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International
Journal
Of Modern Engineering Research (IJMER)

# Design and Manufacturing Simulation of Preform for Thread Rolling Operation

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***ABSTRACT:-*** *Modeling and designing of bolt using three-dimensional finite element analysis is continuing to gain importance. Because it is expensive for iterating the actual die, simulation has gained importance to bring down cost of designing. There are many methods available for forming bolts but in the present work, design and simulation of upsetting process for ISO metric hexagonal bolt is carried out for M20X2.5, M30X3.5 andM42X4.5 size bolts. The forging parameters such as number of stages, underfill, effective stress and forging load are determined using AFDEX metal forming simulation tool. It was found that there was no underfill in the produced component, stress values are within the acceptable level and load required to form the bolts have been determined.*

***Keywords:-*** *AFDEX, Hexagonal Bolts, Process Design, Simulation ,Upset Forging.*

## I. INTRODUCTION

There are many types of joints used in various industries today, among which bolted joints plays an important role and is among widely used joints because of various advantages such as ease of assembling and disassembling, lower costs and the ability of bolt to withstand longitudinal and transverse loads. Use of plastics and composite polymers are increasing in the low-stress applications, still there is a need for disassembling most of the fasteners which are being manufactured from metals and alloys [1]. Manufacturing of these bolts have been the subject of interest for many researchers from many decades and it still holds opportunity for newer developments in this area. Because of the extensive use of bolts in various applications, it has been optimized from the point of design as well as from the manufacturing aspects. Bolts are manufactured using different methods of forming process such as shearing, sizing, upsetting or heading, forward and backward extrusion, etc. [2]. Finite element analyses of the designs have been playing an important role in the design of forming components. Computer simulation of forming processes is a technique which can depict the behavior of the workpiece in the actual process. Using the plasticity of the given workpiece material and tools associated, the simulation can describe the stresses, strains and microstructural changes related to the processes [3]. Nowadays many numerical analysis tools are available for the simulation of the forming process such as DEFORM 2D, DEFORM 3D, AFDEX, FORGE, ANSYS, STATISTICA, Qform, MSC Superforge and many other methods [4][5][6].

Simulation technique are applied using the AFDEX (Advisor as friend for Forging Design Experts) software, which is a FEM(Finite Element method) based package uses Lagrangian approach, has the capability to predict different parameters of forming process such as effective stress and strain, filling of dies, load required and temperature of the workpiece. Many works have been carried out using this software package for simulating various mechanical components [6][7][8]. In the present work, Metric series bolt blanks in particularly M20, M30 and M42 bolts are forged using upsetting method through simulation in the view of further thread forming the blank and parameters such as stress, flow, under fill and load required are found out. This work focuses mainly on the forming loads, stresses involved and flash for the material Stainless Steel AISI SS -316(200C)

## II. METHODOLOGY

The methodology is given in flow chart of the Fig. 1. The first step before simulating the whole process is to model the dies and billet for the process. This step plays a key for whole of the process as the model holds the geometrical information about the billet and the dies. After the process is completed, the model is updated based on the obtained values. After the modeling, 3D file is imported to the AFDEX module using the. STL format as the AFDEX identifies binary values. Once the models are imported the material properties and the forming conditions such as the die type, lubrication, speed of die, mesh size and stroke length are entered into the module. Before running the simulation, the proper positioning of the billet with respect to the dies is ensured. As the alignment is difficult in the AFDEX environment, the proper positioning is done while creating the model with slight room for alignment. Once the position is made, meshing is auto generated by AFDEX. After the simulation is done, the flow analysis is made and results are interpreted to find out whether the result obtained is optimal. The results obtained through simulations have been discussed.

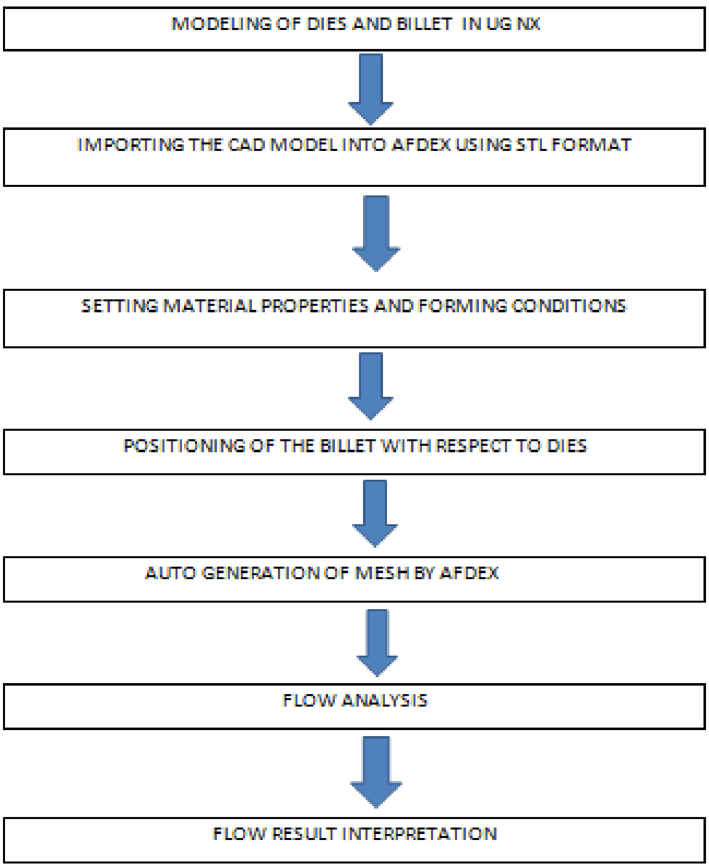



**Figure 1 Flow Chart of Simulation Process**

**Table 1 Composition of Element weight in % of AISI SS steel**

| AISI | 316 SS |
|---|---|
| C | 0.08 |
| Mn | 2 |
| K | 0.045 |
| S | 0.03 |
| Si | 0.75 |
| Cr | 16-18 |
| Ni | 10-14 |
| M | 2-3 |

**Table 2 Mechanical Properties of AISI SS - 316**

| Mechanical Property | Value |
|---|---|
| Ultimate Tensile Strength | 579 MPa |
| Yield Strength | 290 Mpa |
| Hardness Rockwell | 79 |
| Density | 7.99 $m/cm^3$ |

## III. DESIGN OF BOLTS

The parameters of the bolts used for simulation are shown in the Table 3, [9]. As the blanks are needed to be thread rolled, the threading portion should be at pitch circle diameter after which threaded portion comes to nominal size. As the nominal size bars are not available in standard, the nearest standard value is chosen. The diameter of bar which are chosen are 18mm, 26mm and 38mm respectively.

**Table 3 Parameters of Bolts**

| Type of Bolt | M20X2.5 | M30X3.5 | M42X4.5 |
|---|---|---|---|
| Major Diameter(d) | 20mm | 30mm | 42mm |
| Pitch Circle diameter (dp) | 18.3mm | 27.6mm | 39mm |
| Pitch | 2.5mm | 3.5mm | 4.5mm |
| Blank diameter | 18mm | 26mm | 38mm |
| Hexagonal head, width | 30mm | 46mm | 74mm |
| Hexagonal head, thickness | 12.315mm | 19mm | 26mm |
| Length of Bolt | 50mm | 72mm | 95mm |

### 3.1 Process Design

In forging processes, design of dies plays a critical role as the load involved depends on the shape of the dies. Dies corresponding to the bolts shown in table 3 have to be designed. First step towards upsetting is to find out the parameters for the upsetting process. The design parameters calculated for the upsetting process is shown in table 4. In any upsetting operation the upsetting ratio decides the number of stages. According to [10], for upsetting in single stage, the upsetting ratio (s) must be less than 2.6. From the table 4, Upsetting ratio for M20 and M30 is below 2.6 whereas the upsetting ratio for M42 is above 2.6. Therefore, for M42 bolt upsetting is carried out in two stages.

**Table 4 Design parameters of Upsetting process**

| Parameters | M20 | M30 | M42 |
|---|---|---|---|
| Volume of required component ($mm^{3)}$ | 27228 | 90150 | 263226.5 |
| Surface area after upsetting, $A_1$ ($mm^2$) | 584.56 | 1374 | 3556.76 |
| Upsetting, $\epsilon_p = \frac{ho-h1}{h2}$ | 0.315 | 0.37 | 0.357 |
| Degree of Upset, $\square_p = \ln\frac{h1}{h0}$ | 0.38 | 0.464 | 0.443 |
| Upsetting ratio, $s = \frac{h_{0hd}}{d_0}$ | 1.877 | 2.52 | 3.18 |

### 3.2 Modeling of Bolts

Based on the process design, the modelling is taken up for the dies. Modelling is done using UG NX software. The orientation of the models should be in the Y-direction for the ease of orientation in the AFDEX software. The position of the upper die and the billet is made in optimal position such that the upper die is just above the billet to give the proper velocity and minimal movement of dies in AFDEX environment. The 3D models are exported to AFDEX using the '. STL' format separately for upper die, lower die and billet.

## IV. DESIGN CALCULATIONS AND ANALYSIS OF FORMING PROCESS

In the present work, forming of bolt preforms is carried out using upsetting operations. upset forging is depicted as shown in the fig. 2. Upset forging is a type of forging in which the pressure affects the workpiece along the longitudinal axis. This type of forging is used in the mass production of parts such as rivets, head bolts, screws and many more components [10]. Billet plays an important role in the process. Billet may be of rolled or forged or drawn depending on the end operation. In this process, three sizes of billets used are 18mm, 28mm and 38mm diameter. Theoretical force values for the upsetting process are calculated using Flow stress and Projected area of the Forging. The Flow stress is given by the equation 1. The Y stands for the shape factor which is 5.5 for the upsetting process with simple design and minor flash. $K_{str}$ stands for the yield strength of the material at forging temperature. The forging temperature is $20^0$C and yield strength is 290 N/mm$^2$. The value of M20, M30 and M42 is 1595 N/mm$^2$ as the flow stress is considered same for all three processes.

$$K_{re} = Y \times K_{str} \text{.........................................................} 1$$

Projected area of the forging, A1 which is the hexagonal area and values are 898.72 mm$^2$, 2080.85 mm$^2$ and 3556.76 mm$^2$. Using these equation, the force required is given by the equation 2. The values are 909786N, 3339348.7N and 5742095N for bolts.

$$F= A_1 . K_{re}(1+(1.\mu d1.)/(3.h1)) \text{.....................................} 2$$

The theoretical force values for forming bolts are 127.56tons, 340.50 tons and 585.53 tons for the three bolts respectively.

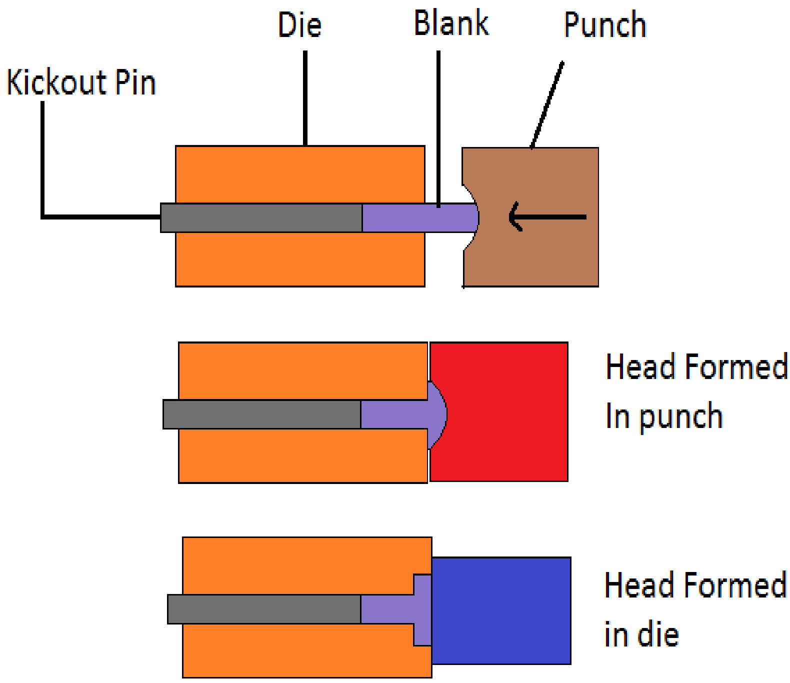


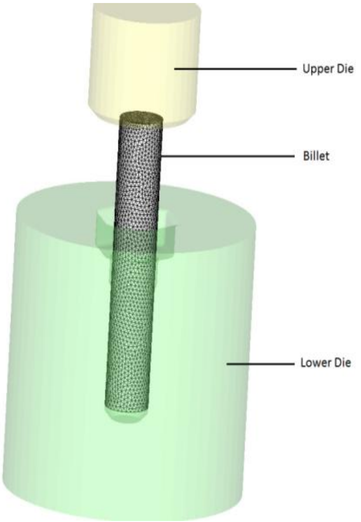

**Figure 2 Heading/ Upset Operation [11]**

## V. SIMULATION OF PROCESS

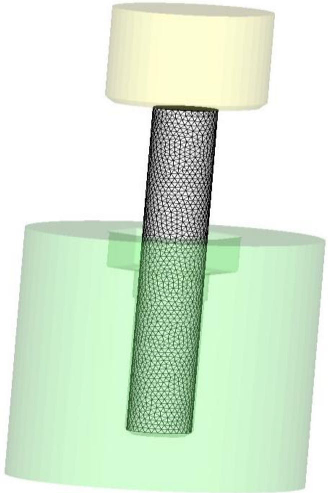
The die movement will cause the material from the billet to flow into the die cavity. For this to happen, various input needs to be specified before starting the simulation. Table 5 presents parameters selected for the simulation. The models created in the NX is loaded into the AFDEX preprocessor environment '.STL' format. When the simulation is initialized, the models are auto-meshed to 3D tetrahedral meshing as shown in the Fig 4.

**Table 5 Forging Parameter used for Simulation for upset forging**

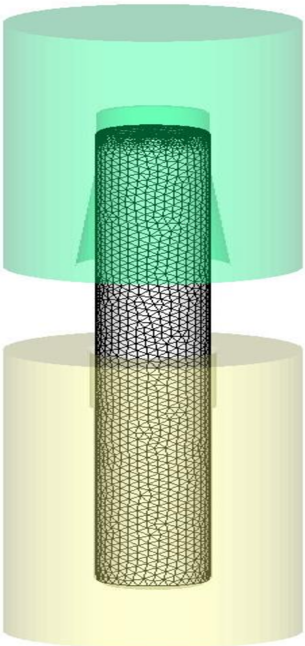
| **Type of forming** | **Cold Forging** |
|---|---|
| **Type of Simulation** | 3D without Flash |
| **Type of Analysis** | Flow analysis |
| **Deformation** | Rigid Plastic |
| **Billet material** | AISI 316SS(T = 200C) |
| **Translational velocity** | 300 mm/sec in y direction |
| **Lubrication Used** | Oil cold(steel) |
| **Friction Value** | 0.025 |



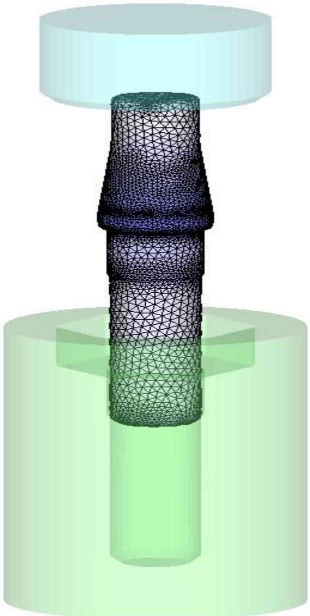

M20 Initial Mesh Generation



M30 Bolt initial Mesh generation



M42 Bolt Stage 1 Mesh Generation



M42 Bolt Stage 2 Mesh Generation

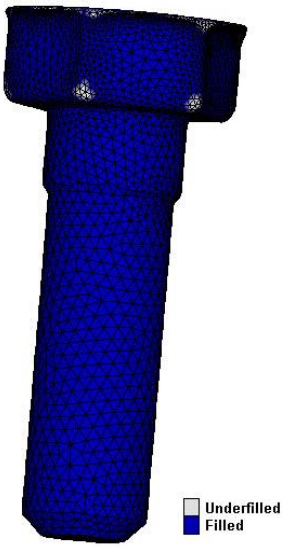
**Figure 3 Mesh Generation during Simulation Process**

## VI. RESULTS AND DISCUSSIONS

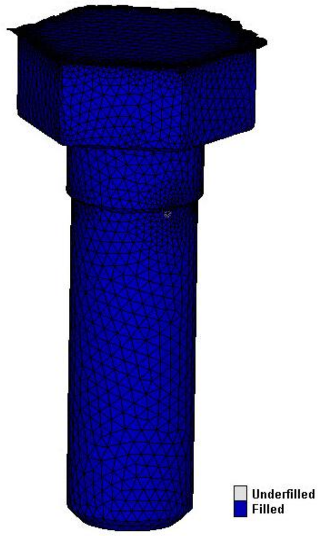
Simulation is performed using Lagrangian approach. Different parameter of the forming is obtained in the post Processor window of AFDEX software. The main interest in this work is to investigate the quality of the bolt in terms of under fill, Stresses and Forging capacity.

### 6.1 UNDER FILL AND FLASH

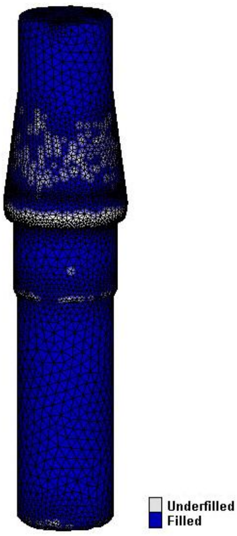
Fig.4 shows the Filled cavity of the component. The blue color represents the filled portion of the billet and white color in the figure indicates the unfilled area of the component. It can be seen that all the three bolts are completely filled and few white spots can be observed but they are in the position of machining area and it does not affect the quality specification of the component. The figure also shows the flash on the head portion of the bolt M20 and M30 which accounts to less than 1% of the component which is negligible and can be cleared using machining process which chamfering the hexagonal head. This filled state without any unfilled area on the surface of component results in better performance of the bolt.



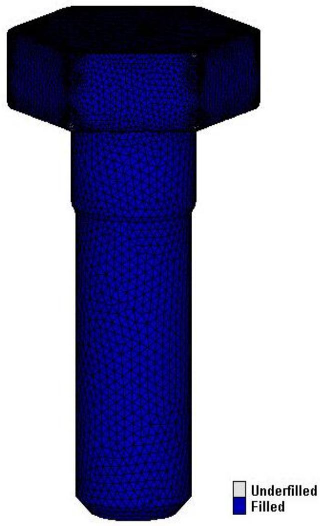

**M20 Bolt**




**M30 Bolt**




**M42 Bolt Stage 1**

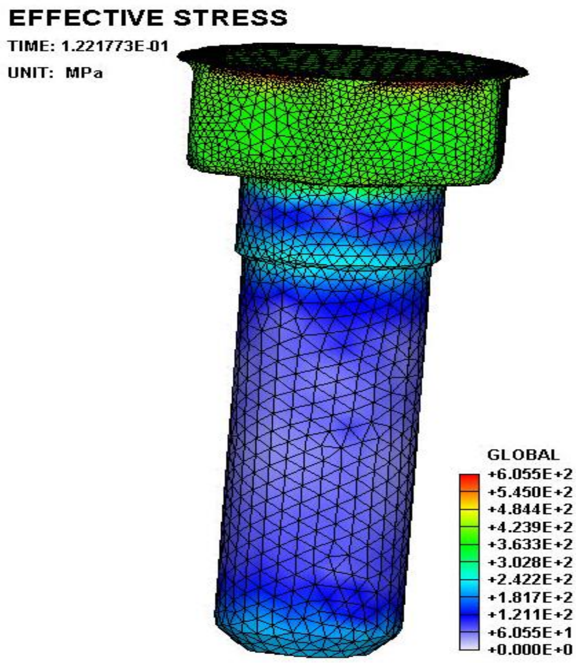



**M42 Bolt Stage 2**

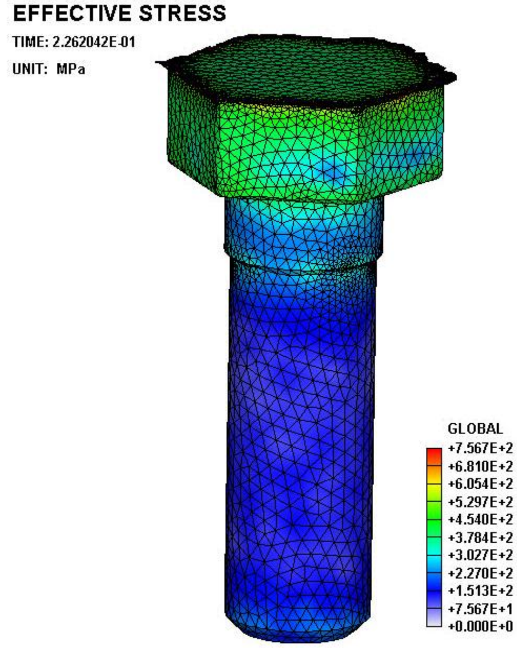
**Figure 4 Underfill of all the components**

## 6.2 EFFECTIVE STRESS

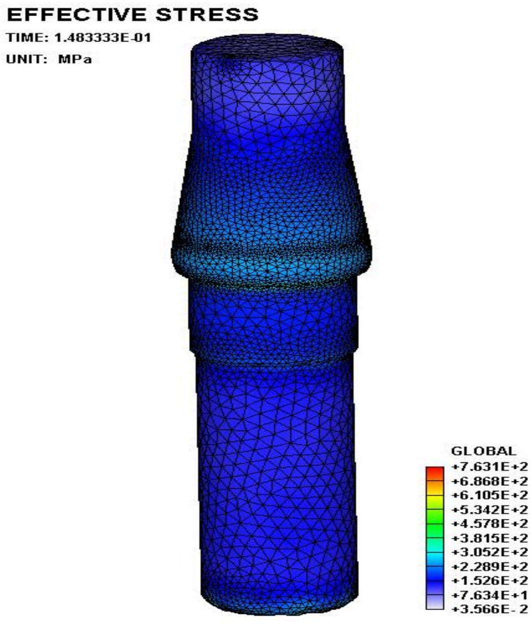
Figure shows the effective stress of the components. It can be seen from the figure that the material does not exceeds the Ultimate Yield stress of the component i.e 579 N/mm$^2$.As majority of work is done on the head of the component, the stress are more at the head region. The maximum and minimum stress for M20 bolt at head region is 584.12 N/mm$^2$ and 377.23 N/mm$^2$, for M30 bolts it is 690 N/mm2 and 237.48 N/mm$^2$ and for M42 bolt it is 596.63 N/mm$^2$ and 453.01 N/mm$^2$. It can also be observed that some of the flash areas of the head region have higher stress value which is more than the permissible value, this indicate there is some fracture in the flash area but it does not affect the main part of the component hence it can be negligible. The shank portion of the bolt has optimal stress values as very little work is done in expansion of the material from blank diameter to the pitch diameter of the component. Grip part has higher value compared to shank part as there is work done in upsetting from the blank diameter to the bolt diameter. These stresses can be relieved by heat treatment after bolt is manufactured completely.



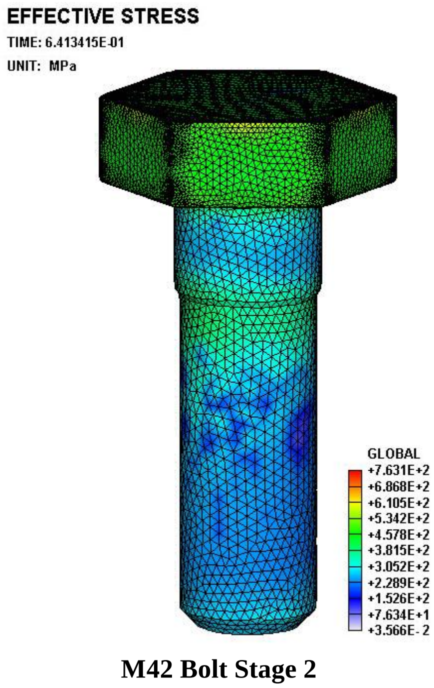

**M20 Bolt**




**M30 Bolt**




**M42 Bolt Stage 1**

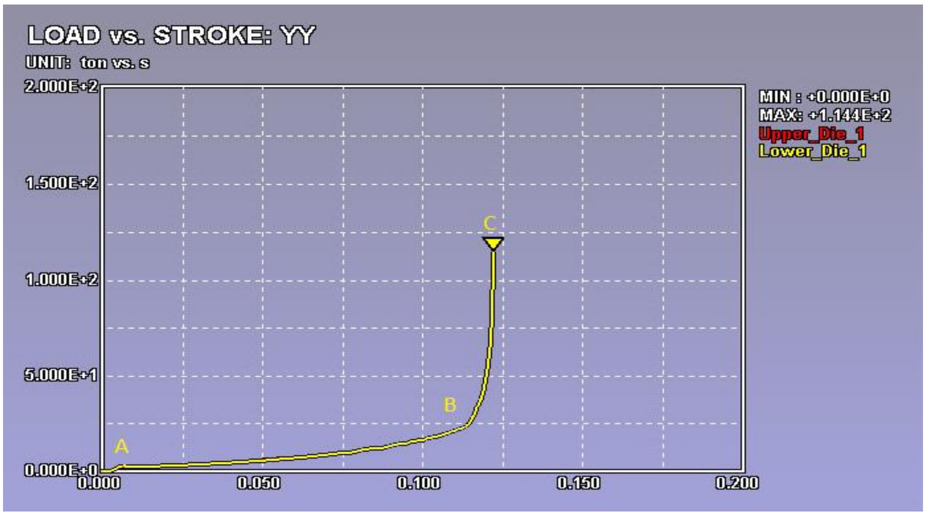



**M42 Bolt Stage 2**

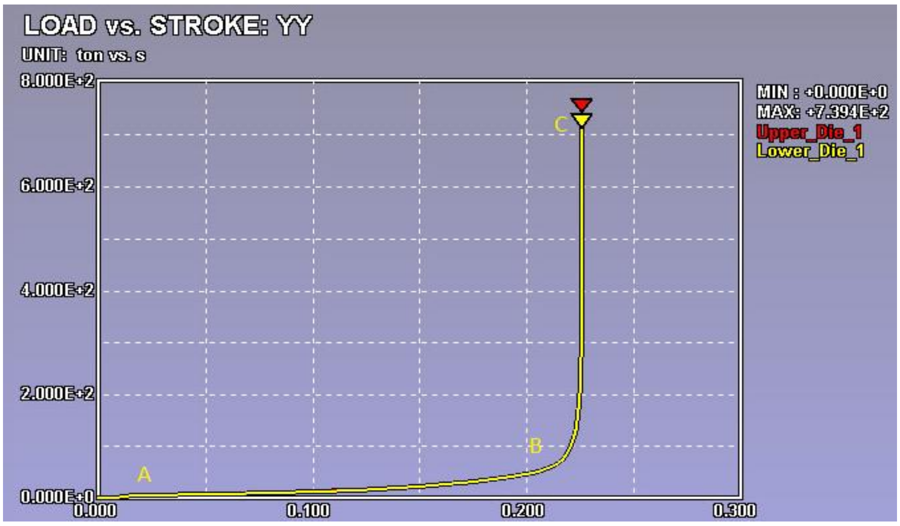
**Figure 5 Effective stresses of all the components**

### 6.3 FORCE REQUIRED

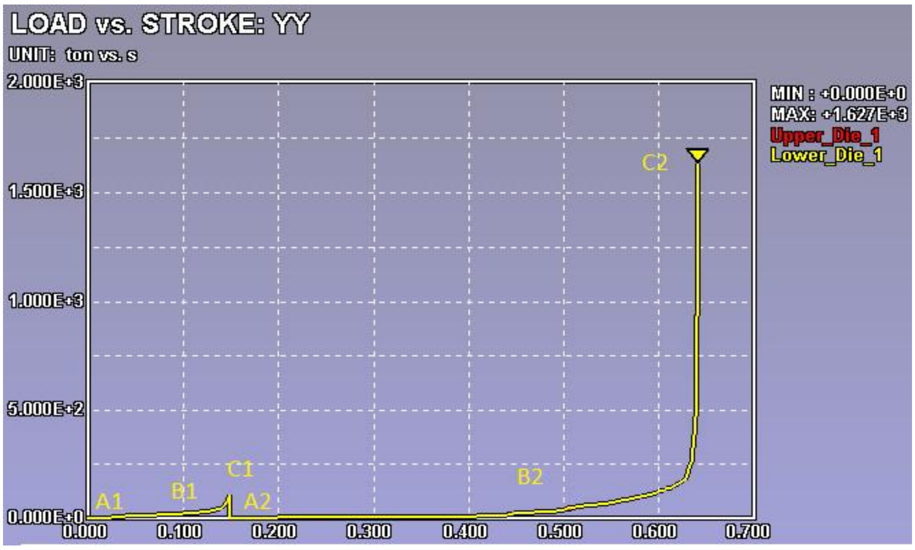
Figure 6 shows the load vs Stroke for the components. It can be seen that there is similar pattern in all the three component, at point A The billet comes in contact with the die, at point B flash begins to form and at point C load increases sharply and die fills the cavity completely. For M42 there are two stages so the points are split as A1 and A2 for stages 1 and stage 2 respectively. It can be seen that the theoretical calculation for M20 is approximately same as obtained load whereas the result of the M30 and M42 bolt varies. This is the result of the work hardening of the material in the cold condition.




**Maximum load utilized by the press is 114.4 Tons for M20 Bolt**




**Maximum Load utilized by the press is 739 Tons for M30 Bolts**




**Maximum load utilized by the press is 1627 Tons for two stages for M42 Bolts**

**Figure 6 Graph of Load vs Stroke in Y Direction**

## VII. CONCLUSION

Present work is focused on the design and forming of the preform for the thread rolling operation. Use of simulation software such as AFDEX makes the designing process easier and cost effective. AFDEX software is very helpful for analysis and simulating forming process. It can be seen that all the components which are designed are completely filled and stresses in the component are less than the ultimate stress of the material. Theoretical and simulated load of the forging processes is calculated. In future work better mathematical relation can be used to narrow down the differences of theoretical to simulated results. Therefore, better quality and cost effective bolts can be produced using the simulation process.

## ACKNOWLEDGEMENTS

Authors would like to acknowledge for providing research grants from TEQIP-II, World Bank grants, Govt. of India. and DHIO, Research and Engineering Pvt. Ltd. Bangalore for their research support.

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