

MICROSTRUCTURAL OBSERVATIONS OF FRACTURE SURFACES FOR A 6063-T1 ECAP PROCESSED ALUMINUM ALLOY

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Presarea în canale la unghiuri egale (Equal Channel Angular Pressing) – ECAP – este o metodă de modificare a microstructurii materialelor, având ca scop obținerea de structuri ultra fine și nanostructuri. Probele investigate au fost procesate până la un număr de nouă treceri. După procesarea ECAP probele au fost testate mecanic la tracțiune, cu ajutorul unei mașini de testat INSTRON 3382, iar suprafețele de rupere obținute au fost investigate folosind un microscop electronic SEM VEGA II – XMU. S-a observat că pentru materialul neprocesat ECAP suprafețele de rupere arată un caracter ductil al acesteia, cu goluri nucleate la limitele de graunte; deasemenea zone de coalescență a golurilor sunt observate. Pentru probele procesate ECAP sunt observate zone fragile de rupere. Ruperea datorată clivajului fragil apare în material în urma durificării datorate deformației cât și datorită rezistenței reduse la clivaj, rezultate în timpul procesării ECAP.

Equal channel angular pressing (ECAP) is a very interesting method for modifying microstructure in producing ultra fine grained materials (UFG) and nanomaterials (NM). The specimens were processed for a number of passes up to nine. After ECAP processing the samples were mechanically tested in tensile tests, using an INSTRON 3382 testing machine and the obtained fracture surfaces were investigated using SEM microscopy, VEGA II - XMU. It was determined that for no ECAP processing, the fracture surfaces show a ductile aspect, with voids nucleated at grain boundaries, areas in which void growth and voids coalescence are present were also observed. For ECAP processed samples, the fracture surfaces show a fragile aspect, with large brittle areas. Internal brittle cleavage fracture occurs in materials because of the high strain-hardening rate and low cleavage strength resulted during ECAP process.

Keywords: aluminum alloys; severe plastic deformation; fracture surfaces

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1. Introduction

The aluminum 6063 alloy is a medium strength alloy. It is normally used in intricate extrusions. Most used applications for 6063-T1 aluminum alloy are in road transport, rail transport, extreme sports equipment, architectural applications, extrusion products, etc. It has a good surface finish, high corrosion resistance, is readily suited to welding and can be easily anodised. Most commonly available as T6 temper, in the T4 condition it has good formability. The 6063-T1 alloy is an aluminum alloy class consisting in 6063 alloy hot extruded in bars with round section and post treated T1 (Solid solution treatment at 521°C + Aging treatment at 177°C + Annealing treatment at 413°C).

Because of the widespread use of these alloys, it is important to understand their mechanical behaviour when exposed to different loading conditions, strain rates and temperatures, and to be able to model their behaviour and later, to predict the behaviour for any of these conditions [1-3].

The research activity in the area of severe plastic deformation (SPD) has increased extremely in the last years due to many interesting properties which can be achieved in bulk materials by SPD [4].

Compared to classical deformation processes, the big advantage of SPD techniques (represented in particular by equal channel angular pressing (ECAP)) is the lack of shape-change deformation and the consequent possibility to impart extremely large strain. SPD has received enormous interest over the last two decades as a method capable of producing fully dense and bulk submicrocrystalline and nanocrystalline materials. Significant grain refinement obtained by SPD leads to improvement of mechanical, microstructural and physical properties [5].

In the ECAP processing a sample is pressed through a die in which two channels of equal cross-section intersect at an angle ϕ and an additional angle ψ define the arc of curvature at the outer point of intersection of the two channels, as shown in figure 1.

Depending on the billet rotation, different deformation routes can be applied. Route A has no rotation of the billet, route BA is rotated counter clockwise 90° on even number of passes and clockwise 90° on odd number of passes, route BC is rotated counter clockwise 90° after every pass (see figure 2), and route C is rotated 180° after every pass [6].

This technique can be applied to commercial pure metals and metal alloys, with FCC, BCC and HCP crystal structures, with coarse grains to fabricate ultra-fine grained materials that have no porosity and higher strength than the non-processed material [7-10].

Most promising mechanical properties are obtained when ECAP route BC is applied. For this reason in this paper route BC was applied.

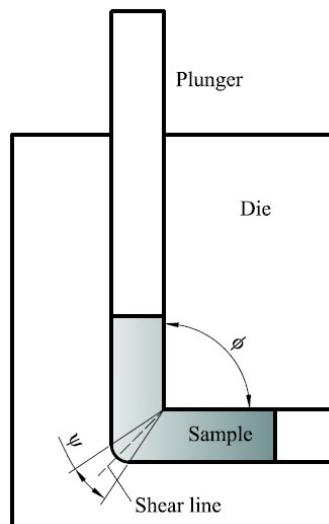


Fig. 1. Schematic illustration of ECAP process.

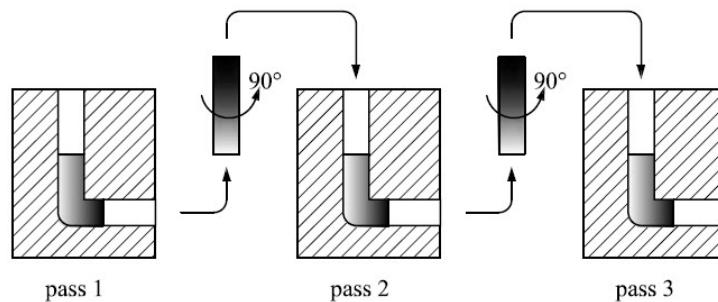


Fig. 2. ECAP route BC.

2. Experimental procedure

Material

A 6063-T1 aluminum alloy was investigated in this study. The chemical composition (wt%) of Al 6063 alloy used in the experiment was: Si 0.467, Mg 0.488, Fe 0.602, Cu 0.103, Mn 0.086, Zn 0.133, Ti 0.012, Ni < 0.02, Cr < 0.08, balance is Al.

The Al 6063 specimens were obtained from 100 cm round billets stock, obtained by casting, hot extruded and heat treated. The specimens were machined such that the specimen axis was perpendicular to the extrusion direction of the billets. The specimens machining for the ECAP processing were performed using an abrasive cutter METKON SERVOCUT M300. The samples size for the ECAP process was 60 x 9.8 x 9.8 mm.

Equal channel angular pressing procedures

The ECAP die had a channel angle $\phi = 90^\circ$ and a corner angle approximately $\psi = 20^\circ$ (Fig. 1). The accumulated equivalent strain values for each of these processes were calculated using the die-channel and relief angles in Eq. (1) [11]:

$$\varepsilon_N = N \cdot \frac{1}{\sqrt{3}} \left[2 \cot \left(\frac{\phi}{2} + \frac{\psi}{2} \right) + \psi \cosec \left(\frac{\phi}{2} + \frac{\psi}{2} \right) \right] \quad (1)$$

where N is the number of passes, ϕ is the channel angle and ψ is the corner angle.

According to Eq. (1) the equivalent strain depends on both ϕ and ψ angles. It decreases when ψ increases and the maximum ($\varepsilon_N \sim 1.15$) is obtained for $\phi = 90^\circ$ and ψ close to zero [12]. Eq. (1), proposed by Iwahashi et al. [11], is an analytical expression for calculating the equivalent strain imposed in each ECAP pass only in terms of die geometric parameters.

The assumptions in this geometric analysis include simple shear, a frictionless die surface, a uniform plastic flow on a plane, a complete filling of the die channel by the workpiece and a rigid perfectly plastic material (no strain hardening behaviour is included). With this assumptions, Eq. (1), doesn't take into account for the effect of friction, strain hardening, strain distribution and deformation gradient, providing a homogeneous value of strain in the whole workpiece.

For channel angle $\phi = 90^\circ$ and a corner angle approximately $\psi = 20^\circ$, the equivalent strain for each pass subjected to each specimen is about 1.05.

The specimens were pressed at room temperature for up to nine passes using a pressing speed of 10 mm/s and ECAP route BC.

Fracture surfaces analysis

For all processed specimens, samples were cut and mechanically tested in tensile tests. All samples were subject to fracture surfaces investigations, using a TESCAN VEGA II – XMU SEM microscope.

3. Results and Discussion

All results for all experiments are based on the current configuration of the specimen.

Equal channel angular pressing procedures

Using Eq. (1) the variation of accumulated equivalent strain was calculated for 1, 3, 6 and 9 ECAP processing passes. Figure 3 shows that the variation of accumulated equivalent strain is linear dependent on number of ECAP passes, the slope of variation is a function of ECAP die geometry, defined by ϕ the channel angle and ψ the corner angle.

Eq. (1), doesn't take into account for the effect of friction, strain hardening, strain distribution and deformation gradient.

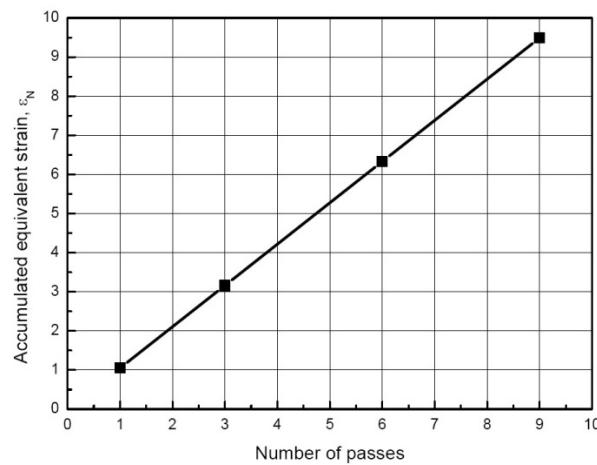


Fig. 3. Calculated accumulated equivalent strain evolution vs. number of passes.

Fracture surfaces analysis

SEM observations on fracture surfaces for all investigated samples are shown in figure 4 to figure 8.

In figure 4a and 4b one can observe that fracture surfaces show a ductile aspect, also can be observed the voids nucleated at grain boundaries, areas in which void growth and voids coalescence are presented. Final shear fracture with fibrous pullout can be observed, indicating plastic deformation before fracture.

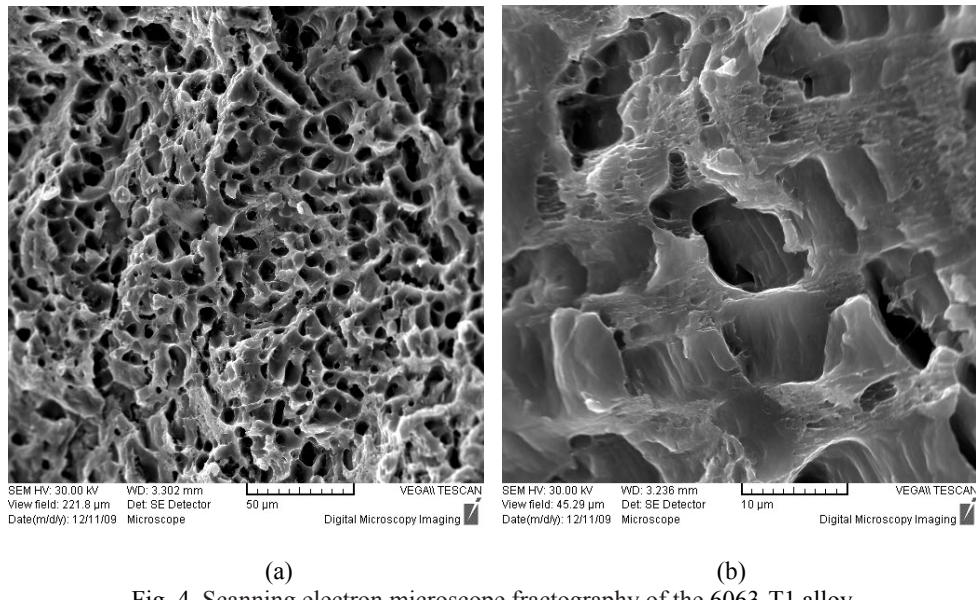


Fig. 4. Scanning electron microscope fractography of the 6063-T1 alloy

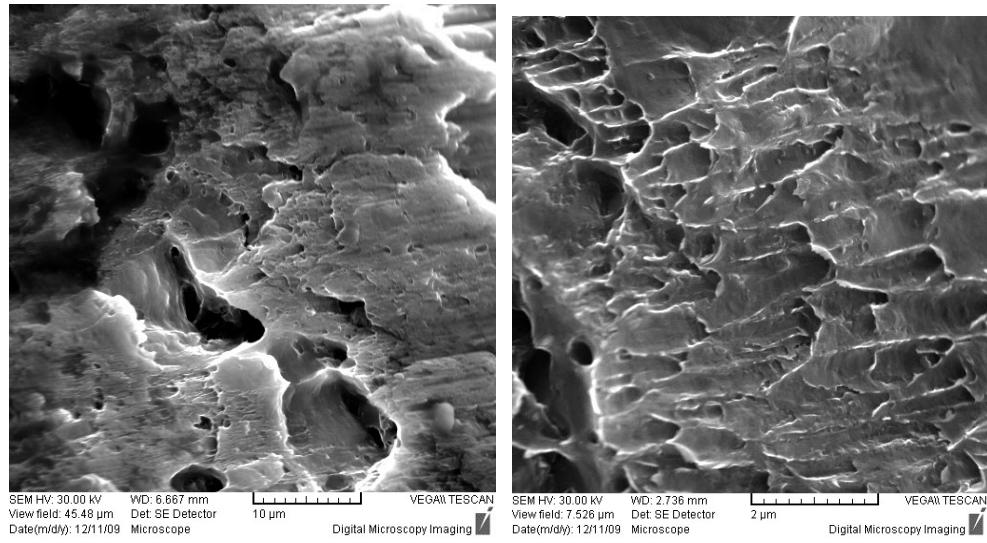


Fig. 5. Scanning electron microscope fractography of the ECAP material with 1 - pass

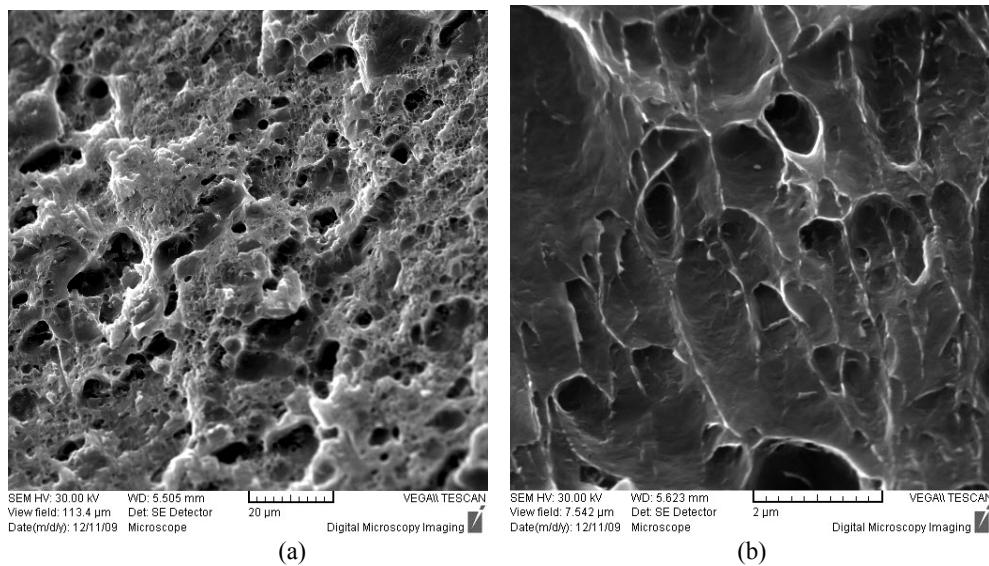


Fig. 6. Scanning electron microscope fractography of the ECAP material with 3 - passes

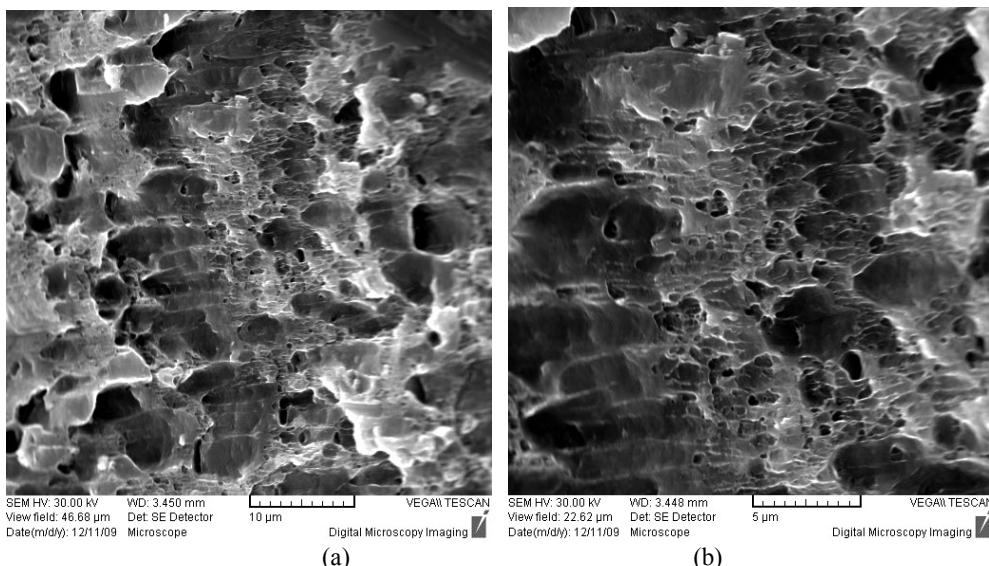


Fig. 7. Scanning electron microscope fractography of the ECAP material with 6 - passes

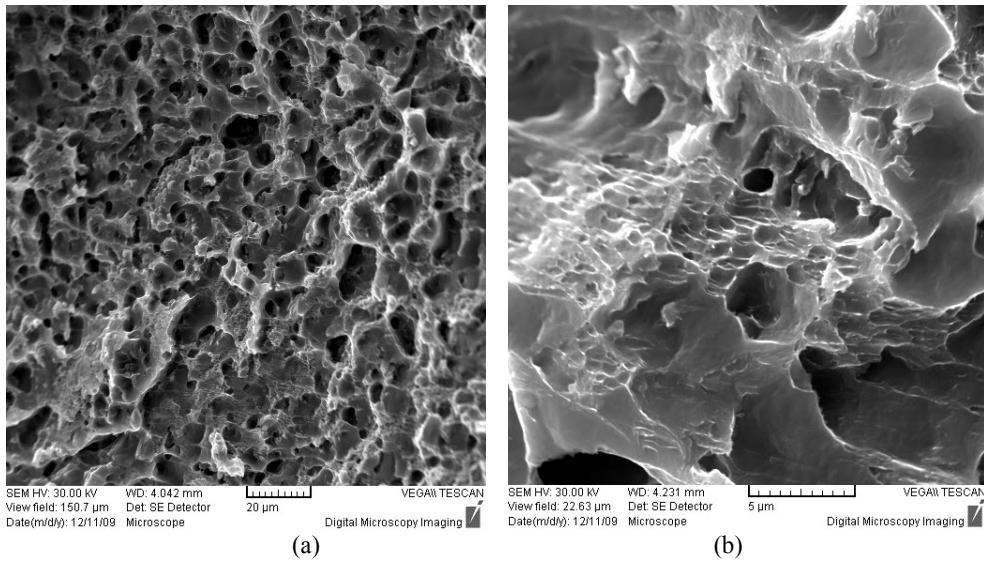


Fig. 8. Scanning electron microscope fractography of the ECAP material with 9 - passes

For one processing step using ECAP route BC, the fracture surfaces presented in figure 5a and 5b, shows a layered fracture surfaces due to the ECAP process. Observing the fracture surfaces, one can see fragile fracture aspects with large brittle fracture surfaces and a small fraction of voids. Internal brittle cleavage fracture occurs in materials because of the high strain-hardening rate and low cleavage strength resulted during ECAP process

After three ECAP passes using BC route, the fracture surfaces presented in figure 6a and 6b, shows that the layered fracture surfaces are no longer present. Also, in this case, the fracture surfaces show a fragile aspect with large brittle fracture surfaces and a fraction of voids bigger than in the case of one ECAP pass.

After six ECAP passes using BC route, the fracture surfaces presented in figure 7a and 7b, show fragile fracture surfaces with a large fraction of voids, also fibrous pullouts surfaces are identified.

For nine ECAP passes using BC route, one can observe that the fracture surfaces presented in figure 8a and 8b, show fragile fracture surfaces with a large fraction of voids and interconnected voids. The percentage of fibrous pullouts surfaces is higher than in the case of six ECAP passes. Also, interconnected cracks are observed.

5. Conclusions

In this study, the fracture surfaces for Aluminum 6063-T1 alloy subjected to the ECAP process were investigated and compared to the Aluminum 6063-T1 alloy with no ECAP processing.

It was determined that for no ECAP processing, the fracture surfaces show a ductile aspect, with voids nucleated at grain boundaries; areas in which void growth and voids coalescence are present were also observed.

For ECAP processed samples, the fracture surfaces show a fragile aspect, with large brittle areas. Internal brittle cleavage fracture occurs in materials because of the high strain-hardening rate and low cleavage strength resulted during ECAP process. Increasing the number of ECAP passes the fraction of presented voids increases. After six passes, fibrous pullouts surfaces are identified, increasing the number of passes the percentage of fibrous pullouts surfaces increases.

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