MATEC Web of Conferences **63**, 01009 (2016) DOI: 10.1051/matecconf/20166301009
MMME 2016

A New Cold Rotary Forging Technology for Automotive Starter Guiding Cylinder with Internal Helical Involute Spline

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Abstract. A new cold rotary forging technology of the internal helical involute spline was presented based on an analysis of the structure of automotive starter guide cylinder. 3D rigid-plastic finite element model was employed. Billet deformation, Billet equivalent stress and forming load were investigated under the DEFORM 3D software environment, then the forming process parameters were applied in the forming trials, and the simulation results are conformed with the experimental results. The validity of 3D finite element simulation model has been verified. The research results show that the proposed cold rotary forging technology can be efficient in handling of the forming manufacturing problems of automobile starter guide cylinder with internal helical involute spline.

1 Introduction

Automotive starter guiding cylinder is the critical part of automotive starter transmission system, it works in a complex condition, and it has to meet the requirements for the excellent mechanical properties. At present, most automotive starter guiding cylinders are manufactured by metal cutting, in which metal streamlines are cut off, thus lowering the mechanical properties. With the rapid increase of automotive starter guiding cylinders production, to explore the advanced manufacturing method of automotive starter guiding cylinders is of great significance to the development of automobile parts enterprises.

Cold rotary forging is an advanced and innovative metal forming technology that, based on the principle of continuous uniaxial pressure and using rotational movements in the dies [1], offers the following advantages: the reduction of the forging load, uniform quality, the strong effect on the mechanical properties, close tolerance and savings in materials cost etc. Many scholars have made some researches on the rotary forging technology. Montoya et al [1] made a kinematic and sensitivity analysis of rotary forging process by means of a simulation model. Han et al [2-4] clarified the difference between the cold rotary forging and conventional forging in the forming process. Qin [5] revealed the contact force response in cold rotary forging through the modeling and simulation. M.J. Roy, D.M. Maijer [6-7] investigated the spinning of a common aluminium automotive casting alloy A356 at elevated temperatures. Wang et al [8-12] developed a 3D rigid–plastic FE method to analyze the cold rotary forging process. Zhou et al [13-18] studied the cold rotary forging process by using analytical and experimental methods. All of these research results provided useful guidelines for the studies on the cold rotary forging process. However, the cold rotary forging technology for internal helical involute spline is not involved.

In this study, Base on the analysis of the structure of automotive starter guiding cylinder with internal helical involute spline, a new cold rotary forging technology was proposed. The cold rotary forging process is simulated using the DEFORM 3D software. The forging experiment was performed under the same process conditions used in the FE simulations. Comparison of the simulation and experimental results shows that the cold rotary forging technology is able to successfully find a defect-free cold precision forging operation for internal helical involute spline.

2 The description of cold rotary forging technology of internal helical involute spline

The cold rotary forging process of internal helical involute spline is illustrated in Figure. 1.

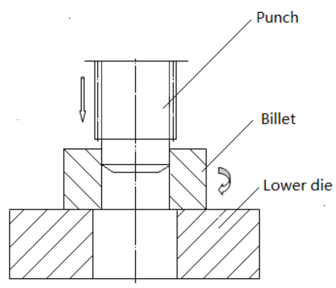

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Figure 1. Schematic diagram of cold rotary forging of internal helical involute spline.

The structure characteristics of the punch is mainly composed of the lower guiding part and the upper forming part, the lower guiding part is used to avoid material flow to the center, and the upper forming part is used to ensure the billet flow in a helical angle so as to form the internal helical involute spline in the process of extrusion. As the punch moves down, the billet rotates around its own axis under the action of the punch. When the rotary forging process is completed, the punch leaves the lower die under the action of returned material device.

3 Forming process and die set design

3.1 Forming process design

According to the final shape of automotive guide cylinder with helical involute spline, the forming process can be divided into ten stages: making billet, annealing, shot blasting, the saponification of phosphorus, forward extrusion, upsetting, backward extrusion cavity, machining guiding hole, the saponification of phosphorus, cold rotary forging internal helical involute spline. The schematic process of these stages was shown in Figure. 2.

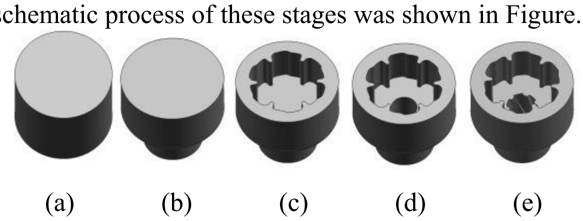


Figure. 2 The forming process of automotive guide cylinder: (a) making billet, (b) forward extrusion, and upsetting, (c) backward extrusion cavity, (d)making guiding hole,(e) cold rotary forging internal helical involute spline.

3.2 Die set design

The die set is mainly composed of upper die and lower die. As shown in Figure.3.

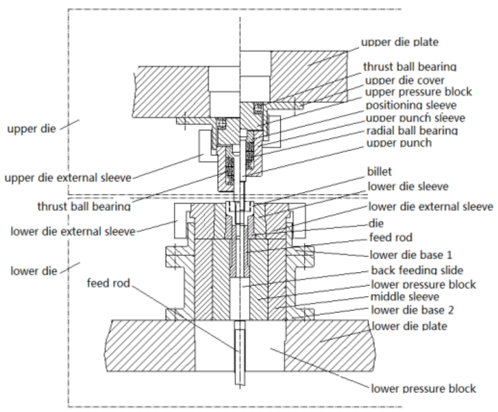


Figure. 3 Schematics of the die set.

When die set works, the upper die drives punch down, and all parts of the punch extrusion in turn in the inner hole of billet, from the beginning of punch extrusion billet to the end of the forming of internal helical involute spline, the punch will extrusion billet along the direction of a spiral angle, and the extrusion process is in stable state. After finishing the extrusion of internal helical involute spline, the punch rotates out of the billet, and the punch withdraws from the lower die under the action of feeding device, the whole rotary extrusion process is complete.

4 Finite element analysis

4.1 Finite element model

In order to evaluate the feasibility of the proposed cold rotary forging technology, a 3D finite element simulation was carried out using commercial finite element software DEFORM 3D. Considering the complexity of the internal helical involute spline, dies geometrical model was built under the NX7.5 software. The models were subsequently transformed into the STL standard format files and imported into DEFORM 3D analysis software by its preprocessor. A 3D rigid-plastic FE model was established under the DEFORM 3D environment, as shown in Figure. 4.

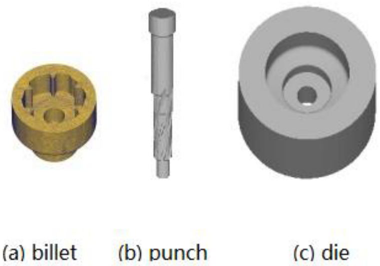


Figure. 4 Finite element model: (a) billet, (b) punch, (c) die.

The billet material for used simulations and experiments was AISI5120, the material model was considered as rigid plastic with Von Mises yield criterion and isotropic hardening model. The mesh was divided into three-dimensional tetrahedral, the gridding number is 197410. Billet temperature is set to 20℃. The punch and die were assumed to be rigid bodies, so their deformations can be neglected when setting up FEM model. The punch speed is set to 12mm/s, and billet is set to turn around its own axis. The solving method of sparse matrix is set to Newton Raphson. The type of friction between billet and punch was assumed as shear friction, and the coefficient of friction is set to 0.12.

4.2 Forming Load Analysis

Forming load has important influences on the accuracy of the forged parts and the die life. The forming load result of the rotary forging process is shown in Figure.5.

DOI: 10.1051/matecconf/20166301009

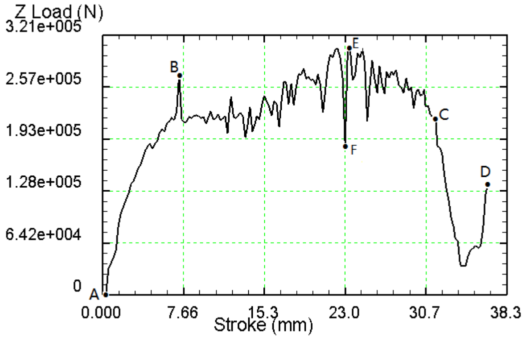
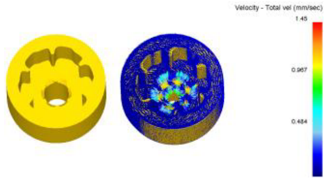


Figure. 5 The forming load result of the rotary forging process.

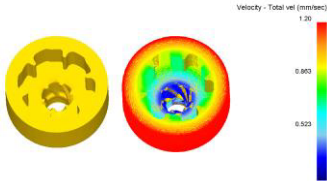
For the convenience of the analysis of the forming load, and the forming load curve is divided into three stages: the initial forming stage, the middle forming stage and the final forming stage. In the initial stage, the curve of the forming loads started from point A to point B. Due to the frictional resistance between the punch and the billet and the billet deformation resistance, the forming load increased quickly from 0 to 272.92KN. The punch was squeezed into the billet to form the initial shape of the internal helical involute spline. In the middle forming stage, the curve of the forming loads started from point B to point C, Along with the increase of the punch stroke, the deformation of the billet became more and more complex, the forming loads began to fluctuate, the maximum value of the forming load occured in point E (305.57KN), and the minimum value of the forming loads occured in Point F (219.02KN), the average value of the forming loads is 246.35KN. At this stage, the main part of the internal helical involute spline has been formed. On the whole, then the forming process of the internal spiral involute spline is in a relatively stable state. In the final forming stage, the curve of the forming loads started from point C to point D. The general trend of the forming loads is decreased at this stage. The forming temperature generated by extrusion concentrated in the forming area, which made the plastic flow of the billet increasing, the forming loads decreased. When the forming process closed to end, the forming loads increased slightly, as the metal flow was hampered by the die.

4.3 Billet Deformation Analysis

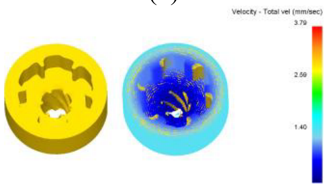
The billet deformation analysis is shown in Figure. 6. In the initial forming stage, as shown in Figure. 6(a), the punch moves down and begins to extrusion billet, and then the material is in the elastic deformation stage. With the increase of metal deformation, extrusion stress increases gradually, when the stress exceeds the material yield limit, the material begins to flow. Due to the limitation of the punch guiding parts, the material can flow only along the circumferential and axial. In the extrusion process of the internal helical involute spline, the friction force between the punch and the billet will drive billet counterclockwise rotating. In the middle forming step, as shown in Figure. 6(b), the forming is in stable state, and the metal flowed smoothly. In the final forming stage, as shown in Figure. 6(c), the internal helical involute spline was formed, and the vector changes of the each node flow speed was uniform, the forming performance of the internal helical involute spline is good, and no defects occurs.



(a)



(b)

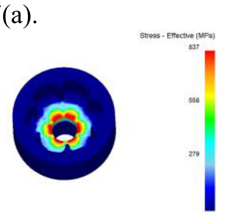


(c)

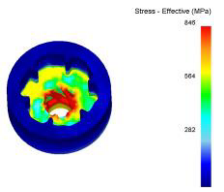
Figure.6 Billet deformation and metal flow results of rotary forging: (a) the initial forming stage, (b) the middle forming stage,(c) the final forming stage.

4.4 Billet Equivalent Stress Analysis

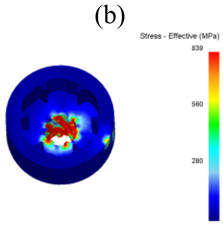
The equivalent stress distribution of the billet is shown in Figure. 7. It can be seen that the maximum stress is located in the contacting area of the punch forming part bottom and the billet in the initial forming stages, as shown in Figure. 7(a).



(a)



(b)



(c)

Figure.7 Billet equivalent stress distribution of the rotary forging: (a) the initial forming stage, (b) the middle forming stage, (c) the final forming stage.

5 Experimental verification

The primary aim of the experiment was to verify the feasibility of the proposed rotary forging technology. This experiment of the cold rotary forging process of automobile starter guide cylinder with the internal helical involute spline was conducted using YJ61-160A hydraulic testing press, which is an industrial metal extrusion hydraulic press made by Jiangdong machinery co., LTD. China, and a forging die sets similar to the simulative process were then fabricated, as shown in Figure. 8. The rest of the experimental conditions were the same with the simulation conditions.

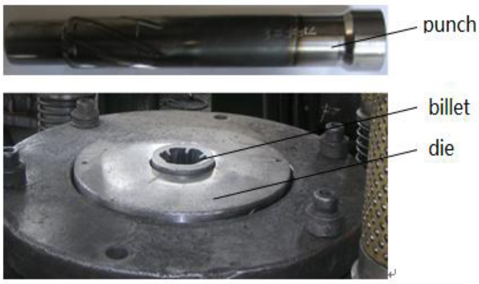


Figure. 8 Tools used for the experiment.

A well-shaped the internal helical involute spline was achieved by the proposed rotary forging process, as shown in Figure. 9(b), and no forming defects occurred. The requirements of mechanical properties of the part are fully met. For comparison, Figure. 9(a) shows the simulated model of the internal helical involute spline. It is evident that a very good agreement was obtained between the simulation results and experimental results.

(a) (b)

Figure. 9 Models comparison: (a) the simulated model, (b) the experimental model.

6 Conclusions

A new cold rotary forging technology for automotive starter guiding cylinder with the internal helical involute spline was proposed. The finite element analysis based the software of Deform-3D and the experiments were performed to investigate metal flow, stress distributions and the forming load. As a result of this study, the following conclusions can be drawn:

(1)The structure of the internal helical involute spline of automotive starter guiding cylinder can be formed through the cold rotary forging technology.

(2)The finite element model built in this paper can predict the forming defects in the rotary forging forming process of automotive starter guiding cylinder with the internal helical involute spline. The model can be used to analyze and optimize the rotary forging forming process.

(3) The friction condition and the velocity of the punch are the main factors of affecting the rotary forging forming. Reasonable friction condition and velocity of the punch can effectively reduce the forming load and improve the full rate of the forming of the internal helical involute spline.

(4)The validity and the feasibility of cold rotary forging process scheme were verified by finite element simulation and actual production.

Acknowledgment

The project was supported by joint innovation project of Jiangsu Province under Grant BY2015057-28.

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