Research on the Shunting Precision Forging of Ribbed Plate Gear Blank Based on DEFORM-3D Finite Element Analysis Under the Framework of New Engineering

Hui Zhang¹, Aiqiong Pan¹, Yanqin Zhang², Zhanling Zhang¹ and Jun Liu¹

1. School of Mechanical Engineering, Zhengzhou University of Science and Technology, Zhengzhou, China
2. City University of Zhengzhou, Zhengzhou 452370, China
Email: focus361@qq.com

Abstract. In order to solve these problems in the precision forging, such as non-saturate, folding, high energy consumption and low material utilization, a certain type motor vehicle of ribbed plate gear blank was selected as the main focus. Based on the principle of shunting and the law of minimum damping, the finite element model of shunting precision forging was established by using finite element numerical simulation software DEFORM-3D, and the temperature field, equivalent strain field and workpiece were analyzed in depth. The results show that the end faces of ribbed plate are flat and there are no folding defects at the bottom. The influence of damage and forming load on forming process and quality provide theoretical basis and technical support for shortening R&D cycle and optimizing reasonable process parameters in actual production.

1. Introduction

Gear is a quite important part of mechanical transmission which is widely used in the automotive industry. The quality of gear is not only related to the processing level method, but also directly depends on the quality of gear blank, especially the gear blank with ribbed plate. There are three main difficulties in forming these gear blank. First, the end face of ribbed plate is not easy to fill that will inevitably affect the accuracy position of the ribbed plate. Second, the bottom of ribbed plate is prone to folding defects, which break the surface integrity and reduce the effective bearing area of the forging leading to the fatigue fracture caused by stress concentration. Third, the conventional forging processes in many aspects, such as the high forming load, high energy consumption, low material utilization and weak competitive ability of product, are deficient. The design scheme can be virtually analyzed and reasonable process parameters can be obtained by using the finite element numerical simulation software DEFORM-3D. Based on the principle of shunting and the law of minimum damping, the finite element model of shunting precision forging is established in this paper. Finally, a practical, high education, economical and reliable forming process scheme for precision forging of gear blank is presented, which can provide theoretical guidance and technical support for the actual production process. It is also an important part of the new engineering construction.

2. Process Optimization

This paper regards the ribbed plate gear blank of transmission within a certain type motor vehicle as the object of research, as shown in Figure 1. The gear blank is a typical centrosymmetric part with maximum diameter of 71.5mm and height of 18mm. The optimized principle of shunting is shown in
Figure 2, comparing with those of original process, which could greatly reduce equipment depreciation and energy consumption because of eliminating heating after pre-forging and cutting flash.

![Forging drawing of gear blank.](image)

**Figure 1.** Forging drawing of gear blank.

![Optimized process chart.](image)

**Figure 2.** The optimized process chart.

### 3. Establishment of Finite Element Model

In this study, the gear blank was taken as plastomer and the mould was perceived as rigid body. Considering the symmetry of parts and saving computing time, 1/4 model was taken as the research object. The forging material is 40Cr and flow model of rigid plastic mechanics is adopted: 

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

where, \(\dot{\varepsilon}\) is the equivalent strain, \(\dot{\varepsilon}\) is the equivalent strain velocity, and \(T\) is the deformation temperature. Shear friction coefficient and shear friction model were applied in the molding process: 

\[
\dot{\epsilon} = mk = m \cdot \sigma / \sqrt{3},
\]

where, \(m\) is the shear friction coefficient of 0.3, \(k\) is the shear yield strength. The finite element model of this 3D mold is shown in Figure 3 with specified parameters: gear blank material of AISI 4120 stainless steel, tetrahedral grid cells umbers of 40000, preheat temperature of 300°C, friction press working speed of 60 mm/s, incremental step distance of 0.1 mm/step, coefficient of heat transfer of 11 N/s/mm / °C.

![3D model.](image)

**Figure 3.** The 3D model: (a) female die, (b) male die, (c) finite element modeling.
3.1. Temperature Field Analysis
The workpiece temperature decreases because of the heat transfer between mould and air. It has been verified the longer the contact time with the mold, the faster the temperature drops. However, the deformation of the ribbed plate is quite large, part of the mechanical energy transform into the internal energy of the leading to the temperature of the ribbed plate is higher than other parts. As shown in Figure 4, preforming and final forming temperature are over 1000°C, which is conducive to further filling the die. As the temperature increases, the maximum forming is gradually decreases. When the temperature drops to 1050°C. The maximum forming load is about 386KN basically reaching the maximum tonnage of equipment. For the reason that the temperature drops rapidly in closed forging, the starting forging temperature is set to 1100°C to ensure the best molding effect.

![Figure 4](image)

**Figure 4.** The temperature distribution charts: (a) step 538 of male die (left) and female die (right), (b) step 616 of male die (left) and female die (right).

3.2. Equivalent Stress Field Analysis
Compared with the traditional process, there is no large strain in the workpiece cavity, which can obtain more uniform microstructure. However, in the preforming process, the ribbed slab is narrow and deep, so large deformation occurs at the bottom of the ribbed slab and the workpiece groove, where the equivalent stress is more serious than other parts. On the basis of minimum damping law, redundant gear blank is more tend to flow in the groove because of its squeezing action when shunting process scheme is performed. The flowing gear blank could be raw material for the final forming so that just a simple upsetting is required to fill the small rounded areas in the finish die. As shown in Figure 5, the maximum equivalent stress of preforming and final forming are respectively 273 MPa and 411 MPa indicating deformation resistance reduction and forming quality improvement significant the of this part.
Figure 5. Effecting curve of friction coefficient on maximum forming load:
(a) Sep 538, (b) step 616.

3.3 Damage Distribution Analysis
Damage graphs of shunting process program are shown in Figure 6. The damaged parts of preformed and final formed workpiece mainly occur at the outedge of the workpiece and the bottom of ribbed plate. The damage figures range from 0.01~0.607, which is mainly caused by the friction between workpiece and mould during the forming process. Besides, these parts have reserved no less than 2mm machining allowance to meet the design requirement.

Figure 6. Workpiece damage graphs: (a) step 538, (b) step 616.

4. Forming Load Analysis
Because similar materials were used in these simulations, there may be some differences in the forming load. As shown in Figure 7 below, the simulation results reveal that the initial load of preforming rises slowly. The load increases rapidly and reaches about 200T when the ribbed plate is formed. Finally, the maximum forming load is about 300T at the moment of mold closing. In the initial stage of final forming, the deformation is less and the load rises slowly. The load has a sharp increase when process upsetting the face and rounded corner of the ribbed plate. The forming load reaches about 500T within range of the actual equipment tonnage, which decreases about 20% compared with the traditional process scheme.
5. Numerical Simulation Results Analysis
The simulation results of the workpiece are shown in Figure 8, it can be observed that the face of the ribbed plate is fully formed with no lack of material and high accuracy of position. Meanwhile, there is no folding defect at the bottom of ribbed plate and a few burr at the bottom of the outer edge of it. According to the simulation results, the forming quality of ribbed plate gear blank is excellent that could meet the technical requirements of production.

6. Conclusion
(1) In order to improve forming quality of the shunting precision forging, a series of affecting factors are considered in depth and optimized in the aspects of temperature field, equivalent stress field, damage of the workpiece and the forming load. The results show that the material deformation is easier and the tonnage of forming equipment declines compared with the traditional process scheme.
(2) The simulation show excellent results, the end faces of ribbed plate are flat and there are no folding defects at the bottom.
(3) The finite element simulation technology can be used to study the forming law of metal in a short time, which could short the development cycle and provide technical guidance for the process optimization design.

7. Project Sources
1. This project is sponsored by 2017 Henan Province Education and Teaching Reform Research and Practice Project: the Reform and Practice of Applied Talents Cultivation Mode Based on New Engineering Construction [2017SJGLX136].
2. The study originated from 2016 Technological Research Projects of Henan Science and Technology Department: Research on Key Technologies of Clay 3D Printing Equipment [162102210331].

8. References
[1] Song J H, Im Y T 2007 Process design for closed-die forging of bevel gear by finite element analyse Journal of Materials Processing Technology. 192–193 1-7
[2] Doege E, Bohnsack R 2000 Closed die technologies for hot forging Journal of Materials Processing Technology. 98 165-170
[3] Sedighi M, Hadi M 2010 Preform optimization for reduction of forging force using a combination of neural network and genetic algorithm Proceedings of the Institution of Mechanical Engineers. 224 1717-24
[4] Luo S M, Fang Y 2009 Numerical simulation on precision forging of spiral bevel gear China Mechanical Engineering. 485-7
[5] Li W 2015 Discussing the precision forging process of tooth preform Forging Technology. 4 9-13
[6] Avci E 2013 A new method for expert target recognition system: genetic wavelet extreme learning machine (GAWELM) Expert Systems with Applications. 40 3984-93
[7] Saman K, Abdolrahman D. 2011 Design and manufacturing of a straight bevel gear in hot precision forging processing using finite volume method and CAD/CAE technology IntJ Adv Manuf Technol. 56 87-95
[8] Guo J Q, Wang W J 2010 Numerical simulation and experiment on precision forging of driven spiral bevel gear 2010 International Conference on Computer Application and System Modeling(Taiyuan: North University of China ). 11 pp169-171