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A Review on Plastic Deformation in Equal Channel Angular Pressing

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ABSTRACT

Because of its potential to produce ultra fine grains Equal Channel Angular Pressing (ECAP) is widely being used now a day in almost all manufacturing sector. The physical and mechanical properties have been increasingly recognized by ECAP. In all most all manufacturing processes, with the help of plastic deformation the required shape and size are obtained for example ,sometimes products its self will be deformed through rolling, extrusion, drawing etc, and by another deforming process called the metal removal through grinding, milling and cutting operation. In these processes, load is applied on the material and the processes are continued till they get the required strain or grain refinement but it is not possible in conventional deformation. But in this sever plastic deformation process (SPD), we choose the channel angle of either 60º,90º, 112.5º, 120º, 135º and so on, that depends upon the type of material and if you are using composite material than the reinforcing particle will play an important role. There are 4 types of routes or process used in (SPD) are as follows Route A, Route $B_{C,}$ Route B_A, Route C. In this paper we will discuss about the effect of all these channel angles (few of them) about their strain rate grain refinement etc. Along with these, we will also discuss regarding the microstructures of SPD processed samples with as cast samples.

Keywords: *Equal Channel Angular Pressing, channel angle, Types of routes, Grain Refinement, strain rate, microstructures.*

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1. INTRODUCTION

The Equal Channel angular Extrusion (ECAE) was invented by Vladimir Segal in 1977 and this process is also called as (ECAP) Equal Channel Angular pressing in later stages. It is an innovative method for inducing large plastic deformation to the materials without changing the size or general shape or dimensions of the billet. Here we are using a two split dies of equal cross-section, intersecting to form a ‘sharp’ corner. Deformation occurs at the die corner ie at the bent portions as the billet is pressed. If the billet or work piece is punched through the die, the process is called ECAE also be called as ECAP and if the specimen is drawn through the die, then the process will be ECAD (Equal Channel Angular Drawing). Out of the above two process ECAE or ECAP and ECAD better one is ECAP. Based on the angle of intersection of the die channels the effective strain per pass is dependent and it is also depends on the fillet radius also but it's negligible. By using ECAE or ECAP which uses uniform plastic deformation, there is an increase in material strength, and ultrafine equiaxed grains (UFG) are produced.

Refinement of the grains through SPD is one of the techniques, which provides finer grains and also enhance the properties like ultrahigh strength and combination demanded to enhance ductility for ambient and cryogenic temperature applications. On the other hand, for producing bulk ultrafine grained (submicron or nanostructure) metals sever plastic deformation (SPD) is an effective tool. Equal channel angular pressing (ECAP or ECAE) is one of the best SPD techniques is also developed for producing ultra fine grain structures in submicron level by introducing a large amount of shear strain into the materials without changing the billet shape or dimensions [13]. Besides that, people studied the influence of various types die structure and extruded materials on the effect of refining crystal, and found that with the die structures the effect of extrusion was different, especially the included angle of channels, ø, the die outer corner angle, ψ, and the radius of outer angle, *R* [18].

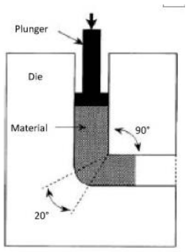

Fig.1 Shows the Schematic Diagram of ECAP Process.
Source: Zhang et al. (2008)

Various Parameters that have been used in the course of carrying out experiments are as follows:

1. Temperatures are ranging from –200ºC to 1330ºC also even more depending on the test material. Corners angles of 90º and 120ºare more common. 60ºand 135º have also been reported and many more corner angles have been reported. Different corner angles provide varied amount of strains per each pass.

2. Between the successive extrusions or passes there is a change in the orientation of the billet. To do equal channel angular pressing routes to be followed are as follows. Routes A, B, C, and D or A, B_A, C and B_C respectively. These are the routes to be followed by many researchers and they have been accepted universally as well.

3. Dies for ECAP either may be circular or square cross sectional may be used but in some of the journals they have used circular and squares, while doing analysis circular cross section gives better results during analysis using ABAQUS tools by many researchers I have read.

1.1Aluminum and Aluminum Alloys: Aluminum alloys are alloys in which the predominant metal will be aluminum (Al). The alloying elements copper, magnesium, manganese, silicon, tin and zinc. There are two types of aluminum classified as follows, namely casting alloys and wrought alloys, both of which are further subdivided into the heat-treatable and non-heat-treatable about 85% of aluminum is used for wrought products, for example in all most all conventional manufacturing process like rolling extrusion etc . Cast aluminum alloys yield cost-effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys. Alloys composed mostly of aluminum have been very important in aerospace manufacturing since the introduction of metal-skinned aircraft.

Non-Heat Treatable Aluminum Alloys: Alloying the aluminum with other elements the characteristic strength of non-heat treatable aluminum alloys is initially created. Different types of aluminum alloy consist are as follows. They are (1xxx series), manganese alloys (3xxx series), silicon alloys (4xxx series) and magnesium alloys (5xxx series). The alloys are further strengthened by using heat treatment process like strain hardening and various degrees of cold working.

Heat-Treatable Aluminum Alloys: The commercial heat-treatable alloys are having some exceptions, with respect to the solutes involved in developing strength by precipitation based on ternary or quaternary systems are used. By heat treatment process the strength and hardness can be significantly increased, alloys are as follows 2xxx, 6xxx, and 7xxx series wrought alloys and 2xx.0, 3xx.0 and 7xx.0 series casting alloys.

In the heat-treatable wrought alloys, with some notable exceptions (2024, 2219, and 7178), such solute elements are present in amounts of mutual solid solubility are within the limits at a temperatures below the eutectic temperature (lowest melting temperature).

1.2 CHARACTERISTICS OF DIE GEOMETRY: The Channel angle or the corner angle will vary from 60° to 150°, this will influence strain homogeneity on the material. The greater strain homogeneity obtained in an angle closer to 90° compared

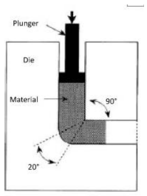

Fig.2 ECAP with Channel Angle 90°
Source: Zhang et al. (2008)

To all other channel angle while keeping the outer corner angle as 0º,5º,10º,15º etc [9]. Fig 2 illustrates the above condition.

It can be understood that the deformation behavior is more complicated with channel angles ø < 90°, and becomes smooth with channel angles ø > 90°.

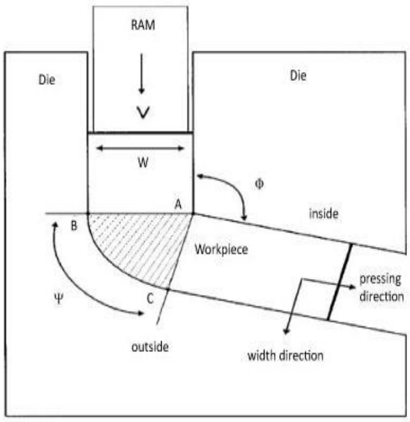

Fig. 3 shows ECAP with Channel Angle 'ø' greater than 90
Source: Yoon et al. (2007)

There is a less sheared zones are formed in non-strain hardening materials of the round corner die conditions and in strain hardening materials the deformed geometry was predicted to be almost independent of the die corner angle as told by the many researchers. The optimum die corner angle among the conditions in this study is ψ is equal to 0°-30°, which may enhance the homogeneity of strain of severely plastic deformed work pieces during ECAP. When the die corner angle is zero, strain rate is relatively homogeneous within the deforming zones along the line AB will be high compared to the cases of the round corner dies, in which the strain rates are locally high in the inner corner region i.e. (near A) and gradually decrease with the distance from the inner corner point A towards the point B. and There is a less sheared zone in the round corner ECAP process due to the shorter length of the die outer part is > 0° than in the case of sharp corner (= 0°). It should also be noted that the round die corner not only reduces the overall shear deformation but also intensify the strain in homogeneity [17].

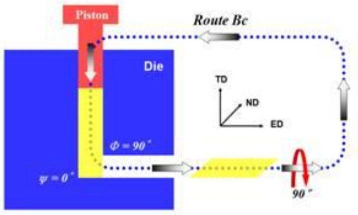

Fig. 4 shows ECAP with Corner Angle 'ψ' is 0° & ϕ=90º.

Channel has an inner angle of 120° and an outer angle of 60°. This makes the design easier to extrude the sample or material through this channel and in each pass a large imposed plastic strain can be obtained. During ECAP, the deformation of sample is non-uniform. The deformation area in the middle of the sample or billet is close to pure shear and the bottom portions are not subjected to pure shear [18].

Since the strain imposed in ECAP increases with decreasing channel angle (below 90º), it may be advantageous to perform the pressings using channel angles which are less than 90°. Where, High pressures are required to successfully produce billets without the introduction of any crack [10].

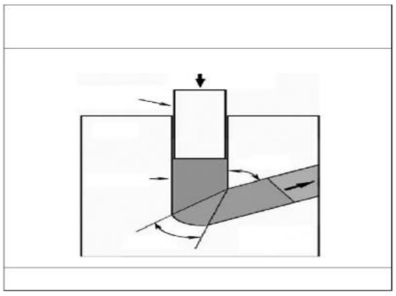

Fig. 5 shows ECAP with Channel Angle 'ø' less than 90°.
Source: Ruslan et al. (2006)

1.3 CHARACTERISTICS OF PROCESSING ROUTES: Processing routes mean the directions followed by the billet or test sample. ROUTE A (0°), all passes; the billet is not rotated between successive passes. ROUTE B or B_A: (90°), N even, (270°) N odd; the billet is rotated (90°) clockwise and counterclockwise alternatively. ROUTE C: (180°), all passes; the billet is rotated (180°). ROUTE D or B_C: (90°), all passes; the billet is rotated (90°) clockwise [11] is explained in the below fig.

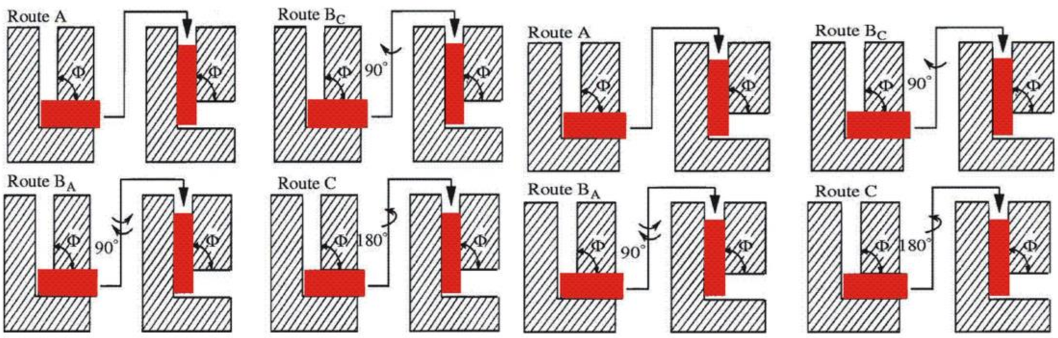

Fig. 6: Processing Routes in ECAP
Source: Samuel (2011)

For Al6082 alloy processed through route C, The dislocation density and the sub grain size reached their maximum and minimum values, respectively, even after 1 pass. The yield strength increases monotonously even after the saturation of the dislocation densities and the grain size indicating that the more equilibrated high angle grain boundaries have higher strengthening effect than the non-equilibrium boundary structures [12].

A commercial 6082 aluminum alloy at pre-described conditions was subjected to ECAP at elevated temperature 150 °C using route B_C through 120° channel angle. The grain orientation distribution reached the random case of dislocation density and the sub grain size [15].

For Al6082 alloy processed through route A, There is an increase of the yield stress of the alloy by the increase of the dislocation density and grain size is decreased [5].

During the processing of 6082 aluminum alloy, the maximum absolute value for yield stress was reached by route B_C, the minimal value by route C.

For the area reduction after fourth pass, for route B_C the tendency to decrease and for B_A shows gain after eighth pass. For the elongation, route C tendency to increase and for B_C, B_A has tendency to decrease. The phenomenon of high ductility along with high strength was revealed for Al6082 after eight passes of ECAP for route C.

For purity Al (99.999%), Ultimate tensile strength in dependence on ECAP passes through route C with channel angle 90°.

Pure Aluminum processed through route C, the dead zone subtended by the work piece is independent of its geometry, whereas the load-displacement curve is dependent on the work piece geometry.

A uniform and stable plastic strain distribution in the material after every even (2, 4, 6) pass can be attained.

The rate of increase in load required to extrude the work piece decreases with increasing number of ECAP passes [7]. Commercial purity aluminum 1050 processed through route B_C and C. the higher yield strength values for route B_C, though the equivalent strain achieved in both the routes are same. Route C the average grain size relatively increased and the misorientation angle relatively decreased after the compression deformation, even the percentage area with grains less than 1 m size decreased after compression, and finally the percentage of boundaries having high angle boundaries also decreased after the compression deformation [4].

2. CONCLUSIONS

Various materials have been tested over the years using ECAE. These materials include metals, composites, polymers and ceramics. There has been reported significant occurrence of super plastic flow in materials after ECAP. Nano-grained materials of grain size less than 1µm have been produced with the use of ECAE. Most interesting is the one reported by Berbon et al., 1999 where refinement occurred from 500 µm to 0.6 µm after four passes through a 90º die for an Al-1%Mg alloy. The various routes have been found to be of significant importance in the properties of the ECAPed products. It has been concluded that a microstructure of equiaxed grains separated by high angle boundaries is a prerequisite for achieving high tensile ductility's and this is attained most readily when processing using route B_C. Severe plastic deformation induced by equal channel angle pressing is capable of producing significant grain refinement. To obtain high strain rate super plasticity. Uniform and unidirectional deformations can be produced under relatively low pressure and load for massive products Production of Ultrafine-equiaxed Grained (UFG) materials has been achieved, e.g., grain size less than 1 µm. The crystallite size decreased and the dislocation density increased as a result of ECAP deformation.

The higher strain hardening of the ECAPed samples during simple compression in the initial part of the deformation is due to the refined structure and the relatively high boundaries misorientation.

Compacted powder has been found to increase in density up till about the fourth pass for Al85Ni10Y2.5La2.5. The relation between strain in homogeneity and die geometry has been recognized. High strength and high ductility phenomenon can be obtained.

Loading conditions can be predicted. Significant increase in micro hardness is obtained after the first pressing through the ECAP dies. Leads to minimize the development time and cost.

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