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SEVERE PLASTIC DEFORMED PURE ALUMINUM BY EQUAL CHANNEL ANGULAR PRESSING

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ABSTARCT

Samples of an aluminum alloy were subjected to an equal channel angular pressing (ECAP) at room temperature for one pass. For the several specimens severe plastic deformation process was interrupted to observe the material flow. Also are studied the force variation in SPD process and hardness in different zones of the deformed sample.

KEYWORDS: Severe Plastic Deformation (SPD), Equal Channel Angular Pressing (ECAP), grain refinement

1. Introduction

Mechanical behavior of a material is dependent on the microstructure of the material. Refinement of grain size is increasing yield stress.

That was confirmed by many experimental results, meaning that mechanical behavior of a metal may be different if its grain size changes. In order to improve properties of metal many methods on how grain size changes were studied. Severe plastic deformation (SPD) was defined as a metal forming process in which an ultra large plastic strain is introduced into a bulk metal in order to create ultra fine grained metals [1,2].

In the conventional metal forming process as such rolling, forging and extrusion, the imposed plastic strain is generally less about (2.0). When multi pass rolling, drawing and extrusion are carried out up to a plastic strain greater than 2, the thickness and the diameter became very thin and is not suitable to be used for structural parts.

In order to impose an extremely large strain on the bulk metal without changing the shape, many SPD processes, have been developed.

Various SPD processes such as equal channel angular extrusion or pressing (ECAE, ECAP) [3], high pressure torsion (HPT) [4], accumulated roll bonding (ARB) [5], repetitive corrungation and straitening (RCS) [6], cycling extrusion compression (CEC) [7] have been developed. Now it is well established, ECAP is the most well known processing method among the groups of severe plastic deformation methods.

ECAP can be performed on a single specimen repeatedly because the specimen's cross section shape does no change after ECAP and through repeated ECAP.

2. Experimental procedure

The study was carried out on a commercial aluminum alloy (Al-0.25%Fe-0.15%Si in wt. with further minor impurities) supplied in 5 mm rolled plate. From this plate two half billets of 5mm x 10mm x 40mm were cut. One of the billets was engraved with grids of 1mm x 5mm by scratching on a universal mill. For a better observation of metal flow the surface engraved was painted. The other was free of grids. Then the two half billets were SPD together.

Specimens were lubricated with a suspension of graphite powder in mineral oil in order to reduce the friction between the samples and die. Then the billets were pressed in an equal channel angular die. In any part of the die the cross section are 10mm x 10mm and are not smaller than the initial cross section of the die. The channels inner intersection angle is 90^0 and ψ, the outer curved corner of the die is 10^0. In Figure 1 is shown the ECAP die and the plunger.

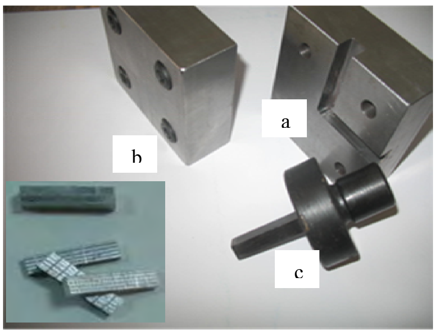

Fig.1. *The ECAP die and aluminum specimens a. body die, b. die cover, c. plunger*

The die was assembled with four screws. Then a careful alignment of the plunger and the vertical channel of the die were carried out. The necessary force for SPD process was provided with a 200 kN force hydraulic press

Fig.2. *The20 tones force hydraulic press and the equipment for force measuring*

Force measuring was performed with a Hotttinger Spider 8 device using a home made sensor designed for this peculiar application. The tensometric sensor was calibrated under very precise force system. The calibration lines for loading and unloading are closer in fact to a single trace (fig. 3). The sensor constant (slope) is 176927.

After one pass of ECAP a new specimen was put in the die to push out the first specimen. The ECAP process was conducted at room temperature. In this conditions ECAP process became a semi continuous deformation process capable to produce a large quantity of fine grained metal.

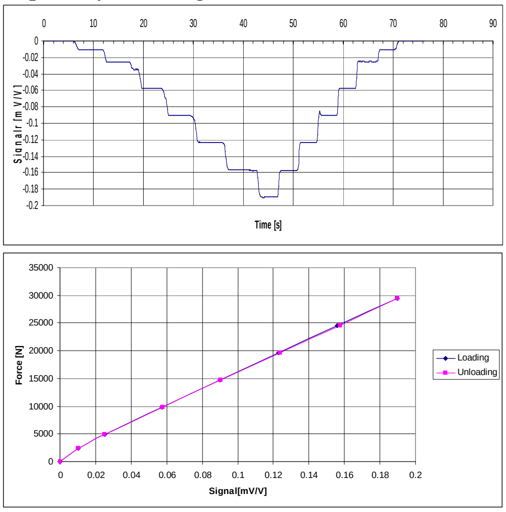

Fig.3. *Sensor calibration*

3. Results and discussions

3.1. Material flow

The overall rid deformation patterns of aluminum samples after one ECAP pass using the designed die with ϕ is 90^0 and ψ 10^0 are shown in figure 4.

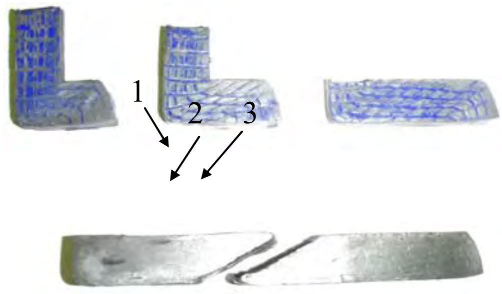

Fig.4. *Grid deformation patterns of Al after one ECAP pass*

It is clear that a uniform shear deformation occurs. Also we observe that the top of sample zone in contact with plunger and the end sample zone show an inhomogeneous flow.

3.2. Estimation of strain in designed ECAP die

The total strain is composed of three terms: e_d, e_{Si}, e_{Se}

$$\varepsilon_{total} = \varepsilon_d + \varepsilon_{Si} + \varepsilon_{Se}$$

were :e_d- strain in deformation zone, e_{Si}- strain on the entry surface of the deformation zone, e_{Se}-strain on the exit surface of the deformation zone [8]

We'll find:

$$\varepsilon_d = \frac{\Psi}{\sqrt{3}}$$

$$\bar{\varepsilon}_{si} = \bar{\varepsilon}_{se} = \frac{1}{\sqrt{3}} ctg\left(\frac{\Phi + \Psi}{2}\right)$$

And total strain:

$$\varepsilon_{total} = \frac{1}{\sqrt{3}}\left[2ctg\left(\frac{\Phi + \Psi}{2}\right) + \Psi\right]$$

Considering values for □= 90^0 and ψ=10^0

we will find $\varepsilon_d = \frac{\Psi}{\sqrt{3}}$ = 5.773,

$$\bar{\varepsilon}_{si} = \bar{\varepsilon}_{se} = \frac{1}{\sqrt{3}} ctg\left(\frac{\Phi + \Psi}{2}\right) = 0.484 \text{ and}$$

$$\varepsilon_{total} = \frac{1}{\sqrt{3}}\left[2ctg\left(\frac{\Phi + \Psi}{2}\right) + \Psi\right] = 6.74$$

3.3. Force variation

The force versus punch displacement is shown in figure 5.

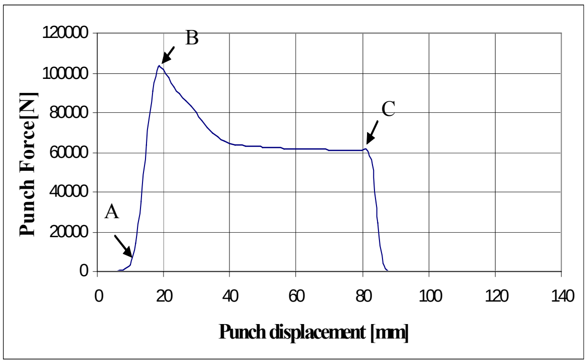

Fig.5. *Punch force-displacement curve*

Referring to this figure the extrusion pressure increase is due to the initial easy movement of the specimen in the die (A). Then the rate increase in pressure intensifies (A to B) until the pressure reaches a local maximum (B) after which it reach as point C.

Peck punch force indicates the force required for the start of extrusion, and is the most important factor to be considered in designing an ECAP die [13]

The reason of this behavior is the restriction of the next channel of the die that leads to forging of the billet.

3.4. Hardness of ECAP processed aluminum

The hardness HV_5 of received material and ECAP processed is shown in table 1. The hardness test was made on the named zones 1, 2 and 3 (fig. 4)

Aluminum as received		d_1	d_2	d_{med}	HV [MPa]
		0.299	0.298	0.2985	104.05
SPD processed	1	0.288	0.284	0.286	113.35
	2	0.284	0.278	0.281	117.41
	3	0.265	0.265	0.265	132.02

A significant increase of the hardness is observed on share zone of one pass aluminum severely plastically deformed.

4. Conclusions

(1) An ECAP die with ϕ =90^0 and ψ =10^0, was designed and machined.

(2) A study of metal flow in ECAP process using this die was developed. The study reveals that the shear deformation is not found only on the end of the sample and on the contact surface of the billet with the punch.

(3) The force variation in ECAP of aluminum billet points out a peck around 100kN respectively the pressure determined on 10mm x 10mm cross surface around 1 GPa.

(4) The significant hardness is observed on the shear zone because of grain refinement.

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