The Study of Plastic Deformation Behaviour of If-Steel during Equal Channel Angular Pressing through 120^o Die Angle by FEM

Malothu Ramulu, Arakanti Krishnaiah

***Abstract*— The plastic deformation behaviour of IF Steel during Equal Channel Angular Pressing (ECAP) has been studied (with two channels intersects at 120^o) by Finite Element Method (FEM) using ANSYS software package. A sound knowledge of the plastic deformation and the load is necessary for understanding the relationships between plastic deformation, grain size and mechanical properties of IF-Steel. It is observed that the precise results were obtained in comparison to the analytical models reported in the literature. It is also found from analysis that processing geometry of die and the friction between the die and the work-piece has great influence on the extrusion pressure and flow in the process, where these parameters lead to strain distribution of workpiece becomes inhomogeneous and non uniform.**

***Index Terms*— Severe Plastic Deformation, Equal Channel Angular Pressing, Finite Element Analysis, Ultra Fine Grained, Workpiece, If-Steel.**

I. INTRODUCTION

Interstitial-free (IF) steels constitute an important class of steels having carbon content less than 0.01 wt.%. These steels are extensively used in automotive industries for making car bodies owing to the high formability that they posses. In recent years, efforts have been made to improve the strength of this class of steels by means of grain refinement mostly through Severe Plastic Deformation (SPD) processes. The primary idea in all of severe plastic deformation (SPD) processes is to develop very large plastic deformations within metals and alloys, with associated dislocation substructures and then to use the processes of recovery, recrystallization and rearrangement of microstructure to develop the crystalline microstructures of interest. SPD processes are of great interest in industrial forming applications, as they give rise to significant refinement in microstructures and improvements in mechanical and physical properties. However, most SPD processes result in ultra fine grain sizes in most materials. Equal Channel Angular Pressing (ECAP) is the most common technique in which very large plastic deformations are developed by forcing a metal rod (the sample) through a die, with a die axis that changes direction suddenly (resulting in substantial shear deformation). The sample dimension after pressing remains the same. The plastic deformation behaviour of the materials subjected to ECAP was analyzed various numerical experiments for the die angles of 90°, 120° and 150°, different friction conditions, and different round corners under plane strain condition and an isothermal system [1-2]. There are four basic processing routes (A, B_A, B_C and C) in ECAP, in route A the sample is pressed without rotation, in route B_A the sample is rotated by 90^o in alternate directions between consecutive passes, in route B_C the sample is rotated by 90^o in the same sense (either clockwise or counterclockwise) between each pass, in route C the sample is rotated by 180^o between passes and these routes introduce different slip systems during the pressing operation so that they lead to significant differences in the microstructures produced by ECAP. IF Steel was processed by room temperature ECAP upto 8 passes using routes A and C and the experimental results on microstructural evolution and the variation of the mechanical properties were found [3-4].

A schematic diagram representing such a process is shown in figures 1 & 2 with a hard plunger forcing a metal sample between two channels of equal size connected by an angular section (thus the name Equal Channel Angular). The magnitude of the shear strain that is developed in a single pass of the specimen through the die is determined by the die geometry and particularly the included angle ϕshown in the figure. The angle ψ subtended by the external radius is also an important parameter. Various obtuse die angles and dimensions may be used and die design is critical a critical part of an effective ECAP process [5]. The friction between the die and the work-piece has great influence on the extrusion pressure and flow in the process; this was studied by finite element modeling [6]. Recent studies on the plastic deformation behavior during ECAP suggested that the influence of material properties, die geometry, friction conditions, back pressure, load, temperature etc. play vital role on microstructure and grain size of the workpiece [7-13].

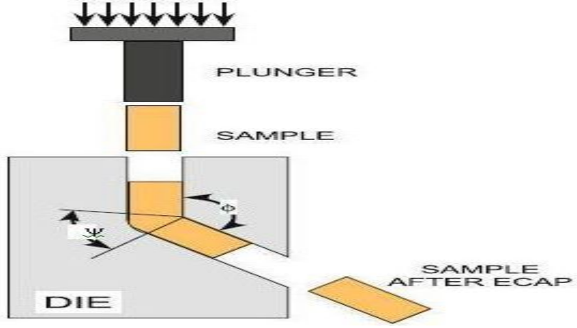

Figure 1: Schematic view of the die used in equal channel angular pressing (ECAP) [5]

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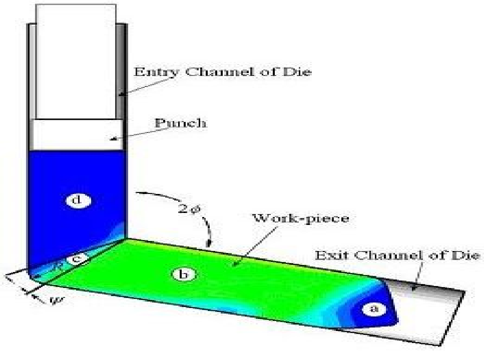

Figure 2: The principle of the ECAP schematically shown [6]

In the present study, a quasi-static solution to the ECAP process by the FE modeling was done using two channels at angle of intersection 120°, considering only single pass of pressing and adopting a plain strain condition. The generalized Coulomb law was assumed in all cases.

II. FINITE ELEMENT ANALYSIS

The two-dimensional plane strain element (Plane 182) was carried out using the ANSYS package. The material properties used are for If Steel. The workpiece is considered of dimensions 10 mm (width) x 50 mm (height) and unity thickness since a plane strain condition is assumed. The stress strain relation is

$$\sigma = 544.96(0.004852 + \varepsilon)^{0.235}$$

The material properties are

Table 1: IF-Steel Material Properties	
Young Modulus	195000 Mpa
Poisson ratio	0.29
Yield Stress	186 Mpa

For the contact the elements considered are Target 169 and Contact 172. The workpiece was modelled with four node plane strain elements. Only one half of the model is considered and symmetric boundary conditions have been applied. A smooth fillet radius was chosen to avoid convergence problems. The friction coefficient between the die channel (Rigid target surface) and workpiece (Contact surface) are 0.00, 0.05, and 0.10. In order to compare the results with the results previously published [14] the values of friction coefficient (μ) are taken as 0.00, 0.05 and 0.1.

III. RESULTS AND DISCUSSIONS

Figure 3, 4 and 5 show the extrusion force for unit thickness Vs workpiece displacement for the friction conditions 0.0, 0.05 and 0.1 respectively. It can be observed as expected the increase in the friction coefficient requires higher pressures or punch loads. It can be seen that an increase of extrusion force initially (upto 7.5 mm for zero friction condition) and afterwards decreases in the extrusion force. This is in agreement with the results published by others.

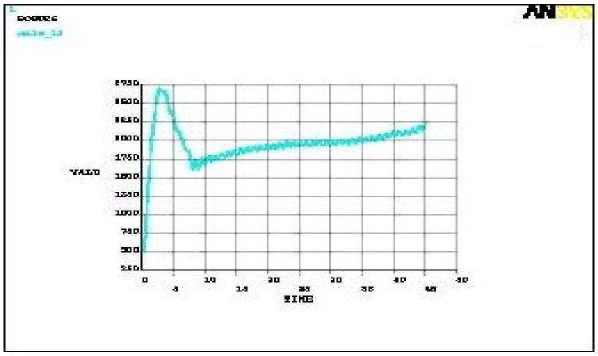

Figure 3: Extrusion Force Vs Workpiece Displacement (μ = 0.00)

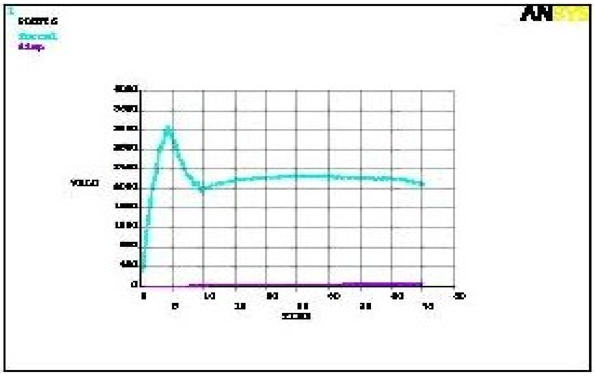

Figure 4: Extrusion Force Vs Workpiece Displacement (μ = 0.05)

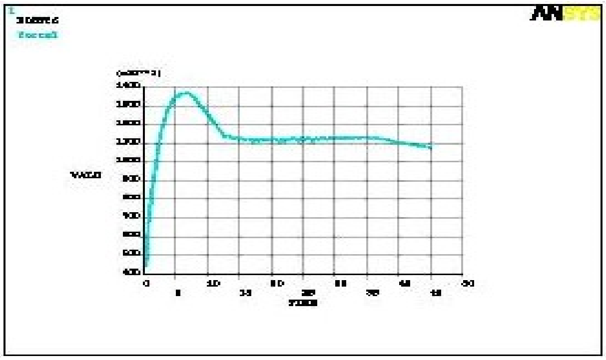

Figure 5: Extrusion Force Vs Workpiece Displacement (μ = 0.1)

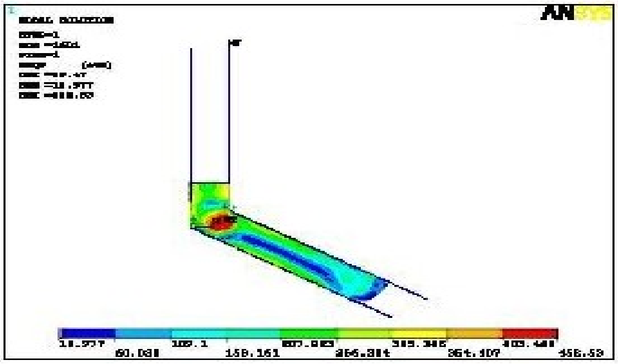

Figure 6: Von Mises Stress (μ = 0.0)

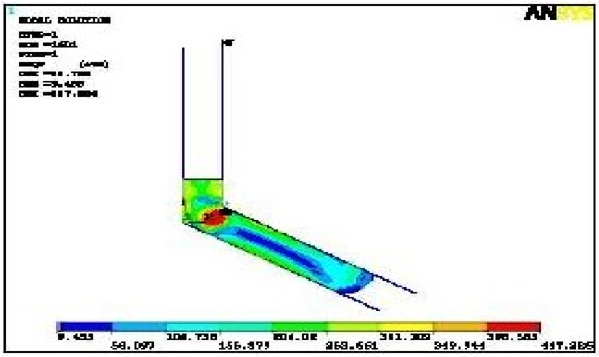

Figure 7: Von Mises Stress (μ = 0.05)

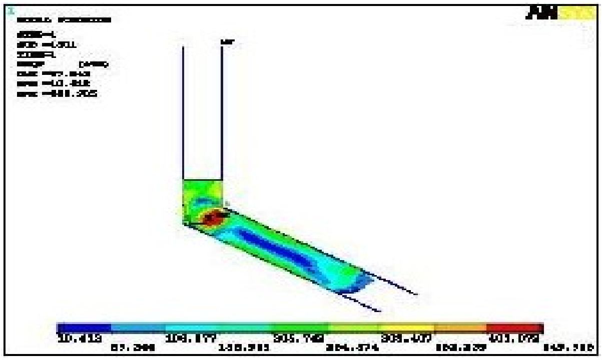

Figure 8: Von Mises Stress (μ = 0.1)

Figure 6, 7 and 8 show the Von Mises stress for the friction conditions 0.0, 0.05 and 0.1 respectively. This is a very important to understand the material behaviour i.e. if the Von Mises Stress exceeds the Ultimate Tensile Stress (UTS), then the material is considered to be at the failure condition.

Figure 9, 10 and 11 show the Von Mises Plastic Strain respectively. In this it is observed that the strain reaching high value is highly localized and it is not uniform and same on the total workpiece. A new methodology has to be developed so that the work piece undergoes high plastic strains over the entire workpiece uniformly.

Figures 12, 13 & 14 give the Shear Strain for the friction conditions 0.0, 0.05 and 0.1 respectively. Since shear strains give an indication of the plastic deformation undergone and indirectly the microstructure.

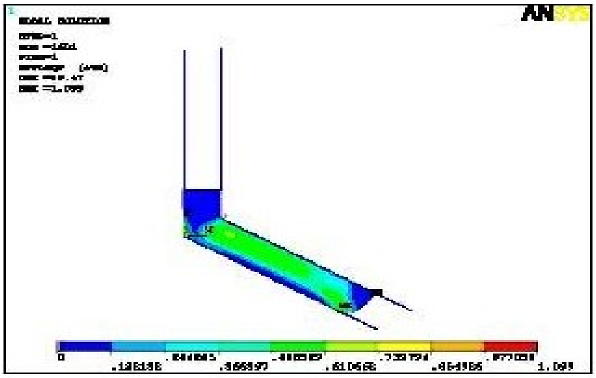

Figure 9: Von Mises Strain (μ = 0.00)

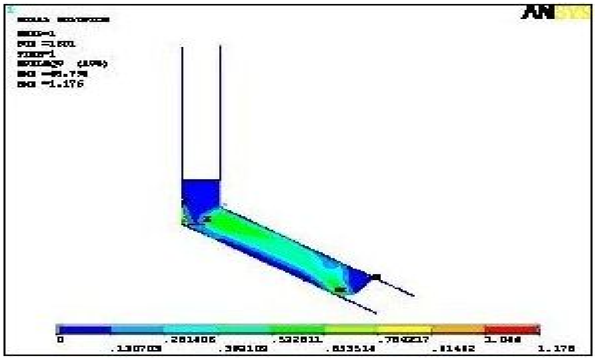

Figure 10: Von Mises Strain (μ = 0.05)

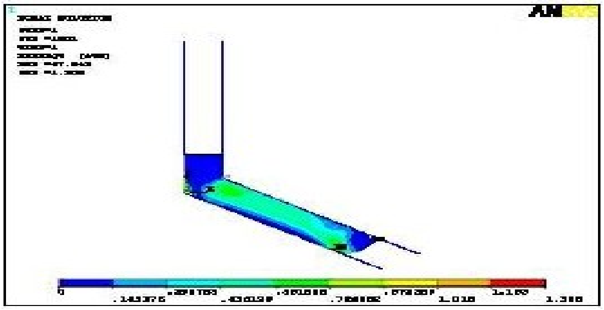

Figure 11: Von Mises Strain (μ = 0.1)

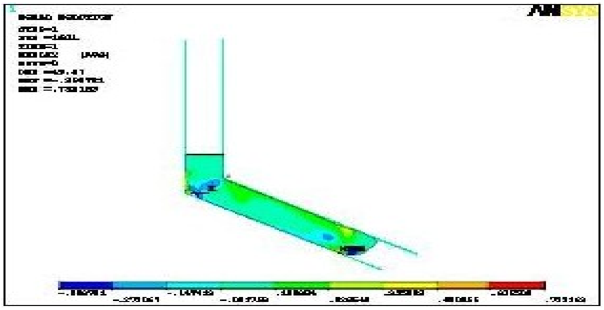

Figure 12: Shear Strain (μ = 0.00)

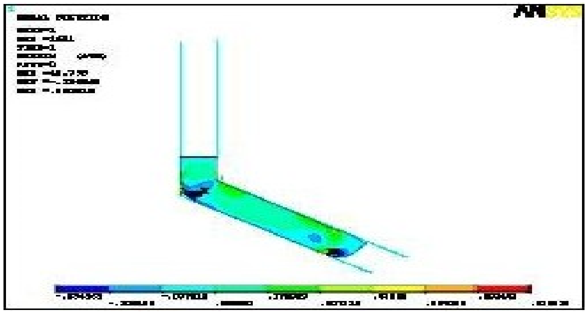

Figure 13: Shear Strain (μ = 0.05)

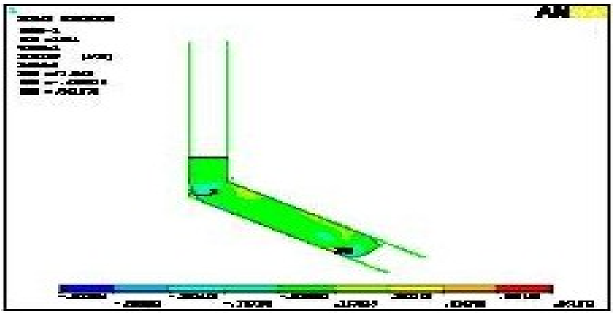

Figure 14: Shear Strain (μ = 0.1)

CONCLUSIONS

Plastic deformation behaviour of IF-Steel during ECAP is analyzed under plain strain condition by assuming the generalized Coulomb law in all cases through finite element method using ANSYS package. These were carried out considering strain hardening and frictional contact. It is found that the plastic deformation behaviour of IF Steel during ECAP is localized and the extrusion pressure increases with increasing friction. Also it is found that the deformation is inhomogeneous and non uniform.

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