Finite Element Analysis of Equal Channel Angular Pressing Die

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***Abstract*— It is well known that large deformation results in microstructures with small grains and extensive dislocation cells development, often leading to corresponding increases in strength. Many limitations associated with the conventional metal deformation techniques can be overcome by ECAE, a method was developed and patented in the former Soviet Union. The benefits of ECAE come from its ability to impose intense simple shear deformation through innovative die design. Unlike conventional extrusion processes, the cross-section of billets extruded via ECAE is not reduced. This process, therefore, can be applied repeatedly through multi-pass operations to achieve strains of significant magnitudes while preserving the billet size.**

Keywords*— Equal Channel Angular Pressing (ECAP), Severe Plastic Deformation (SPD)

I. INTRODUCTION

Because of the widespread use of these alloys, it is important to understand their mechanical behavior when exposed to different loading conditions, strain rates and temperatures, and to be able to model the behavior and later, to predict the behavior for any of these conditions. In order to improve mechanical properties of these alloys many processing routes can be applied.

Materials processing by severe plastic deformation (SPD) have received vast focus in the research community the last five to ten years due to the unique physical and mechanical properties obtainable by SPD processing. The process of SPD is based on intense plastic deformation of a work piece, resulting in alteration of the microstructure and texture, in principal reduction of the grain size to the sub- micron or the nanometer scale. The most common process of SPD is the equal channel angular pressing (ECAP), which involves pressing a billet through a die consisting of two channels of equal cross sections, intersecting at an angle, typically 90^{O}. The process of ECAP allows us to introduce very large plastic deformations to a work-piece without altering the overall geometry of the work-piece [1].

During the last decade, equal-channel angular pressing (ECAP) has emerged as a widely-known procedure for the fabrication of ultrafine-grained metals and alloys. This review examines recent developments related to the use of ECAP for grain refinement including modifying conventional ECAP to increase the process efficiency and techniques for up-scaling the procedure and for the processing of hard-to-deform materials. Special attention is given to the basic principles of ECAP processing including the strain imposed in ECAP, the slip systems and shearing patterns associated with ECAP and the major experimental factors that influence ECAP including the die geometry and pressing regimes. It is demonstrated that all of these fundamental and experimental parameters play an essential role in microstructural refinement during the pressing operation [2].

Equal channel angular pressing (ECAP) is an effective tool to impose large plastic strains. The process has attracted considerable interest as a method to refine microstructure by deformation processing. The concept is to subject a material to simple shear in order to introduce large strains in repeated pressing operations leading to grain refinement to the sub- micron or even nano-scale, which will ultimately improve strength and toughness characteristics of the material [3].

ECAP process involves simple shear deformation that is achieved by pressing work piece through die containing two channels of equal cross section that meet at a pre-determined angle. Deformation occurs in the immediate vicinity of the plane lying at the intersection of two channels as shown in figure 1

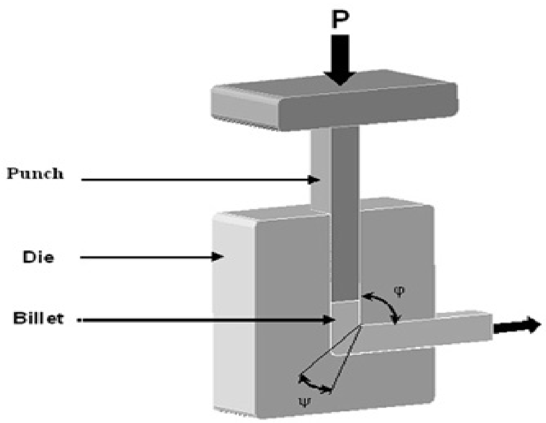

Figure 1: Equal Channel Angular Pressing Die

The effective strain imposed on the work piece increases with decreasing channel angle. Important advantage of ECAP process is that a large amount of simple shear deformation can be imposed in single of multiple process steps without changing the cross section of the work piece.

II. METHODOLOGY

- Defining the objective of the work.
- Literature review.
- Study and selection of various parameters affecting ECAP.
- Finite element analysis by considering defined parameters.

III. TERMINOLOGY OF ECAP [4]

Figure 2 shows the highlights of its two most important terminologies:

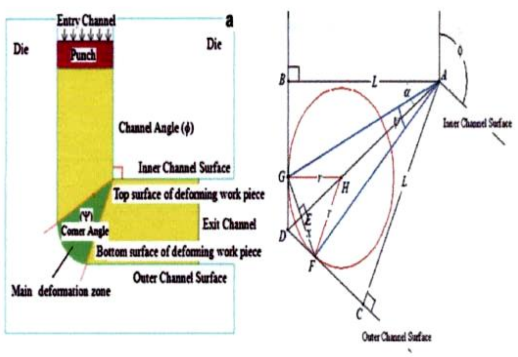

Figure 2. Terminology

The above figure 2.1 shows the terminology of ECAP die, they are

Channel angle (Φ): It is the angel between two channels of die. It may be acute angle, right angel or obtuse angel.

Corner angle (Ψ): For any given channel angle (Φ), the minimum and maximum value of a corner angle (Ψ) can take as 0 and π- Φ, respectively. For FEA, channel angle (Φ) can be modeled by specifying an equivalent fillet radius (r) in the main deformation zone at the outer channel surface as shown in Figure 2.

IV. EFFECT OF PARAMETERS ON ECAP: [5]

1. With increasing corner angle, the strain at the bottom surface of the deforming work piece exhibiting strain hardening, constitutive material behavior decreases till a corner angle 45^o and increases thereafter. This is attributed to synergistic effect of mixed mode of deformation and asymmetric nature of the corner gap.

2. With low corner angles ($\Psi <= 40^o$), processing of materials with high percentage of flow softening characteristic is difficult. Friction has a pronounced effect on the deformation behavior, with increasing friction in a die without any corner angle, a strain hardening material sticks to the outer channel surface forming a dead metal zone and the strain distribution becomes inhomogeneous.

3. If a corner angle is provided, the effects of friction are reduced and the strain distribution becomes homogenous irrespective of the constitutive material behavior.

4. Providing fillet at the inner channel surface junction where the two straight channels meet helps to process materials with high percentage of flow softening.

5. The optimum corner angle and inner fillet radius for deforming a variety of engineering materials with behavior ranging form strain hardening to flow softening through an ECAP die with a chanel angle of 90^o was found to be 30^o and 3 mm, respectively.

V. SCOPE AND OBJECTIVE

There exists a variety of methods to impose large plastic strains on materials in order to produce fine-grained microstructures. Forging, extrusion, drawing, and rolling have been used for this purpose, but they all have significant drawbacks. Multiple reductions of the initial billet cross-section are limited by the geometrical change of the work piece,require high loads, and result in a non uniform deformation.

In the present work, by considering the die used in ECAP and analyzing the die for stress variation under different working conditions of above consolidation of MMC process and showing the stress variation on die under several parameter variations. The deformation behavior of square cross sectioned sample of an ECAP die with a channel angle 90^0 and corner angle 90^0 is simulated using ANSYS.

VI. EXPERIMENTAL PROCEDURE

The dimensions of the die used in consolidation of aluminum alloy are taken from the journals on ECAP; they are mentioned in reference section. The overall dimensions are shown in Figure 3. [6]

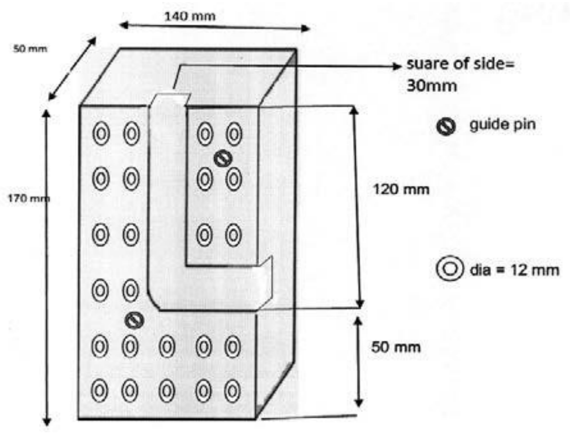

Figure 3. Die

For analysis in ansys the model is assumed to be a 2D problem with no thickness.

The corner angles for different channels are calculated by the equation.

$$\varphi = 2tan^{-1}\left[\frac{rcos\left(\frac{Ø}{2}\right)\sin\left(\frac{Ø}{2}\right)}{L - rcos2\left(\frac{Ø}{2}\right)}\right]$$

Where,

$\boldsymbol{\varphi}$=corner angle (0^{o}-90^{o})

Φ =channel angle (90^{o}-150^{o})

r= corner radius (mm)

L= width of channel (30 mm)

Calculation for corner radius which is used in analysis:

Table 1: Corner radius for various channel angles.

Channel Angle	Corner Angle	Corner Radius
At Φ=90	$\Psi=0^{0}$	r=0 mm
	$\Psi=45^{0}$	r=17.57 mm
	$\Psi=90^{0}$	r=30 mm
At $\varphi=120^{0}$	$\Psi=0^{0}$	r=0 mm
	$\Psi=45^{0}$	r=23.159 mm
	$\Psi=90^{0}$	r=23.923 mm
At $\varphi=150^{0}$	$\Psi=0^{0}$	r=0 mm
	$\Psi=45^{0}$	r=43.539 mm
	$\Psi=90^{0}$	r=93.755 mm

Properties used for analysis:

1. Fluid:

In application of ECAP i.e. in consolidation of Al-6061 and flyash MMC. This mixture is pressed at velocity 0.2-20mm/mim and back pressure 50-200 Mpa through channels at temperature 600-800^{0} c .Here we are assuming the flow of above mixture in channel as fluid flow with the fluid properties as below. And is temperature distributions within a region, as opposed to elements that model a network of one-dimensional regions hooked together .We can als also use FLUID141 in a fluid-solid interaction analysis.

2. Structural:

The die used in above process is taken as Structural element is treated as plane42 element in ANSYS. The element is defined by four nodes having two degrees of freedom at each node: translations in the nodal x and y directions.

FEM model

The model with fluid –structural entity will be analyzed and building of the model of entire domain including fluid and structural regions, two types of elements used they are Typel- fluid 141 (FLOTRON CFD) and Type2 – plane 42. (SOLID-QUAD 4 NODE 42). Material properties are shown in table 5.2

Table 2: Properties of fluid Material

		T1	T2	T3
CFD Fluid 141	Temp in^{0} C	677	702	752
	Density in g/cm^{3}	2.372	2.304	2.349
	Viscosity	1.298	1.264	1.126

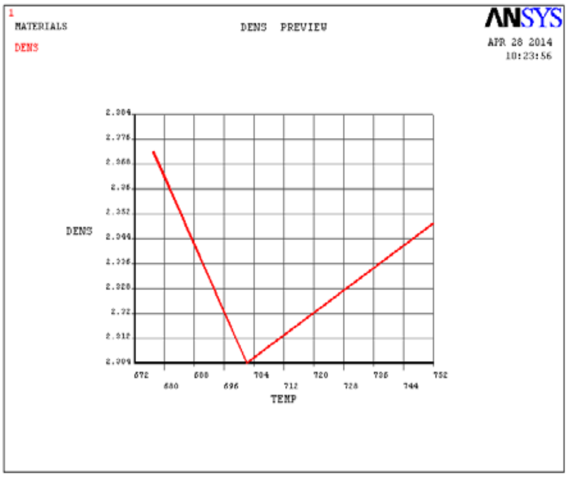

Figure 4: Density of fluid material

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Linear isotropic material properties.

Table 3: Properties of the structural material

Plane 42	EX	PRXY
	2.049e5	0.3

Meshed model with boundary conditions shown in figure.

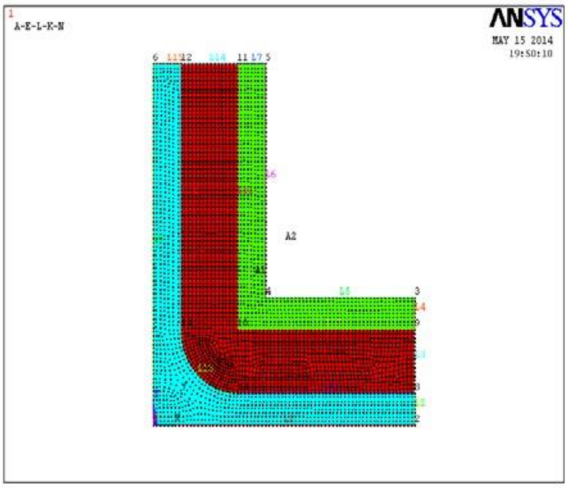

Figure 5. Meshed model with boundary conditions

Vector plot of the fluid analysis shown in figure.

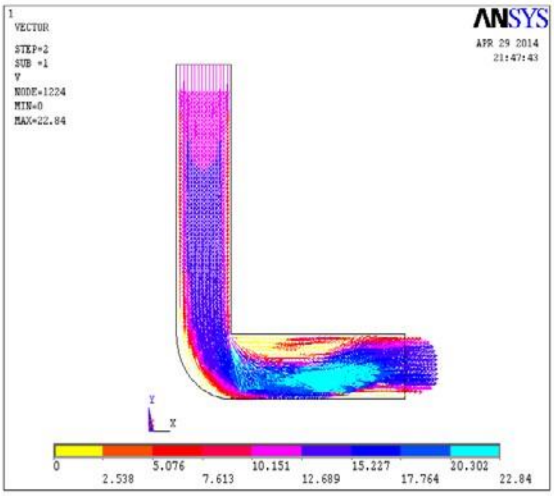

Figure6. Vector plot of the fluid analysis

Deformed shape of the channel with von mises stress shown in figure

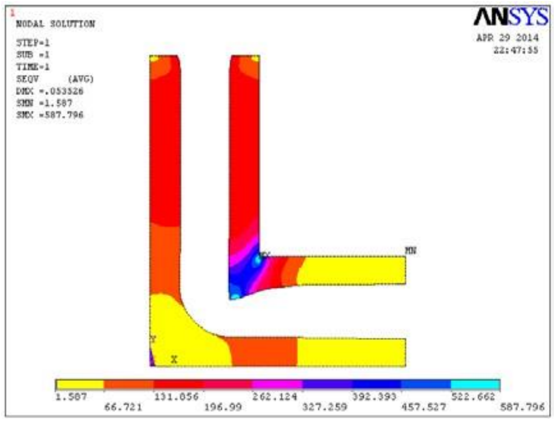

Figure 7. Deformed shape of the channel with von mises stress

VII. RESULTS AND DISCUSSIONS

The stress analysis is carried out on ECAP die. The stress is compared by changing the various parameters such as channel angle (Φ), corner angle (Ψ) (inner radius) and velocities. The main objective of the analysis is to find out the stress distribution in the variation of values of different parameters mentioned.

1. Analyses of ECAP die with various channel angle.

The analysis carried out on ECAP die of various channel angles of ($\Phi = 90^0, 120^0$ and 150^0) and input velocities are varied from 0.2mm/min to 20mm/min and with constant corner angle zero degree ($\Psi = 0^0$).

The figure 8 shows the variation in Maximum Stress with different velocities for ECAP die of different Channel angles.

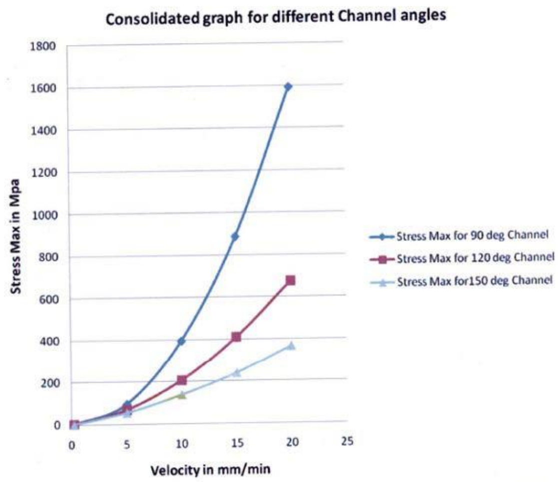

Figure 8. Consolidated graph for different channel angle.

2. *Analyses of ECAP die with various corner angle.*

The analysis carried out on ECAP die of various corner angles of ($\Psi = 0^0, 45^0$ and 90^0) and input velocities are varied from 0.2mm/min to 20mm/min and with constant channel angle ($\Phi = 90^0$).

The figure 9 shows the variation in maximum Stress with different velocities for ECAP die of different Channel angles.

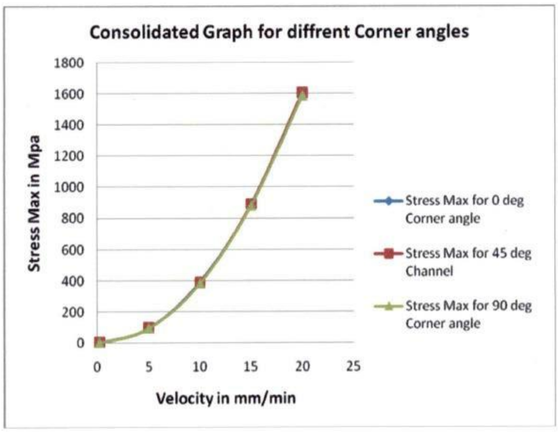

Figure 9. Consolidated graph for different corner angle.

VIII. CONCLUSION AND FUTURE WORK.

The following conclusion can be made from the analysis.

As the Channel angle is varied by keeping the velocity of the input material and corner angle constant the stress value decreases considerably. And as the velocity is increased there is a drastic increase in the stress value is accrued.

As the Corner angle is varied by keeping velocity of input material and Channel angle constant there is an increase in stress value is accrued. And as the velocity is increased there is enormous increase in stress value is accrued.

From the analysis it can be concluded that the die having the following design parameter can be considered as optimal design for the fabrication of composite material.

- Channel angle (Φ) $=150^0$.
- Corner angle (Ψ) $=0^0$.

Future Work

Nevertheless, it is demonstrated also that, in order to achieve advanced properties after processing by ECAP, it is necessary to control a wide range of micro structural parameters including the grain boundary misorientations, the crystallographic texture and the distributions of any second phases. Significant progress has been made in the development of ECAP in recent years, thereby suggesting there are excellent prospects for the future successful incorporation of the ECAP process into commercial manufacturing operations. Further work can be carried out for the same project work by using 3D analysis and the results of 2D and 3D analysis can be compared.

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