APPLICATION OF KNOWLEDGE ENGINEERING AND COMPUTATIONAL INTELLIGENCE FOR STRUCTURAL TOPOLOGY OPTIMIZATION OF FORGING CONNECTING ROD DIE

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ABSTRACT

In this paper the phenomenon of metal flow through forging die cavity and thermo structural plasticity has been studied from the view points of mechanics, physics and metallurgy. An analytical algorithm has been established and placed in the optimistic way of sequences in need to design an intelligent knowledge based expert system. And a developed research process methodology has been used to refine the mechanics of plasticity, forging product development cycle time with improved error free quality. The research results are applied to mechanics of metal flow and strength of materials, and of course, are used as indispensable tools for analyzing the metal forging processes. This process methodology will leads to develop an automated, robust, quick, quality, accurate & decision making tool for society in order to achieve the power/cost/time/skill effectiveness even if operated by an unskilled user. This paper also summarizes a case study to validate and review the developed process automation tool in need to get a virtual prototype die model with the prediction of forging process variables and parameters for connecting rod. This work will be worth full for forging industrial applications in estimating forging load.

Keywords: Computational intelligence, Connecting rod die, knowledge engineering, Structural Topology Optimization
I. INTRODUCTION

The increasing worldwide interest in the production of forging products leads the researchers to study on forging technology. Net shape forming processes have a special place in forging and it is one of the most important goals for metal forming technology to achieve due to its economical benefits.

In a study reported by B.L. Repgen [1] based on fatigue tests carried out on identical components made of powder metal and C-70 steel (fracture splitting steel), he notes that the fatigue strength of the forged steel part is 21% higher than that of the powder metal component. He also notes that the components which are manufactured by forging process have acquired the best mechanical properties for the functional purposes than other processes. Hyunkee Kim et al. [2] has demonstrated an application of computer aided simulation to investigate metal flow in selected forging operations. Taylan Altan, Victor Vazquez et al. [3] described an investigation of metal flow and perform optimization in flash less forging of a connecting rod. Also in the late 19th century J.H. Liout and D.Y. Jang [4] has described their view on forging parameter optimization considering stress distributions in products through fem analysis and robust design methodology. In the early 19th century, Victor Vazquez, Taylan Altan [5] has demonstrated a work on Die design for flash less forging of complex parts. One of the early studies was carried out by Kudo [6, 7] for theoretical analysis of the experimental tests. It was chosen for its simplicity. He described a general method of analysis that could be used to analyze forging and extrusion type processes to produce predictions of forming loads. Another forging load calculation study was made by Yilmaz and Eyercioglu [8]. Geometry is recognized and simplified in order to make the calculations easy. The forging load estimation is then made for each region separately. The results can be put into together in building block manner to obtain the load required for the deformation of rather complex axisymmetric forging. H. Grass et al. [9] has demonstrated an importance of application of 3-D FEM simulation of hot forming processes for the production of a connecting rod. Also the finite element modeling and control of new metal forming processes has been studied by J. L. Chenot and E. Massoni [10]. A one of final study was carried out by Necip Fazil Yilmaz and Omer Eyercioglu [11] on Knowledge based reverse engineering technique for near net shape axisymmetric forging die design.

Although the theories and the experimental results are explained in many text books, the confirmed design process methodology for connecting rod die for forging process is not known well. So in this paper, the history of phenomenon of metal flow through forging die cavity and the analysis thermo structural plasticity has been reviewed to develop a global design process methodology for connecting rod die forging.

II. KNOWLEDGE ENGINEERING

Knowledge engineering is the development of knowledge base through the process of mechanism of knowledge acquisition by adapting a suitable scientific methodology.

II.1 KNOWLEDGE ACQUISITION

It has been achieved by implementing the scientific data, basic principles, related theories in the optimistic way of sequences and coded format that can be used in an automated application. Submit your manuscript electronically for review. Process of extracting the knowledge through human expertise from existing proven Theories, Methodologies, Thumb rules, Laws, Corollaries, Technical Literature, Standard Engineering Procedures, Established Engineering Equations, Experimental Data, Codes of Practice and Expert’s opinions. In another way, knowledge acquisition module processes the data entered by the expert and transforms it into a data presentation understood by the system of Computer.
II.2 SCIENTIFIC METHODOLOGY

Here we have developed a knowledge base based on mathematical modeling techniques from Statistical, Empirical and Simulation analysis approach for the design and cost optimization of forging die for flash less forging.

II.3 STATISTICAL AND EMPIRICAL ANALYSIS APPROACH

In this approach detailed process methodology for the determination of unknowns i.e. process parameters, variables and material properties for the flash less forging is described. Also a structured mathematical modeling has been developed by implementing the scientific data, basic principles, related theories in the optimistic way of sequences.

II.3.1 PREDICTION OF FORGING LOAD AND DIE PRESSURE

The Fig. 1 (a), (b), (c) shows the design variables used in determining the Forging load and Die pressure at various sections of connecting rod die based on research data review.

“Fig. 1 Important Topological characteristics of connecting rod die for the determination of Forging load and Die pressure at various sections of connecting rod die: (a) Connecting rod die - Top and side view, (b) Sectional side view, (c) Plan area of the connecting rod taken for case study”
Based on this sensitivity study Schey has developed an empirical formula for calculating forging load $P$ –

Load Edger: Load Edger and Blocker can be calculated by following equations –

$$B = \frac{A}{L}$$

(1)

$$P = 4 \times \left[1 - (0.001 \times Ds)\right] \times \left[1.2 + \left(\frac{20}{Ds}\right)^2\right] \times \left[1 + 0.1 \times \frac{L}{B} \times \frac{A \times y}{1000}\right]$$

(2)

Load Finisher- Load require for forging component in finisher die is approximately (2/3) of load require for forging component in blocker die.

$$P_{\text{finisher}} = \left(\frac{2}{3}\right) \times P_{\text{blocker}}$$

(3)

II.3.2 Prediction of Maximum Principle Stress

Maximum principal stress acting on the die surface can be calculated by knowing the total forging load acted on the die surface. As we have already calculated the total forging load acting on the die surface, by "equation 2". Therefore the Maximum stress acting on the die surface is given by following equation-

$$\sigma = \frac{P}{A}$$

(4)

II.3.3 Prediction of Strain rates

In this case the load is acting along the direction perpendicular to the length of the component therefore the deflection is along the thickness or height of the component. This can be calculated by using the true strain or engineering strain equation-

$$\varepsilon = \ln \left(\frac{h0}{h}\right)$$

(5)

II.3.4 Prediction of Average Flow Stress

The average flow stress is given by the following equation-

$$\bar{\sigma} = \sigma \times \varepsilon$$

(6)

III. Computational Intelligence

The following steps shows the use of computational intelligence in building a expert system to design a connecting rod die for forging process in need to achieve or predict optimum process variable parameters.
III.1 COMPONENT REVIEW (2D-DRAWING)

In this process user has to review the 2D drawing of component being forged received from customer to analyze and predict the process for 3D modeling technique (see Figure 4).

“Fig. 2 Two Dimensional (2D) drawing model of connecting rod”

III.2 CAD MODELING (FEATURE BASED 3D MODELING)

This process involves conversion of received 2D drawing sheet into a live 3D CAD model using a high end 3D modeling tool like UNIGRAPHICS NX-2. It is useful to design & create virtual die blocks model by subtracting the geometry of component being forged with forging allowances from standard available metal die cubes about parting line, see Fig. 4.

III.3 GEOMETRY OR PROFILE RECOGNITION FOR COMPONENT BEING FORGED

A high CAD package UGNX-2 can easily recognize the required topological parametric values of extreme peripheries of component being forged [8]. This can be done automatically by a developed coded auto control program. The outcome of this program generates a datasheet (See Appendix-I).

III.4 USER INTERFACE

User has to give the required inputs manually to the inference engine iFORGE. These required inputs are values generated by datasheet in last step (See Appendix-II-V).
APENDIX (I) - DATA SHEET SHOWING VALUES OF GEOMETRICAL PARAMETERS OF CONNECTIN ROD DIE USING CAD TOOL UNIGRAPHICS NX-2, AND DATA SHEET SHOWING VALUES OF FINITE ELEMENT ANALYSIS OF CONNECTIN ROD DIE USING SIMULATION TOOL DEFORM F3 VER. 6.0.

<table>
<thead>
<tr>
<th>Measurement of Mass Properties</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Displayed Mass Property Values</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>$379658.327458419$ mm$^3$</td>
<td></td>
</tr>
<tr>
<td>Area</td>
<td>$6687.73191854545$ mm$^2$</td>
<td></td>
</tr>
<tr>
<td>Mass</td>
<td>$2.984049127$ kg</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>$22.26904872$ N</td>
<td></td>
</tr>
<tr>
<td>Radius of Gyration</td>
<td>$0.058320985$ mm</td>
<td></td>
</tr>
<tr>
<td>Center of Mass</td>
<td>$-1.40573548236$.0.1315350722.0.016875385 mm</td>
<td></td>
</tr>
</tbody>
</table>

Detailed Mass Properties Analysis calculated using accuracy of $0.000000000$

Information Units in Area:
- Density: $0.000000000$
- Volume: $379658.327458419$ mm$^3$
- Area: $6687.73191854545$ mm$^2$
- Mass: $2.984049127$ kg
- Weight: $22.26904872$ N
- Radius of Gyration: $0.058320985$ mm
- Center of Mass: $-1.40573548236$.0.1315350722.0.016875385 mm

Moments of Inertia (Centroidal):
- $I_{xx}$, $I_{yy}$, $I_{zz}$ $= 1957.27391651$, $88.09947609231$, $0.99860.1315350722.0.016875385$

Moments of Inertia (Spherical):
- $l = 2902.208213864$

Products of Inertia (Work):
- $P_{xxw}$, $P_{xyw}$, $P_{yzw}$ $= 0.000171777$, $-9.759957559$, $19.143070673$

Products of Inertia (Centroidal):
- $P_{xxc}$, $P_{xyc}$, $P_{yyc}$ $= 0.000086807$, $-1.158817435$, $1.521857143$

Radii of Gyration (work):
- $R_{xx}$, $R_{xy}$, $R_{yz}$ $= 25.484466628$, $172.1612650$, $172.1612650$

Radii of Gyration (centroidal):
- $R_{xx}$, $R_{xy}$, $R_{yz}$ $= 25.484466628$, $172.1612650$, $172.1612650$

Radii of Gyration (spherical):
- $R = 0.0683602083$

Design Inputs:
- Forging component weight without flash weight (Mfis):
  - Use $1$ Kg
- Length of initial block (Lb):
  - Use $2$ mm
- Width of initial block (Bb):
  - Use $3$ mm
- Height of initial block (Hb):
  - Use $4$ mm
- Density of material (alloy steel C7050) (T):
  - Use $5$ Kg/m$^3$

Design Out puts:
- Enveloped weight (Wenvlp):
  - Use $6$ Kg
- Dimensionless shape difficulty factor (S):
  - Use $7$

Calculation of shape difficulty factor (S):

Calculation of slug weight:

Design Inputs:
- Diameter of slug at the big end (DBE):
  - Use $1$ mm
- Diameter of slug at the small end (DS):
  - Use $2$ mm
- Thickness of slug at both ends (T):
  - Use $3$ mm
- Value of constant (pa):
  - Use $4$
- Density of material (alloy steel C7050):
  - Use $5$ Kg/m$^3$

Design Outputs:
- Big end slug weight (WBE):
  - Use $6$ Kg
- Small end slug weight (WSE):
  - Use $7$ Kg
- Total slug weight (Wred):
  - Use $8$ Kg

APENDIX (II) - IMAGES OF VISUAL BASIC WINDOWS SHOWING THE AUTOMATION OF THE PROJECT.
The developed inference engine has being driven by the intelligent agent i.e. the codes of Visual Basic Language. It calculates the optimum values of all the forging process variable parameters for the geometry being forged (See Fig. 3) [11].
III.6  3D DIE MODELING

User need to scale the 3D geometry of the component being forged with respect to the optimum forging allowances given by the iFORGE in last step. This scaled geometry of component being forged has to be subtracted from standard available metal die cubes about parting line to design & create virtual die blocks model (See Fig. 4).

III.7  CAE ANALYSIS (FINITE ELEMENT ANALYSIS METHOD)

The performance of forging dies have been checked through CAE simulations in order to predict the optimum values for required forging load, die stress, limits of deformation, initial preform temperature, die life against number of forging cycles and frictional forces at die preform interfaces (See Fig. 5).
III.8 INFEERENCE FEEDBACK LOOP

If there is a remarkable deviation seen between CAE and iFORGE results, then user has to go for trial and error method by varying shape difficulty factor and which is also less time consuming.

IV. RESULT AND DISCUSSION

The variation of design variables with the different analysis approaches (i.e. Analytical, FEA) is shown in below table. Following table shows that these values show good conformity with both the analysis approaches taken under considerations.

<table>
<thead>
<tr>
<th>Design Variables</th>
<th>Test Methods</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Analytical</td>
<td>FEA</td>
<td>(%) Error</td>
</tr>
<tr>
<td>Flash Land Width (b) (mm)</td>
<td>8.926</td>
<td>8.121</td>
<td>5.1</td>
</tr>
<tr>
<td>Flash Thickness (t) (mm)</td>
<td>2.968</td>
<td>2.426</td>
<td>14.5</td>
</tr>
<tr>
<td>Ratio (b/t)</td>
<td>3.16</td>
<td>3.34</td>
<td>10.2</td>
</tr>
<tr>
<td>Flash Weight (Wflash) (kg)</td>
<td>1.43</td>
<td>1.2</td>
<td>8</td>
</tr>
<tr>
<td>Cut Weight (Wall) (kg)</td>
<td>4.23</td>
<td>4.34</td>
<td>3</td>
</tr>
<tr>
<td>Load Edger (N)</td>
<td>12.98*10E5</td>
<td>8.28*10E5</td>
<td>34</td>
</tr>
<tr>
<td>Load Blocker (N)</td>
<td>10.93*10E6</td>
<td>9.73*10E6</td>
<td>7</td>
</tr>
<tr>
<td>Load Finisher (N)</td>
<td>06.98*10E6</td>
<td>6.31*10E6</td>
<td>9</td>
</tr>
<tr>
<td>Maximum Principle Stress (N/mm2)</td>
<td>386.57</td>
<td>350</td>
<td>11</td>
</tr>
<tr>
<td>Deformation/Strain Rate (mm)</td>
<td>0.31</td>
<td>0.33</td>
<td>10</td>
</tr>
<tr>
<td>Average Flow Stress (N/mm2)</td>
<td>115.2</td>
<td>104.75</td>
<td>8</td>
</tr>
<tr>
<td>Flow Stress at Flow Zone1 (MPa)</td>
<td>271.52</td>
<td>240.23</td>
<td>12.1</td>
</tr>
<tr>
<td>Flow Stress at Flow Zone2 (MPa)</td>
<td>599.52</td>
<td>543.39</td>
<td>8.4</td>
</tr>
<tr>
<td>Flow Stress at Flow Zone3 (MPa)</td>
<td>649.52</td>
<td>610</td>
<td>6.5</td>
</tr>
</tbody>
</table>

“Table. 1 Validation of design variables - FEA and Analytical approaches”

“Fig. 6 Result Validation (Analytical, FEM & practical) for process variables”

From the above results review it is clear that the forging process variables which have been predicted by this automated tool show good conformity against both analytical and FEA approaches by small marginal error.
V. CONCLUSION

Thus in this study with the help of computational intelligence and knowledge engineering, structural topology optimization of forged steel connecting rod die has been achieved. The developed process automation tool can able to predict the forging process variable parameters with precision and accuracy. The developed tool is linked with the commercially available high end CAD/CAM/CAE packages. Also in order to predict the forging load and die stress values combination of Statistical, Empirical and Simulation analysis approaches have been used and verified by FEM. After the identification of geometry, the design rules have been stored in the knowledge base in such a way that every industry (designer) can define and add its own values. The developed inference engine uses Visual Basic programming codes to interact with the developed knowledge base and user interface. It has been proved and validated by comparing the output results with both experimental and Finite Element Analysis methodologies. The experimental and Finite Element results show good conformity. The advantage of developed tool is that no tooling has to be built and the number of experimental tryouts can be significantly reduced. The future scope of this dissertation may lead on to develop an Expert System with the help of Artificial Intelligence to reduce the total design cycle time.

VI. ACKNOWLEDGEMENTS

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REFERENCES