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# Design and Simulation of Forging Die Towards Improving Life of Closed Die

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**_Abstract_**

*Forging is the metal forming process which is used for forming complex shaped component with geometrical accuracy. More than fifty percent of the forgings are processed through this way. Forged components required in many engineering sectors, most of them in the automotive sector. The majority of the safety critical component and load bearing structural components are process through it. By using forging process production of complex component is faster with less material waste. It is very difficult to do number of experimental testing and production trials are being done in the industry in order to develop a strongly formed manufacturing process of complex component. Such practices involve huge investment in tools and raw materials as well as valuable time and efforts. To take the virtual trials and simulation-based design finite element method is best suitable tool. At lower cost it would lead to improvement in life of die. As a sample case, a real-life automotive driveline component like yoke, is taken for investigation. Based on finite element analysis simulation is dine in Simufact. Different trials were done by using a forging press machine and validated against those predicted in Simufact software. The relation between them was found to be similar and satisfactory. A yoke is used in the propeller shaft of heavy vehicles is considered as a sample component. The research involves analyzing the initial effects of (1) workpiece temperature, (2) friction, (3) die temperature, and (4) Flash Thickness were examined. To obtained the results the forging process was design in PTC Creo 3.0, simulated in Simufact Software and experimental setup and examined using two-level full factorial design of experiments (Analyzed with Minitab and MS. Excel). The product reviewed was at the Varsha Forging Waluj, Aurangabad.*

**Keywords:** Die life improvement, Simufact, ANOVA, Taguchi, modeling

## INTRODUCTION

All manufacturing processes, forging can be considered as one has been constantly revolutionizing and evolving along with man since the conception of fire. Metal forming is sign of technology, wealth, and power. Today's outputs of automotive, aerospace, and industrial products are controlled by the countries that are producing the majority of accurate metal parts using the most cost-efficient process control [1].

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### Forging Processes

Forging is performed by applying compressive forces, through two dies, to a metal (work-piece) above the yield strength resulting in plastic deformation of the billet [2]. This process refines the grain structure of the metal, removes any gas pockets, or voids, improves chemical segregation, mechanical and physical properties, and therefore increases reliability and consistency. By manipulating the process and output properties, parts are held to exceptionally tight tolerances.

 

These parts require only a few processes to produce a finished product. With these exceptional controllable properties and versatility, it is easy to see the importance of forged parts to almost every facet of industry [3].

**Forging Future**

As the technological trend of producing smaller, less expensive, and more reliable products continues, the forging industry, which produces the components, will continue to grow. Forging is most reliable and environmentally friendly process [4]. The future of forging is an energy efficient, automated process with little scrap, and a much higher turnover rate. It will be safe, clean, and environmentally friendly. To achieve this, research in improving the empirically driven processes used today must be preformed of the most adopted metal forming process. Superior micro structure makes forging process attractive [5].

**Problem Statement**

Die failure contributes to increase in production costs. Due to micro cracks generated in forging die it will reduce the life of forging die. The defects occur in part was major problem in industry due to die life reduced. The ability to predict failure of forging dies is important to any industry that which forges parts, or incorporates forgings into part design.

From prediction die temperature, temperature of workpiece, friction can be optimized to obtain the most efficient and cost-effective manufacturing process possible.

## METHODOLOGY

1. Study of different forging process and process parameters of forging die.
2. 3D modeling of forging die and component for various values of parameters using creo3.0 software.
3. Simulation of model to verify the predicted and experimental results.
4. Use a multi-factor three level design of experiments to determine the effects and interactions of varying parameters on process outputs and accurately determine die life.

**Product Die Design**

The component which is formed during forging process is yoke. Model of component and dies which is design in PTC creo3.0 as shown in Figure 1(a) and b).

## DESIGN CONSIDERATIONS

**Determination of Billet Size for the Experiment**

Study of machine drawing component Sand model was generated using the solid modelling software. Creating 3D model by using Creo 3.0. The next step is to decide the input billet size for the processing. Refer data which is generated from model, we can find the followings:

1. Finished component net weight = finished component volume (from model) x density
   Volume of forging =20962.1 $mm^3$
   Density of material = $7.85\times10^{-6}$ $kg/mm^3$
   Therefore, the net weight of the component is 0.165 kg
2. Forging component net weight = volume of the forged component (from model) × density
   Volume of forging = 29949.3 $mm^3$
   So, the net weight of the component is 0.235 kg
3. Flash loss = (15 to 20) % of the net forging weight
   = 0.65kg (considering the upper limit)
4. billet weight = Net weight of the forging + Flash loss
   =0.305 kg
5. Approx. yield of production = (Net weight of the forging/input weight of billet) × 100
   = 83.4 %

 

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For complex shapes of forging generally preferred round, square, rectangular shaped billets. Considering round billet with rounded dimension:

- Diameter 25 mm, length 73 mm weight 0.305 kg
- The derived input billet dimensions are diameter 25mm, L 73 mm.

**Figure 1.** (a) 3D model of final machined component, (b) Die design stage.

**Actual Experimental Setup**

The actual trial was taken at the forging division of Varsha forging located at B7 MIDC Waluj, Aurangabad. Machine facilities present in plant for experimental work.

1. Mechanical cranked press of capacity 800T was used for the forging operation. In following image, the setup is shown in Figure 2.
2. For manufacturing of forging dies VMC Vertical Milling machine was used.

The method is used for analysis is simulation in Simufact software. In simulation predicts the desired behavior of component and die based on mathematical and computational models. In this experimental model finite element formulations are used [6].

Verification refers to checking of formed model in forging. Whereas validation refers to checking of the exact model to predict the real-life situation. The validation of the initial results is found essential for:

- Assume value and input values are should be justified or correct.
- Correlation between the actual value and predicted value the actual findings

To validate the model, an actual trial was conducted on the press machine. The input parameters were measured during the process. Input values for the simulation model, along with some suitable assumptions.

 

**Figure 2.** Mechanical screw press with automated induction heating arrangement validation and verification of experimental procedure.

The validation criteria were set as:

- Mapping of generated flash pattern and its dimensions at the last forging stage. (i.e., finisher stage)

In the actual finding the component material is processed through two stages of forging. (blocker and finisher). Similarly, trial is performed using SIMUFACT software. The generated flash pattern in both the actual and the simulation result was found identical and similar. The metal flow pattern is also found similar. The comparison between actual and predicted flash pattern is same which is observed in Figure 3.

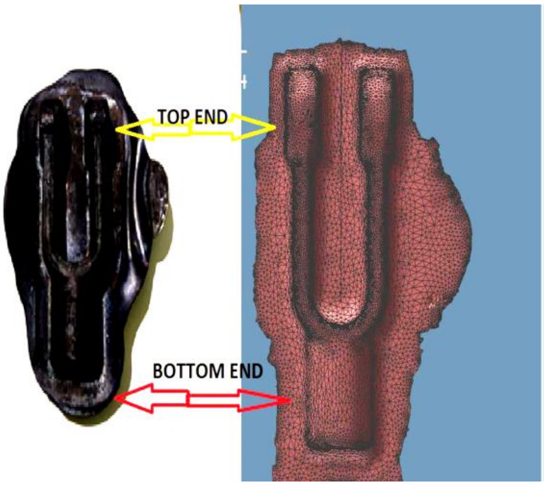


**Figure 3.** Comparison between actual vs. Predicted flash pattern; different views.

 

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### *Actual Component; Simulation Prediction*

It can be observed from the Table 1 that there exists a variation of 4.5% between the actual findings and predicted value. Considering the complex geometry, two stage forging and the amount of metal flow involved, this correction can be considered good to proceed for further experimentation.

**Table 1.** Dimensional validation table for flash width/pattern (actual/predicted).

| S.N. | Region of Observation | Actual trial findings | | Predicted by simulation | | Variation in % w.r.t actual trail findings |
|---|---|---|---|---|---|---|
| | | *Observed values (mm)* | *Mean* | *Observed values (mm)* | *Mean* | |
| 1 | TOP END (Flash generated) | 7.2<br>7.5<br>7.3<br>8.1<br>8.5 | 7.7 | 6.954<br>7.854<br>7.12<br>7.52<br>7.56 | 7.4 | 4.14% |
| 2 | BOTTOM END (Flash generated) | 7.5<br>7.1<br>7.7<br>8.2<br>8.5 | 7.8 | 6.887<br>6.995<br>7.216<br>7.92<br>8.12 | 7.42 | 4.87% |

From the Table 2, its observed that predicted weights of model and actual weight is similar.

**Table 2.** Dimensional validation table for component weights (actual/predicted).

| S.N. | Weights (kg) | Predicted model weight (kg) | Actual finding weight (kg) |
|---|---|---|---|
| 1 | Cut wt. | 0.280 | 0.300 |
| 2 | Forging wt. | 0.218 | 0.240 |
| 3 | Machining wt. | 0.141 | 0.151 |
| 4 | Flash wt. | 0.054 | 0.05 |

## RESULT AND DISCUSSIONS

Simulation is caried out to analyze the metal flow in die cavities and checked forging load and effective stress is required to deform the metal. Grey relation analysis is used to determination of optimal parameter.

### Design by Simulation

Simulation is the process of conducting experiments based on computer, founded on mathematical and logical modelling techniques. The finite element-based modelling is the most used simulation technique for engineering analysis. Design by simulation is a systematic approach where the objective is to perform virtual iterative trials to understand the effect of parameters on the output and the overall behavior of the system as a whole [7].

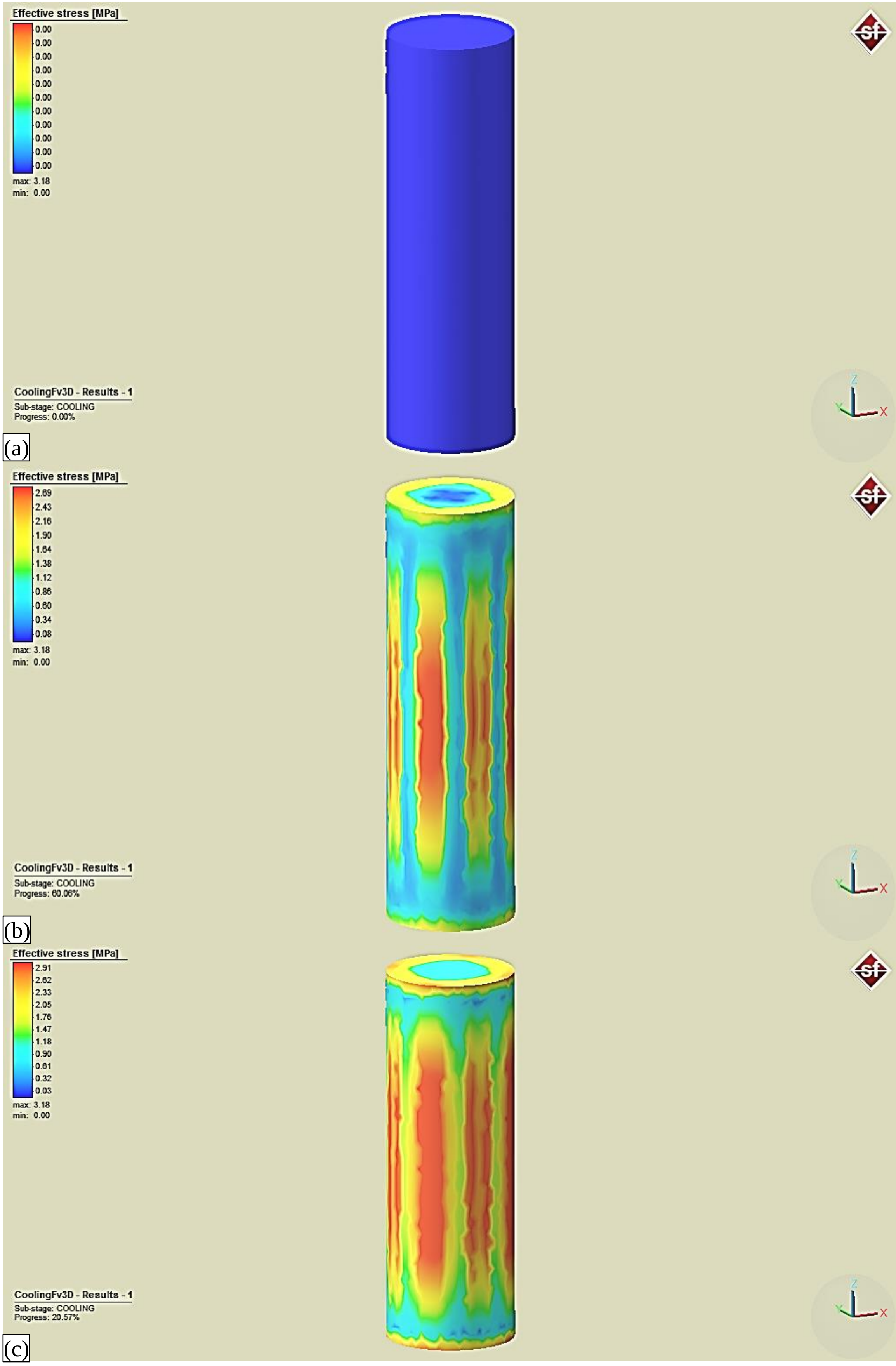
### Stage-wise Simulation Results

The simulation results are interpreted by using post-processor. The output parameters can be customized by understanding of the process. The stage wise deformation and the resulting metal flow behavior are shown in Figures 4–6. It shows the transformation of billet geometry; into the complex shaped component along with the effective stress distribution during the process [8, 9].

The result shows that, the metal flow at the blocker stage is maximum whereas it is minimum at the finisher stage.

The predicted load stroke curve and temperature distribution for the blocker stage is shown as a sample an upsurge in temperature (to 1150°C) is observed, at the end of deformation process from initial input value (to 1000°C). This is the conversion of mechanical work into heat energy, during the process of material deformation [10].


Effective stress [MPa]
max: 3.18
min: 0.00
CoolingFv3D - Results - 1
Sub-stage: COOLING
Progress: 0.00%
(a)
Effective stress [MPa]
2.69
2.43
2.16
1.90
1.64
1.38
1.12
0.86
0.60
0.34
0.08
max: 3.18
min: 0.00
CoolingFv3D - Results - 1
Sub-stage: COOLING
Progress: 60.06%
(b)
Effective stress [MPa]
2.91
2.62
2.33
2.05
1.76
1.47
1.18
0.90
0.61
0.32
0.03
max: 3.18
min: 0.00
CoolingFv3D - Results - 1
Sub-stage: COOLING
Progress: 20.57%
(c)

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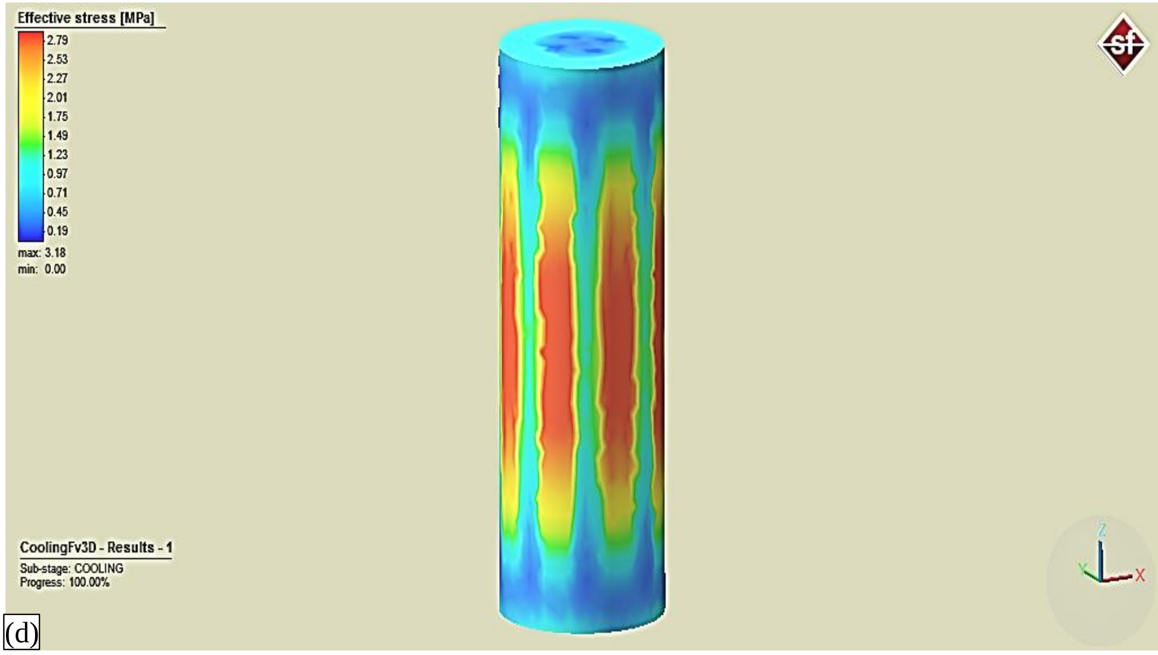
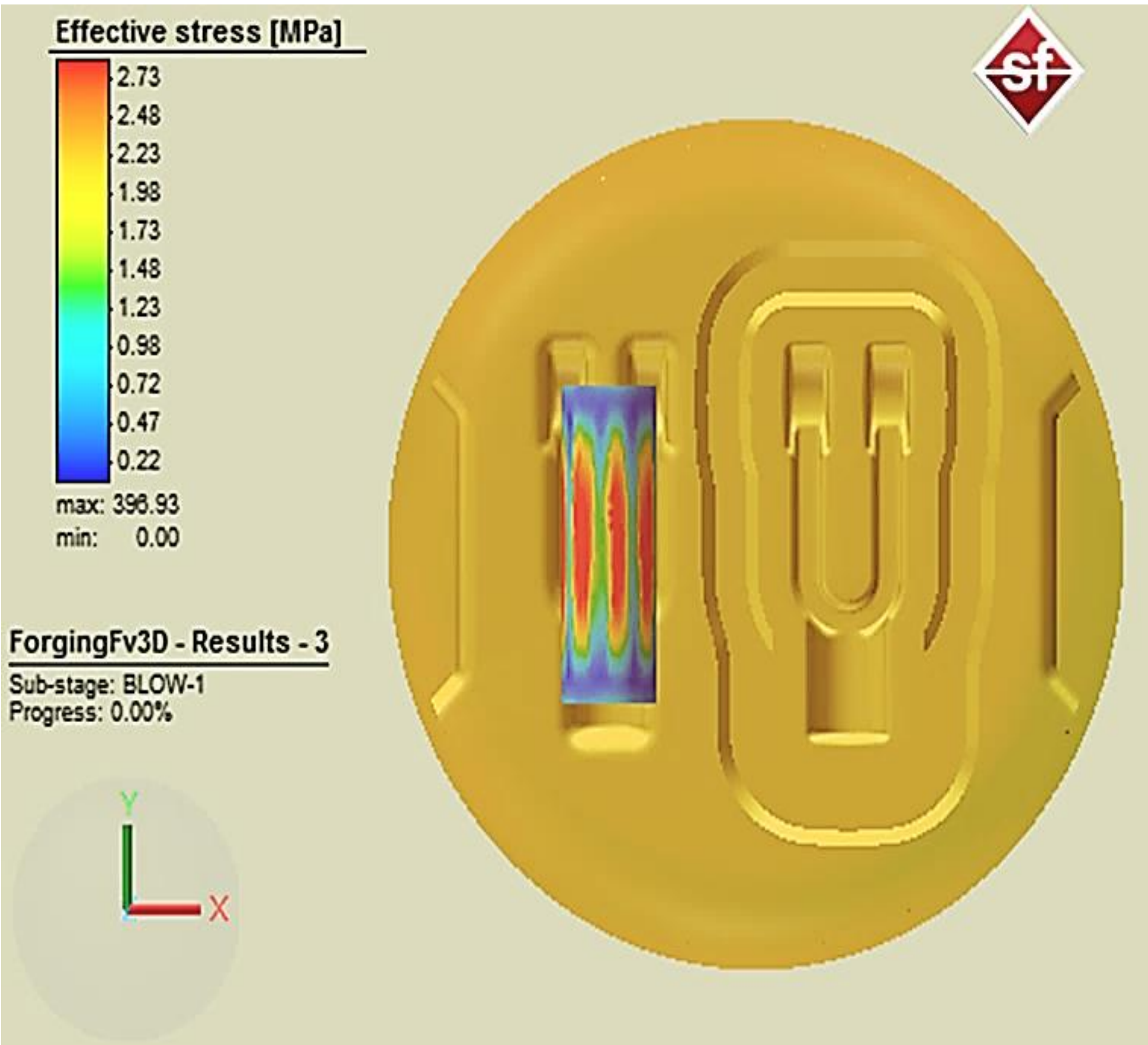
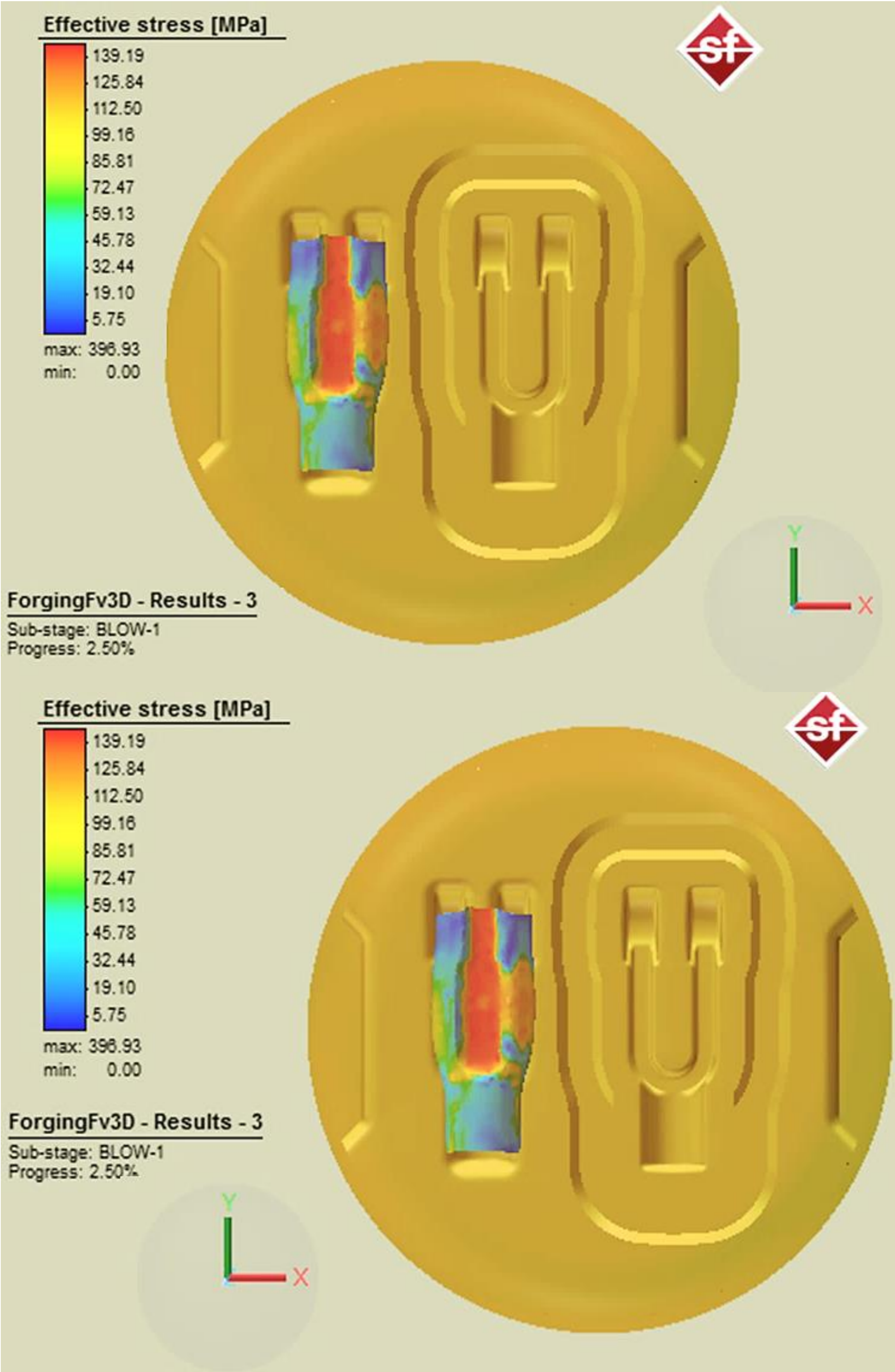
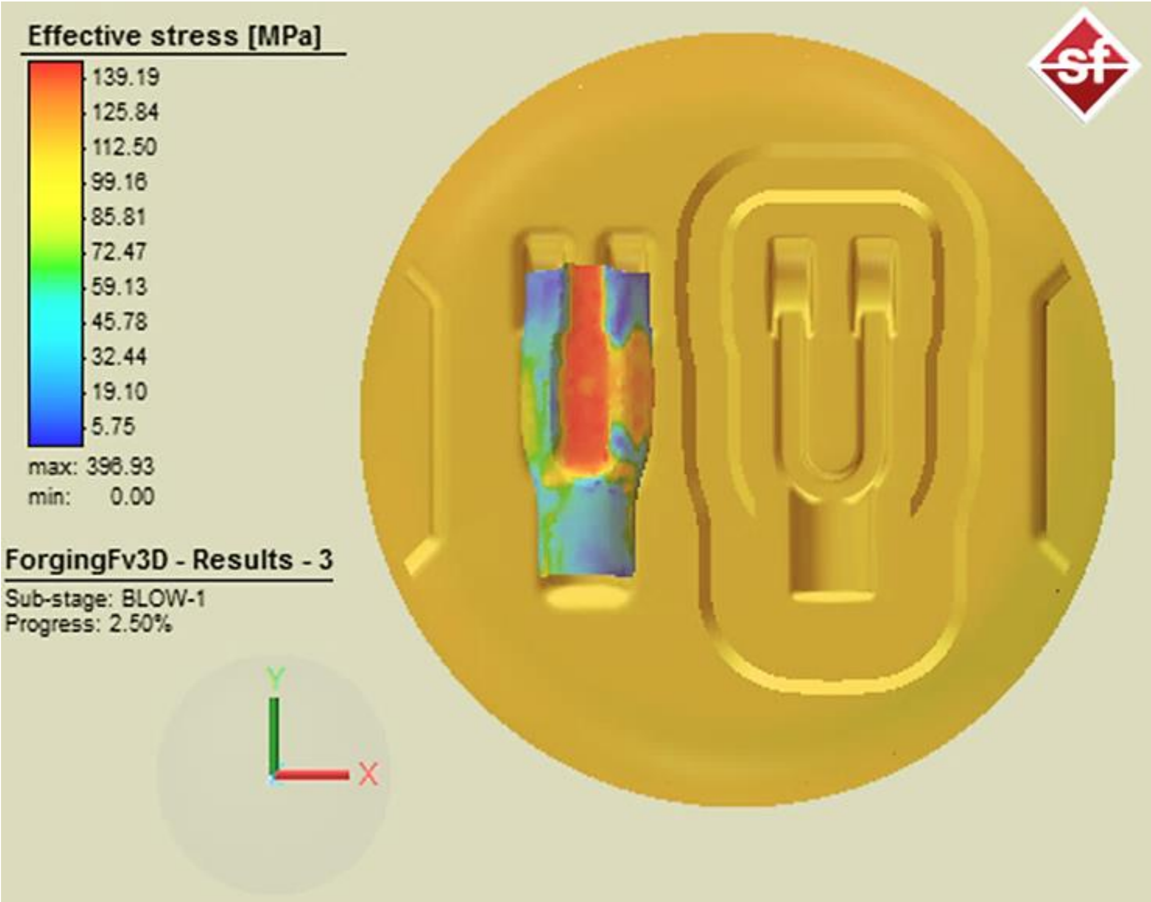



(d)

**Figure 4.** (a-d) Step-wise simulation result of workpiece; Effective stress plot.




Effective stress [MPa]
139.19
125.84
112.50
99.16
85.81
72.47
59.13
45.78
32.44
19.10
5.75
max: 396.93
min: 0.00
ForgingFv3D - Results - 3
Sub-stage: BLOW-1
Progress: 2.50%
Y
X
Effective stress [MPa]
139.19
125.84
112.50
99.16
85.81
72.47
59.13
45.78
32.44
19.10
5.75
max: 396.93
min: 0.00
ForgingFv3D - Results - 3
Sub-stage: BLOW-1
Progress: 2.50%
Y
X


Effective stress [MPa]
139.19
125.84
112.50
99.16
85.81
72.47
59.13
45.78
32.44
19.10
5.75
max: 396.93
min: 0.00
ForgingFv3D - Results - 3
Sub-stage: BLOW-1
Progress: 2.50%
Y
X


Effective stress [MPa]
182.48
170.59
158.70
146.80
134.91
123.02
111.13
99.24
87.35
75.46
63.57
max: 396.93
min: 0.00
ForgingFv3D - Results - 3
Sub-stage: BLOW-1
Progress: 12.55%
Y
X

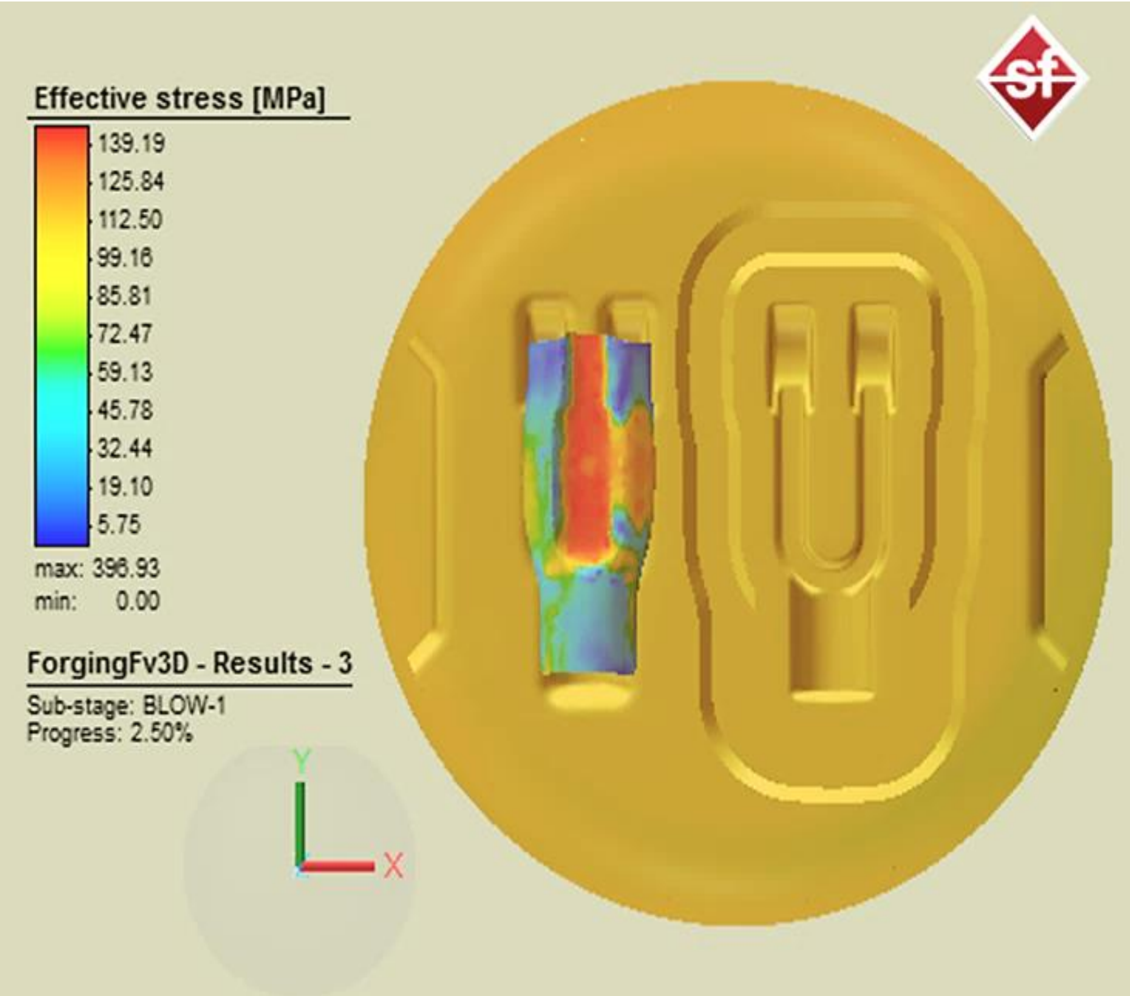
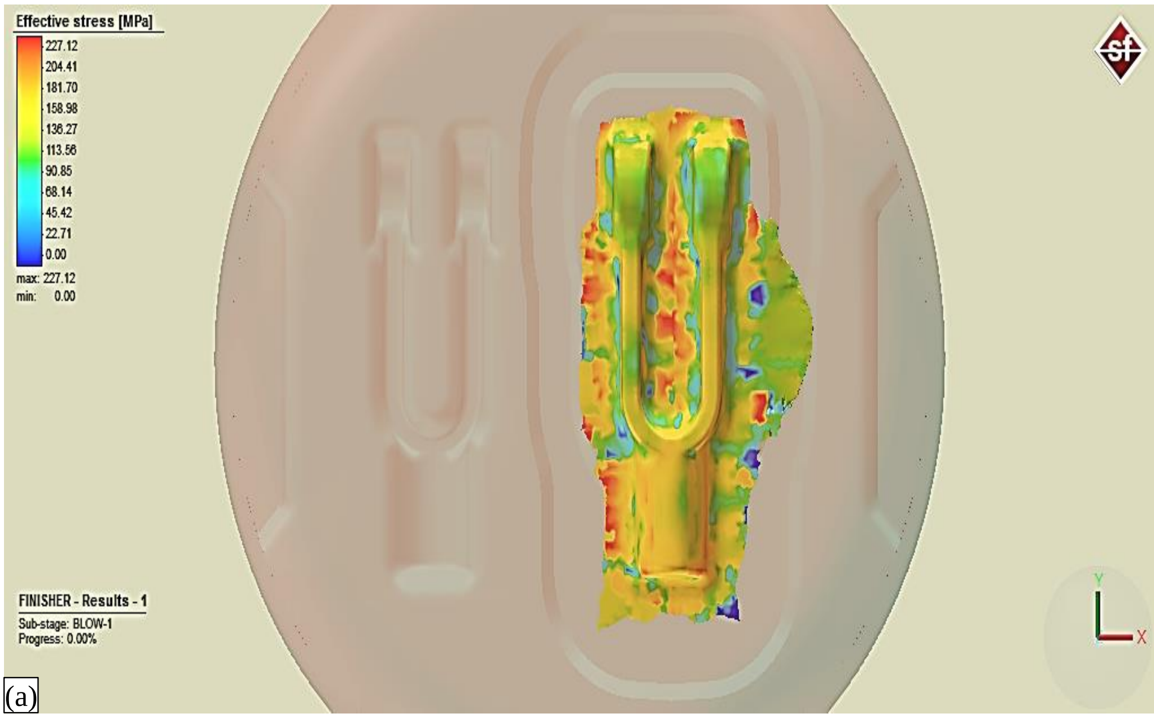



**Figure 5.** Step-wise simulation result of blocker; effective stress plot.



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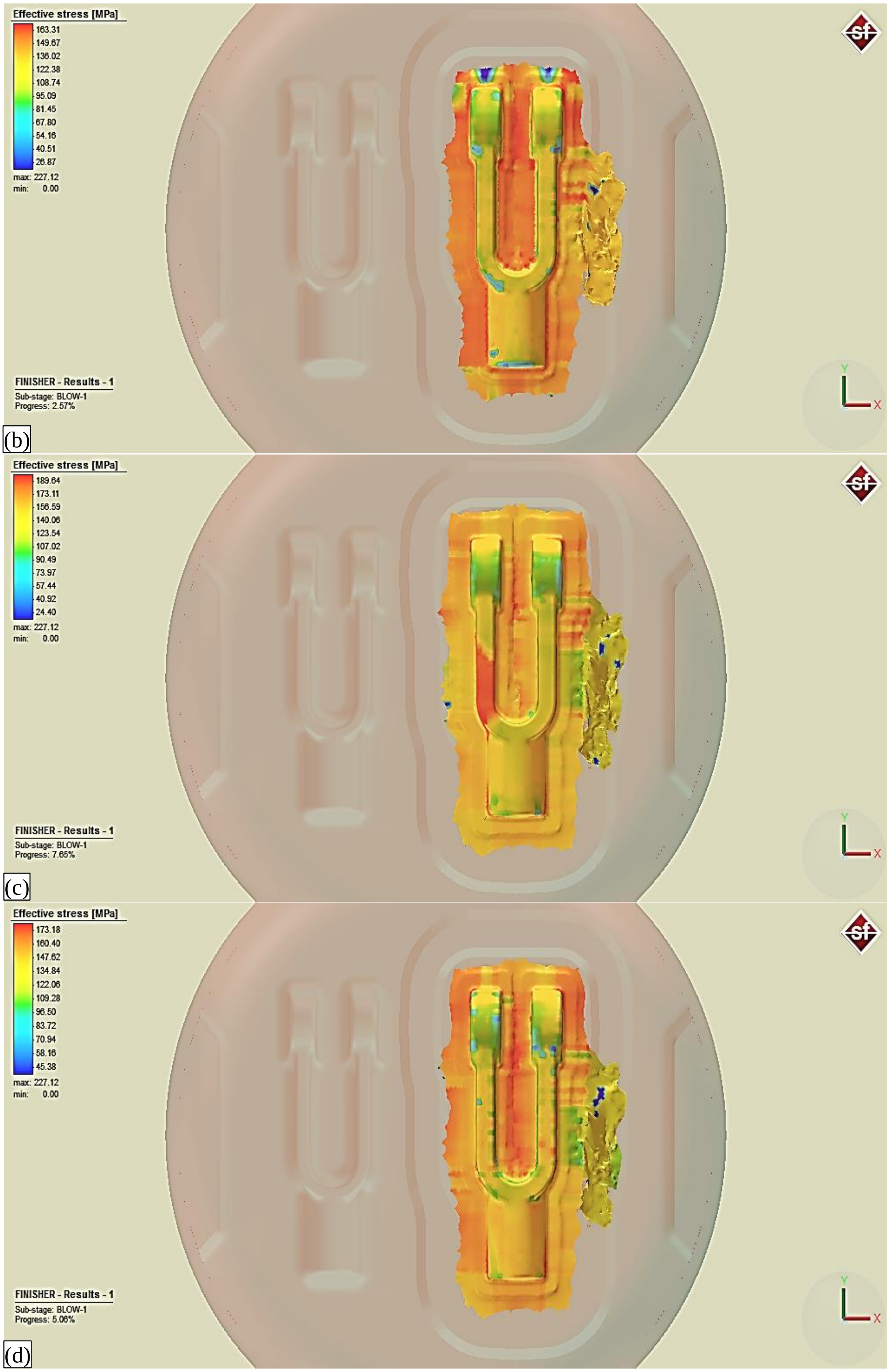


 

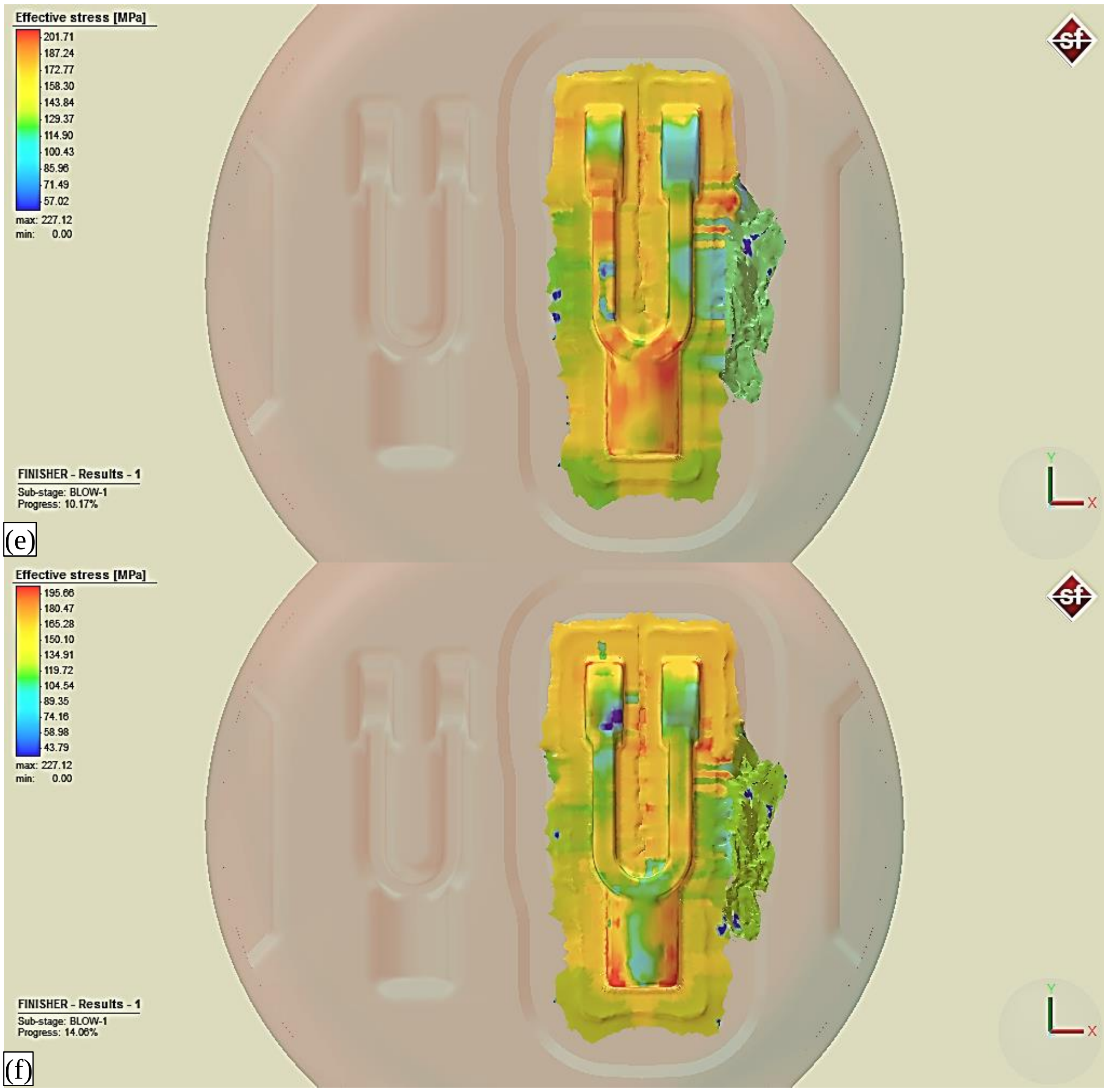


**Figure 6.** (a-f) Step-wise simulation result of finisher; Effective stress plot.

Billet is round which used for forming and bottom die and finished component as shown in Figure 7.

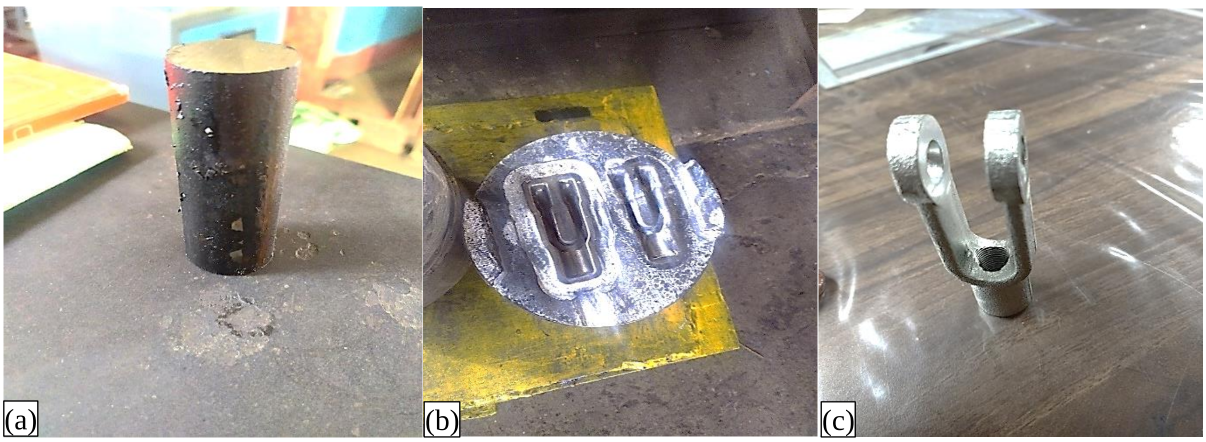


**Figure 7.** Actual set up showing billet and die used for experimental trial. (a) Input billet material, (b), Blocker and Finisher bottom die, (c) actual component without flash.

 

**Experimental Details Aiming Design of Experiments:** A set of experiments with varying level of these parameters were planned via simulation to capture the effect on forging load and effective stress [12, 12]. The selected levels are as shown in Table 3.

**Table 3.** Process parameter and their level.

| Parameters | Level | | |
|---|---|---|---|
| Workpiece temp (°C) | 1000 | 1150 | 1200 |
| Die Temp (°C) | 200 | 200 | 250 |
| Friction | 0.6 | 0.8 | 0.7 |
| Flash thickness(mm) | 1.5 | 2 | 3 |

## Experimental Results

The summary of the simulation result is shown in Table 4.

**Table 4.** Experimental finding of forging load and effective stress at different levels of input parameter.

| RUN | Workpiece Temp (°C) | Die Temp | Friction Factor | Flash Thickness | Blocker | | Finisher | |
|---|---|---|---|---|---|---|---|---|
| | | | | | *Forging Load (kN)* | *Effective Stress (MPa)* | *Forging Load (kN)* | *Effective Stress (MPa)* |
| 1 | 1000 | 200 | 0.6 | 1.5 | 13906.2 | 239.858 | 749.05 | 239.842 |
| 2 | 1000 | 200 | 0.8 | 2.0 | 12500.7 | 351.52 | 842.30 | 335.5 |
| 3 | 1000 | 250 | 0.7 | 3.0 | 1433.2 | 299.6 | 801.20 | 278.2 |
| 4 | 1150 | 200 | 0.8 | 3.0 | 1460.6 | 396.932 | 507.02 | 227.121 |
| 5 | 1150 | 200 | 0.7 | 1.5 | 1389.2 | 125.23 | 503.50 | 271.5 |
| 6 | 1150 | 250 | 0.6 | 2.0 | 15299.3 | 130.51 | 643.20 | 321.2 |
| 7 | 1200 | 200 | 0.7 | 2.0 | 1524.2 | 345.2 | 841.20 | 325.4 |
| 8 | 1200 | 200 | 0.6 | 3.0 | 1945.5 | 399.2 | 696.50 | 348.2 |
| 9 | 1200 | 250 | 0.8 | 1.5 | 20309.6 | 239.637 | 1023.50 | 237.92 |

## Grey Relational Analysis

The optimization of multiple performances characteristics using GRA includes the following steps:

1. Normalization of the experimental results
2. Determination of deviation sequences.
3. Determination of grey relational coefficient (GRC).
4. Determination of grey relational grade (GRG).
5. Determination of optimal parameters.

For finding grey relational grade, find normalized values and grey relation coefficient as shown in Table 5 and Table 6.

**Table 5.** Normalized values of experimental data.

| Exp. No | Billet temp | Die temp | friction factor | Flash thickness | Blocker forging load | effective stress |
|---|---|---|---|---|---|---|
| 1 | 1000 | 200 | 0.6 | 1.5 | 0.315289 | 1.457094 |
| 2 | 1000 | 200 | 0.8 | 2.0 | 0.384492 | 1.457094 |
| 3 | 1000 | 250 | 0.7 | 3.0 | 0.929432 | 1.457094 |
| 4 | 1150 | 200 | 0.8 | 3.0 | 0.928083 | 1.457094 |
| 5 | 1150 | 200 | 0.7 | 1.5 | 0.931599 | 1.457094 |
| 6 | 1150 | 250 | 0.6 | 2.0 | 0.246695 | 1.457094 |
| 7 | 1200 | 200 | 0.7 | 2.0 | 0.924952 | 1.457094 |
| 8 | 1200 | 200 | 0.6 | 3.0 | 0.904208 | 1.457094 |
| 9 | 1200 | 250 | 0.8 | 1.5 | 0 | 1.457094 |

**Table 6.** Grey Relational Coefficient (blocker).

| Exp. No | Billet temp | Die temp | friction factor | Flash thickness | Forging load | Effective stress |
|---|---|---|---|---|---|---|
| 1 | 1000 | 200 | 0.6 | 1.5 | 0.447904 | -0.16526 |
| 2 | 1000 | 200 | 0.8 | 2.0 | 0.477506 | -0.16526 |
| 3 | 1000 | 250 | 0.7 | 3.0 | 0.995686 | -0.16526 |
| 4 | 1150 | 200 | 0.8 | 3.0 | 0.993017 | -0.16526 |
| 5 | 1150 | 200 | 0.7 | 1.5 | 1 | -19.6117 |
| 6 | 1150 | 250 | 0.6 | 2.0 | 0.421975 | 1 |
| 7 | 1200 | 200 | 0.7 | 2.0 | 0.98688 | 1 |
| 8 | 1200 | 200 | 0.6 | 3.0 | 0.948063 | -19.6117 |
| 9 | 1200 | 250 | 0.8 | 1.5 | 0.34926 | -19.6117 |

**Table 7.** Grey Relational Grade (blocker).

| Exp. No | Billet temp | Die temp | friction factor | Flash thickness | Avg. Grade | Rank |
|---|---|---|---|---|---|---|
| 1 | 1000 | 200 | 0.6 | 1.5 | 0.141321 | 6 |
| 2 | 1000 | 200 | 0.8 | 2.0 | 0.156122 | 5 |
| 3 | 1000 | 250 | 0.7 | 3.0 | 0.415212 | 3 |
| 4 | 1150 | 200 | 0.8 | 3.0 | 0.413877 | 4 |
| 5 | 1150 | 200 | 0.7 | 1.5 | -9.30585 | 7 |
| 6 | 1150 | 250 | 0.6 | 2.0 | 0.710988 | 2 |
| 7 | 1200 | 200 | 0.7 | 2.0 | 0.99344 | 1 |
| 8 | 1200 | 200 | 0.6 | 3.0 | -9.33182 | 8 |
| 9 | 1200 | 250 | 0.8 | 1.5 | -9.63122 | 9 |

Table 7 shows highest grey relational grade, indicating the optimal process parameter set of Billet temp (1200), Die temp. (200) and Friction (0.7) and flash thickness (2.0) for the best multiple performance characteristics among the 9 experiments. Here the Experiment 7 has the highest rank so it is the Optimal Experiment value in Blocker that gives minimum amount of forging load and effective stress.

## CONCLUSIONS

In this work to study the metal forming behavior during closed forging die the reference sample automotive component which is used in vehicles is Yoke.

The effect of selected input parameters on forging load and effective stress is determined. Design of experiments in that Taguchi method is used to find best possible combination for the desired response

- The billet temperature, die temp, flash thickness and friction are found to have a significant effect on the forging load. Among the four, the temperature of the input billet is found to be the most significant parameter followed by flash thickness and friction factor, in that order.
- The forging die life prediction is valuable tool in the cost reduction, design, and optimization of forging dies for the forging industry.
- Analyzing complex metal forming characteristics in a closed die hot forging process. Finite element analysis is best.
- A best result is observed during validation of simulation output with actual manufacturing data, in terms of flash pattern and dimension prediction of component.

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