Rigid–plastic finite element simulation for process design of impeller hub forming

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Abstract

A torque converter impeller hub is usually made through sequential cold forming processes: forward extrusion, upsetting, piercing and finishing. The finishing process is a closed-die forging where the load increases abruptly due to flash formation and the defect of the under filling in the finished product is happened occasionally. In this study, rigid–plastic finite element simulation was applied to analyze the deformation characteristic of the whole impeller hub forming processes and to optimize the process. As a result, two kinds of improvement for the impeller hub forming process satisfying the limit of the machine's load capacity and the geometrical quality are suggested and the results are verified by experiment.
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1. Introduction

In the cold forming process, the material in a die flows continuously into the complex geometrical shape of the die under the progressive forming procedures. When the die design and the preform design of material are not optimized, internal damages of material like as void and micro-crack occur. According to the accuracy of initial volume of material shape, difference between the designed and the final shapes are sometimes happened [1]. A poorly estimated initial volume of material may cause the geometrical forming defects such as the underfilling or the overlapping in the forging process. Therefore, the optimization of the forming process is required to obtain the proper product without any damage.

Recently, the numerical simulation techniques using the rigid–plastic finite element method (FEM) have been successfully applied to investigate the forming characteristics of various forming processes such as the stress–strain state of the material and clarify the effects of various forging parameters on formability [2–6].

The forming process of torque converter impeller hub used in an automobile's transmission consists of the sequential cold forming processes: forward extrusion, upsetting, piercing and finishing operations. The final finishing operation governing the final shape of impeller hub is a closed-die forging process. In this forming operation, the forging load increases abruptly due to flash formation and geometrical forming defects of the underfilling occasionally occurs due to the limit of the forging machine's load capacity. Moreover, excessive initial volume of material may cause the failure of forming die and forming machine.

In this research, cold-forming processes of a torque converter impeller hub are analyzed by the rigid–plastic FEM, and process improvements to obtain the proper product without any underfilling defects and failure of the forming machine are suggested.

2. The basic equations of rigid–plastic FEM

Rigid–plastic finite element simulations using DEFORM software [7] are performed. The basic equations of the rigid–plastic finite element are as follows:

Equilibrium equation:

$$\sigma_{ij,j} = 0 \tag{1}$$

Compatibility and incompressibility condition:

$$\dot{\varepsilon}_{ij} = \tfrac{1}{2}(u_{i,j} + u_{j,i}), \quad \dot{\varepsilon}_v = u_{i,i} = 0 \tag{2}$$

Constitutive equations:

$$\sigma'_{ij} = \frac{2\bar{\sigma}}{3\dot{\bar{\varepsilon}}}\dot{\varepsilon}_{ij}, \quad \bar{\sigma} = \sqrt{\frac{3}{2}(\sigma'_{ij}\sigma'_{ij})}, \quad \dot{\bar{\varepsilon}} = \sqrt{\frac{2}{3}(\dot{\varepsilon}_{ij}\dot{\varepsilon}_{ij})} \tag{3}$$

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Boundary conditions:

$$\sigma_{ij} n_i = F_j \text{ on } S_F, \qquad u_i = U_i \text{ on } S_U \qquad (4)$$

where σ_{ij} and $\dot{\varepsilon}_{ij}$ are the stress and the strain velocity, respectively. $\bar{\sigma}$ and $\dot{\bar{\varepsilon}}$ are the effective stress and the effective strain velocity, respectively. F_j denotes the force on the boundary surface of S_F and U_i denotes the deformation velocity on the boundary surface of S_U.

Weak form for rigid–plastic FEM can be determined by applying the variational method on Eqs. (1)–(4):

$$\int \left(\frac{2\bar{\sigma}}{3\dot{\bar{\varepsilon}}} \right) \dot{\varepsilon}_{ij} \delta \dot{\varepsilon}_{ij} \, dV + \int K \dot{\varepsilon}_{kk} \delta \dot{\varepsilon}_{ii} \, dV - \int_{S_F} F_i \delta u_i \, dS = 0 \quad (5)$$

where V and S are the volume and the surface area of the material, respectively. K is the penalty constant.

3. Impeller hub forming processes

The material used for the impeller hub forming is SCR420H. In order to get mechanical properties of tested material for analysis, a compression test for the circular bar is performed. The stress vs. strain curve for the test is shown in Fig. 1. The friction constant m was taken by 0.1 from the cylindrical compression test [4]. A press with a maximum load capacity of 6.37 MN is used in the forming experiment.

The real forming process of the impeller hub consists of five forming operations as shown in Fig. 2. The cylindrical bar with initial height of 34.1 mm and diameter of 50 mm is manufactured into final product through the sequential forming processes: forward extrusion, upsetting, piercing, finishing and machining.

Through forward extrusion and upsetting operations, counter punch is used. In the piercing operation, the center area is punched to insert into a shaft. After the finishing operation—the last operation in the forming process—the final product is made by the machining operation. After
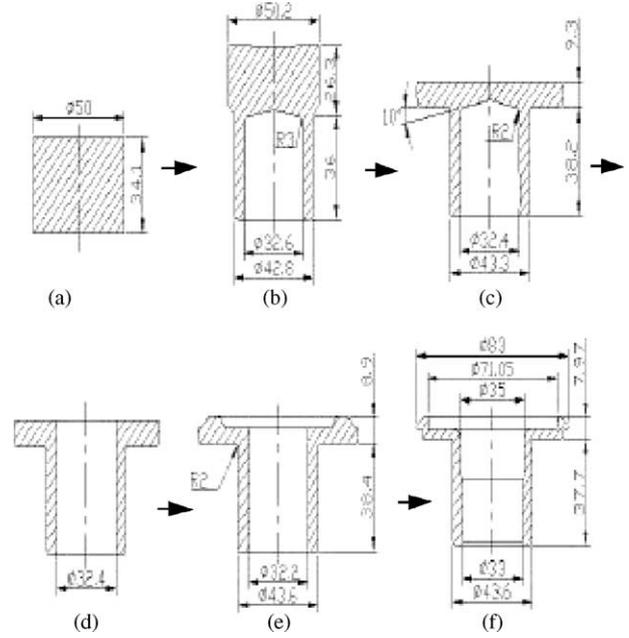

Fig. 2. Schematic description for the sequential forming processes of the impeller hub (conventional): (a) bar cutting; (b) forward extrusion; (c) upsetting; (d) piercing; (e) finishing; (f) machining.

each forming operation, heat treatments are carried out to relieve the local stress concentration occurred during the each forming operation. In this research, the forward extrusion, the upsetting, and piercing operations are assumed to be the isothermal cold forming processes. The piercing and the machining operations are excluded from this study.

4. Finite element simulation of conventional forging process

4.1. Forward extrusion operation

The flow pattern of material mesh configurations during the forward extrusion operation is shown in Fig. 3. It is clear the A area, inlet of die to form a long narrow legs, shows more straining than the B area. The maximum load in this forward extrusion operation is 3.52 MN.
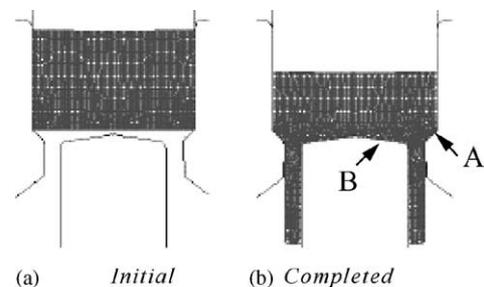

Fig. 1. Stress vs. strain curve for the SCR420H from the compression test.

Fig. 3. FEM simulation for the forward extrusion operation (conventional).