Design optimization of alloy component with E-CAP Process Using DEFORM 3D software

Pramod Kumar[1], Vijay Bhan Dinkar[2], Dr. Vinay Yadav[3]
[1]*MTech scholar, Department of Mechanical Engineering RNTU, Bhopal, India*
[2]*Asst. Professor, Department of Mechanical Engineering RNTU, Bhopal, India*
[3]*Vice-Principal of RNTU, Bhopal, India*

ABSTRACT- **An angled channel, either square or circular, is usually used to handle billets in the ECAP process. The material is then deformed by shear deformation in both channels (entry and exit). This point is called the channel angle (Φ) and it is recognized that the angle subtended by the outer arc is the corner angle (Ψ). In three dimensions (3D), DEFORM-3D evaluates the flow of complicated metal forming processes. It is a sophisticated process simulation system. Material flow can be forecasted with DEFORM 3D while eliminating the time and cost of shop testing. A 3D FEM model again for effective stress, efficient strain, extrusion load, as well as the ECAP temperature deforming maps of Al–2024 were taken into account and carried out during this study. According to our results, both the channel angle and corner angle strongly influenced the forming load. As the maximum load increases, so do mechanical properties like strength, hardness, and so on. It will be shown from FEM results that billet top surfaces have the highest tensile modes and significant plastic strain concentrations in the zone are the most crucial to crack initiation.**

***Key Words* - DEFORM-3D, AI-2024, E-CAP, FEM, and UFG-structured.**

I.INTRODUCTION

A. E-CAP Overview

When metallic materials are stressed enough, plastic deformation is eventually achieved. Since the ability of many materials to plastic deformation seems restricted, attempts to distort materials seriously typically lead to failure. When restore processes prevail throughout plastic deformation. The processes for restoring metals are dynamic recovery. These aid to alter the microstructure even by arrangement of line flaws in surface defects (bordering), thus lowering its distance and improving its microstructure. E-CAP has been one of Segal's early 1980s severe plastic deformation (SPD) processes. A metal billet is usually handled via an angled channel in the E-CAP process, either square or circular. Both channels (entry and exit) are then crossed with a shear plane, in which the material is subjected to shear deformation. This point is called the channel angle (Φ) and it is recognized that the angle subtended by the outer arc is the corner angle (Ψ). For the most typical ECAP (Φ = 90o, Ψ = 0o), the effective strain introduced after that a single pass is around 1.15." As a result of the SPD, the grain becomes refined and hence the yield strength increases as geometric borders provide effective obstacles for the movement of dislocation [4, 5]. Furthermore, following many ECAP passes, an exceptionally high ductility can be seen in several materials [6–8].

The SPD techniques can reduce the size of the particle which eventually improves the micro or mechanical characteristics. It has recently come to light that perhaps the SPD application can help refine the grain size of various metals and alloys to the sub-micrometer and Nano scale level [1]. The widely known Hall–Petch connection demonstrates that maybe the material strength may be increased by lowering the average material grain size and by assigning an equation to average grains size both produce stress and friction stress σ (1):

$$\sigma y = \sigma 0 + kd^{-1/2} \qquad (1)$$

Here, k = yielding constant, d = size of Ultra-finished grain material (UFG).

This relationship gives the way to enhance strength, termed as grain boundary reinforcement.

B. Severe Plastic Deformation (SPD)

SPD procedures that could be explaining by metal forming techniques can be effective and inexpensive in producing UFG material, because the severe strain is applied on bulk samples while maintaining virtually the same dimensions of something like the material leading to UFG material production. As the total size of the samples throughout the operation does not vary, the technique may be repeatedly used to produce very high stresses.

A variation of such a recovery process, called a continuous dynamical re-crystallisation (cDRX) or a geometric dynamic recovery process (gDRX), is considered to be used to further refine grains by means of severely plastic deformity (SPD). In cDRX, cells and sub grains divide grains, these eventually grow into borders of high-angle grain. In gDRX the wide strains of deformation create tight grain borders that meet or pinch off, which lead to finer grains. When materials can indeed be deformed repeatedly plastically without a clear change of shape, extreme plastic deformation gets achieved, i.e., the general shape is that at the beginning of both the deformation. Several approaches for obtaining SPD are used, a most popular being equal channel-angular pressure (ECAP). Currently, a number of new techniques for developing the finest seeds materials utilizing SPD have already been introduced. The advantage of SPD is that it generates refined grains at relatively low temperatures. SPD additionally provides high-density components, which may be used in a variety of automotive, aerospace, and defence applications. Table 1.1 summarizes the various SPD methods, including schematic designs and the plastic strain that may be achieved.

Table 1.1: Summary of major SPD processes

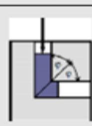
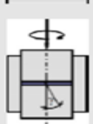
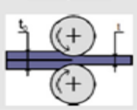
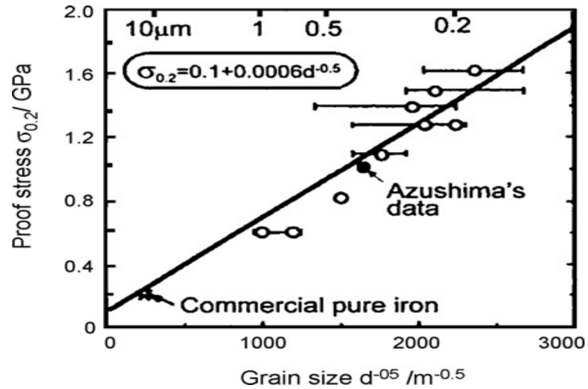
Process name	Schematic representation	Equivalent plastic strain
Equal channel angular extrusion (ECAE) (Segal, 1977)		$\varepsilon = n\frac{2}{\sqrt{3}}\cot(\varphi)$
High-pressure torsion (HPT) (Valiev et al., 1989)		$\varepsilon = \frac{\gamma(r)}{\sqrt{3}}, \gamma(r) = n\frac{2\pi r}{t}$
Accumulative roll-bonding (ARB) (Saito, Tsuji, Utsunomiya, Sakai, 1998)		$\varepsilon = n\frac{2}{\sqrt{3}}\ln\left(\frac{t_0}{t}\right)$

Figure 1.1 [6] shows the connection between proof stress and particle size in pure iron. According to the Hall–Petch connection, the proof stress changes inversely with the square root of the grain size. The proof stress of ultra-fine-grained irons with sub-micrometre grains would be found to be five times higher than those of commercially pure iron.



"Fig. 1.1: Relationship between proof stress and grain size of pure iron

Equal Channel Angular Pressing

The ECAP has been initially introduced in Minsk by Segal with his team members in the early 1980s at an institution there in former Soviet Union, which was also known as equal-channel angular extrusion (ECAE). A well lubricated material sample is pushed via a plunger by two crossing canals that meet at such an oblique angle called the die channel angle Φ.

ECAP is one of most often used severe plastic deformation processes for driving nano or ultra-fine grain microstructures at low temperature homologues. The method works through creating a high shear strain via repetitive extrusion stages, which is ideal for materials used during industrial applications.

One of the many procedures used for producing nano-structured materials, there is only a possibility for producing large samples appropriate for industrial applications using extreme plastic deformation processes (SPD).

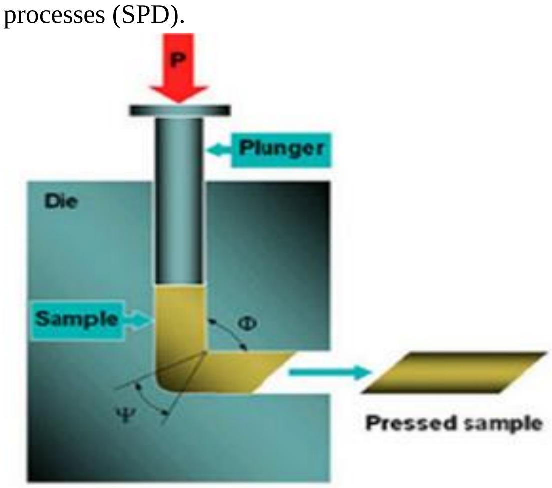


Fig 1.2: Principle of ECAP

Equal Channel Angular Pressing (ECAP) this is amongst the most used Severe Plastic Development

Methods (SPDs) for the production of high-quality grains, mechanical and physical characteristics in a variety of metals and alloys. Recently, several fundamental features of SPD methods, including the production of ultrafine kernels as well as the processes that underline their great strength, have shown strong and increasing attention. In SPD-ECAP investigations, aluminum as well as its alloys Cu and Ti are primarily used, with Ti seriously being taken into consideration with orthopaedic implants.

II.LITERATURE REVIEW

Kangxuan Ren (2021) Zn-Cu alloy's as-cast microstructure is mostly made up of equi axed -Zn grains. Triple heterogeneous microstructure, including heterogeneous distribution of $CuZn_4$, precipitates after eight runs of ECAP, "η-Zn grain size, and η-Zn grain texture was generated as the precipitates-free zones (PFZs) and precipitates zones (PZs). The PFZs in all ECAP alloys exhibit the similar microstructure with fine grains (5.4–15.4 μm) and strong texture intensity (13.88–21.26)." In low-temperature ECAP alloys, the PZs are made up of ultrafine $CuZn_4$ precipitates with DRX grains having weak texture (4.90-8.48), but following high-temperature processing, these include DRX grains with an even greater texture intensity (41.91-42.09) than the PFZs.

Li, Y., Jiang, (2021) "Pre-homogenization and high-pass RD-ECAP processing offers an efficient method for AZ91 alloy's second phases' homogeneity and grain refinement. The ductility is enhanced by the fine grain structure with high SF basal, which also creates favourable circumstances for DRX in subsequent plastic forming, facilitating SPHRR. After SPHRR on the PH + ECAP alloy, the sample exhibits a bimodal grain structure with a large fraction of fine recrystallized grains with an average grain size of 3.6 μm and a low amount of coarse un-recrystallized grains with an average grain size of 75.6 μm. With an ultimate tensile strength of 420 MPa, yield strength of 335 MPa, and elongation-to-failure of 19%, the PH + ECAP + R alloy exhibits excellent mechanical properties. This is primarily due to the bimodal grain structure, relatively high SF basal associated with fine DRX grains, and the dynamically precipitated nano-scale second phase particles. (4) The pre-homogenization and RD-ECAP pre-processing could indeed efficiently produce a homogenous fine-grain structure, which is appropriate to improve the plastic formability of difficult-to-deform materials like magnesium alloys. As either a result, there is a bright future for these processes in industrial settings.

LuleSenoz et al. (2020) the objective has been to optimise the mechanical and microstructural optimization of equally channel-angular pressure (ECAP) parameters was given. The L9 (33) orthogonal array was evaluated with three distinct parameters (processing temperature, processing route and number of passes) at three levels. Those parameters were tested using the X-ray diffractometer, the optical microscope, and the impact on Al–Zn–Mg alloy micro-structure characteristics, Vickers experimental micro-hardness test was used to assess electron Microscopy, electron backscatter diffraction and electron transmission microscopy and grain were described among the specimens collected. Eight ECAP passes in route Bc at 100 °C are shown to fulfil the best micro-hardness value and also the lowest kernel size value as a requirement. Micro-structural studies have shown that the size as well as the number of passages and ECAP pathways have been greatly impacted by the temperature. The results show that the increased ECAP temperature causes the proportion of HABs to fall, grain size to grow and grain equivalents to rise.

Taghiabadi et al. (2020) "presented friction stir processing (FSP) Designed to enhance the mechanical & quality index of cast A356 Al specimens including various quantities of recycled chips (0, 25, 50, and 75 wt percent). To this purpose, improved FSP parameters (the rotation speed of 2000 rpm and the travel speed of 12 mm/min was presented for the as-cast samples). The results show a large decrease in tensile characteristics and quality index of both the alloys, as both a result of increase in recycled A356 alloy. For example, adding 25, 50, and 75% machining chips toward the alloy lowered its quality index correspondingly by 18, 42, and 65%. SEM tensile fractography indicated that the primary variables affecting quality are really the oxides and oxide-associated flaws induced. Furthermore, there were improved characteristics in the samples of FS Ped. The FS Ped quality index of 25, 50 and 75% wt recycled chips were enhanced by 50, 100, and 190 correspondingly compared with the as-cast samples containing the same quantities of machining chips. SEM exams on the microstructure and fracture surface showed that perhaps the elimination of caster defections, in particular, oxide inclusions but instead their related defects are really the leading factors responsible for the quality advancement, and also the ultra-fine distribution of second phase particles and also the formation of ultrafine grains.

Srinivasan et al. (2020) Presented in the current study aluminium composite with VAL12 as matrix and La_2O_3 as dispersoids made from liquid metallurgy using the squash casting method. Dry sliding wear experiments investigate the frictional properties of the as-cast aluminium composites by different variables of service. The preparation samples were examined for their consistent reinforcement distribution, with the use of modern characterization installations. Taguchi orthogonal array technique is used for experiment design when wear and frictional coefficient responses are observed. The mechanistic investigations are conducted either by analysis of the morphology of wear surfaces with SEM. Delamination and abrasion with higher charges owing to thermal adhesivity and mechanisms with lower charges are predominantly present in AMMC. The wear behaviour of AMMCs in un-sliding circumstances is characterized mainly by the load and sliding distance.

Gloria et al. (2019) The most significant types of metallic products discussed, comprising alloys, Ti alloys, Mg alloys, steels, ni super alloys and metal matrix composites (MMC), will offer a review of current progress and emphasize contemporary challenges and prospects connected to aeronautical metals.

Hussein et al. (2018) introduced a new optical non-contact method to investigate commercially pure copper surface roughness. The finite element approach (FE), which simulates the machining process, had been used to prevent stress while orthogonal cutting. Experiments were particularly concerned about the influence on the surface ruggedness of copper from the cutting speed (N) and feed rate (f). The microscope of the scanning electron (SEM) was used to measure the surface changes under various processing conditions. The mathematical model Johnson-Cook has been accepted and used to establish material properties. In addition, according on the machining condition, the maximum Von-Mises stress was anticipated. For the analysis and answer surface methodology (RSM) a coding software package (ABAQUS/CAE) were utilised to display the results. The results indicated a substantial impact on surface roughness as well as the Von-Mises stress of copper by the feed rate/cutting speed relationship. An increase of 14% in surface roughness when increased cutting speed is noticed. A good agreement among experimental and analytical findings were obtained.

Anna Mogucheva et al. (2016) provided an impact on microstructure and mechanical property of an Al-Li-Mg-Sc-Zr alloy submitted to the Equal-Channel Angular Pressing (ECAP) were studied following a post deformation resolution treatment followed by water quenching and artificial mainly stays unaltered. Due to ECAP processing, however, the considerable grain refining alters the precipitation sequence after ageing dramatically. The coarse particles of a S1-phase (Al_2LiMg) are precipitated at high-angle borders in the aluminum-lithium alloy with such an ultrafine-grained (UFRG) microstructure; no development inside the grain-interior of nanoscales occurs of consistent δ′-phase (Al_3Li). Increasing the count of high-angle limits leads to increase with in S1 phase. As both a result, despite considerable ECAP grain refining, no appreciable improvement in strength is achieved.

Ehsan Mostaed et al. (2014) presented Equal channel angular pressing (ECAP) In order to enhance its mechanical characteristics, Mg alloys were examined thoroughly by a common severe plastic deformation (SPD) process. However, the strength of something like the ECAP Mg alloys synthesized was significantly poor due to high processing temperature & texture softening. In just this study, a combination of grain retaining and precipitate hardening even by application of heat treatment has produced high strength and excellent ductility in magnesium alloy ZK60 equal channel angular pressing (ECAP). Due to pre-heat treatment, fine metastable phase particles ($MgZn_2$), which enhanced alloy hardening and improved both strength and ductility, precipitated during the extreme plastic deformation. Whenever the ECAP temperature was gradually lowered, grain has been further refined to around 500 nm but there were more hierarchically precipitated $MgZn_2$ particles. Thus, the yield strength and the ultimate tensile strength increased significantly, however, the ductility was nearly maintained.

III.RESEARCH METHODOLOGY

DEFORM-3D is a sophisticated process simulation system developed to evaluate the flow of complicated metal forming processes in three dimensions (3D).

A. DEFORM-3D Software Overview

DEFORM 3D is a handy and effective tool that can forecast material flow even without cost or delay of shop testing in industrial forming processes. Applications typical include:

- Closed die forging
- Open die forging machining
- Rolling
- Extrusion
- Heading
- Drawing
- Cogging
- Compaction
- Upsetting

DEFORM-3D It offers designers and analysts who work in a variety of applications, development and research an extraordinary degree of freedom. DEFORM-3D allows user routines & variables defined by the user. Complex, arbitrary contact, multi-distorting body capabilities lets people to model mechanical joints and combine stress analyses.

B. Analyses Procedures

First, the pre-processor, whereby data necessary for simulation were produced, mounted, or even updated, or where the database file is generated.

Pre Processor

1. A pre-processor to create, assemble or change data for simulation analysis and generation of the necessary database file.
2. A graphical user interface is used by DEFORM Pre-processor to compile the data needed for the simulation.
3. Input Data Includes Following Things:
   a) Object description
   b) Material data
   c) Inter object conditions
   d) Inter material data
   e) Simulation controls

Simulation

1. A simulation engine for such performance of numerical computations necessary for analysis and the writing towards the database file of findings.
2. The motor of a simulation reads its database file, conducts calculations of the real solution and attaches relevant database solution data.
3. The simulation engine additionally interacts the with "Automatic Mesh Generation (AMG)" system smoothly to build a fresh FEM mesh on the workpiece when possible.

Post Processor

- A postprocessor enabling reading and viewing the results of the database from simulation engine and also for the extraction of numerical data.
- The postprocessor seems to have a graphical user interface for viewing geometry, field data like pressure, temperature and stress, and additional simulation data like loads.
- The post-processor could also be used for eliminating visual or numeric data for further usage.

FINITE ELEMENT METHOD SIMULATION

A 3D FEM model again for effective stress, efficient strain, extrusion load, as well as the ECAP temperature deforming maps of Al−2024 were taken into account and carried out during this study. The DEFORM-3D V.6.1 software was used for the rigid-visco plastic 3D FEM simulations. DEFORM-3D is indeed a FEM-based analysis software for the various processes of metal forming. Contrary to most FEM DEFORM-3D software, it has a simple graphical interface to easily read and analyse data. The DEFORM-3D software has three steps in simulating. The workpiece was considered a rigid-plastic body for conducting simulations. Thus, in sections with a diameter 20 mm, dividing mould comprising lower die, top die, and ram and length 70 mm, the inner corner angle in the lower die channel was adjusted from ϕ = 90° to 135º, the angle of the corner from = 0°C to 30°C. The corner angle was also modified. The physical model, the assembly model of both the geometry of the workpiece, a punch & die is as shown in Fig 3.1 was produced with CATIA V5R21.

The third phase in pre-processing seems to be the meshing procedure for workpieces. The temperature was 20°C, with 4161 nodes and 3908 polygonal surfaces to create the domain discretion and meshes. When the elements have been overly deformed throughout forming process simulations, their mesh was automatically re-meshed. In pre-processing, the fourth step is to break and load the die and punch in another way that the workpiece. Next, appropriate contact limit and friction coefficient criteria are applied between the die, punch and also workpiece. The contact limits between the die, punch, and workpiece could be generated automatically.

DEFORM-3D "will automatically achieve the tolerance between both the die-and-punch on the side as well as the workpiece on another. Then perhaps the contact nodes will be created. Depending just on state of both the forming process, the value of something like the coefficient friction between both the die and punch on either side or the workpiece on another. The top surface of the workpiece is in full contact with the punch that moves at 1 mm/s constant rate."

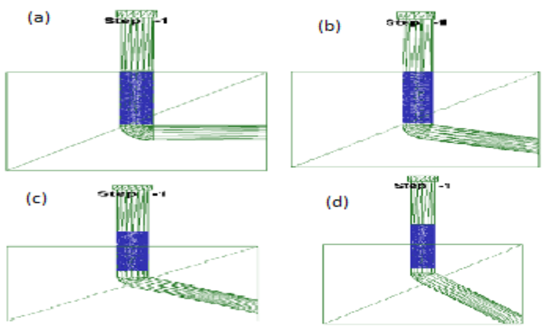
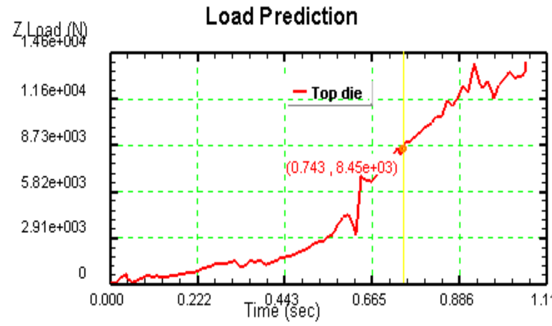


Fig.3.1: Assembly diagram of billet, ram and die with different channel angles (a) 90º, (b) 105º, (c) 120º and (d) 135º

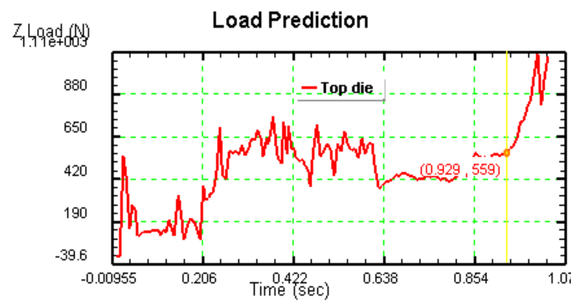
IV.RESULTS AND ANALYSIS

A. Analysis of The Extrusion Load

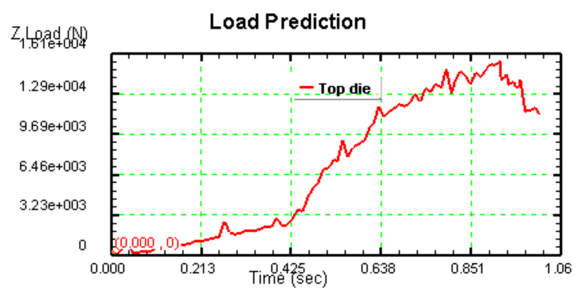
A time load curve shown in fig. 4.1 just at beginning of a sharp load increase, indicating the introduction of Billet into in the corner of something like the die channels and indeed the sudden effect of Billet's z axis direction component and the creation of frictional contact the with canal wall, causing a very rapid increase. If 1.07 s is recorded with maximum 1.11e+3 N. The loading curve swings over time upwards and downwards, due of the contact with both the channel wall Billet and death, leading to a change of friction. The load curve eventually lowers, coming into reasonably stable condition. Thus, adequate lubrication of both the die channel during the actual extruder operation may significantly lower the extruder load, reduce the energy consumption and increase molds life.



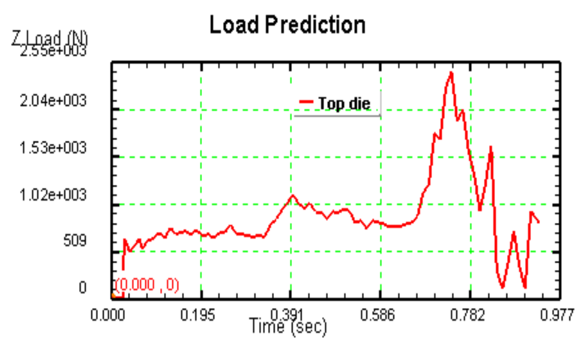
(a) Channel angle (90º) and corner angle (0º)



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



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

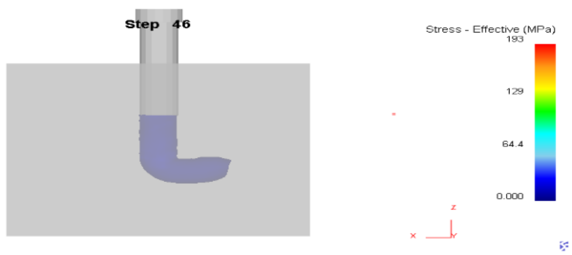


(d) Channel angle (135º) and corner angle (30º)

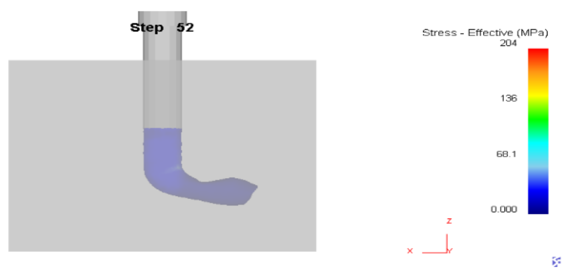
Fig. 4.1: The load time curve of the extrusion process

B. Stress Analysis

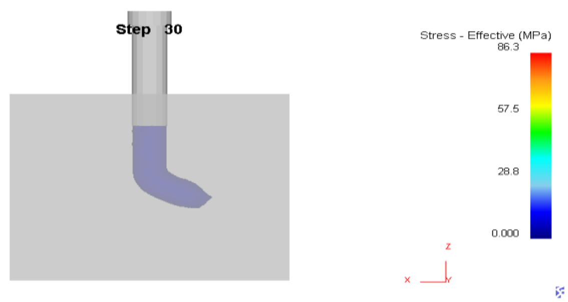
For stress distribution (Fig. 4.2) the highest stress may be noticed inside the channel's corner area. External radius decreases the maximum stress and increases the dispersion of stress. Additional internal radius reduces the maximum stress and then further distributes its stress distribution. These occur at both 90˚and 120˚of corner angles 0˚and 20˚. It is also noticed that with every corner radius of the any simulation instance, the maximum stress that happens on 120˚ channel angle was greater than the 90˚ channel angle.



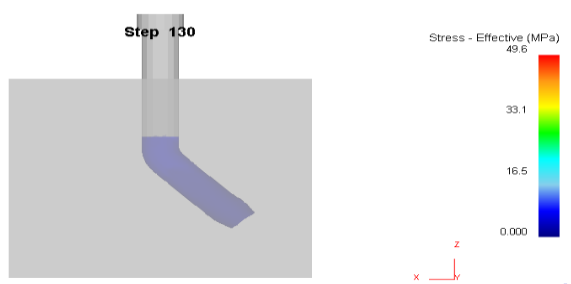
(a) Channel angle (90º) and corner angle (0º)



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



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

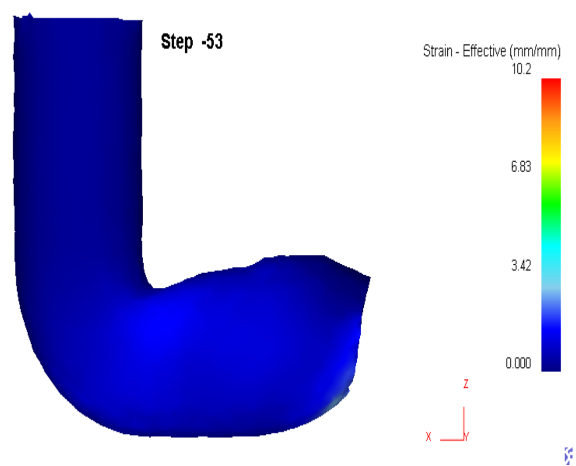


(d) Channel angle (135º) and corner angle (30º)

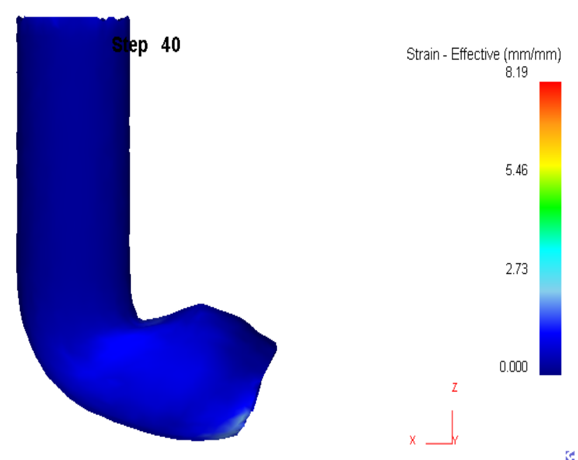
Fig. 4.2: Effective Stress distribution in billet

C. Strain Analysis

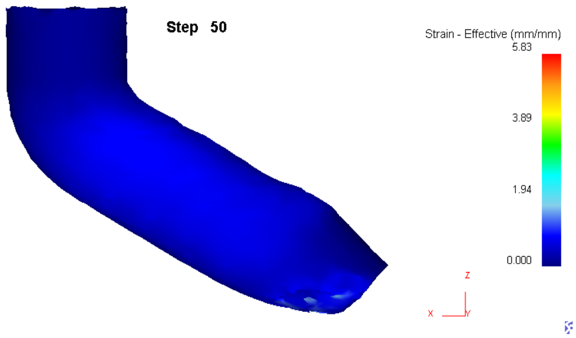
The strain pattern changes inside the lower, middle and top part of the workpiece as it moves past the die is shown in Fig. 4.3. Fig. 4.3 shows the curve of the strain of the workpiece. Well at bottom of the workpiece beneath the ECAP with a maximum loading contour of 135 per channel angle without a specific internal or external radius (Fig.4.3d). The strain is lowered when the outside radius has been entered (Fig.4.3b), and even less when the inner radius is present (Fig.4.3c).The same tendency occurs when the channel angle was 120˚ surface of the work piece, compared to the channel angle of 90˚, only at lower stresses. A lower pressure can be noticed when both ECAP dies as well as all pressure temperatures increase the outside corner angle. The channel angles (135°) and corner angles (30°) also give more pressure than others.



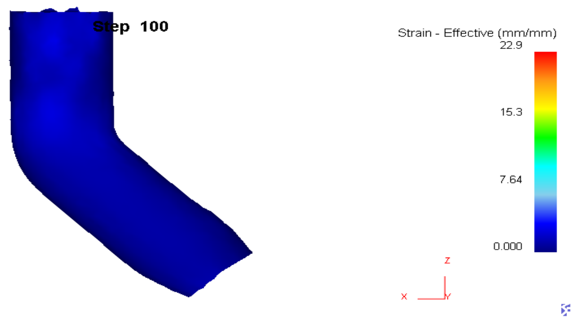
(a) Channel angle (90º) and corner angle (0º)



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



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



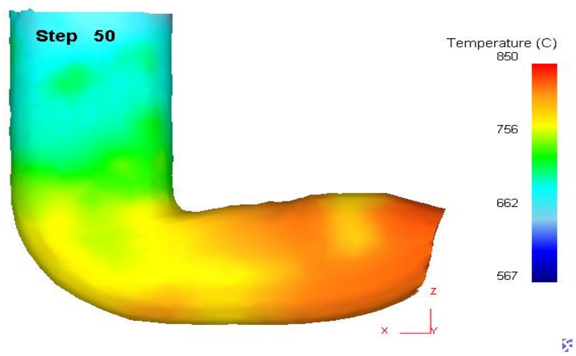
(d) Channel angle (135º) and corner angle (30º)

Fig 4.3: Effective Strain distribution in billet

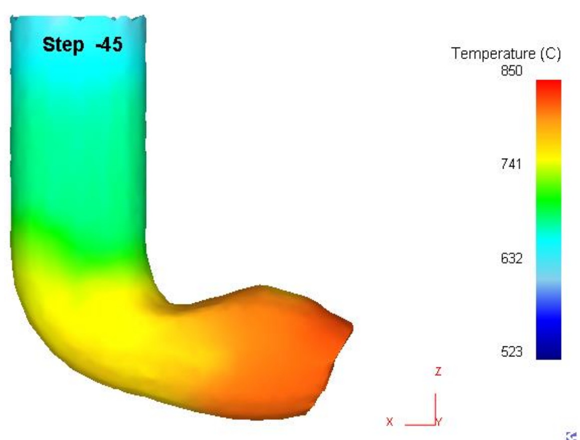
The strain began on the radius. The pressure starts later on when a workpiece passes through an unknown corner radius (which is a), yet the size is larger than the size for workpieces having corner radii passed through. This seems to be particularly the case in the lower area of the parts. This should be noted that now the allocated material characteristics are elastic, however for ECAP the strain may be expected to approach the workpiece's plastic area already. The simulation using simply elastic properties may nevertheless clearly show the how strain will be when the workpiece of magnesium alloy goes thru the ECAP die with the characteristics as specified. Results in [21] show that tiny ultra-fine grains were produced if the material is subject to significant plastic deformity owing to change inside the channel and angles of the corner. This one is done by the fact that ECAP with a 30o angle and a 135o angle of a channel produces higher plastic strain than some other angles. In other words, fewer pressing passes are needed if a steeper angle ECAP die is utilised to produce a certain strain amount. Therefore, with lower die angles, the impact is evident. This concept is supported by the stress intensification just at bottom portion of the ECAP samples. On average, the induced stress value has been reduced as shown by prior study, while the die angle and the external angle have increased [2]. In addition, the lower-angle dies substantially increase the strain in homogeneity with in pressed billets, thus making it more difficult to fluidize the material and increasing the burden value. As both a result an ECAP die with only an angle of 90°, along with a minimum value of both the outer angle, is necessary to also have a high strain, less homogeneous stress distribution.

D. Temperature Distribution

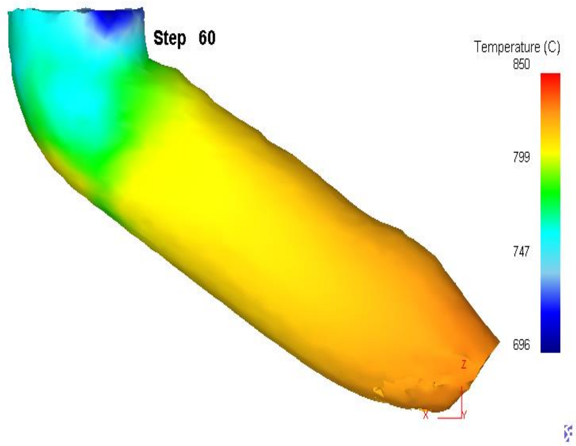
Among main reasons for its complicated influence on microstructural development and fluctuations of specified variables are the ECAP temperatures. In all the ECAP dies having various channell angles 90º, 105º, 120º and 135º Figs. 4.4 illustrates the strain distribution of billet pressed at different temperatures. Due to Al-2024 high energy failure stacking (SFE), The low-angle grain boundaries can indeed be completed by raising the temperature resulting in an enhanced recovery at high temperatures [23]. In other words, the production of DRV is accelerated as even the temperature increases and the threshold strain for such beginning of subgrains is also reduced.



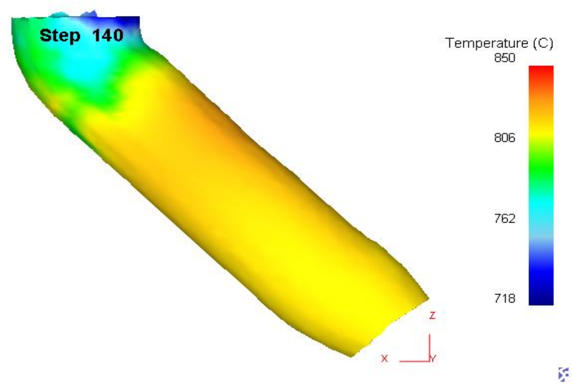
(a) Channel angle (90º) and corner angle (0º)



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



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



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

Fig 4.4: Temperature distribution in billet

V.CONCLUSION

The ECAP process for Al2024 Alloy were simulated with a finite element analysis. In this research, the following things could be emphasised.

1. From of the results, the forming load was strongly carried out from both the angle of the channel or corner. The maximum load grows progressively and hence mechanical characteristics like as strength, hardness, etc. improve.
2. For all channel and corner angle values, a maximum workpiece temperature is obtained at the deformation zone."
3. A drop in the plastic strain level was due to the rise of the angled die or outside corner angle. The lower pressure and strength of the work temperature during ECAP was attained on the counter side. Nonetheless, the workpiece stress and tension are uniform during one pass. By increased pass rates, ECAP and consistency can be enhanced.
4. FEM results show that what a billet top surface that will have the highest tensile mode of maximum stress inside the zone and the concentration of significant plastic strain has been the most important section of crack development.

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