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A study on precision cold forging process improvements for the steering yoke of automobiles by the rigid–plastic finite-element method

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Abstract

The steering column in a steering system, one of the main devices of an automobile, is a very important part to attain stability and steady movement of the vehicle. The steering yoke, the core part of steering column is manufactured through various processes, such as hot forging, machining, and assembly by welding.

This study proposes a new method for manufacturing an united steering yoke of high manufacturing productivity, improved mechanical properties and low cost through precision cold forging. The rigid–plastic finite-element method for precision cold forging has been used in order to reduce development time and die cost. Practical considerations in the manufacturing stage such as hardness in heat treatment, and coating condition in lubrication have also been investigated.

The results have been applied successfully in mass production.

Keywords: Precision cold forging; Steering yoke; Rigid–plastic finite-element method

1. Introduction

The forging process is one of the most representative metal forming processes and can be classified into hot and cold forging according to the forming temperature. As the hot forging process is performed at hot working temperature, i.e., above the recrystallization temperature, the work-piece undergoes large plastic deformation and hot forging is usually used for producing the blocker. On the other hand, cold forging is a special type of forging process wherein cold metal is forced to flow plastically under compressive force into a variety of shapes, with several forming steps being used to produce a final part of relatively complex geometry, starting with a slug or billet of simple shape. Some of the advantages provided by this process are: (a) high production rate; (b) excellent dimensional tolerances and surface finish of the forged parts; (c) significant savings in material and machining; (d) higher tensile strengths in the forged part than in the original material, because of strain hardening; (e) favorable grain flow to improve strength. By far the largest area of application of cold forging is the automobile industry [1].

Until now, the steering yoke which is the object of this study, has been manufactured by hot forging or welding of forged head and shaft parts because of technical difficulties (Fig. 1). Thus the hot forged steering yoke can not satisfy the required accuracy, and also involves economical loss and increase of the process number due to secondary machining being unavoidable [2].

In this paper, however, the precision cold forging process for the steering yoke of an automobile has been analyzed by using a rigid–plastic finite-element analysis code, DEFORM-3D. Fig. 2 shows the manufacturing process proposed in this paper. Experiments also have been performed through the optimized process.

2. Finite-element analysis

The rigid–plastic finite-element program has been used in order to reduce development time and die cost for precision cold forging.

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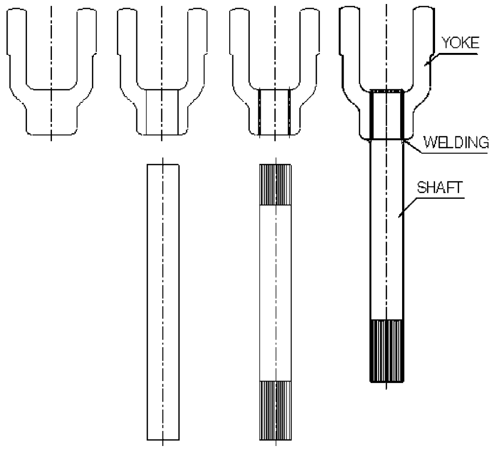


Fig. 1. Schematic illustration of conventional method for manufacturing the steering yoke.

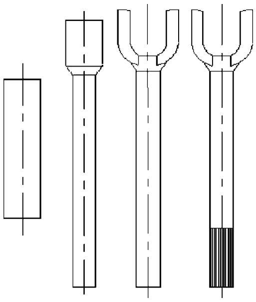


Fig. 2. Schematic illustration of precision cold forging for steering yoke.

2.1. Governing equations

The manufacturing process for steering yoke has been analyzed by using commercial finite-element code, DEFORM-3D [3]. The governing equations which were used in this analysis are as follows:

Equilibrium equation : $\sigma_{ij,j} = 0$ (1)

Compatibility equation : $\dot{\varepsilon}_{ij} = \frac{1}{2}(u_{i,j} + u_{j,i})$, $\dot{\varepsilon} = u_{i,i} = 0$ (2)

Constitutive equation : $\sigma_{ij}{}' = \dfrac{2\bar{\sigma}}{3\dot{\bar{\varepsilon}}}\dot{\varepsilon}_{ij}$ (3)

Boundary conditions : $\sigma_{ij}{}' n_i = F_j$ on S_F, $u_i = U_j$ on S_U (4)

where σ_{ij} and $\dot{\varepsilon}_{ij}$ are the stress and strain rate of the deformable material, respectively. Also $\bar{\sigma}$ and $\dot{\bar{\varepsilon}}$ are the effective stress and effective strain rate of the deformable material, respectively, F_j is the force at the boundary surface, and U_j the deformation rate at the boundary. Therefore the following weak form can be obtained:

$$\int_V \left(\frac{2}{3}\frac{\bar{\sigma}}{\dot{\bar{\varepsilon}}}\right)\delta\dot{\varepsilon}_{ij}\,\mathrm{d}V + \int_V K\dot{\varepsilon}_V\dot{\varepsilon}_{ij}\,\mathrm{d}V - \int_{S_F} t_i\delta u_i\,\mathrm{d}S = 0 \quad (5)$$

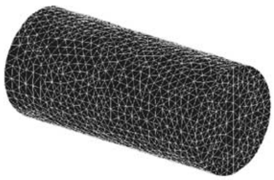
2.2. Results of finite-element analysis

Although the steering yoke is manufactured through three process steps, only first and second processes are analyzed.

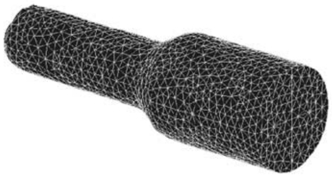
Considering the symmetry of the steering yoke, 1/4 of the whole body is analyzed. The material is assumed as rigid–plastic with the die and punch as rigid. The Coulomb friction coefficient, μ is assumed to be 0.1.

Fig. 3 shows the original and deformed shapes of each process. Figs. 4 and 5 show the predicted forging load of the first and second process respectively. Steady-state distributions are shown during the first process. In the second process, there appear large strains at the point of contact with the punch.

The predicted forging loads were about 60 t for the first process, and 430 t for the second process, respectively. Because the capability of press used in this study was 500 t, it was needed to reduce the forging loads.



(a) original mesh configuration



(b) after forward extrusion (the first process)

(c) after backward extrusion (the second process)

Fig. 3. Original and deformed mesh configurations.

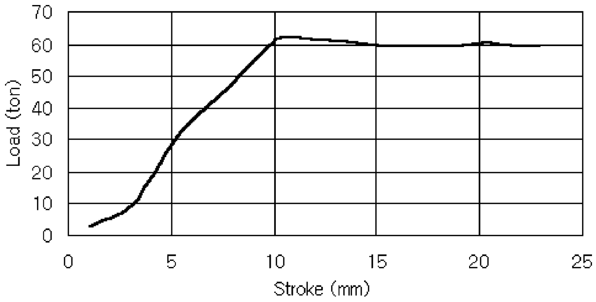


Fig. 4. Predicted forging load during the first process.