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EFFECT AND ANALYSIS OF DIE ANGLE ON STRESS DISTRIBUTION DURING ALUMINUM ROD EXTRUSION PROCESS

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***Abstract*— A larger die angle allows for smoother and more uniform material flow through the die. This reduces the likelihood of material sticking to the die surface or experiencing irregular flow patterns that can induce stress concentrations. With a larger die angle, the strain rate (the rate at which the material deforms) tends to be lower. Lower strain rates are associated with reduced stress levels in the material. Maximum temperature is as high as 334 K. It can be observed that temperature decreases with increase in die angle. From the results it is observed that maximum temperature is as high as 334K when die angle is 30°.In the extrusion process, temperature typically does not decrease with an increase in the die angle. In fact, the die angle itself is not a direct factor that influences temperature changes in the extrusion process. Temperature control in the extrusion process is primarily achieved through heating elements and other process parameters, rather than by directly adjusting the die angle. The die angle primarily influences the extruded product's geometry and flow patterns.**

Keywords— Finite Element (FE), Die Angle, Stress Distribution, Aluminium Rod, etc…

I. INTRODUCTION

The importance of analysis for the extrusion process lies in the determination of forming load, flow characteristics, temperature and state of stress and strain. Flow pattern A is obtained in extrusion of homogeneous materials in the presence of friction at the die interface only. In the corner of the leading edge of the billet, a separate metal zone (known as the dead metal zone)is formed between the die face and the container wall. Flow pattern B is obtained in homogeneous materials when there is friction at both die and container interfaces, resulting in an extended dead metal zone. Flow pattern C is observed with billets having in homogeneous material properties or with non-uniform temperature distribution in the billet; a more extended dead metal zone is formed and the material undergoes a more severe shear deformation at the container wall [1].

A. History of Aluminum Extrusion

Aluminum extrusion, or the extrusion process, owes its beginnings to three men – Joseph Bramah, Thomas Burr, and Alexander Dick. Each of them advanced and perfected the process so that inventors from the industrial revolution could improve it. Though the goals of these men may not have been to create aluminum extrusion, they did take the first steps in developing the extrusion process [2].

Fig.1.Extruded Aluminum

Impressed with Bramah's extrusion process and his hydraulic press, Thomas Burr, in 1820, combined the two inventions to develop a hydraulic press to force metal through a die. Burr's goal was to extrude lead pipe using a faster and more reliable process. At the time, extrusion was named "squirting". The present process of hot extrusion dates back to 1894 when Alexander Dick melted non-ferrous metal to be forced through a die. Though there have been many changes over the last hundred years, the design and developments of Dick, Bramah, and Burr remain the foundation for the modern extrusion process [2].

B. Types of Aluminum Extrusions

Extrusion is a part of so many industries that it is not possible to create a complete list of every one of its types. The descriptions below contain a very general over view of the various kind so of extrusion and their use. A more complete set of information can be found at the various manufacturers' websites [4].

Aluminum extrusion profiles can be divided into standard common profiles such as corners, duct, square and round, T, U, and Z. All extrusion manufacturers have these profiles on hand and immediately available or die to form them. They come in a wide range of sizes and lengths. The second group of aluminum profiles is complex and intricate shapes that require special dies and tooling. These can include profiles with screw attachments, specialty corner profiles, handles, handrails, and transition strips with shanks. Unlike the standard aluminum profiles, complex profiles are special ordered and may require the engineering of a die to match the requirements of the profile [4].

C. Aluminum Angles

The standard extruded aluminums angle is a L – shaped part with two legs that are formed by bending the extrusion to a 90 degree angle. Aluminum is an ideal metal for the manufacturing of this long, narrow shape because of its high strength-to-weight ratio and corrosion resistance. The legs of the angle are either equal or unequal and have sharp corners. The bent L-shape extends the length of the material creating horizontal and vertical flat surfaces that add strength to the unit in both directions. L-shaped components are used as structural support. In the building industry, they are referred to as aluminum angle irons or aluminum angle bars [4].

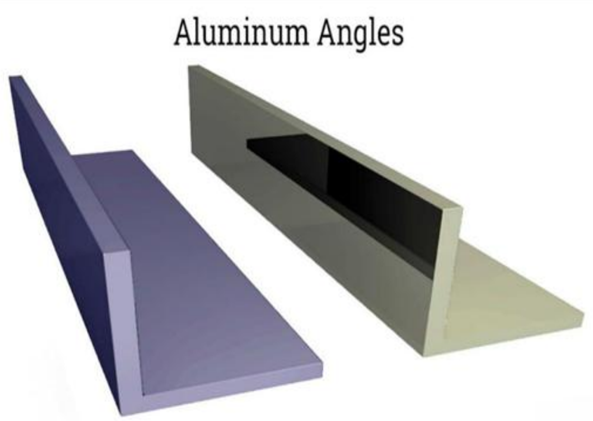

Fig. 2 Aluminum Angles

Aluminum beams are large, oblong pieces of metal, constructed from aluminum alloys, and is used as horizontal support in building construction. Aluminum beams are a preferred alternative to steel, which is stronger but heavier and wood, is lighter but weaker [4]. Structural Aluminum is used for beams because of its light weight, which makes it easier to install. Structural aluminum is weather resistant, doesn't corrode quickly, is able to withstand high and low temperatures, and doesn't rust when exposed to water. Aluminum beams last longer without any need for maintenance or upkeep and come in different shapes including unequal or equal I beams, the most commonly used, unrounded and C-shaped channels, H beams, and T beams.

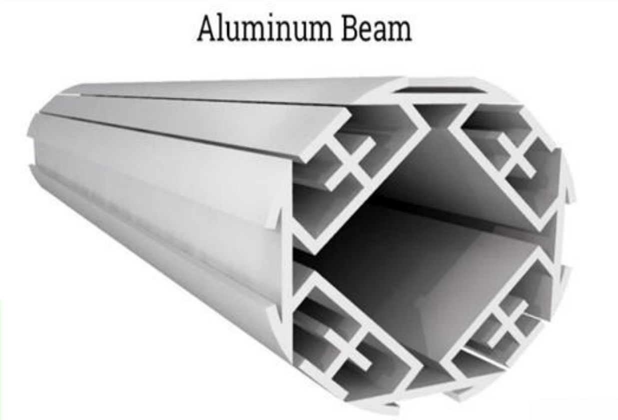

Fig. 3 Aluminum Beam

D. Aluminum Profile

Aluminum profiles are the shape of extruded aluminum products and include trim caps, rods, angles, bars, and channels, which are a small portion of the wide range of configurations and size that aluminum profile can take. Profiles can be hot, cold, or warm extruded through a die that has the shape of the profile. There are standard profile designs that are generally used, or profiles can be custom designed for special applications. The most common alloys used in the fabrication of profiles are 6061, 6063 and 1100 aluminums [5].

E. Heat sink

A heats ink is a metallic device that absorbs thermal energy, or heat, from another object using thermal compounds known as thermally conductive materials. Heat is absorbed from the object at a relatively high temperature and transferred to the heat sink, which has a larger heat capacity. Extruded heat sinks are a thermal energy solution for both low and high volumes and are used in refrigeration, heat engines, cooling medical devices, lasers, and CPUs.

Fig 4 Heat Sink

Heat sink applications are used by production processes that require efficient heat dissipation such as the electronic, military, medical equipment, industrial manufacturing, appliance, and LED lighting industries. Extruded heat sinks vary in design by length, noise level, speed, width, style, height, and weight. Other forms of heat sinks, that are not extruded, are stamped, bonded, or folded, which have higher production costs [6].

II. FINITE ELEMENT ANALYSIS AND METHODOLOGY

A. Finite Element Method

In the current research work, a thermo-mechanical analysis of ax symmetric extrusion process is carried out through FEM based software ABAQUS (Standard). Finite Element model of ax symmetric extrusion process having die and billet shown in Fig.5. Finite element method (FEM) is one of widely used means for the analysis of many manufacturing process such as aluminums extrusion, as well as other forming processes. Both two and three dimensional aspects of extrusion can be investigated with this valuable tool.

During the extrusion process, the billet gets shorter and the friction surface and container decreases. Therefore, the necessary ram force decreases during the process. The die is also preheated before loading the first billet. A previous study has shown that many factors greatly influence metal flow in forward extrusion, such as the interface behaviour between the die and billet, distribution of thermal stresses along the contact area, and finally the die geometry.

In addition, the influence of reduction ratio and die half-angle on extrusion was been studies for the hydrostatic extrusion process and can be utilized for the forward conventional extrusion process.

Some mechanical characteristics of the extruded material will be change during the extrusion process, like the strain hardening. Many finite element solution methods were presented by researchers using ABAQUS software. By these solutions, they try to estimate the optimum die design and the relationship between the forward extrusion pressure and the die radius. Other studies try to combined tools of physical modeling technique and Finite Element simulations through studied the material flow behavior over a conical punch. By using ABAQUS, the optimum die angle for conical die can be determine. In cold extrusion the radii of curvature of this extruded alloys and the average hardness along the product was to be increase with the increasing of the die length.

B. Modelling, Simulation and Analysis Method Modelling Of Process

Modelling the parts can be done by different ways. The modelled parts can be imported from CATIA software. In this study, die, billet container modelled as 3D, and in all cases the billet is modelled as deformable part, as shown in Fig.5. Where the consists of three main parts: rigid die, rigid billet container, deformable billet. In analyses and simulation process by ABAQUS, the parts modelled as 2D ax symmetrical geometric.

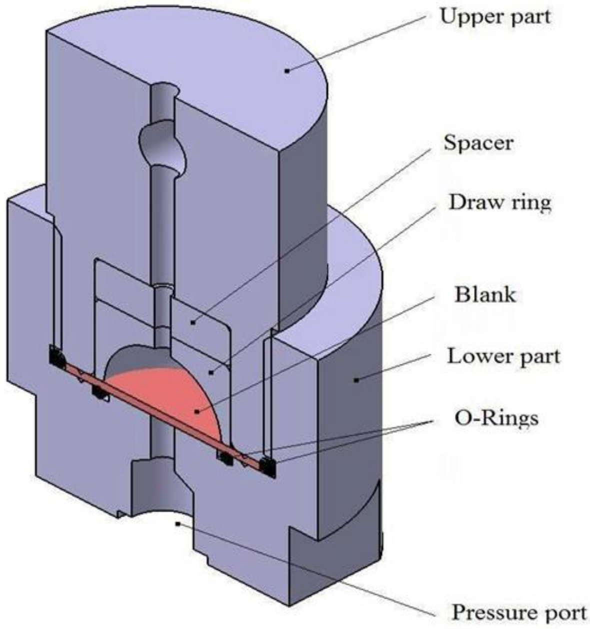

Fig. 5: Cross-Sectional View of Assembly Dies

To investigate the simulation and analysis purpose of extrusion proses by ABQUS, an accurate two dimensional design was built with accurate dimensions and tolerances. Material and material properties was defined and assigned to there parts. All required steps like the model mesh, a properly boundary conditions was selected. Also optimisation process for this analysis was done by re-meshing the model much time to fine the element and get accurate results. During the simulation, re-meshing facility was triggered to help the analysis of large de-formation. The meshed parts are shown in Fig.6.

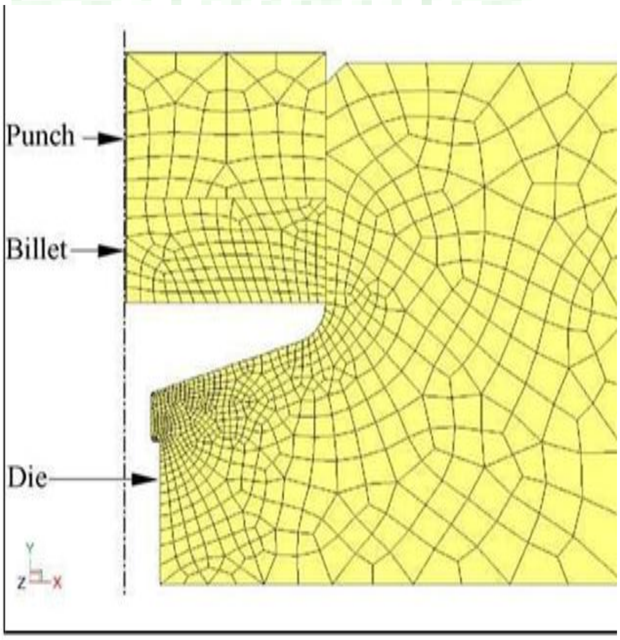

Fig.6 Finite element model of extrusion process

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The theory of the FE analysis of the extrusion process in presented, with the detail description of analysis step, interaction, boundary condition and meshing.

C. Analysis Step

There are many types of interaction process between the parts, and a lot of factors ill effects on metal flow and the resulting properties, such as billet length, container surface, extrusion ratio and extrusion speed. Also the actual die configuration, the section and its surface finish, the condition and shape of the bearing surfaces over which the aluminium flows and the die temperature also contribute. In this study, we used a unique method such that the section is cooled and handled after leaving the die. With this method, it can be seen that a process, described as being like 'squeezing toothpaste from a tube', controlled a quite complex set of parameters.

III. RESEARCH METHODOLOGY

A. Objectives of Study

- To design a disusing Caria software for an extrusion die
- To analysis of stress and temperature distribution during extrusion process
- Analysis of stresses and strain distribution in the de formation process
- To design and develop an extrusion setup (Dies)
- Performing simulation using Combined extrusion-forging process using FEM (Finite Element Method) based of ware package DEFORM3D

Accordingly, the present study has been done through the following steps. The methodology for our work is as follows:

- First, we designed ie with various profile angle 30°,45°,60°usingCatia software
- Then we design punch and billet
- After design, we import the seemed tries instil format in deform 3d
- Then we run simulation and obtain results.

B. Geometrical Parameters

Billet diameter = 80 mm
Billet length= 60 mm
Extruded rod diameter=40mm Half die angle=30°,45°and60°below.

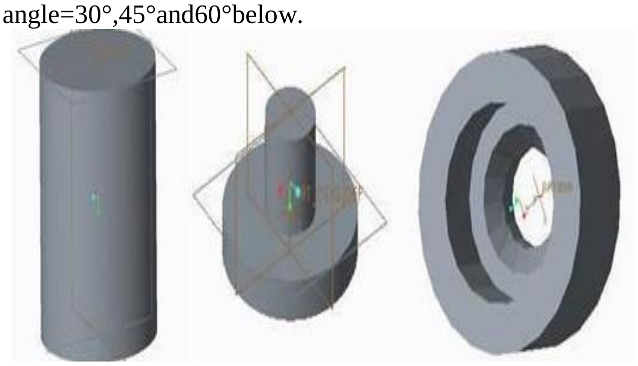


Fig.7: Billet, punch and die

We modeled our billet, punch and die using Catia software for simulation work in deform 3d.

C. Material Properties

Billet is modeled as rigid plastic material. Power law equation has been used for modeling stress and temperature distribution. Al2024 is heat-treatable aluminum alloy with copper as the primary alloying element. It issued in applications requiring high strength to weight ratio, as well as good fatigue
resistance. Due to its high strength and fatigue resistance, Al2024 is widely used in aircraft structures.

Table I: Physical Properties of Work Material

Properties	
Work material	Al 2024
Density (Kg/m3)	2780
Young's Modulus (GPa)	73.1
Poisson's ratio	0.33
Coefficient of thermal expansion	23.8 E- 6
Sp. Heat (N/mm2/°C)	0.875
Thermal conductivity (W/m/K)	121

D. Fem Using Deform-3d

Finite element analysis consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in the designing of new products and improvement of existing product design. Traditionally, the metal forming process the tproducesan acceptable product has been accomplished by extensive previous experience and an expensive and time-consuming cycle of trails, evaluations and redesign. Such a traditional forming design approach is rapidly being replaced by more efficient computer simulation.

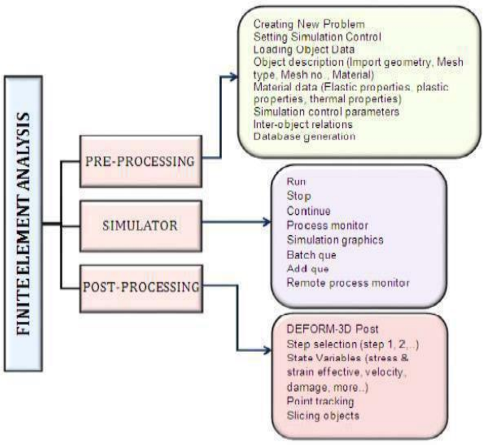


Fig.8: Major Components Of FEM Simulation For Combine Dextrusion Process

There are various metals forming analysis software that can realistically simulate material forming processes. Among them, DEFORM3 D is one, which is popular among there searchers and industries. DEFORM3D is powerful simulation software designed to analyze the three-dimensional flow in the complex metal forming process and metal cutting problems.

The simulation software mainly consists of three major components pre- processor, simulation and post processor as shown in Fig. 8.

E. **Pre-Processor**

The pre-processor is used for taking the input parameters like temperature, coefficient of friction, material data, etc. The input like billet, punch and die have been done in 3D modeling software called Catia. These solid models are directly imported to pre-processor for forming process analysis. By using this input data pre-processor will generate one database file which is used in the simulation process. The major input parameters required in pre-processor are shown in Fig. 9.

Simulation Control

In this, units were changed to the SI system. Lagrangian incremental type simulation followed during the process. We should give starting and stopping criteria for the simulation process in this section. In the 'step' section we will give the number of simulation steps required to complete the product. The length of travelling of the punch or number of simulation steps was taken as stopping criteria.

Materials

Is otropicandrigid- perfectly plastic material type was used. The commercially available aluminum is chosen as the material.

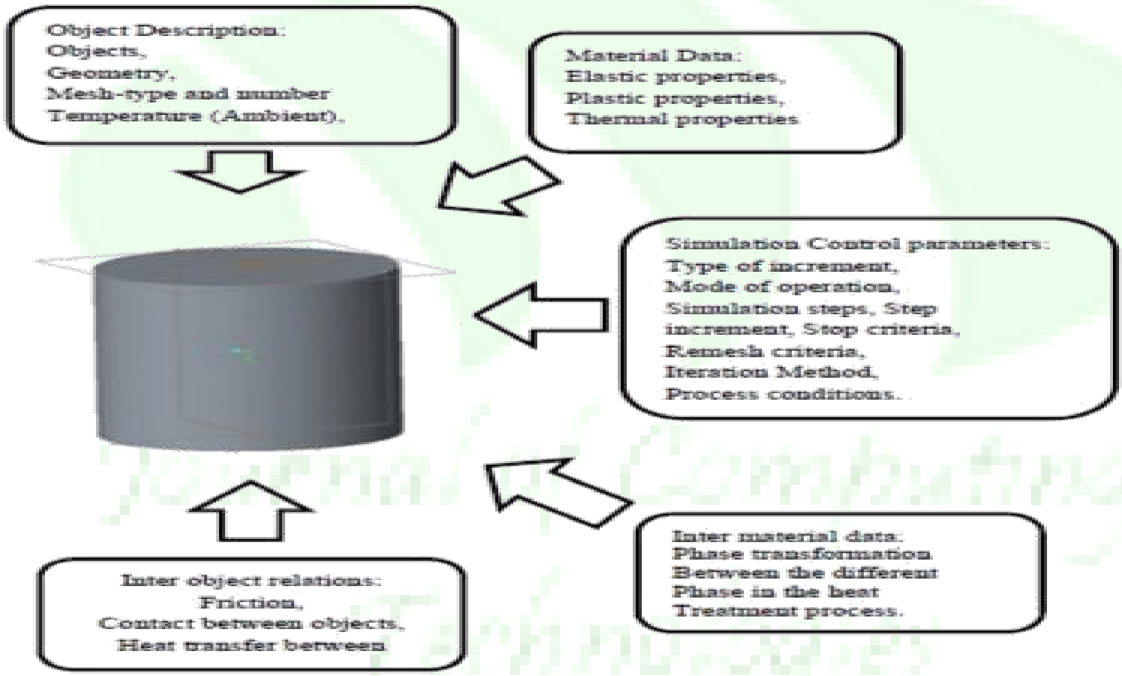


Fig. 9: Major Input Parameters Required Simulation Process

Object Description

In this section, the three objects billet, punch and die were imported from the modeling software as. stl files. The solid models of billet, punch and bottom die are shown in Fig.10. Here billet is chosen as plastic and punch, die were chosen as rigid objects. Punch was taken as primary die which compresses the billet.

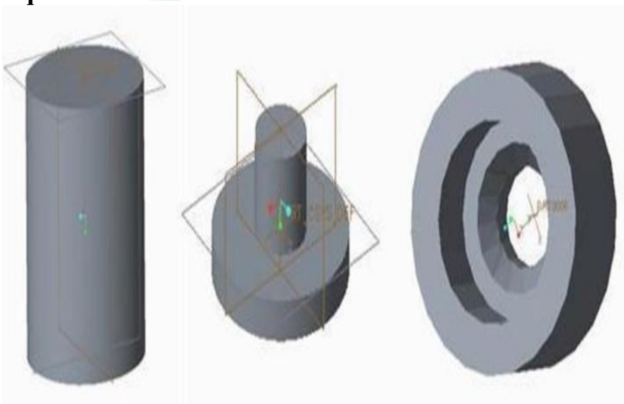


Fig. 10: Objects Required For Simulation Process

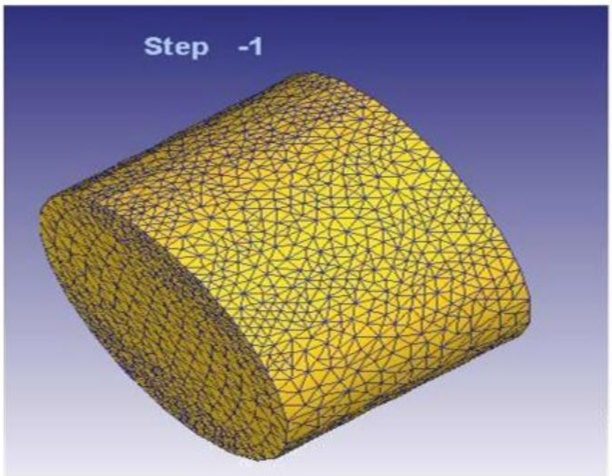
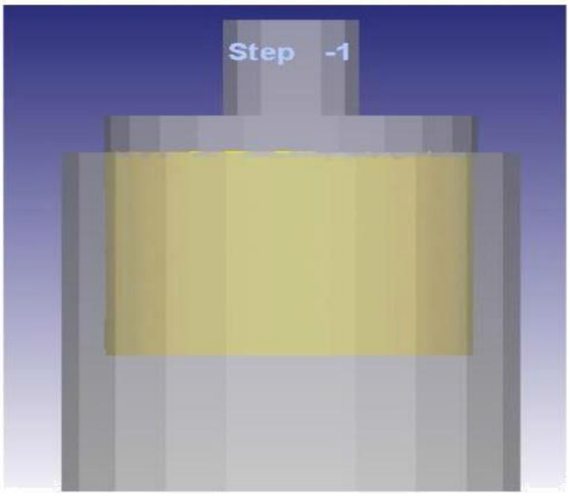


Fig. 11: Meshing Of Billet in Deform-3D

20,000 mesh elements were considered red during the meshing process. Ambient temperature was considered for simulate process because it is a cold working process.

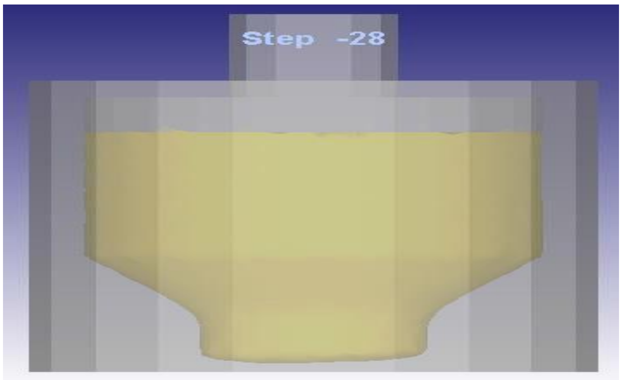
IV. SIMULATION

The simulation engine will perform the numerical calculations required to analyze the process, and write the results to the database file. The simulation engine reads the database file which is coming from the pre-processor and it calculates the solution for the given simulation problem.
According to input data the finite element simulation performs the numerical calculations to solve the problem. The simulation engine will run till it satisfies the stopping criteria which are mentioned in the pre-processor simulation controls. After stopping the simulation engine required product will be obtained from post processor. The Fig. 12 shows the punch, billet and die assembly set up before and after the simulation process.



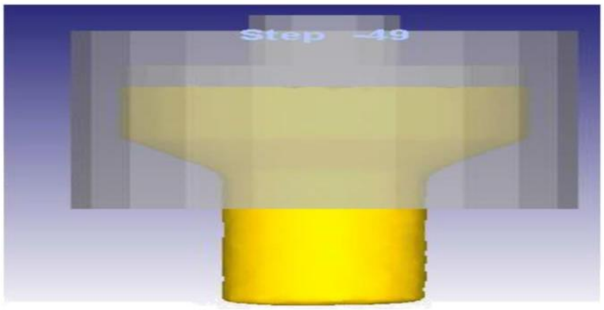
(a)

Before starting simulation, we position billet, punch and die in deform 3d. This is our step 1



(b)

In above fig. after simulation initialization, punch travels this is our step 28.



(c)

Fig 12: Assembly of objects before and after simulation

In above fig.12 after simulation initialization, punch travels this is our step 49.The model of punch, die and work- pieces created in Creo 3.0. For the simulation of extrusion process the DEFORMF3 is used. The hexahedron elements are used for meshing; the number elements are used for work-piece is 20000, for punch 20732 and for die 20732.

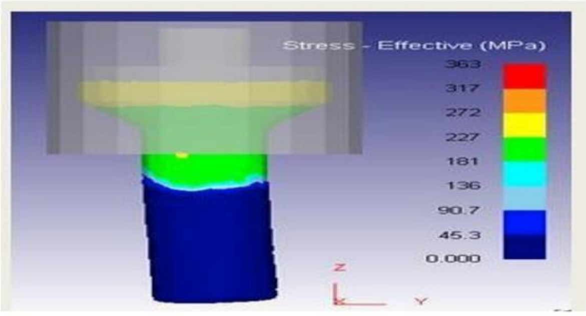
V. RESULT AND DISCUSSION

A. Effective Stress Distribution

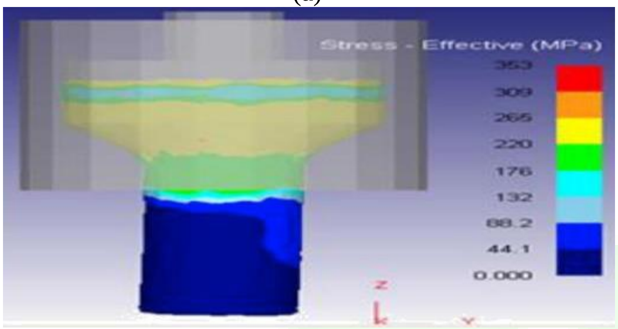
A typical stress contour is shown in Figure 4.1.Maximumstress is as high as 363 MPa. Stress variation wrt die angle shown in Fig. 13. It can be observed that stress decreases increase die angle. From the results it is observed that maximum stress is as high as 363 MPa when die angle is 30°.

Table II. Simulation result for effective stress

Experiment no.	Punch velocity	Coefficient of friction	Die angle	Effective Stress MPa
1	2.5	0.15	30°	363
2	2.5	0.25	45°	353
3	2.5	0.35	60°	332



(a)



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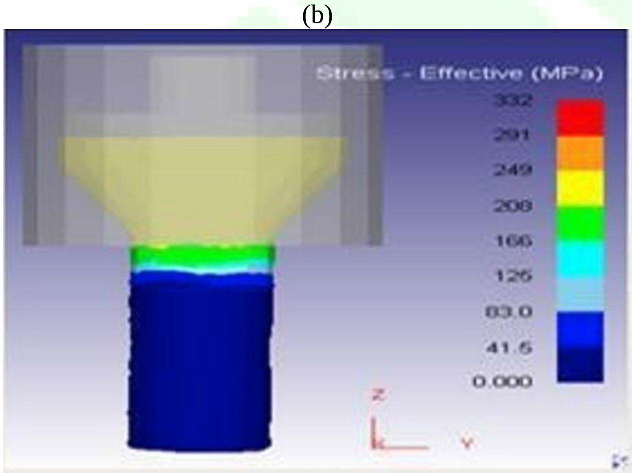
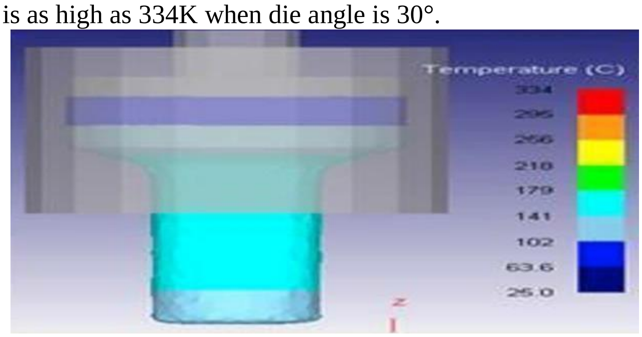


(c)

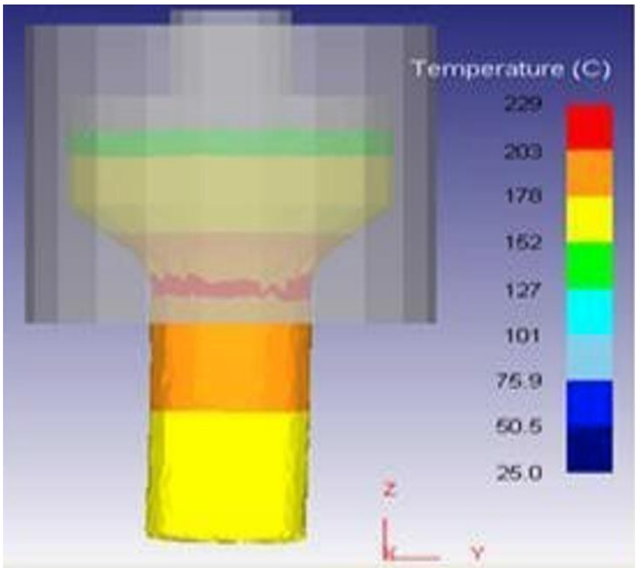
Fig. 13 Simulation Result for Effective Stress at Different Die Angle

B. Effective Temperature Distribution

A typical temperature contour is shown in Fig. 14. Maximum temperature is as high as 334 K. It can be observed that temperature decreases increase die angle. From the results it is observed that maximum temperature is as high as 334K when die angle is 30°.



(a)



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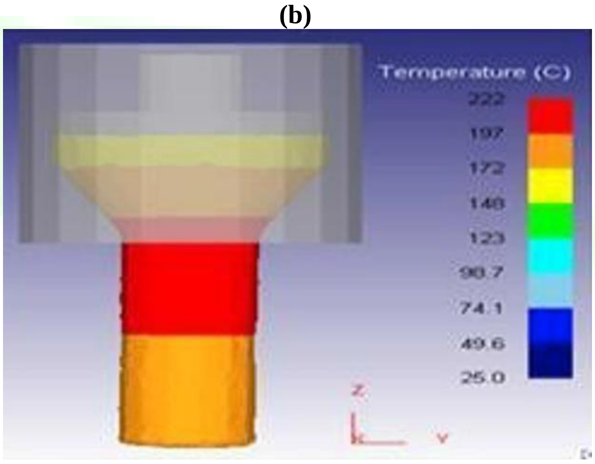

(c)

Fig.14: Simulation Result For Temperature At Different Die Angle

Table III. Simulation Result for Temperature

Experiment no.	Punch velocity	Coefficient of friction	Die angle	Temperature, °C
1	2.5	0.15	30°	334
2	2.5	0.25	45°	229
3	2.5	0.35	60°	222

VI. CONCLUSION AND FUTURE SCOPE

This study analyse extrusion process of Al alloy using deform 3D software. Further, the effect of extrusion die angle on stress and temperature was also investigated. The following conclusion can be drawn:

Maximum stress is as high as 363 MPa. It can be observed that stress decreases with increase in die angle. From the results it is observed that maximum stress is as high as 363 MPa when die angle is 30°.In the extrusion process, stress generally decreases as the die angle increases. The die angle refers to the angle formed between the extrusion direction and the surface of the die orifice. This is due to following reasons:

A larger die angle results in a more gradual change in direction for the extruded material as it passes through the die. This reduces the contact area between the material and the die surface, leading to less friction. Lower friction means less resistance and, consequently, lower stress on the material.

A larger die angle allows for smoother and more uniform material flow through the die. This reduces the likelihood of material sticking to the die surface or experiencing irregular flow patterns that can induce stress concentrations. With a larger die angle, the strain rate (the rate at which the material deforms) tends to be lower. Lower strain rates are associated with reduced stress levels in the material.

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