INCREASING THE LIFE OF HOT FORGING DIE OF AN AUTOMOTIVE PART

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ABSTRACT. *There have been traditional methods for the hot forging dies / tools to improve their fatigue lives. There should be a suitable computer simulation method to increase the fatigue life (total no. of forgings produced by the die) of forging die. This paper focuses on the modeling, simulation and analyses of the hot forging die for connecting rod of a 70 c.c motorcycle. The development of a 'CAD' model of forging die and conversion of sharp corners / edges in the cavity to fillets, of possibly optimum sized radii, were done through suitable 'Designing and Simulation' tools. After this optimization, different stresses in the forging die would reduce. Next included, by using a reputable 'Analyses' software, is the analyses of different stresses for the un-simulated and simulated forging dies which helped to predict the Fatigue Lives of these dies. The software used should be capable of achieving the all accurate results, as in this working. The final results are in the form of decrease in the different stresses of cavity and the increase of Fatigue Life of die cavity.*

Keywords. Hot Forging Die, Corner radius, Simulation, Stress, Fatigue Life.

1 INTRODUCTION

In forging industries of Pakistan, usually there was no practice to calculate or analyze different stresses produced in the hot forging dies. There was no suitable software available for calculating & predicting these stresses and fatigue lives of hot forging dies. Generally more thermal stresses & other stresses were produced at sharp corners present in the forging die, due to which the die had less Fatigue life. A forging die is usually changed after its traditionally calculated life has been spent. Often, the radii of different fillets or corners are not optimum values. The material of die might not be right or with exact grade. Material of die is usually not tested in all respects. Therefore, die have to be given an optimum design, minimizing all stresses produced in it, so as increasing the fatigue life of die.

In this research, specific material of the die would be used. The mechanical forging press of required capacity will be recommended. Analyses for different stresses of the die have to be done which will help to predict the Fatigue Life of die. Now a days, for better design of hot forging dies, sharp edges / corners are converted to fillets of nearly optimum sizes and the dies are with estimated dimensions. The lubricant used in these dies, lowers the thermal stresses produced. After optimizing design and analyses for different stresses, the Fatigue Life of forging die for connecting rod would be increased.

Purpose of this research is to model and simulate the hot forging die of connecting rod of motorcycle through suitable Designing and Simulation tools. For this, a 'CAD' model of die will be developed with the help of a design software and the simulation will be done. Then the analyses for different stresses will be performed with the help of an 'Analyses' software. The expected results would be in the forms of the decrease in different stresses and increase of Fatigue Life of hot forging die.

2 Forging Die, in Impression Die Forging:

Impression die forging presses metal b/w two dies (tooling) that have a precut profile of the required part.

First we should have the geometry of completed part for the beginning of design of a forging die and process. The part shape, material to be forged and the kind of forging equipment to be used are considered. Then the design of finisher die is worked out having allowances for flash, shrinkage, fillet and corner radii, positioning of parting line etc.

Fig. 1 shows the main concept of impression-die forging. It shows, the upper and lower dies pressing the metal, the excess material in the form of 'flash' in the area covered called the flash land. The dimensions of flash and billet (raw material for forging) dimensions affect:

i) The allowance for flash ii) The forging energy
iii) The forging load iv) The die life

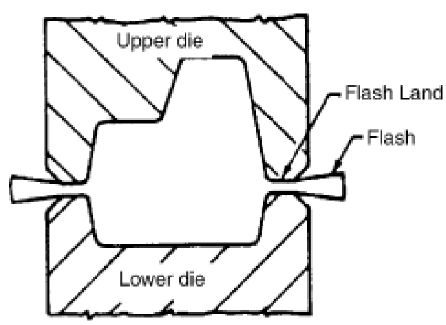

Figure 1: A die set in impressed-die forging having flash

2.1 Design of Finishing Dies:

[1] stated that first the forging geometry is obtained from the machined part drawing by modifying this part. Starting with the forging geometry, the die designer designs the finisher dies by:

- Selecting the appropriate die block size and the flash dimensions
- Estimating the forging load and stresses, that the dies are not subjected to excessive loading

The dimensions of flash should be optimized. To fill the die cavity it is desirable to increase the die stresses by restricting the flash dimensions (thinner and wider flash on the dies), but designer should not allow the forging pressure to reach a high value, which may cause die breakage. The forging load increases with the decreasing flash thickness and increasing flash-land width. The finite-element method (FEM) is most widely used method in this field. To analyze stresses in the dies, process simulation using FEM-based computer codes is generally used. Thus, conditions that appear most favorable can be selected. The local die stresses are estimated by means of elastic FEM analysis.

In estimating the forging load empirically, the surface area of the forging, including the flash zone, is multiplied by an average forging pressure known. The forging pressures encountered in practice vary from 20 to 70 tons/in^2. Neuberger and Pannasch conducted forging experiments with various carbon steels and low-alloy steels using flash ratios, w/t (where w is flash-land width and t is the flash thickness), from 2 to 4 (Fig. 2). They found that the variable that most influences the forging pressure, Pa, is the average height, Ha, of the forging. The lower curve relates to relatively simple parts, whereas the upper curve to slightly difficult ones [1].

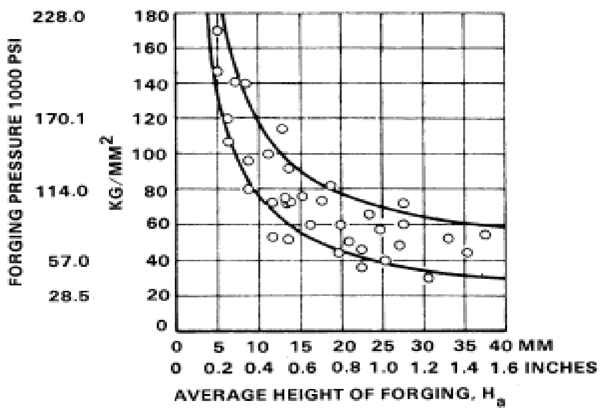

Figure 2: Forging pressure versus average forging height, for forging at w/t, from 2 to 4

For corner radius value, in the 0.5 mm radius die, there is a smooth stress concentration. The stress level is significantly reduced. The stress decreases while the radius increases, up to a limit value of 0.5 mm, over which the radius seems to have less influence.

2.2) AISI H13 Steel:

Hot forging die must be impact resistant, wear resistant, maintain strength at high temperatures. AISI H13 steel is the most reputable, hot work tool steel, especially for forging, giving a good toughness and high temperature strength, high harden-ability, and a moderate wear resistance. 'Toughness' is the ability of material to absorb energy without fracture. Energetically its use has been extended with better result. H13 can resist thermal softening to 550°C. 'Hardness' is the resistance to wear, abrasion or indentation. At HRC = 55, AISI H13 has tensile yield strength = 1.65 GPa and tensile ultimate strength = 1.99 GPa. AISI H13 is Nitrided with a case hardness over 1000 V.P.N. Tables I and II indicate mechanical properties and thermal properties of AISI H13 respectively.

Table I. Mechanical Properties

Properties		T°C
Density (x 1000 kg/m^3)	7.76	25
Poisson's Ratio	0.30	25
Elastic Modulus (GPa)	210	25
Bulk Modulus (GPa)	140	25

Table Ii. Thermal Properties

Properties		T°C
Thermal expansion (10^{-6}/°C)	10.4	20 – 100 more
Thermal conductivity (W/m.K)	28.6	215 more

3 Modeling and Simulation, Software used (Setup and Analyses), Presentation of Data and Results:

3.1 Modeling and Simulation:

The 3D Geometry of hot model (including 1.5 % shrinkage allowance) of the connecting rod forging was imported in 'SolidWorks Premium'. The Model of hot forging die was then prepared by the 3D Geometry imported. Different sizes of this hot forging die were estimated. The Length of this forging die is 209.2 mm, width is 100 mm and the total height of die is 197.5 mm (height of each block is 98.75 mm after the reduction in height of each block by 1.25 mm, to have a total flash allowance of 2.5 mm thickness). That model of forging die is shown in Fig. 3, by an enlarged view. Each die block (either upper or lower) can be taken as the mirror of the other. Both have the symmetrical half-cavities for connecting rod forging. Lower die cavity is shown here in

which except some large fillets, all are the sharp edges or corners. That is before simulation.

The Normal stresses and Equivalent stresses developed in the hot forging die determine the Fatigue Life of forging die.

3.3 Comparison of Data of the Normal Stress Analyses between the Un-simulated and Simulated Forging Dies:

In the Figs. 5 and 6, by observing the different color

The Fig. 4 shows the forging die after the simulation. The simulation has been done in 'SolidWorks Premium', by converting the sharp edges and corners of cavity to fillets, of nearly optimum sizes. These fillets range from 0.5 mm to 0.8 mm size (mostly 0.5 mm used). In the Fig., these fillets are highlighted as green.

3.2 Software used (Setup and Analyses):

The software used for the analyses of hot forging die for different stresses produced and Fatigue Lives, was 'ANSYS Workbench'. All the data were resulted of the Setup input (for both the Un-simulated and Simulated forging dies). The Setup included the Loads, Supports and Thermal condition. The estimated Load was 3.3354 x 10^6 N (340 tons). The Loads (a forging load and its reaction) were along y-axis. Two Fixed Supports were applied to support the upper and lower dies. For Thermal condition

of this forging die, the temperature of whole die was taken as 215°C.

coding, we come to know that different colors at all the positions are showing different Normal stresses for all those respective positions of dies (in the cavities of these dies, positions of different colors can be clearly seen by zooming in and rotating the upper and lower die cavities of a die, in the software). In the Figs. 5 and 6, analyses/mathematical models of Normal stress of Un-simulated and Simulated dies respectively, are presented. In these figures, minimum values are actually maximum in -ve sense.

There is increase of 0.14 x 10^8 Pa in the maximum +ve Normal stress and decrease of 0.08 GPa in the maximum -ve Normal stress, by simulation. Here, as the value of maximum -ve stress (produced in each of both dies) is much greater than that of maximum +ve stress and the fatigue failure of forging die occurs due to the greater value of maximum stress (either +ve or -ve), therefore after simulation, the increase in maximum +ve Normal stress is not so harmful, as the decrease in maximum -ve Normal stress is beneficial. Therefore all other -ve Normal stresses of forging die decreased also, as shown.

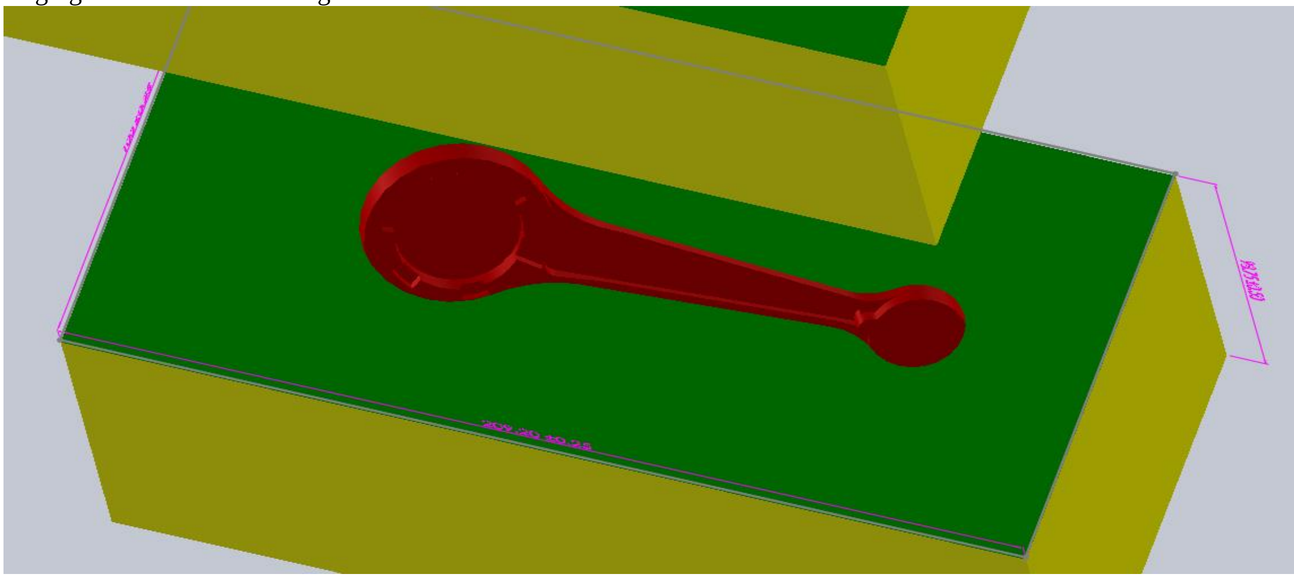

Figure 3: Zoomed in view of hot forging die, showing the sharp edges and corners of lower die cavity (Un-simulated die)

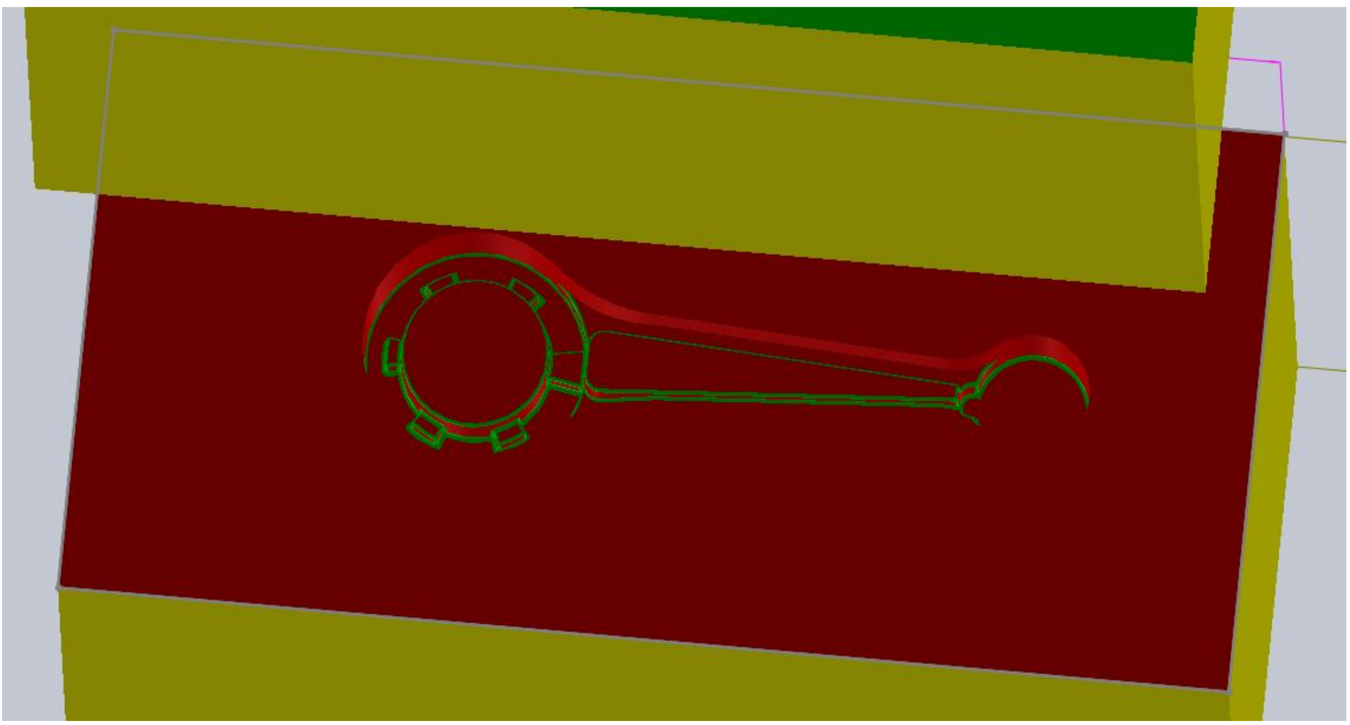

Figure 4: Fillets, of different sizes made in the cavity of hot forging die (Simulated die)

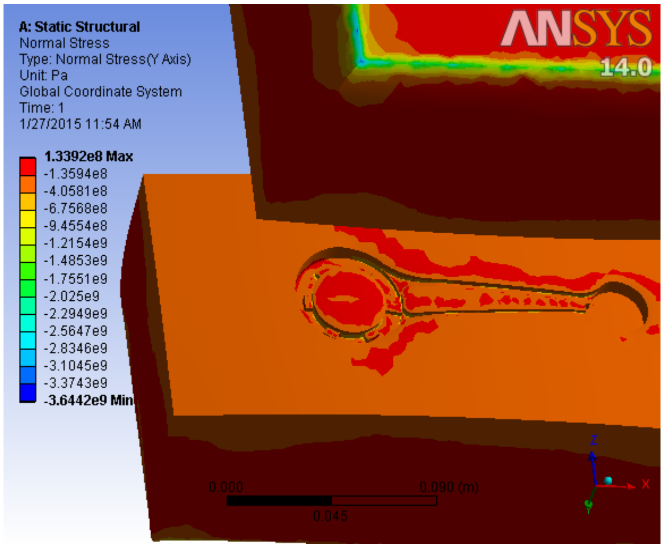

Figure 5: Presentation of data of the Normal Stress analysis (un-simulated die)

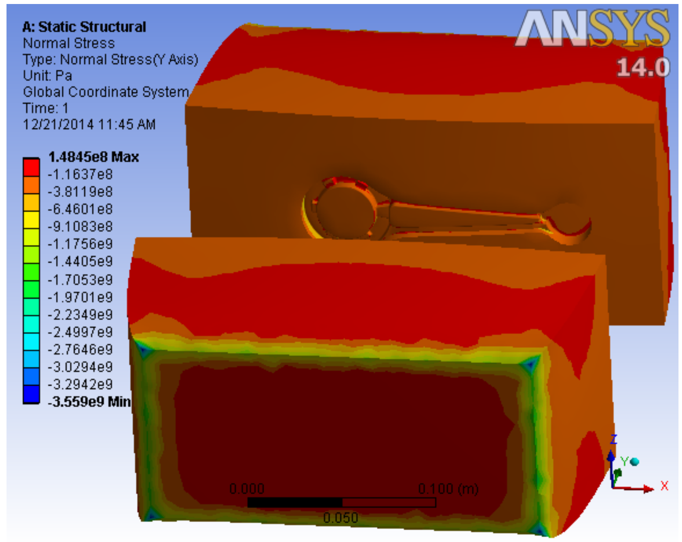

Figure 6: Presentation of data of the Normal Stress analysis (simulated die)

3.4 Comparison of Data of the Equivalent Stress Analyses between the Un- simulated and Simulated Forging Dies:

In the Figs. 7 and 8, analyses of Equivalent stress of Un-simulated and Simulated dies respectively, are presented. There is a decrease of 0.36 GPa in the maximum Equivalent stress (simulation).

Although the minimum Equivalent stress produced in Simulated die is greater than that of the Un-simulated die, but in the cavity, most of the Equivalent stresses have been reduced by simulation, as shown in Figs. 7 and 8 and in the (graph) Fig. 12.

3.5 Comparison of Data of the Fatigue Life Analyses between the Un-simulated and Simulated

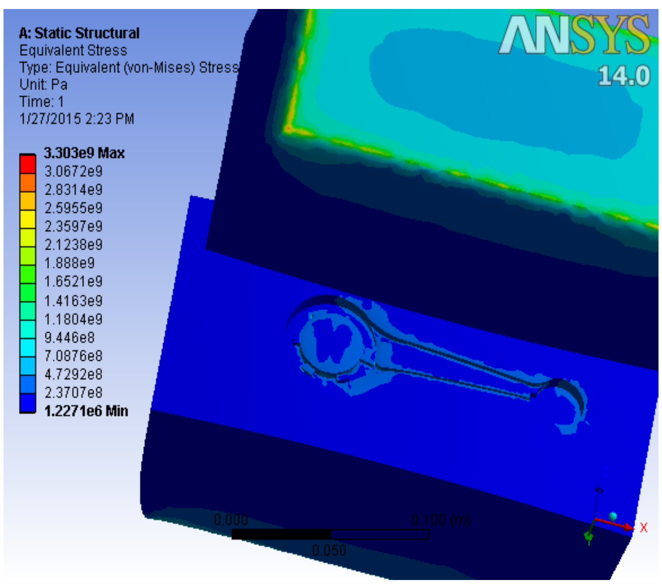

Figure 7: Presentation of data of the Equivalent Stress analysis (un-simulated die)

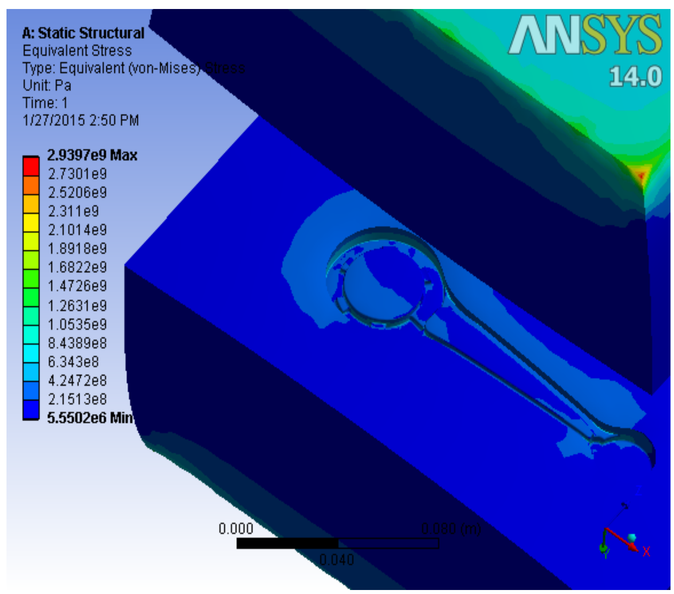

Figure 8: Presentation of data of the Equivalent Stress analysis (simulated die)

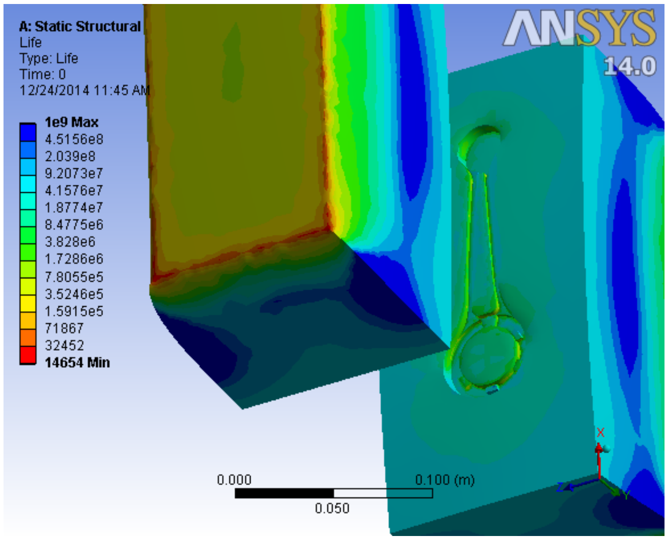

Figure 9: Presentation of data of the Fatigue Life analysis analysis (un-simulated die)

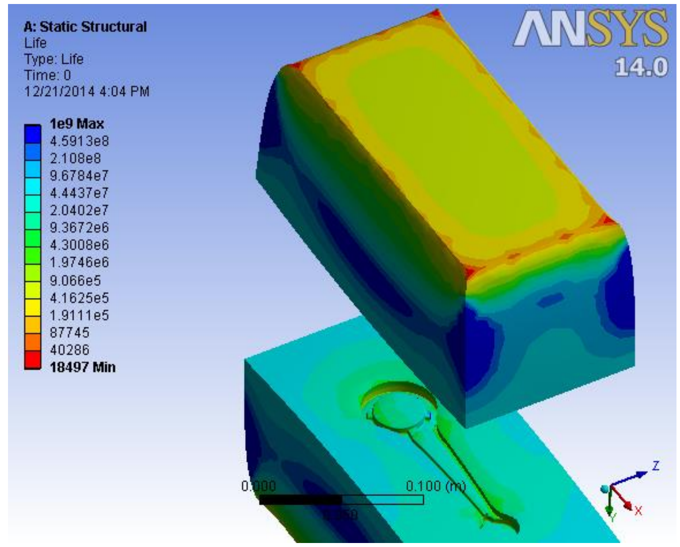

Figure 10: Presentation of data of the Fatigue Life (simulated die)

Forging Dies:

In the Figs. 9 and 10, by observing the different color coding, we know that different colors at all the positions are showing different Fatigue Lives for all those respective positions of dies.

In the Figs. 9 and 10, analyses of Fatigue Life of Un-simulated and Simulated dies respectively, are presented. There is an increase of 3843 cycles in the minimum Fatigue Life.

The Fatigue Lives in the die cavity have been increased by simulation, as shown in Figs. 9 and 10 and in the (graph) Fig. 13.

3.6 Graphical Representation of the Data values obtained and Results:

The Figs. 11, 12 and 13 are the graphs, showing the variations respectively in different stresses produced and fatigue life, mainly in the die cavity along the longitudinal axis, for the un-simulated and simulated forging dies. Each graph figure has two different trend-lines which are the curves of best fit (respectively for the un-simulated and simulated dies). From these graphs, it can be seen that total length of hot forging die is 209.2 mm and length of the die cavity is 123.6 mm (along axis from 55.8 to 179.4 mm). hese graph figures are explained below *3.6.1) Comparison of Normal Stresses produced in the cavities of Un-simulated and Simulated Forging Dies: (Referring Figs. 5 and 6)*

In Fig. 11, the variation in Normal stress in the Un-simulated forging die is shown as red. There are different stresses produced on different levels. It means that a level contains the same stress but may be on more than one position. The level of maximum -ve Normal stress within the cavity is -0.811 GPa which is on three positions of cavity, as shown. In the Fig., variation in Normal stress in the Simulated forging die is shown as black. Similarly there are different stresses produced on different levels. The level of maximum -ve Normal stress within the cavity is -0.778 GPa which is on the two positions of cavity, as shown.

Therefore, there is a decrease of 0.033 GPa in the maximum -ve Normal stress in the die cavity, by simulation.

3.6.2) Comparison of Equivalent Stresses produced in the cavities of Un-simulated and Simulated Forging Dies: (Referring Figs. 7 and 8)

In Fig. 12, the variation in Equivalent stress in the Un-simulated forging die is shown. There are also different stresses produced on different levels. The maximum Equivalent stress in the cavity is 0.827 GPa which is on just one position of cavity. In the Fig., variation in Equivalent stress in the Simulated forging die is also shown. For that, the maximum Equivalent stress in the cavity is 0.739 GPa, as shown.

Therefore, there is a decrease of 0.088 GPa in the maximum Equivalent stress in the die cavity.

3.6.3) Comparison of Fatigue Lives obtained in the cavities of Un-simulated and Simulated Forging Dies: (Referring Figs. 9 and 10)

In Fig. 13, the variation in Fatigue Life in the Un-simulated forging die is shown (red). There are different values of Life obtained, on different levels. It means that a level contains the same Life but might be on more than one position. The minimum Fatigue Life obtained in the cavity is 3.5246 Lac cycles which is on just one position of cavity (Fig.). In the Fig., variation in Fatigue Life in the Simulated forging die is also shown (black). Similarly there are different values of Life obtained on different levels. For that, the minimum Fatigue Life obtained in the cavity is 4.1625 Lac cycles which is on the two positions of cavity, as shown.

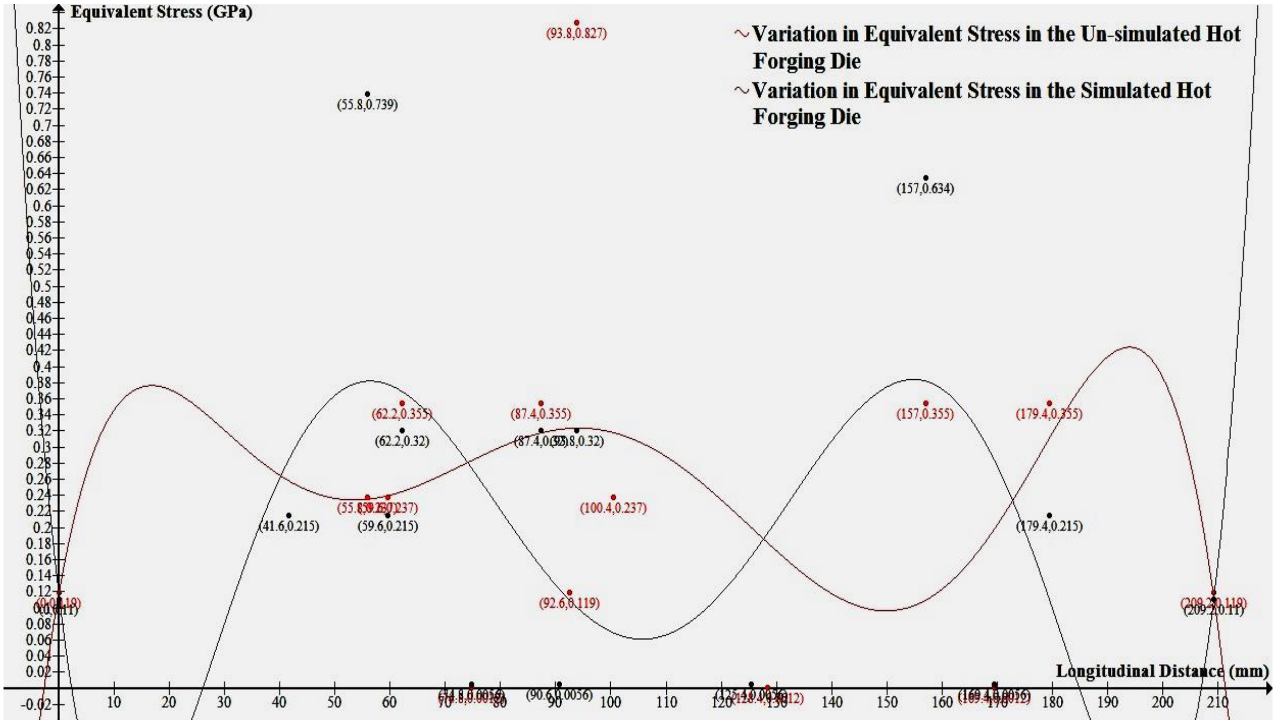

Figure 11: Variations in Normal stress in the Un-simulated and Simulated Forging Dies

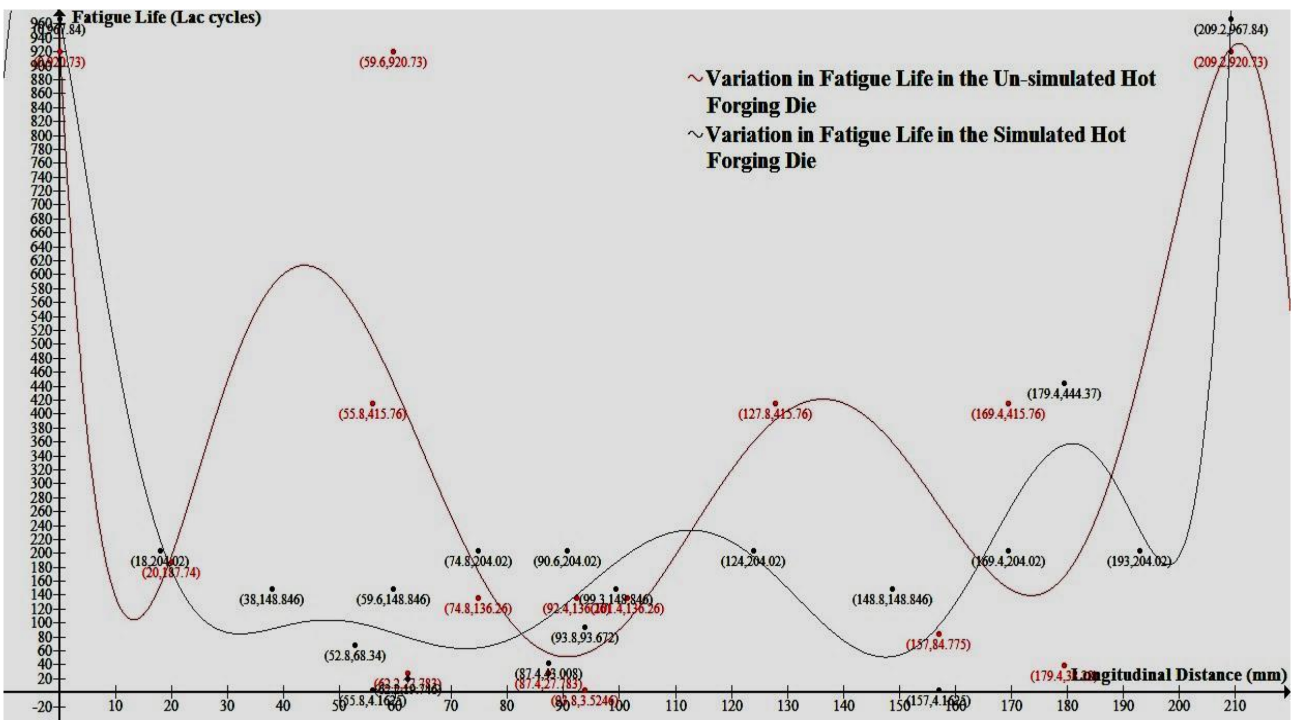

Figure 12: Variations in Equivalent stress in the Un-simulated and Simulated Forging Dies

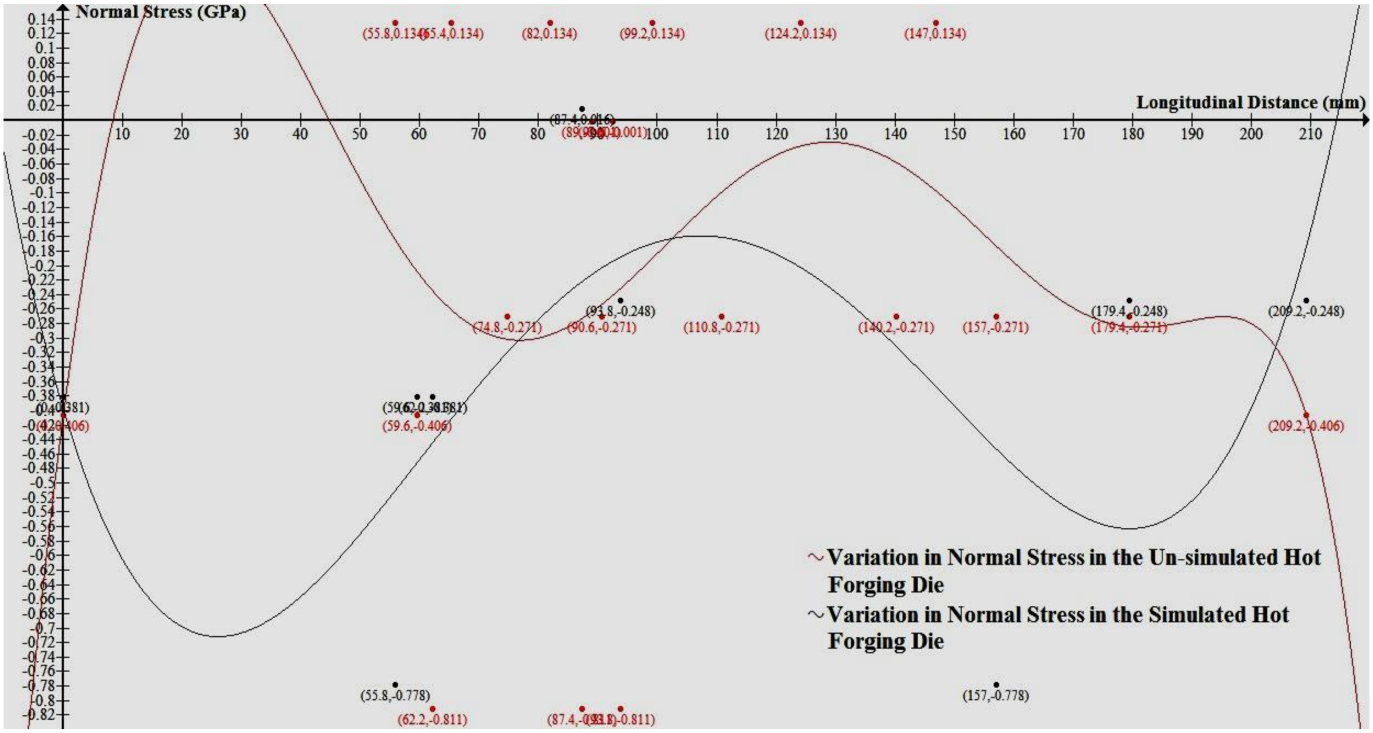

Figure 13: Variations in Fatigue Life in the Un-simulated and Simulated Forging Dies

Therefore, there is an increase of 0.6379 Lac cycles in the minimum Fatigue Life of the cavity, by simulation.

4 CONCLUSION:

On the basis of this research, the conclusion is as follows:

- The simulation of this sort of hot forging die could be done by converting the sharp corners and edges of the die cavity to the fillets of possibly optimum sized radii. Therefore, different stresses produced in this forging die were reduced.
- After refining the 'mesh' of model again and again (in the 'ANSYS Workbench'), all accurate results for both the Un-simulated and Simulated forging dies were obtained.
- After reducing the different Normal stresses and Equivalent stresses developed in the die cavity, the Fatigue Life of this forging die has been increased.
- This forging die would be used for mass production, on a mechanical forging press of capacity, 500 tons.
- The die would be used to produce forgings of the estimated flash thickness of 2.5 mm.

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