International Journal of Mechanical Engineering and Technology (IJMET)
Volume 8, Issue 8, August 2017, pp. 9–19, Article ID: IJMET_08_08_002
Available online at http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=8&IType=8
ISSN Print: 0976-6340 and ISSN Online: 0976-6359

FINITE ELEMENT SIMULATION OF ALUMINIUM ALLOY SUBJECTED TO EQUAL CHANNEL ANGULAR PRESSING (ECAP)

V. Jaya Prasad
Department of Mechanical Engineering, JNTU Kakinada, India

S. Kamaluddin
Department of Mechanical Engineering,
Chirala Engineering College, Chirala, India

N. Mohan Rao
Department of Mechanical Engineering, JNTU Kakinada, India

ABSTRACT

In the present study, the optimum extrusion parameters were investigated for minimum strain coefficient of variance in equal channel angular pressing based on the analysis of whole steady zone. The simulation process was done for Al 5083 alloy using deform 3D software at two different channel angles 90^0 and 120^0 and with two distinct routes A and C. The model employed to simulate the pressing for two consecutive passes to both A and C routes with shear angle 120^0. Analytical models are also used to validate the obtained computational solutions. Results showed that channel angle and friction coefficient have significant influences on deformation behaviour, strain coefficient of variance and punch load evolution.

Key word: Equal Channel Angular Pressing, Finite Element Analysis, Severe Plastic Deformation, Deformation Homogeneity.

Cite this Article: V. Jaya Prasad, S. Kamaluddin and N. Mohan Rao, Finite Element Simulation of Aluminium Alloy Subjected To Equal Channel Angular Pressing (ECAP), *International Journal of Mechanical Engineering and Technology*, 8(8), 2017, pp. 9–19.
http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=8&IType=8

1. INTRODUCTION

Severe plastic deformation (SPD) technique has been widely used to produce ultrafine grained materials and achieved several improvement in properties in last decades. Materials Processing by SPD entrust to several experimental methodologies of metal forming that can apply very large strains on materials leading to exceptional grain refinement. Another feature is that the shape is retained by using special tool geometries that prevent free flow of the material and thereby produce a significant hydrostatic pressure. Ultrafine-grained materials possess excellent mechanical and physical, such as high strength and toughness at room temperature, high strain rate and superplastic behaviour. In this paper Equi Channel Angular Extrusion (ECAP) type of SPD technology is adopted.

About ECAP

Equal-Channel Angular Pressing (ECAP) or Equal-Channel Angular Extrusion (ECAE) is one of the well approved technique that are used for the production of the polycrystalline materials with a grain diameter in the sub micrometre. This necessitates pressing a billet through a die, consisting of two channels of homogeneous shape and cross sectional dimension that are positioned under a predetermined angle φ and additional angle ψ that defines arc of curvature.

When comparing the construction of the die for ECAP with that of extrusion. For Conventional extrusion: $\varepsilon_{total} = \varepsilon_1$

For ECAP: $\varepsilon_{total} = \varepsilon_1+\varepsilon_2+\varepsilon_3+\ldots\ldots+\varepsilon_n=n*\varepsilon_1$

The strain induced in a billet when it is processed in N number of passes through the die of an ECAP may be estimated as a function of φ and ψ under ideal conditions as,

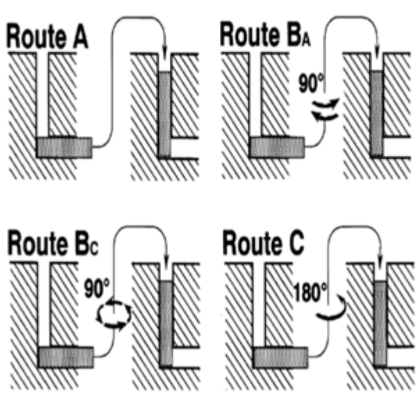
$\varepsilon_{eff}=N/\,(3)^{0.5}[2\cot\,(\varphi+\psi)/2+\psi\text{cosec}\,(\varphi+\psi)/2]$

According to above equation the effective strain decreases with increasing channel angle and with increasing corner angle. Using this equation it can be shown that the equivalent strain per pass during ECAP decreases from its maximum of $\varepsilon_{eff} = 1.15$ at $\varphi = 90^0$ and $\psi = 0^0$ to its minimum of $\varepsilon_{eff} = 0$ at $\varphi = 180^0$ and $\psi = 0^0$.

Different routes of ECAP

Since the ECAP technique was invented, Segal[1] noted that different microstructures can be developed in any selected material by rotating the sample between each presses since any rotation changes the operative shear plane and shear direction when the sample passes through the corner . After that, different routes of ECAP were widely studied, and four typical processing routes were finally published, shown in Figure 1.1. In route A, samples are pressed with no rotations between passes; in route B_A and B_C, samples are rotated by 90º in alternate directions or the same direction between each pass; in route C, samples are rotated by 180º between passes.

The experimental observations using samples of high purity aluminium proved that route B_C refines the microstructure of material most effective, route C does less effective, route A and B_A are the least effective to refine microstructure.



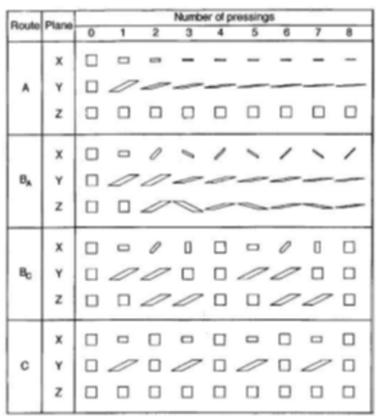


Figure 1.1 The four routes of ECAP **Figure 1.2** Shearing characters of the four ECAP route

From the above Figure 1.2 route B_c will refines the microstructure more effectively compared to other routes.

A.V. Nagasekhar et al. [2] designed ECAP and specimens undergone 3 passes using two different processing routes: Route A, where the specimen orientation was kept constant between passes, and Route B, where the specimen was rotated by 180° about its longitudinal axis in between passes. K.R. Ravi et al. [3] investigated on ECAP of Al–5wt% TiB2 insitu composite. They processed ECAP at room temperature till 4 passes. Large particle free zones having 50–100 µm size present in as cast condition lessened to 20–30 µm by ECA pressing. The composite became homogeneous after four passes. A significant grain refinement nearly 500 nm observed by ECA pressing but the average size remained unchanged at 0.5–0.6 µm. Kazeem O. Sanusi et al. [4] studied on ECAP technique for formation of ultra-fine grained structure on copper billets. They explained the factors influencing the grain refrainment in ECAP such as channel and curvature angles, pressing speed, pressing temperature and about different routes in ECAP. Finally they evaluate grain size of copper specimen before and after ECAP. Neil de Medeiros et al. [5] studied numerical and experimental analysis of AA1100 deformed by ECAP. Two distinct routes (A and C) are considered on equal-channel angular pressing (ECAP) process via numerical and experimental analysis at room temperature to evaluate the distribution of the effective plastic strain.

2. SIMULATION OF ECAP

2.1. Introduction to Finite Element Analysis

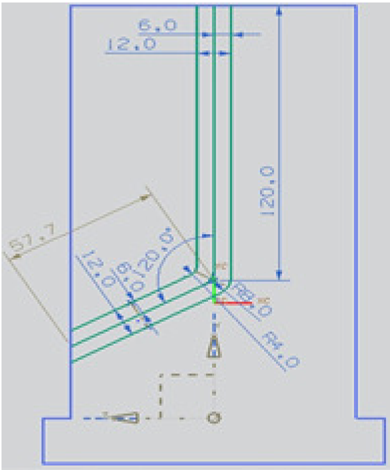
The aluminium 5083 alloy is deformed via equal channel angular pressing using vertical type hydraulic press at room temperature. The process was done using two different channel angles (90^0 and 120^0) and with two distinct routes (A and C). Coefficient of friction is also one of the main parameters in forming process. So we consider different friction coefficients in simulation to determine its effect on stress distribution and prime mover capacity. The die was designed with two circular channels intersected at angles equal to 90° and 120^0 in CATIA V5.

The die geometry employed to deform the billet for one pass is presented with a shear angle of 120^0 and 90^0 degrees. The model employed to simulate the pressing for two consecutive passes to both A and C routes with shear angle 120^0. The effect of each route was attributed on the billet by means of different geometric configurations of the die. The second pass using the route A the billet was forced to upward. The second pass of route C was simulated by rotating to 180º. In the FEM modelling, the die outer fillet radius and the channels cross-section are similar to the tooling used in the experimental tests. Material assumed is continuous, isotropic and homogeneous. Heat generated due to deformation and friction was neglected. The von Mises flow rule is used. The displacement and rotation in x, y and z direction for all nodes of the die were arrested. The Pressure applied on the top surface of the work-piece resulting in the sample displacement. Dislocation is perpendicular to the plane and rotations about other two directions were detained.

The basic geometry parameters of the channel are die angle φ, corner angle ψ defined by outer Coupling radius R, inner coupling radius r and channel width b. The angle φ varied in the range 90^0-120^0. As the angle between the channels decreases, the extrusion pressure to be applied on the punch increases and the shear deformation of the billet increases. Lower shear angles are used only for extrusion of highly ductile materials like Lead. The geometry of the die is shown in the Figure 2.2.1.

2.2. Pre-processing of DEFORM 3-D

We consider punch and die are the rigid bodies and work piece as the deformable (plastic) body and the dies as cold forming steel dies which has a friction coefficient as 0.12. In the inlet part of the channel there is a compression of the billet and forming of its forepart as shown in Figure. 2.2.1, Δh means ram displacement.



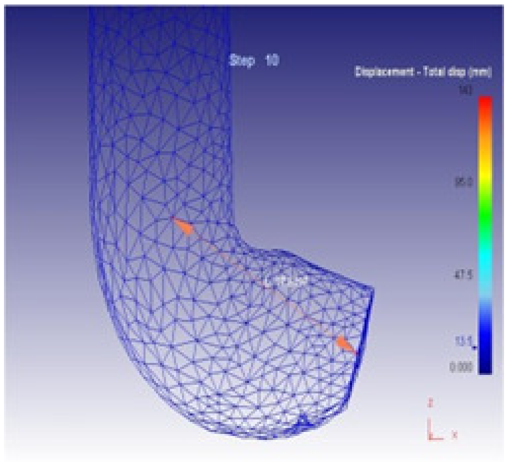


Fig 2.2.1 Die Design **Fig 2.2** Position of the billet at $\varphi = 90^0$ and Δh=18 mm for 10 steps.

3. RESULTS AND DISCUSSION TO SIMULATION

Figure 2.2.1 shows the three-dimensional FEM modelling developed to simulate the process of the billet after one pass with channel angles of 90^0 and 120^0. Below figures show the stress distribution of ECAP process with routes A and C having shear angle of 120^0.

3.1. Stress distribution along the length of the billet:

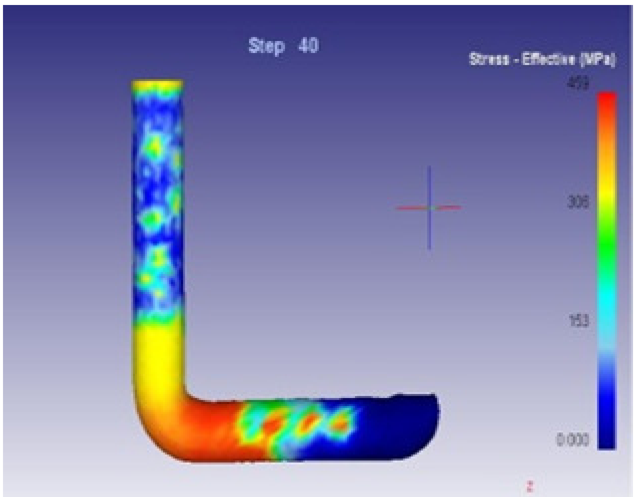


Figure 3.1.1 Effective Stress distribution in billet having 90^0 shear

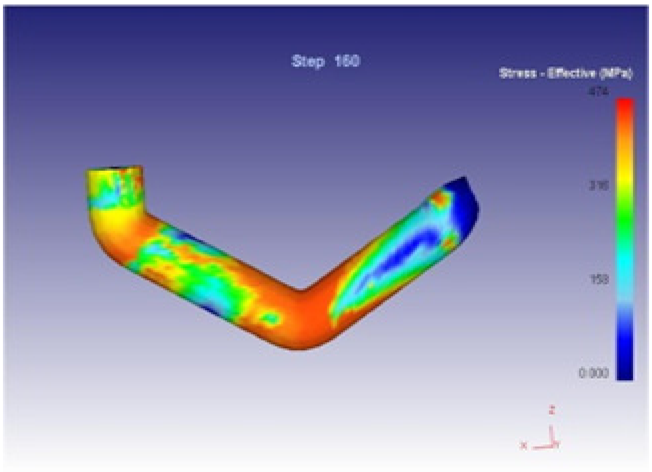


Figure 3.1.3 Effective Stress distribution in billet having 120^0 shear in Route A

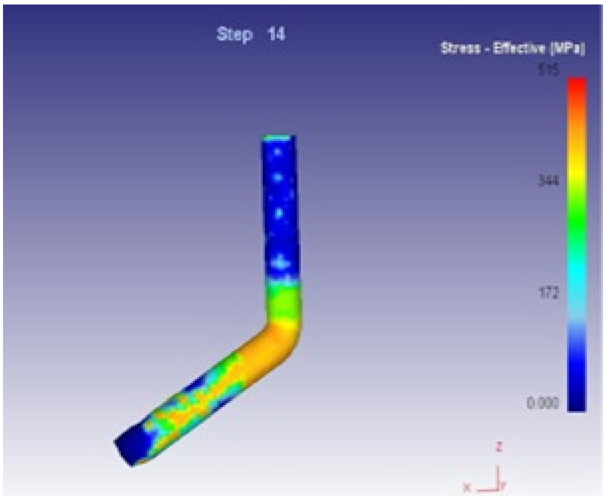


Figure 3.1.2 Effective Stress distribution in billet.

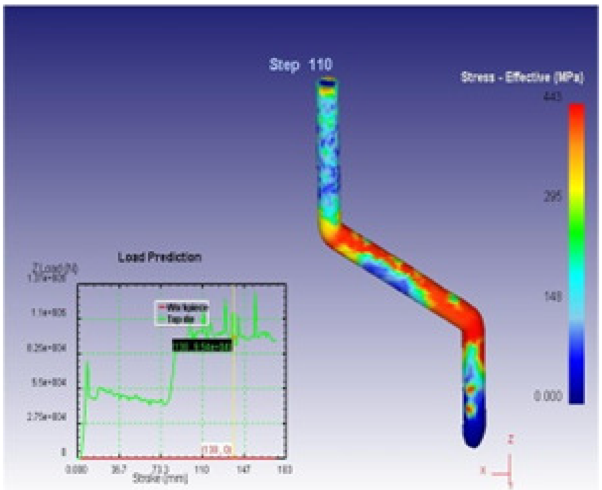


Figure 3.1.4 Effective Stress distribution in billet having 120^0 shear in Route C

From the Figure 3.1.1 and 3.1.2 the maximum stress is induced in the billet where there is maximum shear and as the shear angle decreases the stress induced will also increases. From this we can conclude that as the shear angle decreases the shear strain induced in the billet increases and only highly ductile materials only can process by ECAP.

The stress variation is not only along the length of the billet but also across the cross section of the specimen. Stress induced on the outer fibres of the billet is maximum and minimum at the centre of cross section. This is due to friction between billet material and the die surface.

Table 3.1.1 Effective stress, strain, load and pressure

Sl. No	Shear angle(φ)/ Route / Friction Coefficient (μ)	Effective stress(MPa)	Effective Strain		Simulated Value of average load (N)	Pressing Pressure Requirement of Sample (P) MPa
			Simulated	Analytical		
1	$\Phi=90^0$	459	0.9105	0.9069	2.8*e04	1967.78
2	$\Phi=120^0$	422	0.6121	0.6046	2.2*e04	1791.85
3	Route A &$\Phi=120^0$	474	1.1858	1.2101	2.7*e04	1823.31
4	Route C &$\Phi=120^0$	482	1.1942	1.2101	4.5*e04	1836.54
5	$\mu=0.00$ &$\Phi=120^0$	410	0.601	0.6046	9.2*e03	314.15
6	$\mu=0.12$&$\Phi=120^0$	422	0.6121	0.6046	2.2*e04	1791.85
7	$\mu=0.25$&$\Phi=120^0$	441	0.6290	0.6046	3.3*e04	3392.69

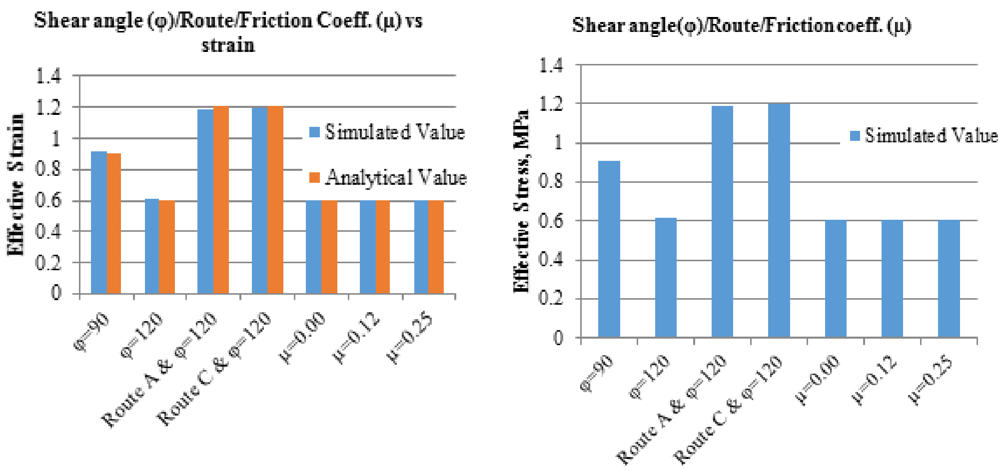


Figure 3.1.5 Shear angle (φ)/Route /Friction coefficient (μ) vs. Effective Stress and strain graph

3.2. Effective strain distribution along the length of the billet

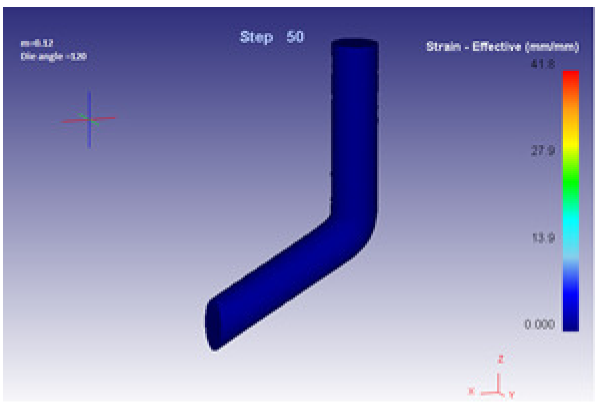


Figure 3.2.1 effective strain distribution in billet having 120^0 shear

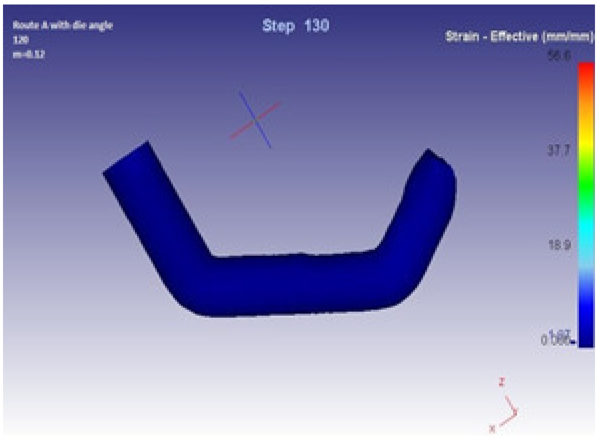


Figure 3.2.3 effective strain distribution in billet having 120^0 shear in Route A

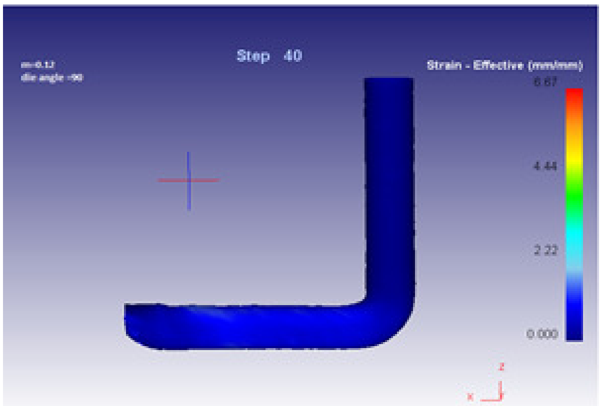


Figure 3.2.2 effective strain distribution in billet having 90^0 shear

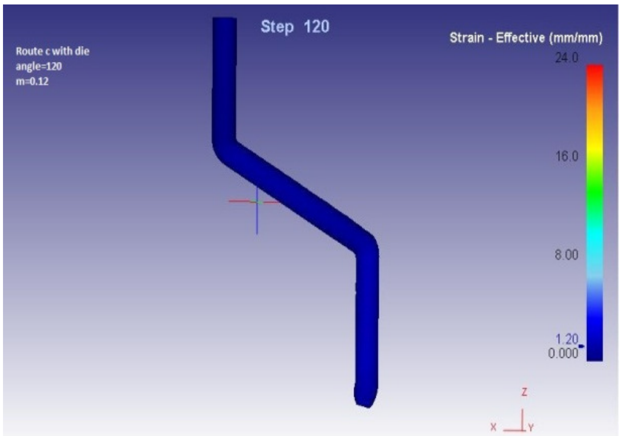


Figure 3.2.4 Effective strain distribution in billet having 120^0 shear in Route A

Effective strain

$\varepsilon_{eff} = N/ (3)^{0.5}[2\cot(\varphi+\psi)/2+\psi \operatorname{cosec}(\varphi+\psi)/2]$

N = Number of passes.

Φ = shear angle

Ψ = Angle of curvature.

3.3. Load vs stroke curves

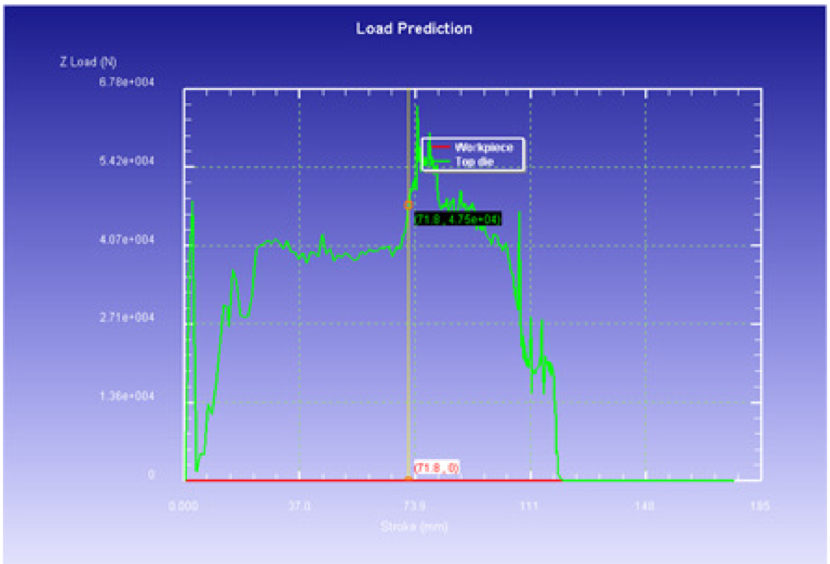


Figure 3.3.1. Load vs stroke curves for 120^0 shear.

From the Figure 3.3.1 the max load required in case of 90^0 shear is greater than 120^0 shear. About 60% more load i.e 1.7*e04 is required to deform in case of 90^0 than 120^0 shear.

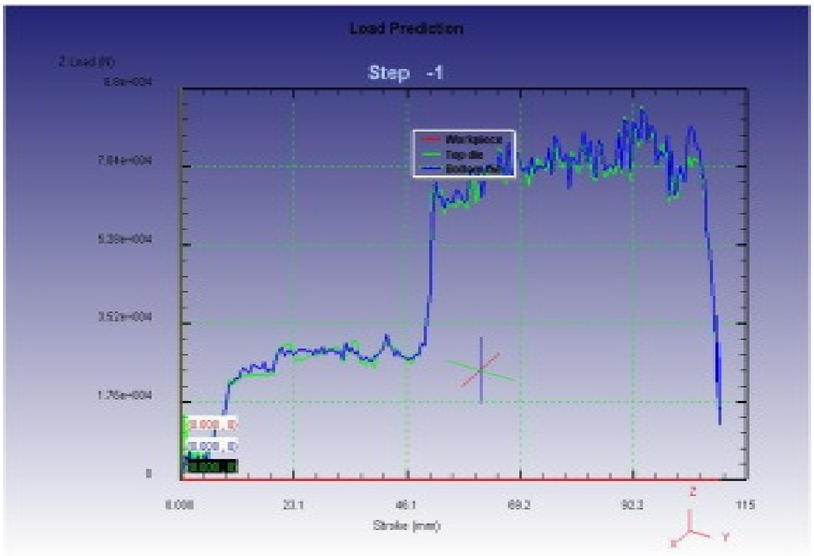


Figure 3.3.2 Load vs. stroke curves for routes A with 120^0 shear.

From Figure 3.3.2 the sudden rise of load is due to second shear of the billet which is 1.8*e04 for route A, route C with 120^0 shear.

The pressing pressure requirement of sample (P) using upper-bound analysis is represented by

$P=\tau_0 (1+m)*[2\cot (\varphi+\psi)/2+\psi] +4m\tau_0 [(l_i+ l_o)/a]$

τ_0 = Yield Shear stress of Al-5083 300 MPa

m = coefficient of friction

φ = Shear angle of Die.

Ψ = angle of curvature.

3.4. Effect of coefficient of friction on the load vs. stroke curve

Figure 3.4.1 Coefficient of friction=0.12 having shear angle=120^0

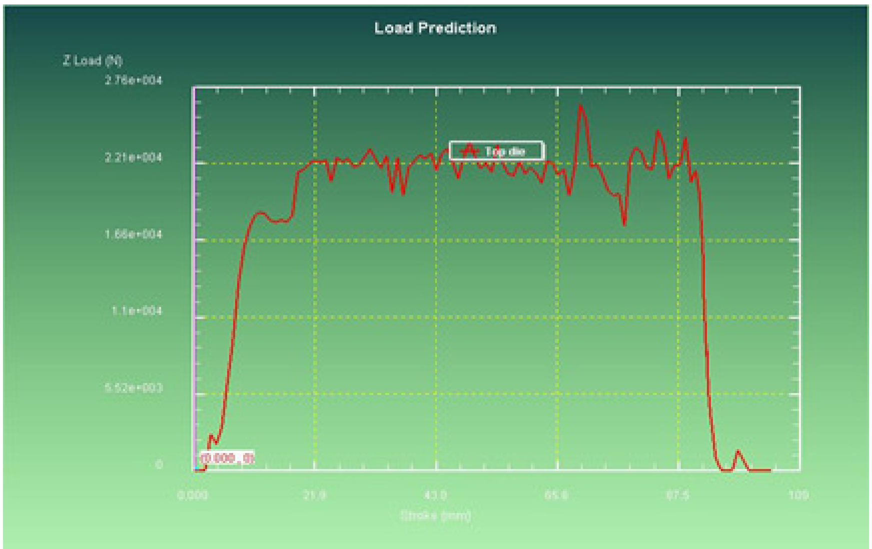


Figure 3.4.2 Coefficient of friction=0.25 having shear angle=120^0

The above figures load versus stroke plots are shown for different coefficient of friction. From above we can conclude that if coefficent of friction is increased from 0.12 to 0.25 , it requires 50% more load to be applied on the billet for the same die angle. So friction also plays an major role in ECAP process. Due to the friction the stress induced across the cross section also increases.

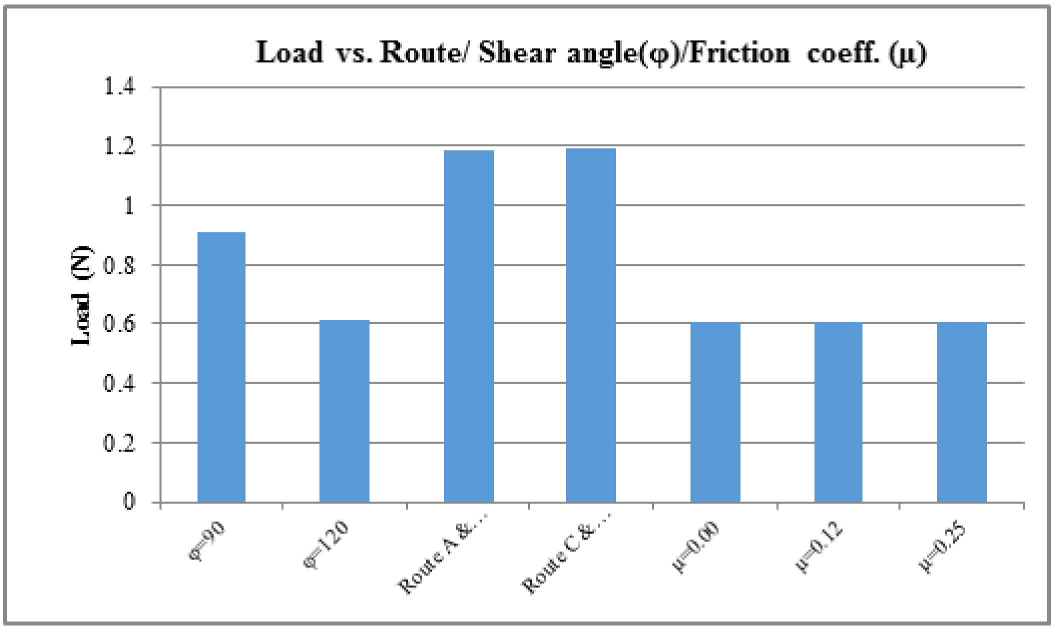


Figure 3.4.4 Load vs. Route/shear angle/Friction graph

From the above results the load requirement to deform the billet is mainly depends on the different parameters such as friction coefficient, shear angle, route of deformation. Route C requires more load requirements when compared to Route A.

4. CONCLUSION

1. 1. As the shear angle decreases the stress and the strain induced in the billet will increases which results more grain refinement. Due to this the strength of the material will increases. But only ductile materials can be processed through ECAP with decrease in shear angle at room temperature. At high temperatures Brittle materials can also be processed through ECAP.
2. 2. From the Table 3.3.1 we can conclude that Route C induces more stress than Route, which tells that the strain induced in Route C is more than Route A. So the grain refinement is more in Route C compared to Route A.
3. 3. In Table 3.1.1 we compare the values of simulation with analytical result which gives that the analytical results are similar to the simulation results. So the simulation which we have done is correct.
4. 4. From the Table 3.1.1 we show that the coefficient of friction is also one of parameter in grain refinement. As the coefficient of friction increases the strain induced in the billet is also increases, which concludes that grain refinement is more. But it requires more load to deform the billet. One of the main disadvantage of increase in coefficient of friction is the surface finish will reduces.
5. 5. From the Figure. 3.3.2 We can prove that ECAP process improves the strength of the material because the load required to deform the billet in the secondary shear is more than 65% compared to first pass. So as the number of passes increases the load required to deform the billet will also increase.

REFERENCES

[1] V.M Segal. Investigation of special deformation technique equal channel angular extrusion (ECAE) to control materials structure, texture and physico-mechanical properties. *Mater. Sci. Eng.,* A 386 2004, pp. 269–276.

[2] A.V. Nagasekhar, Uday Chakkingal and P.Venugopal. Equal Channel Angular Extrusion of Tubular Aluminium Alloy Specimens Analysis of Extrusion Pressures and Mechanical Properties. *Journal of Manufacturing Processes* Vol. 8/No. 2 2006.

[3] M. Saravanan, R.M. Pillai *, K.R. Ravi, B.C. Pai, M. Brahma Kumar. Development of ultrafine grain aluminium–graphite metal matrix composite by equal channel angular pressing. *Composites Science and* Technology, 67, 2007, pp. 1275–1279.

[4] Kazeem O. Sanusi1, Oluwole D. Makinde and Graeme J. Oliver. Equal channel angular pressing technique for the formation of ultra-fine grained structures. *S AfrJ Sci,* 2012, 108(9/10).

[5] Neil de Medeiros, Luciano Pessanha Moreira, Jefferson Fabrício Cardoso Lins, and Marcel Carneiro de Souza. A Numerical and Experimental Analysis of Aluminium Aa1100 Deformed by Different Ecap Routes”.

[6] Martin FUJDA and Tibor KVAČKAJ. Mechanical Properties and Microstructure of Al 6082 Aluminium Alloy Subjected to Severe Plastic Deformation.

[7] Ghader Faraji, Mahmoud Mosavi Mashhadi, Hyoung Seop Kim. Tubular channel angular pressing (TCAP) as a novel severe plastic deformation method for cylindrical tubes. *Materials Letters*, 65, 2011, pp. 3009–3012.

[8] F. Djavanroodi, B. Omranpour, M. Ebrahimi M. Sedighi investigates. Designing of ECAP parameters based on strain distribution uniformity, 2010.

[9] S.C. Yoon, P. Quang, S.I. Hong and H.S. Ki. Die design for homogeneous plastic deformation during equal channel angular pressing. *Journal of Materials Processing Technology*, 2007, pp. 187–188, pp. 46–50.

[10] Sreenivas P, Anil Kumar R and Sreejith P. S. Effect of Applied Axial Force on FSW of AA 6082 - T6 Aluminium Alloys. International Journal of Mechanical Engineering and Technology, 8(1), 2017, pp. 88–99.

[11] P. Radha Krishna Prasad, P. Ravinder Reddy and K. Eshwar Prasad. Effect of Welding Parameters on Mechanical Properties of Friction Stir Welded Joints of AA6082 and AA6061 Aluminium Alloys. International Journal of Mechanical Engineering and Technology, 8(6), 2017, pp. 564–574.

[12] F. Djavanroodi∗, M. Ebrahimi. Effect of Die Channel Angle, Friction and Back Pressure in the Equal Channel Angular Pressing Using 3D Finite Element Simulation. *Materials Science and Engineering*, A 527, 2010, pp. 1230–1235.