Finite element analysis of AISI 8620 alloy spur gear hot forging

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Abstract. Among all manufacturing processes, a forging process has a remarkable position in which parts with desired mechanical properties and minimum wastage of material can be produced. Despite of mentioned advantages, forging process has few drawbacks such as high tonnage capacity machineries, expensive dies, high initial investment and die failure. The overall cost of the forging process directly depends upon the required forging load, ejection load and dies arrangements. In this paper, Finite Element Analysis (FEA) of a spur gear forging process made of low carbon alloy steel (AISI 8620) is carried out. Two load reduction methods (elastically attached die and relief hole) are simultaneously used and analyzed using DEFORM-3D software. The required forging load is compared between non-elastic die arrangements and elastic die arrangements with the relief hole. Velocity distribution is also discussed at nine different locations.

1. Introduction

Traditional manufacturing of spur gears has many disadvantages, such as more material wastage, less production, more cost and many more [1]. Over the past several decades, near-net-shape (NNS) or net-shape manufacturing has been turned into a well-known practice in the metal forming that saves time, energy and material. Therefore, forging process has tremendous potential for mass production such as automobile components and general engineering applications. Despite these favorable advantages, the economics of fully formed spur and helical gears for power transmission have not been considered to be acceptable and cannot be until a sturdy processing path is identified [2]. The overall performance of the forging operation requires an understanding of not only the flow stress of the material and frictional conditions, but also the mode of flow of the material, ejection process, forging load and die life [3].

In spur gear forging, total forging load mainly consists of deformation load and friction load. When cylindrical preform (workpiece) is forged, because of friction between die surface and cylindrical surface, the barrelling effect is produced and friction load increases. Forging load can be reduced up to 34% and better corner filling can be achieved by using the concave preform compared to simple cylindrical billet [4]. The change in friction load amount is more decisive when the coefficient of friction increases from 0.1 to 0.2. The forming load increases when the number of teeth increases and module is fix [5].

Zuo et al (2015) investigated the gear forging process. They mainly focused on corner filling, workpiece stress, die stress, and forming load. They used DEFORM-3D simulation software for FEA and AISI 8620 as workpiece material. They used relief-cavity thickness concept and observed that forging load reduced up to 20% at 3mm relief-cavity thickness.
2. Forming process and die design
In closed die forging flash formation is zero, hence billet dimension and die design is crucial. The hollow cylindrical billet is used to forge NNS spur gear and the diameter of the workpiece is equal to the dedendum diameter of the internal gear die. The detail and 3D model of forged gear is shown in figure 1. Forging of spur gear has several possibilities of die arrangements. Elastically attached die with machine frame and taper punches requires less forging load [7]. Peripheral relief and relief hole also reduce the required forging load [8]. In this paper combined effect of relief hole and elastically attached die is investigated. Die design process is complex, time consuming and requires thorough knowledge. The present die consists mainly four components: (a) bottom die, (b) counter punch, (c) middle (cavity) die and (d) top die. Bottom die and counter punch are static while middle die and top die are moving components.

| Type          | Spur gear |
|---------------|-----------|
| Material      | AISI 8620 |
| Module        | 4         |
| Number of teeth | 12       |
| Face width    | 20mm      |
| Centre hole   | 8mm       |
| Pressure angle| 20°       |

*Figure 1. Three dimensional model and specification of forged spur*

3. Finite element analysis of spur gear forging process
Trial-and-error based inspection of forging tooling design is costly and time consuming. To eliminate practical experiment based evaluation of tooling designs, FEM simulation and modelling software is used. On the basis of FEM result die dimensions can be obtained for further practical experiment. DEFORM-3D has been keen in forging process finite element analysis for the last couple of decades [9]. In the present investigation, FEM based software DEFORM-3D v6.1 is used for the forging process simulations. The numerical simulation software works in three stages: (a) pre-processor, (b) solver and (c) post-processor. Modelling of the die components and the workpiece are prepared in ProEngineer Wildfire 4.0. All the geometries are converted into stl file and inserted into DEFORM-3D environment.

3.1 Numerical simulation conditions
The simulations are executed using the commercial software DEFORM-3D. The billet material is AISI 8620 and die components are AISI H13. The modulus of elasticity and poisson ratio of AISI 8620 are 206.7 MPa and 0.3, respectively [6]. The flow stress of the AISI 8620 can be defined as a function of strain, strain rate and temperature.

\[ \sigma = f(\varepsilon, \dot{\varepsilon}, T) \]  

(1)

Here \( \sigma \) is flow stress, \( \varepsilon \) is strain, \( \dot{\varepsilon} \) is strain rate and \( T \) is temperature of the workpiece material. The value of flow stress at various strain, strain rate and temperature can be obtained from the DEFORM-3D material library under the hot forging condition [6].
Only the workpiece is considered as plastic material and rest of the components are selected as rigid bodies (non deforming). The workpiece deforms as per von-mises flow rule. Meshing is generated as solid mesh with near about 15085 nodes and 71012 tetrahedral elements. Remeshing is required during the numerical solution when large plastic deformation occurs of the element. The automatic remeshing is chosen during simulation by providing the relative interference depth 0.7. The workpiece temperature is set to 980°C [10] and the die components are pre heated at 150°C temperature. The friction factor between die components and material contact surfaces is 0.3. Punch velocity for the simulation is set as 3mm/s and maximum stroke is 14.1mm (Including dwell time). Elastically attached die environment is given by providing relative motion between top die and middle die with scaling factor 1.

4. Results and discussion

- Figure 3 represents the relation between forging load and top die movement. Spur gear forging process comprises three stages namely, (1) primary upsetting, (2) tooth cavity filling and (3) tooth corner filling. During primary upsetting height of the billet decreases and diameter of the billet increases. Actual tooth formation starts in tooth cavity filling zone and the forging load increases almost linearly. Spur gear forging requires maximum load at the time of tooth corner filling stage. The drastic growth in forging load during tooth corner filling stage is owing to the sharp corner filling of the gear tooth.

- Figure 4 shows the effective strain distribution at full stroke and maximum strain reach to 5.14mm/mm.

- Figure 5 illustrates the effective stress distribution at full stroke and the amount of maximum effective stress is 670MPa.

- Figure 6 depicts the material flow pattern and the material is flowing towards the periphery and towards the centre. Figure 7 illustrates the velocity variation at different tracking points P1 to P9. Tracking points P4, P6 and P8 are at the dedendum or root of the gear tooth while P5, P7 and P9 are at the addendum of the gear tooth. As shown in figure 7(b, c and d) velocity increases almost linearly at the end of the stroke at point P2, P4 and P9. As shown in figure 7(b) material flow towards centre starts at the time of tooth corner filling stage. Maximum effect of barrelling (bulging) is observed at point P9.
Figure 3. FEA result graph between forging load and top die stroke

Figure 4. Effective strain
Figure 5. Effective stress

Figure 6. Velocity distribution and material flow pattern
5. Conclusions

- Tooth corner filling requires the maximum amount of forging load and more than 45% load is increased during last 0.5mm top die stroke. Maximum forging load reaches to 3435 KN.
- During the same forging conditions the maximum forging load is reached up to 3648 KN in case of non-elastic die arrangements. It indicates that elastic die arrangement reduces forging load up to 213 KN.
- Strain rate also drastically increased in tooth corner filling zone therefore, flow stress increases and further deformation becomes difficult.
- Inward flow of the material reduces the centre hole size of the forged gear.
- Ejection of the forged gear will be comparatively easy in elastically attached die arrangements then non-elastically attached die arrangements. A present die design is practically tested using pure aluminium billet material and good agreement found in ejection of the forged gear.
- The grain flow lines of forged gear are continuous and the forged spur gear will have a good mechanical properties as well as dimensional stability.
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