Effect of Design and Process Parameter to Cold Forging
Die Design: A Finite Element Analysis

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Abstract: Cold forging process can be described as the process where a metal is plastically deformed at room temperature with application of huge pressure. The process not only changes the shape but also improves the properties of the forged parts due to grain size refinement. Currently the Computer Aided Engineering (CAE) tools are widely used as a replacement of the empirical trial and error method. The objective of this research is to model the cold forging process using finite element analysis. The study will investigate the stress distribution, load-displacement curve and effect of die geometry and lubrication to the die performance. Due to geometrical considerations and computational limitations, the study only involve of two-dimensional (2D) simplified model of cold forging process using ABAQUS software.

Key words: Cold forging die, die geometry, lubrication, Finite Element Analysis (FEA)

INTRODUCTION

Cold forging has various advantages including little loss of material, improved strength, geometrical precision of components and high production rates (Button and Roque, 2000; McCormack and Monaghan, 2001). There are several methods of studying forming processes which can be categorized as the analytical, numerical and experimental methods. The validation of analytical and numerical methods is carried out based on the experimental result; therefore to save the cost physical modeling is employed. In most cases numerical methods provide more flexibility than physical modeling since they allow for quick changes in the tooling design (Tong et al., 2003).

Many researchers have take the advantages of computer advancement to integrate CAD/CAM in design of optimal tooling (Jolga et al., 2003) and some of the others integrate CAD/CAM/CAE/RP in demonstrating forging process (Yang et al., 2002). In metal forming, the research can be divided into three main areas;

- Die Design, several tools and approach have been used such as CAD/CAM system, expert system and mostly FEA methods. Improvement of die design for optimal die life is the main area being studied.
- Process Planning, the research is focus on the development of the most efficient and economic process sequence and planning and it is commonly used expert system and CAD/CAM system as the medium.
- Product Performance, here quality and reliability of the final product. The defect such as die filling and cracking behavior are the area of focus. The approach usually taken are physical experimentation method, either physical modeling or real experiment.

In cold forging higher load is needed in order to complete the process. The higher stress applied, the shorter die life, because most of dies failed due to cracking under cyclic load or fatigue and wear (Falk et al., 2001). So that, to improve die performance, stress should be as lower as possible. Initially there are several method proposed to improve die life:

- Improve surface finish
  - Treatment (Farahli and Ghadbeigi, 2006; Wagner et al., 2006; Jeong et al., 2001)
  - Shot peening
  - Nitriding
  - Nitrocarburizing
  - Hard roller burnishing

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In this research, the die performance will only focus on effect of the die geometry and lubrication to the stress and strain lead determination of die life.

**Forging parameter**: There are many parameters that can influence the stress level during the cold forging process. The forging parameter can be divide into two, design parameter and process parameter. The former play roles during the die design process i.e., modeling stage and the latter during it use. Design parameter represents the geometrical aspect of the die such as corner radii and fillet. Process parameter is a variable related to the forging process such as process stages, load applied, shape of the die, preform and lubrication. Machining process of the die also consider as process parameter. The effect of some of the parameters have been studied numerical and experimentally. Figure 1 shows the forging parameters division.

**MODELING**

Main objective of this study is to investigate the effect of process and design parameter to die performance. For that reason two parameters i.e., geometrical aspect and lubrication aspect are selected to represent the design and process parameter respectively. The cases are dividing into two, with and without lubrication. As shown in Fig. 2, there are two radiuses involve i.e., R1 and R2 which can be further divided into four sets of model shown in Fig. 3. Details of parameter setting as list in the Table 1. Note that for set 1, the radius for both R1 and R2 are zero denoted that it is a sharp edge.

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**Fig. 1**: Forging parameters

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Fig. 3: Four sets of die geometry

Table 1: Four sets of model used in the simulation

<table>
<thead>
<tr>
<th>Set</th>
<th>Radius 1, R1 (mm)</th>
<th>Radius 2, R2 (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>12</td>
</tr>
</tbody>
</table>

Fig. 4: Meshed model of the die and billet

Table 2: Material property of the die and billet

<table>
<thead>
<tr>
<th>Part</th>
<th>Property</th>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Die</td>
<td>Material</td>
<td>Tool Steel</td>
</tr>
<tr>
<td></td>
<td>Modulus of Elasticity, E</td>
<td>193 GPa</td>
</tr>
<tr>
<td></td>
<td>Poisson Ratio</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>Density</td>
<td>7.83x10^3</td>
</tr>
<tr>
<td>Billet</td>
<td>Material</td>
<td>Copper</td>
</tr>
<tr>
<td></td>
<td>Modulus of Elasticity, E</td>
<td>110 GPa</td>
</tr>
<tr>
<td></td>
<td>Poisson Ratio</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>Density</td>
<td>3.95x10^3</td>
</tr>
</tbody>
</table>

The model developed is a quarter of the model as a case study. The meshed model is shown in Fig. 4. The bottom line of the billet is fix in the x and y direction, whereas the axisymmetry side of the billet is fix in the x direction only. In order to avoid die sliding to the right, it has been fixed in the x direction. Load is applied from the top (y direction). Number of elements should be control not to exceeding 1000 element due to the software used is student version.

The properties for the die and billet are listed in Table 2. The die is meshed using triangular meshing, whereas the billet is meshed using quadratic meshing, this is because the die is the key of this study.

RESULT AND DISCUSSION

The forging process involve two contacted surfaces i.e., die and billet at different strength, one of the surface will deform to follow the other stronger surface. Here several parameter need to be taken into consideration especially the geometry of the die and lubrication. Theoretically these two parameters are related to each other as suggested in the general friction model used by
Omer (2004). In the model, the lower contacted area, the lower stress induced. By using the developed model, a study of closed-die forging is studied. The analysis is using the available software named ABAQUS.

Figure 5 to 7 shows the contour of the effective Von Mises stress at different friction coefficient of the die. Only result for the set 4 is used. The results are at 30% deformation of the billet due to the highest stress occurs throughout the process. For each of the cases, the highest stress is found to occur at right bottom area of the die, where there is a contact between die and billet. This is due to the plastic deformation and the sliding of the billet on the die surface. To study the effect of friction, coefficient of friction used for each of the models is 0.05, 0.1 and 0.15. The focus of the study is to see the maximum stress occurs, mainly tool stress. The result indicates that, by increasing the coefficient, the maximum stress is reduced.

Fig. 5: Set 4, friction = 0.05

Fig. 6: Set 4, friction = 0.1
Fig. 7: Set 4, friction = 0.15

Fig. 8: Stress-strain curve for set 1

The stress-strain curve for set 1 is shown in Fig. 8. It is shown that for there is no tremendous effect due to the friction coefficient changes. Even though this is not the final stage of the forging process, the result can still be used for reference.

After that the maximum stress at different displacement is plotted as shown in Fig. 9 (a-d). The stress begins after 11 mm because it is an initial location of the die or the gap between billet and die.

The result indicates that the maximum stress is at distance 16 mm for almost all of the cases for set 2 to 4 and the value is 350 MPa but for the set 1, it reached earlier i.e., at 14 mm distance. As conclusion, from these series of analysis shown that modifications of the corner radii have little effect. The result may be different at the end of the forging process as the project only analyze at the middle of the process.
CONCLUSION

The objective of this study is to investigate the effect of design and process parameter to forging die performance. From the numerical result it can be concluded that:

- The result indicates that for sharp corner, the maximum there is achieved earlier that corner with radii.
- This is shown that by implementing corner with radius, stress induced can be reduced.
- In the other hand, for the case of friction effect, the result indicate that, the effect can be seen if the coefficient of friction used is 0.15 or more.

ACKNOWLEDGMENT

The authors would like to thank the School of Mechanical Engineering and Universiti Sains Malaysia for their cooperation and fund provided (A/C 6035175).

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