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A Study on Stress Analysis of AISI 1045 and Reducing Rejection Rate of Work in Forging Using Deform-3d

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ABSTRACT
The traditional process of forging is often determined based on experiences which require repeated testing and repairing of dies. It also involves long production cycle and high prototype cost. Closed die hot forging process is one of the most adopted methods for forming complex shaped parts with satisfactory geometrical accuracy. Over sixty percent of the forgings are processed through this route. The metal flow analysis of the process is complex due to the involvement of a large number of parameters. A number of experimental testing and production-trials are being done in the industry in order to develop a robust manufacturing process. Such practices however involve huge investments in tooling and raw materials, including a great deal of development time and effort. In recent years, finite element method has emerged as a suitable tool for virtual process trials and simulation based design. The aim of this study is to model and conduct FEA on metal element using SOLIDWORKS and DEFORM-3D software packages. This would lead to an improvement in overall efficiency of the process at a lower cost. Through this analysis study, an attempt has been to make to gain an insight into the process parameter influencing the closed die hot forging and their interaction. As sample case, metal component is taken for investigation. A simulation-driven approach using a commercial package (DEFORM-3D), based on finite element method, and was adopted. The result will be useful for tool and die developers as well as work developers for optimizing the forging process and to analyze deformation in the components especially in automotive parts.

Keywords: DEFORM-3D, Deformation, FEA (Finite Element Analysis), Forging, Optimizing

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I. INTRODUCTION

Forging is defined as a metal working manufacturing process in which the useful shape of work piece is obtained in solid state by compressive forces applied through the use of dies and tools. The required shape is obtained from a simple shape like billet, bar, ingot into the desired shape in one or more stages. It is one of the oldest methods in metalworking operations, dating back at least 4000 B.C. Forging were first used to make jewelry, coins and various implements by hammering metal tools made of stone. Traditionally, forging was performed by a smith using hammer and anvil. Using hammer and anvil is a crude form of forging. The smithy or forge has evolved over centuries to become a facility with engineered processes, production equipment, tooling etc.

Forging is often classified according to the temperature at which it is performed: '"cold," "warm," or "hot" forging. Forged parts can range in weight from less than a kilogram to 170 metric tons. Forged parts usually require further processing to achieve a finished part [1]. The main advantage of hot forging is that as the metal is deformed work hardening effects are negated by the recrystallization process.

Usually, the shapes of components manufactured by forging are complex; and many defects are induced during the process of forging such as incomplete forging penetration, Surface cracking, cold shut, under filling, flakes, improper grain flow [2,3]. Simulation and manufacturing of a connecting rod from ultra-fine grained material and isothermal forging [4] and reduce crankshaft defects [5].

The authors have analyzed the effects of varying coefficient of friction, the changes in structure and temperature field in the forging process [6] and to perform die stress analysis. The authors have summarized the distribution of stress and strains in the various regions of the part as well as the die. The authors have been able to analyze the material flow of a forging component using DEFORM™-3D [7]. Simulation of stresses, strains and temperature at different regions have also been done for defect analysis [8]. The aim of this research is to provide an introduction to finite element analysis of forging process of a sample metal component utilizing DEFORM-3D Software [9]. This research would be beneficial to provide an insight into FEA for a novice designer [10].

This paper has been divided into 5 sections. First section is the introduction about forging and a brief about the utilization and objective of this research paper. In the second section, various literature reviews are discussed. In the third section, the methodology being followed in the paper is being discussed. Third section discusses about the numerical simulation of the forging process. In the fourth section various results and findings from the numerical simulations are being discussed. Fifth section gives the conclusions of the research.

II. LITERATURE SURVEY

The broad objective of the literature survey is to provide requisite background information relating to the proposed study. The identified areas of the survey include:

2.1 Closed die forging (CDF) process and the process parameters

The forging process is deployed aiming at transforming the simple part geometry, into the desired final shape by controlling plastic deformation. In closed die forging (also known as impression die forging), the die imparts pressure on the material through the interface which results in the generation of cavity shaped component. The hot forging criteria together with closed die condition can produce a higher degree of deformation with reasonable geometrical accuracy, making it a preferred process for mass production of parts with complex shape [11].

The closed die hot forging process is most suitable for generating complex shaped work parts with reasonable profile accuracy [12]. The process is quite complex from the analysis point of view as there exist several parameters, that can influence the process and to reduce rejection rate [13, 14]. The physical phenomena defining a complex closed die hot forging operation are generally difficult to express in terms of quantitative relationships. A typical closed die hot forging process comprises many input variables that may be clubbed into the following groups [15]:

• Product variables
• Material variables
• Tooling parameters
• Machine parameters
• Deformation zone characterization
• Tool and work interface behavior

These parameters in broader terms can be classified into two categories: design and process parameters.

The design parameters include the preform shape design and die design. The preform shape design is primarily dependent upon the number of stages involved. The die design includes parameters such as flash thickness, flash width, draft angle, corner and fillet radius, input billet geometry etc.

The process parameters include input temperature of billet and die, interface friction, speed of deformation etc. These have been studied in a number of publications; some of them would be dealt with.

2.2 Approaches for Analysis of the Closed Die Forging Process

Several methods, developed over time, exist for analyzing the metal forming processes. The methods can be broadly divided into Analytical Methods and Numerical methods.

The main objective of such analysis is to:

• Establish a kinematic relationship between the under formed part and formed part, so that the metal flow during the process can be predicted.
• Predict the process output parameters such as load, stress, strain, temperature etc.

2.2.1 Analytical Methods

The analytical methods known are mostly based on certain assumptions, which help simplify the formulation and an approximate solution is derived. Some of the common analytical methods and their approaches are as follows:

2.2.1.1 Uniform Deformation Energy Method

This method is based on energy balance or ideal work concept. In this method, a homogeneous deformation is assumed without considering the effect of friction. An average value for the forming load and stresses can be estimated by using this method.

2.2.1.2 Slab Method

In this method, the work-piece is assumed to be comprised of several small sections termed as slabs. Simplified assumptions are attributed for stress distribution in such slabs. The method of solving involves formulation of equilibrium equations and solving the same between the stress compatibility and boundary condition. The variation of temperature and flow stress is not included in the formulation. So, this method gives an approximate value for stress distribution and forming load prediction.

2.2.1.3 Slip line Field Method

This method is mostly suitable for plane strain situations. Work material is assumed as rigid and ideal plastic in nature. The velocities are found out by comparing the flow pattern at different stages of deformation. The actual flow pattern is generated by imprinting fields are calculated using plasticity equations from the stress distribution. The effect of phenomenon such as strain hardening is not included in the formulation. The variation in flow stress and its effects are also not considered. So, this method is not suitable for finding out the exact nature of distribution of stress throughout the work piece; as it occurs in the real life.

2.2.1.4 Visio-plasticity Method

This method combines the experimental findings to the calculation. The work piece is practically deformed and velocity vectors grids on the surface of the work piece. The load and strain rates are calculated based on velocity vector and the stress distribution is obtained by using appropriate plasticity equation.

2.2.1.5 Upper Bound Method

In this method, a suitable kinematically admissible velocity field is assumed, so that it satisfies the velocity boundary condition. The calculation is based on limit theorem concept and can predict approximate load and velocity distribution.

A review of the above-mentioned analytical methods revels that, some of the idealized assumptions in calculation, limit their capabilities for handling complex metal forming cases such as closed die hot forging process. Moreover, none of the methods consider the effect of temperature gradient in work material and its effects during the processing, which is predominant with CDF process.

III. METHODOLOGY

Tools used –SOLID WORKS, Deform-3D

DEFORM 3D is FEM based software used for dynamic analysis. It will be useful to know about the flow of material in die cavity after simulation [16].

Typical applications include: close die forging, open die forging, machining, rolling, extrusion, heading, drawing, cogging, compaction, upsetting.

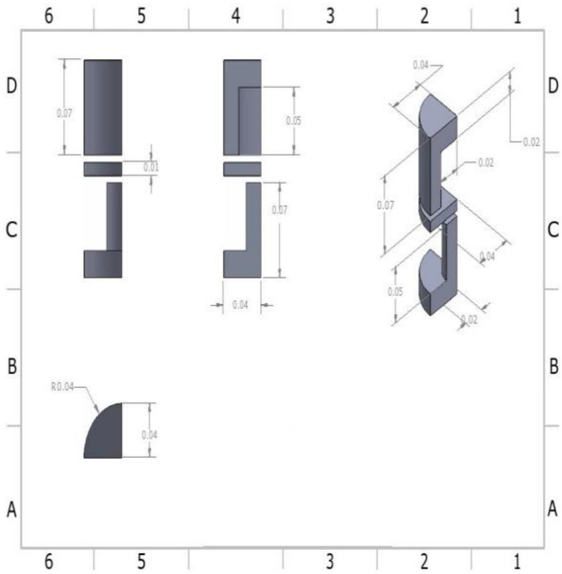

Fig. 3.1 Drawing parts in SOLIDWORKS

3.1 Dimensions of die

The total dimensions of the die and work piece are labeled in the figure 3.1 given above using solid works software.

3.2 Steps of simulation

Step 1:

Selecting the new problem in file in DEFORM 3D.

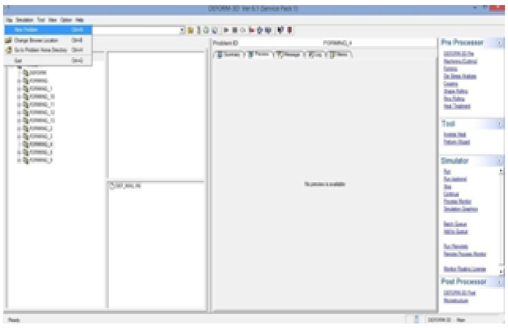

Fig 3.2.1Selecting the problem

Step 2:

Selecting the type of problem setup as close die forging is the forming process.

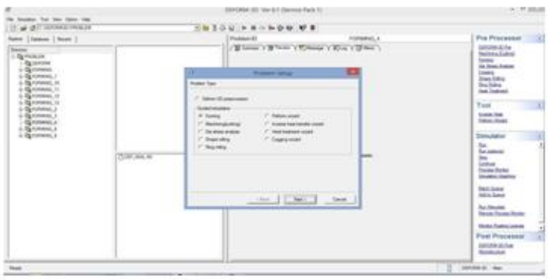

Fig 3.2.2 Selecting the problem type

Step 3:
Uploading the work piece and dies from SOLIDWORKS in STL format and generating meshing. Meshing means dividing work piece into smaller parts. Mesh parts are joined by number of nodes.

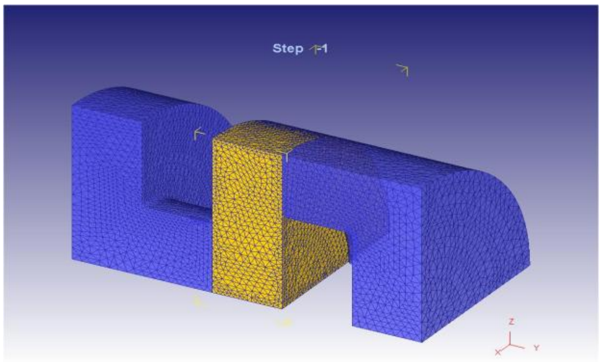

Fig 3.2.3 Uploading work and die for generating mesh

Step 4:
Uploading of upper and lower die as shown in the figure is done.
Position of dies and work piece is done by setting XYZ axes. Start the stress, strain, velocity, temperature, damage analysis using different values of coefficient of friction.

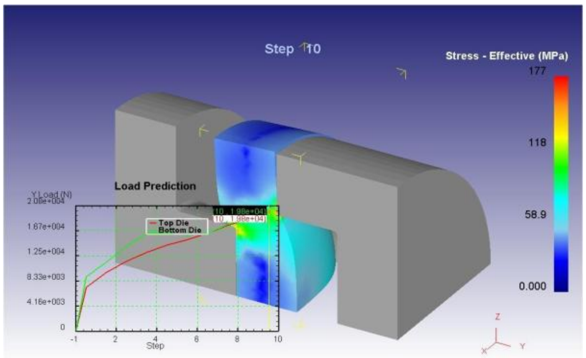

Fig 3.2.4 Work stress analysis

IV. RESULTS & DISCUSSIONS

The process parameters in the simulation are as follows:

SL. No	PARAMETER	VALUE
1	Work piece Material	AISI 1045
2	Die material	AISI H-13
3	Work piece temperature	1200 ^{0}C
4	Die temperature	200^{0}C
5	Work piece volume	18832 mm^3
6	Die velocity	1mm/s
7	Coefficient of friction	0.3,0.4,0.5,0.6,0.7
8	Heat transfer Coefficient	11
9	Number of steps	10

4.1 Effective stress analysis

The stress diagram of the forged component is as shown in figure. It can be seen from the figure that the maximum effective stress of the forging process occurs where the edges of top die and bottom die come in contact with the work piece.

As the top die moves, the blank is made to come in contact with bottom die. Due to which the work piece is subjected to great deformation, large stress, thus prone to wear, cracking. According to the deformation, the stress and strain trajectories of the forged component are studied by 10 points of P1~P10.

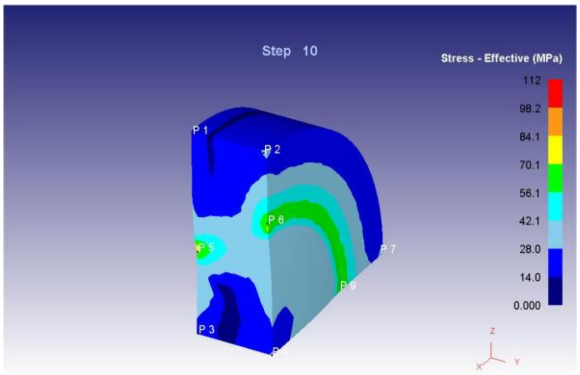

Fig 4.1.1 Effective stress in work piece

As seen in the figure the P10 is the maximum stress point with a value of 75.4MPa, followed by points P5, P6, P7 which indicate that the region where the edges of both top and bottom die come in contact with the work piece is the region of high stress. Similarly, from the graph P8 is the point of minimum stress, whose value from the graph is obtained as 22.9MPa.

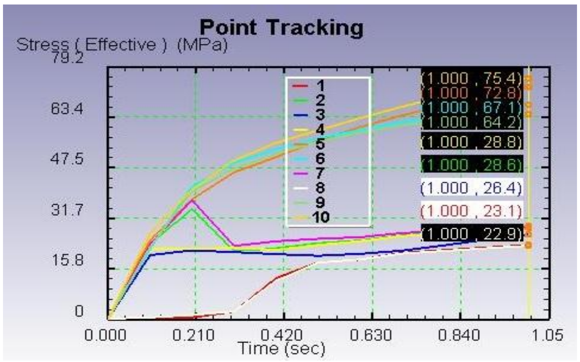

Fig 4.1.2 Graph of effective stress in work piece

4.2 Effective strain analysis

The strain diagram of the forged component is shown in figure. The strain present in the work piece at the last step of simulation is shown. The strain at 10 points (P1~P10) in the work piece is analyzed.

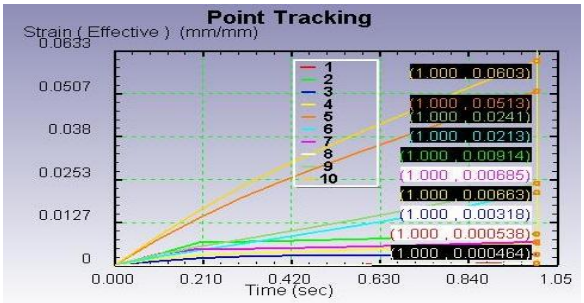

Fig 4.2.1 Graph of effective strain in work piece

We can see that the point P10 has the maximum strain of 0.0603mm, followed by the points P5, P9, P6 and the minimum strain is obtained at point P3, whose value is 0.000464mm, followed by P4, P7, P2 hence we can conclude that the region where the top die makes contact with the work piece is the region of maximum strain.

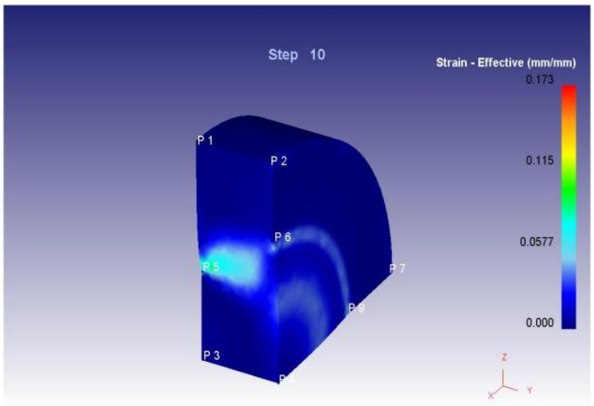

Fig 4.2.2 Effective strain in work piece

4.3 Analysis of velocity vector field

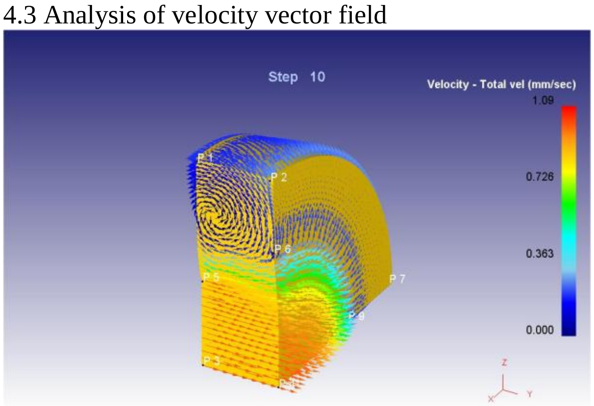

Fig 4.3.1 Velocity vector field diagram

The Velocity vector field diagram is shown in the figure. From the graph given below it can be seen that maximum velocity of the material is at point P4 and P10 whose value is 1mm/sec, followed by the P7, P2, P6, P9 which indicates that edges of both top and bottom die come in contact with the work piece is the region of high velocity of flow of work material. The lowest velocity is at the point P5 whose value is 0.182 mm/sec. The above results indicate that the region where the top die makes contact with the work piece is the region of maximum velocity of flow.

It is noted that the velocity of material flow is minimum where the bottom die is in contact with the work piece. The direction of flow of material particles is from P3, P5 to P4, P6. The surface which contact with the top die is in direction from P6, P9 to P2, P7 and then travels in curly way towards P1 and P8.

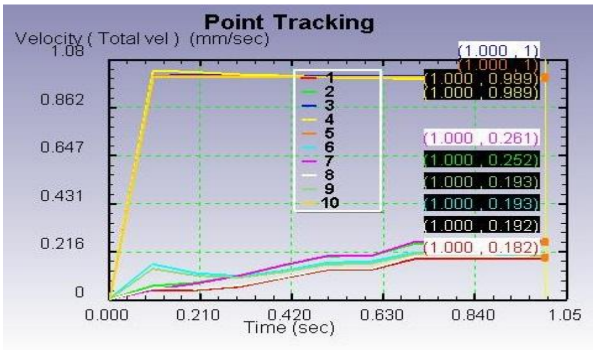

Fig 4.3.2 Graph of velocity vector field diagram

4.4 Temperature analysis

The maximum temperature is in order of points P1, P4, P2, and P7 in corner surface of work piece. At the bottom surface temperature distribution decreases from points P3, P10, and P5. The junction between the upper die and lower die slides at the points P9, P8 have the intermediate temperature range values.

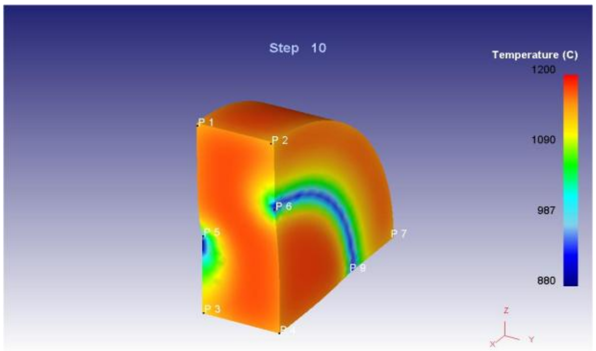

Fig 4.4.1 Temperature analysis diagram

The temperature distribution graph given below shows the temperature variations at each and every marked point as described above.

The maximum temperature obtained after 1.05 seconds of forging process is 1150^0C. The intermediate temperature is found out as 1120^0C and the lowest value is 980^0C.

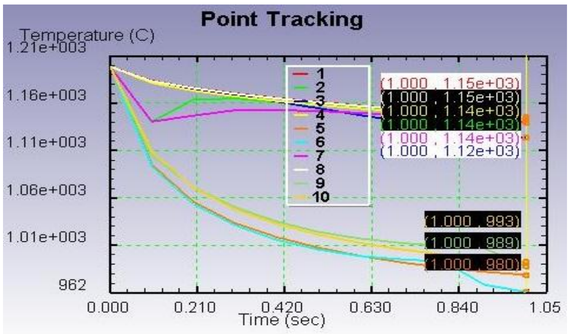

Fig 4.4.2 Temperature distribution graph

4.5 Damage analysis

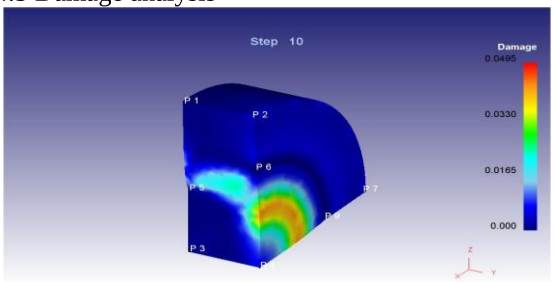

Fig 4.5.1 Part under damage analysis

The maximum damage to the workpiece is at points in between P6, P9 and P4 which means the sliding surfaces between the dies. The minimum damage occurs in the region where at centre and outer lateral surfaces.

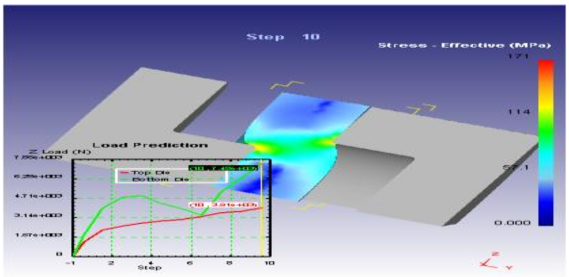

Fig 4.5.2 Maximum stress vs Damage analysis

Here damage occurs at maximum stress and strain points.
For different set of coefficient of friction, stress and stain values changes. As value of coefficient of friction increases the stress values get also increases.

V. CONCLUSION

Thus, with the help of DEFORM-3D, simulation was carried out at different values of coefficient of friction. Through this analysis we reach at a conclusion that stress at workpiece can vary with various input parameters and we can find out all the resultant stress, strain, damages at different points choose randomly in a work piece at any time using the graph obtained. This study gives importance for future reference in manufacturing of works in forging process by regulating stresses at different points. Some of the old analytical methods revels that, some of the idealized assumptions in calculation, limit their capabilities for handling complex metal forming cases such as closed die hot forging process. Moreover, none of the methods consider the effect of temperature gradient in work material and its effects during the process.

The maximum stress is found in central part of the work piece. Thus points of maximum damage also occur by seeing in analysis data. Therefore, to reduce stress and damage, the remedial measure is to thicken the billet at these points. Thickness can vary depending upon the stress value at these points as stress is the force per cross sectional area. As cross sectional area increases stress can be reduced and bring to uniform stress in all the points of the work piece.

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