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Influence of Process Parameters on Equal Channel Angular Pressing Process Towards Stress, Strain And Deformation

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Abstract- In this work, a 3D FEM model was considered and performed to obtain the effective stress, effective strain, extrusion load and temperature distribution maps of Al−2024 deformed by the ECAP. 3D FEM simulations were carried out using the DEFORM-3D V.6.1 software. DEFORM-3D is a FEM based program to analyze different metal forming processes. Unlike, most FEM software DEFORM-3D provided an easy graphical interface that provides easy data preparation and analysis. In this study influence of process parameters on equal channel angular pressing process towards stress, strain and deformation have been explored.

Keywords- Equal channel angular pressing, stress, strain, deformation,

I. INTRODUCTION

The evolution of microstructure of metallic materials during plastic deformation has been extensively studied over the last few decades [1,2] It is generally accepted that if metallic materials are deformed at room temperature, average subgrain/cell size decreases with strain. Hence, plastic deformation processing can be a possible method for grain refinement of metallic materials.

In recent years, severe plastic deformation (SPD) process was developed by Russian scientists as a new method of manufacturing bulk specimens having ultrafine grained (UFG) microstructure [3]. The SPD processed materials show not only the unique physical and mechanical properties inherent in various UFG materials but also a number of advantages over nanostructured materials manufactured by other methods through powder processing. Several methods of SPD processing, such as equal channel angular pressing (ECAP), [4–6] high pressure torsion straining (HPT), [7] accumulated roll bonding (ARB), [8] multiple forging, [9] multipass coin-forging, [10] repetitive corrugation and straightening, [11]conshearing, [12] continuous confined strip shearing, [13] equal channel multi-angular pressing (EC- MAP) [14] etc., have been developed to process bulk materials with UFG microstructures. Among them, the ECAP process is so far the most viable forming procedure to extrude material by use of specially designed channel dies without a substantial change in geometry and to make an UFG material, see Fig. 1. The properties of the materials are strongly dependent on the plastic deformation behaviour during pressing, which is governed mainly by die geometry (a channel angle, corner angle [15] and perform geometry), material properties (strength and hardening behaviour), [16,17] and process variables (temperature, lubrication and deformation speed) [18]. Because the evolution of microstructures

Application of sufficient stress on metallic materials inevitably results in plastic deformation. As thecapacity for plastic deformation of most materials is limited, attempts to severely deform materialsusually lead to their failure. As thecapacity for plastic deformation of most materials is limited, attempts to severely deform materialsusually lead to their failure. However, if during plastic deformation restoration mechanisms prevail (mechanisms where crystalline defect density rearranges or annihilates) the ability of a material.Application of sufficient stress on metallic materials inevitably results in plastic deformation. As the capacity for plastic deformation of most materials is limited, attempts to severely deform materials usually lead to their failure.

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II. PAST STUDIES

Lule Senozet al. (2020) presented optimization of equal channel angular pressing (ECAP) parameters was aimed to improve the mechanical and microstructure properties of Al–Zn–Mg alloy using the Taguchi method with ANOVA analysis. Three different parameters (process temperature, processing route, and the number of passes) with three different levels were examined so L_9 (3^3) orthogonal array was employed. The effects of these parameters on the microstructure properties of Al–Zn–Mg alloy were studied using X-ray diffractometer, optical microscopy, scanning electron microscopy, electron backscatter diffraction and transmission electron microscopy and mechanical properties were measured by Vickers micro-hardness experimental tests.

Dumanićet al. (2020) presented simulate high-pressure die casting of A356 semi-solid aluminum alloy using casting process simulation tool. Taking into account the viscosity of the semi-solid slurry and the mold-filling characteristics in high-pressure die casting, the mold for semi-solid aluminum alloy had been designed.

Chen, Lianget al. (2020) presented the hot extrusion process of an Al-Zn-Mg plate studied via numerical and experimental methods. The multi-objective optimization method was employed to optimize the structure of the feeder chamber. Additionally, an extrusion experiment was conducted using the optimal feeder chamber. Based on above analysis, the optimal structure of the feeder chamber was obtained, and the standard deviation of the flow velocity was decreased from 0.827 to 0.499 mm/s.

Taghiabadiet al. (2020) presented friction stir processing (FSP) applied to improve the mechanical properties and quality index of cast A356 Al specimens containing different amounts of recycled machining chips (0, 25, 50, and 75 wt %). Toward this end, the as-cast samples were subjected to optimized FSP parameters (rotation speed of 2000 rpm and traverse speed of 12 mm/min). According to the results, increasing amount of recycled A356 alloy substantially reduced the tensile properties and quality index of the alloys.

Srinivasanet al. (2020) presented Aluminum composite with VAL12 as matrix and La_2O_3 as dispersoids fabricated through liquid metallurgy route involving liquid forging operation through squeeze casting process in the present investigation. The frictional characteristics of as-cast aluminium composites are studied under dry sliding wear tests by varying the service factors. The samples prepared were examined for its uniform distribution of the reinforcement, phases formed using advanced characterization facilities.

Kahramanet al. (2019) examine the surface roughness value of aluminum 7075 workpiece material during milling operation by considering three steps: (1) the multi-nonlinear regression (MNLR) modeling basis of Taguchi design, (2) optimization based on signal to noise ratio (S/N), and (3) probabilistic uncertainty analysis depending on Monte Carlo technique as a result of depth of cut, cutting speed and feed rate. The depth of cut of 0.2 mm, cutting speed of 900 m × min^{-1}, and feed rate of 0.1 mm × $tooth^{-1}$ were determined as Taguchi-optimized conditions with a surface roughness of 0.964 μm.

Angellaet al. (2019) presented an innovative method that aimed to improve toughness behavior in Al alloys. The unconventional method introduces an intermediate warm working step between the solution treating and the final ageing treatment for the high resistance aluminum alloy AA7050. The results showed several benefits starting from the grain refinement to a more stable fracture toughness KIC behavior (with an appreciable higher value) without tensile property loss. A microstructural and precipitation state characterization provided elements for the initial understanding of these improvements in the macro-properties.

III. OBJECTIVES OF STUDY

1. To do 3D FEM simulation process for Al 2024 alloy using DEFORM-3D software at different channel angles 90º, 105º, 120º and 135º and corner angles 0º, 10º, 20º and 30º for the single ECAP pass. To obtain the results regarding the effective stress and strain, temperature, extrusion load on channel angle and corner angle.

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IV. RESEARCH METHODOLOGY

In this work, a 3D FEM model was considered and performed to obtain the effective stress, effective strain, extrusion load and temperature distribution maps of Al−2024 deformed by the ECAP. The rigid-viscoplastic 3D FEM simulations were carried out using the DEFORM-3D V.6.1 software. DEFORM-3D is a FEM based program to analyse different metal forming processes. Unlike, most FEM software DEFORM-3D provided an easy graphical interface that provides easy data preparation and analysis. The steps involved in simulation using DEFORM-3D program consists of three steps. First, the pre-processor, where the simulation model created, assembled, or even modified the data required in the simulation, and generating the database file.

The second part is the simulation module where the calculations needed to analyse the forming process and writing of the results to the database file are performed. The simulation module reads the database file, performs the actual solution calculation, and appends the appropriate solution data to the database file. Furthermore, the simulation module enables the automatic mesh generation (AMG) system to generate a new FEM mesh. Post processor is the last step that allows reading the database from the simulation module and displays the results accordingly.

For performing simulation, workpiece was considered to be a rigid-plastic body. Therefore, the Billet considered is circular in section with diameter of 20 mm and length 70 mm, split mould including the bottom die, the top die and the ram, the bottom die channel interior angle has been varied from ϕ = 90° to 135°, corner angle has been varied from Ψ = 0° to 30°. CATIA V5R21 software was used to establish a physical model, the assembly model of workpiece geometry, the punch and die is shown in Fig. 1. The third step in the pre-processing is the workpiece meshing process.The processing temperature was 20°C and the domain discretization and meshing was made using 4161 nodes and 3908 polygonal surfaces for the workpiece.

The mesh was automatically re-meshed if the elements became too distorted during the forming process simulations. The fourth step in the pre-processing is the die and the punch drawing and loading into the program in the same way used in the case of the workpiece.

Finally, the contact boundary conditions and the coefficient of friction among the die, punch, and the workpiece were applied. The contact boundary conditions among the die, the punch, and the workpiece can automatically generate. The tolerance between the die and punch on one side and the workpiece on the other side can be obtained automatically by DEFORM-3D and then the contact nodes are generated. Then, the value of the coefficient friction between the die and punch on one side and the workpiece on the other side can be set depending on the forming process condition. The workpiece top surface is in a complete contact with the punch which moves with a constant speed of 1 mm/s.

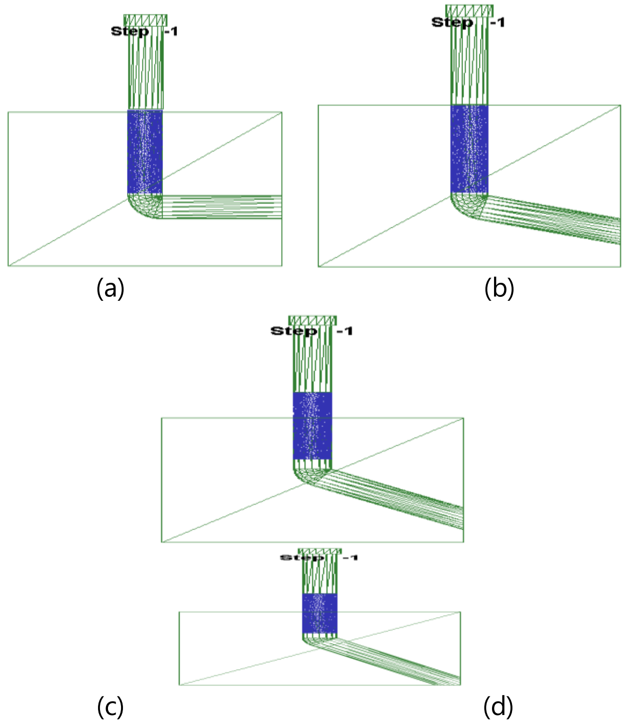


Fig 1: Assembly diagram of billet, ram and die with different channel angles (a) 90°, (b) 105°, (c) 120° and (d) 135°

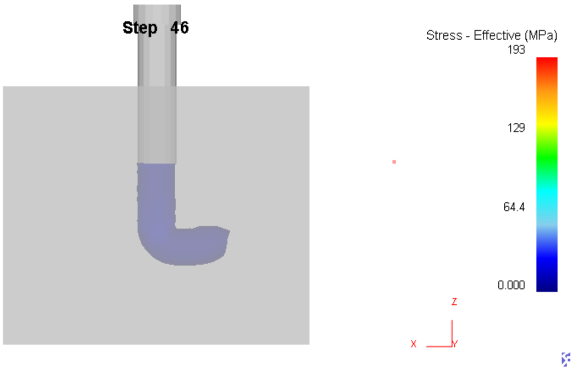
V. SIMULATION RESULTS AND ANALYSIS

The result obtained from thesimulations and their analyses are presented in the following paragraphs.

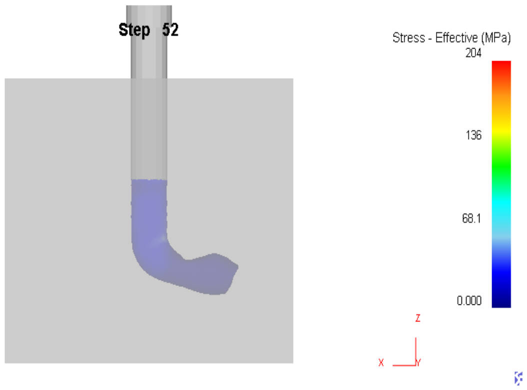
1.Stress analysis

In terms of stress distribution, it can be observed that the maximum stress occurs within the corner region of the channel. Presence of outer radius lowers the maximum stress and widens the stress distribution.

Presence of additional inner radius lowers the maximum stress and spreads the stress distribution even further. These happen on both 90˚ and 120˚ channel angles with corner angle 0˚ and 20˚. It is also noted that maximum stress that occurs on 120˚ channel angle is higher than on 90˚ channel angle for any corner radius for all simulation cases.

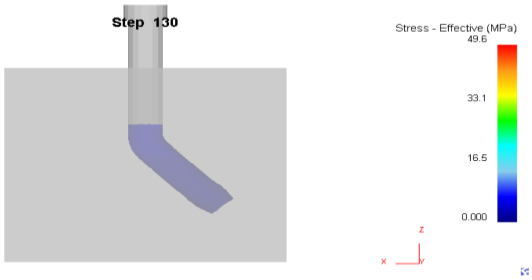


(a) Channelangle (90º) and corner angle (0º)



(b)Channel angle (105º) and corner angle (10º)

(c)Channel angle (120º) and corner angle (20º)



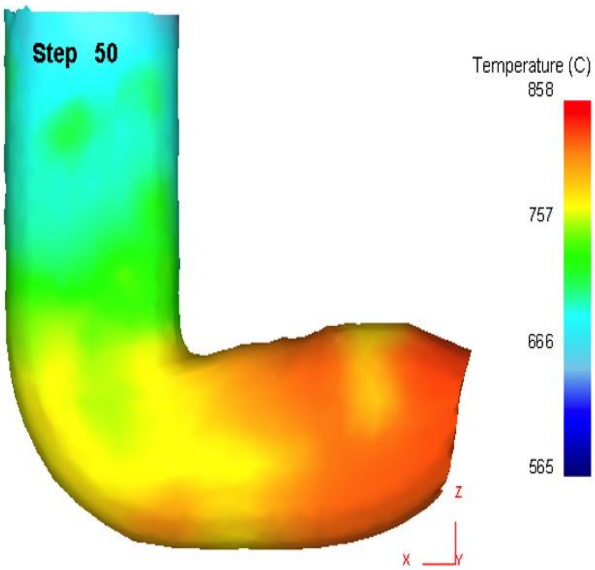
(

d) Channelangle (135º) and corner angle (30º)

Fig . 1: Effective Stress distribution in billet

Temperature distribution

The ECAP temperature is the most important parameter among others because of its complex effect on microstructural evolution and variations of stated variables. Figs.4.4 indicates the strain distribution in the billet pressed at different temperatures in both ECAP dies with different channel angles 90º, 105º, 120º and 135º. Because of high stacking fault energy (SFE) of Al-2024, it can be concluded that the portion of low-angle grain boundaries is increased with increasing the temperature that consequently yields faster recovery at elevated temperatures [23]. That is to say, as temperature rises, the formation of DRV is facilitated and the critical strain for commencement of sub-grain arrangement decreased as well.



Channel angle (90º) and corner angle (0º)

Fig 3. Temperature distribution in billet

VI. CONCLUSION

Finite element analysis was utilized to simulate the ECAP process of Al2024 alloy. The following points can be highlighted from the present investigation. It can be concluded from the results that the forming load is effected highly from the both channel and corner angle. Also the maximum load of increases gradually hence mechanical properties are improving such as strength, hardness and so on. The maximum work-piece temperature is obtained at the deformation zone for all values of channel and corner angles.

1. An increase in die angle or outer corner angle caused a decrease in the plastic strain level. On the counter side, a lower amount of strain and force has been obtained with an increase in working temperature during ECAP. However stress and strain of workpiece is bovious non-uniform for one pass ECAP and uniformity can be improved with the increase number of pass.
2. It was perceived from FEM results that the most critical section potent to crack formation is the billet top surface that is due to high tensile mode of maximum principal stresses on the zone as well as concentration of large plastic strain.

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