APPLICATION OF FINITE ELEMENT METHOD IN HOT FORGING OF AUTOMOTIVE COMPONENT - DIFFERENTIAL SPIDER

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ABSTRACT **-**In this paper the application of Finite Element Method (FEM) numerical simulation on hot forging process of automotive component Differential Spider is presented. The simulation has been carried out with the help of software DEFORM-3D. This paper also gives an overview of complete die design process i.e., conversion of component drawing to forging drawing, addition of allowances, draft allowances, design of flash and gutter. In this paper two die sets are developed with different gutter shape for forging of Differential Spider and simulated using DEFORM-3D to get the optimum die set for facilitating complete filling of the die.

Keywords **-Closed die hot-forging, Finite Element Method, DEFORM-3D, Die Design, Differential Spider.**

1. INTRODUCTION

Forging is one of the manufacturing processes involving the shaping of the metals or alloys using localized forces applied with the help of a pair of dies by plastic deformation [1]. The forging process produces a component which has very high impact and fatigue strength, minimum wastage of the material giving maximum yield, close tolerance and minimum machining. There is a renewed interest in analyzing forging process by different simulating techniques [2 to 4]. DEFORM-3D is one of such techniques which are a Finite Element method (FEM) based process simulation system designed to analyze various metal forming processes and widely used in industry. Differential spiders are used in assemble of differential in trucks, buses, cars etc., to support the bevel gears and for transmitting load from the pinion and ring to the rotating axles & protect the vehicle parts from getting damaged. A typical assembly of differential gear net is shown in Fig 1. The differential spider has complex geometry and difficult to forge. The design of the die impression and process parameters are very important and proper die filling will give the correct shape of the forging. DEFORM-3D simulation is helpful for forging process in predicting and eliminating forging defects and helping in selection of proper process parameters and die design.

. A three dimensional model of the component is developed in CATIA-V5R19 and the simulation analysis is done in DEFORM-3D. Two die sets with different gutter design are analyzed for complete filling and an attempt is made to establish best die design

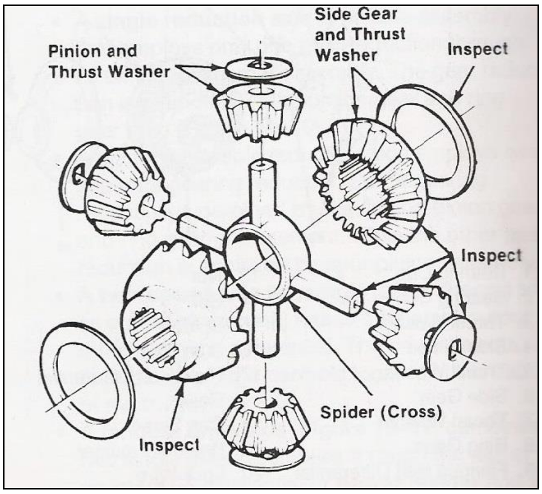


Fig 1: Differential Spider Gear Net Assembly

2. METHODOLOGY

Initially a 3D-CAD model of the component is made using CATIA V5. The first step in designing is to select the parting line. Then the finish allowances, draft allowances, Corner and radii are added to component drawing to get forging drawing and the corresponding model is made. After this die block size is selected and sinking of die is done. Die material is selected depending on the process, equipment and the billet material. In Industries Differential spiders are manufactured by closed die hot forging process. Hence the same process is adopted for analysis. Type of equipment i.e., hammer or press is decided based on the type of material and availability of the equipment. Then the forging simulation is carried out using FEM based simulation software DEFORM-3D. The simulated results are analyzed for defects like under filling, lap, crack and overstressing. If there are any defects then the design of the die is modified and re-simulated till the defects are cleared. After the simulation is over with less defects, then the product goes for production.

The work piece material considered for the present work piece is AISI 8620 Low alloy steel. The Mechanical properties are shown in the Table 1.

Table 1. Properties of AISI 8620 alloy steel

Tensile strength	530 MPa
Yield strength	385 MPa
Hardness	149 BHN
Density	7850 kg/m^3
Poisson's Ratio	0.3
Forging Temperature	850-1200^{0}C

Fig 2: Solid Model of Differential spindle

3. Die Design:

a. Solid Model of Differential spindle

The solid model of the Differential Spider is shown in the Fig. 2.

b. Selection of parting line

As the component is symmetric in about horizontal plane parting line is selected along the horizontal plane which also takes take of avoiding deep cavities.

c. Finish Allowance

Machining is required only on the top and bottom surface of the component hence finish allowance is considered only on top and bottom surface. The maximum height is less than 205mm hence the finish allowance considered is 1.5mm from the Table 2.

Table 2: Finish allowances for drop and press forgings [5]

Over (mm)	But Not Over (mm)	Minimum Allowance per surface (mm)
-	205	1.5
205	410	2.5
410	610	3.0
610	915	4.0
915	-	5.0

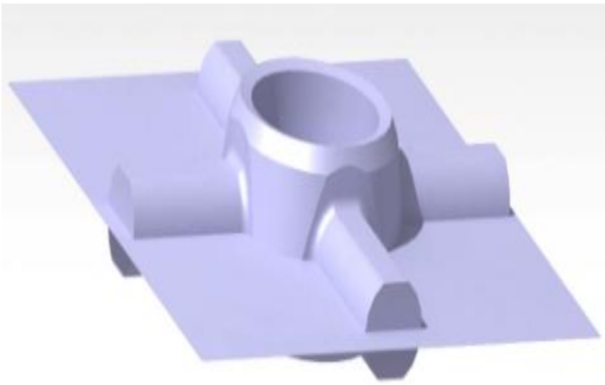


Fig 3: CATIA model showing parting line

d. Draft Allowances

As the component has natural draft outside, so further draft is not provided. But an internal draft is provided for easy removal of the component.

e. Corner and fillet radius

If the fillet and corner radius are not provided properly then there may be chance of under filling. Hence large fillet radius is provided at the portion where the arms meet the rib. This enables easy filling of arms. Corner and radius are decided as per ref. [6]

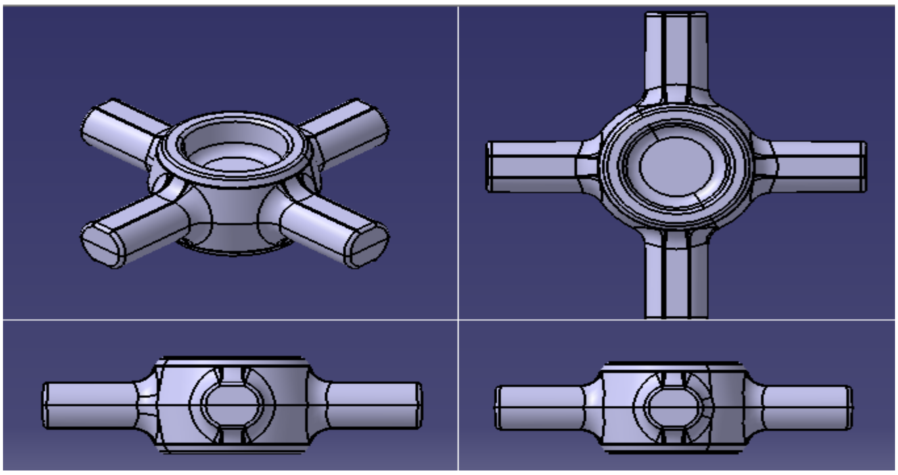


Fig 4: Forging Model of Differential Spider

Table 3. Flash Thickness Calculations

Author	Flash Thickness	Result (mm)
Vieregge	$t = 0.017D + \frac{1}{\sqrt{D+5}}$	1.32
Neuberger & Mockel	$t = 0.89\sqrt{W} - 0.017W + 1.13$	1.78
Teterin & Tarnovski	$t = 2\sqrt[3]{W} - 0.001W - 0.009$	1.61

f. Design of Flash and gutter

The primary role of flash is to generate desired restriction to undesired metal flow. The calculation for the flash thickness is mostly empirical, developed by different researchers. As flash design is an important input to the process, calculation is done using different methods [7]. The result of the same is summarized in Table 3. Flash thickness obtained by Neuberger & Mockel is considered. Corresponding flash land was calculated by considering w/t = 4:1. Hence the flash width is taken as 7.12mm.

Gutter design: Gutter is designed on the basis of flash dimensions. For finding gutter dimension Ref [6] is used.

g. Die block size selection

Top Die Dimensions

Diameter of the die ≥ Total diameter including flash and gutter + 2 X 1.5 (Maximum depth of the impression in the die)

≥ (106 + 2 X 13 + 2 X 32) + 2 X 1.5 (15)

≥ 241 mm

Height of the die ≥ 2 to 3 times maximum depth of the impression in the die

≥ 2.5 X 15

≥ 37.5 mm

Considered die block dimensions = Ø300mm X 260mm (to take the advantage of weight) which can be used for forging.

Bottom Die Dimensions

As the component is symettric both the die blocks have same dimensions and the considered die block dimensions are = Ø300mm X 210mm.

After die block size selection die sinking is done. 3D model of bottom die is shown in the Fig 5.

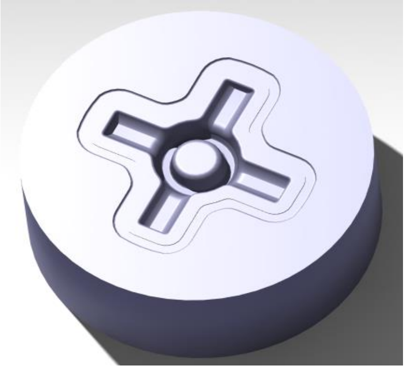


Fig 5: 3D Model of Bottom Die

h. Billet Dimensions

Volume of the die cavity obtained is 301940.013mm^3

Hence Billet of dimensions Ø60mm X 105 mm is taken.

4. Simulation

It is very difficult to establish a production process in the shop floor through experimentation. Also it is very expensive and time consuming. Hence simulation of forging process can be effectively used to reduces the no of trails. Through simulation various defects like underfilling, lap, crack, overstressing can be checked and design modification can be done depending on the type of defect araised.

Before the start of simulations the process parameters are to be given and the parameters used in this simulation process are shown in the Table 4.

Table 4. Forging Parameters

Type of forging	Hot Forging
Work piece material	AISI 8620
Die Material	H13
Coefficient of friction	0.3
Equipment	Drop Hammer
Dwell time	10 sec
Max height	200 cm
Temperature	1200^{0}C

The assembly of die set before and after simulation is shown in Fig. 6 and Fig. 7 respectively.

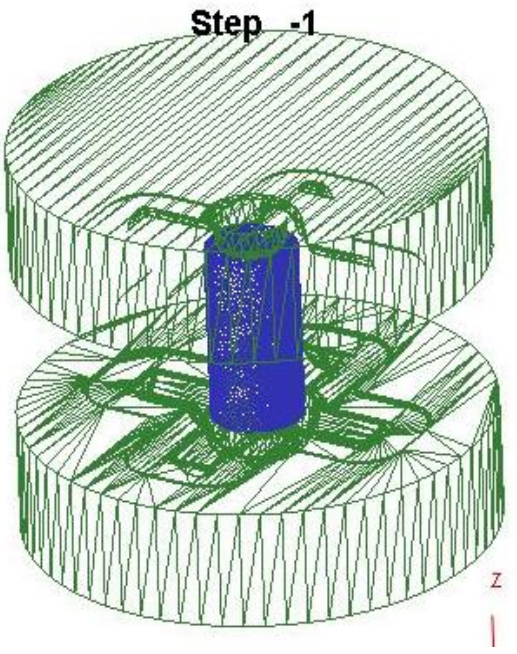


Fig 6: Die & billet before Simulation

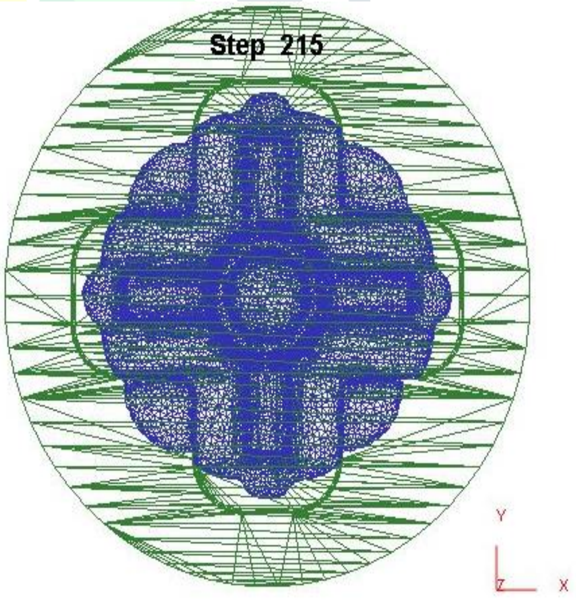


Fig 7: Simulation Result

The simulated results show that even though the volume of the billet is less than the cavity of the die, metal flushed out of the die cavity resulting in a defective forging. This is due to the fact that very less relief is provided in the space between the arms. Hence the gutter shape is made circular instead of plus (+) shape. This shape enables the material to flow into the gutter. The modified die is shown in the Fig. 8.

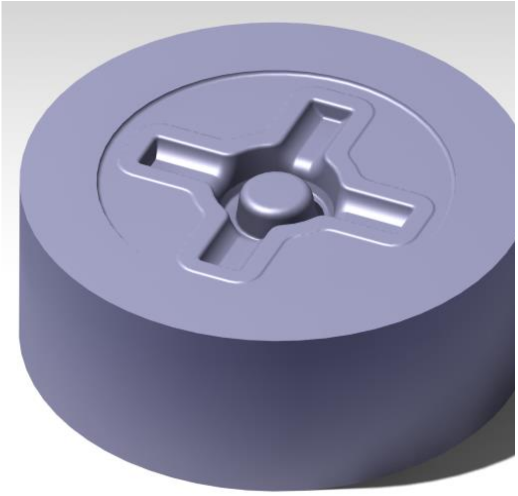


Fig 8: Die with Modified Design

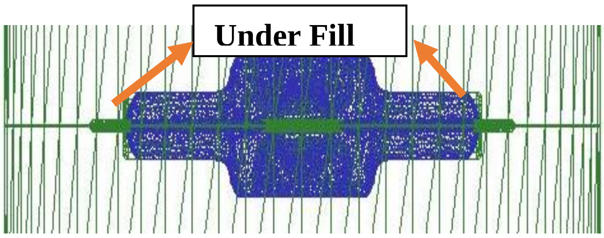


Fig 9: Simulation result of Billet 1

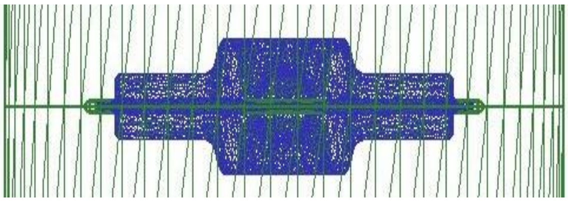


Fig 10: Simulation result of Billet 2

Now the simulation is carried out with the new die design. The result of the simulation is shown in the Fig 9. From the figure it can be observed that there is under filling at the ends of the arms. This under filling is caused due to insufficiency of the material hence a second billet with dimensions Ø60mm X 115 mm is taken and simulation is done. The simulation results shows that thers is no underfilling when the billet 2 is used. It is shown in the Fig 10.

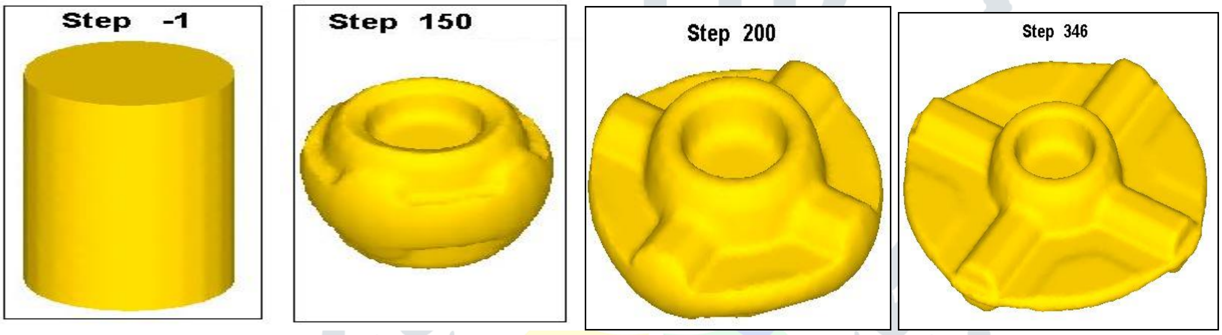
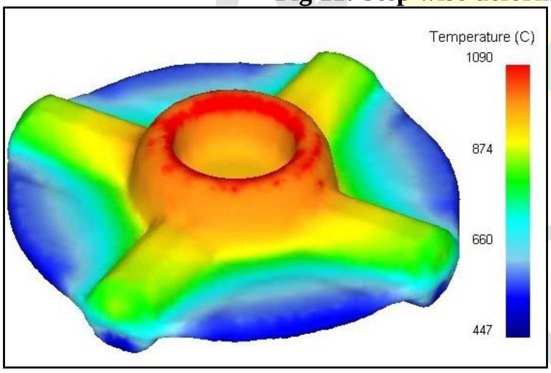


Fig 11: Step wise deformation of Differential spider



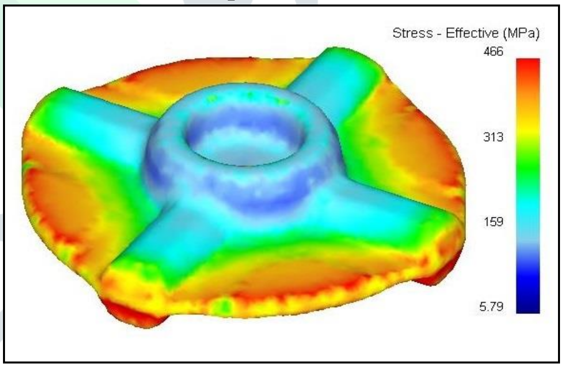
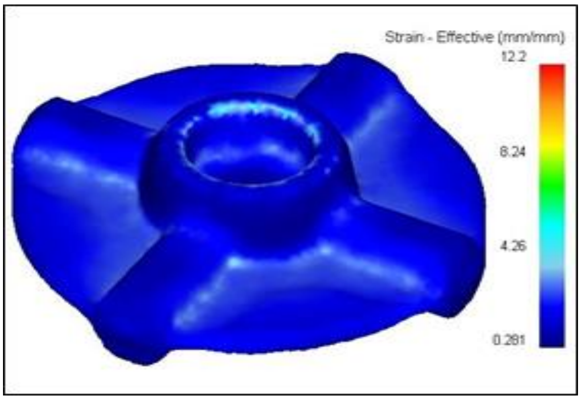


Fig 12: Temperature distribution

Fig 13: Effective-Stress distribution



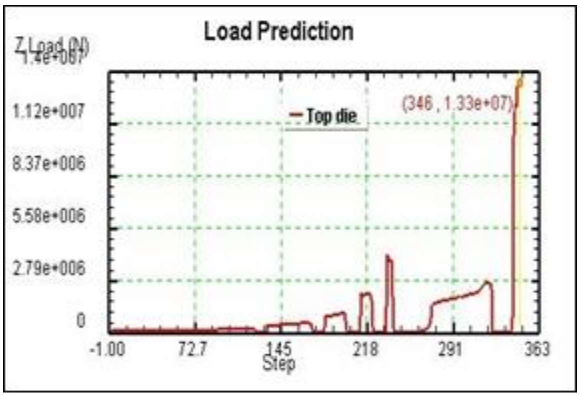


Fig 14: Effective-Strain distribution

Fig 15: Load prediction graphs

5. CONCLUSION:

From the above discussion it can be concluded that

1. This paper presents a method for designing die set for Differential Spider and performing forging simulations using DEFORM-3D. Drop Hammer is used for simulating the forging process for Differential Spider.
2. The first die resulted in under filling at the end of the arms.
3. Under filling effect has been eliminated by changing the shape of the gutter and increasing the billet material.
4. Better die filling is observed while using second billet.
5. Temperature distribution, stress distribution, strain distribution and load can be prediction by using simulation which can be effectively used for improving the process.
6. The forging process can be simulated effectively by numerical simulation DEFORM-3D
7. This paper will provide suitable die design which will help in production process and ultimately produce defect free forging.

REFERENCES

[1] "ASM Metals Handbook" (1996) Vol 14, Forming and Forging.
[2] Martijn H. A. Bonte, Lionel Fourment, Tien-tho Do, A. H. van den Boogaard, J. Huétink, 2010, Optimization of forging processes using Finite Element simulations, Struct Multidisc Optim 42:797–810.
[3] H.M.T. Khaleed, Z. Samad, A.R. Othman, M.A. Mujeebu, A.B. Abullah, M.M. Zihad, January 2011, Work pice optimization and thermal analysis for flash less cold forging of AUV propeller hubs- FEM simulation and experiment, Journal of Manufacturing Processes, vol. 13, 1, pp. 41-49.
[4] Tapas Gangopadhyay, Raj Kumar Ohdar, Dilil Kumar Pratihar, Indrajit Basak, 2011, Three- dimensional finite element analysis of multi-stage hot forming of railway wheels," Int J Adv Manuf Technol 53:301-312.
[5] Indian Standards IS: 3469 (Part I to III) – 1974
[6] S.N. Prasad, R. Sharan, N.P. Saksena, 1982, Forging Die Design and Practices.
[7] Thomas. A., 1995. Die Design, Forging Handbook. Drop Forging Research Association, Sheffield, UK