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FINITE ELEMENT INVESTIGATION OF EQUAL CHANNEL ANGULAR PRESSING (ECAP)

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ABSTRACT
Equal channel angular pressing or extrusion (ECAP) has great potential for developing ultrafine grain structure consisting of homogeneous and equiaxed grains dominated by high angle grain boundaries. In addition the ECAE (equal channel angular extrusion) processed specimens retain their original cross-section, providing capabilities of multi-passing. However the process is discontinuous as the length of the billet is limited due to potential buckling of the extruding ram [1]. For that purpose we are doing the design and analysis of ECAP process by using ABAQUS/explicit solver for various die angles. The main aim of our project is to find the angle at which the maximum strain rates obtained for sever plastic deformation (SPD). To overcome these situations, the study of the angle is required at which it give more strain rate. By creating a die with appropriate angle will provide us good deformation results.

Keywords- *SPD, ECAP, ECAE, FEM, ABAQUS.*

I. INTRODUCTION
The manufacturing and processing of ultra-fine grained and nano crystalline materials have attracted growing scientific and industrial interest in the last decade as a result of the novel and attractive properties of these materials. Ploy-crystalline materials can be classified as nano grain size is in the range 100nm-500nm, as fine grained if grain size is in the range 0.5µm -10µm, and coarse grained if grain size is greater than 10µ. These ultra-fine grained and nano crystalline materials have mechanical properties that include extraordinarily high yield strength, high hardness, improved toughness and ductility with increasing strain rate 1,2,3,4. These materials have been found to exhibit very different microstructure and mechanical behaviors from their conventional coarse grained polycrystalline counterparts, namely ultra-fine grained materials have enhanced super plasticity deformation at low and high strain rate.

Sever plastic deformation is a generic term describing a group of metal working techniques that involve using extreme plastic straining to produce materials by imposing very high shear deformation on the material under superimposed hydrostatic pressure. Sever plastic deformation leads to exceptional grain refinement of the material without introducing any significant changes in the overall dimensions of the specimen or work piece. The development of the principles underlying sever plastic deformation techniques is attributed to the pioneering work of P W Bridgman at Harvard University, which took place in the 1930s. The main objective of sever plastic deformation process is to produce very strong and light weight parts that are use full in every situation. The two most commonly used sever plastic deformation methods – Equal channel angular pressing (ECAP) and High pressure torsion (HPT) were developed to fabricate and process of ultra fine grained materials to better understand the properties of materials in order to design a material with superior performance.

The equal channel angular pressing technique is the more attractive technique because it offers the potential for high strain rate super plasticity by effective grain refinement from macro grained structures to the level of submicron or nanoscale through a special die. This ECAP process was originated by V M segal and colleagues in the 1980s. Their objective when designing the process at the time was to develop a metal forming process with a high strain rate. Since then the process has undergone much modification and modernization in the design of the die, the processing routes and the use of others experimental parameters. Many researchers around the world are continually developing a range of nanostructure materials with exceptionally favorable properties.

The processing of materials by ECAP has undergone active development in several areas. These areas include the development of many different nanoscale metal and alloys and the commercial production of semi-finished products within ultra-fine grained structures using a wide range of metals and alloys [7]. The application of ECAP procedure is currently under investigation for many different materials ranging from aluminum, copper, magnesium and nickel alloy to eutectic and eutectoid alloys and inter-metallic materials.

The aim of this study was to produce ultra-fine grained materials using the ECAP technique, and to examine the micro structural, mechanical and hardness properties of the materials produced. We have also summarized recent articles and new trends in the design of the ECAP die and processing parameters. The applications of the ECAP technique in the manufacturing industry are also discussed.

ECAP (Equal Channel Angular Processing)

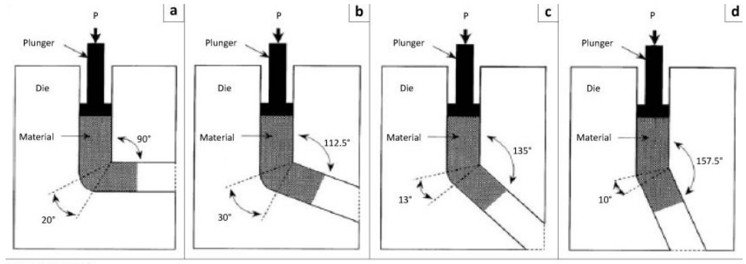
The ECAP die is composed of Two channels with identical cross sections connected through the intersection at a specific angle, usually 90º, 112.5º, 135º and so on [8,9,1011]. The cross section can also be either circular of square. The work piece is machined to fit within the channel and extruded through two intersecting channels with the same cross section using a plunger. (Fig 1) During the ECAP process, adequate lubrication is essential because of frictional influences, tool wear and the loads necessary for plastic deformation. One important advantage of the ECAP process is that it can be passed through the die n number of times without changing the cross section of the work piece, and applied strains can be increased to any level. Factors that influence grain refinement in ECAP are as follows

1) Channel and curvature angles of the die
2) Processing routes

The channel angle is the most significant experimental factor that affects grain refinement because it dictates the total strain imposed in each pass. Most of the experimental work reported to date used channel angles are from 60º - 155º and there has been little or no attempt to compare the results obtained when using dies with different channel angles. Despite the efficiency of the ECAP process with dies that have channel angles greater than 90º can be easily pressed compared to the of 90º channel angle.[Fig 1]

Processing routes plays a vital role in the grain refinement of the samples, by changing the orientation of the specimen between successive presses, complex microstructures and textures can be developed. For attaining profound grain refinement, the development of optimal routes for microstructure control, by changing the orientation after each pass is critical. Three fundamental ECAP routes are defined and utilized to obtain different textures and microstructures. [Fig 2]

1) Route A is when the orientation of the specimen remains unchanged after each pass.
2) Route B is when the specimen is rotated 90º around its longitudinal axis after each pass. If the rotation is always performed in the same direction, it is called Route B_A , and if the rotation direction is alternated between counter clockwise and clockwise, it is called route B_C .
3) Route C is when the specimen is rotated 180º around its axis after each pass as shown in the Fig 2.



Source: Iwahashi et al.[7]

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Figure 1: Shows various channel angles of ECAP

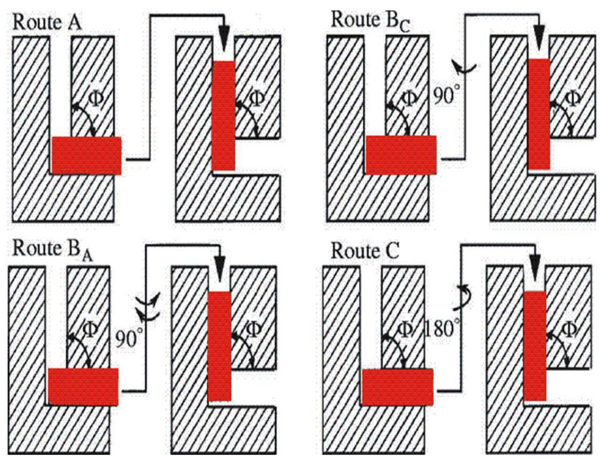

Fig 2: Shows the four fundamental processing routes used in ECAP process

About Abaqus software: Abaqus is a suite of powerful engineering simulation programs based on the finite element method. The unique future of Abaqus include

1) Abaqus contains an extensive library of elements that can model virtually any geometry as well as the analysis.

2) Using Abaqus, you should be able to use various material models to simulate the behavior of most typical engineering materials including metals, rubber, polymers, composites, reinforced concrete, crushable and resilient foams and geotechnical materials such as soils and rocks etc

3) Designed as a general-purpose simulation tool, Abaqus can be used to study more than just structural (stress/displacement) problems. It can simulate problems in such diverse areas as heat transfer, mass diffusion, thermal management of electrical components (coupled thermal-electrical analysis), acoustics, soil mechanics (coupled pore fluid-stress analysis) and piezoelectric analysis.

4) Abaqus offers a wide range of capabilities for simulation of linear and nonlinear applications. Problems with multiple components are modeled by associating the geometry defining each component with the appropriate material models and specifying component interactions. In a nonlinear analysis Abaqus automatically chooses appropriate load increments and convergence tolerances and continually adjusts them during the analysis to ensure that an accurate solution is obtained efficiently. And also you can perform static as well as dynamic analysis

II. METHODOLOGY & MATERIALS

For the FEM analysis by using ABAQUS software we developed the models with different channel angles such as 90º, 120º, 135º, 155º. By using ABAQUS software we have to create a part

1) Billet

2) Die

3) Plunger

Billet: For creating the billet part using the parameters from the dialogue box opened on part as the deformable element 2D plane and select the shell type and approximation of the work space as 200. Then start

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designing the billet with dimension as 45mm length and width as 13.3mm then the billet part is created in both 2D and 3D as shown in the below Fig 3.

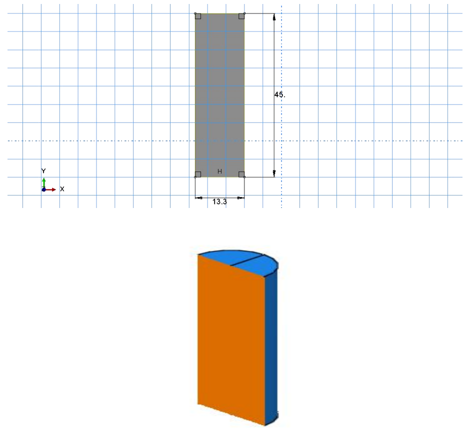
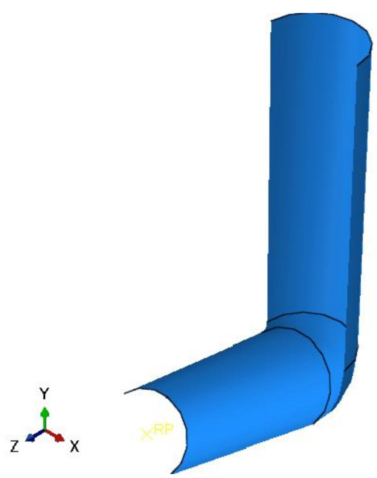


Fig 3: Shows the billet part both 2D and 3D

Die: After completing billet part start constructing die part. Here we have to make 2 parts as the same dimension. From the dialogue box opened after selecting create part select the parameters required such as discrete rigid element from 2D plane and select wire type and give the work space approximation as 200. The die has two sections one is above the angle and other is below the angle. The section above angle is 45mm in dimension and below the angle is 42mm in dimension. And angles between these 2 sections are given by 90º,120º,135º, and 155º for different channel angles were modeled by using Abaqus software and shown in the below Fig 4 for channel angle 120º.



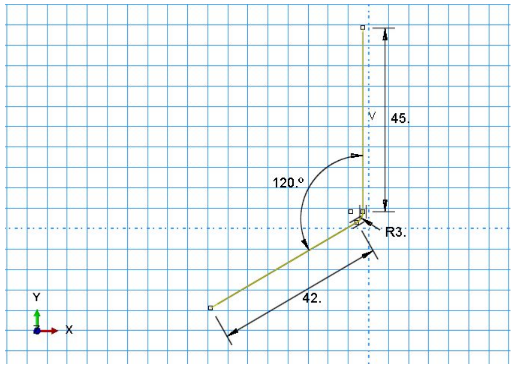


Fig 4: shows 2D and 3D creation of die

Plunger: Coming to the final part of the model that is the plunger has to be designed. It has the same procedure as followed to create die but in this case dimension will be different and also the structure too. The plunger has dimensioned 10mm length and 13.27mm width and radius of 0.5mm. As shown in below Fig 5.

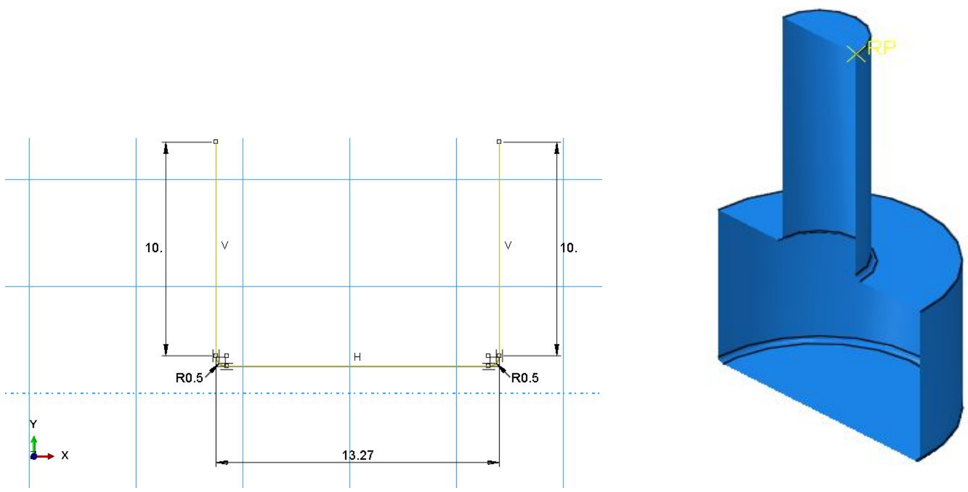


Fig 5: shows 2D and 3D of the plunger part created

Creation of material properties:

After creating the parts we have to assign properties to the parts. But here we only needed to give property for billet because other parts are rigid and only billet part will undergo deformation the properties such as density, elasticity, plasticity, of the material are assign here for aluminum material.

Elastic data

Density 2.7g/cm^3
Young's Modulus: E= 69000 MPa
Poisson's Ratio= 0.33

Plastic data to be incorporated in to the Abaqus software

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	Yield Stress	Plastic Strain
1	60	0
2	90	0.125
3	113	0.25
4	124	0.375
5	133	0.5
6	165	1
7	166	2

Creation of mesh: Mesh generation is the practice of generating a polyhedral mesh that approximates a geometric domain. The term grid generation is often used interchangeably as shown in the below Fig 6.

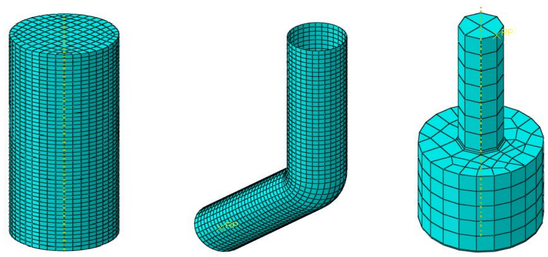

Fig 6: shows the meshed geometry of plunger billet and die

Creation of load and boundary condition: Here we are making die as the stationary part and extrusion of the billet has been done through die cavity. For the extrusion of the billet we applied force or load on the plunger and the plunger is placed over the billet. We have given the boundary condition between the die and billet for the flow of the billet through the die cavity. Also we have given the boundary condition between the plunger and the billet for the transferring of the force or load from the plunger to the billet properly as shown in the below Fig 7.

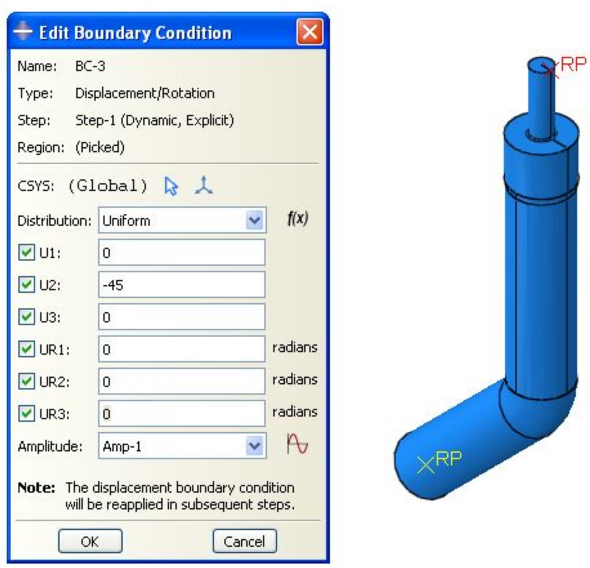

Fig 7: shows the boundary condition applied for the plunger and the billet

III. RESULT & DISCUSSION

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In this we have find the stress and strains for all the channel angles as mentioned above. And we have plotted the stress and strains in this and we have found that which channel angle gives better shear stress among those channel angles as shown in the below Fig 8.

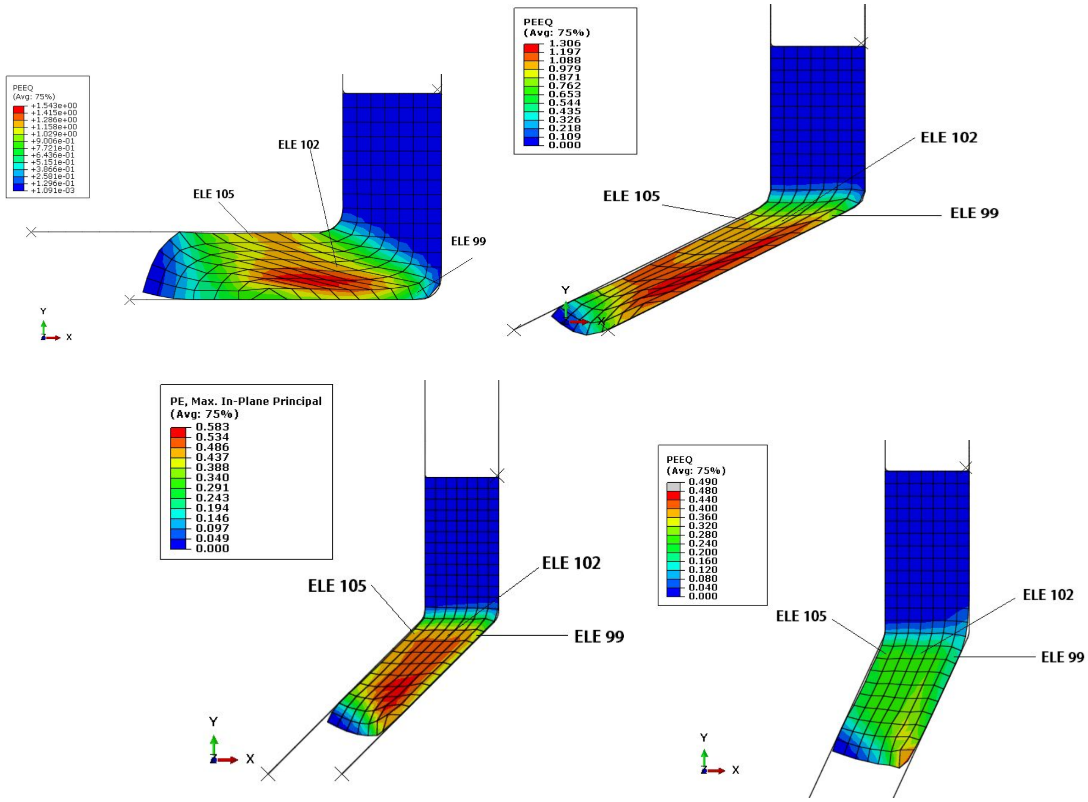
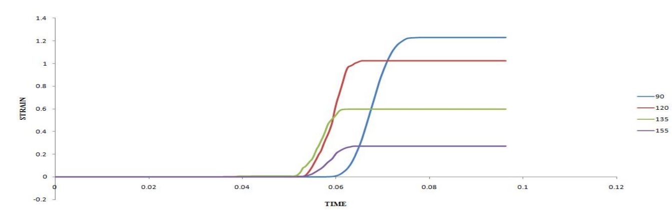


Fig 8: Shows that the shear stresses along the curvature for all channel angles

As shown in the above fig 8 shear stress is more in 90 º compared to the other channel angles.

IV. CONCLUSION



Graph 1: shows strain vs time (for different angles)

From the above graph we have been conducted the analysis on different angles such as 90º, 120º, 135º and 155º. From these angles we have concluded that 90º is having maximum shear strain. By the above single graph we can easily conclude that angle 90º gives more strain rate than the other angles, so by constructing an ECAP die with channel angle of 90º give more strains compared to other channel angle as listed above.

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