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Prediction of ductile fracture in cold forging

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Abstract

In the die design of cold forging, finite element analysis of forging is widely used for prediction of a material defect (underfill, crack, etc.). Various ductile fracture prediction equations have been proposed. But, in the case of use of the conventional equations, the analysis results cannot be matched to the fractures of real parts. Therefore, the authors developed a method for predicting ductile fracture independently, to improve the prediction accuracy of ductile fracture.

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Keywords: Ductile fracture; Finite element analysis

1. Introduction

In recent years, automotive companies manufacture hybrid vehicles and electric vehicles to improve fuel economy of automobiles, as well as environmental performance. As with a conventional engine, forged parts are applied to components of the motor. The cold forging method is applied to the motor main shaft as the axis of the motor, and weight reduction is demanded. In order to realize the weight reduction of this motor shaft, we are developing a hollow shaft.

The cold forging process of the hollow shaft that we developed is shown in Fig. 1. The forging process of the hollow shaft is composed of backward extrusion and forward extrusion. The hollow shape reduces the weight of

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the part by 40%. In the early stages, to achieve good quality, it is necessary to use forging simulation and reduce trial and error for the die design. It is possible that ductile fracture of the material occurs, because the amount of deformation of the material is large. An accurate ductile fracture prediction method is effective for this reason.

Nomenclature

σ_{max}	max principle stress
$\bar{\sigma}$	equivalent stress
a	material constant
σ_m	hydrostatic stress
$d\varepsilon$	increment of equivalent strain
D_f	damage factor (finite element analysis results of ductile fracture)
r	r direction of a polar coordinate system
θ	θ direction of a polar coordinate system
z	z direction of a polar coordinate system
σ_i	stress components of a polar coordinate system (r, θ, z)
ε_i	strain components of a polar coordinate system (r, θ, z)

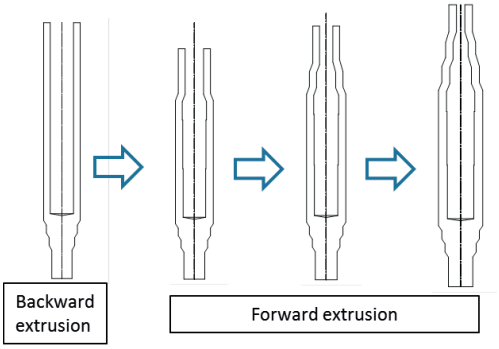

Fig. 1. Forging process of hollow shaft.

2. Problem of the ductile fracture prediction method

2.1. Conventional ductile fracture prediction method

After designing the forging die of Fig. 1, the prototypes were forged. But, at the apical parts of the shaft, ductile fracture of the material has occurred. Before the forward extrusion, residual stress has been removed by an annealing process. In order to investigate the ductile fracture, the authors evaluate the fracture by using finite element analysis. The prediction equations of ductile fracture were Cockroft & Latham's (1968) equation (Eq. (1)) and Oyane's (1972) equation (Eq. (2)), which are widely used.

$$D_f = \int \frac{\sigma_{\max}}{\bar{\sigma}} d\bar{\varepsilon}\,, \tag{1}$$

$$D_f = \int \left(1 + \frac{1}{a}\frac{\sigma_m}{\bar{\sigma}}\right) d\bar{\varepsilon}\,, \tag{2}$$

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