IMPROVING DIE LIFE AND MATERIAL UTILIZATION DURING HOT FORGING THROUGH FINITE ELEMENT SIMULATION

Rani R[1] , Prathap M S[2]

[1]Assistant Professor, Dept. of Mechanical Engineering, NDRK Institute of Technology, Hassan, Karnataka, India
[2]Assistant Professor, Dept. of Mechanical Engineering, Malnad College of Engineering, Hassan, Karnataka, India

***

Abstract - *The aim of the present project is to improve the Hot Forging Die Life and developing a Forging Die Life Model. The project involves analyzing of the initial effects of Friction, Work part Temperature, Die Temperature, Forging press stroke speed on effective die stresses. The Die surface temperatures, die/Work part sliding velocities, die/work part contact pressures are examined. The forging die was modeled using Unigraphics NX6 solid modeling software and simulated with Transvalor Forge2009 software. The product reviewed was a 6-inch diameter forged differential cover. The results obtained after performing few simulation iterations showed that the stress values during forging operation could be reduced by 20% and the die wear also minimized.*

Keywords: Hot forging, Die life, Transvalor Forge2009, Die stress.

1. INTRODUCTION

Forging is a manufacturing technique in which metal is plastically deformed from a simple shape like billet, bar, ingot into the desired shape in one or more stages [1]. In forging process, the service life of dies is very important due to economical reasons and also finishing quality of productions. Die costs range from 10 to 15% of the cost of a forging. One of the biggest components of cost is tooling cost and indirect costs of bad tooling including cost of additional setups, rework, scrap and loss of productivity [2]. Failure of dies in manufacturing operations generally results from one or more of the following causes: Improper design, Defective material, Improper heat treatment and Finishing operations, Overloading, Misuse and Improper handling.

The factors affecting die failure can be subdivided into [2]:

- Tooling Issues – Die material selection, heat treatment, surface engineering, die design and manufacture
- Billet Issues – Billet preparation, steel type
- Process Issues – Forging temperature, lubricant type and application, forging cycle times and other forging practices

The proper design of dies is as important as the proper selection of die materials. In order to withstand the forces in forging, a die must have proper cross sections and clearances. Sharp corners, radii, and fillets, as well as sudden changes in cross-section, act as stress raisers and can have detrimental effects on die life [3].

Development of finite-element (FE) process simulation in forging started in the late 1970s. At that time, automatic remeshing was not available, and therefore, a considerable amount of time was needed to complete a simple FE simulation. However, the development of remeshing methods and the advances in computational technology have made the industrial application of FE simulation practical. Commercial FE simulation software is gaining wide acceptance in the forging industry and is fast becoming an integral part of the forging design and development process. The main objectives of the numerical process design in forging are to:

- Develop adequate die design and establish process parameters by: Process simulation to assure die fill, Preventing flow-induced defects such as laps and cold shuts, Predicting processing limits that should not be exceeded so that internal and surface defects are avoided, Predicting temperatures so that part properties, friction conditions, and die wear can be controlled.
- Improve part quality and complexity while reducing manufacturing costs by: Predicting and improving grain flow and microstructure, Reducing die tryouts and lead times, reducing rejects and improving material yield.
- Predict forging load and energy as well as tool stresses and temperatures so that premature tool failure can be avoided. The appropriate forging machines can be selected for a given application.

2. MATERIAL

2.1 H13 TOOL STEEL PROPERTIES

The Forging dies in service are composed of H13 tool steel. The properties of H13 are depending on the microstructure, composition, and heat treatment. The chemical compositions of H13 are listed in Table 1. The microstructure of H13 steel is composed of a tempered martensitic matrix, with various alloying element carbide precipitates distributed within. These carbides are composed of molybdenum, vanadium, chromium and iron. The size of the carbides varies for each alloying element that composes it. The molybdenum and vanadium carbides tend to be larger in size and clustered together. Carbides, composed of iron and chromium, are distributed evenly and therefore are very fine and do not form clustered colonies. The size of the carbides plays a key role in fracture. Coarse carbides result in lower fracture toughness, due to the stress concentrations imposed. Specifically, H13 is a conventional chromium hot work tool steel utilized in the forging industry predominately for its high impact toughness and resistance to heat checking.

Table -1: The chemical compositions of H13 (in stores)

CONTENT	PERCENT	SPECIFICATION AISE H13
Carbon (C)	0.42	0.32-0.45
Silicon (Si)	1.144	0.80-1.20
Manganese (Mn)	0.332	0.20-0.50
Phosphorus (P)	0.031	0.03Max
Sulfur (S)	0.007	0.03Max
Chromium (Cr)	4.9	4.75-5.50
Molybdenum (Mo)	1.263	1.10-1.75
Nical (Ni)	0.13	0.30Max
Vanadium (V)	0.86	0.80-1.20

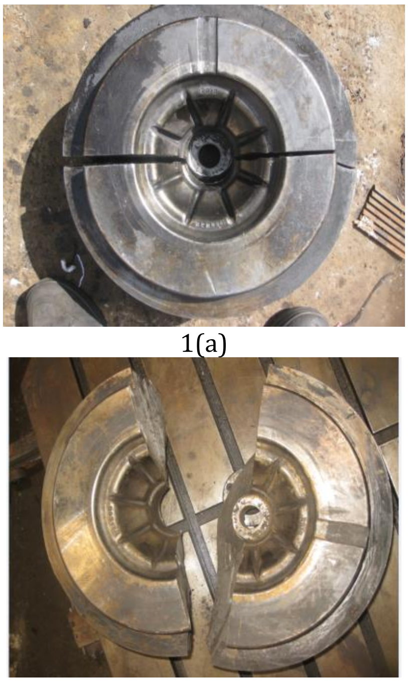
Table-2: The Chemical compositions of superior and premium quality H13

ELEMENT	PREMIUM GRADE ACCEPTED RANGE (wt. %)	SUPERIOR GRADE ACCEPTED RANGE (wt. %)
Carbon (C)	0.32-0.42	0.37-0.42
Silicon (Si)	0.80-1.20	0.80-1.20
Manganese (Mn)	0.20-0.50	0.20-0.50
Phosphorus (P)	≤ 0.025	≤ 0.015
Sulfur (S)	≤ 0.005	≤ 0.003
Chromium (Cr)	5.00-5.50	5.00-5.50
Molybdenum (Mo)	1.20-1.75	1.20-1.75
Nikkal (Ni)	0.30Max	0.30Max
Vanadium (V)	0.80-1.20	0.80-1.20

The chemical compositions of superior and premium quality H13 are listed in Table 2. The notable differences between premium and superior quality H13 are the acceptable amounts of phosphorus and sulfur in the elemental composition. Due to this discrepancy, premium quality H13 exhibits higher impact toughness and improved resistance to heat checking than the superior grade. Toughness is established by holding the carbon content below 0.4 percent and allowing low total alloy content. Increased toughness may be achieved by reducing the size (20-50µm) of chromium and vanadium carbides. Also, H13 employs a high hardenability compared to other tool steels due to its chemical composition. Molybdenum contributes more than the other alloying elements to this property, while Vanadium decreases the value.

3. DIE STRUCTURE AND FAILURE MODE

Die failure is the major problem in any forging industry. Hence in this present project the cause resulting in the die failure of differential cover is analyzed and the same is presented below. Figure 1(a) and (b) is a representative photograph of the appearance of the fractured die. The failure appeared to have started near the center radius of the die and propagated outward.



1(a)

1(b)

Fig- 1(a) and (b): The dies were nearly broken into two pieces by the failures.

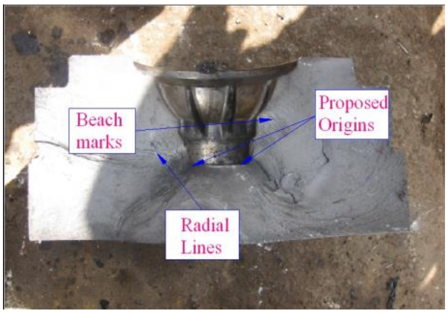


Fig-2: Photograph of die fracture surface with origins, beach marks and radial lines marked

This observation yielded little information about the cause of failure. The fracture surface contained very useful morphologies that enabled conclusions of the origins of failure to be made, Figure: 1(a) and(b) Inspection of the fracture surface under the stereomicroscope and with the naked eye revealed no signs of fatigue. The failure appeared to be brittle in nature, which was expected due to its high hardness, and to have occurred in a very few number of cycles. The radial lines on the surface pointed to the source of failure as being near the center radius of the die which can be seen in the Figure 2.

4. ANALYZING THE DESIGN OF DIE BY 3D FORGE SIMULATION

The material evaluation of the bar stock revealed no signs of any defects. Hardness, chemical analysis and microstructure of the failed die met the required specifications. After material evaluation offender was found to be the forging load and the stress developed at the bottom die during forging operation and because of imprecise perform of billet, the finisher die failed in few numbers of cycles. So it made to optimize the design of preformer die and reduce the cut weight of the billet.

4.1 OPTIMIZATION CONCEPT

The optimization of forging process can be carried out by three steps using forge simulation software below: Modify setups (Fig 3): Parametered Actions (Billet's Length), Sort results : good / bad :Minimizables (Billet's Weight), Exclude unacceptable results : Constraints (No folds, Complete filling)

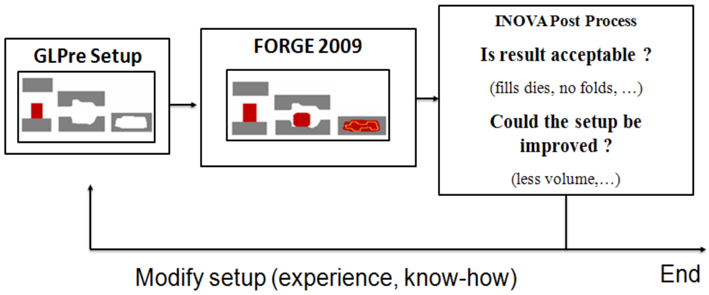


Fig -3: Usual work flow in forging process

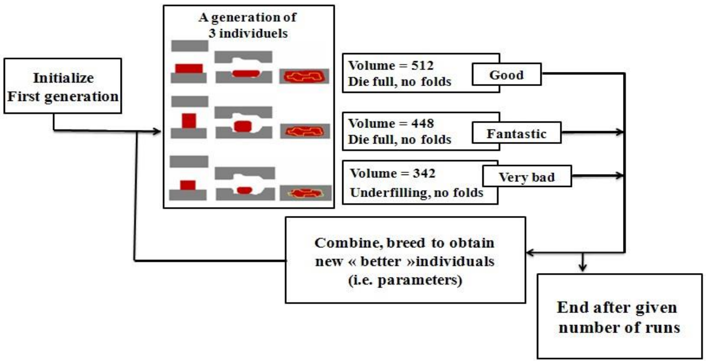


Fig-4: Block diagram of optimization concepts in forging process

To calculate the process outputs, the Transvalor Forge 2009 finite element modeling software was used specifically for simulating the forging process was employed. The results of the multiple Transvalor Forge 2009 simulations were verified.

Table -3: Process Parameters (inputs for simulation)

Work-part (Billet)	45C8
Die Material	H13 Tool Steel or Budrus 2714
Lubricant	Water+Graphite
Lubricant Temperature	Room Temperature
Ambient Temperature	20°C - 25°C
Surface Treatment	Nitriding
Forging Load	1600TN
Press Type	Mechanical Press
Press Stroke Speed	50 stroke per minute
Press Stroke Length	15"
Work-part Temperature Initially	1200°C
Work-part Temperature Finally	900°C to 1000°C
Die Surface Temperature Initially	150°C
Die Surface Temperature Mid-Shift	300°C

5. 3D-MODEL CONSTRUCTION USING UNIGRAPHICS (NX-6)

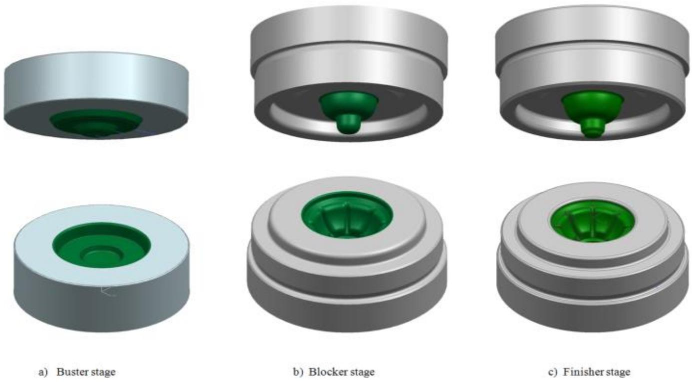

a) Buster stage b) Blocker stage c) Finisher stage

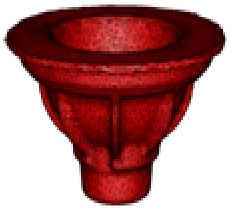
Fig-5 (a)-(c): Unigraphics NX6 Dies part files

Post construction of the dies, the Unigraphics part files (.par) were saved as Stereo Lithography files (.stl or .step) to be imported into Forge 2009 which ensure accurate integration.

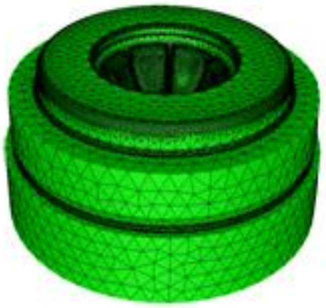
5.1 FORGE 2009 SIMULATION MODELS SETUP

The dies and work-part were imported as .stl or .step files into the forging simulation software Forge 2009, and were then meshed using the default size as shown in figure 6 (before simulation is run dies are surface meshed and billet is volume meshed).

6 (a)



6(b)



6(c)

Fig-6(a)-(c): Upper Die finisher stage, Workpart blocker stage, lower die finisher stage.

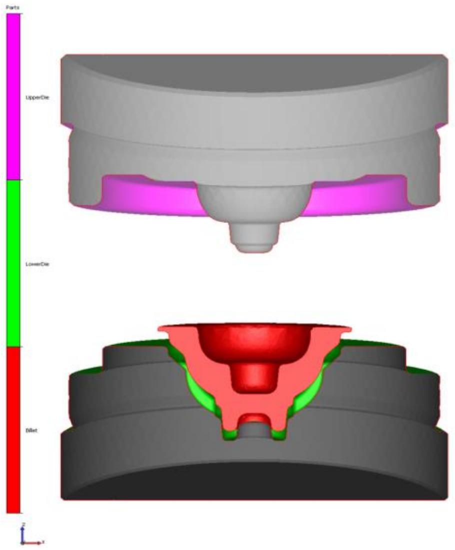


Fig-7: Aligned Forging Process Setup

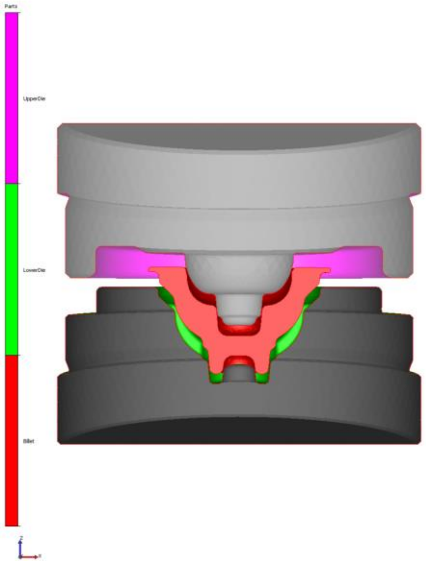


Fig-8: Positioned Transvalor Forge 2009 Setup (sectioned view of Die)

By shortening the upper dies stroke length from the actual distance as shown in above Figure: 7 simulation time can be reduced. To do this the Transform function is used in Forge 2009 and move the upper die down until it touches the top for the work-part which rests in the impression of bottom die as shown in Figure 8.

6. RESULTS

The simulation of the three stages required to forge the Diff. Cover, were simulated in Trasvalor Forge 2009. The process outputs were then analyzed at different stages of the computation and the plots are taken as follows:

1st Iteration:

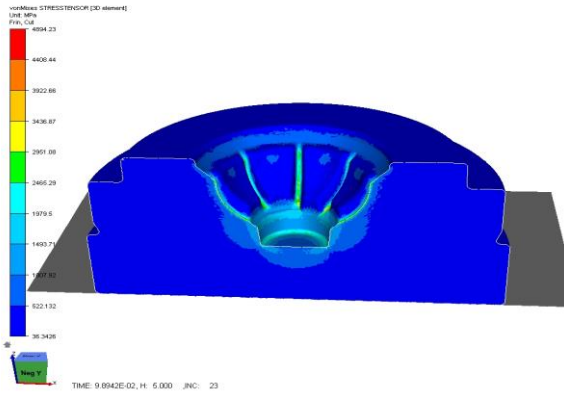


Fig-9(a): 3D Simulation of Die Stress (Mpa) on Lower Die

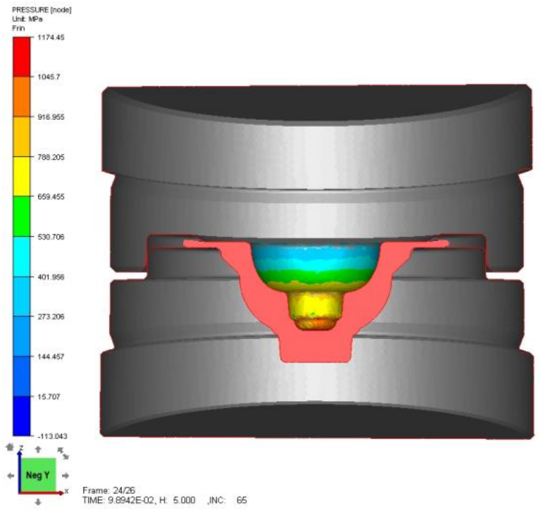


Fig-9(b): 3D Simulation of Die Contact Pressure (Mpa) on Upper Die Punch

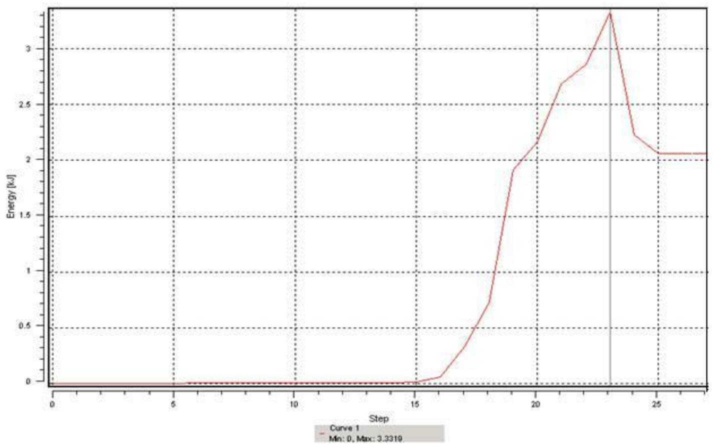


Fig-9(c): 3D Simulation of Net Energy (MPa) Supplied to Upper Die

The stress analysis of Lower Blocker Die Figure 9(a) tells that stresses at the corner radius is high also it is the areas consider being critical. The contact pressure Figure 9(b) is the important parameter to be considered in upper die punch which is subjected to high wear. Once the die stress and the contact pressure are analyzed, the plot of Energy Supplied V/s Stress (Figure 9(c)) of the upper die is taken and finds the sufficient energy required for the operation.

2nd Iteration:

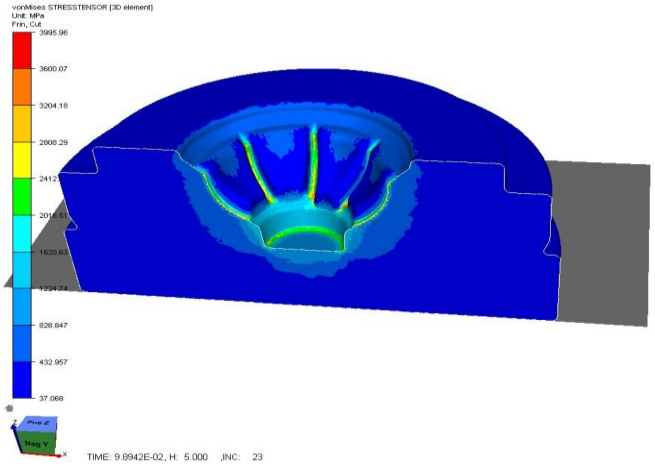


Fig-10(a): 3D Simulation of Die Stress (Mpa) on Lower Die

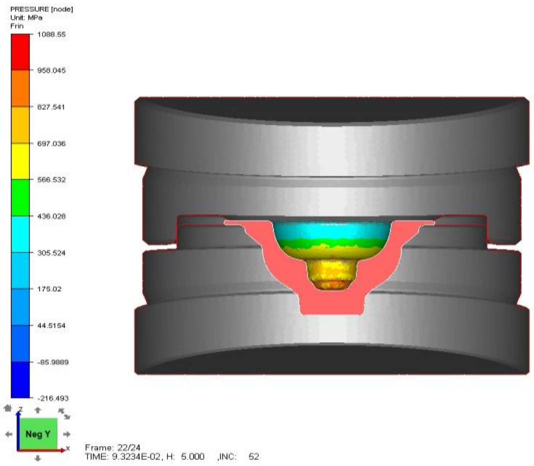


Fig-10(b): 3D Simulation of Die Contact Pressure (MPa) on Upper Die Punch

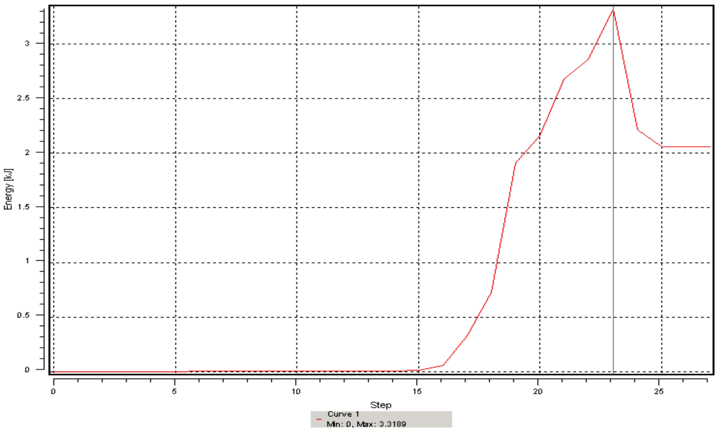


Fig-10(c): 3D Simulation of Net Energy (Mpa) Supplied to Upper Die

6.1 VONMISES STRESSES

Iteration 1	Iteration 2
VonMises Stress Unit: MPa	**VonMises Stress Unit: MPa**
4894.23	3995.96
4408.44	3600.07
3922.66	3204.18
2951.08	2808.29
2465.29	2412.4
1779.5	1620.63
1493.71	1224.74
1807.92	828.847
522.132	432.957
36.3426	37.068

From the above values obtained we observe that approximately 20% reduction of Stress on the Bottom die when compared to Iteration 1.

7. CONCLUSION

To validate the simulated results some basic areas were examined. Assuming that the Temperature of the dies & billet to be under steady state condition, the results of stresses in dies and contact pressure is analyzed. The high contact pressures (seen in Figure: 9(b) & 10(b)) indicate the area of high wear. These areas are the very common areas in which wear was occurring on the real life dies. By considering the simulation results such as die stress and Contact pressure in 1st iteration and by modification of blocker die was carried and 2nd iteration was run. As a result the stress on the dies was reduced approximately by 20%. Also the die wear is minimized.

REFERENCES

[1] S.E. Rusinoff, "Forging and Forming Metals", (1952), American Technical Society, Chicago.]

[2] S. Babu, D. Riberio, R. Shivpuri, "Material and Surface Engineering of Precision Forging Dies", The Ohio State University, June 1999.]

[3] S. Kalpakjian, "Manufacturing Processes for Engineering Materials", (1991) Addison-Wesley.]

[4] 2005 ASM International.. Cold and Hot Forging: Fundamentals and Applications (#05104G)

[5] Bannantine, Julie A. Comer, Jess. J, Handrock, James .L Fundamentals of Metal Fatigue Analysis. Prentice Hall. Englewood Cliffs N.J. 1990.

[6] Bayer, Raymond G. Wear Analysis for Engineers. Vestal, New York: HNB Publishing, 2002.

[7] Berger, Paul D. & Maurer, Robert E. Experimental Design: With Applications in Management, Engineering, and the Sciences. Duxbury Thomson Learning, 2002 Forging

[8] Cai, C., Liaw, Peter K., Ye Mingliang, & Yu, Jie, "Recent Developments in the Thermomechanical Fatigue Life Predication of Superalloys." Journal of Material April 1999. V.15. no. 4.

[9] Caddell, Robert M., & William F. Hosford. "Metal Forming: Mechanics and Metallurgy". PTR Prentice Hall Inc, Englewood Cliffs, N.J. 1993.

[10] Castro, J.T.P. , M.A. Meggiolaro. "Statistical Evaluation of Strain-Life Fatigue Crack Initiation Predictions." International Journal of Fatigue. Vol.26. (2004). Pg. 463-476

[11] Collins, Jack A. Failure of Materials in Mechanical Design: Analysis, Predication, Prevention. Wiley International, USA 1993.

[12] Committee. ASM Handbook: Volume 11, Failure Prevention, Analysis and Prevention. ASM International, USA, 1986

[13] Dobychin, M.N., I.V. Kragelsky, V.S. Kombalov. Friction & Wear: Calculation Methods. Pergamon Press. USSR. 1982.

[14] Forming & Forging Volume 14, 9th Edition Metals Handbook, ASM International Handbook, 1988.

[15] Fatemi, Ali, Zoroufi, Mehrdad. "A Comparative Study of Forged Steel, Cast Aluminum and Cast Iron: Monotonic Properties, Cycle Deformation and Fatigue Behavior". Forging Industry Educational and Research Foundation. March 2003.

[16] Farahamad, Bahram. "Fatigue and Fracture Mechanics of High Risk Parts". Chapman & Hall International Thomson Publishing. 1997

[17] Iwama, Tatsuro, Morimoto, Yashiro. "Die Life and Lubrication in Warm Forging." Journal of Material Processing Technology. Vol.87. 1999: 43-48.

[18] Kalpakjian, Serope. "Manufacturing Processes for Engineering Materials".3rd Edition. Addison Wesley Longman Inc. Menlo Park, California. 1997.