# Manufacturing Simulation for Determining The Influence of Process Parameters on Quality of Forgings

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***Abstract*—Pre-form shape of the billet and die design plays a significant role in bulk forming process for deciding the amount of material consumed and energy along with the material flow analysis. Usually the forging is performed in multiple stages like preformed shape and in stages. The component shape plays an important role as it influence the quality of the final product. The forging quality is primarily identified by the amount of under fill, flash, cracks, uniform stress and strain during the forging process. There has been extensive research carried out by many researchers to perform predetermined work using many methods. In the present work the equivalent static load method is used to optimize the preformed shape which leads to the desired final shape and even distribution of the effective strain using the simulation software. Partial results are demonstrated as the method is used to formulate and solve very few parameters.**

***Keywords—: Pre-formed shape, Equivalent static load method, Simulation, Optimization, AFDEX***

## I. INTRODUCTION

Forging is the working of metal into a useful shape by hammering or pressing. It is considered as one of the oldest metal working arts[1]. Hot and warm forging technology has gained lot of potential in recent times in automotive and aerospace industries[2]. In present scenario because of huge requirements in the forged component and focused towards the reduction in time and cost, it has become very much essential to optimize the process parameters. Usually forging process involves multiple pre-forming processes which are then followed by finishing process. Simulation has become very important tool for the development of new or improving processes. Simulation is being used to simulate number of forming processes in production of components like connecting rods, blade coining and other components using various simulation software tool [3]. The simulation process will bring down the time and cost for development of new products[4].

In this paper the parameters such as billet shape, under fill and stress is taken into consideration to simulate and analyze the closed die forging process. Pre-form shape and optimization of the billet design plays a significant role in bulk forming process for deciding the amount of material consumed and energy along with the material flow analysis[5]. Focus is given on the flow of material and reduction in flash using the manufacturing simulation for the material DIN 1.4401 rolled stainless steel (T=20°-1100°C) which is used for spanner.

## II. LITERATURE SURVEY

Forging components plays a very important role in automotive and aerospace industry. Computer aided simulation is used in studying the material flow in several forging operations[3]. Optimizing the process parameters is very important to improve the quality of forged components. Several works has been reported in this regard. Some of the heavy-duty components which are used in automotive industry and other industrial applications are optimized for increased efficiency to carry high load capacity and high fatigue resistance by refining the grain structure[6].One such parameter is preformed shape, which is optimized by using FE Simulation[7].Numerical simulation techniques is used for verification of voids evolution while forging operations[8, 9].Shape optimization of work piece is done using the equivalent static load for forging process[10]. Influence of the mould design on the solidification of heavy forging is done using numerical simulation[11]. There are different software tool and numerical techniques available for optimizing the processes including DEFORM 3D, AFDEX, FORGE, STATISTICA, ANSYS, FEM, Monte Carlo method and many other methods[12–16].

## III. METHODOLOGY

### A. *Simulation Procedure*

The steps are followed in the present analysis is as depicted in Fig. 1. Preliminary stage part geometry is considered for the analysis and then CAD model is developed using UG-NX software,based on the model, suitable dies are designed. Depending on the model selected and its functional material is selected in such a way that the part can operate in its operating condition. With respect to the material composition and the property for the given product, die material is selected. Once the model is created, forging simulation is carried out by using the forging simulation software called AFDEX (Advisor as friend for Forging Design Experts). After running the simulation, if there are any errors or defects found, corresponding changes are made in die and/or in billet shape and size. Changes can easily be implemented in design stages to improve the quality of final product. This process is continued till the minimal defects are achieved. After getting the least defects through the simulation, the product goes into the CNC machine for its production. The part drawing of the spanner is considered for the analysis is shown in Fig. 2.

B. *Modeling in Unigraphics NX8.0*

One of the preliminary tasks in forging design procedure is the conversion of theavailable machined part data into forged part data. In the process of conversion, the necessary forging envelope, corner and fillet radii and appropriate draft angles are addedto each part cross section. The conventional conversion of the machined part data into forging data requires a large amount of valuable time. In the present CAD procedure, the process of conversion is largelysimplified by making use of the interactivity with the graphic screen. This procedure can be applied to a large number of forging sections and the data required to do this conversion have been saved. The cross section is obtained by 3-D machined part geometry. This cross section needs to be modified to confirm the process limitation, which involves selection of the parting lines, addition of machining and draft allowances, and fillet and corner radii. The selection of these parameters is critical for obtaining defect free forgings.

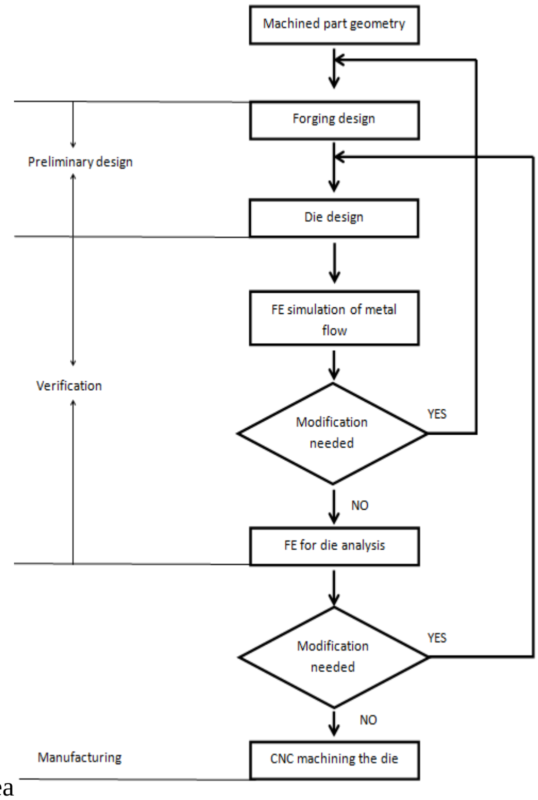


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Fig.1 Flow diagram of a simulation procedure

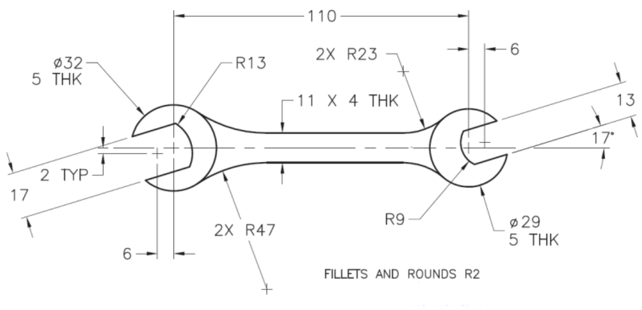



Fig.2 Detail drawing of a spanner

Table 1 Composition of **Element Weight %**

| AISI Number | DIN 1.4401 |
|---|---|
| C | 0.08 |
| Mn | 2.00 |
| Si | 1.00 |
| Cr | 16.0-18.0 |
| Ni | 10.0- 14.0 |
| P | 0.045 |
| S | 0.03 |
| Mo | 2.0-3.0 |

Table 2 Property of DIN 1.4401 Rolled Stainless Steel

| AISI Number | DIN 1.4401 |
|---|---|
| Young's Modulus | 159250 MPA |
| Poisson's Ratio | 0.3 |
| Density | 7850 Kgm/m$^3$ |
| Coefficient of Thermal Expansion | 1.8007E-5 /° C |
| Forging Temperature | 900°-1100°C |

The selection of this angle depends on the forging material, the type of forging equipment and the complexity of the forging. The next modification to the cross section is the elimination of all sharp comers through comer and fillet radii. These radii reduce stress concentration affect, die fill and improve die life. The value of the corner radii have been chosen as 1.5 mm and for fillet radii as 2 mm. Machine allowance of 2 mm is added while simulating for all sides of the component. But for manufacturing purpose the allowance is added depending on its physical structure of the component.

In UG- NX 8 software tool the orientation should be made such that when the part is loaded to the AFDEX software using .STL files the orientation should be in Y- direction as the load applied would be in this direction. It is even possible to orient the parts within the AFDEX software but to avoid the complexity and to make it easier, it is oriented in NX 8 software such that the lower die comes first followed by the billet and on top upper die all oriented in Y-direction. Once the dies and billets are designed the parts are saved individually as '.STL' file extension. The saved .STL files exported to AFDEX software library. The parts are loaded with several parameters as enlisted in the Table 1 & 2.

## IV. ANALYSIS AND OPTIMIZATION OF FORGING PROCESS

### *A. Analysis of the forging process*

Forging process is generally divided into open die forging and closed die forging. Figure3 represents the open die and closed die forging. Billet is pressed to required shape by the application of force. Preformed billet place an important role as it help in reduction of the forces and also helps to save the material. Usually preformed billet are produced using the open die forging or rolling operations. In this paper spanner is considered for the design, the billet is preformed to the required shape using the rolling operation. The preformed billet is obtained as shown in the Fig. 4.

### *B. Optimization process of forging using the equivalent static loads for the displacements*

In this work, Equivalent Static Load(ESL) method is considered for the simulation for optimizing the forging process parameters [10]. ESL for the displacement of static load linear analysis which generate the equal nodal displacement under a dynamic load at an

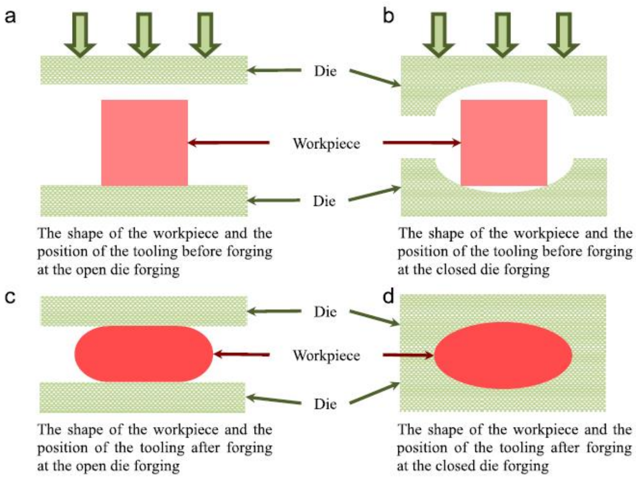



Fig 3: Schematic representation of the forging [10]

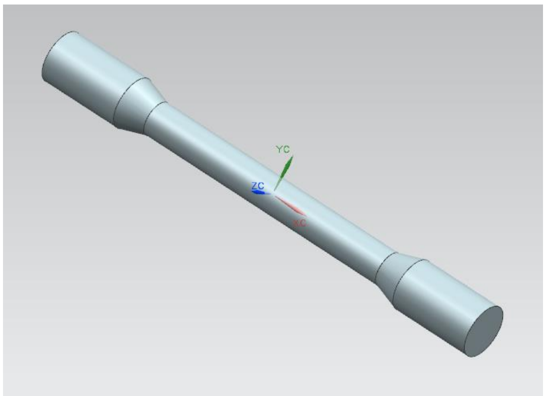


Fig 4: Preformed billet using the rolling operation

arbitrary time of nonlinear dynamic analysis. The governing equation for nonlinear dynamic analysis is

$M(b)Z''_N(t)+C(b)Z'_N(t)+K(b,Z_N(t))Z_N(t)=f(t)$
4.1

where, ($t=t_0,t_1,\ldots t_l$)M is the mass matrix, C is the damping matrix, K is the stiffness matrix, Z'' nodal acceleration vector, Z' nodal velocity vector and the constant L is the total number of time and steps for the required points. Steps that are to be adopted for multiple loading conditions used in linear response optimization process are as follows;

(1) Set the values of initial variables and parameters, b(k)=b(0), where k=0.
Evaluate the displacement and exercise some nonlinear dynamic response analysis for final stage.

(2) Calculate the equivalent static load for the displacements $t_l$ of nonlinear dynamic analysis
$f^f_{eq}=K_L Z^f_N$ ($t_l$-->f)

(3) Optimization static response should be solved.
$b^{(k+1)} € R^n$
for minimization $f(b^{(k+1)})$
subjected to $K_L(b^{(k+1)})z^f_L=f^f_{eq}(f=l)$
$g^f_u(b^{(k+1),}z^f_L) \leq 0$ (u=1,2,…m)

$b_v^l \leq b_v \leq b_v^u$ (v= 1,,…., n)
In linear static response optimization process, external load and lower upper bounds are used respectively.

(4) Update the result and then terminate the process.

The flow chart for the process is as shown in Fig. 5.

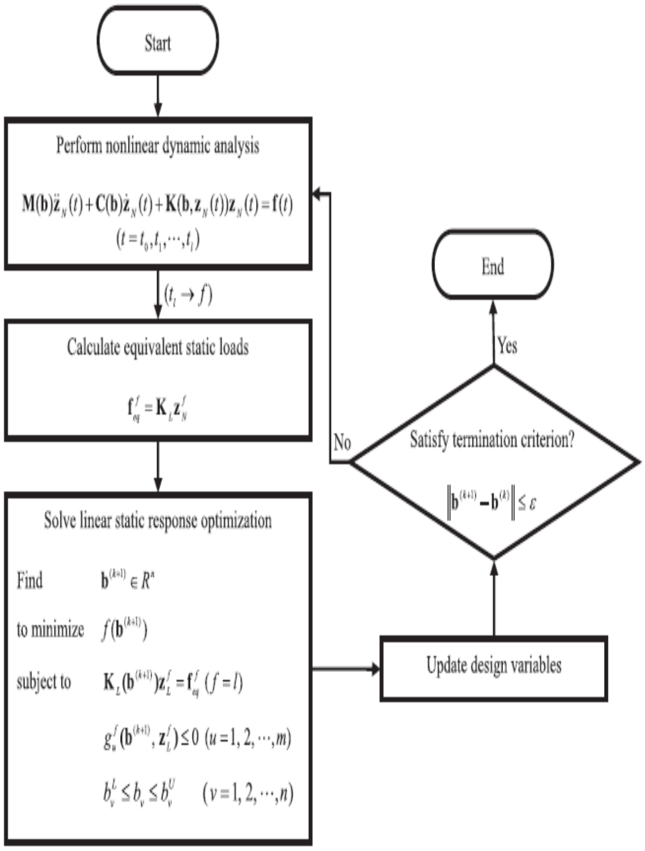
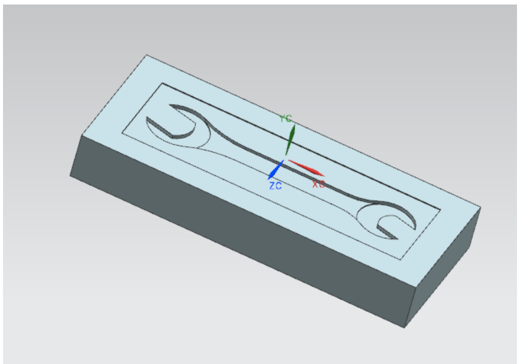
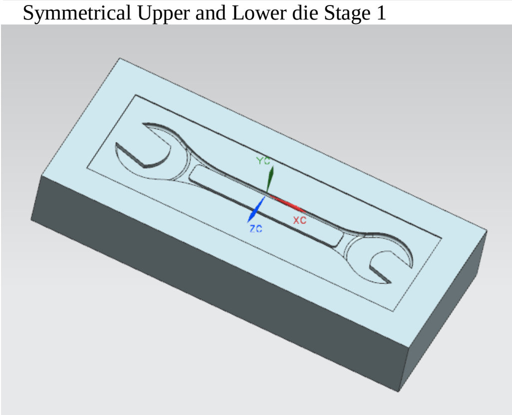



Fig 5: Optimization process using the ESL for the displacement [10]

The proposed method is to satisfy the forging process in optimizing the effective strain conditions. Equivalent static loads cannot generate the same strain effect on both linear and nonlinear analysis. Displacement vector for linear stiffness matrices are different, while for nonlinear it is same. Nodal displacement vector can be calculated from linear static analysis. Von-mises stress and strains are calculated from analyzing the two constructive equations. Figure 6 shows the 3-D model of the upper die and the lower die using the proposed technology.




a. Symmetrical Upper and Lower die Stage 1




b. Symmetrical Upper and Lower die stage 2

Fig 6: 3D model of Upper die and lower die profile

## V. SIMULATION

The upper die movement leads to metal flow of pattern into the die cavity and flash is studied through the simulation process using the AFDEX metal forming simulation environment. The Table 3 presents the parameter selected for the simulation. The models are used as stated in the methodology part which involves loading the part from the NX 8.0 and converting the file to '.STL' format to the AFDEX software. Initial stage of simulation leads to the 3D tetrahedral meshing as shown in the Fig 7.

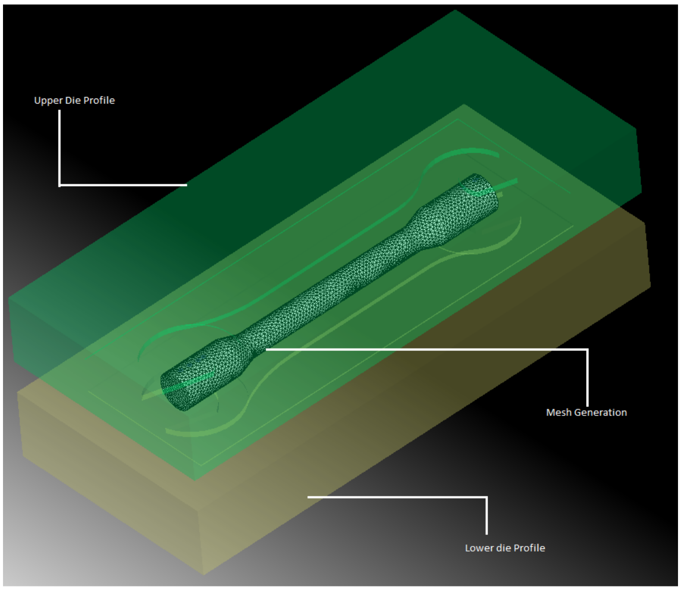


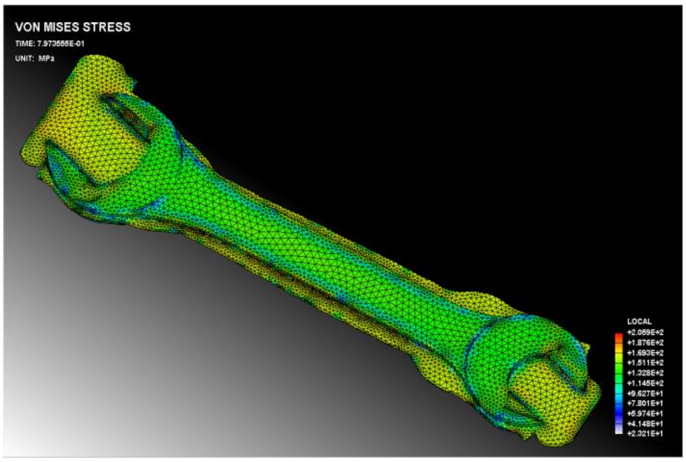

Fig 7: Mesh Generation during simulation process

Table 3 Forging Parameters selected for Simulation

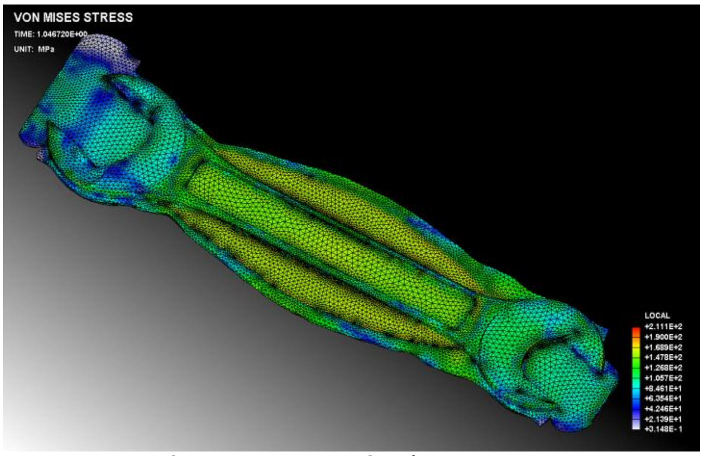
| | |
|---|---|
| Type of forming | Hot Forging |
| Type of Simulation | 3D with flash |
| Type of analysis | Flow analysis |
| Deformation | Rigid Plastic |
| Billet material | DIN 1.4401 rolled stainless steel (T=20°-1100°C) |
| Translational velocity | 15 mm/sec in y direction |
| Lubrication used | Soap cold(Steel) |

## VI. RESULTS

Shape optimization is performed using the ESL technology for effective stress and strain as stated in the methodology. After performing the simulation, the result for the Von-Mises stress is obtained as shown in Fig. 8. It can be observed from both stage one and stage two, stage one shows a uniform distribution of stress and at stage 2, the web have uniform distribution as the stage two concentrates more on forming impression on the web




a. Von Mises Stress values for stage1

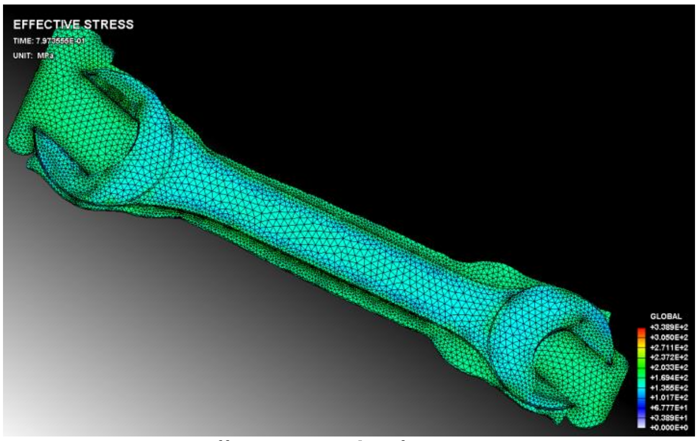



b. Von Mises Stress values for stage 2

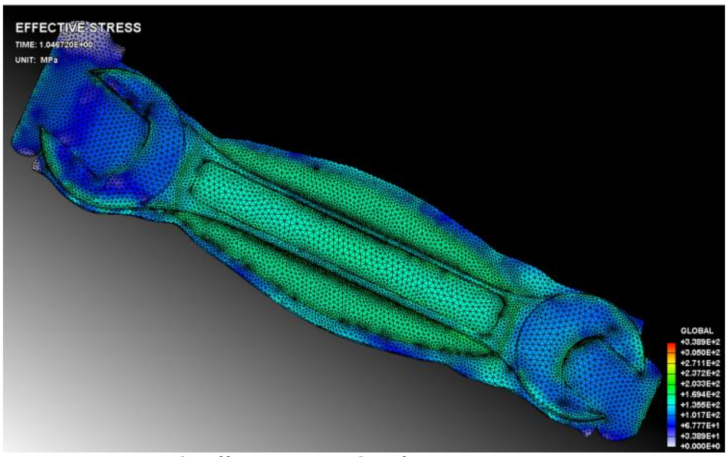
Fig 8: Von Mises stress values for Stage1 and stage 2

Similarly Fig. 9 shows the effective stress distribution for the stage one and stage two which is uniform and also it can be observed thatmaximum stress achieved is 338.9 MPA in stage one and stage two as a result of forging forces for shape deformation. Figure 10 shows the effective strain of work piece at stage one and stage two. It can be seen that there is uniform distribution of strain throughout the component except at few places of spanner head. In Fig. 11, it can be observed that the flash is not much and it do not overflow from the flash gutter nor there are any cracks identified in the workpiece.

The critical component is completely filled and there are no under fill in the head region [Fig. 12]. There are few spots below the head region and it is in the allowable region of the final required component.

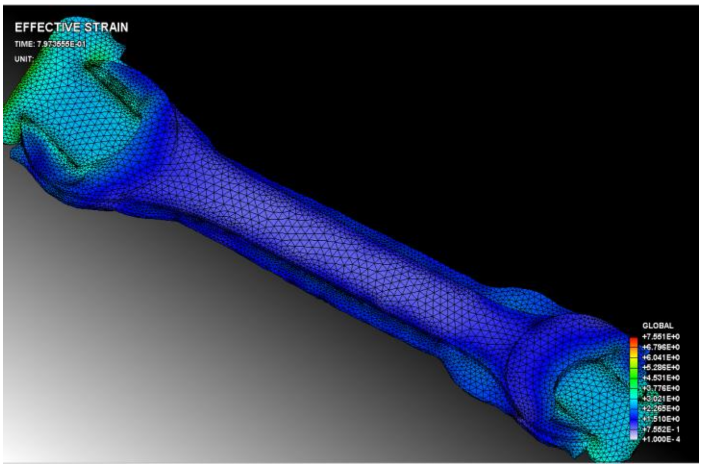



a. Effective stress values for stage 1

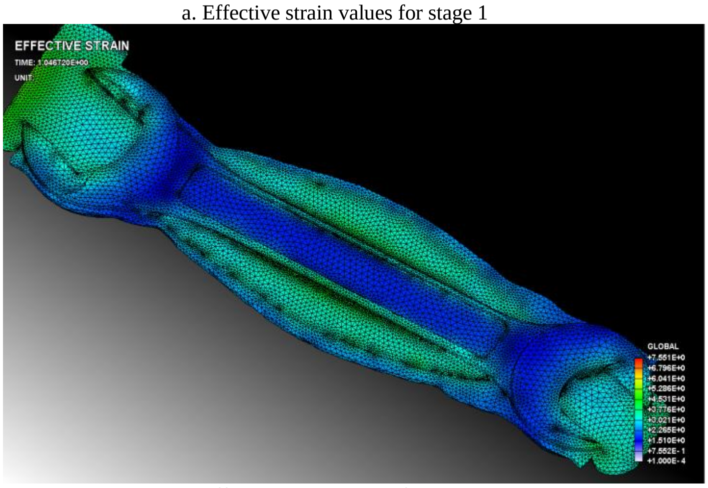



b. Effective stress values for stage 2

Fig 9 Effective stress values for stage 1 and stage 2 for model




a. Effective strain values for stage 1




b. Effective Strain values for stage 2

Fig 10 Effective strain values for stage 1 and stage 2

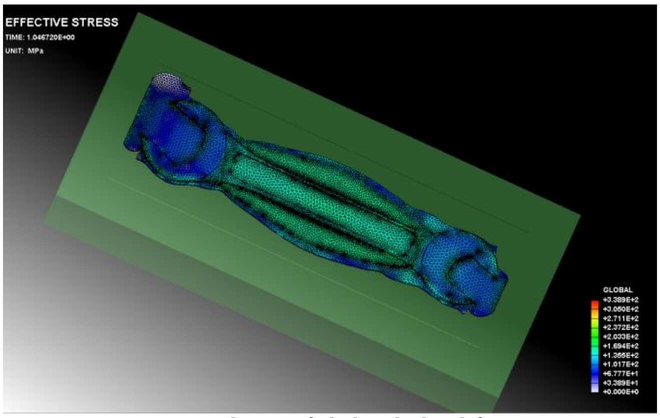



Fig 11 Reduction of Flash and other defects

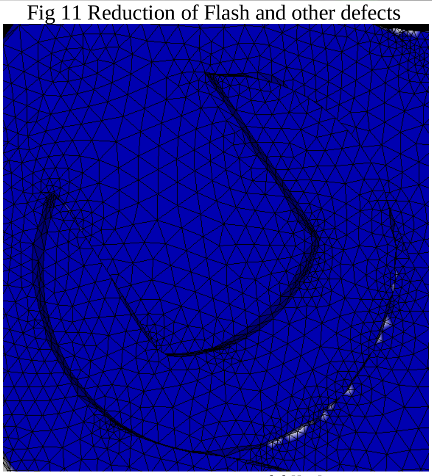


Fig 12: Representation of filled areas

## VII. CONCLUSIONS

It can be concluded that the forging process parameters will have a major influence on the quality of the components produced through forging process. In forging process, required final shape is very difficult to obtain when the initial conditions are not modified because the initial shape of the work piece influences on the final shape. In conventional method it is very difficult to get accurate shape optimization for forging process. Hence equivalent static load shape optimization process should be preferred; it reduces both time and cost of the forging process.It can be applied for both linear and nonlinear dynamic response optimization process. In every stage of simulation, optimization of workpiece should be done, in order to carry out equal distribution of effective strain. In forging process even distribution of strain and material property are very important criterion.Influence of forging parameters can be done by many tooling techniques, different software tools can be adopted for simulation. However optimization of different design variables needs to be analyzed.

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