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Finite Element Analysis of Aluminum Alloy at Many Die Channel Angles using DEFORM-3D

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Abstract*: Equal channel angular pressing (ECAP) is a technique used to impose strain in material which helps to increase the mechanical properties of a material. It is generally used to refine grain size of the material by passing sample through equal channel. In this study, analysis on frictional effect in equal channel angular pressing using aluminum 1100 has been done by using FEM software DEFORM-3D version 10.1. Dies with different channel angle were designed with the help CATIA. This study shows the effect of friction with different die channel angle. It has been found that with the increase in friction, reduction in corner gap is found (dead zone), which may cause material damage and improve strain distribution homogeneity. The result obtained with FEM simulation are compared to those obtained theoretically, thus it is found that the current study is in good agreement to the theoretically result.

Key Words*: Die channel angle, Equal channel angular pressing, Finite element analysis, Friction, Strain.

I. INTRODUCTION

Ultrafine grained (UFG) materials can be obtained by equal channel angular pressing (ECAP). Many Severe plastic deformation (SPD) techniques have been developed to produce bulk ultra-fine grain material. Equal channel angular pressing is widely used method among the several severe plastic deformation (SPD) for obtaining bulk, defect free material. Ultra-fine grains have increased their strength at a lower temperature scale and rapid formability at some elevated temperature therefore seeking an important industrial prospect. According to the Hall-Patch equation [1] grain size of the material is related to the strength of the material which is given by equation (1):

$$\sigma_y = \sigma_0 + kd^{-1/2} \qquad (1)$$

ECAP developed by Segal [2] and Valiev [3] to produce huge ultra-fine grain materials hence improve mechanical properties of the material. Process of ECAP can be seen in figure (1), which shows, a billet is being passed through two equal channel made in die by pressing the billet by a punch. In this process plastic strain is imposed by simple shear at the intersection of the channels. The main advantage which makes this process attractive is that strain can be imposed in this process without any reduction in the cross sectional area of work-piece and it is a very simple procedure that is easily done on a variety of materials..

Lubrication is used in process to reduce friction between the channel wall and work-piece

In this process it is the shear deformation occurs in the material at the intersection of two channels meet an angle 'Φ', to impose plastic strain in the work-piece. Friction is one the factor which affects the strain homogeneity occurs in the material. The speed and temperature are other factors which also affect the process of ECAP. In ECAP the work-piece is passed through channel by three routes differ by rotation of work-piece.

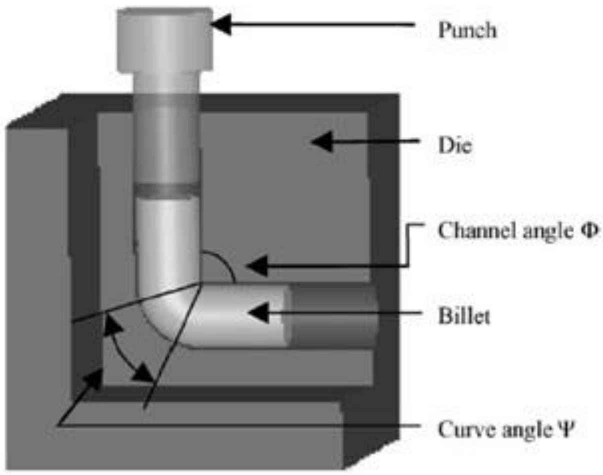

Fig 1 Schematic diagram of an ECAP die showing the channel angle Φ and the cur... angle Ψ

Many studies report says that the magnitud (1) ı imposed in the work-piece while crossing the two channels is determine by the die channel angle 'Φ' and curve angle 'Ψ'. The relationship which is given by equation (2) [4] is:

$$\gamma = 2\cot\left(\frac{\phi}{2}+\frac{\varphi}{2}\right)+\varphi\,\mathrm{cosec}\left(\frac{\phi}{2}+\frac{\varphi}{2}\right) \qquad (2)$$

And the equation (3) [4] which give the relation for equivalent strain (ε_N) with number of passes (N) is given by:

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

Many studies have been done on deformation behavior of material by using finite element method and the value of strain imposed in the material. Oruganti et al. [5] inspected the influence of friction and strain rate sensitivity on the actual strain for channel angles valued larger than 90^0. Nagasekhar et al. [6] examined the effect of acute die channel angles ($\Phi \leq 90^0$) on the deformation tendency of material constant with 2D FEM in low-friction condition and revealed that the deformation occurred in three steps for die channel angles of $60^0$and 75^0, in comparison to only two steps for $\Phi=90^0$and decrease in the die channel angle resulted in an increase in the punch pressure.

In this paper, numerical analysis of frictional effect of pure aluminum alloy 1100 has been done, using ECAP die with two different channel angles $\Phi= 110^0$ and 120^0 and curve angle $\Psi= 30^0$ with friction factor 0.001 and 0.3. Die of different geometries were made with the help of designing software CATIA. Analysis has been done using software DEFORM-3D version 10.1 for FEM simulation. The result obtained from FEM simulation is compared to the theoretical value obtained from the eq. (3) and the effect of friction has been observed. Also using die channel angle and curve angle each of 90^0 using material Brass-CDA365 simulated result is obtained for strain imposed and compared with theoretical result.

II. FINITE ELEMENT ANALYSIS

Finite element analysis is done with the help of DEFORM-3D version10.1 and the numerical results are obtained. Aluminum alloy 1100 is used as work-piece material. Finite element model with round section channel has been used for the ECAP process. Dies used in the simulations are with die channel angle $\Phi= 110^0$ and 120^0 with curve angle $\Psi= 30^0$. Dimensions of the initial billet used in this numerical study are 20mm in diameter and 100mm in length. The billet is taken as rigid-plastic materials and the die and punch were assumed as rigid so there is no deformation. The mesh system with 10000 elements is taken for solid mesh generation and automatic re-meshing is used to accommodate large deformation during all the analysis at room temperature. Other simulation parameters are given in table 1.The ECAP die with both channel angle and curve angle as 90^0 using material Brass CDA-365 with simulation parameters given in Table 2, is simulated, after single pass, the effective strain contour and point wise strain distribution are shown in figure (4) and result for these die parameters also compared with theoretical value.

Table 1

Simulation parameters used in DEFORM-3D For Aluminum 1100

Billet length(mm)	100
Billet diameter(mm)	20
Die outside diameter(mm)	250
Punch speed (mm/sec)	1
Time increment (sec)	0.1
Temperature (^{0}c)	20
Friction factor	0.001 & 0.3
Die channel angle	110^0 &120^0
Curve angle	30^0

Table 2

Simulation parameters used in DEFORM-3D for Brass CDA365

Billet length(mm)	80
Billet diameter(mm)	15
Die outside diameter(mm)	255
Punch speed (mm/sec)	0.5
Time increment (sec)	0.1
Temperature (^{0}c)	20
Friction factor	0.2
Die channel angle	90^0
Curve angle	90^0

A. *Effect of Friction Coefficient on Deformation Behavior*

Different simulated contours obtained from Finite Element Analysis are shown in figure (2). Using these contours the deformation behavior of the samples was studied. The pressed work-piece can be alienated into three main regions along the pressing direction i.e. the head of that deformation zone, the main part of deformation zone and the tail if given deformation zone. During ECAP, there is a generation of corner gap which is also known as dead zone, especially in the vicinity of the lower part of the deformed sample. It can be seen from the figure (3) that the corner gap generated is reduced when we use increased friction coefficient of 0.3 instead of using 0.001, used in other case.

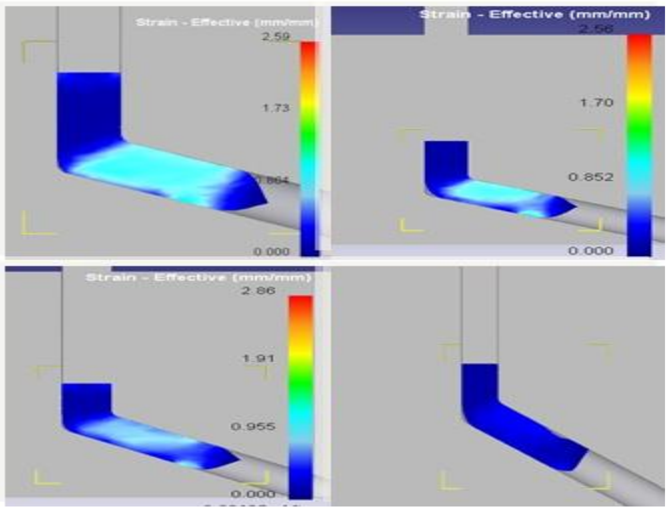

Fig 2 Effective strain contour with different channel angle and different friction condition with die channel angle 90^o and frictional coefficient of 0.001

This dead zone may cause the material failure, so to reduce this corner gap use of high friction coefficient is recommended during equal channel angular pressing. So it may be concluded that friction reduces inside the upward bending of given sample and roots smaller gap in its outlet channel.

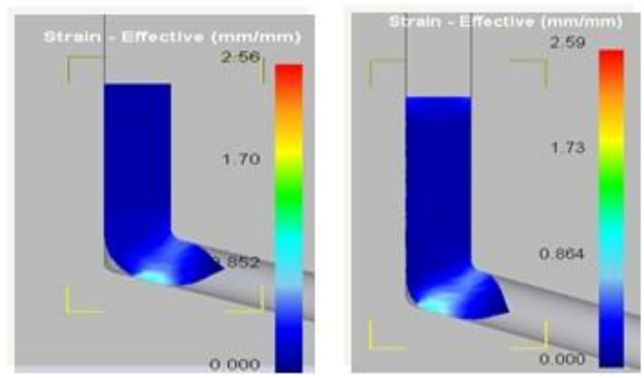

Fig 3 The corner gap with die channel angle 110^0 (a) with friction coefficient 0.001, (b) with friction coefficient 0.3

B. ***Effect of Die Channel Angle***

Table 3

Evaluation of effective strain Values
Gained by simulation with its
Speculative values for Aluminum type 1100

	Φ= 110^0, Ψ= 30^0	Φ=120^0,Ψ= 30^0
Theoretical	0.742	0.622
FEM simulation	0.866	0.676

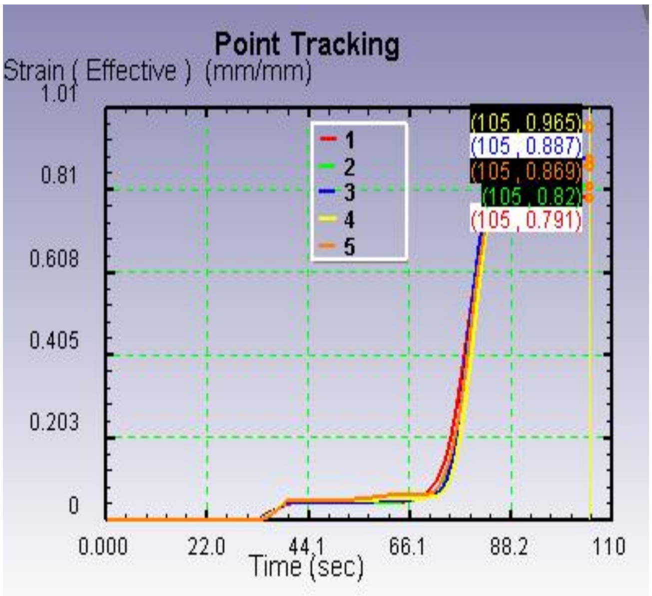

Fig 4. Point wise strain values obtained in the process at the cross section taken at mid of billet with die channel angles of 90^o

With die channel angle Φ= 110^0 and 120^0 material in its outer corner region undergoes a amalgamation of bending and shear instead of their pure shear, this leads to an increase in effective strain when moving from bottom to top. With different die channel angle the value of strain imposed in material is also different. The strain imposed is larger in magnitude in case of less channel angle, so to impose higher amount of strain in material, use of smaller channel angle is recommended. Results obtained from simulation and the theoretical results are shown in table (3) & (4). Thus results obtained from FEM simulation compared with theoretical value and found a good agreement between them.

Table 4

Evaluation of effective strain values
Gained by simulation with its
Speculative values for Brass type CDA365

	Φ= 90^0, Ψ=90^0
Theoretical	0.907
FEM simulation	0.922

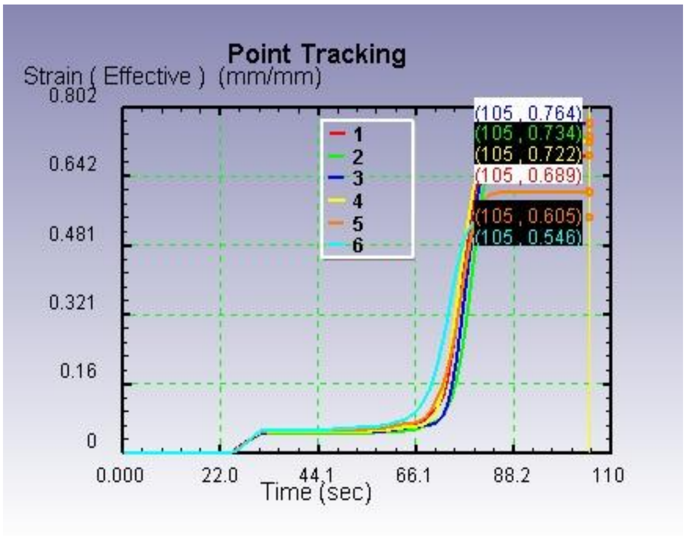

Fig 5. Point wise strain values obtained in the process at the cross section taken at mid of billet with die channel angles of 110^o

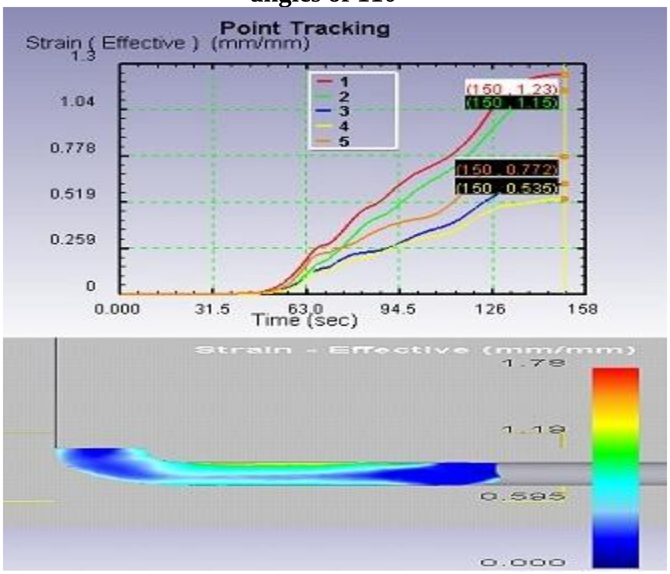

Figure (6) Showing effective strain contour of Brass CDA 365 next ECAP thru die channel angles v/s curve angles of 90^0

III. CONCLUSION

Simulation of aluminum alloy 1100 with different die channel angle and different friction coefficient in ECAP was done by using 3D FEM software DEFORM-3D, following conclusions are drawn:.

- ➢ Lower friction coefficient induces large corner gap (dead zone) which may lead to material damage during ECAP and may get a defected material at the end of the process whereas higher friction coefficient eliminates the corner gap which is generated at lower part of work-piece during ECAP.
- ➢ The die channel angle, ϕ directives the total strain levied in each pass. A better strain homogeneity distribution is obtained with less magnitude of strain with larger die channel angle.
- ➢ Use of small die channel angle and higher friction magnitude is suggested for producing uniform deformation behavior or strain behavior and to reduce the corner gap (dead zone).

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NOMENCLATURE

σ_y	Yield stress (N/mm^2)
σ_0	Friction stress (N/mm^2)
k	Constant of yielding
d	Grain size of material (m))
ε_N	Equivalent strain (mm/mm)
γ	Shear strain (mm/mm)
N	Number of passes
Φ	Die channel angle (^{0})
Ψ	Curve angle

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Alok Soni is currently working as an Assistant Professor in the Department of Mechanical Engineering, GLA University Mathura. He has more than 8 year of teaching experience. He has completed M.Tech in Production Engineering from MNNIT, Allahabad. His research area is production engineering. He has published 05 research papers in various national and international journals of repute. . He is life member of Indian Society for Technical Education.

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