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A Case study for near net Shape – Flashless forging for full yoke (Sleeve Yoke OMNI)

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Abstract: *Forging is a metal forming process commonly used in industry. Forging process is strongly affected by the process parameters. In a progressive press forging process, an initial block of metal (billet) is compressed between two dies halves in each stage to produce a complex part. The shape of the initial billet is crucial in achieving the desired characteristics in the final forged part. The metallurgical property as well as the geometry of the final product are strongly dependent on the shape of initial work piece as well as on the perform shapes at each of the subsequent forming stages. The major issue, which restricts imparting large deformation to the billet are the tensile stress, which later results in cracking. Bulge is also undesirable from near net shape manufacturing point of view, as it will require secondary processing like trimming Traditionally, an experienced designer uses his or her expertise and design data handbooks for optimizing the initial billet shape. Design of the optimum preform for near net shape forging is a crucial step in the design of many forging products In this study, the same is arrived at using profile map, which is generated using the results of FE simulations of varying geometrical and processing parameters.It is shown that preform map offers a powerful tool for near net shape forging*

Keyword*: finite element ,preform, press forging; profile map; near net shape*

I. Introduction

1.1 In metal forming process, Net shape forging can be defined as the process of forging components to final dimensions with no post forging machining necessary. Near-net shape forged components, on the other hand, are forged as close as possible to the final dimensions of the desired part, with little machining or only grinding [1] after forging and heat treatment. Automotive industry is the main customer of near net shape forging components. Today's market is characterized by requirements for short delivery times, low costs and high quality. The supplier is confronted with smaller production and delivery batch sizes and an increasing type variation of part types. Automobile producers are more and more interested in parts which need minimal machining or are ready to assemble. Near Net shape forging parts can fulfill these requirements. The preform design used in near net shape forging processes is an important aspect for improving product quality and decreasing production cost. In the past, preform design was accomplished by empirical design, approximate analysis and trial-and-error. This task is now supported by the finite-element method and the backward tracing scheme [2]. Preform is material part that has undergone preliminary shaping but is not yet in its final form. In preform all process parameter and part geometry is defined in advance by which near net shape is easily found. through the use of simulation technique. This computer- aided simulation will reduce number of expensive die tryouts[3]

1.2 Background**:** This product is the main part in propeller shaft's universal joint as shown in PHOTO 1 . In PHOTO 1(a) the final product full yoke is presented. The product is forged in 4 multistage [4] operation steps. Each operation consists of a stroke between a male and female die. The 4 multi stage-operation method is based on the flashless die technology, developed in the press forge [4]. Flashless forging technology means that the external material during production is as less as possible. Earlier the part is manufactured by drop forging process in three stages (fullering, blocker and finisher) as shown in Fig 2 . Design is provided with minimum of 15% flash margin and 1.5mm minimum machining allowances per side which can be controlled to 3% flash and 0.5mm machining margins per side by flashless/near net shape forging concept .Fig. 2a and Fig. 2b shows the old hammer dies and produced forging part.

Photo 1 1, Photo 1 2

Fig 1a *Prop. Shaft Omni*

Photo (1) Prop. Shaft Omni

Photo (1a) *Final* forged part

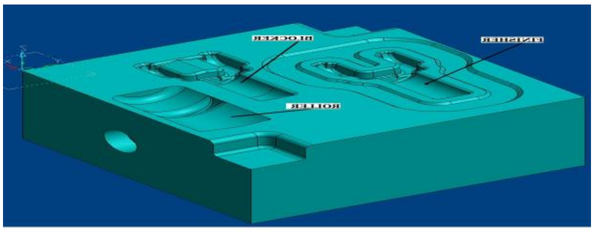


Fig (2a) Old Drop forging die design

Fig (2b) Drop forged part

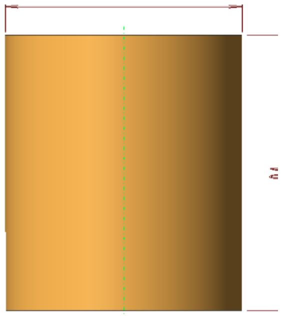


Fig (3a) STAGE -1 (Blank)

Figures showing the Drop forging process stages

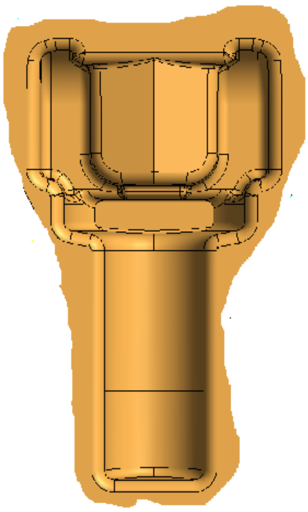


Fig. (3c) STAGE -3 (Blocker)

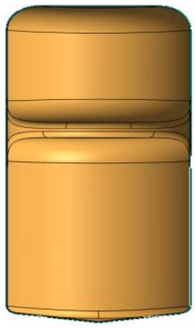


Fig (3b) STAGE -2 (Fullering)

Fig. (3d) STAGE -4 (Finished)

Comparison Table 1

Parameters	Drop Hammer	FE Model
Material	C-45	C-45
Blank weight (kg)	1.450	0.993
Blank size (mm)	Φ50 X 84	Φ 48X70
Temperatu(°c)	1250	950
Max Load (N)	2000	340
Allowances	!5%	3%

1.3 Design Research

1.3.1 Design Research – 1

To achieve near net shape / flash less forging, the design was changed to vertical forging where the contact area between the top punch, bottom die and the work piece was minimized so that minimum flash could be achieved [5}.To achieve this Preform Design it was conceptualized that the stem portion will be in one cavity only and there would be no contact of the other half of the die.The other half which would be in contact and where there will be flash formation will only be in the yoke portion. So the conceptualized photo is as shown in the Fig.(4a) & (4b)

1.3.1.1 Operation 1

Gathering or upsetting is done in the top head keeping the stem diameter same which is as per the volume required for making yokes with 3% (Burning and Flash) allowance as shown in Fig (4a)

Fig (4a) STAGE -1

1.3.1.2 Operation 2

Turning the vertical piece at right angle and slight upset so that the sufficient material is achieved for yoke filling up.

Fig (4b) STAGE -2)

1.3.1.3 Operation 3

Again turning the piece to right angle and forging it to final shape.

Result: **-** The yoke found unfilled and huge flash formed unevenly as shown in the Fig (4c)

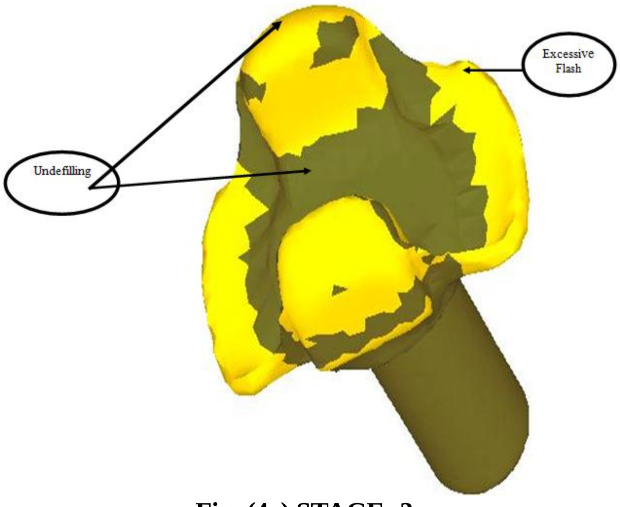


Fig. (4c) STAGE -3

1.3.2 Design Research – 2

To overcome the problem of underfilling and excess flash in design research 1, design research 2 was coceptualised as shown below from Fig (5a) to (5e)

1.3.2.1Design and development approach

Fig (5a) Stage -0 (billet)

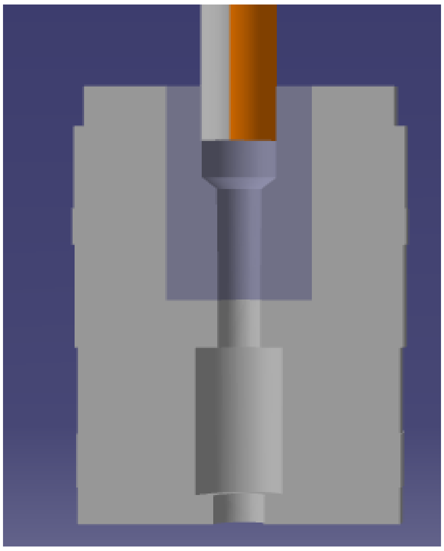


Fig (5b) Stage -1 (forward extrusion- FE model)

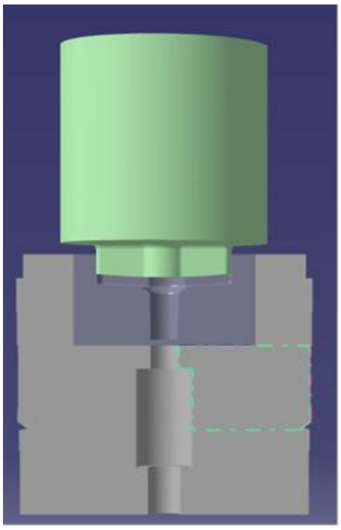


Fig (5c) stage2 T- formation (FE model)

Fig(5c) T – formed

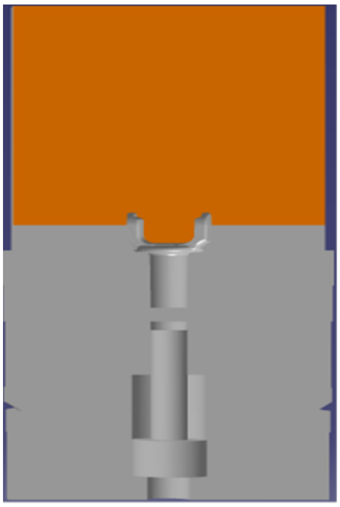
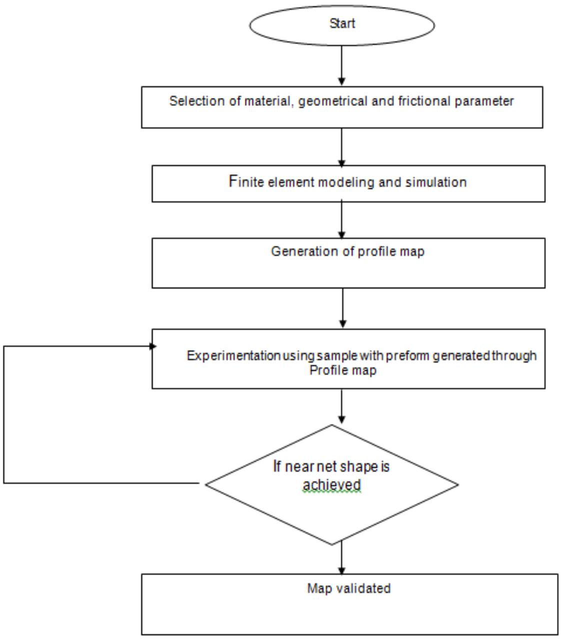


Fig (5d) Stage -3 Bending of T (FE model)

Fig (5e) Stage -4 (Finished yoke)

II. Methodology

Methodology followed during the tenure of this study is given in the form of flowchart as followed-



Flow chart 1

III. Production Flow Diagram

Material Inspection

↓

Billet Cut
Weight 0.997-0.998 gm
Billet dia 49mm

↓

Graphitisation

↓

Heating
Temp. 950 ± 50°C

↓

Forward Extrusion
(1st stage)

↓

T- Shape (2nd stage)

↓

Bend shape (3rd stage)

↓

Final near net shape (4thstage)

Flow Chart 2

Fig. 6 a (Near net shape Forged Part)

Fig. 6 b (FE Model)

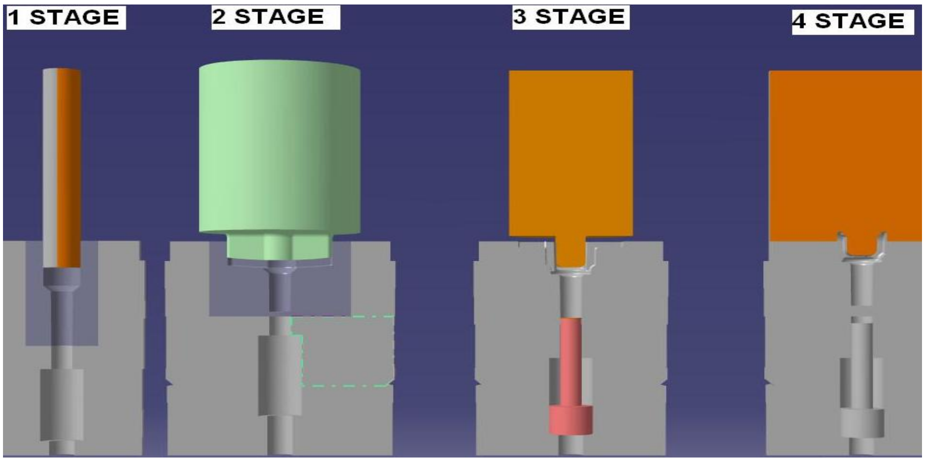


Fig 7a (Four stages die design)

IV. Deform Simulation / FE Models

The FE model for all four stages consist of three parts i.e. top, bottom and partgeometry . Part geometry [6] used in each operation is the outpui of previous operation. The top and bottom dies are selected as rigid bodies while the part is in plastic form. Because the die blocks have to retain their shape.

In Table 2 the friction parameters **[7]** in all stages are presented:

Stage 1		
Contact	Friction Coefficient	Heat Transfer Coefficient
Lower die	0.3	11(N/sec/mm/C)
Upper die	0.3	11(N/sec/mm/C)
Piece	0.3	11(N/sec/mm/C)

Stage 2		
Contact	Friction Coefficient	Heat Transfer Coefficient
Lower die	0.3	11(N/sec/mm/C)
Upper die	0.3	11(N/sec/mm/C)
Piece	0.3	11(N/sec/mm/C)

Stage 3		
Contact	Friction Coefficient	Heat Transfer Coefficient
Lower die	0.3	11(N/sec/mm/C)
Upper die	0.3	11(N/sec/mm/C)
Piece	0.3	11(N/sec/mm/C)

Stage 4		
Contact	Friction Coefficient	Heat Transfer Coefficient
Lower die	0.3	11(N/sec/mm/C)
Upper die	0.3	11(N/sec/mm/C)
Piece	0.3	11(N/sec/mm/C)

Table 2

V. Production explanation

In this chapter, the complete production of product (full yoke) will be explained. All the possible problems that appear in the production will be described. Each operation is defined clearly so a good idea about the main problem of this subject can be made

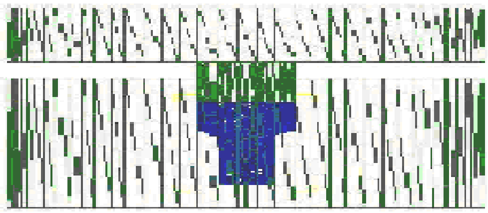
5.1 Preparation: The starting product consist of a steel alloy cylinder with a diameter of 48 [mm] and a height of 70 [mm]. The cylinder will be called in the future piece. The piece is preheated in an induction furnace till it has the temperature of 950°C. This means also that the volume of the epiece changes because of the big temperature difference. With the formula the new volume can be calculated. (1) With expansion coefficient α= 0.000012 [1/K] and ΔT = 950 [K], the diameter increases to 48.633 [mm] and the height increases to 70.924 [mm]. So these lengths have to be used in the FE model well as in first operation die, After heating the cylinder cools for 18 seconds, because in that time the cylinder is transported from the induction heater to the first operation place, After that the piece has to be placed in the center of the die of the first operation, this is very important for the good centering of the product. This takes atleast 1.5 secs. The 19.5 secs of transportation and cooling has to be simulated as well in the numerical simulation

5.2 operaration1: After positioning of the piece, the first stroke takes place. This operation is the forward extrusion operation [8] and has a couple of aims. First of all it removes the scale and redistribute the material to the shape of the end product. Next to that, it also rejects the piece if the weight tolerance is exceeded. Because if the weight tolerance is exceeded, the piece will not fit in the die of the second operation. Further it ensures the exact positioning in the die of the second operation

The final distance between the upper and lower die is 24.435 [mm]. In figure7(a), the upper and lower dies of operation 1 are presented. The parameters, which can be changed for the research, are given in Fig(7a) ,Only the height can be changed, because by changing the height, also the angle shall change. This will ensure to keep the same volume between the two dies

In Fig (8a) the filling of the original geometry after operation 1 is presented. After the stroke, the upper die will go up and the piece will be transported to the lower die of operation 2. This takes 1.5 seconds and in this time, the piece will cool again.

1st Stage Die & Punch



1st Stage Component

Fig. 8a (FE Model of the die in closed condition and component

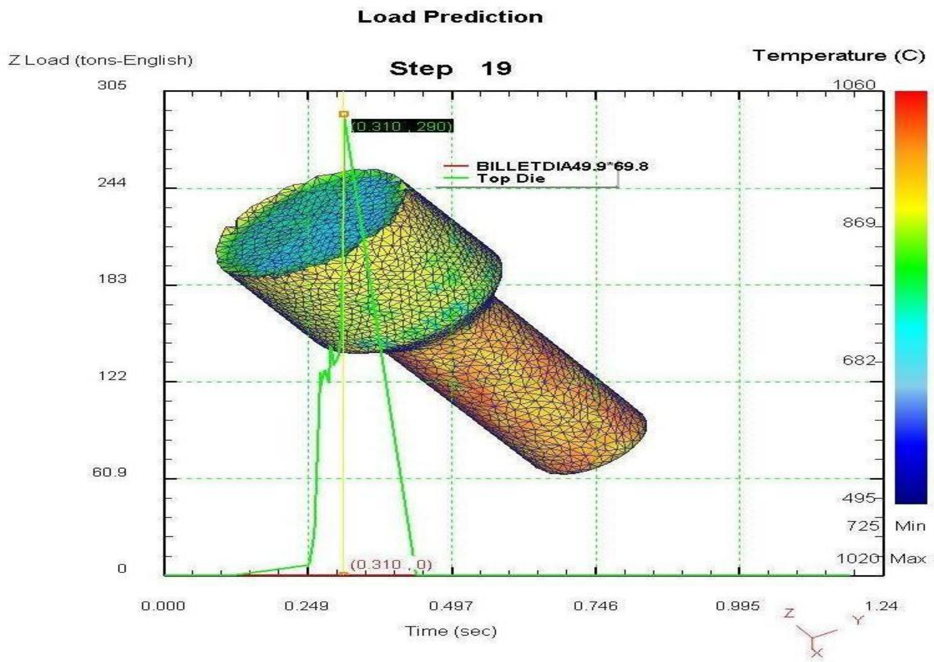


Table 3 State variable parameters for Stage 1

Stage1				
Sr. No	contents	minimum value	maximum value	
1	Effective Strain (mm/mm)	0.01120	3.20000	
2	Effective Stress (Mpa)	39.5	440.0	
3	Effective Strain rate (mm/mm/sec)	0.06490	769.00000	
4	Temperature (^{0}C)	725	1016	
5	Volume (mm^3)	135773.43		
6	Displacement (mm)	48.95130	98.30460	
7	Velocity (mm/sec)	18.66	2492.72	

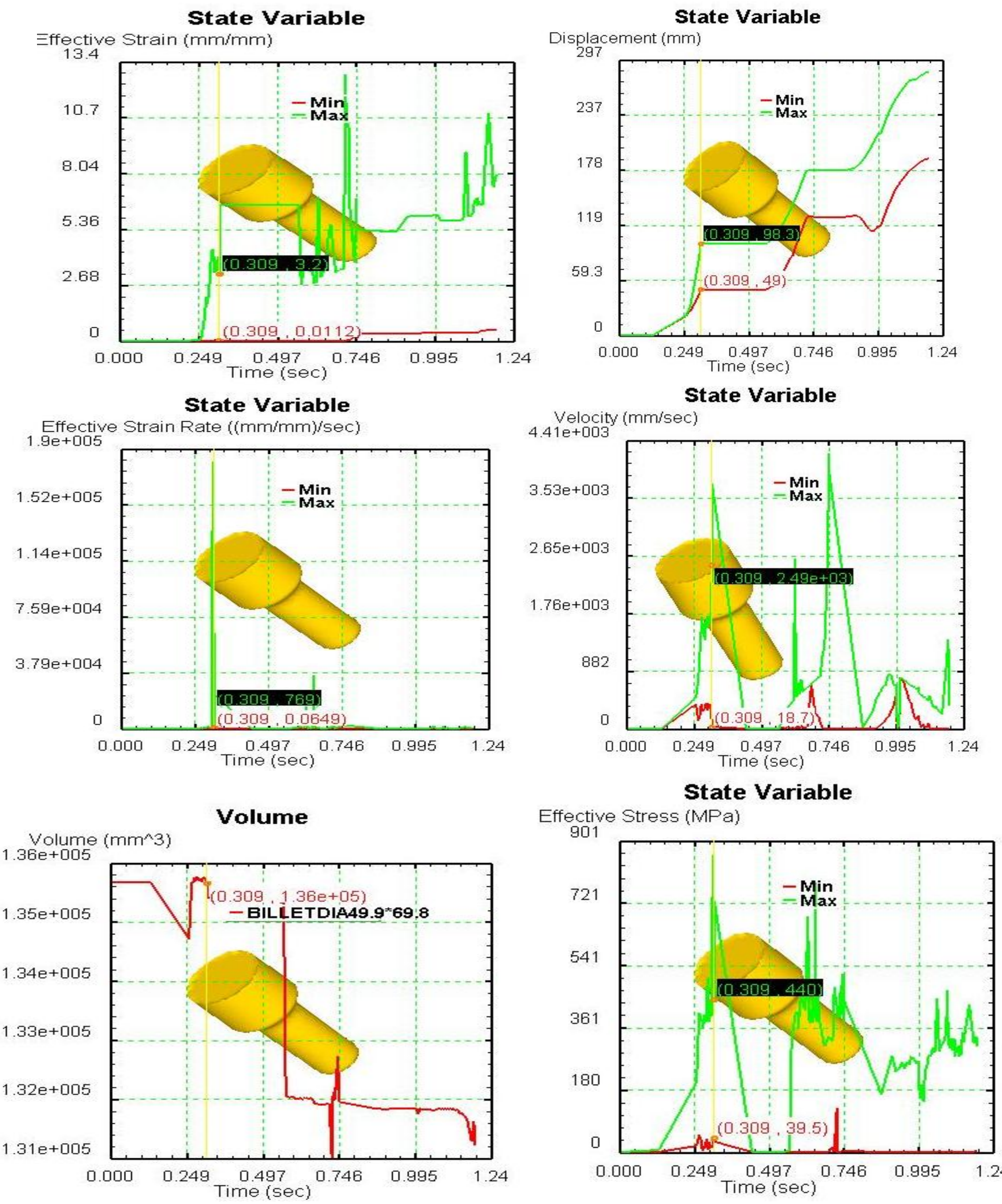


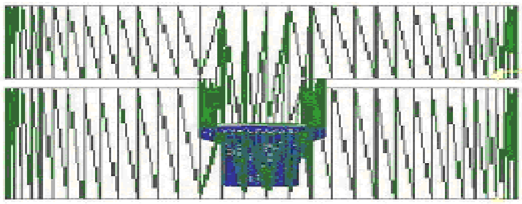
Fig. 8b State variable & graph for operation 1

5.3 operation 2: After the transportation of the operation1 , the piece will be placed in the lower die of operation 2, which also takes 1.5 seconds. The second operation is the preforming operation in T shape and has also a couple of aims. First of all it creates arms equal to calculated length of forks the side walls of the die would restrict the flow of material and control the width of forks without any flash. Thickness of forks can be adjusted by adjusting the stroke length

In Fig(9a), the upper and lower dies of operation 2 are presented. In this operation a lot of parameters can be changed. This is also the reason that the solution first has to be found in the second operation.

Now the second stroke takes place. The final distance between the upper and lower die depends on the filling of the point where the upper and lower die comes together. See the arrow at Fig (9a) The filling of the corner has to be approximately the same as the filling in Fig(5c). A shape in the corner like that, gives a good filling in the top of the die and also a good flashless filling at the end of operation 4.

2- STAGE DIE & PUNCH



2- STAGE COMPONENT

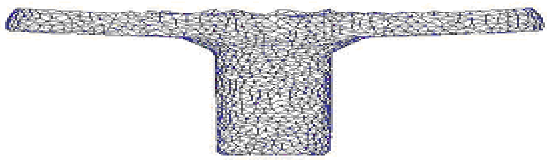
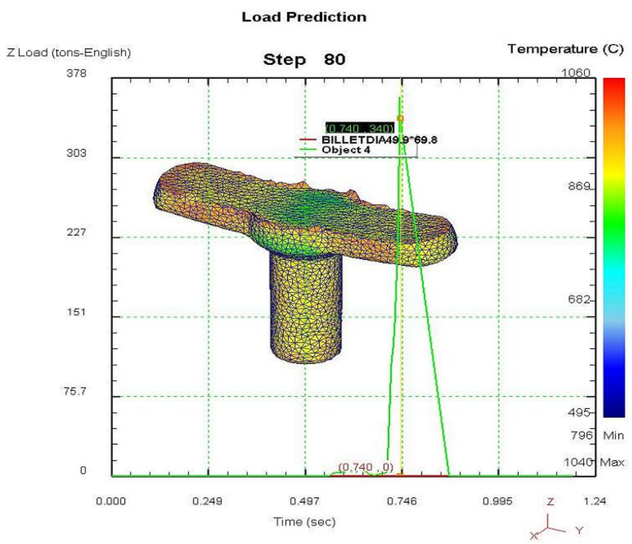
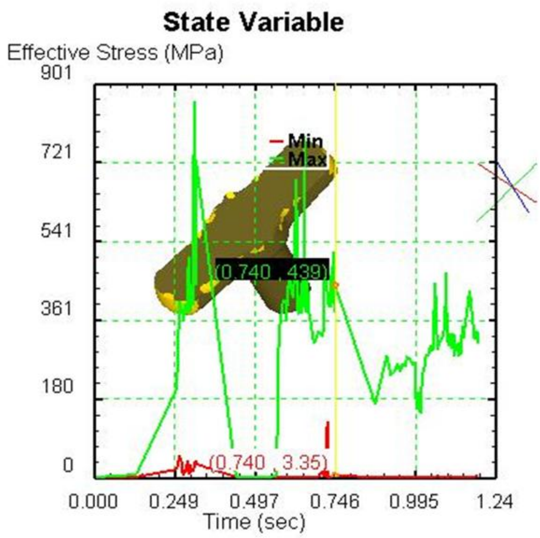


Fig. 9a FE Model of the die in closed condition and preform in T Shape

Table 4 State Variable parameters for Stage 2

SR .NO	CONTENTS	MINIMUM VALUE	MAXIMUM VALUE
1	Effective strain(mm/mm)	0.35200	5.33000
2	Effective stress(mpa)	3.34	439.0
3	Effectivestarin rate(mm/mm/sec)	0.**01570**	2356.0000
4	Temeperature(°c)	796.**38**	1042.*58*
5	Volume (mm³)	131827.26	
6	Displacment(mm)	127.2800	177.48000
7	Velocity(mm/sec)	0.0463	3950.0





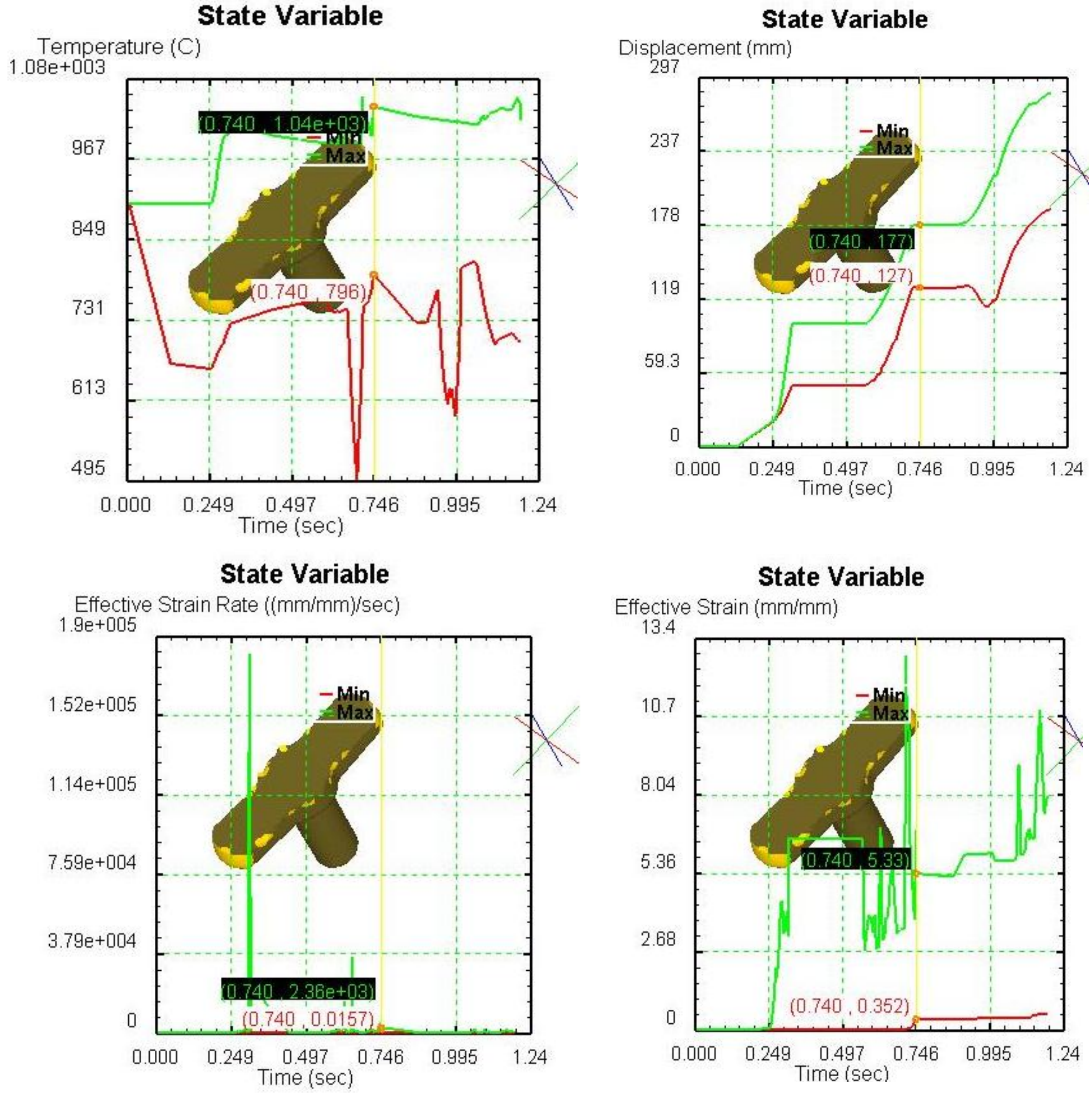


Fig. (9b) State variable graph for operation 2

5 .4 Operation 3

After the operation 2, the piece will be transported in the lower die of operation 3, which also takes 1.5 seconds. In Fig (10a), the upper and lower dies of operation 3 are presented. In this operation only one parameter can be changed. This because of the fact that the shape of the end product is prescribed. Now the third stroke takes place. The final distance between the upper and lower die depends upon the proper bending of piece in the die. If the whole die is filled, it isn't necessary to press further. In DEFORM [9] this is easily seen with the graphical function of the normal pressure.

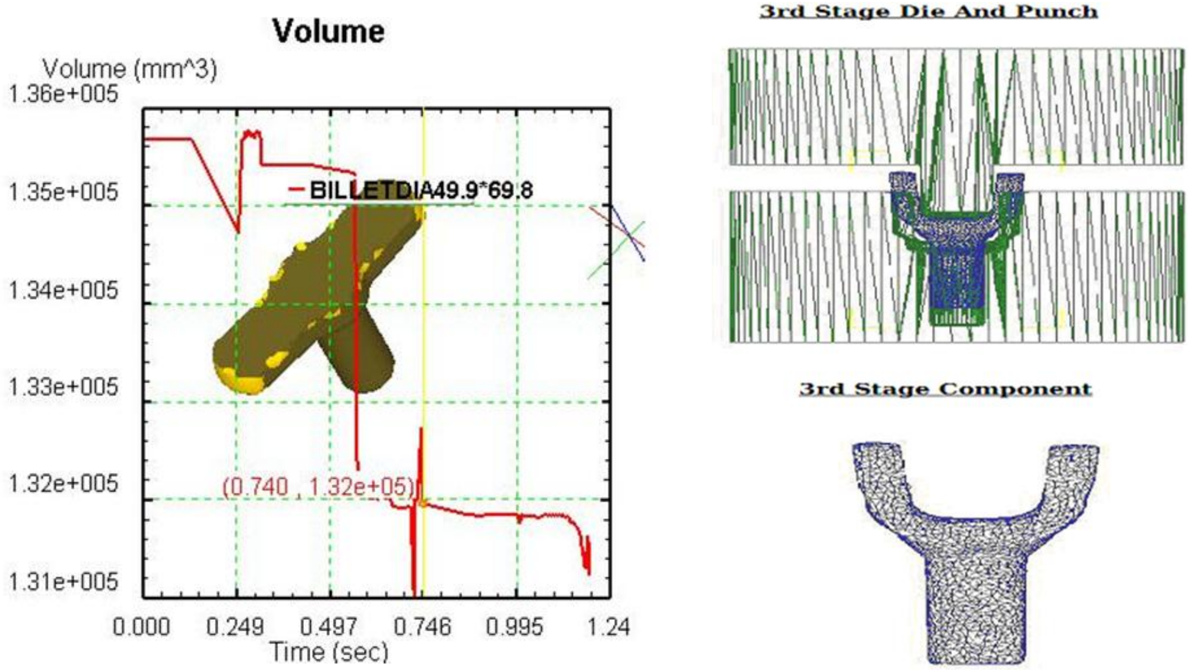
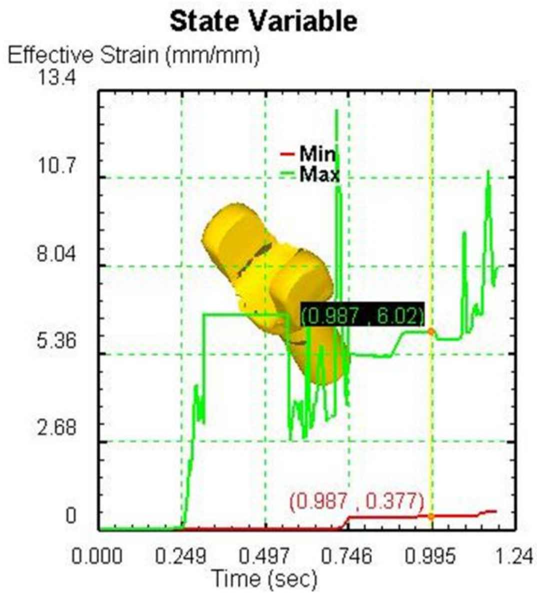


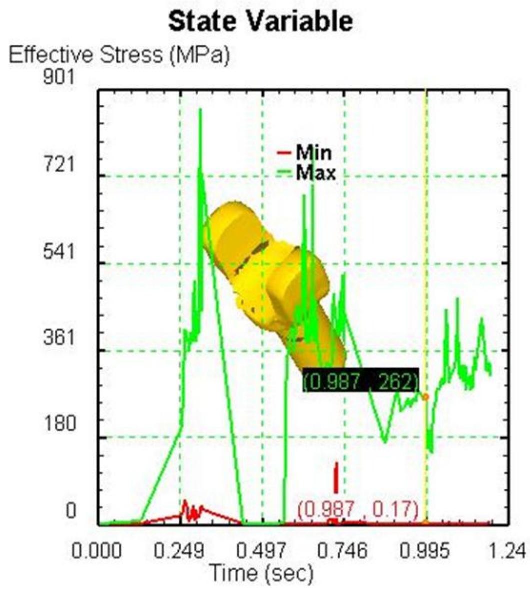
Fig 10a FE Model of die in closed condition and perform after bending of T

STAGE 3

SR .NO	CONTENTS	MINIMUM VALUE	MAXIMUM VALUE
1	Effective strain(mm/mm)	0.37700	6.0200
2	Effective stress(mpa)	0.17	282.0
3	Effectivestarin rate(mm/mm/sec)	1.87000	62.27000
4	Temeperature(°c)	589.00	1020.00
5	Volume (mm³)	131704.50	
6	Displacment(mm)	117.35000	217.58000.
7	Velocity(mm/sec)	490.1200	680.43

Table 5 : Stage Variable Parameters for Stage 3





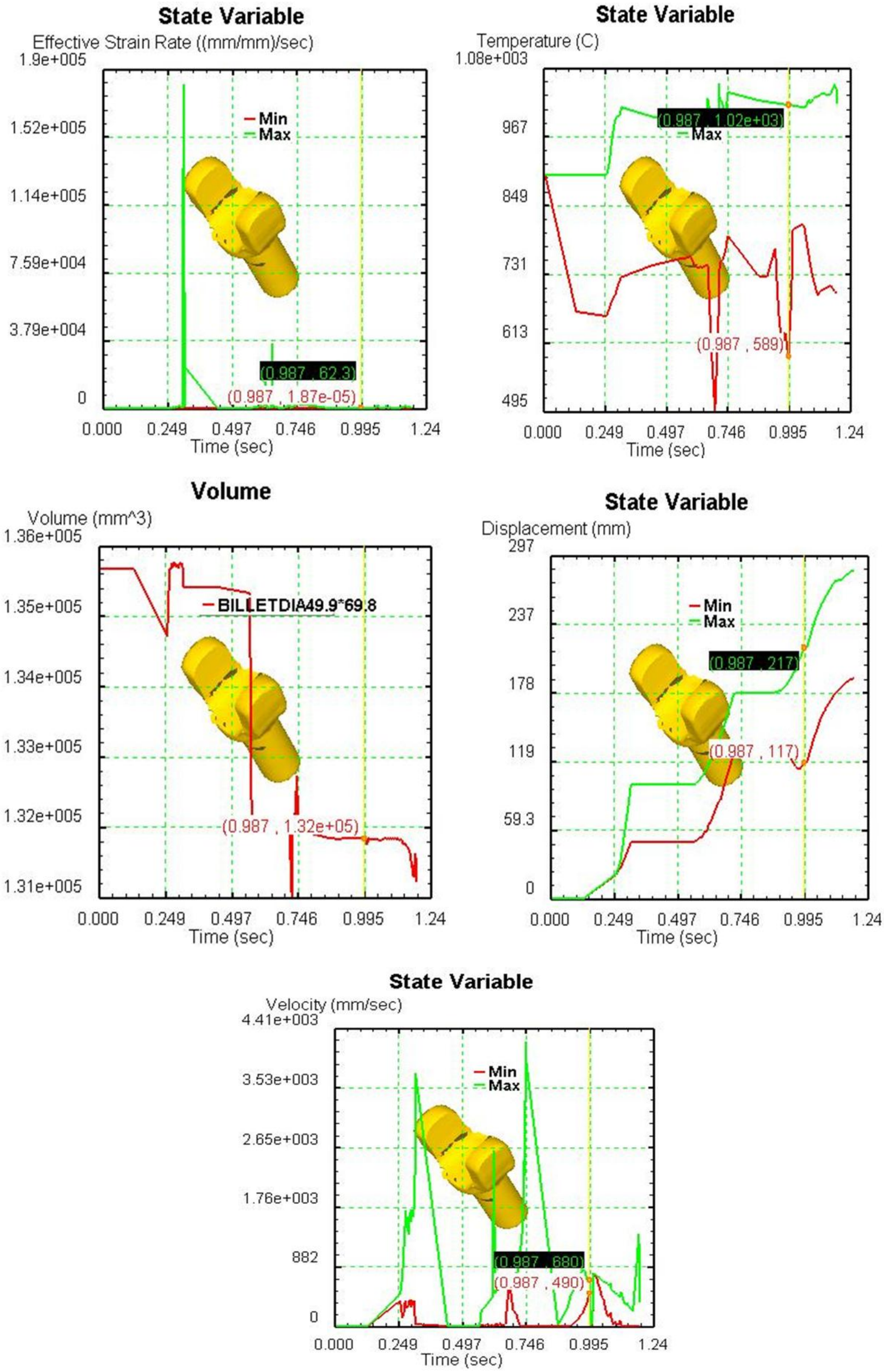


Fig. 10b State variable graph for operation 3

5.4 operations 4 After the Operation 3, the piece will be transported in the lower die of operation 4, which also takes 1.5 seconds. In figure 7, the upper and lower dies of operation 4 are presented. In this operation only one parameter can be changed. This because of the fact that the shape of the end product is prescribed.

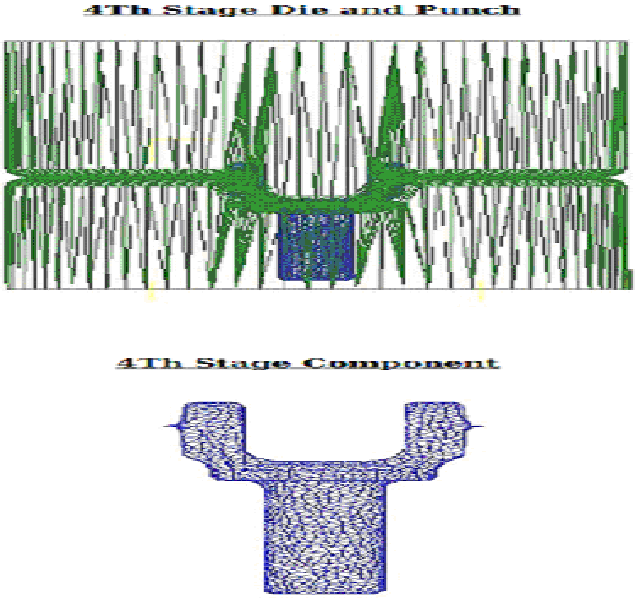


Fig. 11a FE Model of the die in closed condition and final near net shape Full Yoke

Now the fourth stroke takes place. The final distance between the upper and lower die **depends on the filling of the top of the die**. If the whole die is filled,and the total length is achieved it isn't necessary to press further. In DEFORM 3D this is easily to see with the graphical function of the normal pressure.

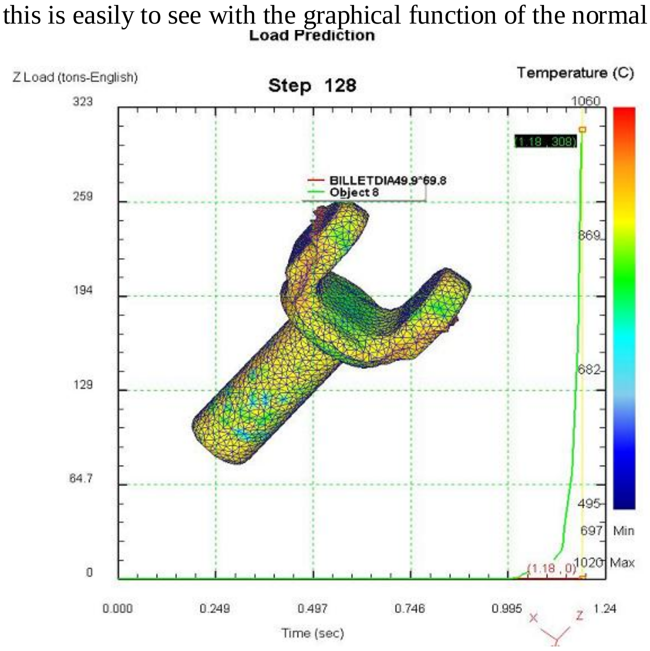
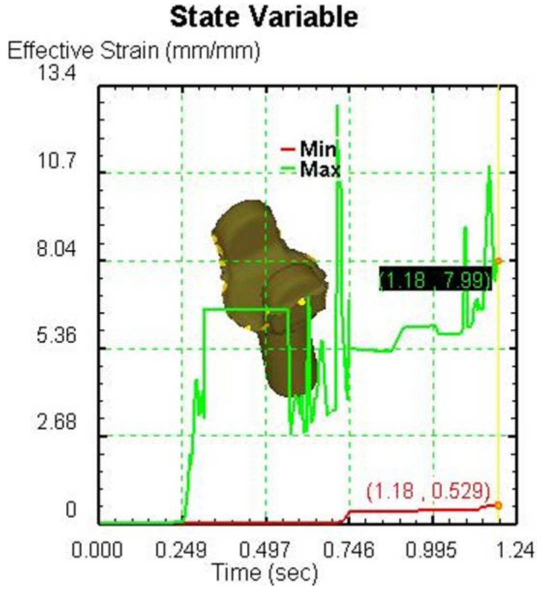
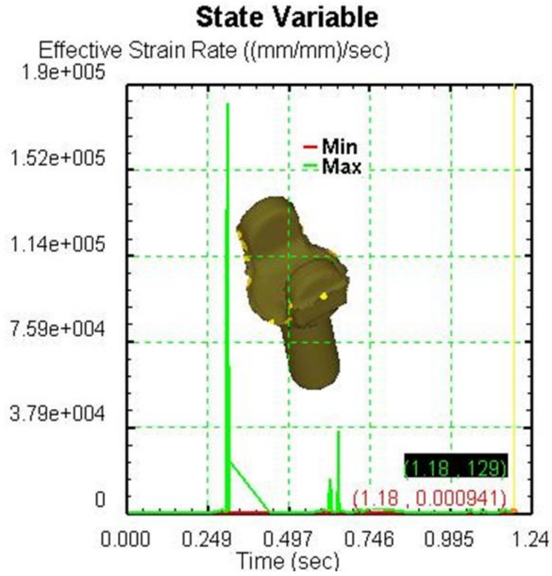
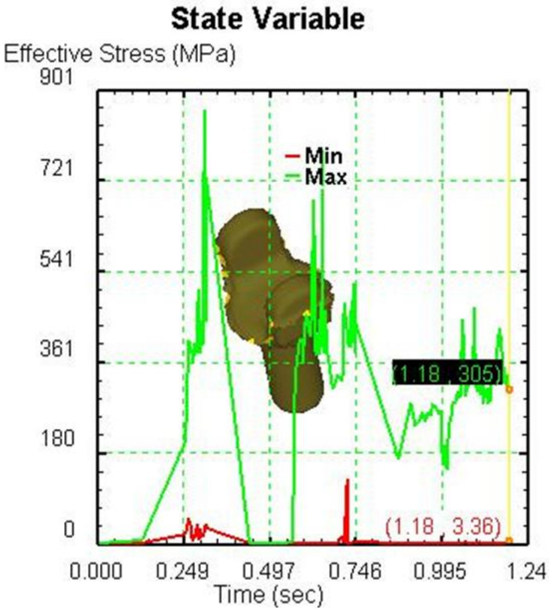


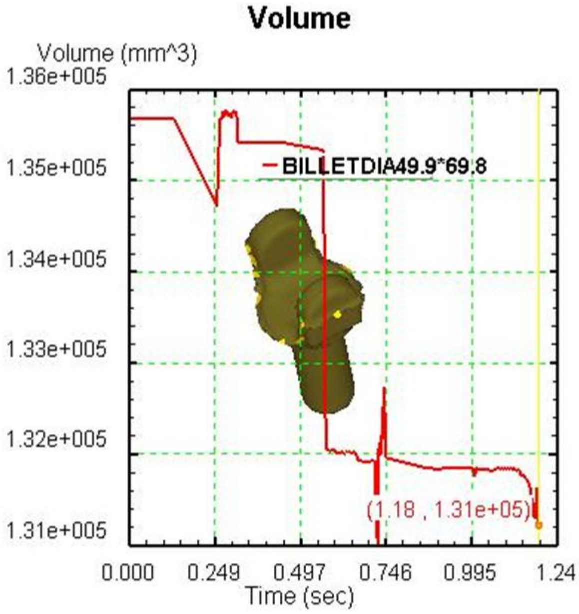
Table 6 State variable parameters for stage 4

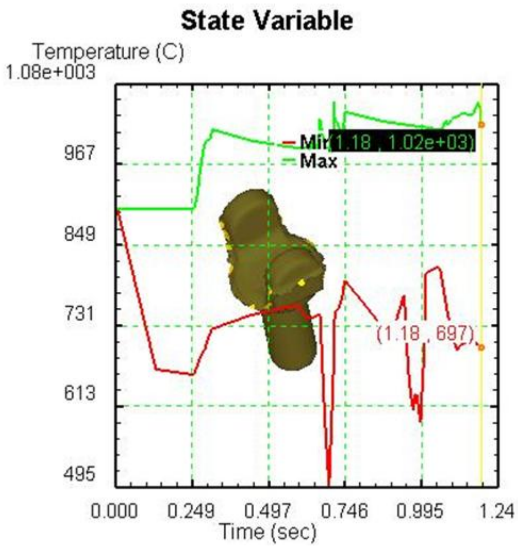
SR .NO	CONTENTS	MINIMUM VALUE	MAXIMUM VALUE
1	Effective strain(mm/mm)	0.52800	7.99400
2	Effective stress(mpa)	3.3638	305.1160
3	Effectivestarin rate(mm/mm/sec)	0.00094	62.27000
4	Temeperature(°c)	589.00	12874.00000
5	Volume (mm³)	131035.59	
6	Displacment(mm)	190.01100	282.54000.
7	Velocity(mm/sec)	0.0100	348.26

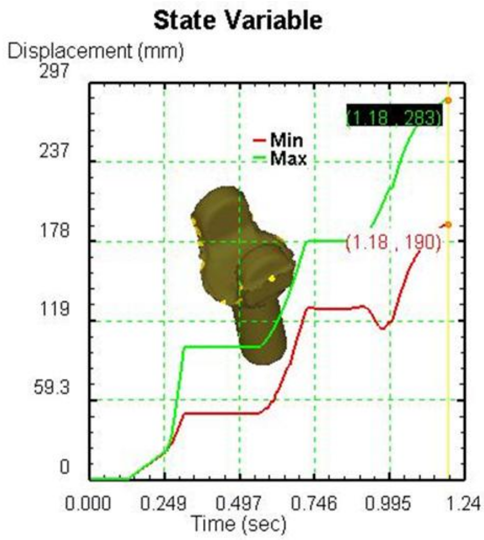

State Variable
Effective Strain (mm/mm)
13.4
10.7
8.04
5.36
2.68
0
Min
Max
(1.18 , 7.99)
(1.18 , 0.529)
0.000
0.249
0.497
0.746
0.995
1.24
Time (sec)


State Variable
Effective Strain Rate ((mm/mm)/sec)
1.9e+005
1.52e+005
1.14e+005
7.59e+004
3.79e+004
0
Min
Max
(1.18 , 129)
(1.18 , 0.000941)
0.000
0.249
0.497
0.746
0.995
1.24
Time (sec)


State Variable
Effective Stress (MPa)
901
721
541
361
180
0
Min
Max
(1.18 , 305)
(1.18 , 3.36)
0.000
0.249
0.497
0.746
0.995
1.24
Time (sec)


Volume
Volume (mm^3)
1.36e+005
1.35e+005
1.34e+005
1.33e+005
1.32e+005
1.31e+005
BILLETDIA49.9*69.8
(1.18 , 1.31e+05)
0.000
0.249
0.497
0.746
0.995
1.24
Time (sec)


State Variable
Temperature (C)
1.08e+003
967
849
731
613
495
Min
Max
(1.18 , 1.02e+03)
(1.18 , 697)
0.000
0.249
0.497
0.746
0.995
1.24
Time (sec)


State Variable
Displacement (mm)
297
237
178
119
59.3
0
Min
Max
(1.18 , 283)
(1.18 , 190)
0.000
0.249
0.497
0.746
0.995
1.24
Time (sec)

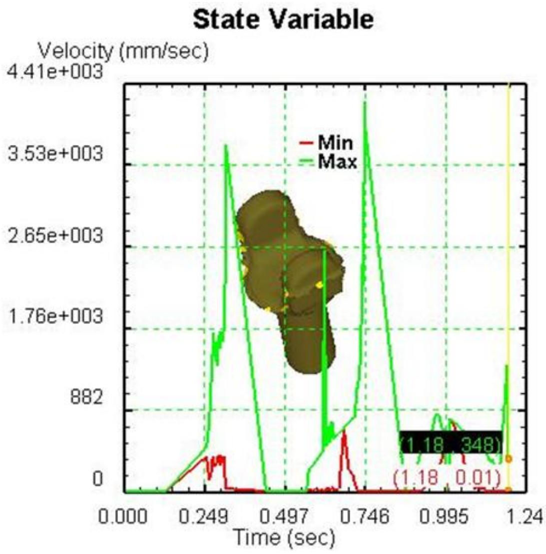
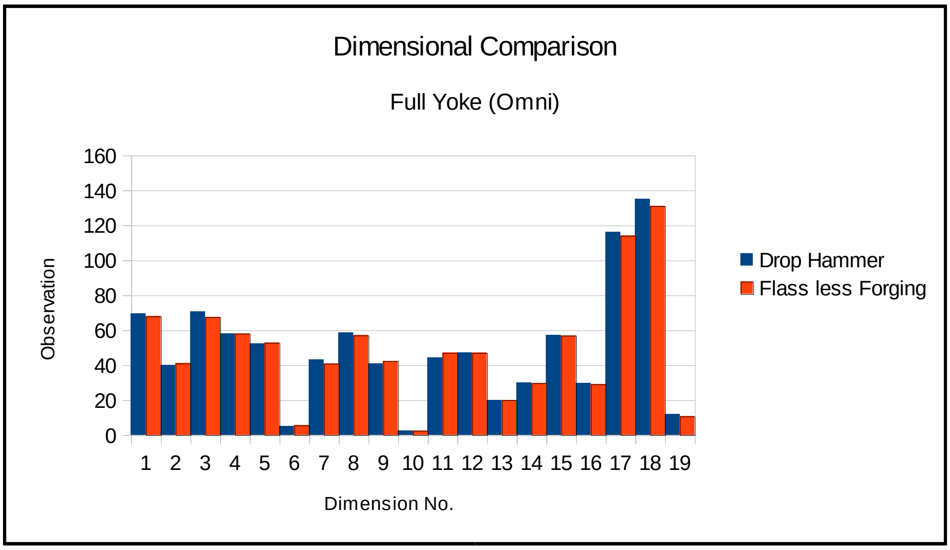


Fig. (11 b) State variable Graph for operation 4

VI. Result & Comparison

Sr No	Dimensions Obtained Through(hammer forging route) (mm)	Dimensions Obtained Throughflashless forging route (Press forging)(mm)
1	69.5	67.91
2	40.00	41.00
3	70.50	67.60
4	58.00	58.00
5	52.20	52.75
6	5.00	5.50
7	43.00	40.90
8	58.40	57.00
9	40.73	42.36
10	2.30	2.50
11	44.2	46.98
12	47.00	47.00
13	19.80	19.96
14	29.80	29.64
15	57.00	56.90
16	29.50	29.00
17	116.00	114.00
18	135.00	131.00
19	11.80	10.70

Table 7



Graph 1

6.1 Metallurgical Test Reports and Comparison

DATE	METALLURGICAL PROPERTIES	HAMMER	PRESS (1500 TON)
17/9/2012	HARDNESS	197 BHN	229 BHN
	TENSILE (DATA AS PER HARDNESS VALUE)	68 kgf/mm²	79 kgf/mm²
	IMPACT	22 Joule	44 Joule
	GRAIN SIZE	6-8 ASTM	5-8 ASTM
	GRAIN FLOW	OK	OK

Table 8

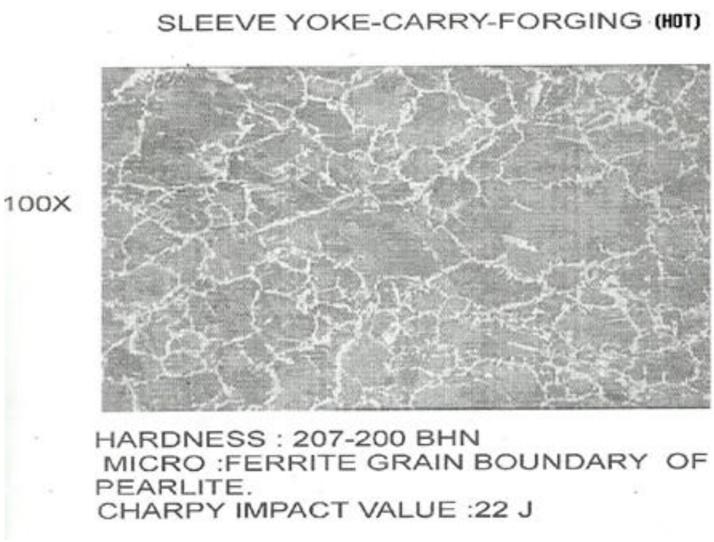


Photo 2 (Micro Structure of Hot Forging on Hammer)

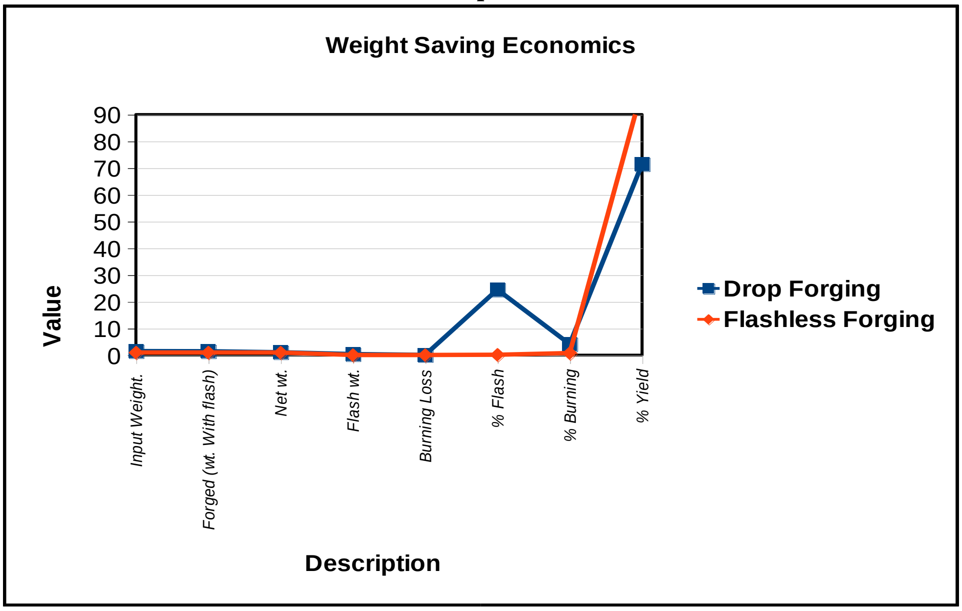
Photo 3 (Micro Structure of Near Net Shape forging on 1500MT Multi Station Press)

6.2 Weight saving Economics Reports and comparison

WEIGHT SAVING ECONOMICS					
SR.NO	Description	Drop Forging (kg)	Flashless Forging (kg)	Wt. Saving	% Saving
1	Input Weight.	1.47	0.945	0.525	35.71
2	Forged (wt. With flash)	1.41	0.938	0.472	
3	Net wt.	1.05	0.937	0.113	7.69
4	Flash wt.	0.36	0.001	0.359	
5	Buming Loss	0.06	0.007	0.053	
6	% Flash	24.49	0.11		24.38
7	% Buming	4.08	0.74		3.34
8	% Yield	71.4	99.2		27.7

Table 9

Graph 2



VII. Conclusion

The aim of this project is reached at GNA Udyog Ltd.. It will be used as a prototype for all other Yoke flashless or Near Net shape forging.In this case a study has been carried out for near net shape – flashless forgingfor full yoke omni, a child part to be fixed in propelleor shaft of omni vehicle (a LCV) made by Maruti Suzuki ltd (India). In this study the preform die design changes required for flashless forging of sleeve yoke through warm forging route is carried out. It has been concluded that preform design plays a very important role to achieve near net shape – flashless forging, the yield improved from 71.4 % (closed die hot forging through hammaer route) to 99.2% flashless/near net shape warm forging through press forging route. Finite element analysis is carried out for different stages of preform & finisher forging for the elements – effective strainn rate , effective stress, temperature, volume displacement & velocity. Such application of preforms & simulation techniques will help achieve optimum utlisation of material resulting in economical utilsation of components

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