Die Life Improvement In Hot Forging Using Design of Experiment

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Abstract*- Forging involves very high amount of compressive forces to deform the metal which ultimately results into the maximum die stress. Due to maximum die stress the wear of the die is taking place. Due to die stress there may be chances of creating a die cracks. So here the objective is to reduce the die stress in the forging. Here in this paper the forging of a front axle beam is taken and iteration carried out using different parameter value during forging operation and to find out the optimized parameter for forging operation. There are parameters like billet temperature and die temperature which responsible for the die stress. So iteration of these dies is carried out for different values of these parameters for the die stress values. In forging of front axle beam currently there are two operation which are blocker and finisher which are to be carried out separately, so in this project the integral die concept is used where the both operation is to be carried out in a single die block to reduce the die stress which is called as an integral die. So in this project analysis to be carried out for both separate as well integral dies and to find the comparative matrix.*

Keywords- Forging Process, Die Life, Front axle beam, Die Stress.

I. NOMENCLATURE

F	Force (T)
Sa	Stress amplitude (MPa)
E	Energy (KJ)

II. OBJECTIVE

As forging involves high amount of stresses to deform the metal into the final shape, which is leads to the increasing die stresses. So the main objective is to reduce the die stress during forging operation. There are many parameters which affect the die life due to increasing die stress. So objectives is to check the die stress values for separate die forging using different values of selected parameters like die temperature and raw material temperature. Also to find the die stress values for integral dies which combines two operations in the single dies. So the final objective is to form the comparative matrix for both the separate die forging and integral die forging and to track the optimized parameter.

III. INTRODUCTION

Forging is a manufacturing process by which a billet of simple cross-section is plastically deformed by compressive forces, forging classified according to the temperature at which the process is done: cold forging (a type of cold working), warm forging, or hot forging (a type of hot working). Forged parts are ranged from kilograms to tones. Forged parts are used in a machines and mechanism in which it is required the part is to have a high strength. Such forging components required further machining to achieve finished part. Today forging is a major worldwide industry.

Forging tools (dies) are subjected to sever pressures, which are determined by the effect of state of stress. The tools and dies must be made of suitable materials to accommodate these pressures and parameters, and need to be designed with configuration, which provide the maximum resistance to plastic yielding. The tool and die materials are selected and manufactured with greater care. As life of an any die or impression can be enhanced but this paper mainly focuses for increasing the die life of a front axle beam, which will in turn be useful for dies with any impression.

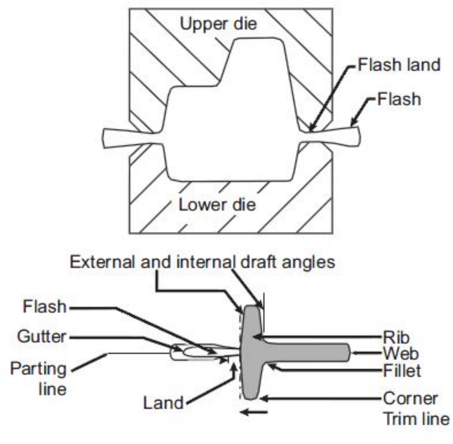

Figure 1: Impression Die Forging[4]

Impression-die forging is also called closed-die forging. In impression-die forging, the metal is placed in a die resembling a mold, which is attached to the anvil. Usually, the hammer die is shaped as well. As you can see in the Figure 1 that impression is divided into the two halves and gap is maintained which is called as a flash to come out the material out of the impression after it gets filled. The hammer is then dropped on the heated billet, causing the metal to flow and fill the die cavities. [4] The hammer is generally in contact with the work-piece on the scale of milliseconds. Depending on the size and complexity of the part, the hammer may be dropped multiple times. Excess metal is squeeze out of the die a cavity is referred to as flash. The flash cools more quickly than the rest of the material; this cool metal is stronger than the metal in the die, so it helps prevent more flash from forming. This also tends the metal to completely fill the die cavity. After forging, the flash is removed. [1]

Most engineering elements and metal and alloys can be able to forge via conventional impression die methods, among them are: carbon and alloy, tool steels and stainless, aluminum and copper, alloy, and certain titanium alloys.

Some metals may be forged cold, but iron and steel are almost always hot forged. Hot forging avoids the work hardening that would result from cold forging, which would increase the difficulty of performing secondary machining operations on the piece. Also, while work hardening may be desirable in some conditions, other methods of hardening the piece, such as heat treating, are generally more cost-effective and more controllable.

IV. LITERATURE REVIEW

Manas Shirgaokar[1], The main objectives discussed in this chapter are, develop adequate die design and process parameters by Process simulation to assure die fill, preventing defects such as laps and cold shuts, controlling the process parameter limit. Improve part quality by: Predicting and improving grain flow and microstructure, reducing trial and error methods and improving material yield. Predict forging load and energy and temperatures so that: Tool failure can be avoided; appropriate forging press can be selected. This paper helps me to understand the process design in hot forging.

Ebara[2]; In this research paper researcher summarized all the influencing variables while hot forging operation which leads to the failure of the dies. The failure analyses examples for hot forging is explained in this paper with four influencing variables such as:

- **Die materials:**
  There are many reasons regarding failure due to die material like non-metallic inclusions, insufficient cleanliness and inadequate heat treatment.
- **Die design:**
  He explained parameters like insufficient impression shape, insufficient pre-forming shape.
- **Die manufacturing:**
  Insufficient pre-heating of dies, inadequate surface treatments and weld repair.
- **Forging operations:**
  Insufficient heating of billet and inadequate lubrication applied during forging operation.

So in my project I used parameters which are in the list of forging operations in this paper. This paper is helpful for me because it focuses on the reasons for the die failure.

Siamak Abachi[3]; In hot forging operation, die wear is the main reason for the failure if dies. In this paper author explained the wear analysis of forging dies.

From the finite volume study of dies for hot forging is studied and concluded that the region of high stresses may occur, there is more plastic deformation of dies which results into the more forging dies wear.

So while doing my project I taken care that in the impression die there should no sharp geometry in blocker operation as it leads to high stresses.

T.Altan[4]; In this paper author explained basics of forging. Author explained process variables in forging design process. This paper includes the data related to how actually blocker and finisher relation is to be maintained.

This paper also delivers a brief knowledge about process simulation variables to predict metal flow and forging stresses.

V. METHODOLOGY

The methodology for this very project is called as “Design of Experiment” also known as DOE, this methodology basically uses a procedure that involves carrying out a number of trials by using different combination of the few selected parameters, which are: Die sprays, Die design (Flash thickness, Land width, Height of dies), Impression on the die, Stresses developed on the die, Die block material, Temperature of billet, Temperature of die, Condition of press used.

Out of the above eight parameters we've decided into three parameters to be selected which are:

1. Height of dies
2. Temperature of billet
3. Temperature of die

The reason why these three parameters were selected was because, out of all the eight parameters, it was possible for only these three parameters (Height of dies, Temperature of billet, temperature of die) to tweak their values in the software in an economical manner and cause major changes in terms of results. The methodology of DOE arranges these parameters in the following manner:

Table No.1: Tolerance range for each parameter

Parameter	Min	Max
Die height	350mm	275mm
Billet Temperature	1150°C	1200°C
Die Temperature	150°C	250°C

As seen in the table 1, every scenario will have different results as each scenario has a different combination of minimum and maximum values of the three selected parameters.

As there are three parameters selected so $2^3 = 8$ iterations or scenario are to be carried out. These 8 scenarios to be arranged as per respective minimum and maximum values of the selected parameters. Results will be considered in terms of force and die stress.

The scenarios will be arranged in the following manner:

Table No.2: DOE methodology with selected values

1] BILLET TEMPERATURE (°C) (after Reduce Role) : 1150 – 1200			
2] DIE TEMPERATURE (°C): 150 – 250			
3] HEIGHT OF DIE (mm): 275 – 350			
SCENARIO NO.	INPUT PARAMETERS		
	BILLET TEMP.	DIE TEMP.	DIE HEIGHT
1	1150	150	275
2	1200	150	275
3	1150	250	275
4	1200	250	275
5	1150	150	350
6	1200	150	350
7	1150	250	350
8	1200	250	350

scenario no. 1 to no. 4 are identical to scenario no. 5 to no. 8 in terms of billet temperature and die temperature there won't be any change in metal flow, forces, energy and die wear. Thus, only die stress analysis is carried for scenario no. 1 to no. 4. So the dies are to be analyzed for the 8 scenarios as shown in table no.2. After comparing the results of these 8 scenarios the optimum parameters is to be selected so as to reduce the die stress which ultimately increase the die life.

VI. SIMULATION

The process modeling for the simulation process of forging component consist of hypermesh and forge software. In forge software we do the die stress set up and metal flow set up. So we can analyze both metal flow and stresses induced in the dies.

So basically there are two stages in the forge software is pre-processor and post-processor. In pre-processor we do the set up of dies and apply material input to the raw size for forging. So after set-up and computation we analyze the dies that are we analyze the metal flow and die stresses.

The material used for dies and tooling is Die Steel DIN 1.2714. Die steel is characterized by high hardness, wear resistance, and strength combined with sufficient toughness as it is exposed to the high stresses and high temperature. They have good hardening properties due to presence of alloying elements like Cr, Ni, Mo, V. Din 1.2714 is the grade in the German standards. Hardness for die steel in hardened and tempered condition is from 38 to 42 HRC.
Chemical composition for DIN 12714 is as follows,

Table No. 3: Chemical composition for DIN 1.2714

Material	Chemical Composition (% Wt.)						
	C	Si	Mn	Cr	Ni	Mo	V
DIN 1.2714	0.52	0.17	0.87	1.05	1.7	0.38	0.1

In this project the material used for the raw material for the forging of a front axle beam is Medium Carbon Steel. It is also known as mild steel. The advantage of the medium carbon steel is it is low cost material which can shape easily. Composition of the medium carbon steel is 0.29 %-0.54% carbon, with 0.60 %-1.65 % Manganese. Medium carbon steel is ductile and strong, with long-wearing properties.

A. Pre-processor:

After meshing is completed in Hype-mesh, the dies are imported to a software called 'FORGE' for carrying of the metal flow setup in which the adjustment of the dies and the billet is done using X,Y,Z planes along with feeding the various 'Material', 'Geometric', and 'Process' parameters as mentioned above . (The above parameters are needed to be defined for both the processes 'Blocker & Finisher').

In a metal flow setup the die are surface meshed and the billet is volume meshed we are interested deformation of the billet and not the dies, whereas in the case of 'die stress' setup the dies are volume meshed as we want to analyze the stress zones developed on the dies

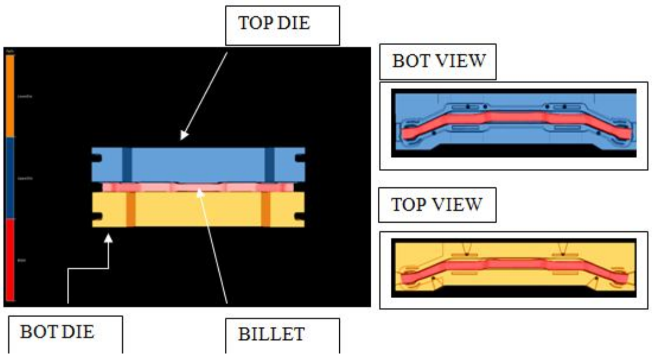

Figure 2: Setup for metal flow in Pre-Processor

For the analysis on die stress as state variable a 'Die stress' setup is supposed to be carried out. As mentioned before, the dies in a die stress setup are 'volume meshed' and the result are loaded on these dies which are generated in accordance with the metal flow setup of the same process.

Importance of the dies stresses analyze is very effective as we can track the zone of maximum stresses so that we can avoid the die crack and help to increase the die life. In below Figure 3 the set up for the die stress is shown.

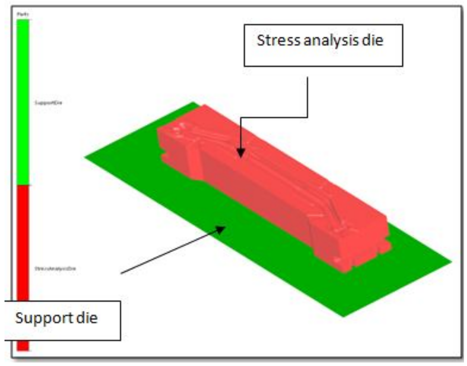

Figure 3: Die stress setup in Pre-Processor

B. Post-processor:

This provides extensive information of the forging process. The output of process modeling can be discussed in terms of the metal flow, the state variables, and equipment response during forging. These output results are viewed in the post-processor.

C. Metal flow:

The information on metal flow is very important for die design. Improper metal flow procedure creates defects in the forging. In real closed-die forging, it is necessary to wait until the forging is finished to see the forged part and the defects in it, if there is one. The advantage of computer simulation of forging is that the entire forging process is stored in a database file in the computer and can be able to track. Whether there is a defect formed and how it is formed can be shown before the actual forging. The lap formation can be able to eliminate by changing the work-piece geometry (the billet or preform), or the die geometry, or both. The computer modeling can again indicate if the corrective measure works or not. The results seen in relation to metal flow of the process in forging are fill up and die wear.

D. Equipment Response:

In process modeling output the equipment response is to be seen in terms of the force generated and energy required. And these output results are to be observed in the following manner: [1]

Force:

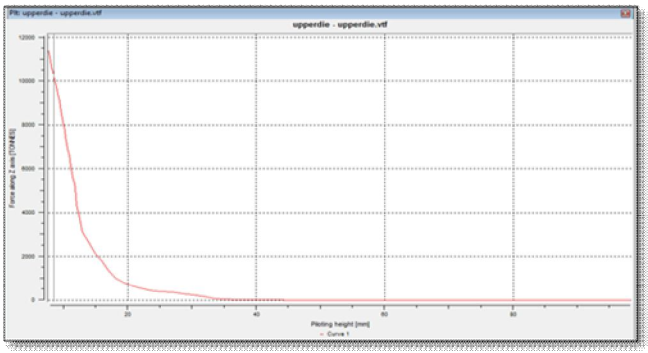

Figure 4: Force developed for the press

X-axis: Ploting height (Land to Land distance in the negative Z direction, taking land as reference) [mm]
Y-axis: Force along the negative Z direction. [TONNES]

Energy:

X-axis: Piloting height (Land to Land distance in the negative Z direction) [mm]
Y-axis: Energy required for that particular punch.

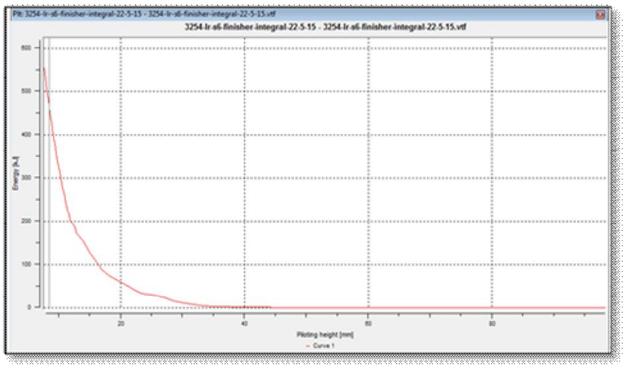

Figure 5: Energy required by the press

E. State Variable:

The distribution of the state variables, such as the strain, strain rate, stress developed in the dies and temperature of the billet, at any stage of a closed-die forging can be able to plot from the database file saved for the forging simulation. In this case we consider only one state variable which is of most importance in the case of 'Die Life'. [1] The history of these state variables can also be tracked. For the analysis on die stress as state variable a 'Die stress' setup is supposed to be carried out. As mentioned before, the dies in a die stress setup are 'volume meshed' and the DR3 result are loaded on these dies which are generated in accordance with the metal flow setup of the same process.

The high stress zone is shown after the die stress analysis in following manner,

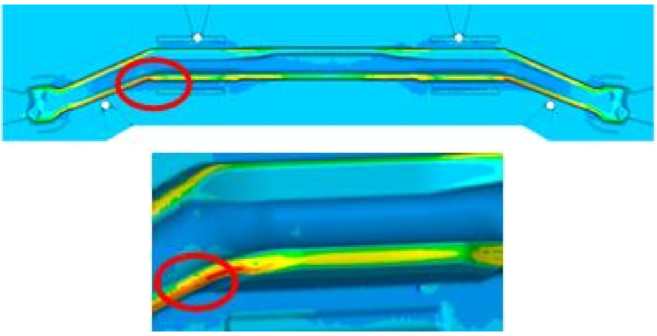

Figure 6: The maximum die stress zone in the dies

VII. RESULT AND DISCUSSION

Based on the above DOE methodology explained, following are the results plotted for eight scenarios and for separate and. Each scenario shows input parameters considered and accordingly what results we got using them. Green label indicates best or optimum possible input parameters, whereas yellow label indicates currently used parameters to forge the part.

Below table is related to blocker die stress and force requirement results in separate assembly, where scenario no. 5 represents currently used parameters and scenario no. 3 represents optimized parameter in terms of die temperature when increased from 150°C to 250°C will result in lesser die stress values by 26.7%.

Table No. 4: Design of experiment for blocker separate dies

(Design of Experiment sheet) for blocker separate						
1] Billet Temperature (°C)				1150-1200		
2] Die Temperature (°C)				150-250		
3] Height of Die (mm)				350-275		
Sr. No	Input Parameters			RESULTS: Die Stress (max) (MPA)		
	Billet Temp.	Die Temp.	Die He-ight	Forces	Top	Bottom
1	1150	150	275	11,950T	1983.1	1777.67
2	1200	150	275	10,931T	1872.23	1600.33
3	1150	250	275	12,447T	1781.21	1789.03
4	1200	250	275	10,965T	1859.78	1538.57
5	1150	150	350	11,950T	2098.91	1657.57
6	1200	150	350	10,931T	1865.23	1466.03
7	1150	250	350	12,447T	1757.76	1732.87
8	1200	250	350	10,965T	1905.51	1489.52

Table No. 4: Design of experiment for blocker integral dies

(Design of Experiment sheet) for blocker integral						
1] Billet Temperature (°C)				1150-1200		
2] Die Temperature (°C)				150-250		
3] Height of Die (mm)				350-275		
Sr. No.	Input Parameters			RESULTS: Die Stress(max) (MPA)		
	Billet Temp.	Die Temp.	Die Heig ht	Forces	Top	Bottom
1	1150	150	275	12579T	1786.8	1756.21
2	1200	150	275	11688T	1648.23	1588.64
3	1150	250	275	12594T	1735.16	1654.34
4	1200	250	275	11628T	1618.66	1561.06
5	1150	150	350	12579T	1758.72	1710.58
6	1200	150	350	11688T	1644.56	1571.25
7	1150	250	350	12594T	1757.76	1652.84
8	1200	250	350	11628T	1590.9	1577.84

Table 5 is related to blocker integral die results in integral assembly, where scenario no. 5 represents currently used parameters and scenario no. 8 represents optimized parameter in terms of billet temperature when increased from 1150°C to 1200°C and die temperature from 150°C to 250°C will result in lesser die stress values by 10.56% and also 8.17% reduction in forces.

VIII. SUMMARY

Following is the summary:

Temperature of die and billet plays a major role in forging process, most of the optimized results on bases of comparison, suggest that die temperature should be maintained at around 250°C whereas billet temperature to be maintained at 1200°C. High stress is only at the weakest zone of the impression on the die which ultimately worn at maximum amount than other which required to pulled out the die for weld repair from production. Due to this the less number of parts can be able to forge in a single run. In this project the weakest zone is cobra section. When compared between separate and integral die assemblies, drastic drop in die stress values observed (25% to 55%). It is obvious that when dies are combined together to form integral dies set gives better strength and rigidity to the impression. Thus, helps to give better productivity and die life, also it decreases the cycle time required for forging as in one stroke the blocker and finisher impression is formed. While performing design of experiments die height parameter was considered, but due to continues production and wear of the dies, height as a parameter cannot be maintained constant also, the results are showing not much difference in stress values with difference in die height which can be neglected. Due to the changes in the die temperature and billet temperature, there has been as considerable drop in force requirement i.e. 8%. As seen in the analysis and discussion chapter we can see that currently in a single run the company able to produce around 950-1000 parts in a single run after which the die is pulled out for a very similar front axle beam due to wear of the impression at the cobra area. So in this project the dies are analyzed under different scenarios and compared the die stress values with each other and we can conclude that if the die temperature is used 250° C then there is a drop in the die stress value.

Based on results and conclusion this DOE suggests that, ‘Integral die’ assembly performs far better than ‘Separate die’ assembly and is beneficial for better productivity in terms of economical aspects.

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