observed at all strain rates. Mishira et al. [9] investigated the high strain rate response of ultra-fine-grained (UFG) copper processed by equal channel angular pressing (ECAP) by three deferent dynamic testing methods: reverse Taylor impact, cylindrical compression specimens, and hat-shaped specimens in Hopkinson bar experiments. There is a significant jump in the strength of UFG copper in going from quasi static to dynamic strain rate tests, which is indicative of high-strain-rate sensitivity.

## Material, Specimens and Testing Device

Commercially Al-6063 alloy was employed in this work. The as-received material was machined in the form of billet whit a dimension of 110 $\times$110$\times$12 $mm^3$. The billets were annealed at 420°C for three hours and were cooled in the furnace at a cooling rate of 18°C/hr. The chemical composition of AL-6063 is provided in Table 1.The extrusion is conducted on a 60 ton Avery universal testing machine.

Table 1: Chemical composition of AL-6063

| Si | Fe | Cu | Mn | Mg | Cr | Ni | Zn | Ti | Pb | Co | Bi | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.44 | 0.93 | 3.50 | 0.59 | 1.02 | 0.03 | 0.005 | 0.38 | 0.04 | 0.10 | 0.005 | 0.004 | Base |

## Ecae Tests

ECAE tests were performed for specimens up to 6 passes at a temperature of 200°C following route A with a constant ram speed of 30 mm/min through a die angle of 90° between the die channels. The tested billets were used for preparation of specimens for impact characterization of the extruded materials. Typical virgin and ECAEed specimens after the 1st, 4th and 5th pass are presented in Figure1.

(a) (b) (c) (d)

Fig 1: Typical specimens: (a) unprocessed, after (b) 1st (c) 4th and (d) the 5th pass

## Grain Size Measurement

The microstructure of the specimens after various extrusion passes was evaluated by metallurgraphy examination of the cross-sections of the material. The grain size was measured according to the ASTM standard E112. The results are graphically shown in Figure 2. The typical microstructures are depicted in Figure 3.The grains of the specimens after the first pass were significantly refined.

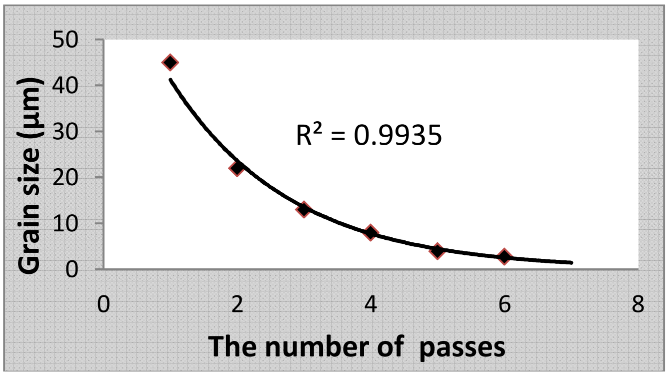
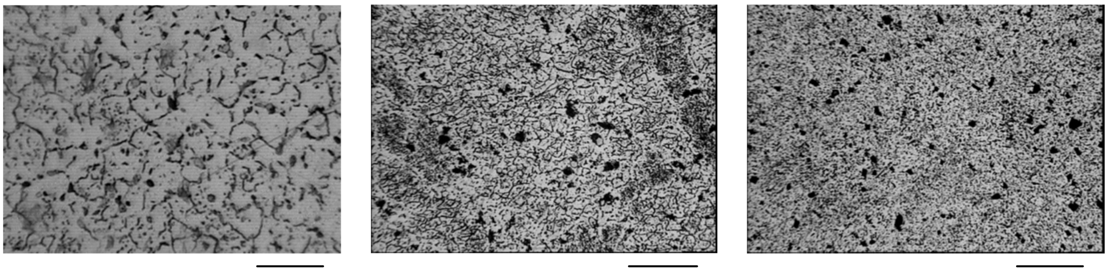



Fig 2: Variation in grain size versus number of passes



As received 200µm After 2 passes 200µm After 4 passes 200µm

Fig 3: The microstructures of the extruded specimens at a magnification of 200

**Impact Tests**

Cylindrical impact test sample whit diameter and high of 10 mm were made from the unprocessed and extruded specimens after each passes. The impact tests were performed using split-Hopkinson pressure bar technique (SHPB) at a strain rate of 1800 $s^{-1}$.True stress-strain curves for samples are obtained using the results of time dependent stress and strain for input and output bars and Kolesky expressions for Split pressure Hopkinson bar. The figures of tested specimens and the split-Hopkinson pressure bar apparatus used in this study are shown in Figures 4 and 5 respectively. The stress-strain curves of the virgin material and the extruded specimens after each pass of ECAE process were shown in Figure 6. As the figure suggest, the yield and ultimate stresses of extruded materials improved by increasing the numbers of ECAE passes. This enhancement is more significant for passes four and six. The yield and total strains are increased by increasing the pass numbers. As shown in figure 7, there is a significant improvement in yield stress after 6 passes of ECAE process.

$6^{th}$ $5^{th}$ $4^{th}$ $3^{rd}$ $2^{nd}$ $1^{st}$ As-received

Fig 4: As-received and extruded specimens after impact test

(a)

(b)

Fig 5: (a) Split-Hopkinson pressure bar apparatus and (b) A specimen installed for test

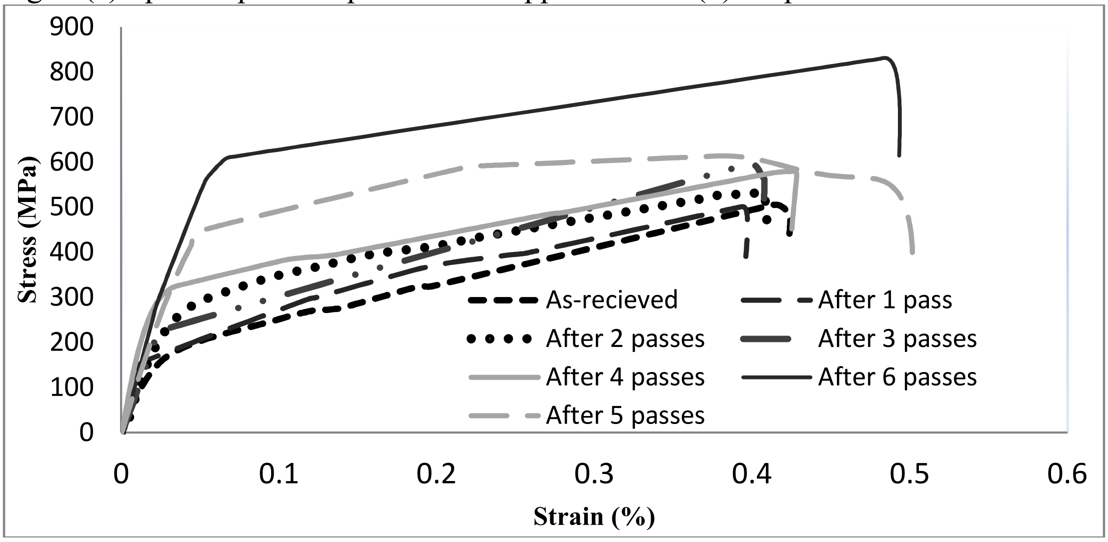



Fig 6: Stress–strain curves for ECAEed process after different passes

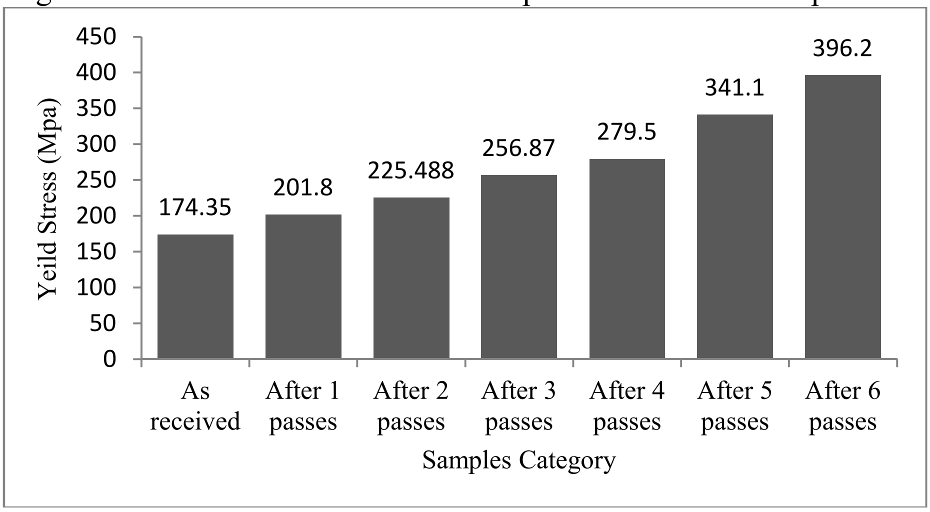



Fig 7: Improvement in yield stress versus number of ECAE passes

## Conclusions

The effect of grain refinement on the strength of Al-6063 alloy was studied in the strain rate of 1800 $s^{-1}$. The results of experiments indicated that the strength of the extruded materials increased by increasing the numbers of ECAE passes and hence the grain refinement. A total increasing in ultimate strength (UTS) and yield strength (YS) 127% and 65% respectively are observed for the extruded material after 6 passes. Optical microscopic examinations show a grain refinement from 45 µm to 2.8 µm.

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