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ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY
School of Engineering

Analysis of Bolt Forming Process and Designing Bolt Forming Dies

A Thesis submitted in partial fulfilment of the requirements for the award of the degree of

Master of Science

in

Manufacturing Engineering

By

Biruk Yacob

Advisor: Dr Wassihun Yimer

Department of Manufacturing Engineering

June, 2015

Adama

CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in the thesis entitled **"Analysis of Bolt Forming Process and Designing Bolt Forming Dies"** in partial fulfillment of the requirements for the award of the degree of master of science in manufacturing engineering is an authentic record of my own work carried out from October 2014 to June 2015 under the supervision of Dr Wassihun Yimer, Mechanical Engineering department, Adama Science and Technology University, Ethiopia.

The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this thesis have been duly acknowledged

Student	**Signature**	**Date**

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with my approval.

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Analysis of Bolt Forming Process and Designing Bolt Forming Dies

By

Biruk Yacob Anulo

Approved by Board of Examiners

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List of Acronyms and Abbreviations

A	area
r	radius
d	diameter
l	length
α	angle
μ	coefficient of friction
φ	plastic strain
ε	elastic strain
σ_r	stress in z direction
σ_z	stress in z direction
σ_t	tangential stress
F_z	force in Z direction
s	displacement
σ_f	flow stress
W_{tot}	total work
W_{id}	ideal work
W_{FR}	work by friction
W_{Sh}	shear work
W_B	bending work
F_{tot}	total force
F_{id}	ideal force
F_{FR}	friction force
F_{Sh}	shear force
F_B	bending force
FEM	finite element methods
LCF	low cycle fatigue
HCF	high cycle fatigue
HMMBI	Hibret Manufacturing and Machine Building
CAD	computer aided design
CAE	computer aided engineering

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Abstract

Cold forming processes are used frequently in the manufacturing of bolt. These processes are characterized often by high tool loads strain with the consequence risk of tool failure. Engineer and researcher are attempting to understand the process and optimize the process. This is being done in an effort to establish more reliable different models of the process, to aid in the selection of the most appropriate forming machines, and in the design of the tooling to be used on these machines. This project deals with analysis of bolt forming process in Hibret Manufacturing and Machine Building Industry (HMMBI). Cold working processes are used in the production of bolt and the bolt is produced from 20MnB4 type of steel. Manufacturing process and practice of production of bolt were studied and strength and weakness of the process was identified. For the analysis of metal forming and die stresses analysis finite element code ABAQUS CAE/6.10/ commercial software were used. The output result of ABQUS CAE is compared with plain strain method and had good agreement with regard to the force required to forging. To optimize the force require to extrude the billet with a given reduction ratio, the die opening angle are reduced from 30^0 to 26^0. The research covers die geometry only to optimize the die life but total die structure better to be studded with support of experimental work to get more reliable result.

Key word, bolt forming process, FEM model and tool life

TABLE OF CONTENT

Chapter one

1.1. Introduction

Mechanical fastening is the act of joining parts with the aid of devices such as screws, rivets, bolts and pins. Fasteners are inserted into overlapping holes in separate parts to create compressive or frictional bond. They may be the smallest component of any manufactured product, but fasteners and fixings are perhaps the most important since nothing would be built without them (1).

Most early threaded fasteners were made by hand, by forging the head, cutting the slot with a saw and fashioning the thread with a file, so no two screws were ever alike. As the geometry of the fasteners became more complicated, with the improvements in manufacturing methods, material characterization techniques and computer technology, high speed formers with high-tech tooling systems were developed. Moreover, some numerical techniques like finite element and finite volume methods started being used to visualize the processes on a virtual environment and perform analyses to improve process parameters.

In the bolt production the recent trend is metal forming process. Cold forming process is used in the forming headed fastener, the most benefit getting from this process are improving micro structure and easy for mass production. Systematically different metal forming problem areas are identified and among them in cold forming process are excessive load damage tool and reduce tool life.

Fastener manufacturing industries need to implement practical and proven computer aided design (CAD), computer aided manufacturing (CAM) and computer aided engineering (CAE) technologies for rapid and cost effective process design and die manufacture to stay in global computation. Recently, finite element (FE) simulation software has become an integral part of forging process design to analyze and optimize the metal flow and conduct die stress analysis before conducting forging trials (2). The main goal of simulation in manufacturing process design is to reduce part development time and cost while increasing quality and productivity.

This chapter includes evolution of screw fastener production, motivation of the work, objective of the study, scope of the study and limitation of the study.

1.2.Statement of the problem

The construction of mega projects in the country demands huge amount of fastener. Hibret Manufacturing and Machine Building Industry (HMMBI) is the only registered company in the country to manufacture screw fastener in mass production.

- ❖ Upsetting, direct extrusion, indirect extrusion and other cold forming process sequence have effect in productivity and total process system. Direct extrusion dies fails regularly when it works for extended time.
- ❖ Some bolt forming machines are out of production because of lack of proper dies in the factory and supplier problem.
- ❖ Even though the tooling costs can consume 5% to 30% of the manufacturing costs of bolt production (3), the factory does not have its own tool and dies manufacturing system and purchased with foreign currency from external supplier.
- ❖ In toadies world demand of standard sized bolts are decreasing and the demands of special size are increasing. It needs deferent tools for special item. The factory has to go through this flexible die design and die manufacturing system to meet the current demand so the tool design and tool manufacturing is crucial.

1.3.Objective of the study

1.3.1. General objective

General objective of this research is to design bolt forming tools through analyze current forging process and to achieve optimum manufacturing process and production system.

1.3.2. Specific objective

This research aim to achieve:

I. To design bolt forming die
II. To analysis bolt forming process
III. To analyze tool failure criteria
IV. To develop two dimensional finite element models of bolt forming process

V. To improve and optimize sequence bolt forming process

VI. To analyze the designed die with finite element method model.

1.4.Limitation

The research aims to optimize the forming process of bolt by improving tool design system. Some factors limit this researches which are:

With the limit of budget, lack of research grant, this research is done by analytical calculation and virtual simulation. If the research would be supported by experimental, the research work is more realistic. Time is another limiting factor.

1.5. Scope of the study

This research covers:

- ❖ The process limit of head forming of the bolt and extrusion of shank of the bolt are analyzed.
- ❖ The geometry of forming tool of head and extrusion of the shank of bolt are designed.
- ❖ Material flows, stress and strain distribution of forming of the bolt are studied using FE method in axiasymmetric plain.
- ❖ Stress distribution of on extrusion dies are analyzed using FE method in axiasymmetric plain.

1.6.Significance of the study

In fastener production which includes almost all processes of cold bulk metal forming processes such as wire drawing, open die and close die extrusion, heading and close die forging, die design has a crucial role affecting the soundness of the product. Some of the fastener manufacturers through out the world have trend design and manufacturing of their own demand of dies with the aid of computer. If HMMBI does implement this study, it is possible to manufacture their demand of tools with combination of future work of this research.

1.7.Content of the study

Chapter one cover introduction, the problem related to bolt forming tool exist in the factory, what going study in this research and limitation that hinder to achieve this aim are discussed here.

Process of bolt forming process upsetting, surface reduction extrusion and their process limit discussed in portion of chapter two. The other portion chapter discus cold working tools what influence the life of forging tool, design consideration in cold working tool and fatigue analysis of tool life.

The third chapter covers the practice bolt production process in HMMBI work shop and problems and good practice are discussed in this chapter.

How to tackle the problem how we got the solution, method, what materials and tools are used and how tools are used are discussed in chapter four.

Starting from material requirement calculation, stress, strain and displacement analysis are discussed for head forming are discussed in chapter 5. Extrusion die opening angle is analyzed and stresses distribution on elastic dies are analyzed in this chapter.

Finally what done and the output are concluded and some recommendations are set for the factory.

Chapter Two-Literature Review

2.1.Bolt Forming Process

For mass production of small or medium-sized mechanical parts, cold-former machines are being used in a wide range of mechanical parts manufacturing industries (4). In cold former forging machine, initial material cut from the bars and performs progressive steps. It includes shearing, forward and backward extrusion, piercing and etc.

Head making is primary operation in bolt forming. Head is formed through the process of upsetting followed by head making and coning.

Another process is reduction of the area of treading portion on bolt shaft. Reduction of cross section is possible by material removal technique or direct/indirect extrusion forming process. With Regards to material saving, production time reducing and improving working material properties, advantage of extrusion process supersede material removal technique.

2.1.1. Material flow

2.1.1.1.Material flow in upsetting

Head is made using upsetting process, upsetting is defined as free forming by which a work piece segment is reduced in length and increasing diameter between usual, parallel plate (5). In cold upsetting the stream lines and flow lines do not coincide during forming (figure 2.1).

In upsetting process metal flow and the deformation distribution are affected by more by friction than by temperature and strain rate. When friction increase for large reduction and for workpiece with initial high diameter to thickness ratios for such case good lubrication become especially important.

2.1.1.1.Material flow in extrusion

For smaller reduction of the cross section the process of open-die extrusion is used instead of solid forward extrusion, especially in fastener manufacturing. Open die extrusion is considered to be a process in which a short billet is pushed through a narrow opening in a conical die that determines the cross section of the final product (6). Free die extrusion (figure 2.2) is reduction of the cross section of solid bodies without supporting the unreformed portion of the component in any condition.

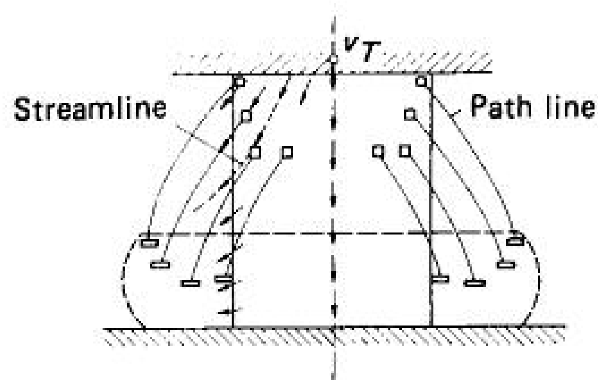


Figure 2.1 Motions in upsetting (nonsteady-state metal forming process) *(Lunge, Handbook of Metal Forming)*

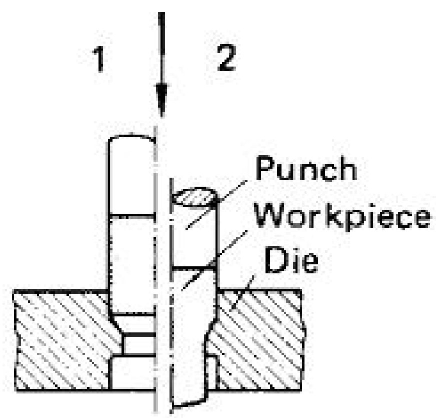


Figure 2.2 schematic representation free extrusion process. 1. Initial shape of the workpiece, 2. Final shape of workpiece *(Lunge, Handbook of Metal Forming)*

Material flow in extrusion is steady state. For a steady state process the strain and path line coincide. Thus it is easily seen that for a steady-state displacement, the other process-related quantities, especially stresses and forces, do not change with time. The flow of the material can be seen by sectioning the workpiece and then inscribing a network of lines which get deformed (figure2.2).

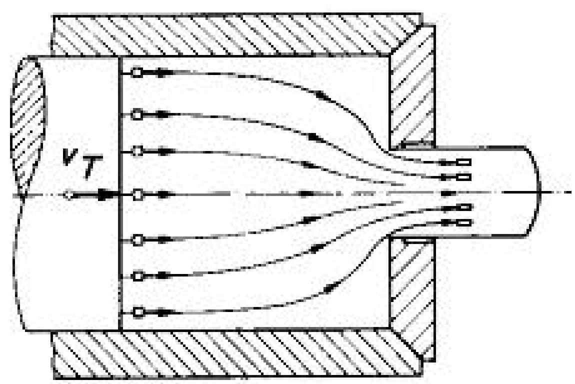


Figure 2.3. Motion in extrusion (steady-state metal forming process) *(Lunge, Handbook of Metal Forming)*

2.1.2. Stress analysis

In order to develop a rational basis for determining the limitations on design and operational factors for metal-forming processes which will ensure a satisfactory product, it is necessary to evaluate the history of the stress and deformation distributions throughout the work-piece (7). Since the force and deformations generally are quite complex, it is usually useful to use simplifying assumption to obtain a good solution. Because the strains involved in deformation process are large, it is usually possible to neglect elastic strain and consider only the plastic strains (plastic-rigid solid).

The requirement of a theory describing the mechanics of metal working process is the ability to make an accurate prediction of the stress, strain and velocities at every point in the deformed region of workpiece. The various approaches differ in complexity and in the degree to which they meet this requirement. In general, such a theory consists of three of equations:

1. The static equilibrium of force equation
2. The Levy-Mises equation expressing a relationship between stress and strain
3. The yield criterion

The methods are used in this paper the simple one slab method and complex one finite element method:

1. The slab method- assume homogonous deformation
2. Finite element method – a technique called the matrix method allows large increments of deformation for rigid plastic materials, with considerable reduction in computational time.

2.1.2.1.Elementary plastic theory (slab method)

Upsetting force can be calculated approximately using elementary plastic theory (). To calculate force distribution of normal stress at the tool-workpiece interface is required. The rectangular slab technique is used for plane-strain deformation and the tubular slab technique for axisymmetric. Axisymmetric upsetting with coulomb friction yields force equilibrium in the radial direction (figure2.4).

$\sigma_r rl\, d\varphi - (\sigma_r + d\sigma_r)(r+dr)l\, d\varphi + 2\sin(d\varphi/2)l dr - 2 r d\varphi dr = 0$--------------------------------2.1

where σ_r is radial stress

σ_z is normal stress

σ_t is tangential stress

r is radius of upsetting workpiece

l is length of upsetting workpiece

$d\varphi$ is changed upsetting angle

μ is friction coefficients

Simplify equation 2.1 with the help of different mathematical tools, sine for small angle; linear deferential equations and Tersca yield criteria and applying boundary condition normal stress is calculated for different friction condition are depicted in figure 2.5.

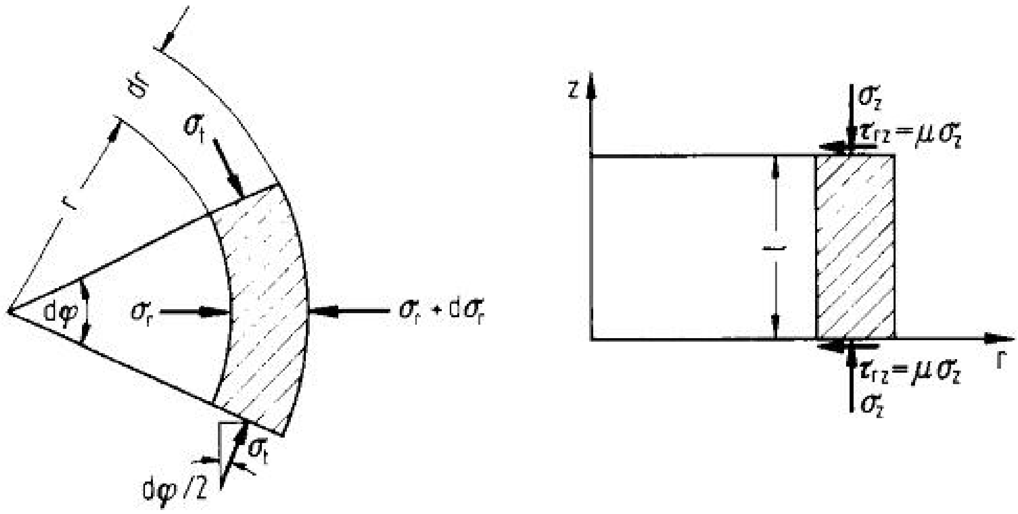


Figure 2.4 Force acting on an annular volume element, axisemmetric forming *(Lunge, Handbook of Metal Forming)*

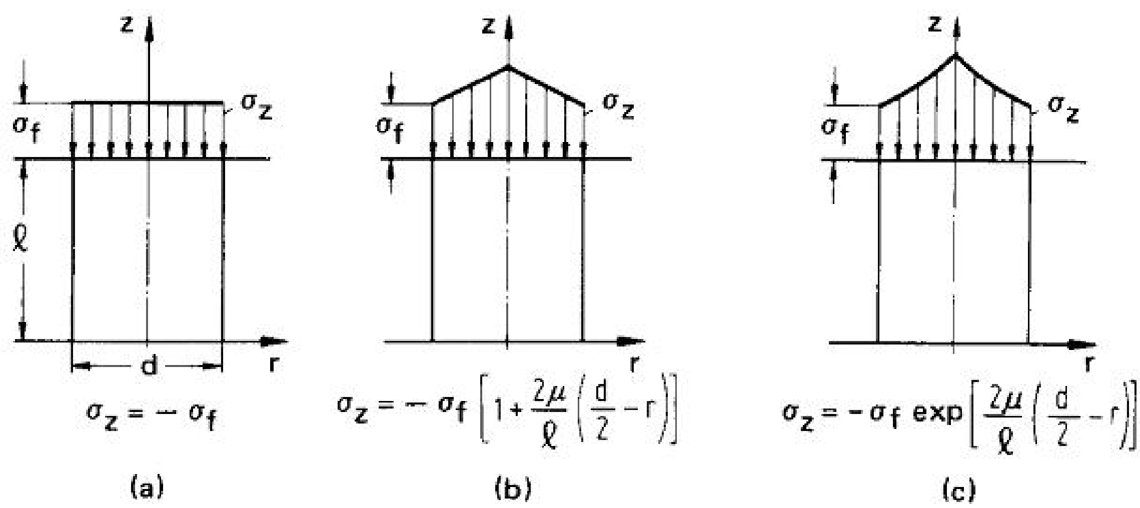


Figure 2.5 Normal stress distribution σ_z at the interface of axisymmetric upset cylinders, elementary theory of plasticity. (a) Frictionless upsetting. (b) Upsetting with friction, series expansion. (c) Upsetting with friction, exponential distribution. *(Lunge, Handbook of Metal Forming)*

Now the forming force is obtained by integrating of the pressure over the contact area A.

$$F_z = \int_A \sigma_z dA \text{--- } 2.2$$

For axisymmetric case considering figure 2.5b

$$F_z = A\sigma_f(1 + \frac{1}{3}\mu\frac{d}{l}) \text{--}2.3$$

Where A is the new area of upsetting work piece

d is the new diameter of upsetting work piece

l is the new length of upsetting work piece

The energy of deformation is obtained from

$$W = \int_{s=0}^{s=l_0-l_1} F_z ds \text{---}2.4$$

Most of this energy is dissipated as heat.

The friction coefficient μ is governed by lubrication, tool-workpiece material paring and temperature. For cold upsetting of steel $0.05 \leq \mu \leq 0.15$ with lubrication, while for hot upsetting of steel μ is between 0.25 and 0.5.

Stress analysis in extrusion process

To analyze stress in extrusion Knowledge of the stress condition in the deformation zone contributes to the understanding of the deformation process (5). For axisymmetric process three principal stresses are presented, axial stress, radial stress and tangential stress.

To analyze the extrusion process some procedure is applied. First the region of material undergoing plastic deformation is to be identified.

The questions arise are: where is the deformation zone? At what region is the deformation zone can value of one of the three principle stress be determined? And which are the maximum and minimum principle stresses?

In figure 2.6 the deformation forces F_{tot} is applied on the punch. The material becomes plastic at cross section 0. The plastic zone extends up to cross section 1. The axial stress σ_z is zero at the exit of the die since the material can flow freely. The axial stress is compressive and increases in the deformation zone up to cross section 0. The stresses σ_t and σ_r are equal since, according to elementary plastic theory, the strains are equal in both the radial an circumferential directions. The stress distribution in the deformation zone is related by

$$\sigma_z - \sigma_t = \sigma_f \text{--} 2.5$$

Since both the tangential and the radial stress are compressive. The variations of σ_z and σ_t are not parallel. The increasing difference between these two stresses is due to the work-hardening effect of the workpiece material ($\sigma_{f.1} > \sigma_{f.0}$).

For the selection of a suitable forming machine tool, the deformation force and the deformation work should be known. Deformation forces include expression for ideal, friction, shearing and bending work in deformation.

$$W_{tot} = W_{id} + W_{FR} + W_{Sh} + W_B \text{--} 2.6$$

Where W_{tot} = total work
W_{id} = ideal work
W_{FR} = work by friction
W_{Sh} = shear work
W_B = bending work

The expression total force F_{tot} can be

$$F_{tot} = F_{id} + F_{FR} + F_{Sh} + F_B \text{---} 2.7$$

Where F_{tot} =total force
F_{id} =ideal force
F_{FR} =friction force
F_{Sh} = shear force
F_B =bending force

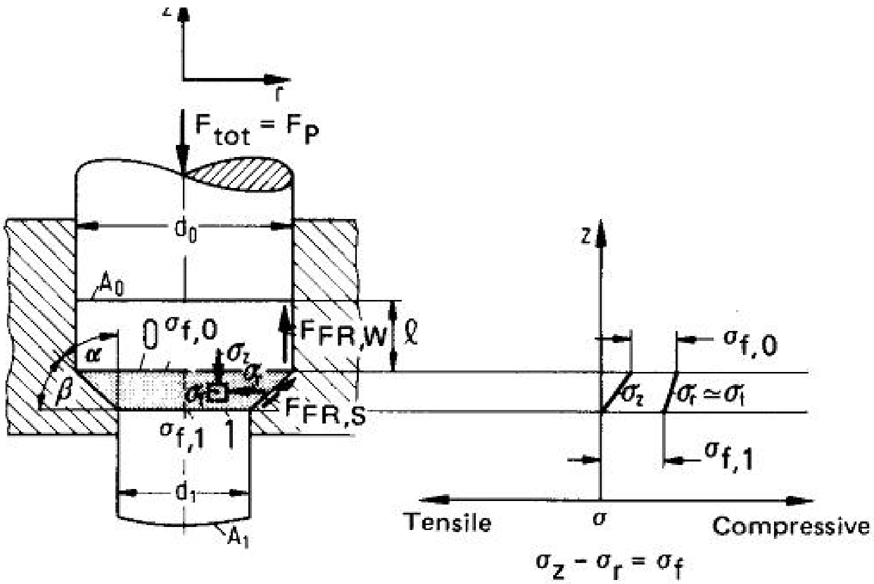


Figure 2.6 stress condition and force in forward extrusion *(Lunge, Handbook of Metal Forming)*

The ideal deformation wok W_{id} in solid forward extrusion- friction and shearing are not considered are presented in the following equation. The mean value, $\sigma_{f.m}$, is generally computed as the average value of the flow of stress before and after deformation.

$$W_{id} = V\sigma_{f.m} \ln\frac{A_0}{A_1} \text{--2.8}$$

Where V is volume work piece A_o= area of work piece before deformation

A_1 = area of work piece after deformation

The friction work W_{FR} for solid forward extrusion consists of two parts: the friction work $W_{FR,W}$ along the container or die wall and the friction $W_{FR,S}$ on the shoulder of the container in the deformation zone.

$$W_{FR}=W_{FR,S}+W_{FR,W} \text{--2.9}$$

The total friction work on the shoulder is given by

$$W_{FR,S} = V\sigma_{f.m} \ln\frac{A_0}{A_1} * \frac{2\mu}{\sin 2\alpha} \text{--2.10}$$

For a die angel $2\alpha=90^0$, the friction work is a minimum for a given tool geometry and workpiece material.

The frictional work $W_{FR,W}$ on the die wall is also give

$$W_{FR,W} = \frac{1}{2}\pi d_0\, \mu\sigma_{f.0}\left({l_0}^2 - l^2\right) \quad \text{-----} 2.11$$

The work required to bend and unbend a material particle in and out of the plastic zone is:

$$W_{SH} = \frac{2}{3}V \tan\alpha\sigma_{f.m} \quad \text{-----} 2.12$$

The shearing work is independent of $\ln\frac{A_0}{A}$ for a non work hardening material.

The total work done in the solid forward extrusion is given by without bending

$$W_{tot} = W_{id} + W_{sh} + W_{FR}$$

$$W_{tot} = V\sigma_{f.m}\left[\frac{2}{3}\tan\alpha + \left(1 + \frac{2\mu}{\sin 2\alpha}\right)\ln\frac{A_0}{A}\right] + \frac{1}{2}\pi d_0\sigma_{f.0}(l_0^2 - l^2) \quad \text{-----} 2.13$$

For the quasi-stationery portion of the extrusion process in the deformation zone with

$$\frac{W}{V} = \frac{F^0}{A_0} \quad \text{-----} 2.14$$

Where the F^o is the total force for container less extrusion (8)

The force F^o is given by

$$F^0 = A_0\sigma_{f.m}\left[\frac{2}{3}\tan\alpha + \left(1 + \frac{2\mu}{\sin 2\alpha}\right)\ln\frac{A_0}{A}\right] \quad \text{-----} 2.15$$

The friction force along the container wall should be added to F^o . $F_{FR,W}$ is

$$F_{FR,W} = \pi d_0 l \sigma_{f.0}\mu \quad \text{-----} 2.16$$

The total force in figure 2.5 is

$$F_{tot} = F^o + F_{FR,w} \quad \text{-----} 2.17$$

2.1.2.2. Finite element method

The application of finite element methods (FEM) to metal forming during the 1970s and early 1980s provided a new perspective on metal-forming practices (9). When using FEM-based programs to analyses engineering problems, the complex geometry needs to be divided into a finite number of simple geometric shapes called elements. The collection of the elements is called a mesh.

The Advantages of using FE simulations illustrated in figure 2.7 and show: reduced lead times, cost down, technological development. Lead times and cost for developing a new part can be drastically reduced by eliminating redundant trials, that can be achieved by virtual trial-and-errors by FE simulations.

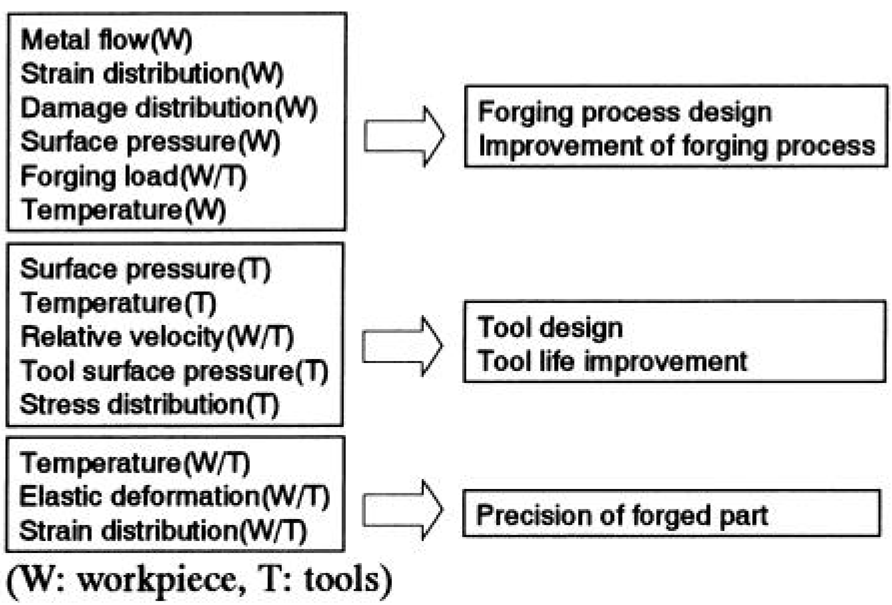


Figure 2.7 Information available from FE simulations and its practical use. *(Hyunkee Kim)*

2.1.3. Process parameter and limits

Upsetting process depends upon in the following process limit (5).

1. Upsetting strain

$$\varphi = \ln\frac{l_o}{l_1} \qquad \text{------ 2.18}$$

Where l_o is original length, l_1 is final length

As forming limit of work material

In cold upsetting of axisymmetric steel objects a maximum strain is 1.6 can be achieved independent of the number of forming steps. For head shapes which are not axisymmetric, upset strain is not meaningful as a measure of deformation, since local transfer of strain depends upon the shape of the head.

The forming limit can be increased by measures that counteract strain hardening or by a more favorable head shape which create an additional radical pressure, thus shifting the mean normal strain to arithmetically smaller value.

2. Upset ratio

$$s = \frac{l_o}{d_o} \text{--} 2.19$$

Where l_o is original length of the work piece and d_o the original diameter of the work piece

The upset ratio *s* is limited the possibility of buckling. The contact faces of the tools and the workpiece should plane as possible and perpendicular to the longitudinal axis of the workpiece to avoid buckling. The ratio limit is also affected by the surface condition and the shape of upsetting tool and combines with lubrication used.

In cold upsetting there is different stage for different values of $s = l\_o/d\_o$ for the value $s \leq 2.3$ can be achieved in one hit. Under this condition the fiber do not display any evidence of buckling.

Numbers of operation for different value of s are:

One operation (single stroke process) $s \leq 2.3$

Two operation (two stroke process) $s \leq 4.5$

Three operation (three stroke process) $s \leq 8.0$

more than three operation (multiple stroke process) With closed die $s \leq 10$ and with open die $s \leq 20$ For closed die s is limited by difficulties during ejection.

3. Specific change in length

$$\varepsilon_1 = \frac{l_1 - l_0}{l_0} \text{---} 2.20$$

As the limit to increase tool loading

The force required rises for upsetting towards the end of stroke. Upsetting force increased is especially exhibited in cold upsetting of smaller head thickness (figure 2.8). High amount of tool wear is exhibited in this situation. The force versus tool travel curve is dependent upon the workpiece geometry: with increasing d_o/l_o ratios the steep rise in force is shifted to smaller values the change in length.

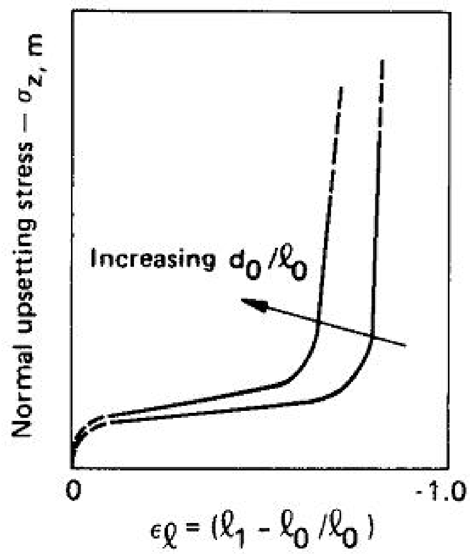


Figure2.8 fundamental development of the specific upset forces --$\sigma_{z,m}$ *(Lunge, Handbook of Metal Forming)*

In addition to the above process limit for heading with shape of dies the following process parameter are considered.

4. Proper filling of the die
5. Minimum flash formation

In extrusion process, it can be seen from the various equation presented earlier for deformation work and the force are dependent upon the die opining angle 2α. From the above formula the friction force on the die shoulder and the shear force are a function of die opening angle.

The various components of forces for solid forward extrusion are plotted schematically as a function of the die opening angle 2α in figure 2.9. The force components that are independent of the die opining angle 2α are the ideal deformation force F_{id} and the friction $F_{FR,W}$ along the die wall. The shear force F_{sh} increase linearly with the die opening angle 2α, while the friction on the shoulder of the die is expressed through a trigonometric function in the force equation.

The optimum die opening angle is also dependent on the coefficient of friction μ and the natural strain $\varphi_{max}=\ln\frac{A_0}{A}$. In other case the optimum die opening angle is independent of the material properties have been established in experimental investigation.

The extrusion processes are characterized by very stresses. These high stresses cause, for example, failure of the die due to very inner pressure, failure of the punch due to buckling, and so on. Although the processes can be operated with reinforced dies and short guided punches to increase the loading limits on the tooling, the limits on the process are still the stresses that can be transmitted through the tooling without tool failure.

2.1.4. Forming tools

Pre-heading tools

When forming in several stages, the design of the heading preform is decisive for a favorable fiber structure of the final shape. The heading pre-form is to be shaped such that:

1. The workpiece is guided correctly (reducing the problem of buckling)
2. No fold type defects formation occurs

There are two type preform header solid preform header and spring-loaded preform header.

Solid preform header

A preform header shape that provide useful is shown in figure 2.10. It is simple, hence inexpensive to produce and apply. It does, however, require close tolerance of wire and barstock. The allowable upsetting ratio is dependent upon the cone and can reach s = 4.5 for the two-stroke process. The most favorable range for the con angle is between 15^0 and 25^0, while the free heading length should always be less than $2.0d_o$ (figure 2.10).

The choice of cone angle is ordered by two limiting cases. For cone angle chosen too small, buckling is likely to occur and too wide tends to the formation of a peripheral fold-type defects during finish heading.

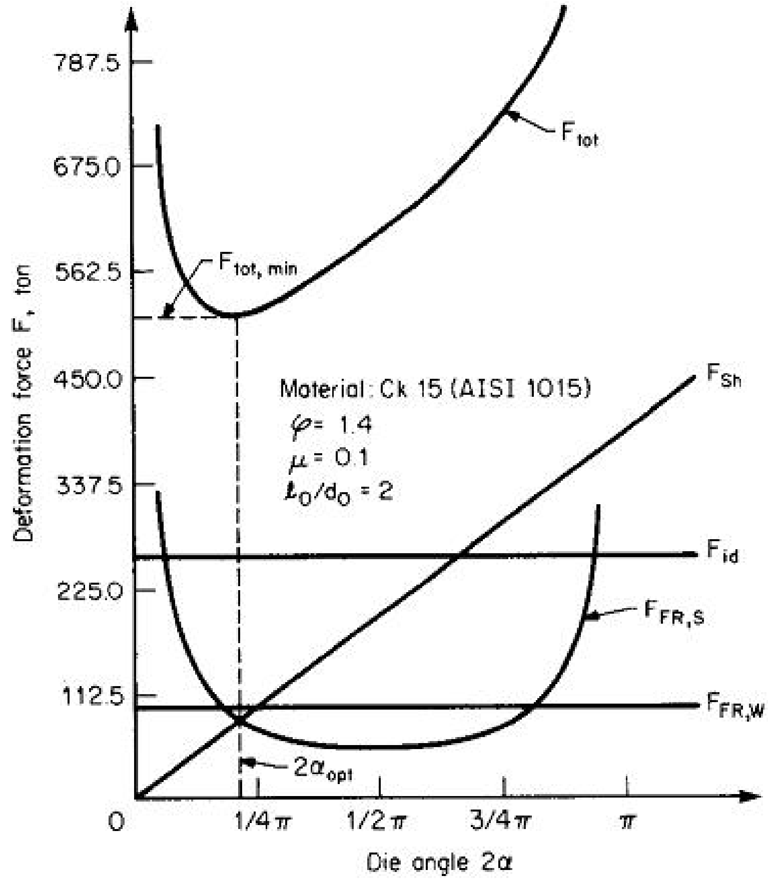


Figure 2.9 determination of optimum die opening angle 2α from the individual force components.

(Lunge, Handbook of Metal Forming)

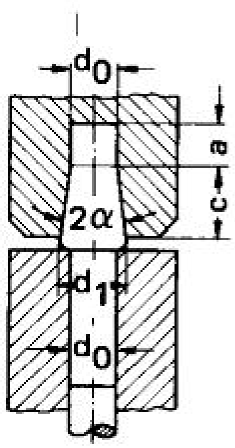
Spring-loaded preform header

Spring-loaded preform header is popular type preform header and an upset ratio s<4.5 can be obtained in the two-stroke process. However, it is more elaborate to produce, more difficult to apply, and hence more expensive than the solid header. It is more flexible than solid header for different volume.

Extrusion dies

Previous research has shown that the extrusion die geometry, frictional conditions at the die–billet interface and thermal gradients within the billet greatly influence metal flow in cold extrusion. The influence of die half-angle and reduction ratio on extrusion force has been researched for the hydrostatic extrusion process and the data obtained can be used for the forward conventional extrusion process. Geometrical characteristics of the extrusion die influence both the extrusion process and the mechanical properties of the extruded material. While it is widely acknowledged that one of the main effects of cold extrusion on the billet material is strain hardening, other mechanical characteristics of the extruded material also change.

The geometrical features of the die land are a critical feature in obtaining defect free cold extruded parts. As the die land length directly influences the amount of friction at the die–billet interface, extrusion die designers use this geometrical parameter to control the metal flow from the die.



Upsetting ratio $s = \ell_0/d_0$	Cone angle 2α, degrees	Guide length a	Length of conical portion of preheader c
2.5	15	$0.6\ d_0$	$1.37\ d_0$
3.3	15	$1.0\ d_0$	$1.56\ d_0$
3.9	15	$1.4\ d_0$	$1.66\ d_0$
4.3	20	$1.7\ d_0$	$1.56\ d_0$
4.5	25	$1.9\ d_0$	$1.45\ d_0$

Figure 2.10 solid preform header *(Lunge, Handbook of Metal Forming)*

2.2.Cold Forging Tools

Near net shape production, new material and forming technique are challenge in metal forming. Due to the direct contact between the tool and object material, stress exerted on tool, which are caused by press forces, heat and material movement. The quality of the tools has a direct influence upon the quality of the finished product, dimensional accuracy, process efficiency and costs of manufacturing. Moreover, tooling system related to the shape of finished product and property transformation resulting from the deformation of the material. Therefore, correct decisions made about selecting and designing of the tools will yield in an effective production process.

In bulk metal forming operations the life of tools is mainly constrained by three causes (Figure 2.11) (3)

- Fracture,
- plastic deformation and
- Wear.

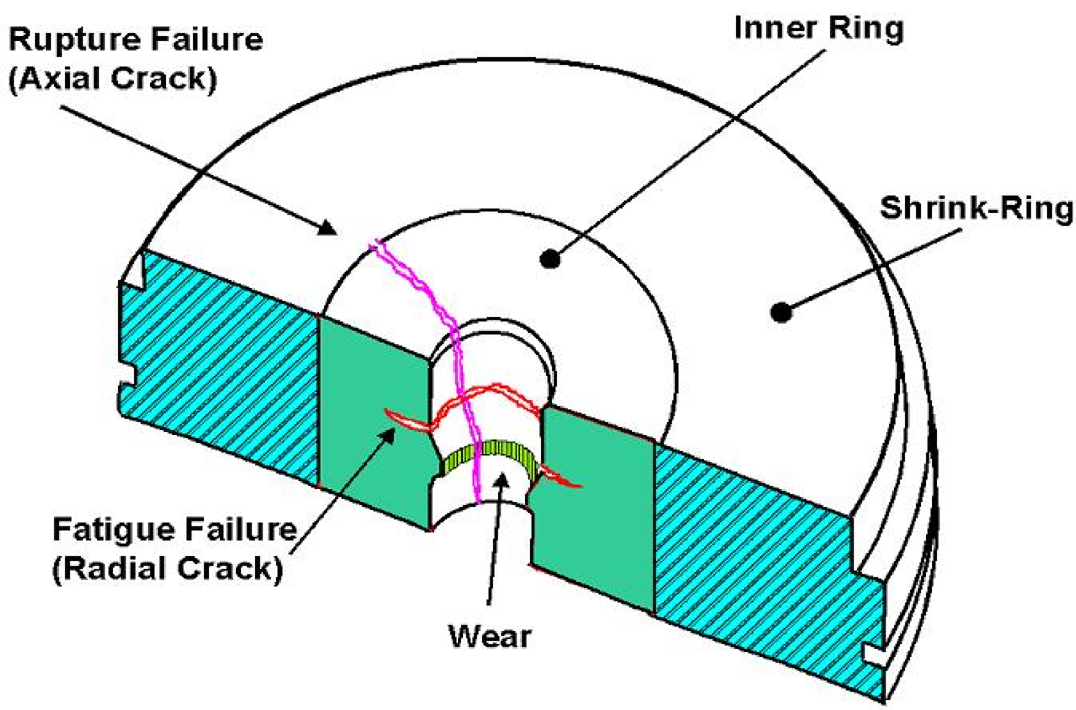


Figure 2.11: Typical tool failures in cold extrusion *(Lunge)*

Depending on the kind of forming process, the frequencies of tool damages and the resulting costs are different. In tool life process consideration - the more complex the part geometry, - the larger the degree of net shape forging, - the fewer the forging operations, - the tougher the billet material, and - the colder the forging operation, the higher will the resulting tool loads be. The higher the tool loads leads the shorter tool life(10).

Because of the high loads, fracture is the main reason for tool failure in cold forming. Thermal load and the contact with hot metal during the deformation process makes wear the most frequent reason for failure in warm and hot forging.

The main kind of surface damage is wear. It is the principal reason for scrapping tools used in warming and hot bulk forming processes because it has a large influence on the tolerances and surface quality of the formed part and thereby on tool life.

Tool fracture is the main danger in cold forming production, because of the high costs arising not only from tool replacement but also from the damage which may be caused by the broken tool in an automatic press environment.

Overload fracture can be avoided using modern techniques of stress and strain estimation, like FEM, but fatigue fracture always occurs in highly loaded tools. Fracture takes place when the sum of mechanical and thermal load exceeds a critical value. This value is not a purely material property: it depends on the state of multiaxial stress.

2.2.1. Factors influencing die life

Factor influencing tool life classified in to (11)

- ❖ Tool-specific and
- ❖ Application-specific failure reasons.

They cover a much more complicated network of factors and consider the entire forming system. Figure 2.12 show tool in the center and entire factor around it.

The average service life of tools for net shape manufacturing is lower than for the production of workpieces with larger tolerance fields. The reasons for early tool failure can be, that

- ✓ the stresses are higher, due to the higher grade of cavity filling, which leads to earlier fatigue fracture
- ✓ less tool wear is allowed because of the narrow tolerance field required for the workpiece

It is difficult to explain simply one factor influence on tool life there is complex relation between them. For example, Altering of lubrication not only changes the contact interface between the tool and the workpiece on a microgeometrical level, but also causes a change in friction conditions, such as

- ✓ the velocity field, and thus
- ✓ the normal and tangential stresses,
- ✓ the contact velocity,
- ✓ temperature conditions on the surface and
- ✓ the forming pressure.

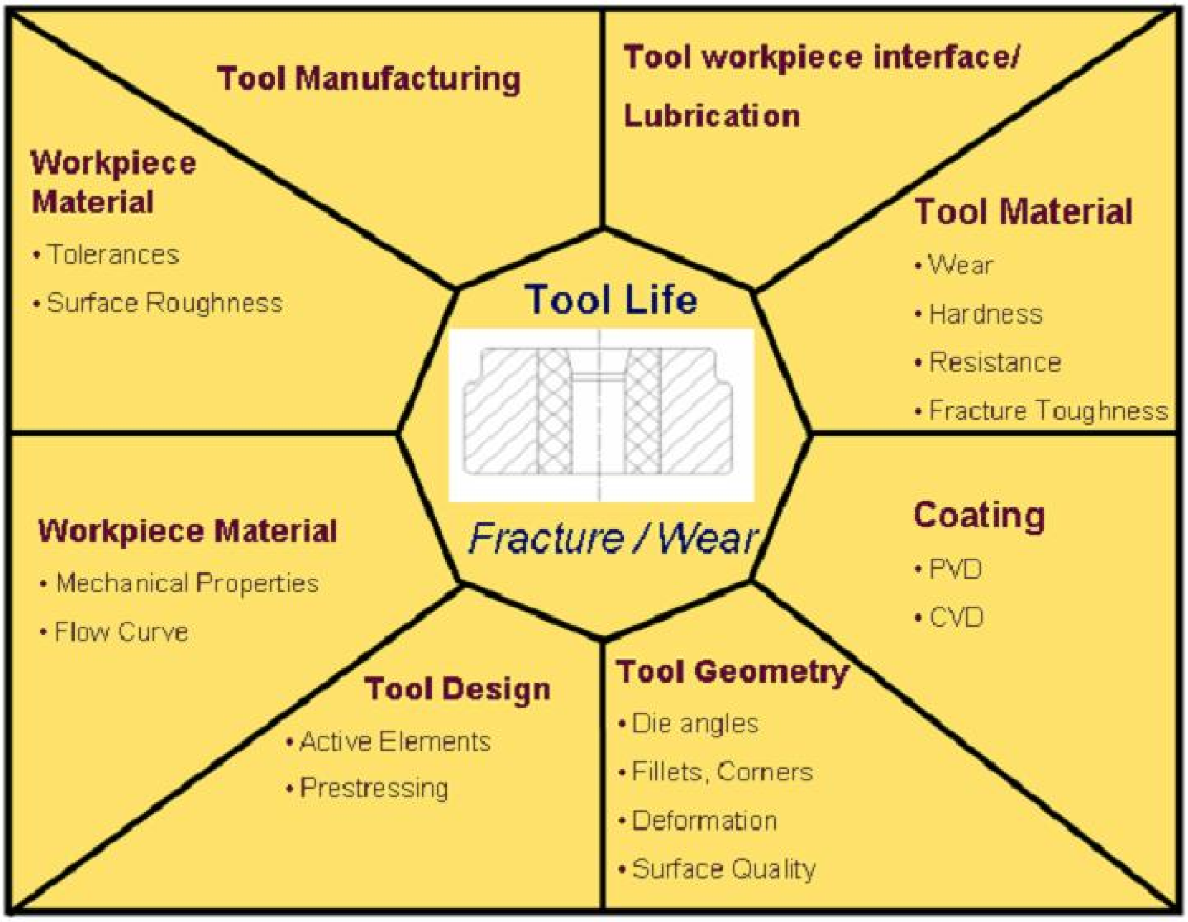


Figure 2.12 Different aspects of tool, workpiece and forming process, determining tool life by affecting wear and fracture behavior of the tool *(Lunge)*

Another dimension in tool life is connected with the traditions and culture of production with human factors.

1) Careless lubrication, preheating or cooling can cause an elevated temperature of the forging die may lead to quick permanent deformation or thermal fatigue or

2) The deviation of workpiece temperature results in either oxidation with elevated friction and wear or in increased contact pressure, higher stresses in tool elements and thus wear or fracture.

The types of failure for identically designed tools in identical utilization environments also vary. Highly loaded cold extrusion tools always break while the main failure reason in mass production of simpler workpieces is wear. Typical failure rates for tools in cold extrusion are example 80% failure by fracture but only 20% replacement due to wear.

Different literatures show that tool life is crucial factor in cold forming process. To optimize tool life there are many alternative solution such are:

- tool design
- tool manufacturing
- tool material
- surface treatment
- on line monitoring

these mechanism are applied in different industries. For this research tool design are discussed later on this chapter.

2.2.2. Die design

To implement this die design and development paradigm, there are two fundamental issues to be addressed. One is to develop a needed approach for die life assessment and the other is to implement the developed approach. To address the first issue, it is necessary to represent and formulate three physical variables, die stress and strain in die working conditions and the preprocessed and configured die material properties (12). These variables are important as many factors affect the die performance and its service life via these factors. In addition, the developed approach needs to establish the correlation between die life with these factors.

To achieve this objective, researchers in metal forming industries have conducted extensive research in this area. To name a few, Falk et al. used different concepts including local stress, local strain and local energy approaches to estimate die service life. As the approaches need to determine the local stress and strain of the die during forming process, the CAE simulation technology is employed for revealing the dynamic stress and strain in their research (13). Knoerr et al. adopted fatigue techniques to identify the root-causes of fatigue failure and developed a strain-based approach for estimation of die fatigue life. The approach used the elastic-plastic analysis model to determine the maximum strain amplitude and further analyze the fatigue life based on the damage analysis concept. All of these efforts are good exploration on die life assessment. Despite the fact that there is not a general way to increase die life, there are some tactics, which do help die service life improvement (14). How to identify and explore these “tactics” needs to systematically correlate the die service life with various affecting factors and mathematically represent the correlation.

2.2.3. Fatigue Analysis

In forging tooling, where fatigue failures usually occur before 10^5 parts have been produced, low cycle fatigue (LCF) is the dominant failure type (15) . LCF is characterized by a localized plastic zone in the tooling that develops under load. The tool material in this zone undergoes cycling in the plastic range during every forging cycle. Crack formation then occurs in the following four phases: (i) crack initiation in the plastic zone; (ii) microscopic crack growth; (iii) macroscopic crack growth, which can be detected by NDT methods; and (iv) catastrophic failure due to sudden rapid crack growth.

in cold forging, these contact stresses can reach extreme values of over 2500 MPa and can cause premature tooling failure. Kurt Lange his companion shows in their work , the contact stress distributions are far from being a uniform stress in the tooling, an assumption often made in tool stress analysis (16). By combining process simulation and tool stress analysis, more exact stress data were obtained, and possible failure due to high localized loads in the tooling were detected and avoided through modifications in the design before the tooling is produced.

In reduction punch stress in cold forging bevel gear analysis stress distribution and modification technique applied to reduce stresses distribution were discussed in their work.

The upper punch failure analysis using numerical process simulation and a subsequent set of stress analyses were used to predict the pressure distribution at the material-die interface and thus improve the design and service life of a punch in cold forging of bevel gears and the geometry of the upper punch tip, seen in Figure 2.13 , was investigated.

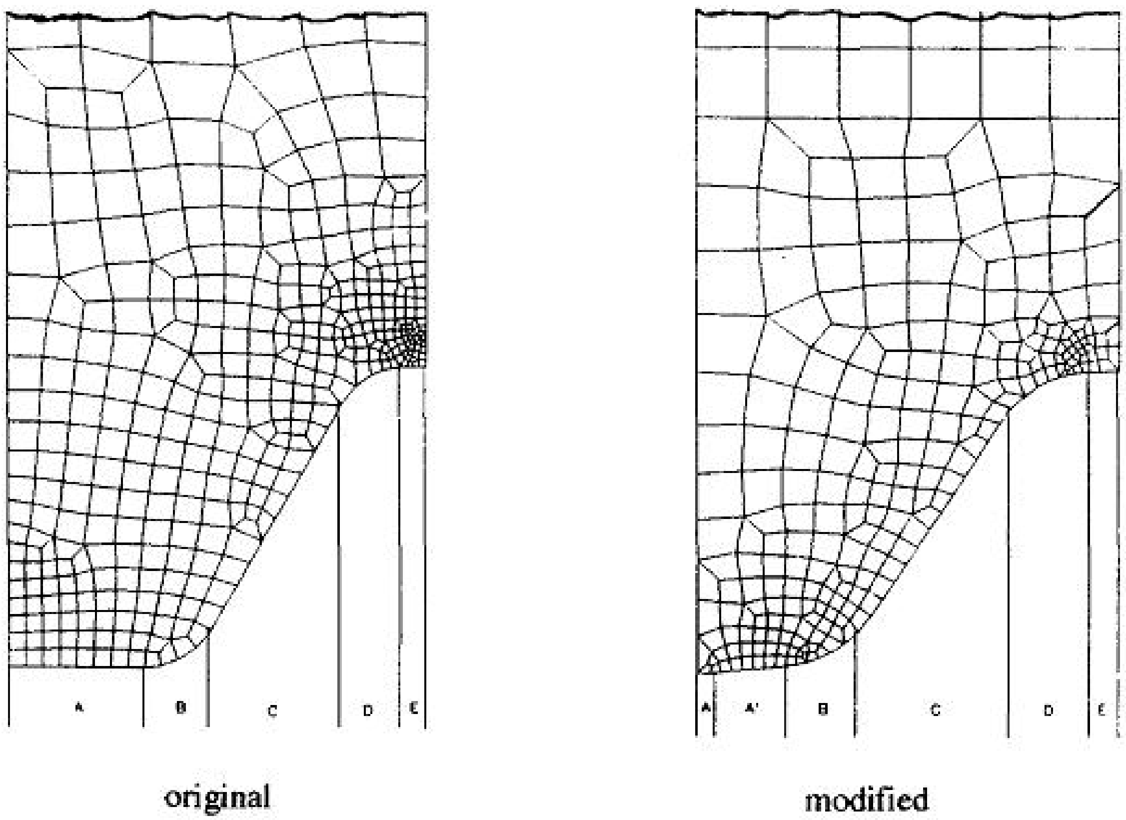


Figure 2.13 FE models of upper punch tips used for stress analysis. (A-face; B-corner radius; C - cone angle; D- fillet radius; E –edge *(Lange / Increasing tool life)*

The original geometry of the punch, which resulted in very high stresses, is compared with the modified geometry. Using the interface pressures calculated by DEFORM® as input, the ABAQUS code was used for the elastic-plastic analysis of the punch stresses. Very high pressures were obtained at the lower punch corner and in the upper fillet radius. By varying the punch geometry, after a few iterations, it was possible to reduce the peak stresses and distribute the punch load more evenly (Figure 2.12 and 2.13). As a result of these geometric changes, the punch life was increased by a factor of 6 to 8.

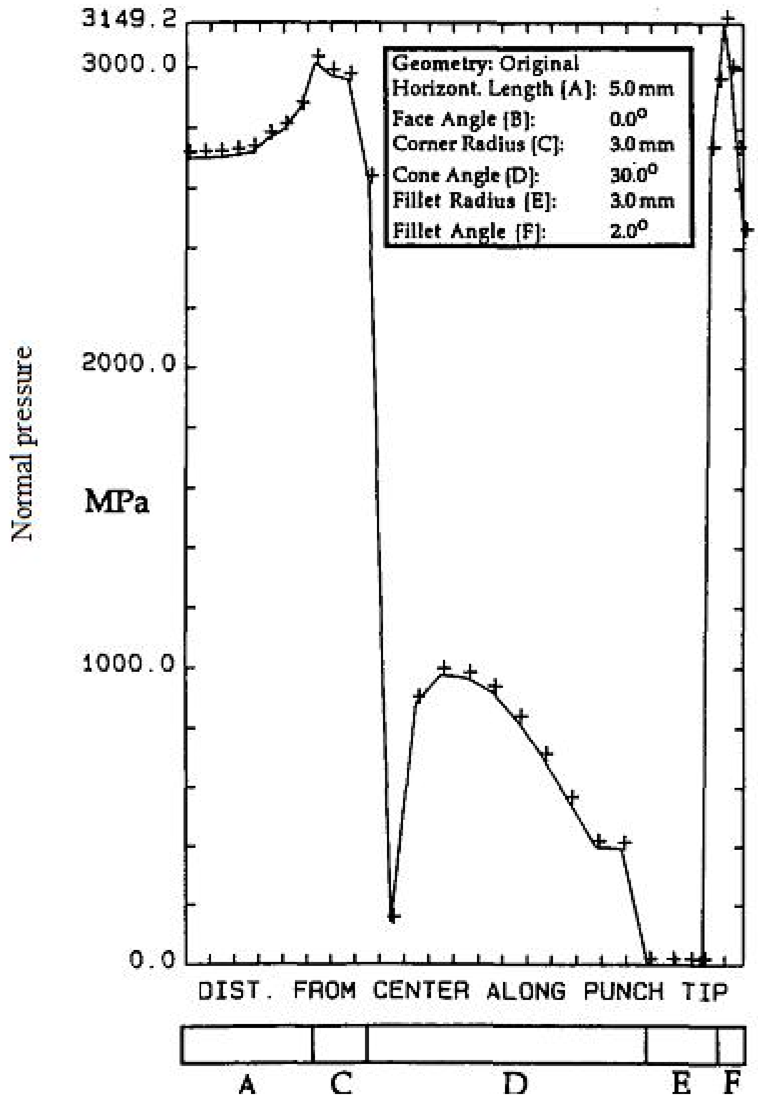


Figure 2.14 Normal stress distribution along the punch tip from the center outwards for the original punch tip design. *(Lange / Increasing tool life)*

2.2.4. Fatigue life analysis approaches

M.W. Fus' in their work of die design life used two analysis approaches, these, stress-life and strain-life approaches (17). The stress-life approach employs the correlation between the die fatigue life and its cyclic stress to assess the die fatigue life; while the strain-life approach uses the total strain the part undertakes to assess die fatigue life. The two approaches have their own applications scenarios. The stress-life approach is mostly used in the case where the die stress is primarily within the elastic range of the material and the fatigue life is high-cycle, usually more than one thousand cycles. However, for the strain-life approach, it is more appropriate in low-cycle scenarios where the fatigue life cycle is less than one thousand times and the applied strain has a significant plastic

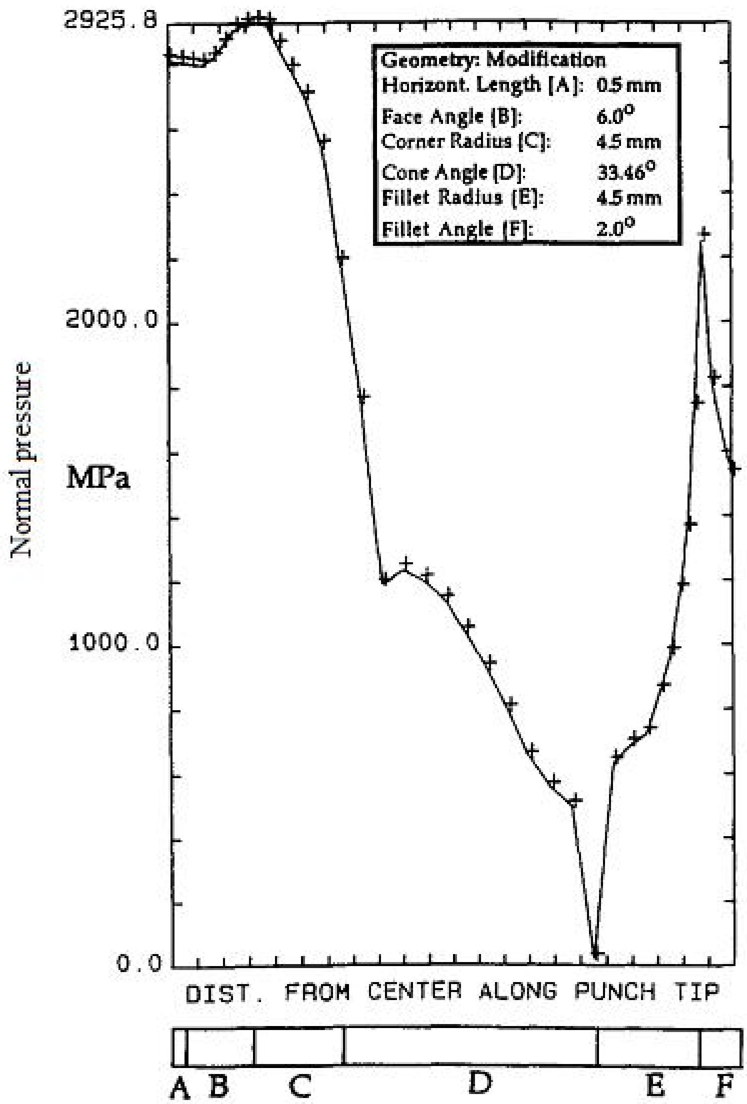


Figure 2.15 Normal stress distribution along the punch tip from the center outwards for the modified punch tip design. *(Lange / Increasing tool life)*

component. From the forming process point of view, it is difficult to say which approach is more suitable for what process as the same forming process could have a different deformation mode and thus whether the stress or strain is dominant is dependent on the detailed part, materials, tooling design, and process configuration.

2.2.4.1. **Stress-life approach**

In the stress-life approach, there are four characteristic stresses defined for articulation of the approach. They are maximum, minimum, mean, and amplitude stresses. Figure 2.16 illustrates their definitions. In the figure, the loading cycles of die in the forming process is shown. In a loading cycle, a metal formed part is usually produced. The die undergoes a forming loading cycle, which leads to the occurrence of the above four characteristic stresses. Among these stresses, σ_{max} and σ_{min} represent the maximum and minimum principal stresses of the die, respectively. σ_m designates the mean stress during the loading cycles, which is equal to the average of σ_{max} and σ_{min}. σ_a, on the other hand, is the stress amplitude in the loading cycles. They are designated as follows

$$\sigma_a = \frac{\sigma_{\max} - \sigma_{min}}{2} \qquad (2.21)$$

$$\sigma_m = \frac{\sigma_{\max} + \sigma_{min}}{2} \qquad (2.22)$$

.

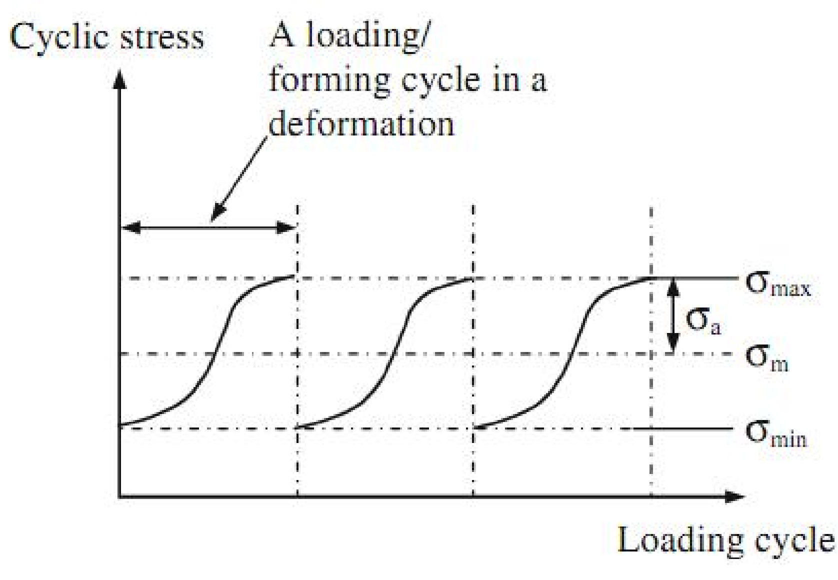


Figure 2.16 The characteristic stresses in cyclic loading cycles *(Fu)*

To establish the relationship of die fatigue life with die stress and the material properties of the die, the following Goodman equation is used

$$\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_u} = 1 \text{-----} 2.23$$

The Goodman equation represents the relationship of die fatigue life with σa, σm and the material properties, endurance limit Se and ultimate strength Su. Based on the equation, a diagram to represent the correlation of cyclic stress and fatigue cycle life, then , S-N diagram, can be constructed. From the S-N diagram, the die fatigue life can be determined based on the given amplitude and mean stresses. Figure 2.17 illustrates the S-N diagram for a given mean stress

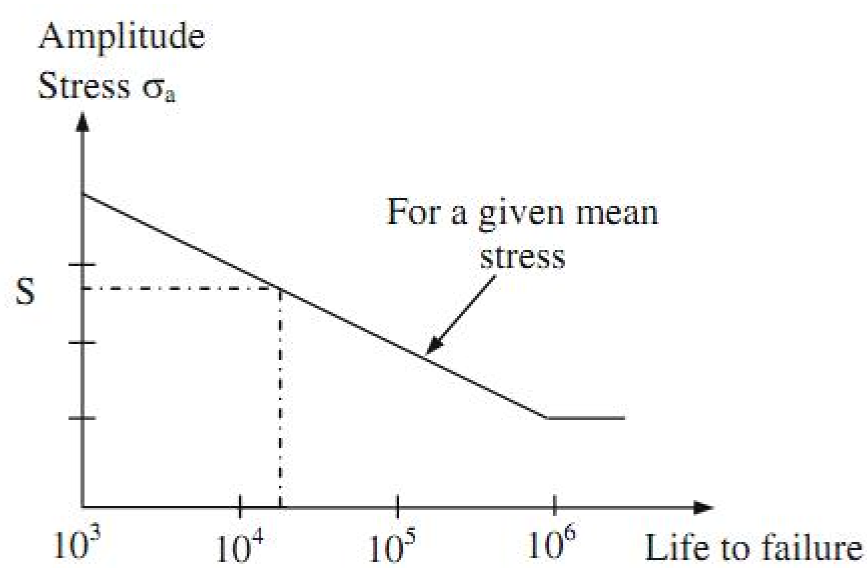


Figure 2.17 S-N diagrams *(Fu)*

2.2.4.2.Strain-life approach

In the strain-life approach, the stress-strain curve is first used to analyze the fatigue durability of die with cyclic loadings in the forming processes. The physical response of die material to the cyclic loadings can be represented in the form of hysteresis loop, as shown in Fig. 2.16 The total strain range Δε and the total stress range Δσ in the hysteresis are used for the definition of strain and stress amplitudes as follows, respectively.

$$\varepsilon_a = \Delta\varepsilon/2 \text{-----} 2.24$$

and

σ_a = $\Delta\sigma/2$--2.25

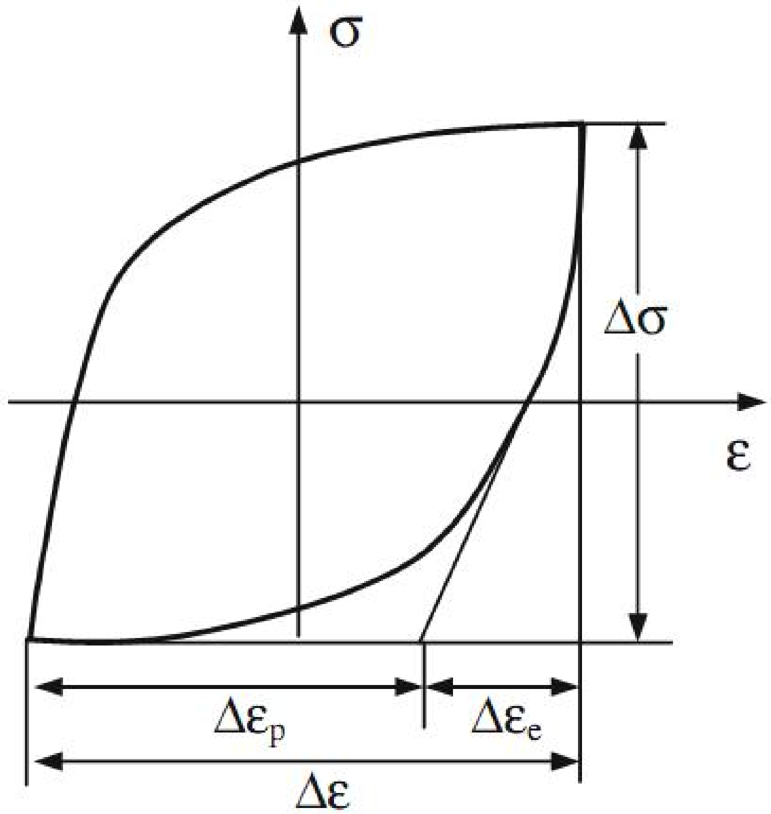


Fig. 2.18 Hysteresis loop and its stress and strain decomposition *(Fu)*

As the total strain is the sum of elastic and plastic strains, therefore,

$\Delta\varepsilon = \Delta\varepsilon_e + \Delta\varepsilon_p$ --2.26

It can be further represented in terms of amplitudes,

$\Delta\varepsilon/2 = \Delta\varepsilon_e/2 + \Delta\varepsilon_p/2$ --2.27

By employing Hooke's law, Eq. (2.26) can be expressed in the following

$\Delta\varepsilon/2 = \Delta\sigma/(2E) + \Delta\varepsilon_p/2$ --2.28

From the context of material fatigue, on the other hand, Basquin presented the stress-life data in the following equation

$$\Delta\sigma/2 = \sigma_f(2N_f)^b \quad \text{---2.29}$$

where $\Delta\sigma/2$ is the true stress amplitude. 2Nf is the cycles to failure. σ'_f is the fatigue strength coefficient, which is approximately equal to the true fracture strength. b is the fatigue strength exponent or Basquin's exponent with the range between −0.05 and −0.12. Furthermore, Coffin and Mansion found that the relationship between the plastic strain and fatigue life could be represented as

$$\Delta\varepsilon_p/2 = \varepsilon_f(2N_f)^c \quad \text{---2.30}$$

where $\Delta\varepsilon_p/2$ is the plastic strain amplitude. ε'f is the fatigue ductility coefficient, which is approximately equal to the true fracture ductility, and c is the fatigue ductility exponent ranging from −0.5 to −0.7. Using Eqs. (2.28) and (2.29), the total strain in Eq. (2.27) can be represented as

$$\Delta\varepsilon/2 = (\sigma_f)(2N_f)^b + \varepsilon_f(2N_f)^c \quad \text{--2.31}$$

Equation (11) provides a basis for the strain-life approach for die fatigue analysis and is schematically illustrated in Fig. 19. In the strain-life diagram shown in Fig. 2.17, the total strain-life diagram is the summation of elastic and plastic lines. At large strain amplitude, the diagram approaches the plastic line, while it approaches the elastic line at low amplitude. For different materials, the strain-life diagram could be different. The construction of the strain-life diagram is generally based on the experimental data of the fatigue test of the materials.

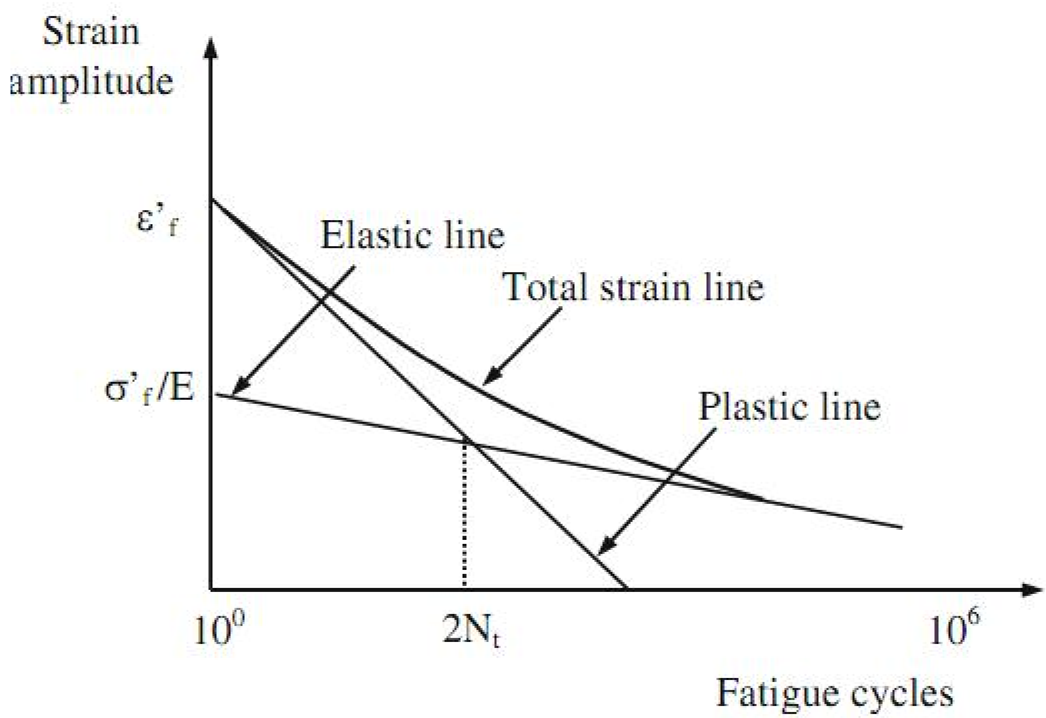


Fig. 2.19 Strain-life diagram *(Fu)*

In the case of forward extrusion two investigations performed at the Institute for Metal Forming at the University of Stuttgart by Reiss and Hettig provide detailed information on tooling materials for cold forging and on fatigue failure (15).

Hettig monitored the crack initiation and propagation in forward extrusion dies using two different die materials, two transition radii and two different die opening angles. Thus, a number of different stress-strain responses were induced in the critical area of the tool inserts at the transition radius.

Figure 2.20 shows the tool layout of the forward extrusion tooling and indicates the parameters that were varied during the investigation. Table 2.1 gives an overview of the parameter combinations that were investigated with the fatigue analysis concept.

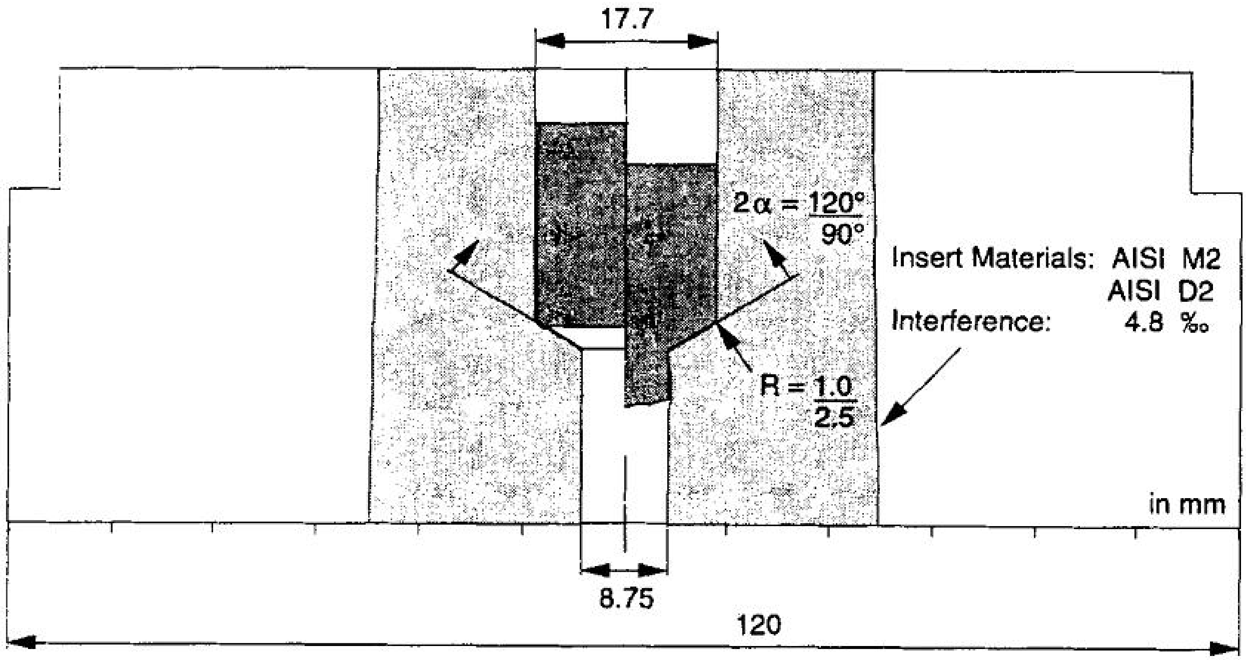


Figure 2.20 Layout of tooling and calculated material flow used for die life investigations at Institute for Metal Forming, University of Stuttgart *(Markus Knoerr)*

Table 2.1. Parameters of analyzed test cases for the forward extrusion investigation.

Case	Insert Material	Hardness [HRC]	Die opening angle 2α [°]	Transition Radius R [rnm]	Insert life to crack initiation
I	AISI M2	61	120	1	50 - 400
II	AISI D2	60	120	1	65 - 200
III	AISI D2	60	90	1	900- 1000
IV	AISI D2	60	90	2.5	10,000 - 11,000

Process simulations were performed for the three geometrical variations that is listed in Table 1 to determine the contact stress distributions. The predicted material flow for the variation 2α = 120°/R = 1 mm is shown in Figure 2.19. The normal contact stress distribution at the die-workpiece interface for the two different die opening angles and a transition radius R =

1mm presented in Figure 2.21. The shallower opening angle 2α = 120° produces a higher tool load.

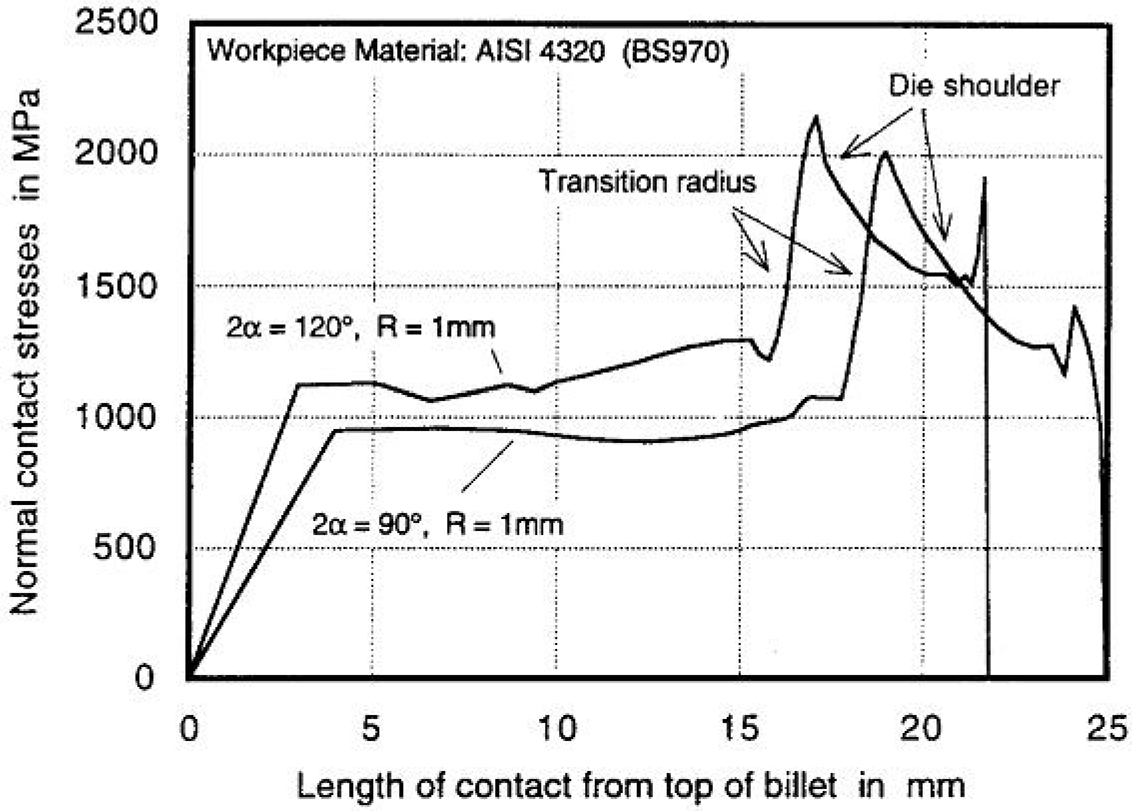


Figure 2.21. Normal contact stress distribution for the geometric variations 2α = 120°/R = 1 mm and 2α = 90°/R = 1 mm. *(Markus Knoerr)*

Elastic-plastic die stress analysis was performed for three points over two loading cycles:

- initial maximum load point,
- unloading after the first loading cycle and
- Maximum load point for subsequent loading cycles.

It was found that these three load points are sufficient to estimate the cyclic behavior of the insert material at the highest loaded zone. Due to the elastic deformation of the bulk cross section of the inserts, the material behavior in the transition radius is strain controlled during the loading cycles. Thus, the hysteresis plot of the stress-strain response will always cycle within the same strain boundaries.

Case from II-IV insert material AISI D2 presented in table 2.1, were analyzed to investigate the effect of geometric variations on the state of stress in the transition radius. Plastic deformation in the transition radius was found for Case II (2α = 120°/ R = 1 mm) and Case III (2α = 120°/R = 1 mm). Case IV, which represents the lowest tool load of the experiments, did not show any plastic zone in the transition radius. Table 2.2 summarizes the analysis results and cyclic material response for the analyzed cases. The normal contact stress peak σ_{nmax}, the maximum equivalent stress σ_{vmax} and the total (ε_{at11}) and plastic (ε_{ap11}) strain amplitude are listed. Table 2.2 also compares the predicted maximum load with measured values provided by Hettig.

Table 2.2. Summary of analyzed results for insert material AISI D2

Case	Geometry	σ_{nmax} [N/mm^2]	σ_{vmax} [N/mm^2]	ε_{at11} (%)	ε_{ap1} (%)	Max. Load [KN]	Measured load [KN]
II	2α = 120°/ R = 1 mm	2150	2810	0,66	0,135	446	450
III	2α = 120°/R = 1 mm	2014	2791	0,54	0,023	408	-
IV	2α = 90°/R = 2.5 mm	1973	2068	0,33	-	390	377

From this table we see that geometry of die affect maximum load and strain of elastic dies. To maximize tool life better to chose optimum geometry. `

Chapter 3: Production Process of Bolt in HMMBI

3.1. History and Background of the Factory

Hiberet Manufacturing and Machine building industry originally established in 1945, the company was renamed as Hibret Manufacturing and Machine Building Industry (HMMBI) and was incorporated into the Metal and Engineering Corporation (METEC) in 2010 (18). MHMBI has five factories: machine building factory, material treatment and engineering factory, mechanical subsystem factory, precision machinery factory and conventional manufacturing factory. The manufactured products primarily serve as input into a wide variety of industrial machinery used by agencies in the public and private sectors.

Services and products of HMMBI are:

MHMBI provide equipment service including upgrading conventional machinery (NC) to CNC, Consultancies on machine tool engineering, Machine erection and commissioning, surface treatment and normalizing; Metallurgical and chemical tests.

Major products produced in HMMBI are Industrial machinery which conventional and CNC lathe, conventional and CNC milling machine; building factory for country's mega projects; production of Spare parts, Engraving, production of medals & pressings products and Bolts & nuts (from M6 to M16)

This research interest is in conventional manufacturing sector especially in bolt and nut manufacturing work shop. The bolts manufactured in the shop are standard items and the shape the bolts head is hexagon. The shop has a capability to manufacture the bolt from M6 to M16 and with different bolt and thread length.

3.2. Bolt and Nut Workshop

Hiberet Manufacturing and Machine building industry's bolt and nut workshop is organized in one building and one row material warehouse. In the building different operation are carried out.

Namely:

- Surface treatment
- Bolt production process
- Nut production process and
- Heat treatment process

Other area are preserved for finished product store and tool store in the building

3.2.1. Surface treatment

Surface treatment area is found at the rear side of the building and it is one of operation line of electro plating and colouring shop. In this shop the workpiece goes through the process of cleaning and lubrication and the finished product goes through either electro plating or colouring process according to customer requirement.

Cleaning of the outer surfaces of the workpiece from scale and dirt are the primary tasks in cold working process. If the raw material is not cleaned well to causes a problem in the working part, production process and forming tools. From the observation of production system of the factory observed that if cleaning quality poor, the surface finish of the product is poor; while the surface cleaning is much poor, the workpiece is not dejected easily from dies and it stops production process. When the surface condition in terrible cases it broke out the working dies.

Cleaning and lubrication process flow chart shown in figure 3.1. Table 4.1 show detail cleaning and lubrication operation for workpiece lubrication (19).

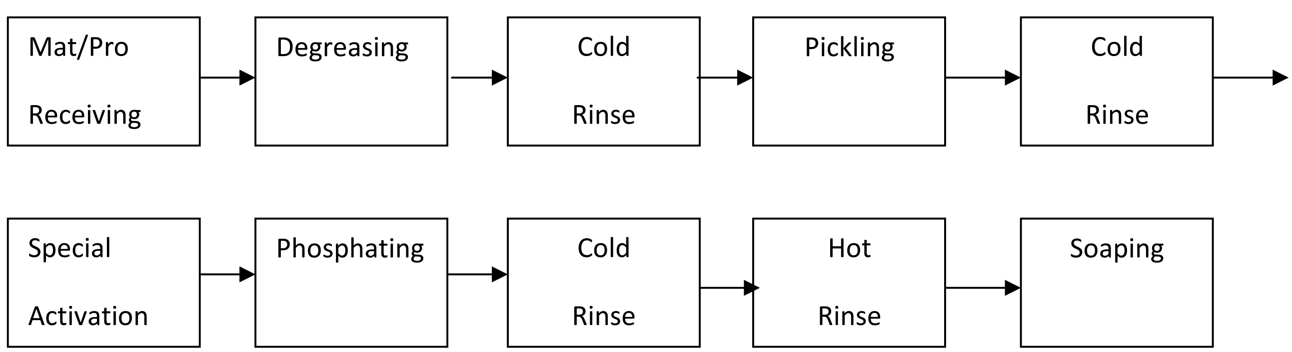


Figure 3.1 cleaning and lubrication line (survey)

Table 3.1

Zinc phosphate treatment sequence of steel billets

Type of operation	Operation
Cleaning	Mechanical cleaning Degreasing Rinsing with cold water Pickling Rinsing with cold water Rinsing with warm water added activators
Phoscoating	Phoscoating Rinsing with cold water Neutralizing
Lubrication	Lubricating with soap, MoS_2, etc. Drying

3.2.2. Bolt Production Process

The factory has six bolt forming machine in the shop. Among this six bolt making machine only four are in use. The two machine out off service with different problem. One of the machine problems is breakdown of mechanical support parts and the remaining one is the shortage of dies which is stud bolt dies.

The press capacity of machine to form bolts are different, some of machine found in the can manufacture from M6 to M16 but the other manufacture specific size. The bolt production process are consecutive process starting from material receiving to finished product; figure 3.2 show process flow chart of bolt production process.

For bolt forming machine operation first the foreman setup the machine. Machine setup process include changing appropriate dies and punch according to production requirement, set gages of cutting off station and assign appropriate forming speed. After setup is completed the foremen operates the machine and take correction action if problem is found and the foreman operate the machine until the production process is smooth. Once the machine start working smoothly and the operator take activities and operate the machine.

Material cleaned and lubricated are loaded in the machine and feed in to roller. Roller role the road and reduce diameter of the part in small amount. The workpiece pass through progressive dies and the die is straightening the wire. Finally the wire stock is fed into the machine by feed rollers to the cut-off station. The end of the wire stock butts against a wire stop or stock gage, which determines the length of the blank. The cut-off station essentially acts as a guillotine to shear off a predetermined blank length. Bolt are formed in mechanical press system and then pass in to threading process.

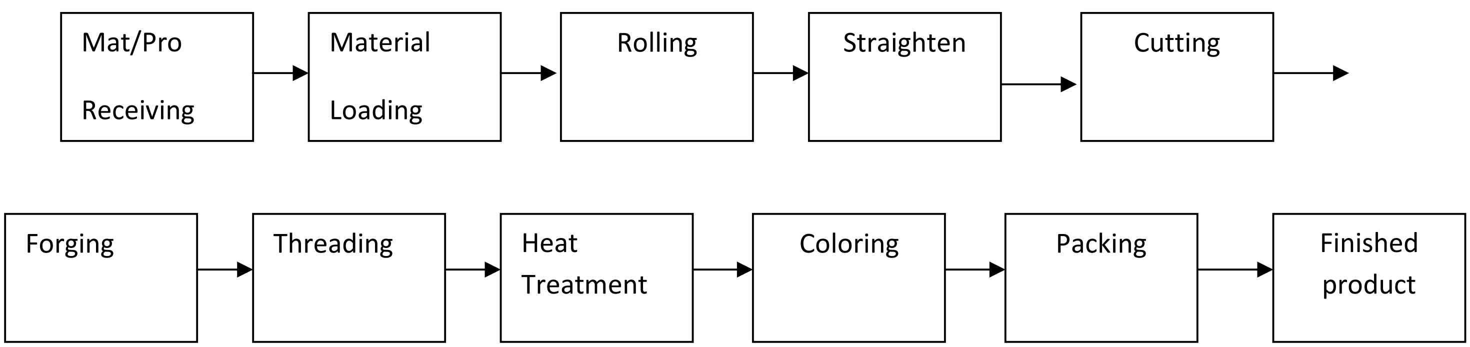


Figure 3.2 bolt production line

3.2.3. **Thread Rolling**

After the bolt is formed the part is feed in to thread rolling machine. Thread rolling is done by forcing a blank between two dies, the faces of which contain thread groves corresponding to the helix angle of the thread. This process is working a process of reciprocal thread rolling in which one die remains stationary while the other die moves. On each downward stroke of the die a blank is threaded. At the end of the stroke, the threaded blank falls into a container.

The advantage of threads by rolling are generally stronger than those which are cut because the rolling process removes no material and the metallurgical structure in the core of the blank is improved through cold working. In addition to producing a stronger thread, the rolling process causes no scrap. The threads also have grater uniformity and accuracy and the process is faster.

3.2.4. **Heat Treating**

Heat treating or annealing is done in electro fired furnaces. Bolts pass continuously through the furnace on a chain belt conveyor and remain in the furnace about an hour. On emerging from the furnace, the bolts fall through a controlled atmosphere into a quench thank. The purpose of this controlled atmosphere, which is a gas which does not support combustion, is to keep the surface of the bolts from sealing upon premature contact with air while hot. Quenching by submerging in an oil solution cools the bolts. After the heat treating operation, the bolts receive a fine water spray as they come out of the oil quench. This removes the water soluble quench oil and drawing compound. This is the total heat treatment process but the factory does not use the process because of high usage of electrical power.

Packing

Packing operation is the final operation in bolt production but some operations precede this. Nutting operation takes place directly after the bolt heat treated. In the nutting operation, the nuts are screwed onto the bolts by hand nutting, but other factories nutting operation takes place with the help of automatic machine.

Bolts and nuts are packed in cardboard containers for general consumer use and bulk orders are generally shipped direct from the factory without the bolt being nutted and unpacked. The contents of filled containers are determined by weight. Packaging system consists of a team in which one main fills a carton, another man weighs the carton and a third man seals the carton.

3.3. **Bolt Forming by Mechanical Press**

The machine produce bolt in multistage-part-formers by deforming the workpiece in consecutive stage. The machines have four stages bolt forming process. The machines are driven by an electric motor which is connected to main shaft by using clutches. Included crank-rod mechanism is connected to the slide and converts the rotational motion into linear motion.

For each forming station there is a pair of dies mounted on stationary and moving block (slide) respectively. In Figure 3.3, the tool layout of a four station bolt forming press is shown. The tool lays either horizontal or vertical orientation but the number of stage is same. Ergonomically the vertical orientation is preferred by the operator.

Generally on the moving block, preform, heading punches, trimming dies are mounted and on the stationary block, split pre-stressed carbide dies are mounted by using steel cases. In bolt forming process sequence the first stage upsetting process taken place, in the second stage finish heading, in the third stage direct extrusion process reduction cross section in threaded length and in the fourth stage trimming operation cutting hexagonal shape head taken place. Figure 3.4 shows sequential stage in bolt forming process.

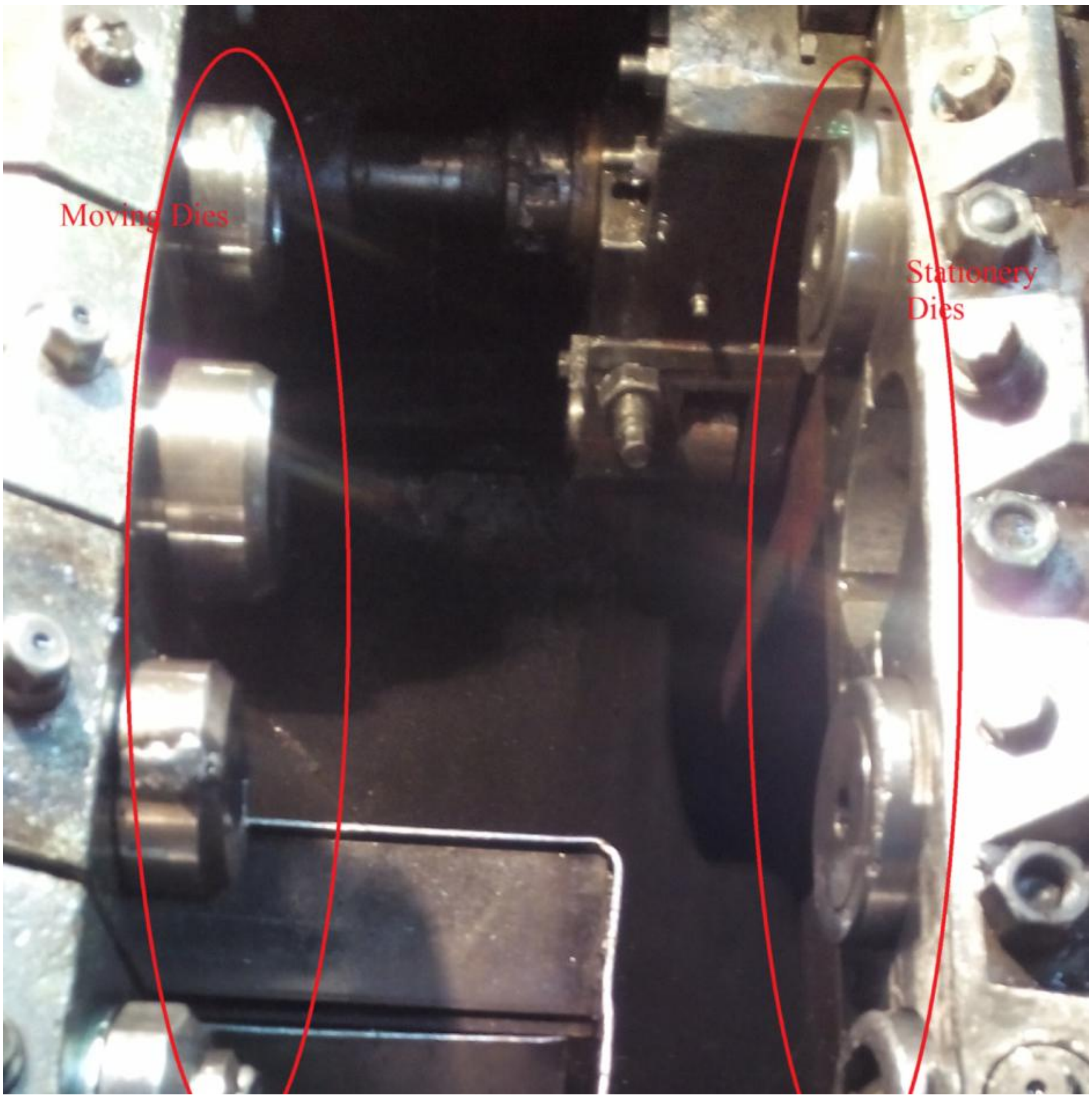


Figure 3.3 the tool lay out four station bolt forming press.

Figure 3.4 Bolt forming sequence

A transfer mechanism, having ‘fingers’ in front of each die, enables the blank to be transferred from one station to the next. Once the blank has been cut to the correct length, the transfer mechanism brings the blank to the upsetting station.

Upsetting punches are used before the Heading Station because they enable heading of a length of wire of up to three times the diameter of the blank material in only two strokes. The transfer mechanism ‘picks up’ the workpiece material and places it at the Heading Station. Heading station is a second stage process the die produce finished heading.

After finished heading process workpiece is transferred in to station three which is extrusion process. In this operation open solid forward extrusion process taken place and reduce the diameter of the workpiece in thread forming portion. Extrusion process varies according to thread length as industry experience it is call half thread and full tread. The final station in bolt forming is trimming operation cutting hexagonal shape taken place only in this operation material removal is exist.

Cooling system

In the start of production material are lubricated in cleaning and lubrication process. Coolant is applied in the forming process. Coolant is used liquid oil helping in dissipating generated heat from forging environment. The coolant also give additional lubrication process.

3.4. **Dies and Tools bolt forming**

The die used to manufacture bolt pre-stressed dies which the die insert is sintered carbide and stress ring is tool steel. Die is assembled conventional method and it has only one stress ring. Figure 3.5 shows assembled typical extrusion dies.

The factory does not have information regarding to tool life, which how many amount one tool can perform before failure? In which operation condition the tools regularly fail? What type of failure is dominant to tool failure?

From factory survey researcher observe that tool life information which early tool failure when in the setup of machine and overload type failure are dominant type of tool failure, figure 3.6 shows some type failed type of tool.

The firm does not have die manufacturing system and purchased dies and tools from external supplier with hard currency. Other bolt forming companies manufacture their own bolt demand that make competitor to the market.

Dies and tools purchasing ordering process is not well established and it is performed by sending sample un-failed dies and tools for supplier. There is no mechanism to check the quality of material type, manufacturing problem, Pre-stressing level, opening angle and transition radius.

These are trends and problems exist in Hibiret manufacturing and machine building industry in workshop of bolt and nut manufacturing. Productivity, plant lay out and material handling processes are not covered in this study.

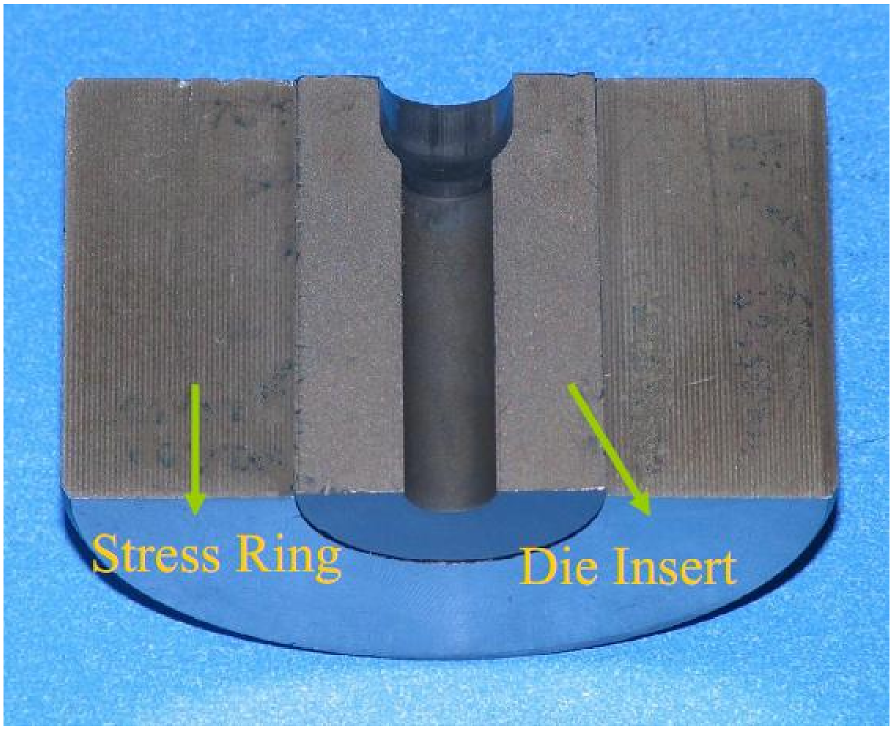


Figure 3.5. Prestressed extrusion die

a b

Figure 3.6. Typical tool failure in factory a) extrusion die failure b) trimming die failure

Chapter 4 Method and material

To meet the objective of the research some organized steps were applied, which are design of the forming process, design of forming tools, and simulation of the process using ABAQUS CAE and analyzing the result.

4.1. Forging process design

The forging process design essentially includes five steps (20)

1. The conversion of the machined part geometry to the forged part geometry to accommodate design considerations and process limitations
2. Determination of the number of preform stages
3. Design of preform dies
4. Design of finisher dies
5. Evaluation of process parameters, namely, forging loads and stresses, energy requirements and stock size

The flow chart of forging process design is shown in figure 4.1. After the process is designed, it is analyzed using ABAQUS finite element code.

4.2 Finite elements Analysis

The flow chart in figure 4.2 represents a method of frame work of CAE simulation for forging process and tool analysis. The CAD models for the process simulation were in Solid Work 2009 Sp0.0 and Abaqus CAE 6.10. and used in FE code ABAQUS CAE and Exclusive.

In this study, the workpiece, punch, bottom die and the die assembly components were constructed in the CAD model before the commercial FEM code ABAQUS 6.10 was implemented to establish the simulation.

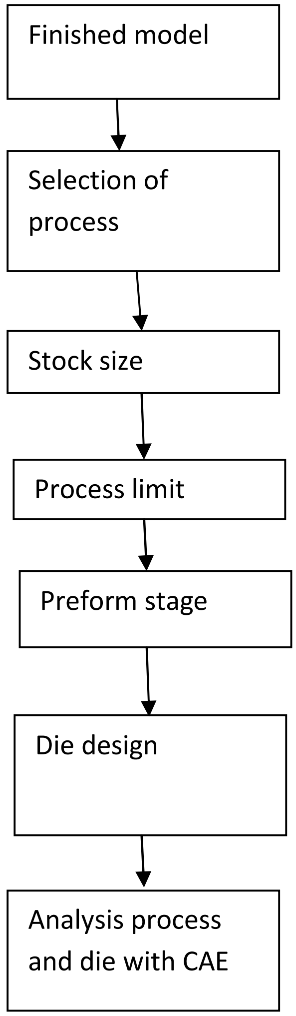


Figure 4.1 flow process of forging process design

4.2.1 Materials

The road that is used for bolt forming is low carbon, 20MnB4 (SAE10B22), and its chemical composition (21) is presented in table 4.1.

The tensile true stress and strain curve of the workpiece would be found from tension test, in the case of this study with different strain rate and different temperature find from literature (22). True stress and true strain curve for 20MnB4 low carbon steel is presented in figure 4.3.

The Poisson's ratio and mass density of the material were taken 0.3 and 7.8gcm^{-3}. The elastic modules of low carbon steel, 20MnB4, as a function of temperature, 210 Gpa at 20 ^{0}C.

The materials used for the die insert and stress ring were 84WC-16Co tungsten carbide and AISI D2, respectively (23). The material properties were obtained from references. For the tungsten carbide die insert, elastic modulus, yield stress and Poisson's ratio were 470GPa, 2100MPa and 0.22, respectively. For the AISI D2 stress ring, these values were 209GPa, 1200MPa and 0.3, respectively.

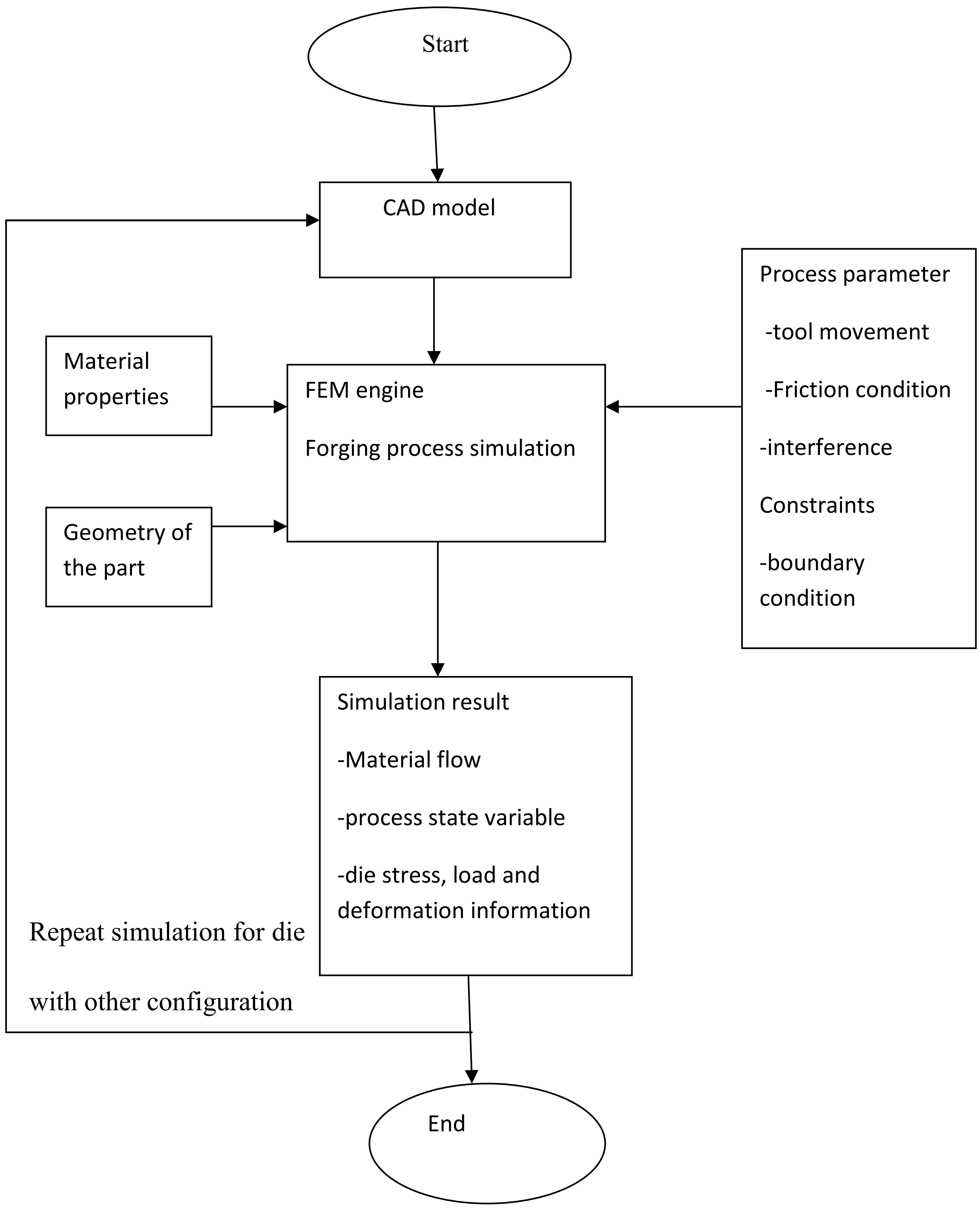


Figure 4.2 Methodology frame work

Table 4.1 chemical composition of 20MnB4 alloy steel in %

Element	Percentage %
Carbon	0.21
Silicon	0.15
Manganese	1.00
Phosphorous	0.015
Sulfur	0.015
Copper	0.1
Chromium	0.08
Nickel	0.1
Molybdenum	0.05
Aluminum	0.02
Boron	0.002

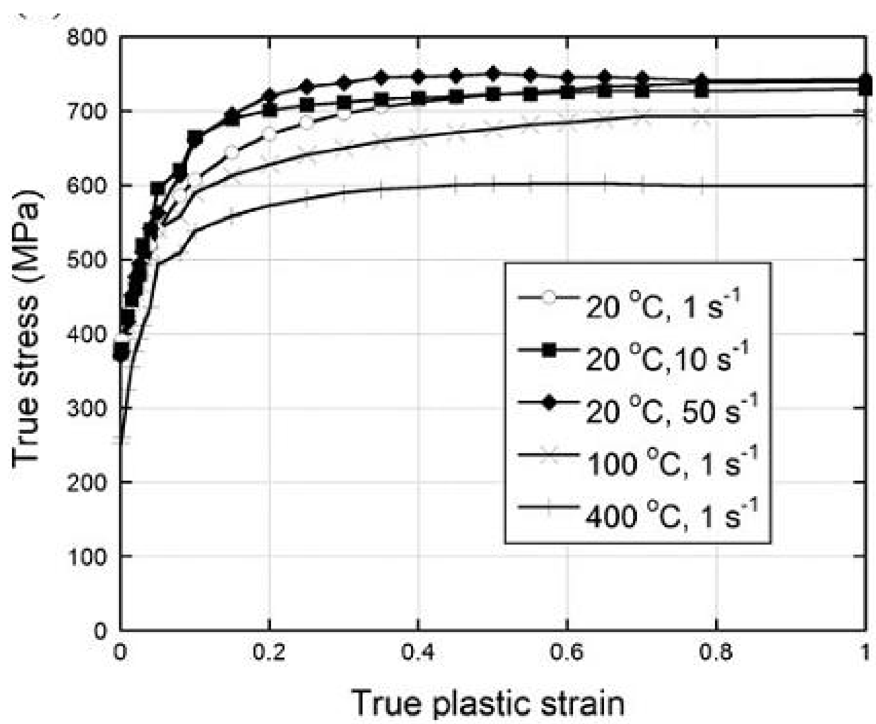


Figure 4.3 True stress-true plastic strain curves of 20MnB4 alloy steel at various strain rates and temperatures

4.2.2. CAD modeling

The CAD modeling of the die the initial workpiece and its consecutive stage were designed using Solidwork and ABAQUS 10.6 CAE.

In the production of M14 bolt with 40 mm length standard bolt production goes through four stages but only three processes were studied. The geometry of workpiece after each process completion and the dies CAD model for each stag will shown in chapter 5.

4.2.3. Procedure finite element Formulation in ABAQUS

In finite element analysis using Abaqus CAE 10.1 used multi procedure it starts from part modeling to visualization the result (24).

Part modeling can be done with CAD software SolidWork, Catia and proenginering and import to Abaqus CAE but in this work for CAE analysis all model was don ABAQUS part modeling. For analysis of material flow and flow stress, parts were modeled axisymmetric space and for dies, punches, and pins were considered rigid and the workpiece were considered deformable. In part modeling in rigid parts reference point was assigned and surfaces were selected according to interaction of faces.

Properties of material in general material properties density was set in mechanical material properties in the section elastic Modules of elasticity and Poisson's ratio, and plasticity section flow stress and corresponding strain. The workpiece were considered plastic rigid, which did not consider any elastic effect on analysis because plastic strain much greater than elastic one.

Meshing in ABAQUS provides two types of finite element meshing methods. They are free meshing and structured method. In free meshing method, user does not have the control on the element size. Structured meshing has control over the element size throughout the meshing area and thereby ensuring uniform meshing in the area. Hence structured meshing has been chosen for the present work. CAX4R type elements are chosen and it is convenient to axisymmetric model. Re-meshing of the parts was done in the middle of processing to maintain the process.

Parts designed independently need to be assembled together. One model can have a number of different parts but only one assembly instants exist in one model. The software support translation and rotation of instants to be assembled.

The next procedure managing step, the step sequence provides a convenient way to capture changes in the loading and boundary conditions of the model, changes in the way parts of the model interact with each other, the removal or addition of parts, and any other changes that may occur in the model during the course of the analysis. In this research dynamic explicit method was used.

After step had been created interaction mode was created between to interaction surfaces. Abaqus/CAE does not recognize mechanical contact between part instances or regions of an assembly unless that contact is specified in the Interaction module; the mere physical proximity of two surfaces in an assembly is not enough to indicate any type of interaction between the surfaces. To interact two instants interaction properties was created, interaction properties were created tangential friction condition penalty 0.1 friction coefficient because Zinc phosphate coating + metal soap lubrication system are used in the factory (26).

Boundary in this step, degrees of freedom constraints, loads and displacements at the desired nodal points are defined. Present formulation involves degrees of freedom constraints and pilot node displacements and speed. In creating boundary condition movement of punch and its speed is critical factor. The upper punch moves downward with the speed of 10 mms^{-1}, it was taken from factory experience. The bottom die and ejector pin were set fixed and stationery.

The next task is creating job and submitting for analysis. In the middle of analysis job will be aborted and take correction action by re-mashing the part.

Finally task was visualizing the result if it is not optimal solution or not as expected iterates the program until optimal solution obtained.

Chapter Five Result and Discussion

5.1. Design of forming process

In this chapter the bolt forming processes for production of M14 X 40 mm length are analyzed, starting from determining the stock up to design of bolt forming dies; using empirical formula (26). The finite element method is implemented for die design optimization.

5.1.1. Heading process

The preparation of the blank was done carefully with, pickling, phosphating and lubricating. The road purchased from the market and pass through surface treatment operation and feed in to bolt forming machine. The diameter of the road is 13.59mm when the road pass shear operation and feed in to fires stage.

Stock length for head

The diameter of the head is 26 mm and its height is 9mm as indicated in figure 5.1. To find the required length of the stock to form bolt head, it is calculated from the theory of volume constant.

Volume of finished head, $V_{head} = D^2 * H * \pi/4$ …………………………………………….. (5.1)

Where: D is the diameter of head

H is the height of head

$V_{head} = 26^2 * 9 * \pi/4 = 4{,}778.36mm^3$

From the industrial experience an extra 1-2%, are added to this volume to make up for melt and pickling loss. But in this design the stock diameter used are pickled and rolled stock. So there is no pickling loss.

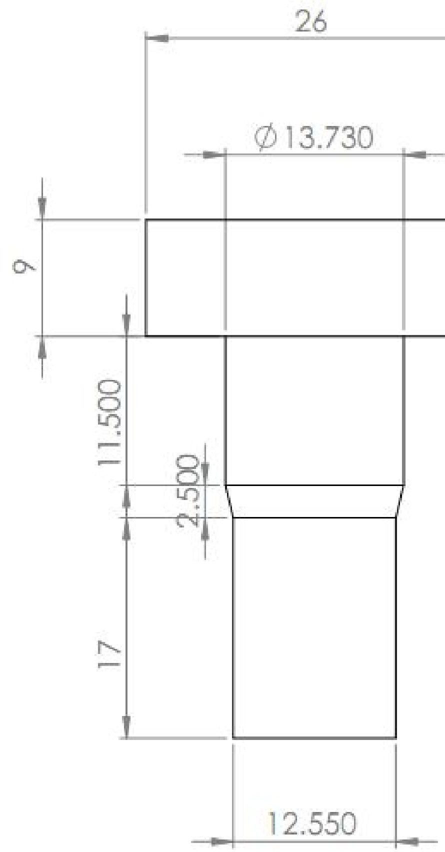


Figure 5.1 the geometry of the bolt after extrusion

For the initial area of the bolt blank is calculated first to determine the length of the bolt and accordingly

$A_o = d_o^2\pi/4 = 13.59^2*\pi/4 = 145.05mm^2$

Where d_o is the diameter of the stock

Then the initial height of the head is found

$ho = V_{head}/\ A_o = 4778.36mm^3/145.05mm^2 = 32.94mm$

Limiting factor of forming head

The following limiting factors are calculated to determine the formability of the blank and accordingly indicated below.

i) **upsetting strain/ Principal strain**

Upsetting strain is one of the constraining factors which govern the formability of the blank and calculated using the relations of equation 2.18.

$$\varphi_{max} = \ln(\frac{h_0}{h})$$

h_o is the original length goes through deformation of head which is above bottom die is shown in figure 5.2. h is the height of the head in figure 5.1.

$\varphi_{max} = \ln(\frac{32.94}{9})$-= 1.3

The upsetting strain is below 1.6 and it is possible to deform the part without defects.

ii) upsetting ratio

The upsetting ratio is one factor govern the possibility of work piece buckle during forming process is calculated using equation 2.9.

$S = l_o/d_o = 32.94/13.59 = 2.42$

Because upsetting ratio (s) is greater than 2.3 and less than 4.5 the number of operation required to form the head without buckling is 2.

iii) Flow stresses

The values of flow stress (σ_f) are approximately found from the flow stress curve for the material 20MnB4 in figure 4.2 for respective strain value. The mean flow stress will be found with simple arithmetic mean calculation (26).

σ_{fo} = 406Mpa for φ is zero and

σ_{f1} = 720Mpa for φ_{max} is 1.3

$\sigma_{fm} = (\sigma_{fo}+\sigma_{f1})/2 = (406+720)/2 = 563$Mpa

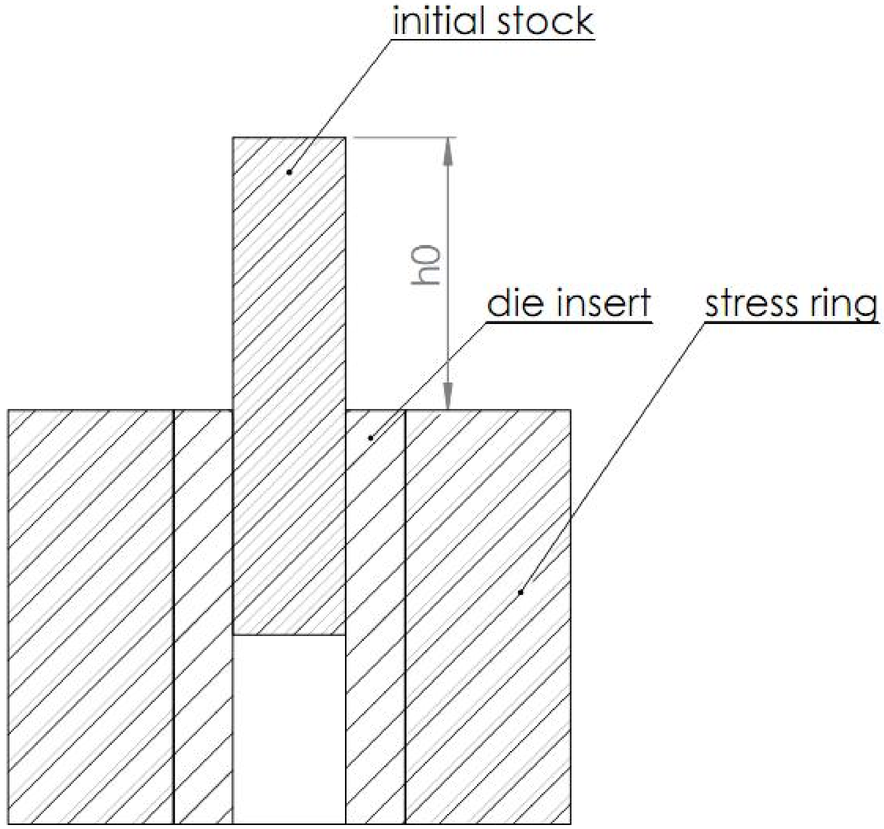


Figure 5.2. tool and work piece assembly in heading process.

iv) Upset forging force

To calculate the upsetting force elementary plastic theory (slab method) equation 2.3 is used.

$$F = A_1 \sigma_{f1} \left(1 + \frac{1}{3}\mu \frac{d}{h}\right)$$

Where A_1 is area work part after upset, d and h are the diameter and height of forged work part respectively. Using friction coefficient μ is 0.1

$F = \frac{26^2\pi}{4} * 720(1 + \frac{1}{3} * 0.1 \square \frac{26}{9})=$

F= 419.08KN

The force require to forge the head is 419 KN.

5.1.2. Preparing shank (extrusion process)

The aim to produce the shank of the bolt shown in figure 5.1 use direct extrusion method and the efficiency of the force η= 0.6 it taken from (26). The efficiency of the force is depends on type of process of extrusion, profile of extrusion and maximum strain.

Volume of finished item

The volume of finished shank which is shown in figure 5.1 un-extruded, conical portion and extruded part are calculated using cylindrical and conical volume equation 5.3

$$V_F = \frac{D^2 \pi h_1}{4} + \frac{\pi h_2}{12}(D^2 + Dd + d^2) + \frac{d^2 \pi h_3}{4} \text{------} 5.2$$

Collecting like terms together

$$V_F = \frac{\pi}{4} * (D^2 h_1 + \frac{h_2}{3}(D^2 + Dd + d^2) + d^2 h_3)$$

$$V_F = \frac{\pi}{4} * (13.73^2 * 11.5 + \frac{2.5}{3}(13.73^2 + 17.73 \, 12.55 + 12.55^2) + 12.55^2 * 15)$$

$= 3897.44mm^3$

Extra volume pickling loss is not consider so the final volume of shank is $3897.44mm^3$

Stock dimension

A_o= $145.05mm^2$

Initial stock h_s of workpiece before pre forming is

$h_s = V_F/A_o = 3897.44mm^3/145.05mm^2 = 26.32$ mm

Total length of stock summing both heights, height of initial stock for head and height of initial stock for shank is 60.02mm. The result is the dimension of the blank to produce Φ14* 40mm bolt is Φ13.59*60.02mm long.

Principal strain

Maximum strain the basic governing the limiting factor of extrusion workability is calculated using the following equation.

$$\varphi_{max} = \ln\left(\frac{A_0}{A}\right) \text{--} 5.3$$

where A_o the area of work piece before extrusion, d_o is 13.73 mm from figure 5.1.

A the area of work piece after extrusion, d is 12.55mm

$$\varphi_{max} = 2\ln\left(\frac{d_0}{d}\right) = 2\ln\left(\frac{13.73}{12.55}\right) \qquad = 0.1797$$

The maximum strain is 0.1797

Flow stress

The values of flow stress (σ_f) are found approximately from the flow stress curve for the material 20MnB4 in figure 4.2 for respective strain value. The mean stress calculated using simple arithmetic mean.

σ_{fo} = 406Mpa for φ is zero and σ_{f1} = 680Mpa for φ_{max} is 0.1797

σ_{fm} = $(\sigma_{fo}+\sigma_{f1})$/2= (406+680)/2= 543Mpa

Extruding force

Extruding (deformation) force calculated using the empirical formula equation 5.4. The equation does not consider friction force and the effect of die opening angle.

$$F = \frac{A_0 \sigma_{fm} \varphi_{max}}{\eta_F} \text{--} 5.4$$

A_o= $d_o^2 * \pi/4$= $13.73^2 * \pi/4$ = 148.05 mm^2

φ_{max}= 0.1797 and η_F= 0.6 from the table

F=(148.05 mm^2*543 N/mm^2*0.1797)/0.6 = 24.1KN

5.1.3. Process Sequence

For the production hexagonal head the process sequence is shown in figure 5.3. In stage 0 degreasing and lubrication are done.

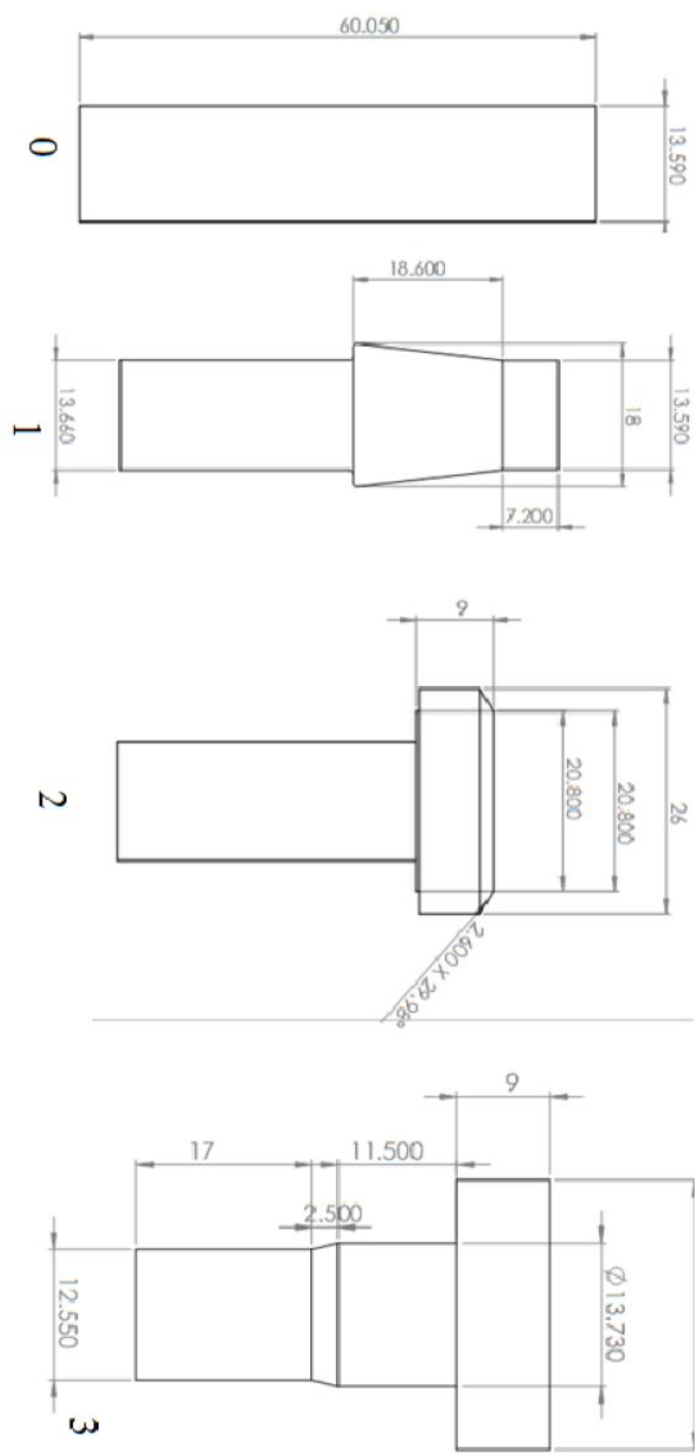


Figure 5.3 process sequence bolt forming

5.2. Die design

In section 5.1 the material required, number operation are analyzed. Punches and die are designed in this section.

5.2.1. Pre-form punch and bottom die design

i) Pre-form design

In bolt head forming process the first operation is a pre-form heading and pre-heading operation is one of the two operations. The factory uses spring loaded pre-form header and to design of conical shape pre-heading the design parameter were depicted in figure 2.10.

For upsetting guide length

Upsetting guide length (a) is less and equal to $0.6*d_o$

$a<=0.6*13.59$ mm = 8.14 mm

The upsetting guide length is 8.14 mm.

The upsetting ratio of head forming s is 2.42 from the same figure 2.10 the cone angle is $2\alpha = 15^0$

Length of conical partition of pre-head (c)

$c=1.37d_o= 1.37*13.59mm= 18.61mm$

Length conical portion of preform header is 18.61mm.

Now pre heading punch considering the outer diameter is 28 mm is presented in figure 5.4.

ii) Bottom die design

The bottom die which support the work piece in stage one process is pre stressed die. The outer diameter of the die is 68mm from the machine data which is equal to the bore of die holder. To got the junction diameter which intersection of insert and stress ring, are calculated using equation 5.5.

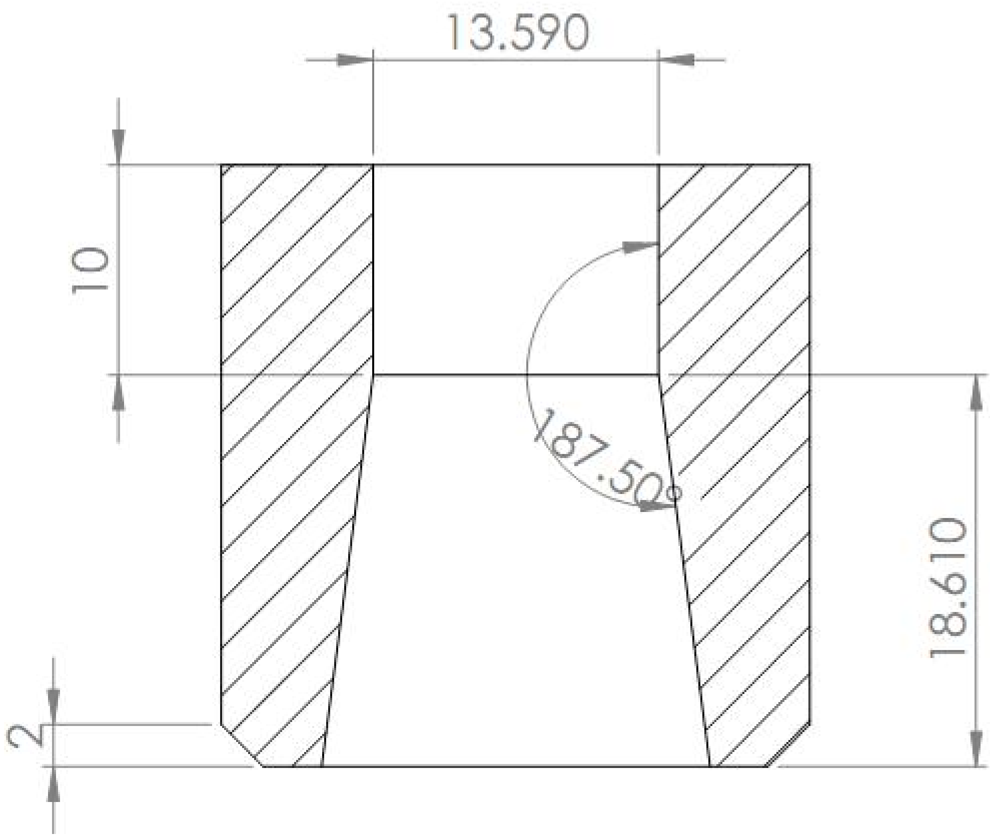


Figure 5.4 pre-form header

$D_j = 0.9\sqrt{D * d}$ ---5.5

Where D is the outside diameter of the die, the bore of die holder

d is the diameter of die bore

d is 13.66 mm from production sequence

$D_j = 0.9\sqrt{68 \square 13.66}$ = 27.42mm

The diameter of insert ring is 28.00mm is selected and the design of bottom dies with the length of 50 mm is shown in figure 5.5.

5.2.2. Finish Heading and Die Design

The second stage of the heading process is finish heading and the punch finish heading and supporting bottom die is designed.

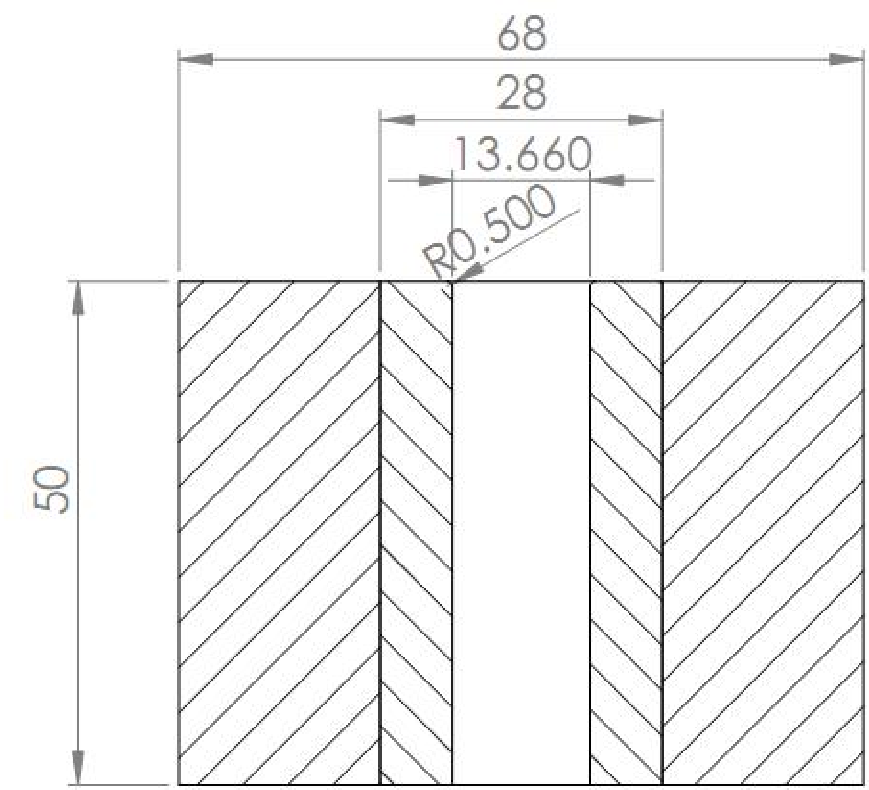


Figure 5.5 bottom die of stage one

i) Heading punch

In the second operation of heading finish heading, stamping of the size bolt and labels was done. The operation is open die upsetting and the profile of punch designed shown in figure 5.6.

ii) **Bottom die design** The bottom die design in the second stage bolt forming the procedure is applied like first stage die. The outer diameter of the die 68mm, inner bore of die is 13.73mm and other profile are shown in the figure 5.7.

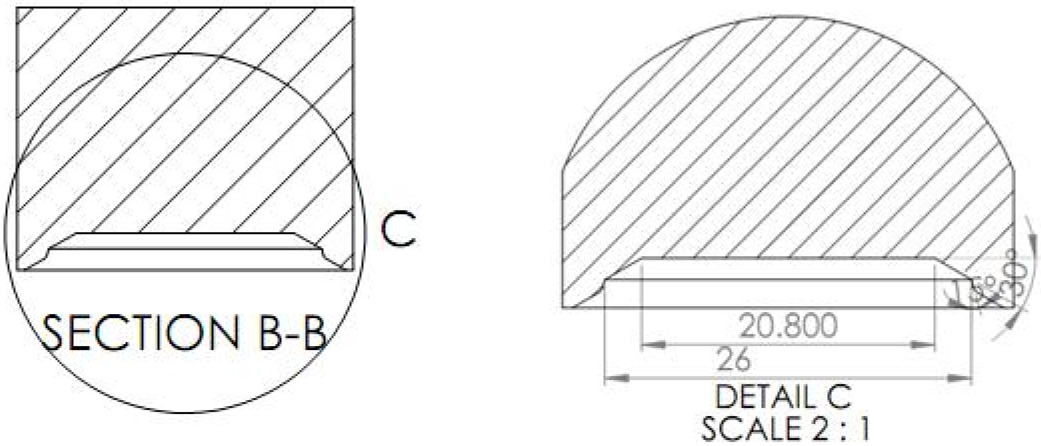


Figure 5.6 finish heading punch

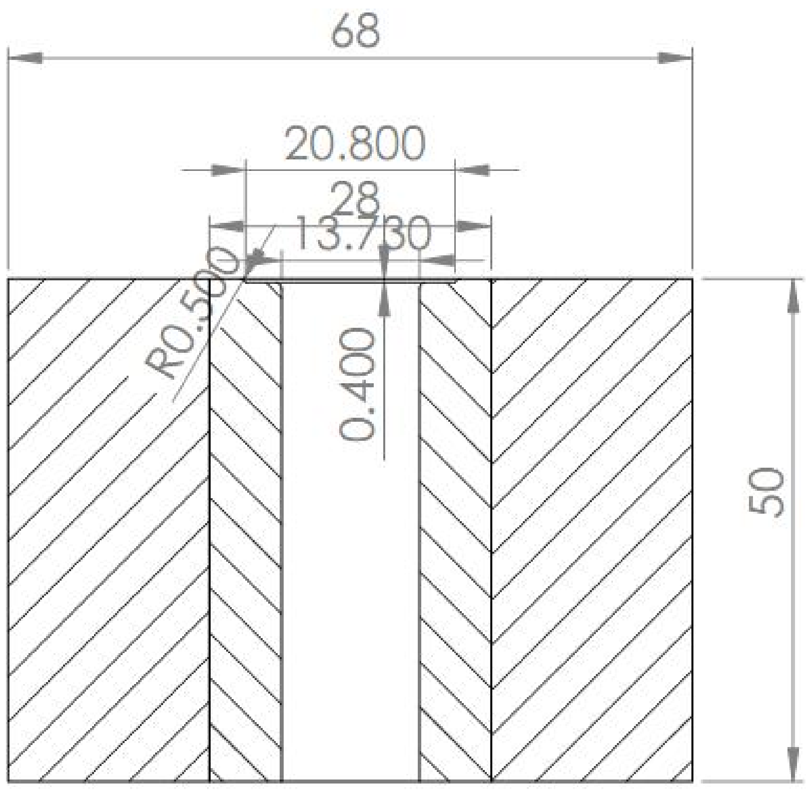


Figure 5.7 bottom die for stage two.

5.2.3. Extrusion Die Design

Normally extrusion dies have to have at least one support (or stress) ring as the internal pressures are high enough to cause axial or transverse cracking due to tangential or tri-axial stresses respectively. If the insert is carbide, then another stress ring is required depending on the ratio of inside diameter to overall outside diameter.

Number of stress ring

Internal pressure of the die is calculated using the equation 5.6.

$$P_i = \frac{F_P}{A_p} - \sigma_{fo} \qquad \text{-----5.6}$$

Where F_p= punch force during extrusion, A_p is area of punch

Extrusion force is calculated in section 5.1.2 is 24.1kN

Area of the punch is the diameter of the punch is 28mm.

$$P_i = \frac{24.1kN}{615.75mm2} - 406N/mm2$$

P_i= 366N/mm2

The internal pressure of the die during extrusion is 366Mpa. So only one stress ring is enough support this load.

Calculating junction diameter

The die orifice of the extrusion die is greater than 3% the extrusion dimension for reason include effect of thermal expansion and deflection of the die under load (27).

The bore diameter of the die is d*(1.03) of work piece diameter d is at stage 3 is 13.73mm.

d= d+ d of 3%= 13.73*1.03= 14.14mm

The outer diameter of the die that depends on the bore of die holder is 68mm.

$$D_j = 0.9\sqrt{D * d}$$

$D_j = 0.9\sqrt{68 \square 14.14}$= 27.5mm

The junction diameter 28 mm is selected.

Calculating initial interference

The carbide insert tangential stress yield capacity is weak and need to be reinforced through stress ring and optimize with interference fit. Calculating initial interference the dies insert and stress ring using equation 5.7 is applied.

$$Z_1 = \frac{d_J * Y_1}{E_1}\left(\frac{1}{k_1} - {Q_1}^2\right) \text{---} 5.7$$

Where D_j is the outer diameter of insert 28mm

Y_1 = yield stress of insert is 2100Mpa, Y_2 = yield stress of ring is 1200Mpa

E_1= elastic modulus of insert 450000Mpa

$k_1 = Y_1/Y_2$ = 2100/1200= 1.75

$$Q_1 = \sqrt{\frac{\left(1+\frac{1}{k_1}\right)}{2} - p_c} \text{---} 5.8$$

$p_c = p_i/Y_1$

p_c= 366/2100= 0.174

$$Q_1 = \sqrt{\frac{\left(1+\frac{1}{1.75}\right)}{2} - 0.174} = 0.782$$

$$Z_1 = \frac{28mm*2100Mpa}{45000Mpa}\left(\frac{1}{1.75} - .782^2\right) \text{-}= 0.03mm$$

Calculating this value interference of insert ring is 0.03mm

This value interference is small because the value take for internal pressure is to small it need to calculate with another method. Using this information and redaction ratio designed die is shown in figure 5.8.

The punch of stage 3 or extrusion process is the same as stage one process.

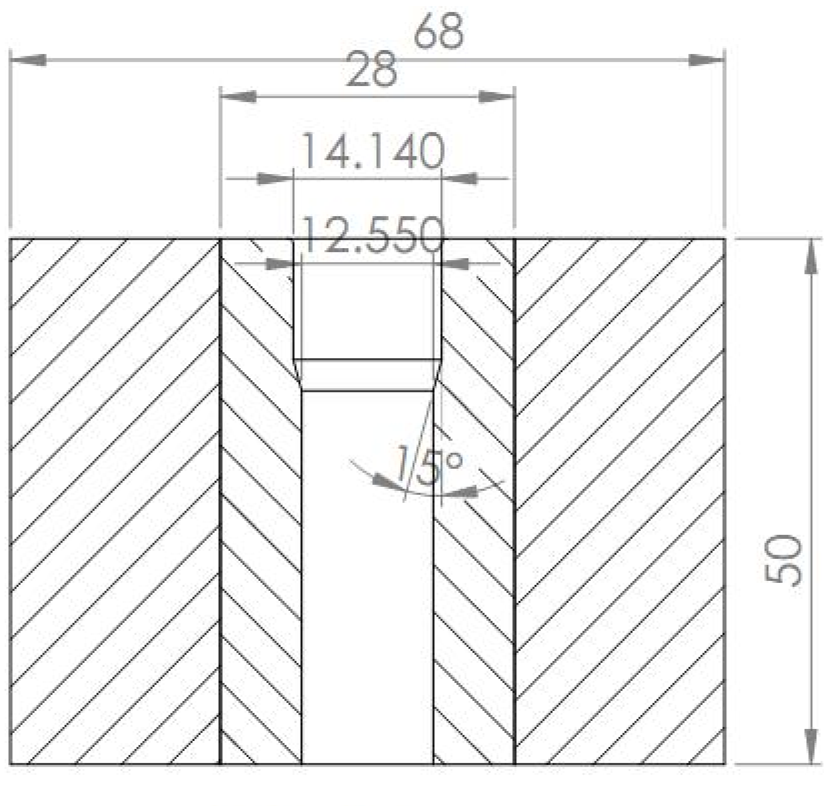


Figure 5.8 designed extrusion dies

5.3. Forming Simulation

Stage 1

In this research the pre heading operation was considered as Stage 1. Figure 5.9 illustrates the work piece and tooling geometries taken from within ABAQUS pre-processor. The top and bottom dies were considered as being rigid, in axisymmetric model the rigid part was presented with wire, while the workpiece as being rigid plastic. Boundary condition was applied to constraint degree of freedom of die and punches. Punches could move only ups and down and the punch speed is 10mms^{-1} (28). All degree of freedom of lower die were constrained. The workpiece elements were free to move and rotate in the tool boundary (29).

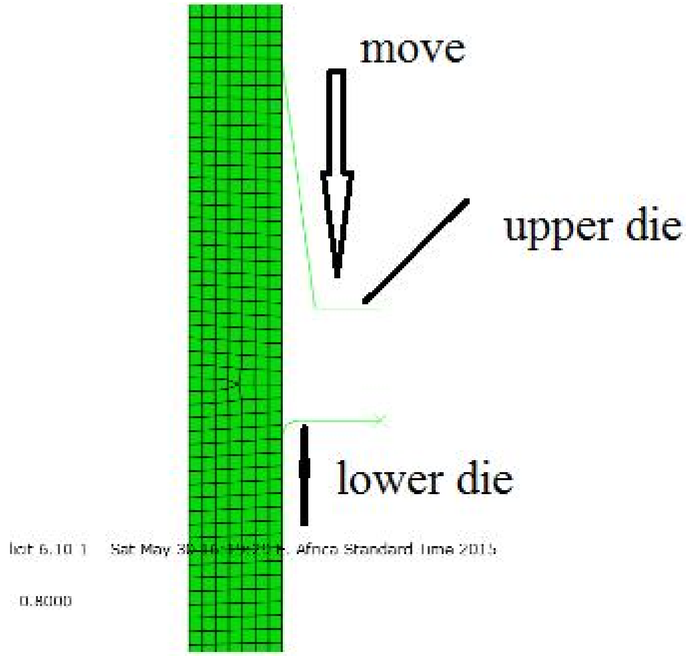


Figure 5.9 the arrangement of tool and work piece at stage one

The flow net pattern at the end of Stage 1 is shown in Figure 5.10. The large distortion of the flow net at the base of the head is clearly visible. Figure 5.11 illustrates the natural strain component within the workpiece at the end first stage. From figure we see that the maximum strain value is 0.490 in CAE analysis.

The maximum true strain computed theoretically for stage found that

$$\varepsilon = \ln\frac{l_f}{l_o}$$

l_o original length goes through deformation in pre-heading is 20.9mm

l_f the original length compressed with 10mms^{-1} for .8 second and become 12.9mm

$$\varepsilon = \ln\frac{12.9}{20.9}$$

ε= 0.482

Maximum strain calculated with analytical method and finite element method approximately the same.

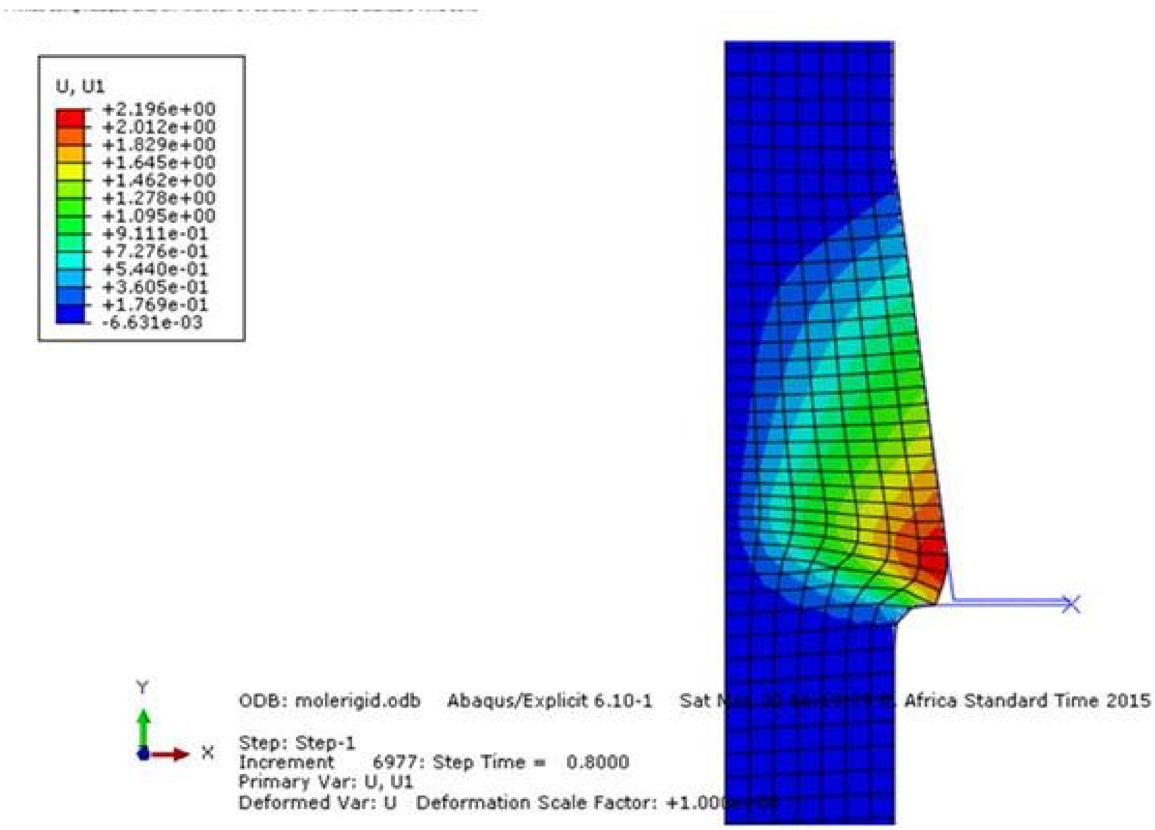


Figure 5.10 Flow net patterns within work piece at the end of Stage 1

Stress distribution in the work piece is shown that larger stress distribution at the base of the head Figure 5.12 shows that stress in workpiece.

Stage two finish heading

The geometry modeling of the stage two work piece was the output result of stage one. The part Coordinates were collected from the last step of stage one and modeled in ABAQUS part modeling mode. The boundary condition applied in this stage similar to stage one. The punch was then introduced into the model and instructed to move downwards at the same velocity of 10 mm/s. The assemblies of punch, workpiece and dies are presented in figure 5.13.

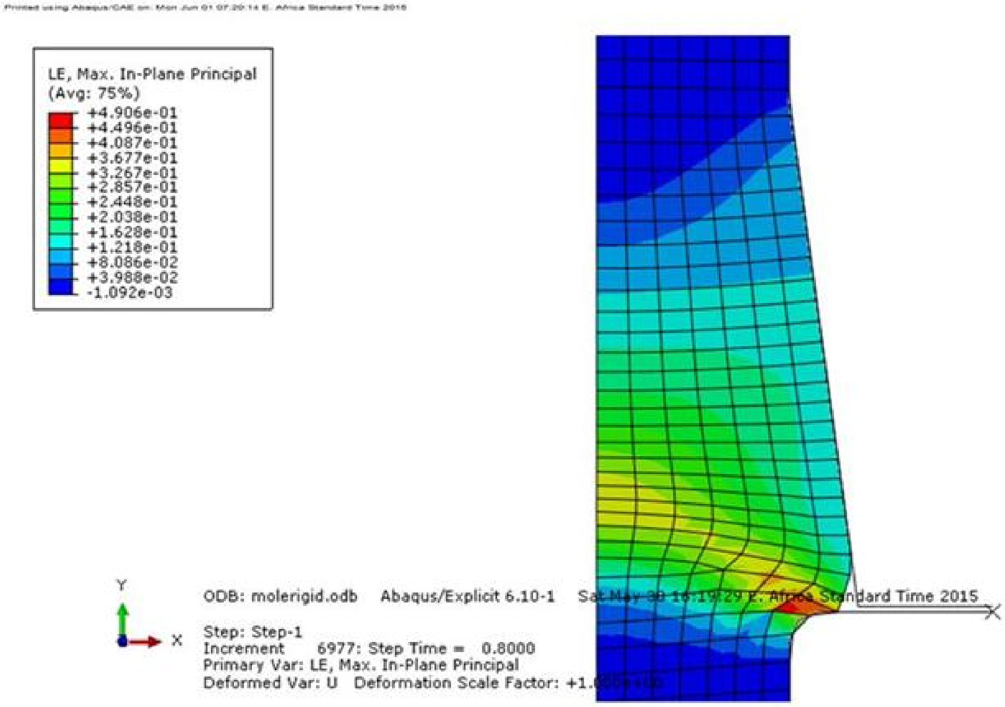


Figure 5.11 Strain components within work piece at the end of Stage 1

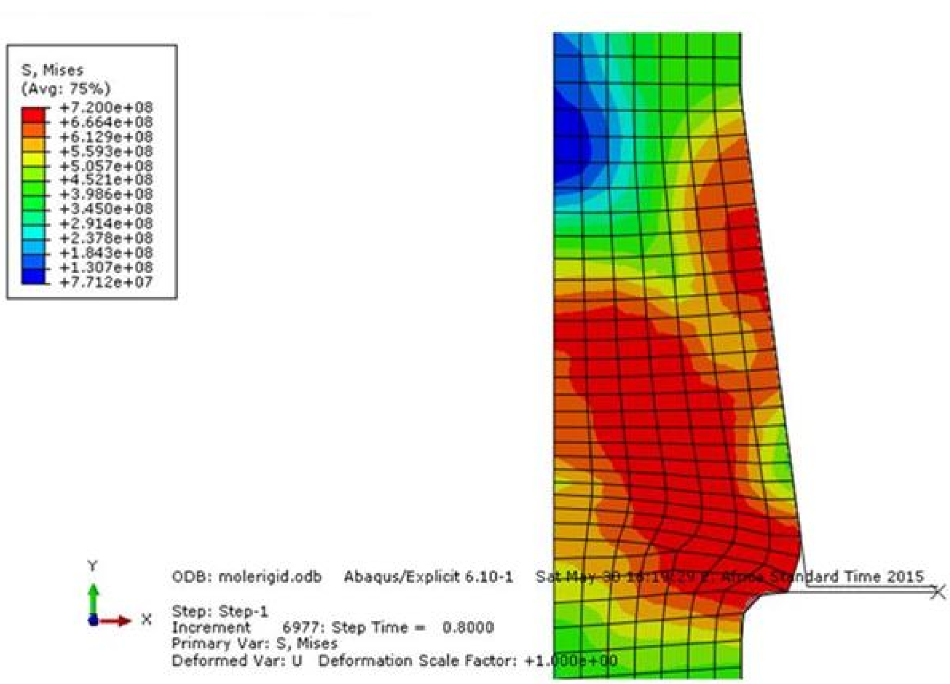


Figure 5.12 stress distribution within work piece at the end of Stage 1.

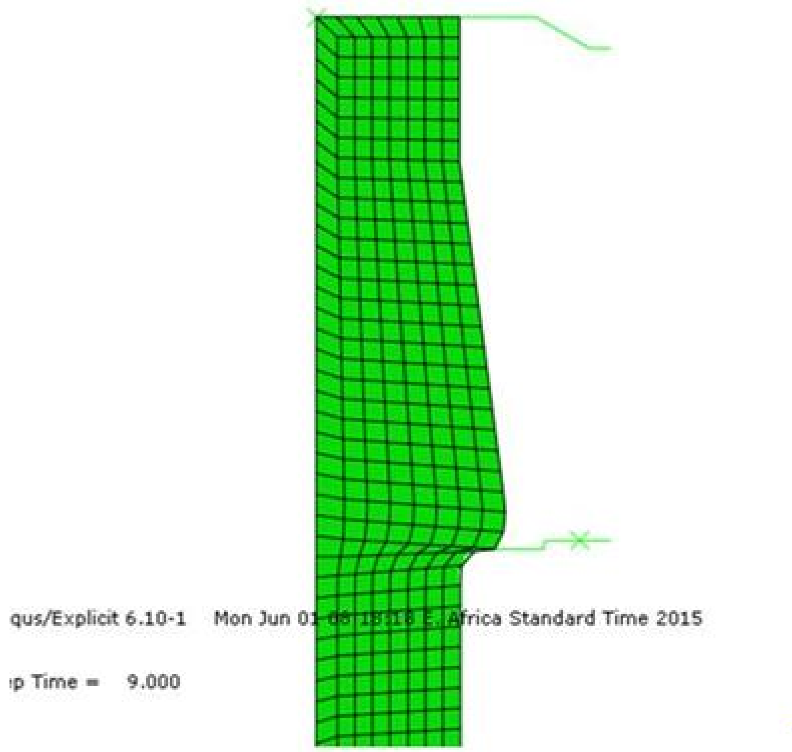


Figure 5.13 work piece geometry at stage two (after stage one)

ABAQUS job is aborted in the middle of analysis and re-mashing was done in the middle of analysis and the element size of the work piece changed from 0.75 to 0.5 mm. The process is open die process and the material free to move in all direction high displacement exhibited in top part and corner of radial direction and figure 5.14 shows the displacement of material.

Figure 5.15 shows high stress distribution almost in the center of head and the greatest distortion illustrated in the corner of bottom die interface. Figure 5.16 shows the maximum strain is the center of head. The maximum strain and maximum stress appear at same place.

5.4. Analysis of extrusion process

The work piece diameter was increased to 13.73 by upsetting in first consecutive operation and its length goes to is 25mm and extrude diameter is 12.55mm. The design of the die was done by varying the die opening angle to get optimum angle to smooth flow of the material. To get optimum die opining angle with maintaining extrusion ratio constant was done by in table 5.1.

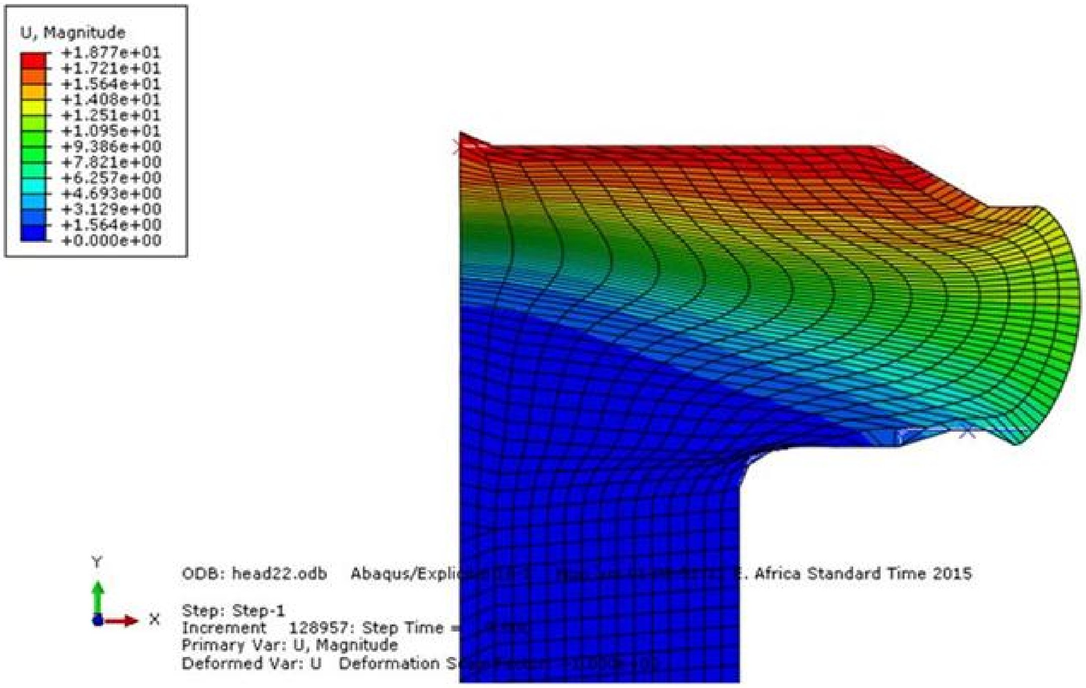


Figure 5.14. Flow net pattern within work piece at the end of Stage 2

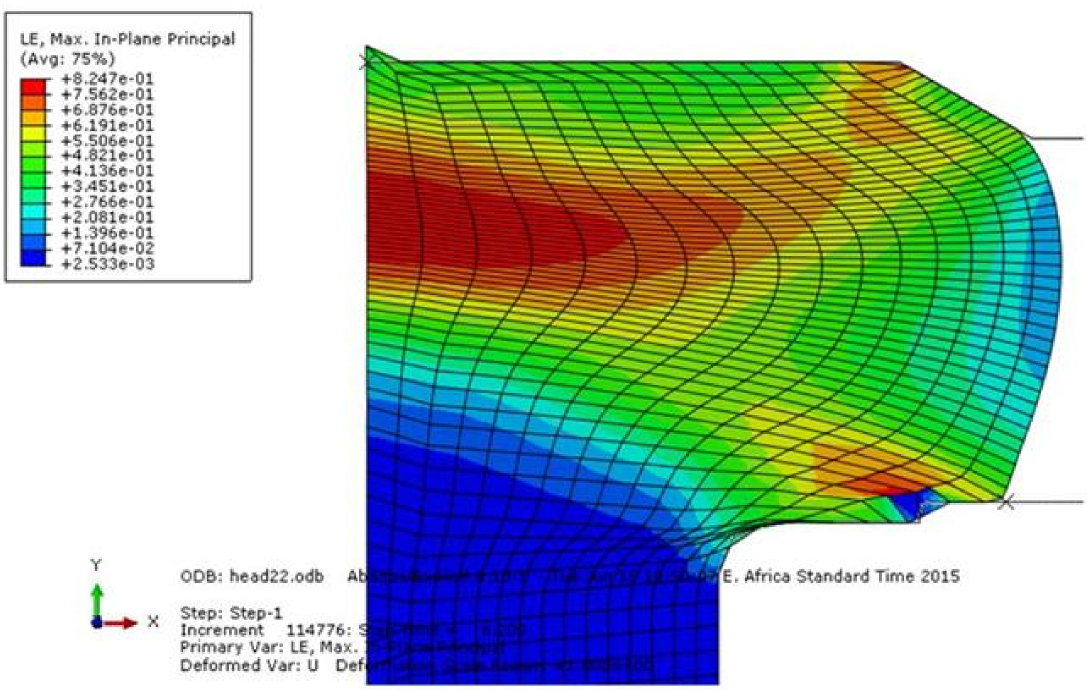


Figure 5.15 Strain component within work piece at the end of Stage 2

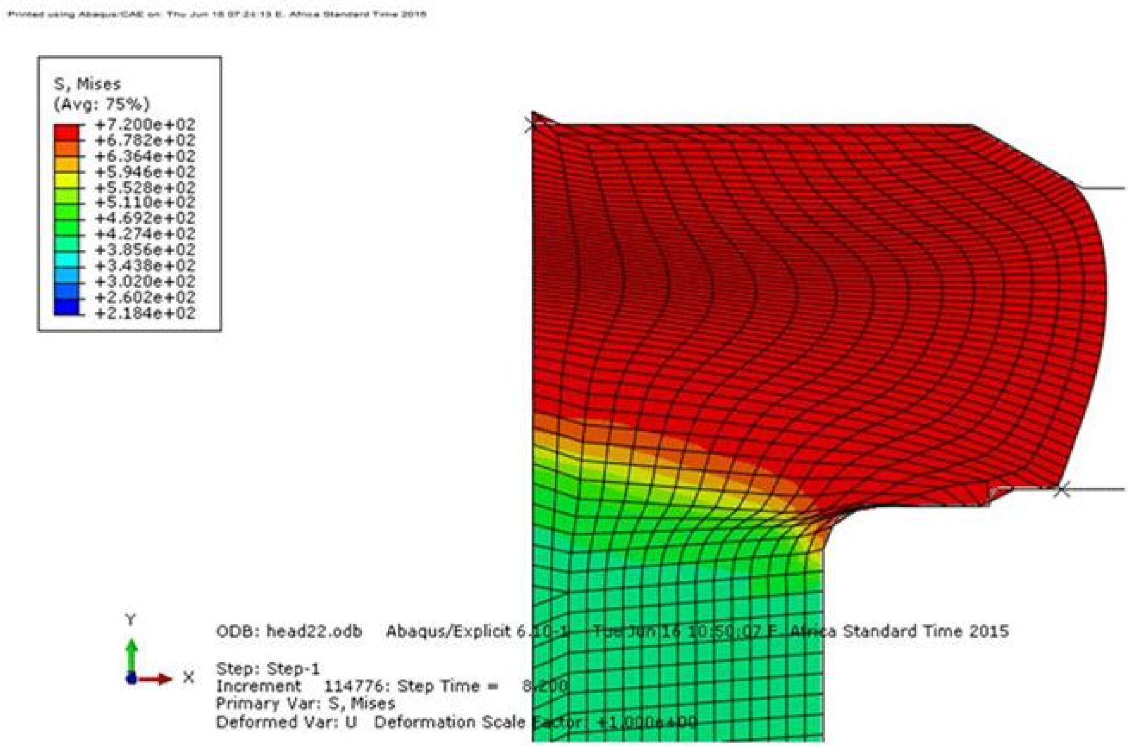


Figure 5.16 stress distribution within work piece at the end of Stage 2.

Maximum extrusion ratio is in the section 5.1.2

φ_{max} =0.1792

Table 5.1. Extrusion iteration value

No	Die opening angle $2\alpha(^0)$
1	60
2	30
3	26

Iteration one: die opening angle $2\alpha=60^0$

The effects of die opening angle with maintaining extrusion ratio was studied and for the first iteration die opening angle 60^0. The boundary condition are applied for tools and workpiece arrangements, which constrain all degree of freedom of extrusion dies (30). Movement of the punch was constrained in x axis, rotation in xy axis and allowed to move in y axis is presented in figure 5.17.

The material flow of the work piece very much distorted. Because in the open extrusion when the punch pressure for extrusion equals the yield stress of the material, upsetting of the billet above the die will take place, rather than extrusion of billet through the die. If the die opining angle is large, the die land is large cause uneven material flow (figure 5.18.) so 60^0 die opining angle is not favorable such type of extrusion..

Iteration two: die opening angle $2\alpha=30^0$

For extrusion die opening angle 30^0 material flow behavior are shown in figure 5.19. The stress distributions are high just above the die wall and reduce at the exit of forming area and the stress is exhibited 660.9 Mpa at the exit of die. The material flow in outer surface work piece is slower than the center of the work piece; the horizontal grid line end points in outer surface of the part lag behind the end point in the center of extrude part. The strain distribution of work piece is shown also in figure 5.20.

Iteration three, die opening angle $2\alpha=26$

For extrusion die opening angle 26^0 material flow behavior are shown in figure 5.21.The stress distribution is maximum just above the die wall and reduce at the exit of extrusion area. At the exit of die the stress is 653.2Mpa. The flow of the material evenly distribute from center to outer surface of the workpiece.

Strain distribution on the workpiece the strain in the outer surface of extrude part is 0.1792 (figure 5.22) it is the same value find in analytical calculation for maximum strain.

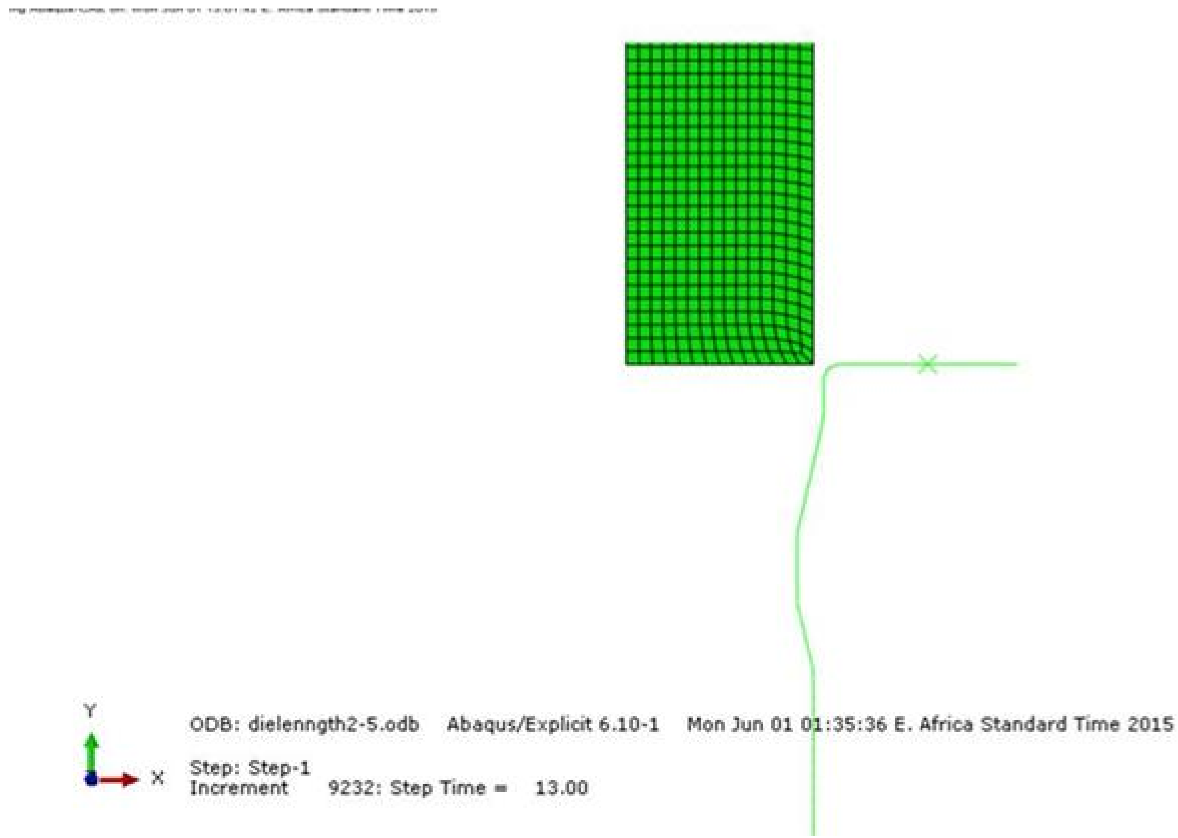


Figure 5.17 arrangements of tools and work piece for extrusion process

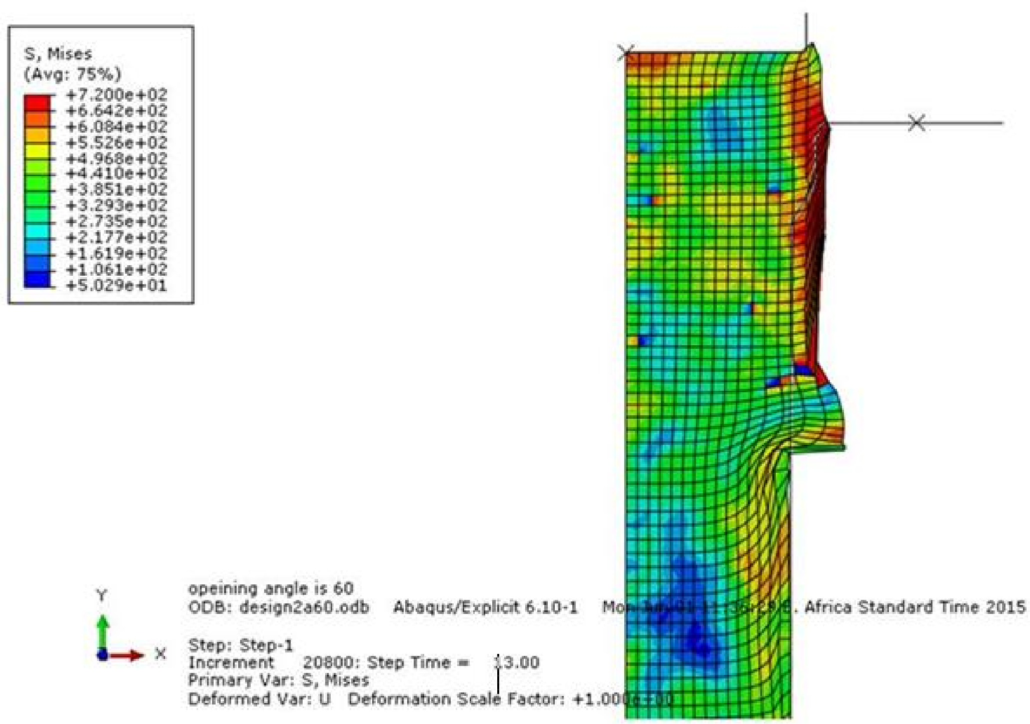


Figure 5.18 the material flow in die opening angle 60^0

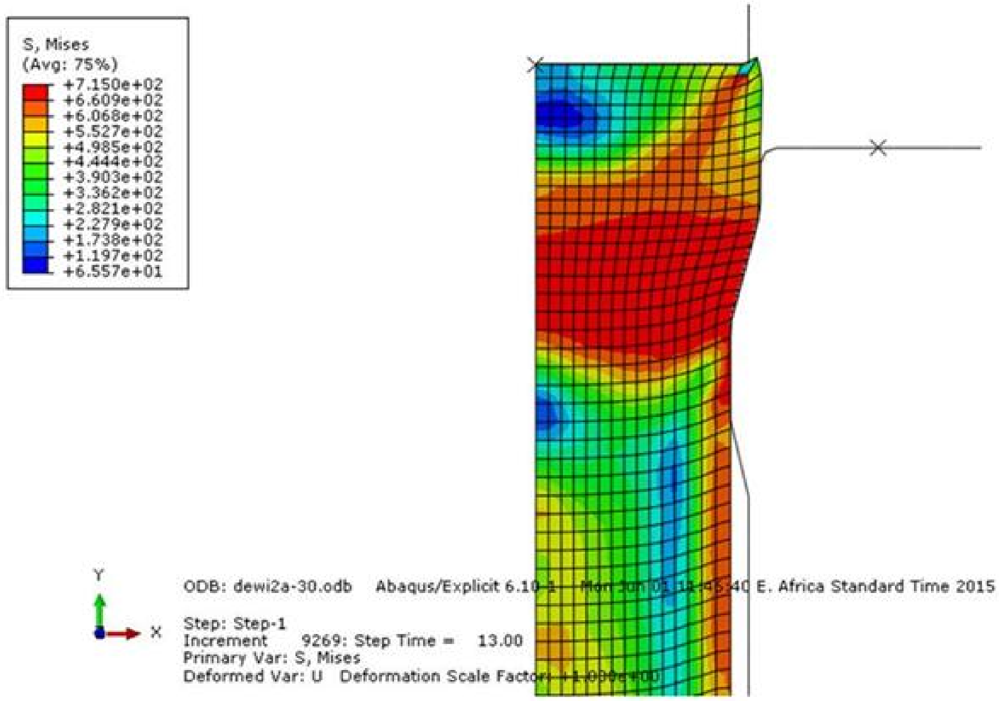


Figure 5.19 Flow net pattern within workpiece in extrusion die opening angle 2α=30

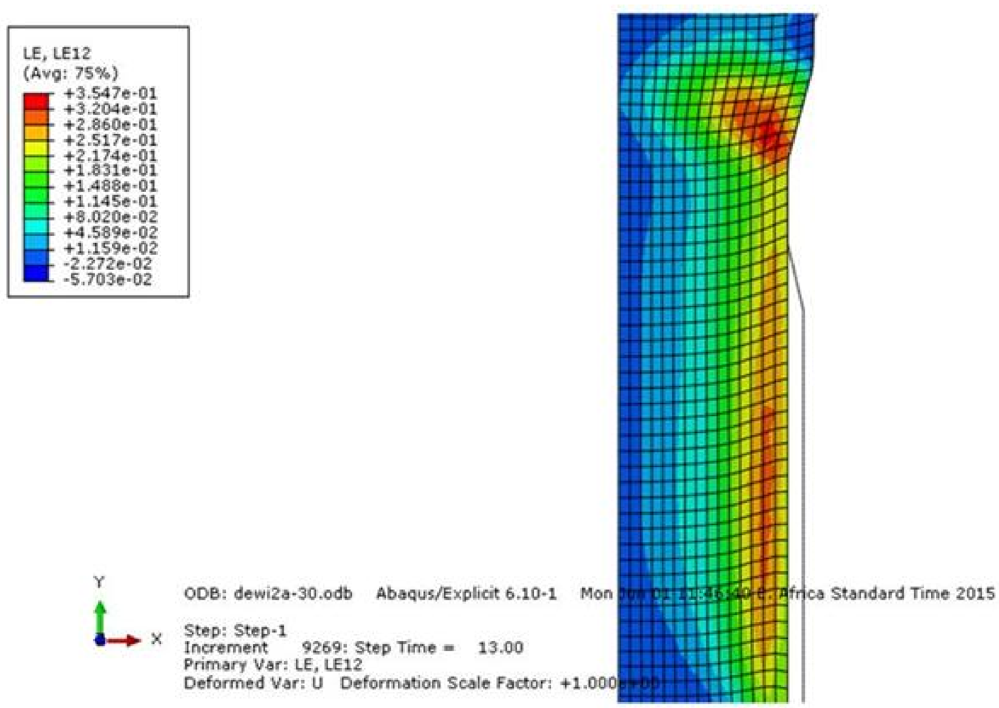


Figure 5.20. strain distribution in die opening angle 30^0

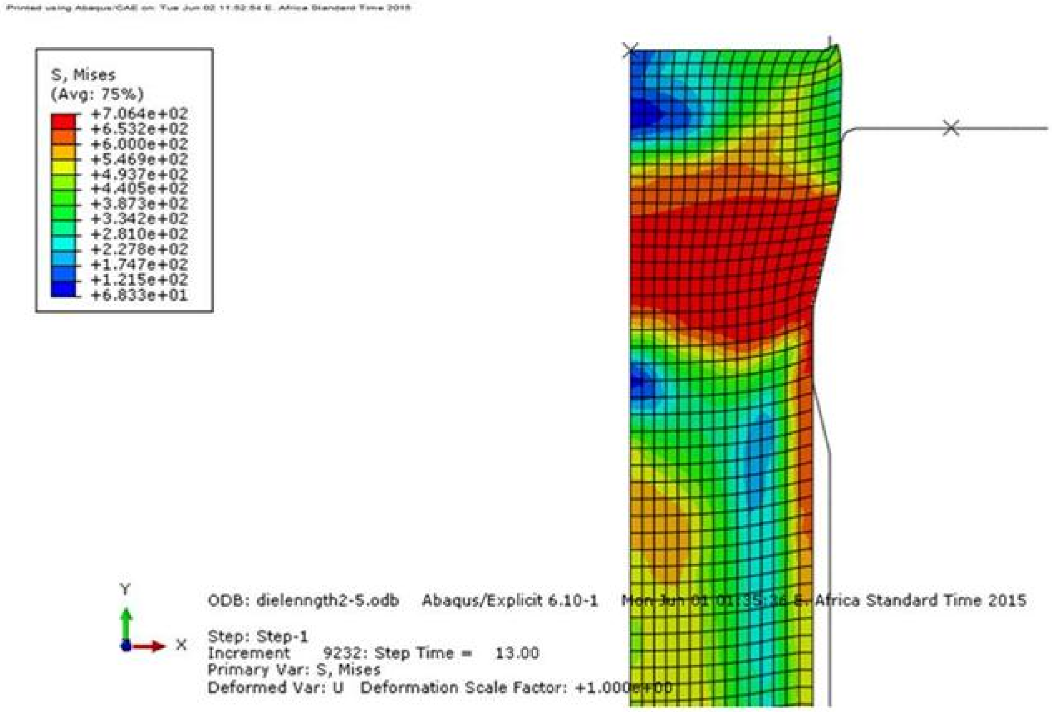


Figure 5.21 Flow net pattern within work piece in extrusion die opining angle $2\alpha=26^0$

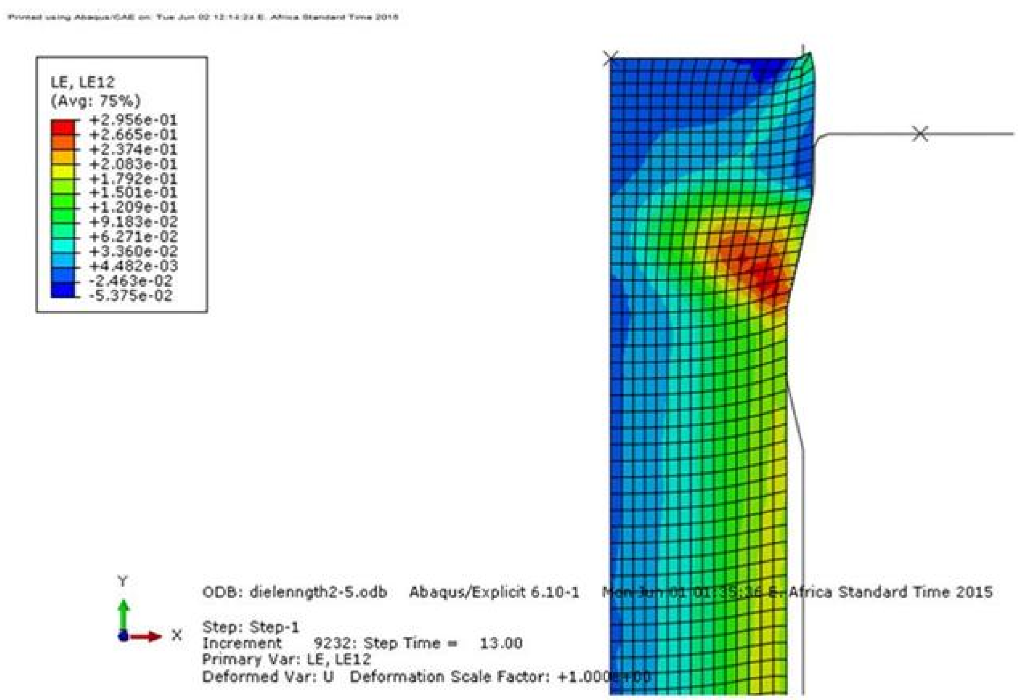


Figure 5.22 strain distribution in die opining angle 26^0

5.5. Calculating extrusion force

Extrusion force calculated in section 5.12 is not considered the die opening angle and friction. To compare different die opening angle this two methods are used.

5.5.1. Calculating force using analytical method

The total force of figure 2.5 is calculated using equation 2.16 and F_{tot} is found from the sum of equation 2.14 and 2.16. Die opening angle affects the force of $F^{o.}$

$$F_{tot} = F^{o} + F_{FR,w}$$

$$F^{0} = A_0 \sigma_{f.m} \left[\frac{2}{3}\tan\alpha + \left(1 + \frac{2\mu}{\sin 2\alpha}\right)\ln\frac{A_0}{A}\right] -$$

$$F_{FR,W} = \pi d_0 l \sigma_{f.0} \mu -$$

To solve this equation first we have to calculate mean flow stress from 0 to maximum strain mean stress calculated from figure 4.2, true strain and stress graph of workpiece.

$\sigma_{f,0} =$ 406Mpa at φ=0

$\sigma_{f,1} =$ 680Mpa at φ_{max} =0.1792

$\sigma_{f,m} = (\sigma_{f,0} + \sigma_{f,1})/2$

$\sigma_{f,m}$= 543Mpa

From this simple calculation the mean stress from 0 to maximum strain 0.1792 is 543Mpa

A_o = area of cross section of workpiece before extrude

d_o= 13.73mm

A_o= 148.05mm^2

l= length of die wall 2 mm

A is the cross section are after extrusion d is the diameter after extrusion is 12.55

μ, friction coefficient is .1

Force for die opening angle 2α=30^0

Putting the value in the equation 2.14

$$F^0 = A_0\sigma_{f.m}\left[\frac{2}{3}\tan\alpha + \left(1+\frac{2\mu}{\sin 2\alpha}\right)\ln\frac{A_0}{A}\right]$$

$$F^0 = 148.05mm2 * 543Mpa\left[\frac{2}{3}\tan 15 + \left(1+\frac{2*0.1}{\sin 30}\right)2*\ln\frac{13.73}{12.55}\right]$$

F^o = 34, 568.2 N

F^o for die opening angle 30^0 is 35.97kN

Force ($F_{s,w}$) along the shoulder of the, which is not affected by die opening angle is

$F_{FR,W} = \pi d_0 l \sigma_{f.0}\mu$—

$F_{FR,W} = \pi$ 13.73mm 2mm 406Mpa 0.1

= 3,502N

The force along the die wall is 3.5 KN

Total force for die opening angle 30^0 is 38.07 KN

Force for die opening angle 2α=26^0

Putting the value in the equation 2.14

$$F^0 = A_0\sigma_{f.m}\left[\frac{2}{3}\tan\alpha + \left(1+\frac{2\mu}{\sin 2\alpha}\right)\ln\frac{A_0}{A}\right]$$

$$F^0 = 148.05mm2 * 543Mpa\left[\frac{2}{3}\tan 13 + \left(1+\frac{2*0.1}{\sin 26}\right)2*\ln\frac{13.73}{12.55}\right]$$

F^o = 33,410 N

F^o for die opening angle 26^0 is 33.4kN

Force ($F_{s,w}$) along the shoulder of the, which is not affected by die opening angle is

$F_{FR,W} = \pi d_0 l \sigma_{f.0} \mu$—

$$F_{FR,W} = \pi \times 13.73mm \times 2mm \times 406Mpa \times 0.1$$

= 3,502N

The force along the die wall is 3.5kN

Total force for die opening angle 26^0 is 36.9 kN

From this value we see that force require for extrusion for 26^0 is less than 30^0.

5.5.2. Total force in ABAQUS CAE

The reaction force in the punch is opposite of extrusion force. The reaction force is plot is found in result of History output. From result date can collect both reaction force and time step and made graph for both 30^0 and 26^0 in figure 5.23. From the graph we see that punch force of 26^0 die opening is less than that of 30^0.

From both methods the extrusion force for 26^0 is less than that of 30^0 and the force found with CAE analysis have good correlation with manual analysis.

5.6. Die stress analysis

For the selected die opening angle stress distribution on elastic dies analyzed using ABAQUS CAE. Analysis was done by changing transition radius of die with radius 1mm and 2mm. Figure 5.24 shows stress distribution on elastic die with die opening angle 26^0 and transition radius 2 mm. Figure 5.25 and 5.26 shows stress distribution along the face of dies from the entrance to the exit of die. From the figure 5.25 and 5.26 we see that stress distribution transition radius 2 mm is better.

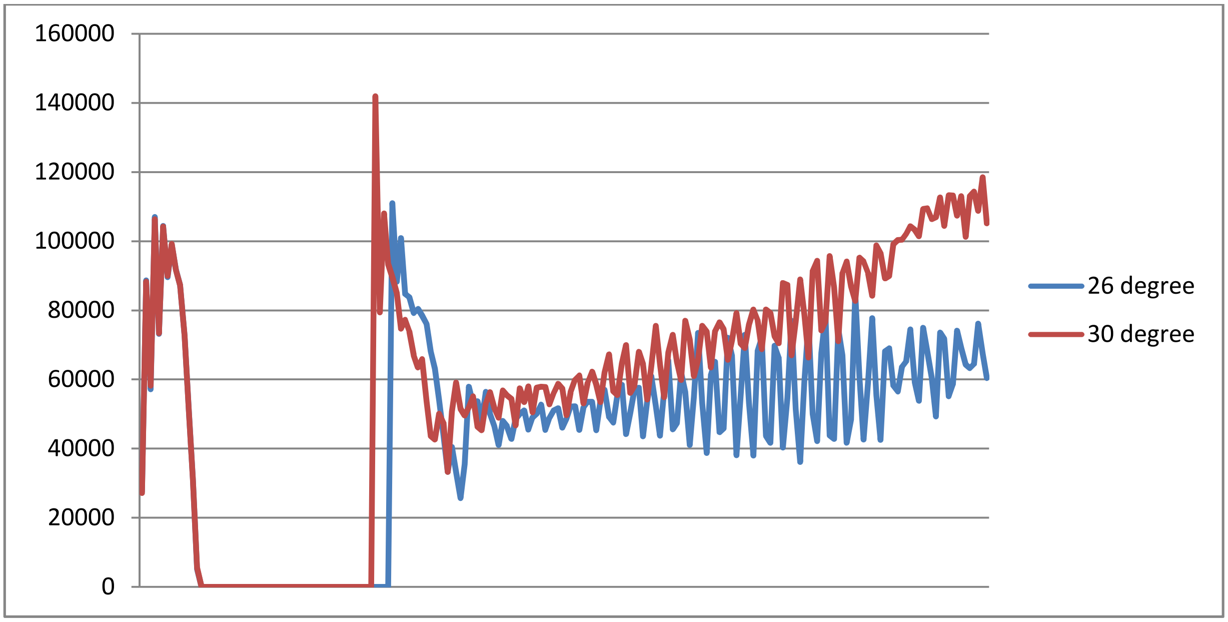


Figure 5.23 the punch reaction force verses step time.

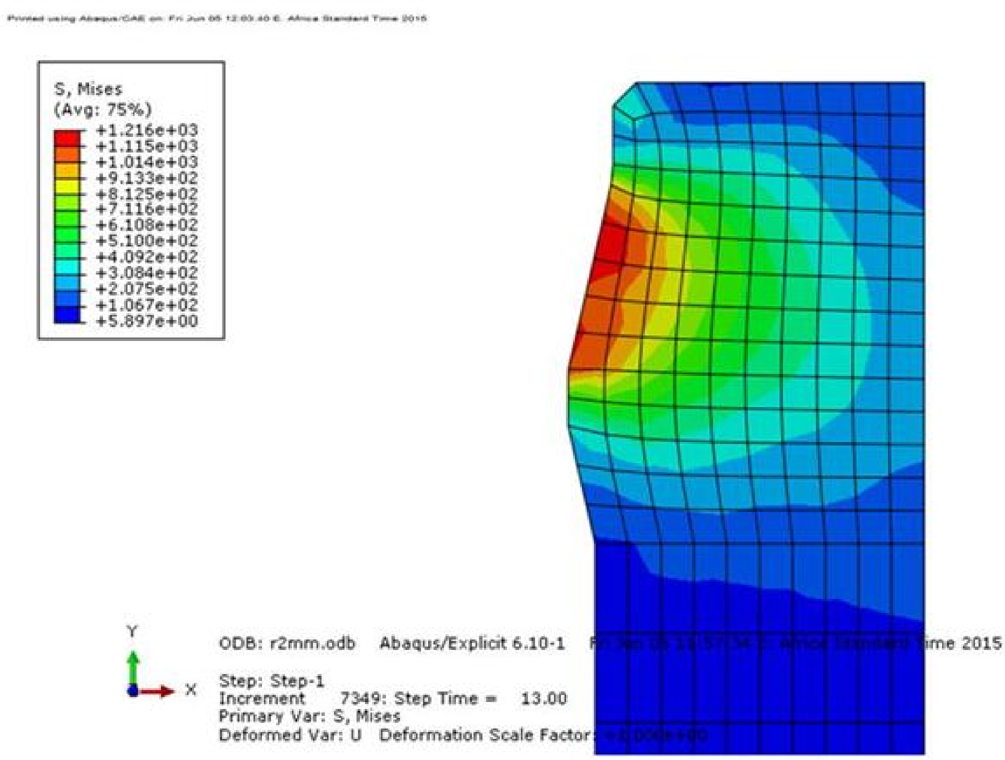


Figure 5.24 stress distribution in dies

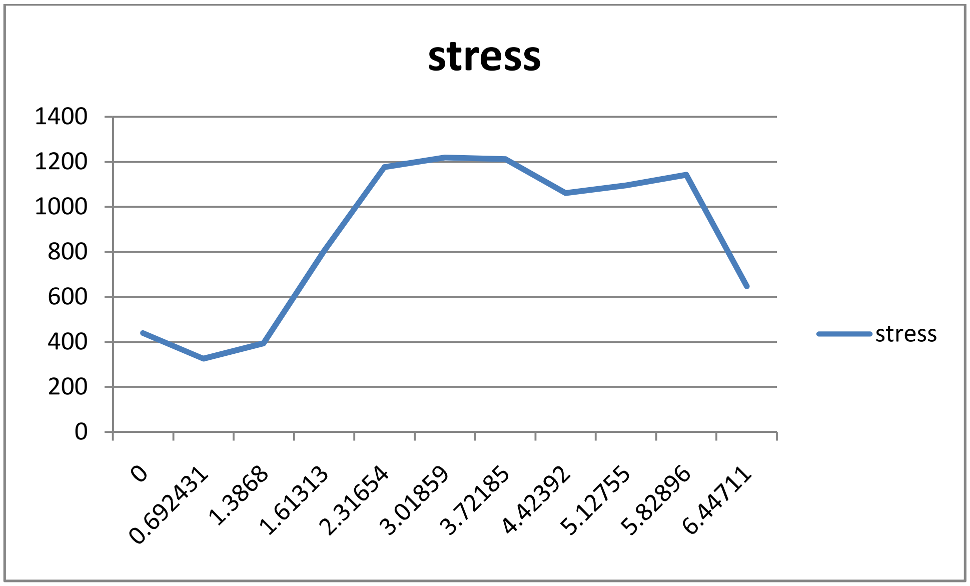


Figure 5.25 stress distribution along the path of die face with 1mm transition radius.

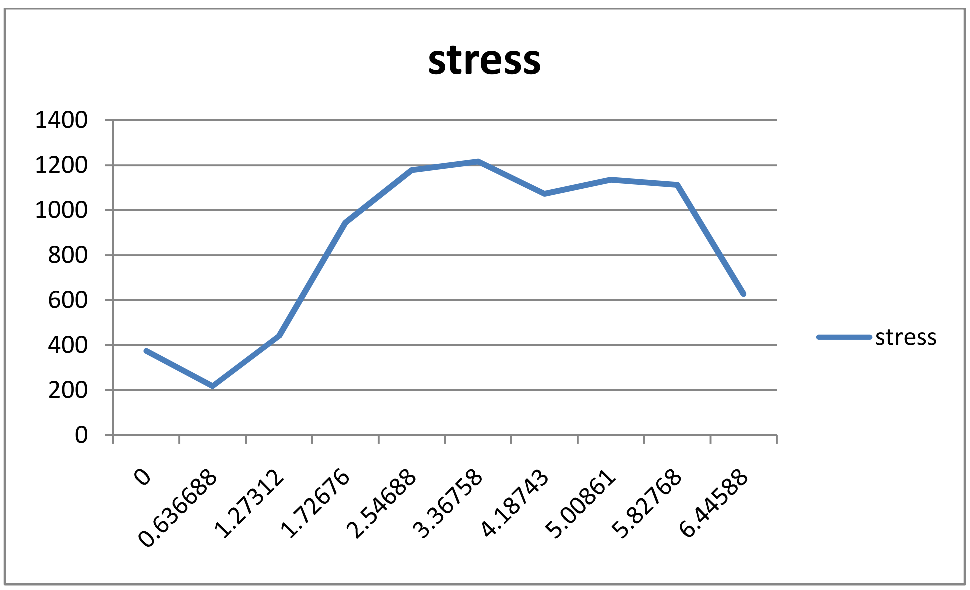


Figure 5.26 stress distribution along the path of die face with 2mm transition radius

Finally die is designed according to the optimum shown in the next page.

Chapter Six

Conclusion and Recommendation

Conclusion

Computer-aided engineering (CAE) simulation is a useful tool to optimize, validate, verify and hence, generate the design solutions before they are implemented. The results can be utilized to analyze the tool design and forming processes during the designing stage as well as in the trouble shooting stage. In this research metal forming process is analyzed using finite element method.

- The requirement of material was calculated using volume constant theory of forming process. Process limit was calculated and selected appropriate number of operation.
- Flow stress, mean flow stress and forming load were calculated using plain strain method.
- Stress, strain and displacement of the material under forming process were analyzed and maximum of these attribute were indentified using finite element method
- Maximum strain found in manual calculation in head forming has good agreement with strain distribution found in FEM.
- The second stage of heading process was open die forming and stress and strain were found to be maximum at center of head.
- To find optimum die opening angle three opening angle (2α), 60^0,30^0,26^0, were studied.
- Smooth material flow process taken place in narrow die opening angle.
- The force required to extrude the billet is less in narrow die opening angle while maintaining extrusion ratio, friction condition constant.
- The force required to extrude the billet through a given angle calculated using plain strain method and using FEM has good agreement.
- Stresses distributions are analyzed along the length in die insert at workpiece and tool interface with different transition radius and 2mm radius is selected.
- From the opening angle and transition radius optimum die geometry are designed but the optimality of the die constrained by the surface finish of the workpiece and lubrication, manufacturing system of the die insert and its surface finish and pre-stressing system of insert and outer ring.

5.2. Recommendation

- The tooling costs can consume 5% to 30% of the manufacturing costs but HMMBI bolt production shop does not record tool life and tool failure causes. So the company should create tool management system.
- Nowadays forming company implement finite element simulation for die filling analysis and tool design system. The HMMBI to stay in the computation should introduce finite element simulation method in the production process and die design.
- HMMBI has non conventional manufacturing process system and the bolt and nut workshop should work with non conventional and precision factory to manufacture their own bolt die demand.
- Friction force the causes of tool failure, production interruption and low surface finish of the products and care must be taken in the cleaning and lubrication process.

5.3 Future Work

The study of this thesis is continued in designing manufacturing process of pre-stressed dies and punches and manufacture tools in HMMBI.

Reference

1. Mert Aygen: Die Stress And Friction Behaviour Analysis In Bolt Forming; master thesis Middle East Technical University, 2006
2. Taylan Altan,Prof. Dr, Gracious Ngaile Dr. and Manas Shirgaokar Mr, State of Cold forging Technology in Global Competition, ERC for Net Shape Manufacturing, the Ohio State University.
3. K. Lange, L. Cser, M. Geiger, J.A.G. Kals: Tool Life and Tool Quality in Bulk Metal Forming ; Annals of CIRP 41/2 (1992), pp. 667-676
4. M. Hirschvogel, H.v. Dommelen, Some applications of cold and warm forging, Journal of Materials Processing Technology, 35 (1992) 343-356
5. K. Lange: Hanbook of Metal Forming , Society of Manufacturing Engineers, McGraw Hill, 1985
6. K. Geethalakshmi and K. Srinivasan, Finite Element Analysis Of Open Die Extrusion Of Al-5Zn-1Mg Alloy,
7. George E. Dieter, Mechanical Metallurgy, McGraw-Hill
8. Geethalakshmi K., A. O. Surendranathan, An Investigation of Containerless Extrusion of Al-Zn-Mg Alloys , Journal of Metallurgical Engineering (ME) Volume 2 Issue 3, July 2013
9. Hyunkee Kim, Tetsuji Yagi, Masahito Yamanaka, FE simulation as a must tool in cold/warm forging process and tool design, Journal of Materials Processing Technology 98 (2000) 143-149
10. Jens Groenbaek Dr., Erik Lund Mr., Tool Optimization by Means of Effective Prestressing System, Conference AsiaForge 2008
11. A. R. Ab-Kadir, A. R. Othmanb, Prediction of Fatigue Life in Cold Forging Punch Design for Fastener Using Integrated FEA and Stress Life Approach, Procedia Engineering 50 (2012) 505 – 515
12. G. Maccarini, C. Giardini, G. Pellegrini and A. Bugini: The influence of die geometry on cold extrusion forging operations: FEM and experimental results; Journal of Materials Processing Technology, 27 (1991) 227-238
13. Victor Vazquez*, Daniel Hannan, Tool life in cold forging - an example of design improvement to increase service life, Journal of Materials Processing Technology 98 (2000) 90-96
14. Nader Asna, On tool stresses in cold heading of fasteners, Engineering Failure Analysis 5 "0888# 210224

15. Markus Knoerr , Kurt Lange, Taylan Altan : Fatigue failure of cold forging tooling: causes and possible solutions through fatigue analysis ; Journal of Materials Processing Technology 46 (1994) 57-71
16. Kurt Lange, Arndt Hettig and Markus Knoerr, Increasing tool life in cold forging through advanced design and tool manufacturing techniques
17. M. W. Fu & M. S. Yong & T. Muramatsu, Die fatigue life design and assessment via CAE simulation, Int J Adv Manuf Technol (2008) 35:843–851
18. HMMBI home page
19. Mark Garietya, Gracious Ngaile, Taylan Altan, Evaluation of new cold forging lubricants without zinc phosphate precoat, International Journal of Machine Tools & Manufacture 47 (2007) 673–681
20. FAEK DIKO, Metal Flow Simulation And Design Of Dies For Closed Die Forging, Doctorial Thesis
21. Cem S. Çetinarslan, Ali Güzey, Tensile Properties Of Cold-Drawn Lowcarbon Steel Wires Under Different Process Parameters, MTAEC9, 47(2)245(2013)
22. U. Ince & M. Güden, An iterative numerical method for determination of temperature-dependent friction coefficients in thermomechanical model analysis of cold bolt forging, Int J Adv Manuf Technol (2013)
23. H. T. Yeo1, Y. Choi and K. D. Hur, Analysis and Design of the Prestressed Cold Extrusion Die, Int J Adv Manuf Technol (2001)
24. Abaqus 6.10, Abaqus/CAE User's Manual
25. A. R. Ab-Kadir, Effect of Corner Radius and Friction Parameters on the Optimization of the Cold Forging Die Design, Modern applied science , February,2009
26. Heinz Tschaetsch, Metal Forming practice
27. T. Z. Blazynski, Design Of Tools For Deformation Processes, Department of Mechanical Engineering. The University of Leeds. UK
28. Conor MacCormack, John Monaghan, 2D and 3D finite element analysis of a three stage forging sequence, Journal of Materials Processing Technology 127 (2002) 48–56
29. M. R. Doddamani, Uday M., Simulation of Closed die forging for Stud Bolt and Castle Nut using AFDEX, International Journal of Engineering and Innovative Technology (IJEIT) Volume 1, Issue 3, March 2012
30. Finite Element Modeling, Simulation And Analysis Of Cold Upsetting Process, lecture note