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Numerical and experimental study on new cold precision forging technique of spur gears①

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Abstract: A new cold precision forging technique is proposed to form a spur gear from a hollow billet, that is blocking the divided flow region and then final forging by the relief hole. 3D-FEM simulation of the whole process of a pure aluminium spur gear is performed using DEFORM-3D^{TM}. The load-stroke curve, effective stress distribution, effective strain distribution, velocity distribution, and so on, are achieved. These results are compared with those achieved using the conventional closed die forging in the same conditions. The results show that this new technique has many advantages over the conventional one. The deformation load is reduced by near 30% and the filling ability of the tooth profile is also improved. Precision forging experiments of spur gears with the new process were performed using material Pb. The experimental results show a good agreement with the numerical results.

Key words: spur gear; cold precision forging; numerical simulation

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1 INTRODUCTION

Gears are widely used in automobiles and other industry fields as the main parts of transferring the movement and energy. Gears are mainly manufactured by metal cutting or by a combination of conventional hot forging with metal cutting, which is expensive and requires a lot of manufacturing time. Because net shape or near net shape manufacturing processes have been paid attentions to in industry, the precision cold forging technique has been developed to be as an important method to manufacture the spur gears. The precision forging of gears has a lot of advantages including less raw material and energy, cost savings, high production efficiency and improved strength. However, the research and development on the precision forging technique of gears, especially for spur gears, has some difficulties in theory and practical application.

The native research work, which is mainly focused on the traditional theoretical analysis and experimental study, still remains at the laboratory level[1－3]. Recently, a finite element method has been widely used to analyze the metal forming process[4－7]. Tuncer and Dean[8,9] reported a precision forging method for hollow parts. Herlan[10] developed the warm forging of straight tooth bevels for the utility vehicle's production to reduce the forging force by the FEM using ANSYS software. John Walters et al[11] used DEFORM^{TM}-3D to simulate the whole forming process of a bevel part. Chenot and his co-workers[12] simulated the cold forging deformation of helical gears by the software FROGE3.

2 NEW DIVIDED FLOW FORGING PROCESS

The traditional manufacturing process of the spur gears is no-flash upsetting and extrusion process using a hollow billet, as shown in Fig. 1. The deformation load is significantly huge and the filling of the tooth shape is poor. In order to improve the present process, a new divided flow manufacturing process is proposed in this paper. In the blocking phase, the divided flow region is deformed in the two end of the billet using a convex structure, as shown in Fig. 2(a). Then the preform with the divided flow region is forged to the desired shape in the final forging step, as shown in Fig. 2(b).

3 FINITE ELEMENT ANALYSIS MODEL

In numerical simulation, parameters of the spur gear are as follows: teeth numbers 18, modulus 1.5, pressure angle 20°, inside diameter 11.5 mm, height 13 mm, see Fig. 3. In order to reduce the machining time, the inside diameter of the billet is also 11.5 mm and outside diameter of the billet is 23 mm, near one of the dedendum circle. According to the constant volume in plastic deformation, the height of the billet is 19 mm by calculating. The other parameters in-

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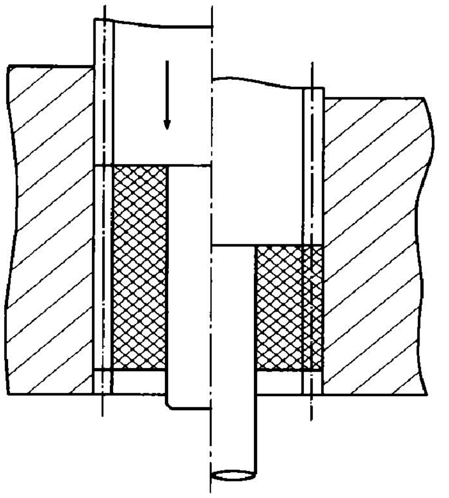

Fig. 1 Scheme of closed upsetting-extrusion process

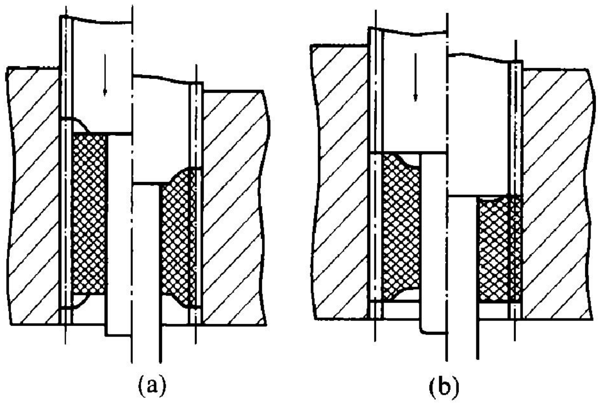

Fig. 2 Scheme of new process
(a) —Blocking step; (b) —Final forging step

Fig. 3 Spur gear part used for simulation

volved in simulation are listed in Table 1. The flow stress of the pure aluminum is $\bar{\sigma} = 170\bar{\varepsilon}^{0.24}$ MPa at room temperature[2]. In order to analyze it effectively, a quarter of the whole object is employed in simulation considering the geometric symmetry. The billet is divided to 38 235 tetrahedron elements and 8 486 nodes, as shown in Fig. 4.

Table 1 Parameters in simulation

Material	Pure aluminum
Temperature/ ℃	20
Punch speed/ (mm·s^{-1})	50
Feed per step/ mm	0. 2
Friction coefficient	0. 1

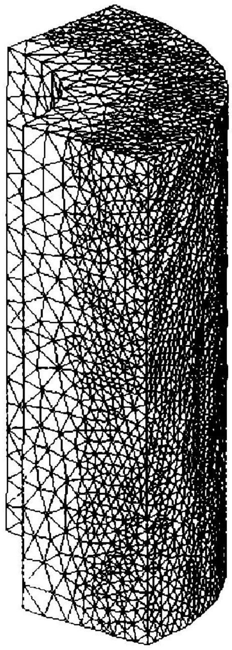

Fig. 4 Grid of quarter of billet for simulation

4 RESULTS AND ANALYSIS OF NUMERICAL SIMULATION

The whole deformation process of the new cold precision forging method of the spur gear is simulated using DEFORM-3D^{TM}. The final deformation grid is shown in Fig. 5. Fig. 6 shows the load-stroke of the blocking step and the finish forging step and one of the traditional upsetting-extrusion process. From Fig. 6, it can be seen that the load of the traditional process is increased significantly compared to the new process under the same simulation conditions. This not only requires a large energy machine but also will damage the deformation tools.

During the finish forging of the new process, the deformation load is reduced clearly and the filling of the tooth shape is also improved. The required load by the traditional process is 60. 5 kN while in the new process the load is only 42. 6 kN due to the divided flowing of the material in the blocking step. The deformation load reduces by near 29. 6% in the new process. Fig. 7 gives the teeth shape of the spur gear of the two processes under the same deformation load. While the deformation load reaches 42. 6 kN, the tooth shape has been filled completely with the new process through divided flow in the blocking step

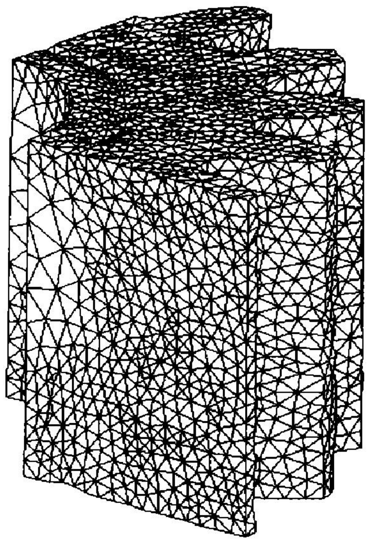

Fig. 5 Final deformation grid of spur gear

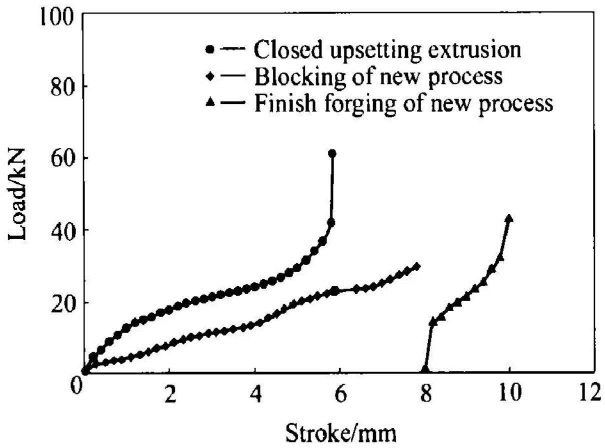

Fig. 6 Load-stroke curves of different processes

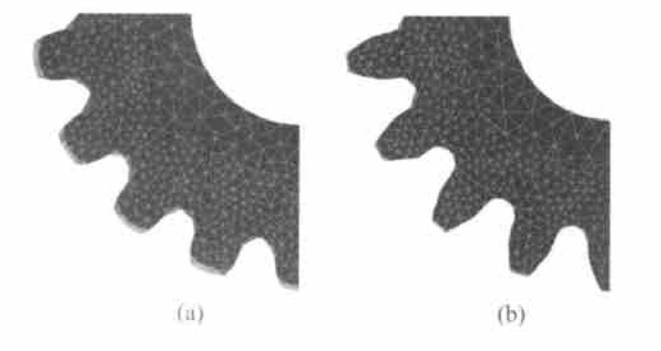

Fig. 7 Teeth shape of different processes under same forming load 42.6 kN

(a) —Filled insufficiently with traditional process; (b) —Filled completely with new process

and insufficiently with the traditional process.

Fig. 8 and Fig. 9 give the distributions of the stress and strain in the blocking step, respectively. The flowing pattern of the material in two ends of the billet is changed due to the convex shape in the upper and lower punches and results in improvement of the filling ability of the tooth shape. From the velocity distributions in the final forging shown in Fig. 10, it can be seen that there exists a demarcating line of the material flowing. The material inside the demarcating line flows inside and in the mean time the material outside the demarcating line continues to fill the gear shape. This flowing pattern results in significantly decreasing the forming load in the final forging step.

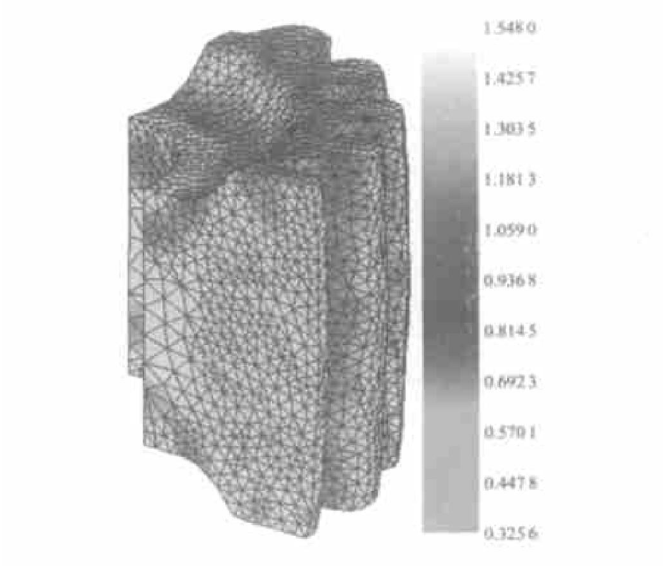

Fig. 8 Strain distribution at 8 mm stroke in blocking step

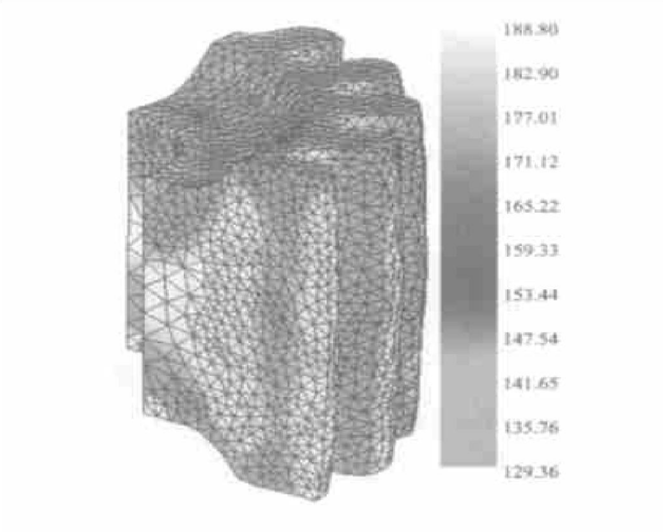

Fig. 9 Stress distribution at 8 mm stroke in blocking step

5 EXPERIMENTAL STUDY

In order to verify the new process proposed in this paper and the numerical analysis results, the precision forging experiments of spur gears were performed using material Pb. Fig. 11 and Fig. 12 show the stroke-load curves of the new process in the blocking and final forging stages, respectively. Comparing of stroke-load curves both in the blocking step and the finish forging step, the similar increasing trends of the two curves exhibited that the new pro-

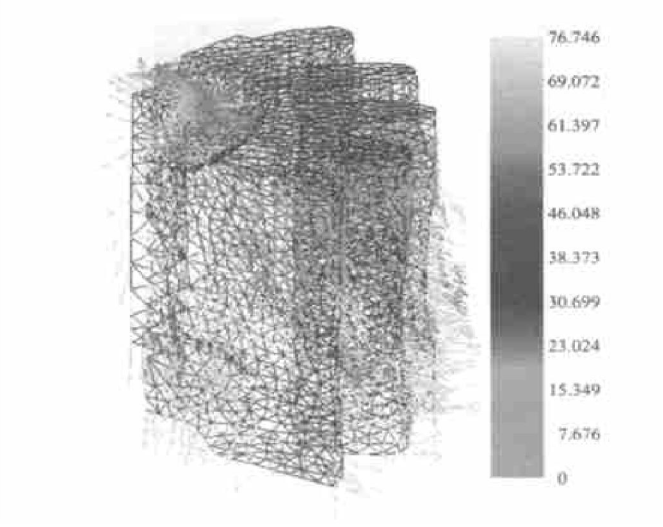

Fig. 10 Velocity field at 2. 1 mm stroke in finish forging step

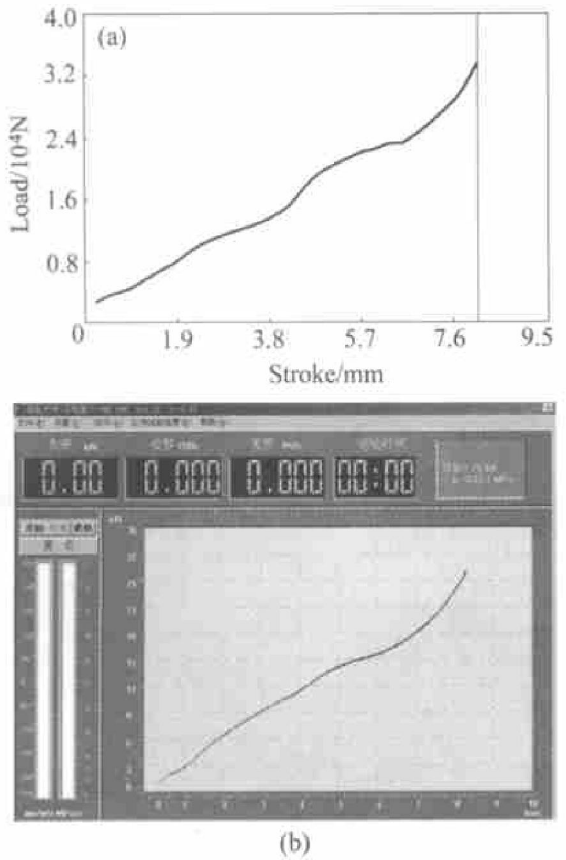

Fig. 11 Stroke-load curves in blocking step
(a) —Numerical; (b) —Experimental

cess proposed in the paper and involving numerical results are reasonable and credible. Fig. 13 shows the experimental parts using the new process.

6 CONCLUSIONS

1) The numerical simulation results show that large loading is required to manufacture the spur gear with the traditional closed upsetting-extrusion process.

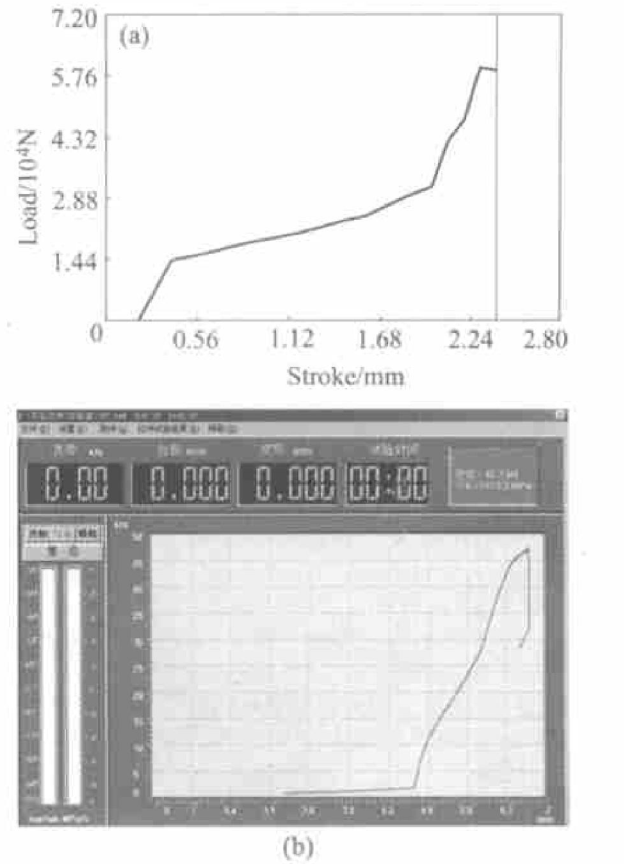

Fig. 12 Stroke-load curves in finish forging step
(a) —Numerical; (b) —Experimental

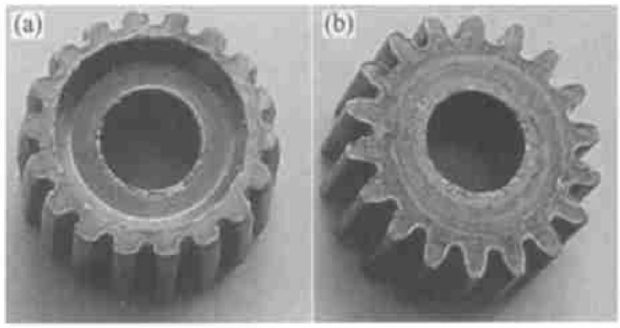

Fig. 13 Experimental parts prepared using new process
(a) —Blocking part; (b) —Finish forging part

2) The new cold precision forging process proposed in this paper suggests that the fabricating process of the spur gear is divided into two steps —the blocking step and the final forging step. The deformation load reduces by near 29. 6% in the new process in the final forging step through performing the divided flow region at the blocking step. Furthermore, the new process can improve the filling ability of the material significantly and obtain the required profile of the teeth. The lower forming load can improve the employment of tools and reduce the elastic deformation of tools. This results in good dimension precision and ejecting the part easily from the tool cavity.

3) Experimental results of precision forging spur

gears with material Pb show that the increasing trends of the numerical and experimental stroke-load curves are similar. This exhibits that the new process proposed in the paper and involving numerical results are reasonable and credible.

4) It can obtain the whole plastic deformation characteristic and material flowing pattern to simulate the precision forging process of the spur gear using the three-dimensional FEM. The numerical results can give a guidance for selecting the process parameter and designing the tool structure, even for industrial application in order to save the R&D time of the product.

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