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A COLD FORGING OF HELICAL GEAR FOR STEERING PINION

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ABSTRACT

The precision cold forging of helical gear for steering pinion has been studied. Because of the large helix angle, there are many difficult problems to control the material flow and part dimension. The die shape was proposed to improve the flow of workpiece. In order to improve the dimensional accuracy of forged part, a FE analysis was performed.

The proposed die shape drives to flow amicably workpiece. The applied load was reduced up to 10 percent, compared to the conventional-shaped-die. The elastic deformation of die has been investigated quantitatively by the 3-dimensional FE analysis. The die-land has been expanded up to 10μm on loading stage, based on the FEM results. Therefore, the elastic deformation amounts should be taken into consideration to improve the dimensional accuracy of forged helical gear.

KEYWORDS: helical gear, die shape, FEM, steering pinion, cold forging

1. INTRODUCTION

Precision forging enables gear teeth to be manufactured to net or near net shaping, resulting in significant savings in raw material and production time compared with conventional machining processes. There are many advantages for precision forging of gears, such as improved properties and attractive production route. However, precision gear forging has the problems related to tooth dimensional accuracy, die design, and volume control.

Specifically, the forging load of helical gear is too high to flow the material into the corners of the tooth cavity fully. Thus the accuracy of the product is easily deteriorated by the elastic deformation of the tools. It is very important to reduce the forming pressure and to accommodate a method to knock out the forged part easily after precision forging of helical gears. Therefore, there are many studies for reducing the forming pressure, specific forming units, and ejecting methods.[1-6]

In this paper, a die shape was proposed to reduce the forming load. The amount of die elastic deformation was investigated to improve the dimensional accuracy for forged helical gear. The preliminary studies were performed by the FEM analysis and then the prototype forgings were conducted by using the hydraulic press. A commercial FEM package, DEFORM-3D™, has been used to analyzed not only the forming process of workpiece but also the stress and elastic deformation of die.

2. FE analysis and Experimental

A steering pinion for automobile is shown in Fig.1. Since helix angle is 28° and teeth length is over the 30mm, there should be many problems in acquiring the good metal flow and dimensional accuracy. The part was forged in a biaxial extrusion way. Fig.2 shows the whole fabrication processes and appearance of forged part. The workpiece material was an AISI4140H, which was heat-treated for spherodizztion and Zn-phosphating. After forging, the forged part was surface hardened by the heat treatment.

- Helix Angle	: 27 - 28°
- Teeth Length	: 30 - 50mm
- No. of Teeth	: 10
- Pressure Angle	: 20°

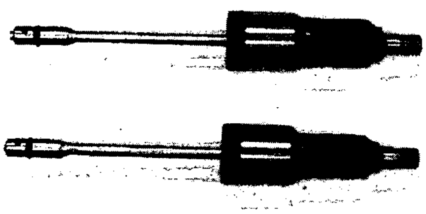
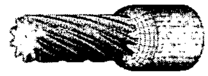


Fig.1 Specification of steering pinion

Process	Details
Material	SCM440H (AISI4140H)
Pre-heat-treatment	Spherodized Annealing
Lubrication	Zn-Phosphate
Forging stage	Extrusion type
Heat treatment	Surface Hardening



C	Si	Mn	P	S	Ni	Cr	Mo
0.38	0.15	0.60	<	<	<	0.90	0.15
0.43	0.35	0.85	0.030	0.030	0.25	1.20	0.30

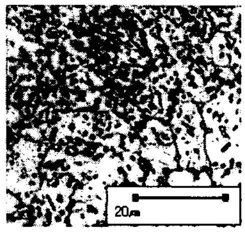


Fig.2 Forging processes for steering pinion

In order to reduce the forging load, SCM440H was heat treated to get the spherodized-cementite, as shown in Fig.2. The flow stress of workpiece was measured by the compression test on the hydraulic press. The measured flow stress is lower than that of the reference data. ($\sigma = 800\varepsilon^{0.23}$, unit: Mpa) The deformation patterns of workpiece were shown in Fig. 3. The regions of extruded helical gear were included in high strain and stress. Therefore, the die for extruded tooth should be manufactured using a high-strength material with an additional surface coating.

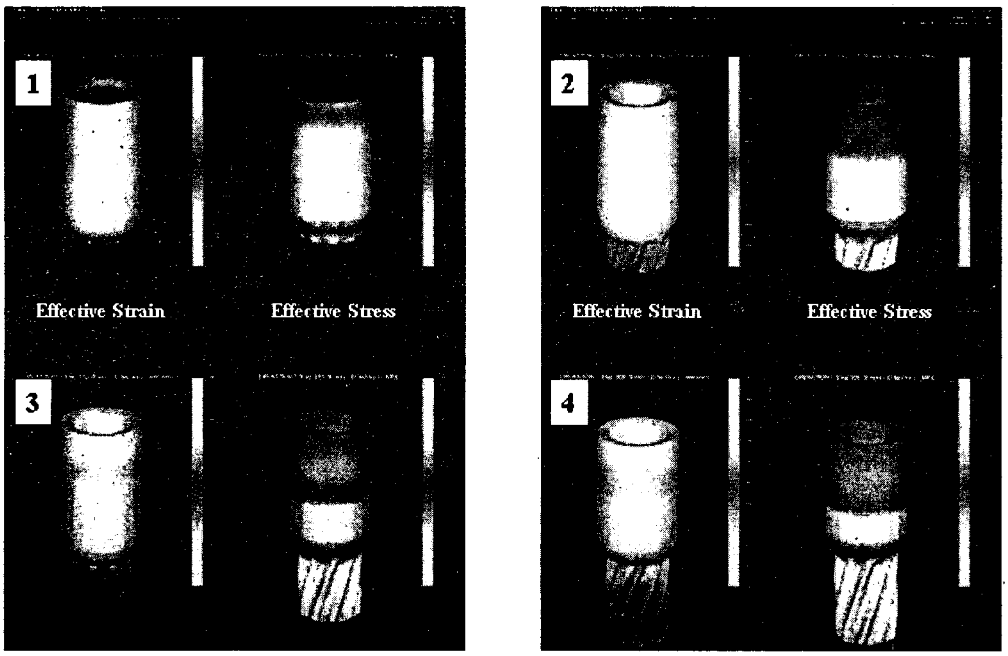
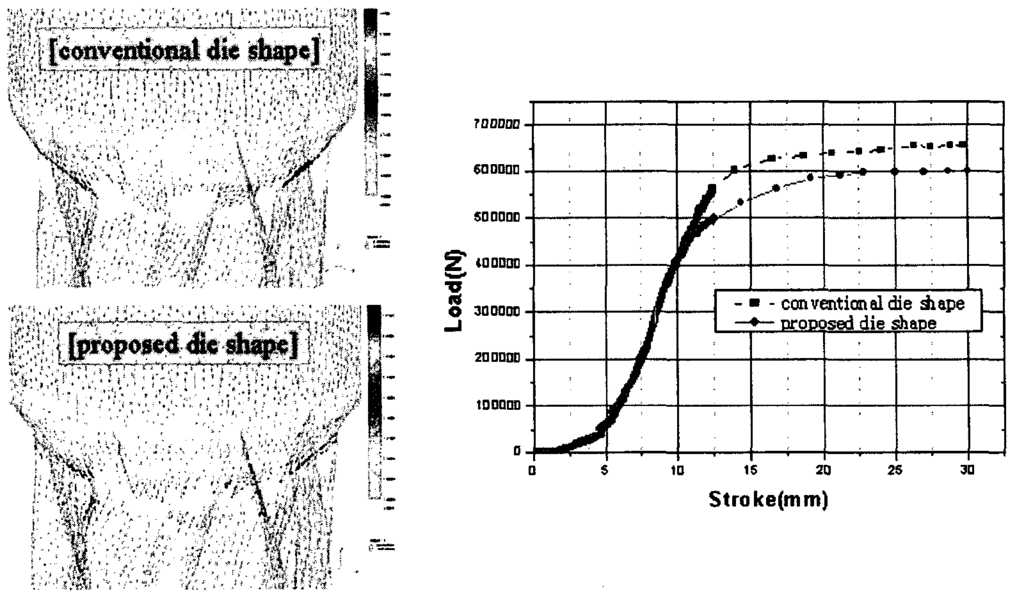


Fig.3 Deformation patterns of a helical gear for steering pinion

3. A die shape proposed for reducing forging load

A control of velocity field is one of the most efficient ways to reduce a defect and forming load. Since flow direction of metal and the axis of press do not coincide each other, specially velocity interruption could be frequently occurred. Therefore, the die shape for helical gear is very important to control the velocity and direction of metal flow. In this study, a die shape was proposed, as shown in Fig.4. A proposed die was simulated to reduce the forming load from 665,000 N to 600,000 N compared with the conventional die design. Fig.5 shows the forged prototype of helical gear for steering pinion. The used die for prototype has been manufactured by the electrode-EDM. The used electrode was machined with the dimension, which was considered not only the elastic deformation of die and workpiece but also a EDM-gap.



[Velocity Distribution] [Forming Load]

Fig. 4 A effects and shape of proposed die for helical gear

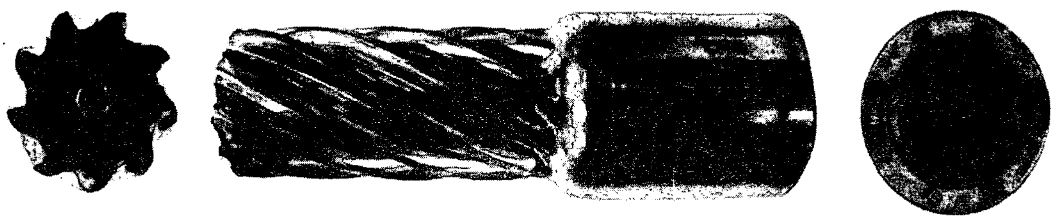


Fig. 5 Prototype helical gear manufactured by a proposed die

4. FE analysis to investigate the elastic deformation of die

The dimensions of die and workpiece are different from each other due to the elastic recovery of forged gear. The dimensional differences would be usually within the range of tens of micron in gear forging. However, the tolerance should be controlled down to several μm for these types of precision gear. Therefore, the elastic characteristics of die and workpiece should be analyzed for precision forged helical gear. To investigate the amount of elastic deformation for die, FE analysis was designed with a special consideration. The simulation for shrink fitting process between stress ring and inner-tip was performed in the first step. And then, the die stress analysis was carried out by the force interpolation from workpiece of the forming simulation. A newly proposed way of FE analysis overcomes the error from the over-estimation of die deformation when the die stress from shrink fitting was simulated without the insert of workpiece. Practically, the differences in die stress analysis come from the fact that the EDM machining is usually followed with the shrink fitting. Fig. 6 shows the distribution of die stress. The predicted displacements of die are within the ranges of 10μm in radial direction in FE analysis, as shown in Fig. 7. The die deflection has been investigated in die-land section. It was found that the differences of deflection depends on the height of die-land section.

No.1	No.2
Node No.	Node No.
4036	4991
4690	4994
5023	5176
4612	5479
4611	5228
4575	5121

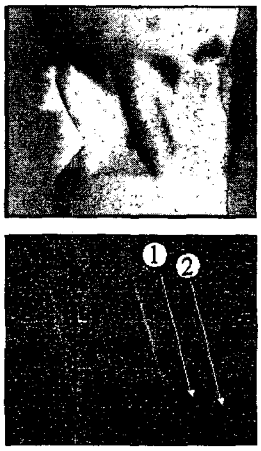


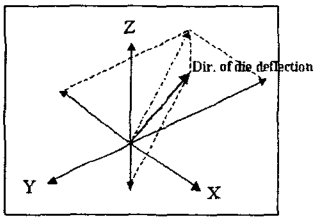
Fig. 6 Die stress distribution on forging stage

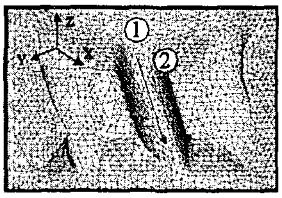
No.1

Node No.	X-axis	Y-axis	Z-axis
4036	-0.01234	-0.01256	-0.00273
4690	-0.01307	-0.00943	-0.00436
5023	-0.01311	-0.00920	-0.00445
4612	-0.01295	-0.00879	-0.00473
4611	-0.01290	-0.00871	-0.00479
4575	-0.01280	-0.00875	-0.00487

No.2

Node No.	X-axis	Y-axis	Z-axis
4991	-0.01394	-0.00803	-0.00562
4994	-0.01408	-0.00790	-0.00561
5176	-0.01409	-0.00789	-0.00554
5479	-0.01435	-0.00791	-0.00533
5228	-0.01439	-0.00776	-0.00525
5121	-0.01442	-0.00772	-0.00521





5. Summary

The forging process of helical gear for steering pinion was investigated to reduce the forging load and improve the dimensional accuracy. A die shape was proposed to reduce the forming pressure and a reduction of forming load was confirmed by the forging of prototype. The elastic deformation of die was predicted quantitatively by the FE analysis. Also, the dimensional changes during the full manufacturing processes could be analysed to get the dimensional accuracy of forged gear into the grinding tolerance.

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