Experimental Investigation and Numerical analysis of Combined Extrusion-Forging Process

A thesis submitted in partial fulfillment of the requirement for the award of Degree of

Master of Technology

in

Mechanical Engineering

Specialization in

Production Engineering

by

Bonda Atchuta Ganesh Yuva Raju
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Department of Mechanical Engineering
National Institute of Technology
Rourkela - 769008, India
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Under the guidance of

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Odisha, India – 769008.

CERTIFICATE

This is to certify that, the thesis entitled "**Experimental Investigation and Numerical Analysis of Combined Extrusion-Forging Process**" being submitted by **Mr. Bonda Atchuta Ganesh Yuva Raju** bearing roll no. **213ME2420** for the award of the degree of Master of Technology (Production Engineering) of NIT Rourkela is a bonafide record of research work carried out by him under my supervision and guidance.

Mr. Bonda Atchuta Ganesh Yuva Raju has worked for more than one year on the above problem at the Department of Mechanical Engineering, National Institute of Technology, Rourkela and this has reached the standard fulfilling the requirements and the regulation relating to the degree. The contents of this thesis, in full or part, have not been submitted to any other university or institution for the award of any degree or diploma.

Dr. Susanta Kumar Sahoo
Supervisor
Department of Mechanical Engineering
National Institute of Technology
Rourkela – 769008

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Abstract

Present manufacturing industries are facing many challenges to produce the products of high strength, resistance to fatigue, heat, corrosion and low production cost. To meet these challenges combined extrusion-forging process is employed to achieve improved material properties, high production rates, and less material wastage when compared with other manufacturing processes such as machining, casting, etc. Combined extrusion-forging process is the advanced metal forming process in which an initial billet is forced through the extrusion and forging die punch setup to get desired product. The flow pattern of metal mainly depends on the frictional conditions at the workpiece/die interface, the geometry of dies and the percentage area reductions. In this process, the estimation of forming load is a bit difficult because the number of process parameters involved, and complexness of analysis. It has extensive applications in automotive and aerospace industries. Present research work focuses on estimation of forming load to produce the product collet chuck holder by this process. The metal flow pattern and die cavity filling has studied in both experimental and simulation analysis. The modelling software Solidworks is used for 3D modelling and Deform3D® is used for the simulation process. The number of experiments has done to compare the results obtained from the simulation process. The results obtained from the experimentation and simulation analysis are in good agreement with each other.

Keywords: extrusion forging process, effective strain, effective stress, finite element analysis, forming load, metal flow pattern.

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Nomenclature

Symbol	Description
σ	Flow stress, MPa
k	Strength Coefficient, MPa
n	Strain hardening exponent
$\dot{\varepsilon}$	Effective strain

Chapter 1 Introduction

1.1 Introduction

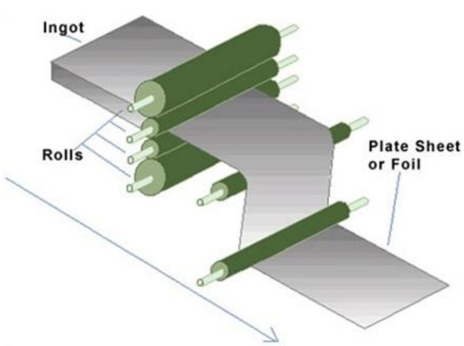
The significance of metals in advanced technology is mainly due to its simplicity to be reshaped into useful shapes like tubes, rods, and sheets, besides its strength, availability, etc.

Vast use of metal shapes may be made in three fundamental processes:

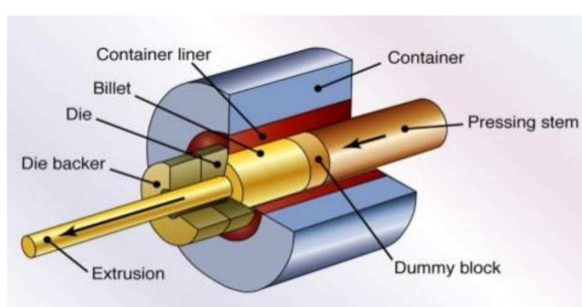
- By metal casting, in which the molten metal prepared and poured into the mould.
- By plastic deformation processes during which the amount and mass of metal are preserved, and the metal flowed plastically and displaced from one place to another.
- By metal removal or machining processes, in which the material is removed to give it the desired shape.

Several processes have evolved for particular metal working applications. Based on the type of forces applied to the workpiece, these processes may be classified into a few categories. These categories are as follows:

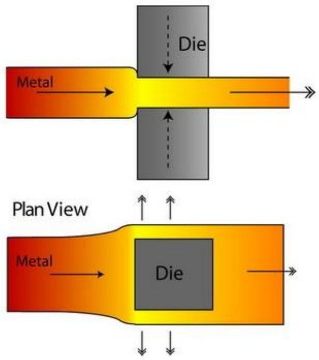
- Compressive Forming: In this forming process, the plastic deformation is primarily attained due to the uniaxial or multiaxial compressive loading. The examples for this compressive forming are rolling, open-die forging, and close-die forging and indenting.



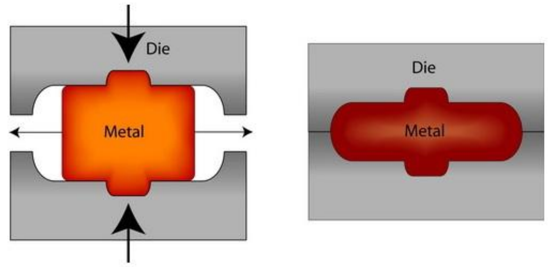
a) Rolling process



b) Extrusion process [1]



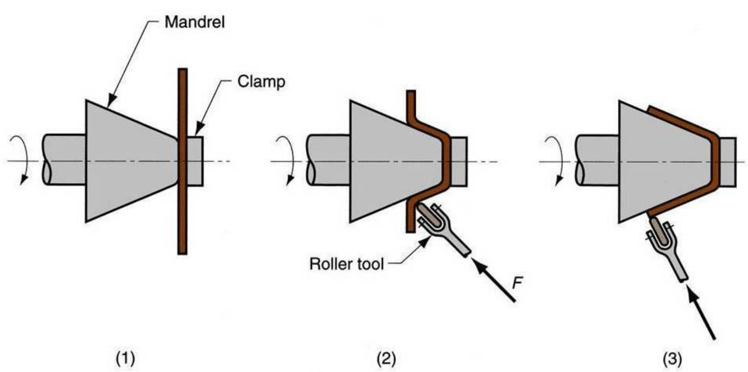
c) Open die forging process [2]



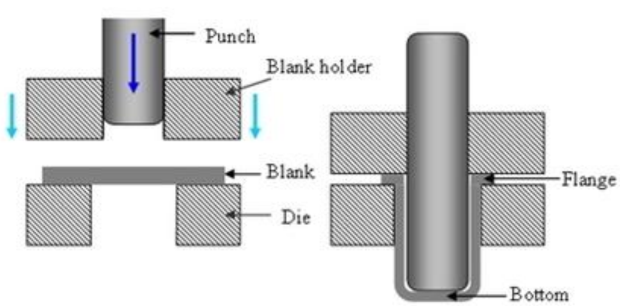
d) closed die forging process [2]

Fig. 1.1: compressive forming processes

- Combined tensile and compressive forming: In this forming process, the plastic deformation is primarily attained due to both tensile stresses and compressive loads. The examples for this combined tensile and compressive forming are pulling through a die, deep drawing, flange forming, spinning, and upset building [3, 4, 5].



a) Spinning [6]



b) Deep drawing

Fig. 1.2: combined tensile and compressive forming processes

- Tensile forming: In this forming process, the plastic deformation is primarily due to uniaxial or multiaxial tensile stress. The examples for this tensile forming are stretching, expanding, and recessing [3, 4, 5].

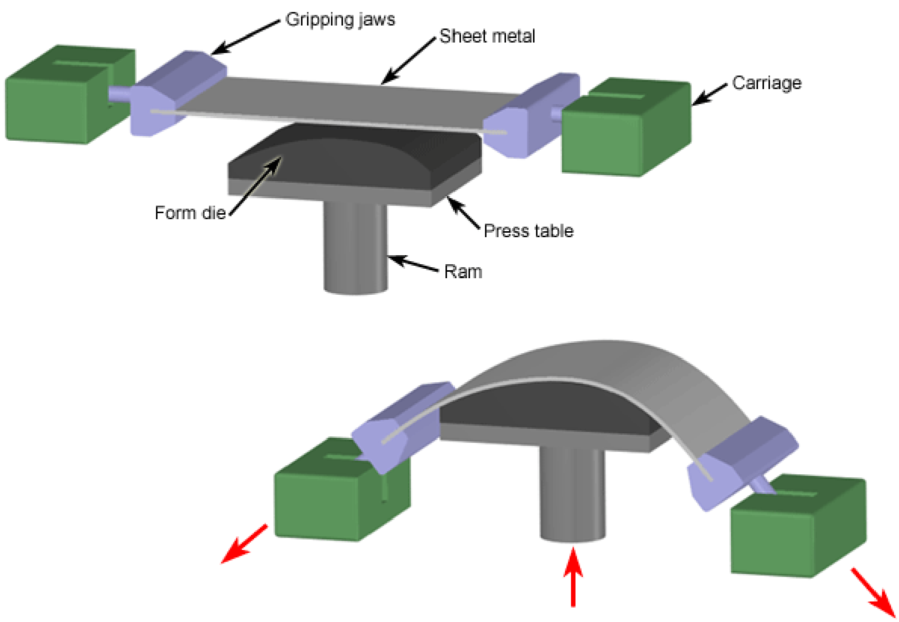


Fig. 1.3: Tensile forming process

- Bending forming: In this forming process, the plastic deformation is primarily due to bending load. The examples for this bending forming are bending with linear tool motion, and bending with rotary tool motion [3].

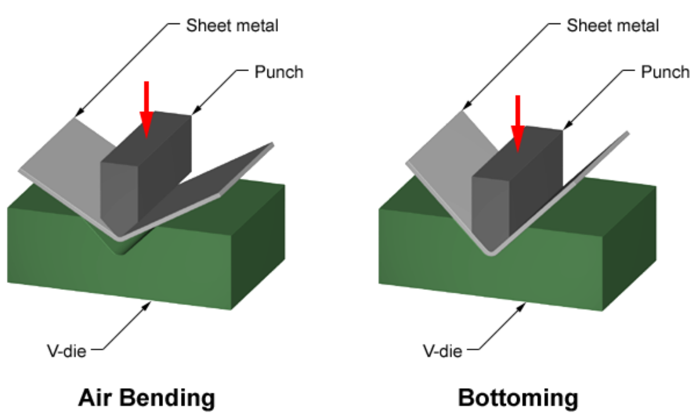


Fig. 1.4: Bending forming process

- Shearing forming: In this forming process, the plastic deformation is primarily due to shearing load. The examples for this shearing forming are joggling, and twisting.

The metal shapes produced by deformation processes are with better mechanical properties than those produced by casting and machining. In advanced metal forming practice, the metal is typically first cast into a shape close to the final product, then it is further deformed into the final product. The steps involved in the deformation can be reduced to least in this way, and more uniform metal deformation has achieved.

Indeed, the plastic forming plays two significant roles at the same time: (1) to achieve a particular shape; (2) to enhance the mechanical properties (rarely other physical properties). For example, the defects like blow holes and porosity occurred in a cast may be abolished by hot-forging or hot-rolling. In most of the products, mechanical properties depend upon the strain hardening during the process. To achieve the optimum structure and properties in other cases temperature, precise control of deformation, and strain rate during the process is required. The thermo-mechanical processing, in which the deformation temperature and degree of deformation are strictly controlled, is an example to improve metal property during the forming process [3, 5].

The forming process is classified into two categories depending on the temperature used for reshaping. They are hot forming and cold forming processes. Hot forming is conducted over the recrystallization temperature, while cold forming is the one below this recrystallization temperature. For example, steel forming over 900 ^{0}C temperature is usually the hot forming [3].

Further metal working process is divided into two types, one is primary mechanical working processes and another is secondary mechanical working processes. Further metal working process is divided into two types; one is primary mechanical working processes, and another is secondary mechanical working processes. The plastic metal working processes which are developed to reduce an ingot into a standard industrial product of basic shapes like sheet, plate, and bar and these plastic metal working processes are called primary mechanical working processes. The Forming techniques that produce a final product or part of desired shape are called secondary mechanical working processes. The examples for secondary processes are sheet-metal forming operations, wire drawing, and tube drawing. Most commonly, the first category is called processing operations, and the second category is called fabrication [3].

Metal forming can also be divided into two types, namely bulk forming and sheet forming. Bulk forming or massive forming processes like rolling, extrusion, forging, etc. usually involves significant changes in cross-section and consequently the wall thickness. The sheet metal forming processes like bending, deep drawing, etc. includes nearly constant wall thickness [3,4].

The evolution of sophisticated materials is giving challenges to the present manufacturing industries. The current manufacturing industries are facing many challenges with these materials from the conventional manufacturing processes to produce a product with higher mechanical properties, less wastage of material, higher productivity and lower capital cost. To meet these challenges an advanced metal forming process called extrusion forging is employed. The combined extrusion, forging process is the bulk metal deformation process in which workpiece undergoes plastic flow when forced it through a series of extrusion and forging dies to get the desired product. Present work collet chuck holder has taken as product shape.

The collet chucks are mainly used in the following applications:

- In the construction of grabbing systems of robots', self-feeding systems within working centres, etc.
- To fix the working tools such as drills, cutters, reamers, etc in the technical helping systems.
- Positioning systems or measurement systems and Control systems, etc.

Collet chucks consists of one or two conical surface/s (it may be either inner side or outer side, a series of longitudinal collars defining a series of elastic areas, called jaws.

1.2 Research Objective

The main objectives of the present research work are listed as follows:

- ✓ To estimation of maximum forming Load (peak punch load) for combined extrusion forging process of given product collet chuck holder.
- ✓ To design the dies and experimental setup using 3d modelling software SOLIDWORKS for the desired product shape.
- ✓ To implement the Finite element simulation process using FEM (Finite element Method) based commercial software package DEFORM3D.
- ✓ To study the load versus punch displacement, effective stress, effective strain, total velocity and metal flow pattern obtained after implementing the FE based simulation process.
- ✓ To perform the experiments using cylindrical aluminium billet on UTM (Universal Testing Machine) of maximum capacity 600 kN with a view to compare the results obtained with simulation results.

1.3 Thesis Outline

Chapter 2: Literature Review

This chapter includes the study of research work which is done on the topic combined extrusion-forging process. The present problem had been derived from the literature review.

Chapter 3: Finite Element Analysis

This chapter deals with the simulation of the Finite element analysis for combined extrusion-forging process of Collet chuck holder. Effective strain, Effective stress, Velocity and metal flow patterns have been analyzed.

Chapter 4: Experimental Analysis

This chapter deals with the design of the experimental setup for combined extrusion-forging process. The product Collet chuck holder was made at different punch movements. Also determination of stress-strain characteristics and friction factor of aluminum has been calculated.

Chapter 5**:** Comparison of Results

This chapter deals with the comparison of results obtained from the experimental and simulation analysis.

Chapter 6: Conclusion and Scope for Future work

This chapter deals with the conclusion obtained from the present research work and scope for the future work.

2.1 Introduction

Present manufacturing industries are facing many challenges to produce the products of high strength, resistance to fatigue, heat, corrosion and low production cost. To meet these challenges combined extrusion forging process is employed to achieve improved material properties, high production rates, and less material wastage when compared with other manufacturing processes such as machining, casting, etc. Many researchers have performed a series of investigations on combined extrusion forging process. To gain some necessary knowledge, implementation of process and methodology used for combined extrusion forging literature review has done. The literature reviews followed during this research work to make the required product using combined extrusion forging are given below.

2.2 Investigation of Past research work

Farhoumand et al. [7] had investigated that the effect of geometrical parameters such as gap height and fie corner radii and process parameter like friction factor. He concluded that an increase in gap height or die corner radii causes the material flow into radial direction. Also, he concluded that the friction factor variations alter the material flow into forward and backward section while the material flow into radial section is approximately independent of friction factor. Plancak et al. [8] had investigated radial extrusion of gear like components. He observed that there is a steep load rise during the last phase of load stroke diagram. Also, he observed that at the tooth part and center portion of the billet the highest strain values and lowest strain values had been obtained respectively.

Jafarzadeh et al. [9] had analyzed the lateral extrusion process of gear like components. He observed that the gap height influences the forming load but friction factor does not have a large influence on forming load. He concluded that by decreasing the billet diameter the effective strain becomes heterogeneous and by increasing friction coefficient the effective strain increasing. Also, the degree of barrelling decreases with decrease of friction coefficient and with increase of billet height.

Brayden et al. [10] had analysed the cold – die extrusion/forging process. He found that neutral radius is the critical factor in the analysis and which occupy a position to achieve minimum energy dissipation state. Also, the initial pressure and sudden rise in pressure during extrusion process due to internal shear is also related to the behaviour of neutral radius.

Buschausen et al. [11] had found that the simulation results show that the proposed test is able to evaluate friction quantitatively and as well as qualitatively. Also, he found that the test conditions are close to those found in industrial production i.e. they exhibit a high interface pressure and large amount of deformation.

Hu et al. [12] had modelled the deformation of rectangular billet using finite element method. He concluded that the numerical result show good agreement with those obtained in experiment in terms of deformed geometry.

Wu et al. [13] had studied the influences of various die shapes on extrusion forging using finite element method. He found that the draft angle and fillet radius affect the extrusion load, strain, and flow deformation at various levels.

Vickery et al. [14] had found that the die hole size influence the behaviour of the workpiece material. The material having a larger die hole will fill first and transition also occurs first.

Narayan Swamy et al. [15] had done an experimental investigation on barreling of aluminum alloy billets during extrusion-forging using different lubricants. He concluded that all values of stress increases with the increase in approach angles under plane and triaxial conditions. Straight line behaviour is observed between hoop strain and axial strain. The rate of change of barrelling radius w.r.t. hydrostatic stress is different for different approach angle.

Paltasingh et al. [16] had done an investigation on lateral extrusion of hexagonal head and concluded that the forming load increases with increase in thickness and cross sectional area of the die cavity. Also, observed that the load increases abruptly during filling of corners of die cavity.

Kim et al. [17] had done an experimental investigation on upper bound analysis of the torsional backward extrusion process. He developed a kinematically admissible velocity field by using stream function. The deformation force reduced by 30% when compared with conventional backward extrusion.

Hur et al. [18] had done finite element analysis for cold backward extrusion process and Diameter ratios and interferences have been determined by the proposed design method. Also, concluded that the final punch stroke was 10 mm, but the maximum pressure on the wall of the die insert was found at the punch stroke 7.3 mm in the extrusion.

Groenbaek et al. [19] had done investigation on cold forging die design and found that die defections due to the working pressure from the part forming can be minimised by the application of high stiffness containers. For gear-shaped dies where tolerances are very critical, the die defection can be reduced by 30-50%.

Giardini et.al [20] had done an experimental investigation on the influence of die geometry and friction conditions on formability in extrusion-forging. Upon investigation, he suggested that the designer uses raft project to identify the most critical zone in dies.

2.3 Closure

After gone through the literature review, many researchers analyzed the extrusion forging process for different products. But in the present research work, the products of different shapes (regular/irregular, complex) which are manufactured by machining or casting process are taken for producing by combined extrusion forging process. Collet chuck holder has taken as the desired product shape that is produced by extrusion-forging process and analysis has done by DEFORM 3D software in the present research work. Collet chuck holders are special tool holders, which use collets to hold the cutting tools in place. It consists of collet, collet nut and the tool holder to secure the cutting tool properly. These devices are used in CNC lathes and milling machines to hold the workpiece or cutting tool. They are mainly suitable for drilling, milling, tapping and boring applications.

3.1 Introduction

Metal forming is particularly attractive in cases where the part geometry is moderate complexity and the production volume are large, so that tooling costs per unit product can be kept low. The Finite element analysis (FEA) is a numerical technique to find the approximate solutions of partial differential equations. It consists of a computer model of a material or design that is stressed and analyzed for specific results. This process is adopted to design the new products and improve the existing design. Traditionally, the metal forming process that produces an 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. There are various metals forming analysis software that can realistically simulate material forming processes. In our present analysis DEFORM®3D is used to simulate the forming (combined extrusion and forging) process to get the proposed product shape.

The simulation software mainly consists of three major components pre-processor, simulation and post processor as shown in Fig. 3.1.

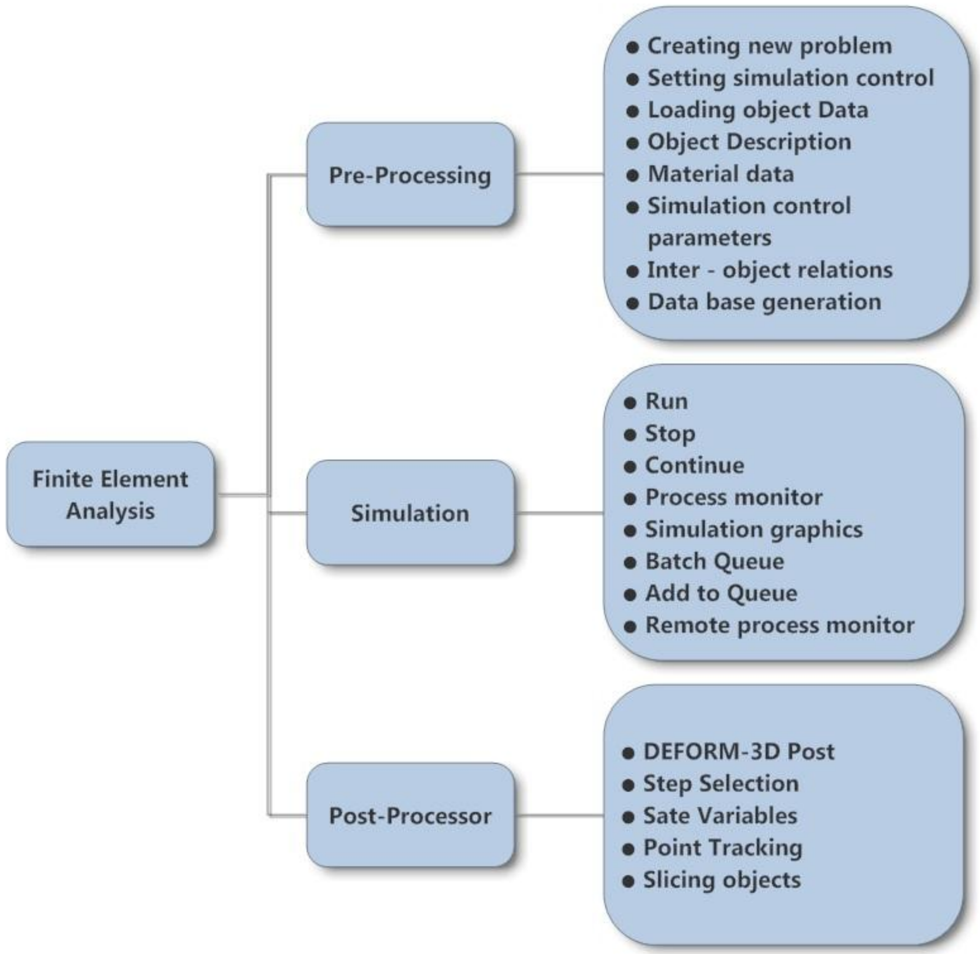


Fig. 3.1: Major components of FEM simulation for combined extrusion-forging process

3.2 Pre-processor

The pre-processor is used for giving the input parameters such as temperature, coefficient of friction, material data, etc. The geometries such as billet (specimen), punch and die have modelled in Solid works 3D modelling software. After modelling the geometries are saved as *.stl* files. These *.stl* files of geometries have directly imported for forming analysis. The pre-processor generates a database file using the input geometries and data, which is used in the simulation process. The Fig. 3.2 shows the major input parameters required in pre-processor for simulation process.

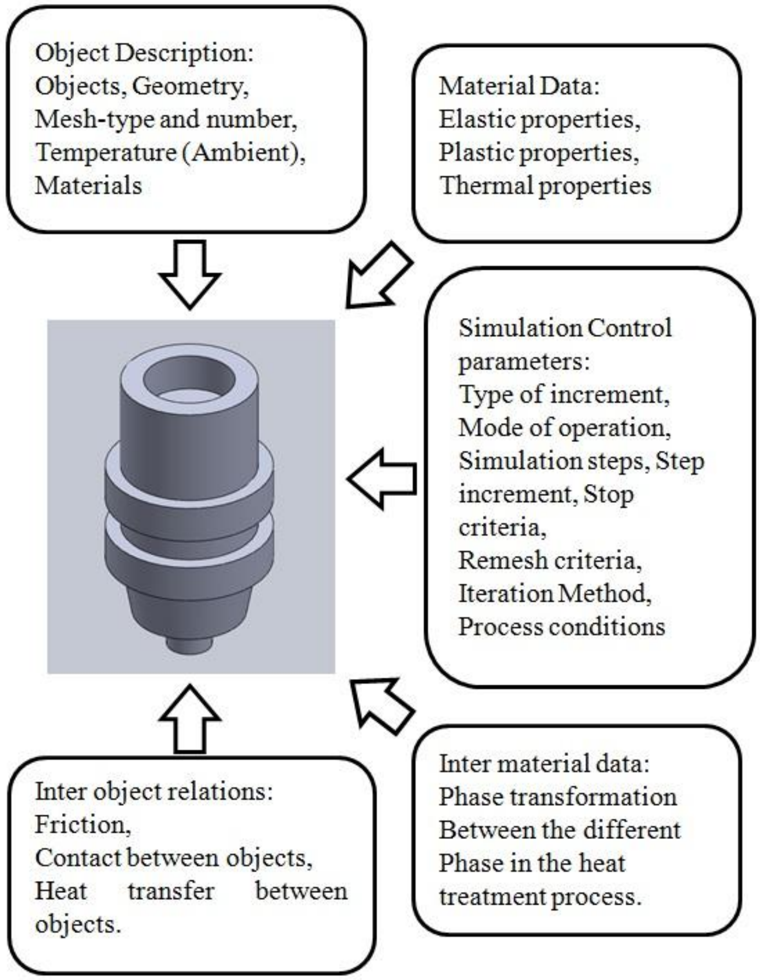


Fig. 3.2: Major input parameters required simulation process

The following are the steps involved in the Pre-processing stage:

3.2.1 Simulation control

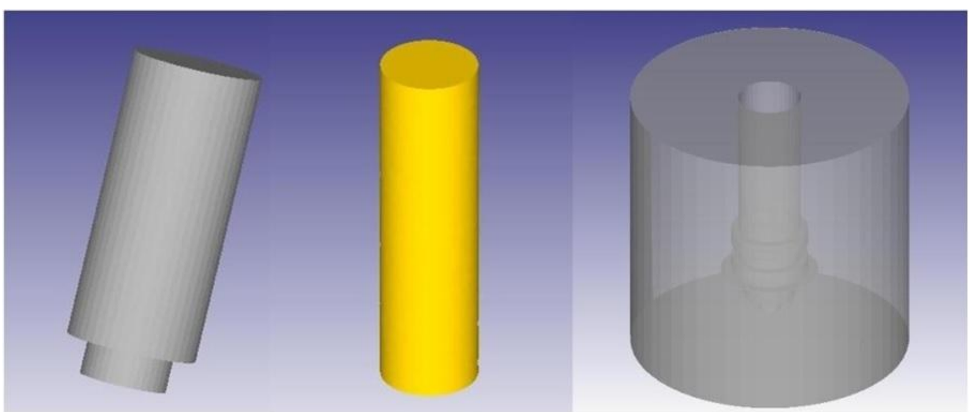
Initially, the units have changed to SI system using simulator control icon. Lagrangian incremental type simulation has followed during the analysis. In this section we should give starting and stopping criteria for the simulation process. In the 'step' section the number of simulation steps required to complete the product should give to process the simulation. The length of punch travel or number of simulation steps has taken as stopping criteria.

3.2.2 Materials

The materials used in this simulation are isotropic and rigid-perfectly. The workpiece/specimen material is taken as commercially available aluminium. The flow stress of the material obtained from the experimental analysis is 132 MPa has taken for the simulation process.

3.2.3 Object Description

The geometries of three input objects such as punch, billet and die have been imported as .stl files. The Fig. 3.3 shows the imported geometries of input objects billet, punch and bottom die. The object type of aluminium specimen (billet) has taken as plastic and punch, die have taken as rigid objects. The punch is used to compress the billet, taken as primary die. For the simulation the number of mesh elements considered is 24,000 on billet during meshing process. Since the process is cold working, the ambient temperature has considered for simulation process.



(a) Punch (b) Billet (c) Bottom Die

Fig. 3.3: Objects required for simulation process.

3.2.4 Inter Object Relations

In order to define relationship between the different objects such as billet, punch, bottom die inter object relations is used in the simulation process. The objects those are going to contact during the simulation process must have a contact relation defined. Punch, or the primary die is defined as the master die and the billet is defined as slave object. In our simulation process, we define friction factor values as a contact relation. This friction factor value is 0.22 which is obtained from the experimental results.

3.2.5 Movement control

Movement controls are applicable to rigid objects like punch and bottom die. In order to do simulation we have to set the three objects in proper positions using the movement control

3.2.6 Boundary condition

The direction of punch movement is only in -Z direction. There is no movement of bottom die and billet.

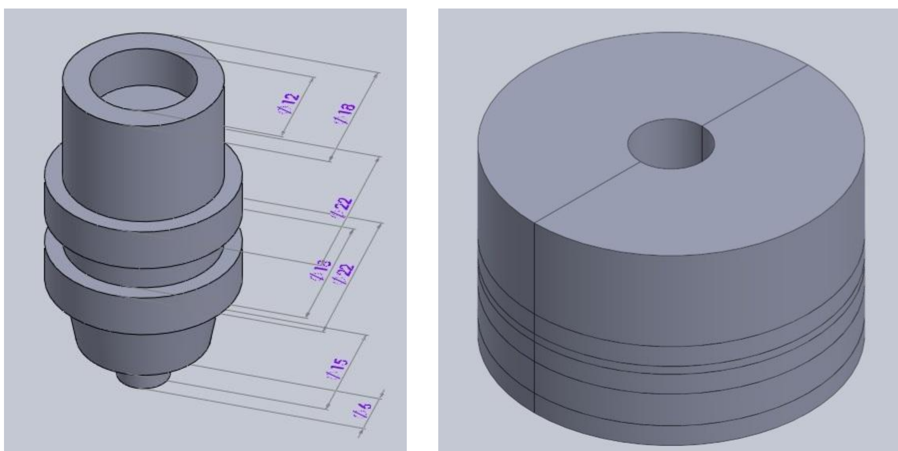


Fig. 3.4: Die design using the dimensions of Collet chuck holder

Table 3.1: Process parameters used in the simulation

Length of billet	54 mm
Diameter of billet	15 mm
Temperature of billet	Ambient
Punch speed	0.3 mm/s
Friction factor	0.22
Flow stress	125 MPa
No. of mesh element	20,000
Average strain rate	1/s
Limiting strain rate	0.01/s

The above Fig. 3.4 shows the dimensions of required product Collet chuck holder. From this we can design the required die for simulation process using 3D modelling software. Table 3.1 shows the different process parameters used in the simulation process. These parameters were used in the pre-processor section.

3.3 Simulation

After giving all the requisite data in pre-processor step, by clicking on the generate database it will checks the data and generates the database. 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. 3.5 shows the punch, billet and die assembly set up before and after the simulation process.

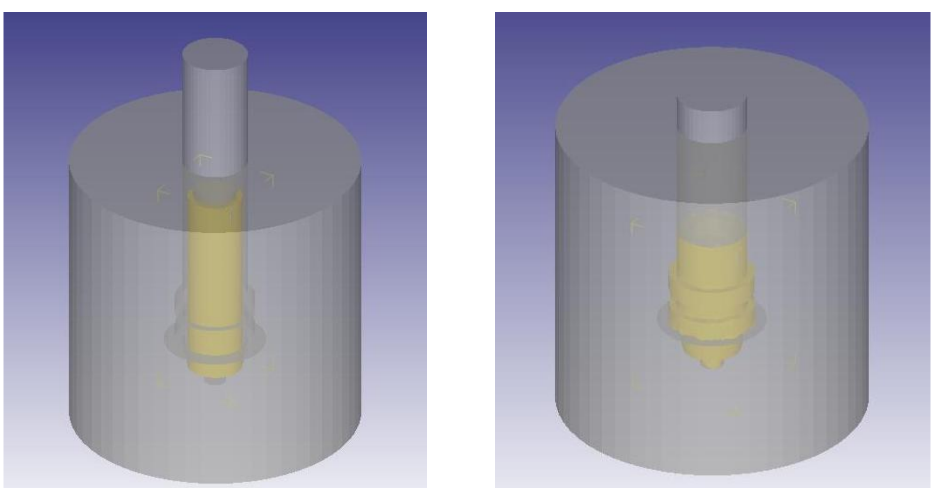


Fig. 3.5: Assembly of objects before and after simulation

3.4 Post Processor

The post-processor is used to view and extract data from the simulation results in the database file. From post processor we can obtain stress, strain, final geometry of the object, and graphs between different parameters and the different steps in forming process etc. Information which is available from the post-processor includes:

- Deformed geometry, including tool movements and deformed mesh at each saved step.
- Line or shaded contours display the distribution of any state variables, including stress, strain, temperature, damage, and others.
- Vector plots: displacement and velocity vectors indicate magnitude and direction of displacement or velocity for every node at each step throughout the process.
- Graphs of key variables such as press loads, volumes, and point tracked state variables.
- Flow net for showing the metal flow patterns in simulations.
- Point tracking to show how material moves and plots of state variables at these points.

3.5 Results and Analysis

The simulation has carried out for different lengths of travel and the results obtained from it have discussed and summarized. The effective strain, effective stress, total velocity and load-stroke curves etc. have been analyzed for combined extrusion forging process.

3.5.1 Stress, Strain, Velocity and Flow pattern Analysis

3.5.1.1 Collet chuck holder for 24.8 mm length of punch travel

The complete formation of given product at 24.8 mm length of punch travel. The characteristics such as effective stress, effective strain, total velocity and metal flow pattern have been shown in the Figures 3.6 and 3.7. From Fig. 3.6 we can observe that the strain is more in the center portion, extruded part and at the top surface of product. The maximum effective strain obtained is 5.14. The effective stress is more in top surface, center circular portion and extruded part of the product. The maximum effective stress obtained is 129 MPa.

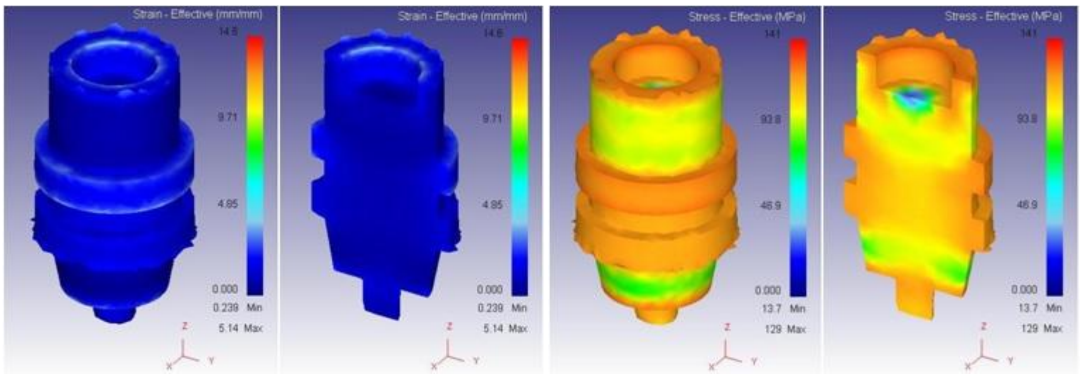


Fig. 3.6: Distribution of Effective strain and Effective stress at 24.8 mm punch travel

From the Fig. 3.7 we can observe that the total velocity at the edge of interface between punch head and billet top portion of the given product. The maximum velocity obtained is 1.11 mm/sec. The metal flow pattern diagram shows that the metal flow is concentrated at middle circular portion and top portion of punch and billet interface of the product.

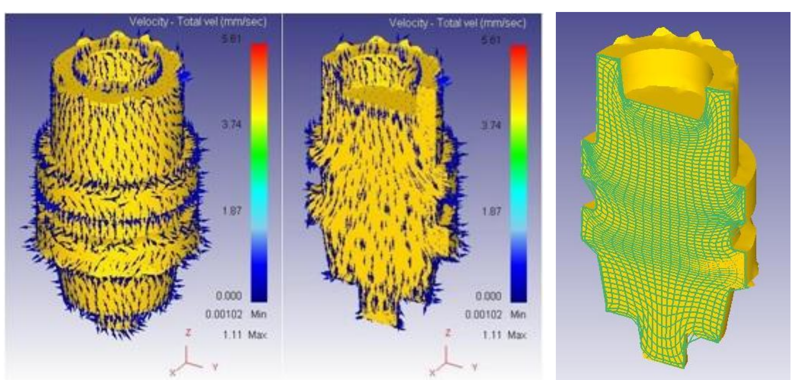


Fig. 3.7: Distribution of velocity and flow pattern at 24.8 mm punch travel

3.5.1.2 Collet chuck holder for 22 mm length of punch travel

During the 22 mm length of punch travel, except the bottom extrusion part remain all parts have completed. The characteristics such as effective strain, effective stress, total velocity and metal flow pattern have been shown in the Figures 3.8 and 3.9. From Fig. 3.8 we can observe that the strain is more at the interface between the punch head and a billet part of the product. The maximum effective strain obtained is 4.68. The effective stress is more at the edge of billet and punch head interface of the product. The maximum effective stress obtained is 126 MPa.

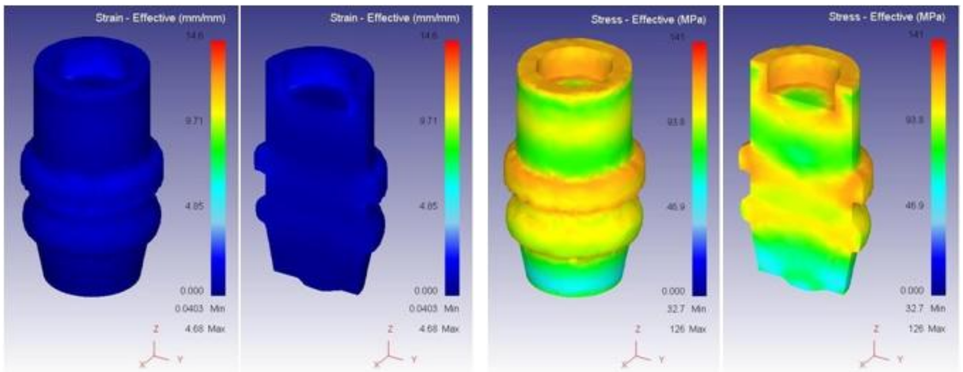


Fig. 3.8: Distribution of Effective strain and Effective stress at 22 mm punch travel

From the Fig. 3.9 we can observe that the maximum velocity is on the top portion of punch and billet interface of the product. The maximum velocity obtained is 0.659 mm/sec. The metal flow pattern diagram shows that the metal flow is concentrated at middle circular portion and top portion of punch and billet interface of the product.

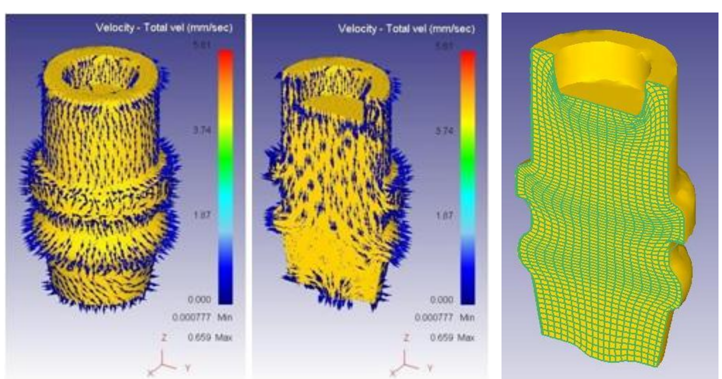


Fig. 3.9: Distribution of velocity and flow pattern at 22 mm punch travel

3.5.1.3 Collet chuck holder for 20 mm length of punch travel

During 20 mm of length of punch travel the tapered part and hole at the top of the product has completed. The characteristics such as effective strain, effective stress, total velocity and metal flow pattern have been shown in the Figures 3.10 and 3.11. From Fig. 3.10 we can observe that the strain is more at the edge of interface between punch head and billet top portion of the given product. The maximum effective strain obtained is 4.33. The effective stress is more at the edge of the interface between punch head and billet top portion of the product. The maximum effective stress obtained is 126 MPa.

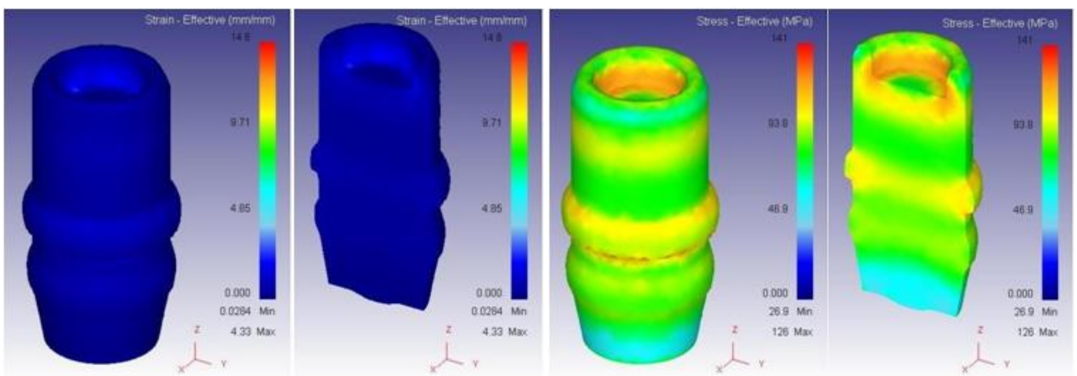


Fig. 3.10: Distribution of effective strain and effective stress at 20 mm punch travel

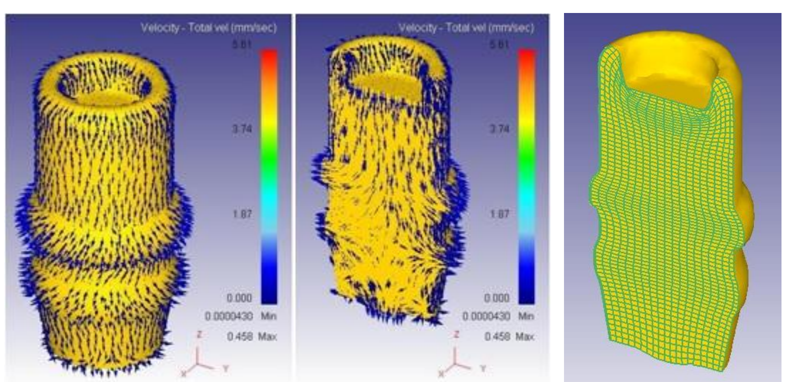


Fig. 3.11: Distribution of velocity and flow pattern at 20 mm punch travel

From the Fig. 3.11 we can observe that the maximum velocity is at the edge of interface between punch and billet top portion of the product. The maximum velocity obtained is 0.458 mm/sec. The flow pattern diagram shows that the metal flow is more at the edge of interface between billet top portion and punch head of the product.

3.5.1.4 Collet chuck holder for 15 mm length of punch travel

Only the initial compression has done during 15 mm length of punch travel and small indentation has formed on the top surface of the product. The characteristics such as effective strain, effective stress, total velocity and flow pattern have been shown in the Figures 3.12 and 3.13. From Fig. 3.12 we can observe that the strain is more at the edge of interface between punch head and billet top portion of the given product. The maximum effective strain obtained is 4.35. The effective stress is more at the edge of interface between punch head and billet top portion of the given product. The maximum effective stress obtained is 124 MPa.

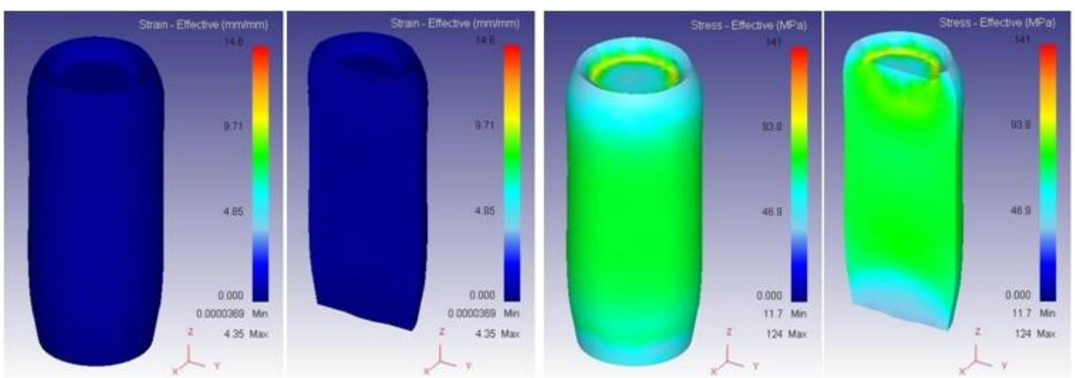


Fig. 3.12: Distribution of effective strain and effective stress at 15 mm punch travel

From the Fig. 3.13 we can observe that the maximum velocity is at the edge of interface between punch head and billet top portion of the given product. The maximum velocity obtained is 0.302 mm/sec. The flow pattern diagram shows that the metal flow is in the initial condition and almost uniform throughout the product.

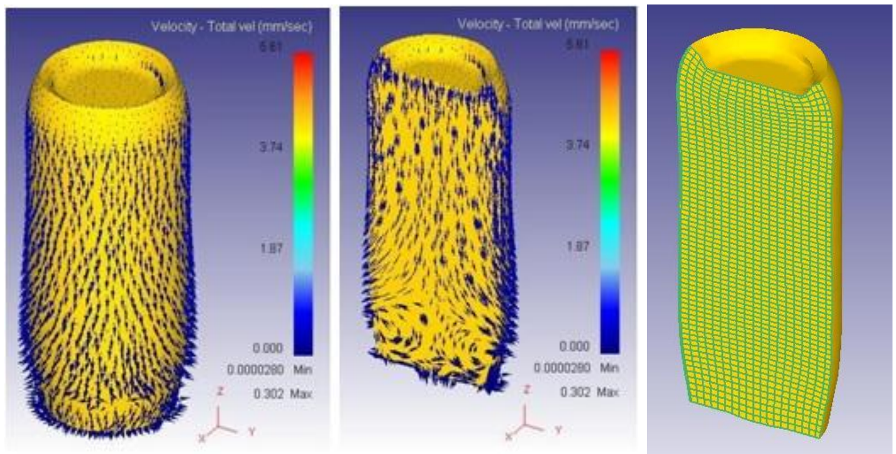


Fig. 3.13: Distribution of velocity and flow pattern at 15 mm punch travel

3.5.2 Variation of load with punch displacement

The Fig. 3.14 shows the complete product formation at 24.8 mm length of punch travel and maximum load of 132 kN is required. Up to 15 mm there is a very less increase in load. In this stage punch head will penetrate into the billet and a small indentation has formed. After 15 mm length of punch travel, there is significant increase in the load because metal will flow into the die cavities of circular and tapered portion of the product. We can observe that up to 15 mm the load obtained is 18.9 kN. After that within 5 mm of punch travel load is increased from 18.9 kN to 45.9 kN. After 15 mm we can observe that there is rapid increase in the load because at this stage metal filled up all the dies. From 20 mm to 24.8 mm there is an increase in load from 45.9 kN to 132 kN. This is because of the formation of flash and extruded part in this stage.

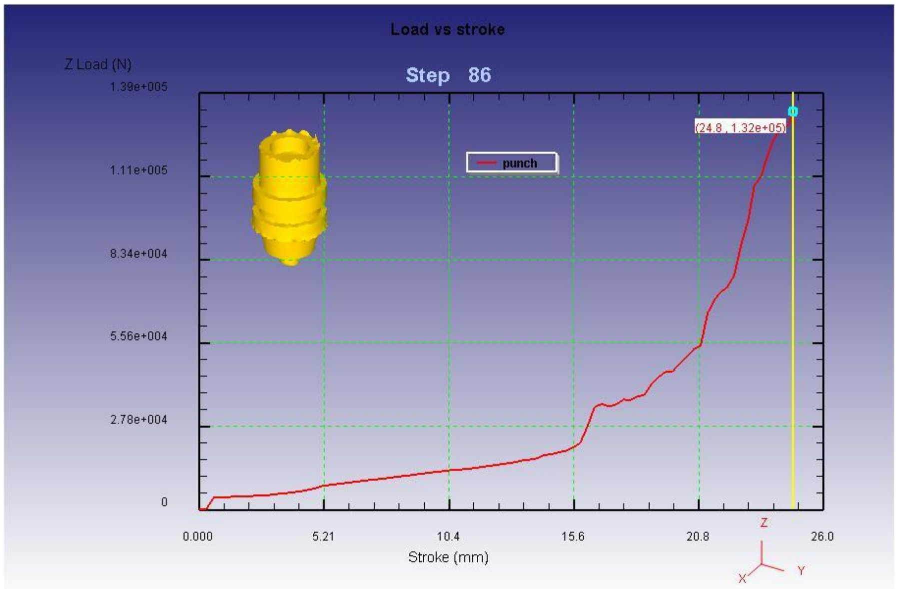


Fig. 3.14: Variation of load with stroke for 24.8 mm length of punch travel

3.6 Conclusion

Finite element based simulation analysis has been implemented for the combined extrusion-forging process to make the product Collet chuck holder. The simulation process has given an idea and visualization of the product before conducting the experimentation. The punch load and length of punch travel gives an idea to design the die set up and experimental procedure. The characteristics such as effective strain, effective stress, total velocity and metal flow patterns have been analysed for different length of punch movements.

4.1 Introduction

In order to compare the results obtained from finite element simulation with experimental results, number of experiments has done in the present analysis. Initially, a setup has designed and fabricated for making Collet chuck holder using combined extrusion-forging process. The number of experiments has done on Universal Testing machine of maximum capacity 600kN using cylindrical aluminium specimen to get final product collet chuck holder. Also, compression and ring tests have done to determine the stress strain characteristics and friction factors respectively.

4.2 Experimental Setup

The experimental setup consists of forging-extrusion dies and die holders, base plate, punch head, container, sleeve, punch rod. The components that have used in the experimental setup have been discussed. The container of dimensions 140mm diameter and 100mm length has made of EN31 steel and having a cylindrical chamber of size 50mm diameter and 100mm length. It can be achieved by turning the outer diameter of the container and drilling the inner chamber with a tolerance of ± .02 mm using wire cut EDM. The cover plate is used to avoid the back slip of sleeve that has placed inside the container chamber during experimentation. The container sleeve has placed inside the container chamber, whose outer diameter should match the diameter of the container chamber and inner diameter should match the diameter of main punch. The function of container sleeve is to guide the punch rod through the container and avoid bulging of punch rod. The die holder -1 and Die holder -2 which have manufactured using similar processes. The circular split dies, and circular taper split die, punch rod and circular punch head have manufactured using D2 steel. The push fit alignment has used for attaching the punch head with punch rod-2. The base plate has made of EN 8 steel.

4.3 Experimental Procedure

The experimentation has done on Universal Testing Machine of maximum capacity 600kN using cylindrical aluminium billet. The components of the experimental setup have thoroughly cleaned, and lubricant (in this case it is grease) should applied to the inner surface of the dies and die holders, punch and sleeve. Also, the specimen is lubricated and placed inside the die cavity, and punch has placed above the aluminium specimen (billet). Now, the container is placed on the die holder, and it is fixed by using bolts. Finally, the sleeve is placed inside the container chamber, and main punch has placed inside the container sleeve. The setup has now finished, and it has placed on the lower table of the universal testing machine of maximum capacity 600kN (shown in Fig. 4.1). Now switch on the machine and set the parameters such as anvil height, strain rate, the diameter of billet, the maximum load and length of punch travel. In this research work the anvil height is 54 mm, diameter of the billet is 15 mm, length of punch travel as 24.6 mm and the punch speed as 1 mm/min have taken. As we have given the length of punch travel as 24.6 mm, the machine stops the process after reaching it. The punch load has recorded for every 30sec of punch travel. After completion of the experiment, the punch dies setup has dissembled, and the die sets containing the final product have removed by applying the gradual load. Finally, the desired product collet chuck holder has produced by using combined extrusion forging process. Experiments have conducted for different lengths of punch travel to investigate the metal flow pattern and die cavity to fill.

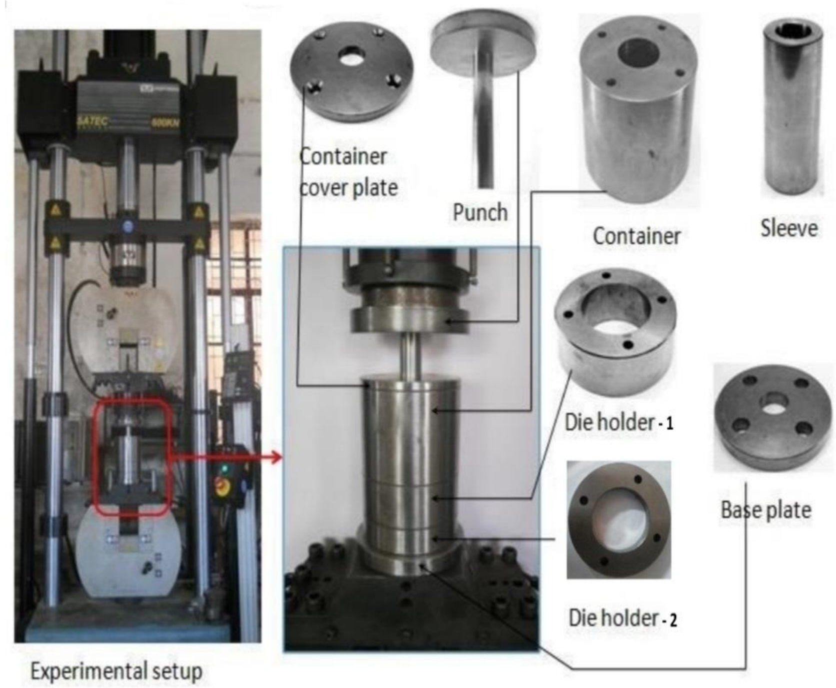


Fig. 4.1: Photographic view of experimental setup with main components

4.4 Determination of Stress-Strain characteristics of Aluminum

The compression test has conducted to determine the stress-strain characteristics of cylindrical aluminum billet, and the flow stress obtained by power equation developed from the stress-strain curve. Initially, the cylindrical aluminium billet of diameter 18 mm and length 32 mm has machined from casted billet material. In order to entrap the lubricant, some oil grooves have made on the top and bottom surfaces of the specimen. The lubricant such as grease has adequately lubricated and placed on the lower table of the UTM. The uniaxial compression test has conducted by applying the gradual load, and the compressive load has recorded for every 0.2 mm of punch travel. The machine has stopped after completion of compression of 2 mm, and the compressed billet has re-machined to the initial billet specifications. The process has continued till the height become 25.25 mm. Finally, the stress-strain curve has plotted and shown in Fig. 4.3.

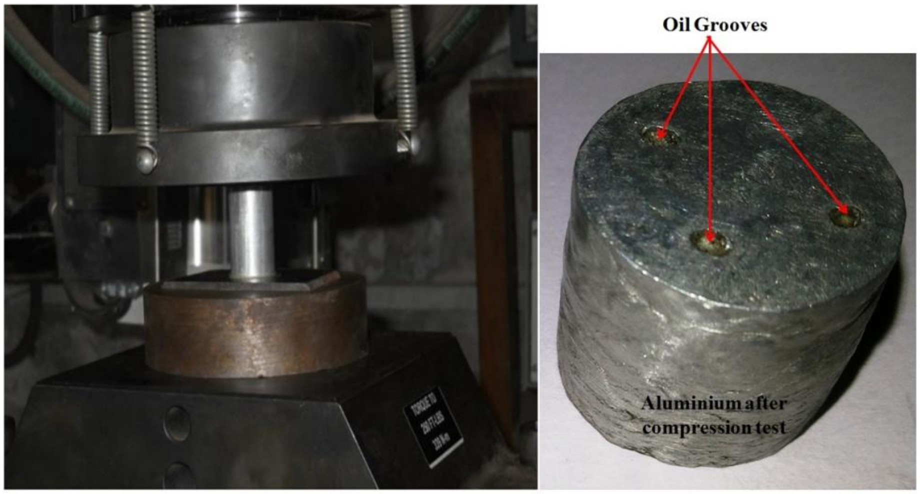


Fig. 4.2: Compression test setup with aluminum specimen

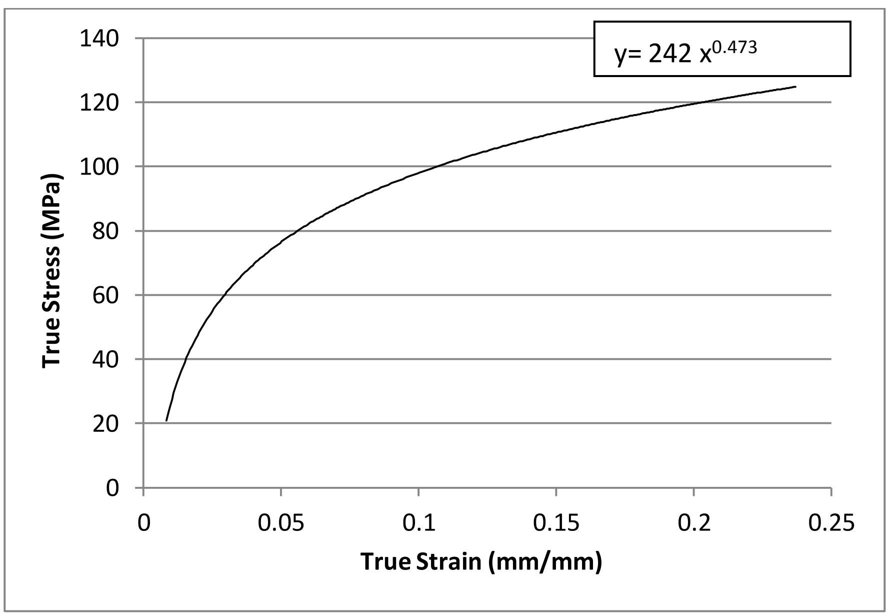


Fig. 4.3: Stress-strain characteristic curve for aluminium

From the Fig. 4.3, we can determine a fitting curve of power equation shown in the equation (1):

$$\sigma = 242\dot{\varepsilon}^{0.473} \qquad (1)$$

By comparing the equation (1) with Holloman's power equation we can get the strength coefficient as 242MPa and Strain hardening index as 0.473. The flow stress obtained from stress-strain curve is 125 MPa and the power equation has used in the simulation process.

4.5 Determination of Friction factor using Ring compression Test

The most important factor which influences the forming load, Metal flow pattern and internal grain structure is the frictional conditions at the interface of billet/die. When a flat ring specimen is compressed plastically between two flat platens, increasing friction means poor lubrication results in an inward flow of the metal while decreasing friction means good lubrication results in an outward flow of the metal. So in compression test, if the internal diameter increases, it represents low friction and if the internal diameter decreases it represents high friction. The Fig.4.4 shows the change in shape of the specimen when it is compressed with lubrication and without lubrication.

In this research work the ring compression test has done for both with lubrication and without lubrication. For this ring compression test a flat ring shaped specimen having OD: ID: H ratio 6:3:2 has considered. According to the ratio, the dimension of the ring has taken as 18:9:6 and ring test has done. To estimate the accurate friction between the die/billet interfaces, two flat die plates with same internal surface conditions have used for compression. After completion of the ring test, from the recorded values a curve has obtained. The standard calibration curves have used to compare the curve obtained from ring test and the friction factors have determined. The friction factor obtained for ring test with lubrication is 0.22 and for without lubrication is 0.28.

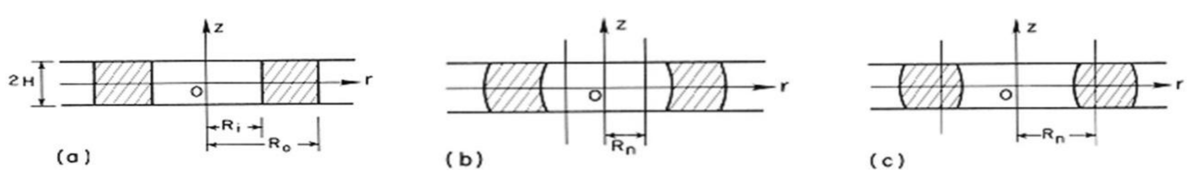


Fig. 4.4: (a) specimen before ring test, (b) Specimen after ring test with lubrication, (c) Specimen after ring test without lubrication

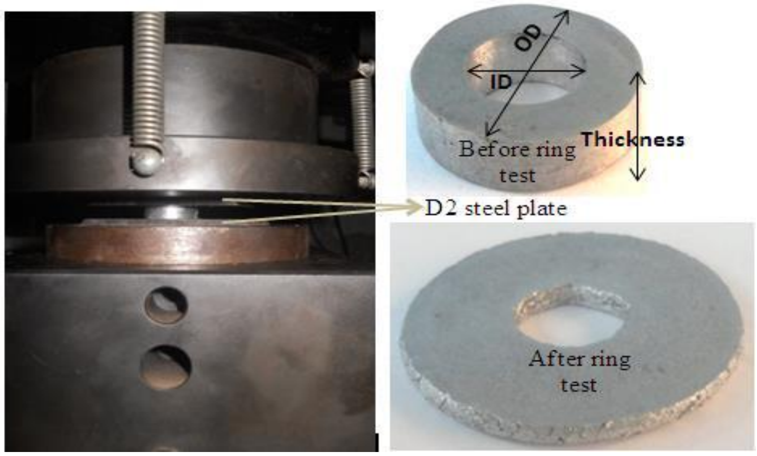


Fig. 4.5: Setup for ring test

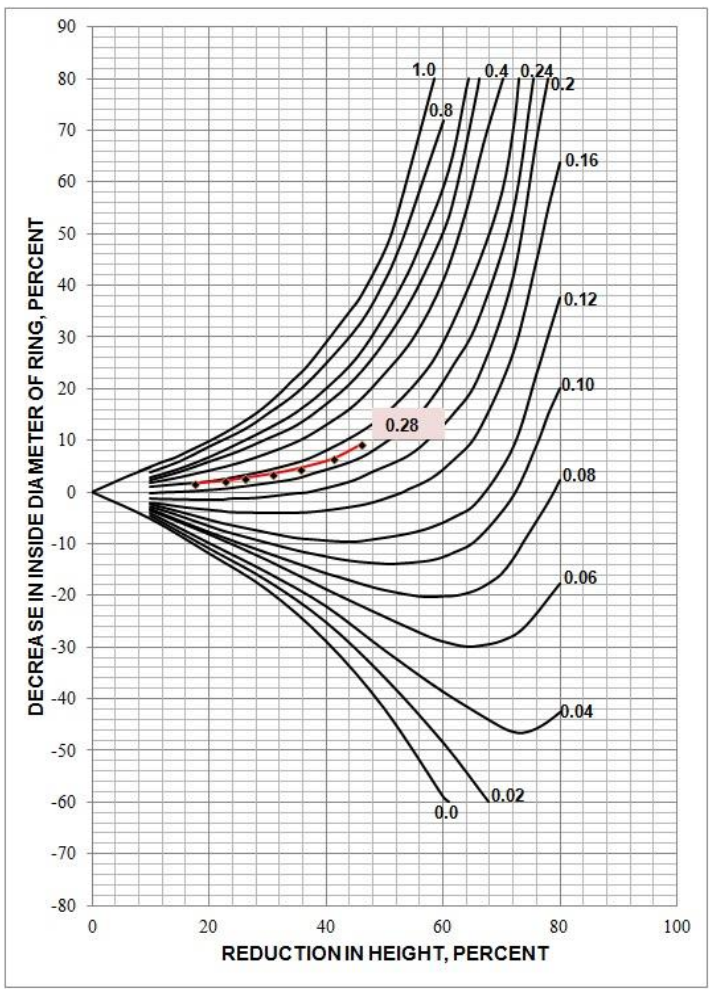


Fig. 4.6: Comparing the Ring test (without lubrication) curve with theoretical standard calibration curve (6:3:2) [21, 22, 23]

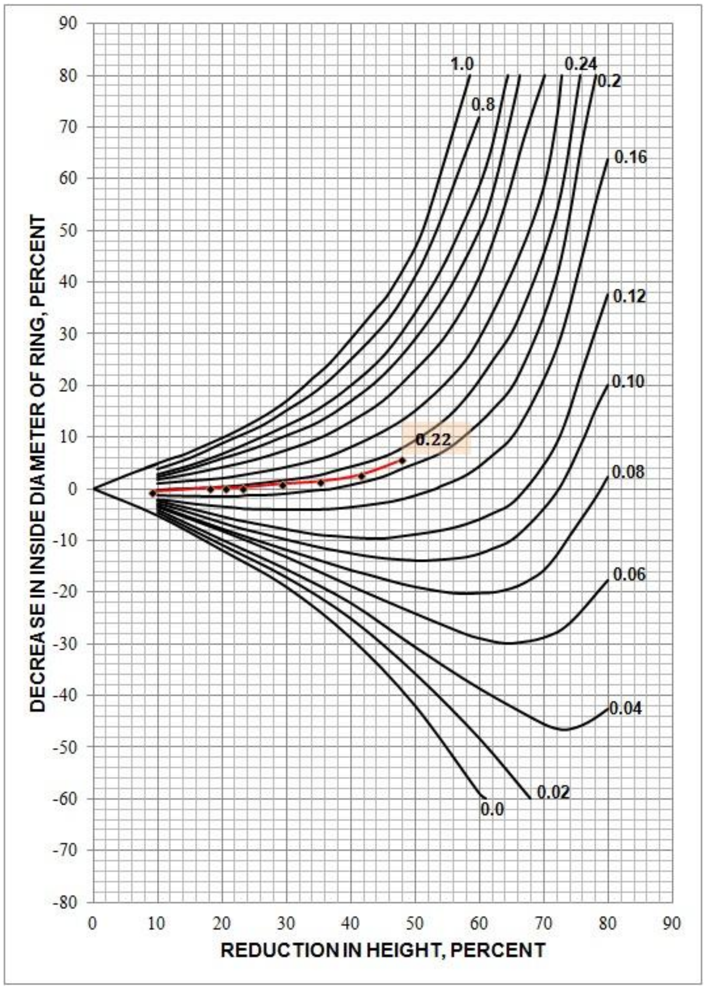


Fig. 4.7: Comparing the Ring test (with lubrication) curve with theoretical standard calibration curve (6:3:2) [21, 22, 23]

The friction factor obtained from the calibration curve has taken as one of the input parameter in the Finite element simulation process. The Figs. 4.6 and 4.7 show the theoretical calibration curves for ring tests with lubrication and without lubrication respectively.

4.6 Various stages in the formation of product during combined extrusion forging process

Experiments have done to manufacture the required product Collet chuck holder using combined extrusion-forging process on a Universal testing machine. It has observed that the whole compression process consists of four stages. The first stage shows the initial compression of the billet. In second stage small indentation hole and forging of the taper die has been completed. In third stage both extrusion and forging are completed. The last circular extrusion part has been completed at this stage. In the fourth stage, flash had come and finishing of the product has been completed. The Figures 4.8 to 4.11 represents the graphs for variation of punch load with punch movement at different punch travel.

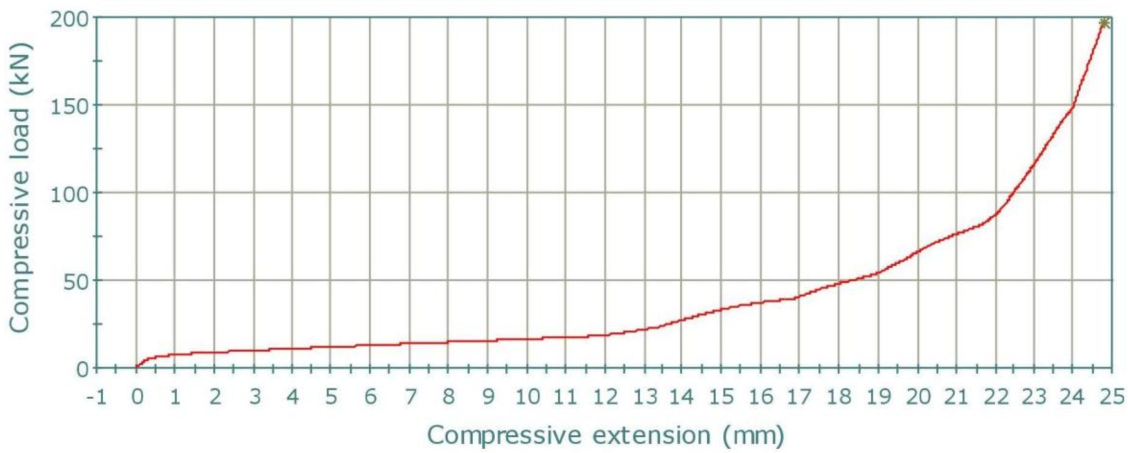


Fig. 4.8: Variation of punch load with stroke for 24.8 mm length of punch travel

The Fig. 4.8 represents the variation of punch load with respect to punch movement at 24.8 mm length of travel of punch. Here the complete product obtained with flash. The load required for complete formation of product is 191.22 kN.

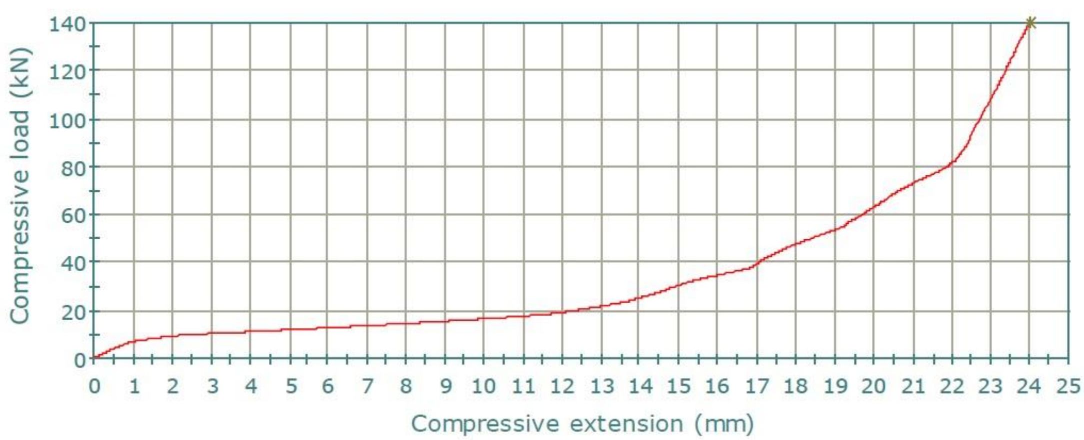


Fig. 4.9: Variation of punch load with stroke for 24 mm length of punch travel

The Fig. 4.9 represents the variation of punch load with respect to punch movement at 24 mm length of travel of punch. There is not much variation compared to the 24.8 mm punch travel. Here the complete product is obtained and flash just started to come out. The load required at 24 mm of punch travel is 139.76 kN. There is significant variation in load for 24.8 mm and 24 mm punch travel. This is because at 24 mm of punch travel, flash is not formed yet and extrusion part also not completed. So 24.8 mm punch travel takes more load than 24 mm punch travel.

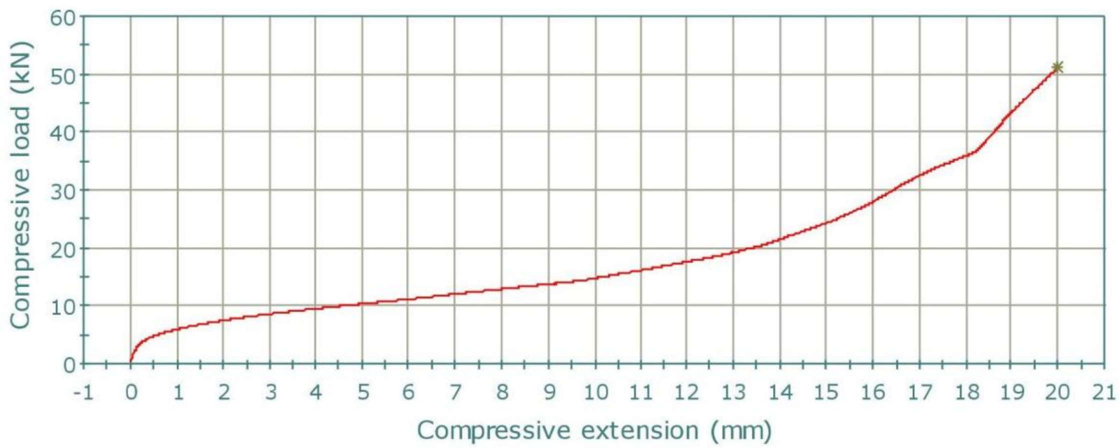


Fig. 4.10: Variation of punch load with stroke for 20 mm length of punch travel

The Fig. 4.10 represents the variation of punch load with respect to punch movement at 20 mm length of travel of punch. In this stage only complete formation of hole in first part and partial formation of tapered part is obtained. Circular part with flash and extrusion part are not started. The forming load required at 20 mm punch travel is 51.08 kN.

The Fig. 4.11 represents the variation of punch load with respect to punch movement at 15 mm length of travel of punch. This stage represents only initial compression. The punch head is penetrated into the billet. The load required at 15 mm punch travel is 22.72 kN.

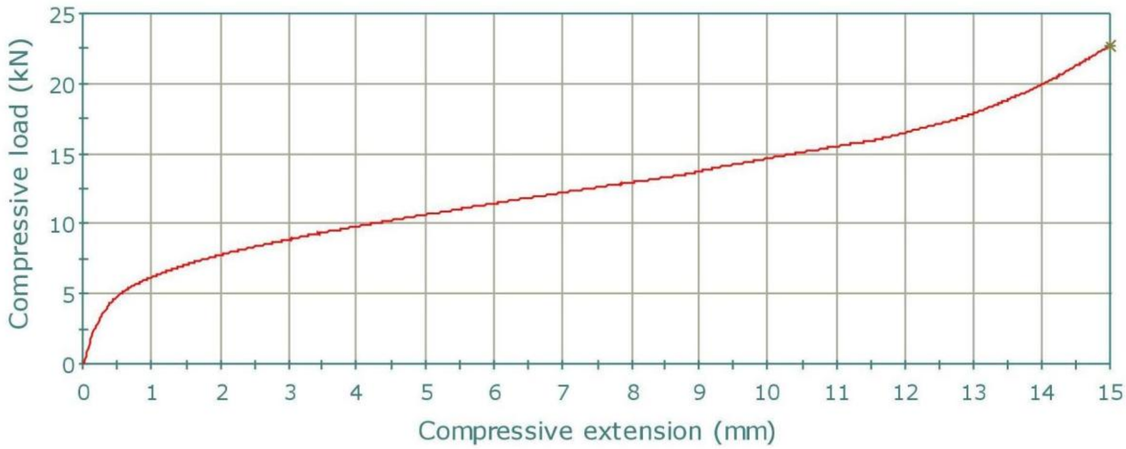


Fig. 4.11: Variation of punch load with stroke for 15 mm length of punch travel

4.7 Conclusion

The experiments have done to produce collet chuck holder using combined extrusion forging at different lengths of punch travel. After completion of experimentation, the following conclusions are drawn:

- ✓ Experimental setup has made for combined extrusion forging process.
- ✓ The maximum forming load has been obtained for different punch movements from the experiments.
- ✓ Flow stress of aluminium has been calculated and friction factor value has been determined from the ring test.

Chapter 5 Comparison of Results

5.1 Comparison of Results

The results obtained from both simulation and experimental analyses are compared to validate them.

5.1.1 Maximum Forming load required for combined extrusion forging to make collet chuck holder

The maximum forming loads (peak loads) for both simulation and experimental analysis have shown in Table. 5.1. It has observed that the difference in maximum forming loads (peak load) obtained both from simulation and experiments are within 30.79% for different length of punch travel.

Table 5.1 Comparison of maximum forming load (peak load) of a combined extrusion-forging process for various punch travel

Different length of punch travel	Simulation peak load (kN)	Experimental peak load (kN)	Absolute percentage error
15 mm	18.89	22.72	16.86
20 mm	45.94	51.08	10.06
22 mm	73.76	81.837	9.87
24 mm	124.61	139.76	10.84
24.8 mm	132.35	191.22	30.79

5.1.2 Deformed shape for different length of punch travel

Experiments and simulation have done for the final product collet chuck holder by using combined extrusion-forging process for the different length of punch travel. The input parameters such as punch speed, friction factor and strain rate, etc. have taken for both simulation and experimental analysis, which are same. Fig. 5.1 shows the final product (collet chuck holder) obtained by this process at the different length of punch travel for simulation and experimental analysis. The different length of punch travel has taken as 15 mm, 20mm, 22 mm, 24 mm, and 24.8 mm for both simulation and experimental analysis. From the fig. 5.1 it is shown that initial compression occurred up to 15 mm length of punch travel. After that, up to 20 mm length, punch head penetrated into the billet, and a small hole will form. At 22 mm length of punch movement tapered part of the product will form. At 24 mm of punch travel, total product Collet chuck holder will form except the flash. At 24.8 mm length of punch travel, the entire product including flash will form.

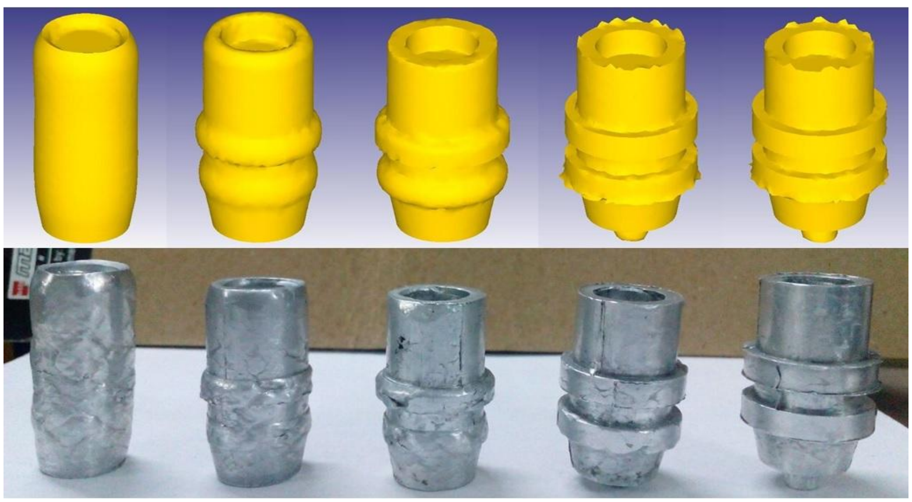


Fig. 5.1: Collet chuck holder at different punch movements for both simulation and experimental analysis

5.1.3 Metal Flow Pattern

The flow pattern of metal for both simulation and experimental analysis by combined extrusion forging process is shown in Fig. 5.2 at 20 mm, 22 mm and 24.6 mm length of punch travel. The distortion of grid line indicates that the process utilizes the maximum amount of redundant work and types of deformation in extrusion-forging. The shear distortion requires energy which is not related to the change in shape of the billet to required product. This work is called redundant work.

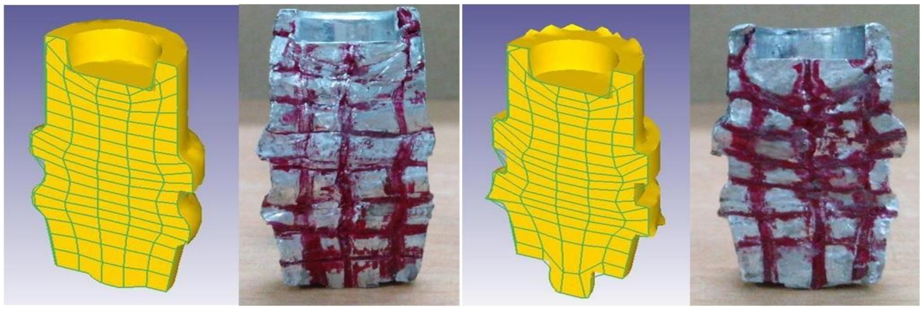


Fig. 5.2: Comparison of flow patterns for both simulation and experimental analysis at 22 mm and 24.6 mm length of punch movement

From Fig. 5.2 we can observe that the distortion of flow pattern is more at the center of the product. Metal flow is mainly concentrated at the center of the product because of the friction between the billet and die interface. The grid pattern at the center part of the product shows that metal flowing towards the circular part and flash part of the product. The grid pattern at the tapered part is trying to penetrate into the extruded part of the product. The grid pattern of the extruded part of the product we can observe in the 18 mm length of punch movement. The grid distortion at the hole in the product is because of the interface friction between billet and punch head.

5.1.4 Variation of Punch load with stroke at different length of punch travel

The following Figures 5.3 represents the graphs between punch load and stroke at different lengths of punch travel. From the graphs we can observe that there is not much variation in the forming loads obtained from both simulation and experimental analysis at 15 mm and 20 mm punch movements. The load variation is more at 24.8 mm and 24 mm punch movements. The experimental load is more compared to simulation load because the interface fiction is more in experimental conditions, practical problems like variation in billet shape and lack of lubricant etc. The graphs show the same variation at different punch movements.

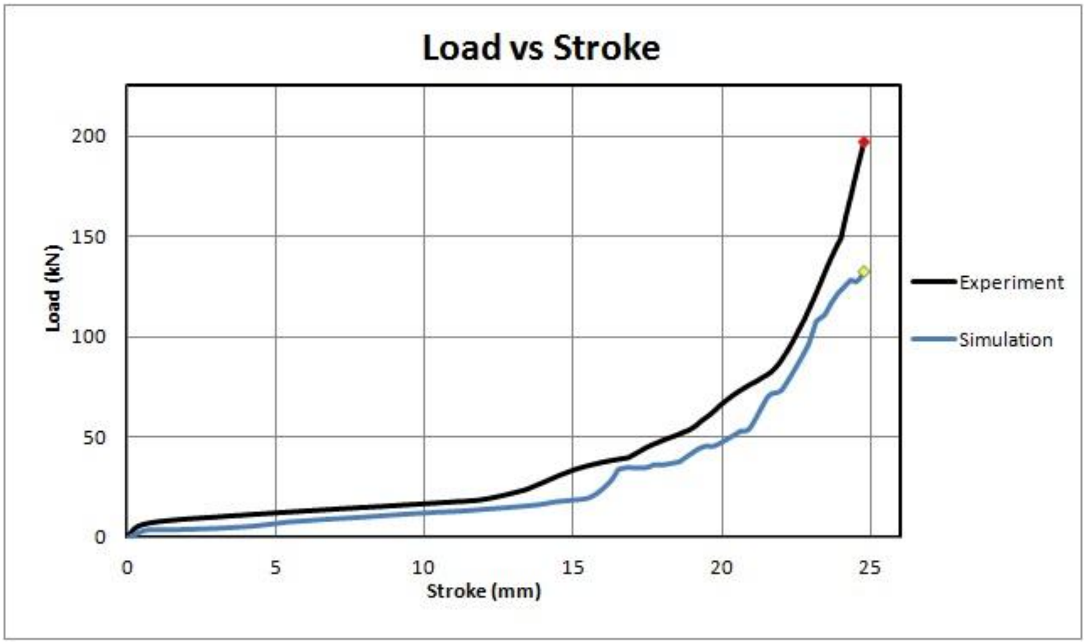


Fig. 5.3: Load vs Stroke graphs at 24.8 mm punch movement for both simulation and experimental analysis

5.2 Conclusion

The metal flow pattern, die filling and load required for different length of travel obtained from experimentation are in good agreement with simulation results. The grid lines in flow pattern show that metal flow homogeneous with friction interfaces. The peak punch loads at different lengths of punch travel have been compared for both simulation and experimental analysis. From the Fig. 5.3 we can observe that there is good agreement between Simulation analysis and experimental results.

Chapter 6 Conclusion and Future scope

6.1 Conclusion

In present research work, simulation and experimental analysis have been done to produce collet chuck holder by combined extrusion forging process. Experimental results are in good agreement with simulation results. From the obtained results, we can draw some conclusions

1. Finite element based simulation has been implemented for combined extrusion-forging process to produce collet chuck holder using software DEFORM 3D and the characteristics such as effective stress, effective strain, total velocity and metal flow patterns have been analyzed.
2. Both experiment and simulation have been carried out for different length punch movement (length of punch travel) and found the various stages during metal filing in dies.
3. Experimental setup for combined extrusion-forging process of Collet chuck holder has been made.
4. Flow stress of aluminum has been calculated, obtained a value of 125 MPa and friction factor value is obtained as 0.22 from the ring test on a universal testing machine.
5. The variation of punch load with respect to displacement curves obtained from experiment shows good agreement with the simulation process.
6. The experimental die filling, metal flow pattern and load requirements are in good agreement with simulation results.

6.2 Scope for Future work

The present research work can be extended further to explore the more aspects of combined extrusion-forging process. The following are the some of the recommendations for future work

- This method extended to do in the hot conditions with other materials.
- Upper bound analysis can be done to verify the results obtained from the experimental analysis.
- The proposed Finite element analysis can be extended to apply for the determination of die stresses.
- This method can be further extended to do analysis for other materials and complicated shapes.

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