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STUDY ON THE NUMERICAL SIMULATION OF NET-SHAPE FORMING PROCESSES FOR BEVEL GEAR

Chen Guoxue, Cao Changzheng, Liu Xiaolong

Department of Mechanical Engineering, Tsinghua University, Beijing, P. R. China

Abstract

In the study, the modeling strategies in connection with the quantitative prediction and improvement of product accuracy and quality are proposed. The analysis models are composed of process chain, geometry of die, interface conditions between die and workpiece, material parameters, forming velocity of machine, and so on. A 3D simulation platform, around the software MSC.Superforge, is built up for the applications in net-shape forming parts. Some results for bevel gear are shown to demonstrate the efficiency of the modeling system.

Keywords: net-shape forming, numerical simulation, die, bevel gear

1 Introduction

With the advances of processing and die technologies, precision forging (net-shape forming) is increasingly getting to be used in manufacturing a variety of structural parts. Characterized by the shorter process sequences, fewer unwanted harmful disposals and saving of both materials and energy, the net-shape forming has been recognized as one of the "green" forming technologies.

The repeatable volume production of forgings with critical precision is a complex systematic engineering. There are many variables to influence the final quality of products: billets, process parameters, tool precision and its performance on working conditions, forming equipment and so on. Any improper operation of every loop in the process chain might make the precision counted in μm lost. In order to obtain the sufficient accuracy to be competitive with machining, multidisciplinary measures of research and development are necessary, including computer science. Therefore net-shape forming is becoming one of high-tech precision technologies.

Some issues on the computer modeling of net-shape forming are dealt with in this paper, and the considerations to connect simulation procedure with the prediction and improvement of product accuracy are proposed. The forming process of bevel gear is taken as an example to provide some suggestions in simulation.

2 Platform of Simulation

An integrated simulation platform with several commercial codes is established in this study, and the necessary interface routines are developed to transfer data between them (Fig.1).

The MSC.Superforge, which uses finite volume method, is chosen as a solver for plastic flow analysis on the platform.

The other codes on the platform include MSC.Marc for deviation analysis of die profile in working, ANSYS or Marc to model cyclic thermal transfer and the error assessment routines developed independently. The neutral data interface Patran is useful for pre- and post-processing of the analysis data.

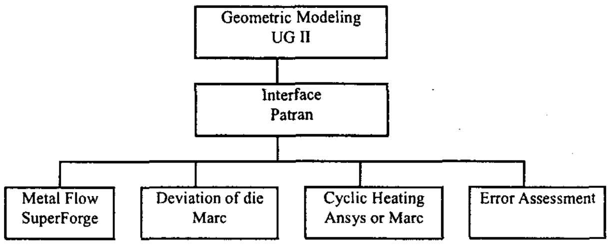
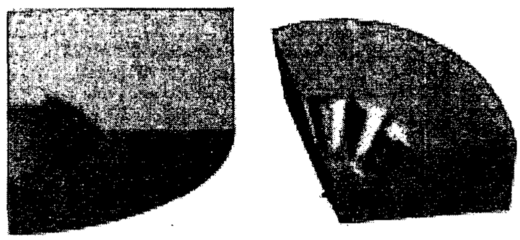


Fig. 1: Simulation platform for net-shape forming

3 Model-Building and Simulation

3.1 Geometric Modeling

Precise geometric modeling is essential to simulate net-shape forming, especially to form the functional surfaces like tooth flank of bevel gears. And considered that the geometric information from simulation and optimization should be implemented by CAM, professional software is necessary. UG-II is chosen in this study. The die models are shown in Fig. 2.



a) Upper die *b) Lower die*

Fig. 2: Geometric model of Gear forming die

3.2 Analysis Model of Metal Flow

The material of bevel gear is 20CrMnTi. The constitutive model in warm forging is described as elasto-viscoplastic in simulation shown by Eq. 1 and Eq. 2 corresponding to pre-forming and final forming phase respectively.

$$\sigma = \max(50,\ 151.5\dot{\varepsilon}^{0.113}) \quad \text{at } 950℃ \qquad (1)$$

$$\sigma = \max(70,\ 151.1\dot{\varepsilon}^{0.0983}) \quad \text{at } 850℃ \qquad (2)$$

For the important effect of strain rate on metal flow patterns, a loading velocity model is established to mimic the ram motion of screw press used in bevel gear forming practice, instead of simple constant velocity.

Both Superforge and Marc allow the full thermo-mechanical coupling analysis. In addition to thermo-physical parameters for billets and tools (steel H13 in this study), Coulomb and shear friction models are put on the workpiece/die interface, the heat transfer from hot workpiece to die and environment is taken into account. As for the production conditions in workshop such process parameters are introduced, such as forming cycle per gear, the transportation time of a workpiece between two processing sites, the tool preheating temperature, the lubrication procedure, etc. All of these construct a fundamental model to simulate the forming processes exactly to some extent.

3.3 Simulation of Bevel Gear forming

The processes of a bevel gear are composed of the following 6 sequential stages: billet heating, transfer to pre-forming, pre-forming, transfer to final forming, finishing forming and consequent cooling. All steps have been simulated in the study to understand the variation rules of final properties of products so as to optimize the processes.

Only half tooth is used in practical simulation because of symmetry during gear forming. The analysis model for pre-forming process is illustrated in Fig. 3, and the results of temperature and strain fields are shown in Fig. 4.

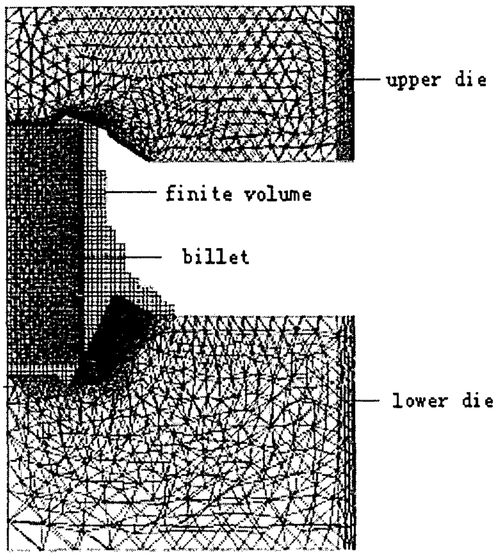
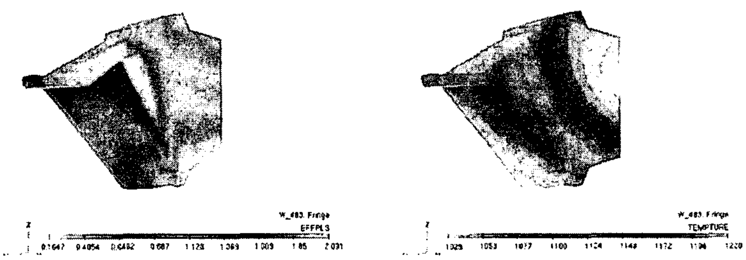


Fig.3: Simulation model of bevel gear forming



a) Effective Strain *b) Temperature*

Fig. 4: Simulation results of bevel gear

4 Modeling of Cooling Process

It is noticed that the successive inheritance of strain and temperature process along the process chain may not be ignored. Examining the 6 sequential processes listed in section 3.3, the accuracy of bevel gear is a product through the whole loops in the chain. The temperature field of workpiece just after ejection from the finishing forming die is the contribution of first 5 processes together and of inherent non-homogeneity. Then such a workpiece undergoes the consequent cooling process, obtaining non-homogeneous shrinkage within body of 3D geometry.

After a complete cycle of the 6 sequential processes for one gear is modelled, the error distribution on tooth flank by cooling is obtained (Fig. 5 and 6). It can be seen that the cooling process makes the whole flank move to centric line, causing tooth thinner. Along an involute (e.g. A6 to H6), the deviations at the tip of tooth flank are more than that at the root because of non-uniform cooling shrinkage from an inhomogeneous temperature field down to the circumstance temperature; and along the length of tooth (e.g. E1 to E11), slightly more shrinkage occurs on the big end of tooth due to higher temperature there at the time of starting cooling.

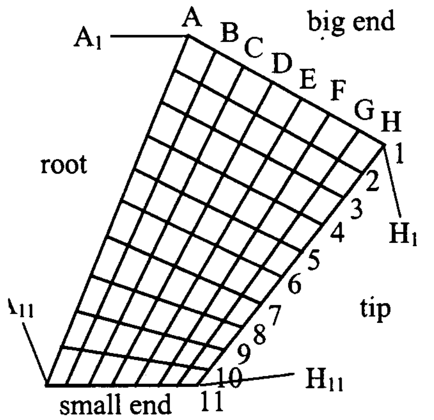


Fig. 5: Measured location on tooth flank

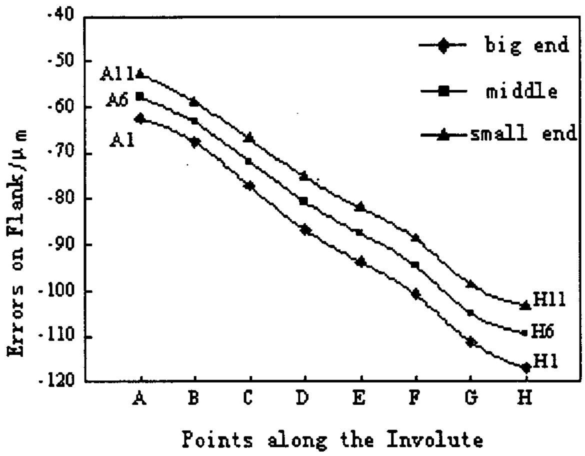


Fig. 6: Non-uniform Errors

Such error distribution induced by cooling will lead the pressure angle of tooth to be larger than the expected, and the increment values vary along the length of tooth (see Fig. 7). The direct effect of this situation on the subsequent assembling is that the engaging zone may be displaced to the root of the small end.

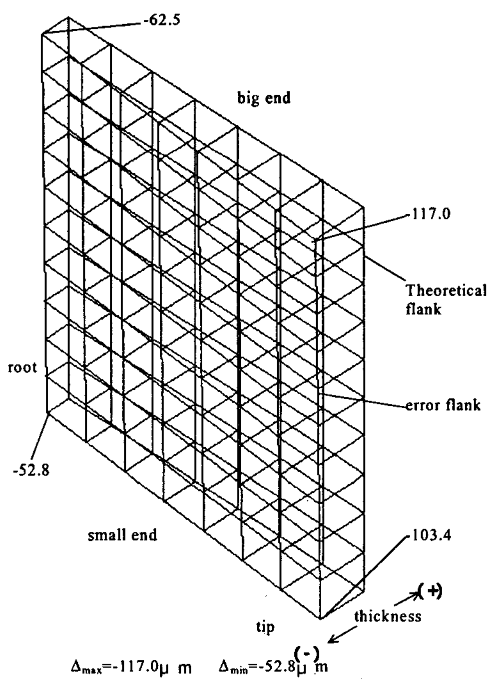


Fig. 7: Tooth flank error after cooling

5 Conclusions

1) It is possible to simulate a complete cycle of sequential processes for net-shaped forming parts.
2) The useful results of simulation rely on analysis model-building as close to the production conditions as possible.
3) The proper compensation for the non-uniform error distribution of final parts should be made to reach desirable accuracy.

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