Vol. 8 № 4 **Trans. Nonferrous Met. Soc. China** Dec. 1998

PREDICTION OF SURFACE DEFECTS IN DISK FORGING PROCESS FOR FGH95 ALLOY USING RING-LIKE BILLET BY COMPUTER SIMULATION①

Li Yuanchun, Cui Jian and Yan Minggao
Beijing Institute of Aeronautical Materials, Beijing 100095, P. R. China

ABSTRACT The forging processes of P/M FGH95 alloy disk using ring-like billet were simulated by large deformation rigid visco-plastic finite element method (FEM). Some surface defects like laps and underfill were predicted. The relative contacting length between billet and die (the ratio of the contacting length to the initial height of billet) was proposed as a criterion to judge whether the lap defects would occur or not.

Key words rigid visco-plastic FEM ring-like billet surface defects

1 INTRODUCTION

Turbine disk is one of the most important parts in aeroplane engines. Forging superalloy engine disks involves expensive die materials, preforms, and equipment. Besides, due to the high forging temperature and high deformation stress, it also demands high press load and strong die materials with high temperature strength.

Compared with cylinder billet, ring-like billet could cut down consumption of raw material and reduce the load needed and the local high stress applied on the mid-part of the die. But it easily yields defects like laps and underfill if the size is not designed suitably. It often wastes a lot and even fails by traditional 'trial and error' design method. These can be reduced by simulating the forging process in a computer. The flow behavior of the materials could be easily known and the defects likely formed in the forging process could be predicted through computer simulation[1-5]. In the present paper, the forging process of P/M FGH95 alloy disk using ring-like billet is simulated by large deformation rigid visco-plastic finite element method. Some surface defects like laps and underfill are predicted.

2 MATERIAL AND FLOW EQUATION

The material used in this study is FGH95 superalloy powder. After degassed, canned and pretreated by 1050 ℃, 3h, AC, it was hot isostatically pressed by 1121 ℃, 127MPa, 3h and then fully densified.

In the simulation, it is assumed that the workpiece temperature stays the same throughout the forging processes. The flow stress as a function of strain, strain rate at 1050 ℃ was obtained from the uniform compression tests. By regression using double index function, we have

$$\sigma = \sigma_s + (\sigma_0 - \sigma_s) \cdot e^{-\alpha\varepsilon} - \sigma_0 e^{-\beta\varepsilon} \tag{1}$$

where $\sigma_0 = 500\,\dot{\varepsilon}^{0.19}$, $\sigma_s = 233.33\,\dot{\varepsilon}^{0.25}$, $\alpha = 0.78\,\dot{\varepsilon}^{-0.19}$ and $\beta = 36$.

3 FEM MODEL

By using the penalized form of the incompressibility, the rigid-viscoplastic variational

---

① Received Nov. 18, 1997; accetped Apr. 9, 1998

functional can be written as

$$\delta\pi = \int_V \bar{\sigma}\delta\dot{\varepsilon}\,\mathrm{d}V + K\int_V \dot{\varepsilon}_V\delta\dot{\varepsilon}_V\,\mathrm{d}V - \int_{S_F} F_i\delta V_i\,\mathrm{d}S = 0 \qquad (2)$$

where K is a large positive constant which penalizes the dilation strain rate component and $K = 10^6$ is used in the analysis, $\dot{\varepsilon}_V$ is volumetric strain rate.

The frictional stress is expressed by arc-tangent model[6]

$$f = -\,mk\{\frac{2}{\pi}\mathrm{tg}^{-1}(\frac{v_s}{a_0})\} \qquad (3)$$

where m is friction factor.

The solution of nonlinear algebraic equations (equation (2)) are obtained iteratively by the Newton-Raphson method. The initial guess for the velocity field is gained by directive iteration method[6].

4 DISPOSAL OF SOME PROBLEMS

The shape of die is described through the combination of straight line and circular arc. Judgments of whether the boundary free nodes contact the die or not are performed by evaluating the equations of nodal displacements and die boundaries. The amendments of penetration of boundary free nodes into die surface and slip of contacting nodes along die surface are made by using vertical projection method. Judgments of separation of contacting nodes from die surface are performed by the sign (positive or negative) of normal projection of nodal force. These explicit disposals could be found in Ref. [7].

5 SIMULATION RESULTS AND DISCUSSION

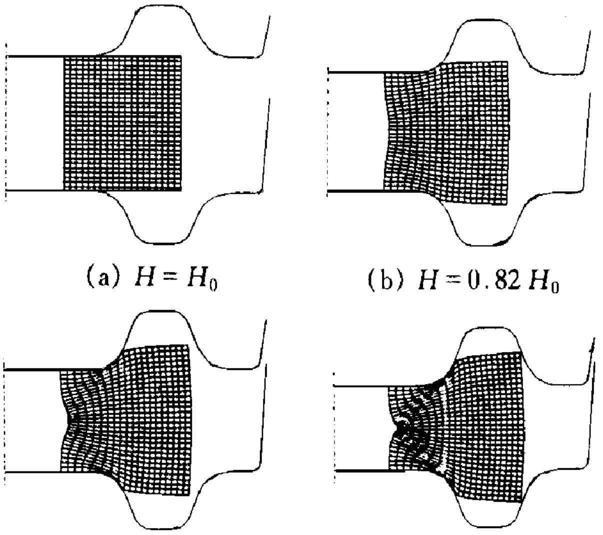
5.1 **Example** 1

As shown in Fig. 1(a), the meridian plane of the initial ring-like billet (the billet size is R (120− 40) mm × 100 mm) are divided by 551 quadrilateral isoparametric elements (600 nodes) (only half section is to be analyzed due to symmetry). The forging temperature is chosen to be 1 050 ℃. The velocity of the upper die is 0.8 mm/s and the bottom die is stationary. The friction factor is chosen to be 0.1.

Fig. 1 shows the deformed meshes at different forging stage. Because the relative contacting length (the ratio of contacting length of billet and die to initial height of billet) is small, the middle part of inner ring gradually indents and lap defect occurs finally. Because the size of billet is too small, serious underfill is formed.

5.2 **Example** 2

The billet size is chosen as R(160− 40) mm × 60mm to enlarge the relative contacting length in the mid-part by reducing the initial billet height. Fig. 2 shows the deformed meshes at different forging stage. It could be seen from the figure that the middle part of the inner ring is gradually embossed and lap will not occur because the relative contacting length is increased. But the outer ring gradually indents and has the inclination to form lap defect because of the small initial relative contacting length on the outer verge of the billet.



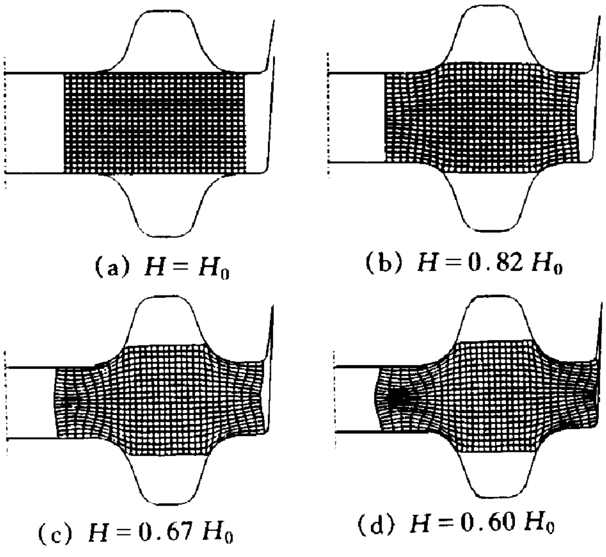
(a) $H = H_0$ (b) $H = 0.82H_0$

(c) $H = 0.67H_0$ (d) $H = 0.55H_0$

Fig. 1 Deformed meshes at different forging stages and formation of lap

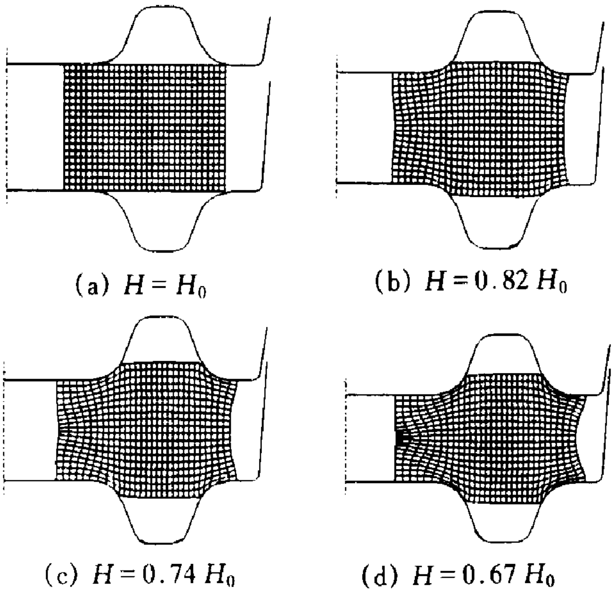
5.3 **Example** 3

The lap defect or the inclination to form lap defect may probably not form even if there is little indention at early forging stage. Fig. 3 shows the deformed meshes at different forging stages


(a) $H = H_0$ (b) $H = 0.82H_0$

(c) $H = 0.67H_0$ (d) $H = 0.60H_0$

Fig. 2 Deformed meshes at different forging stages


(a) $H = H_0$ (b) $H = 0.82H_0$

(c) $H = 0.74H_0$ (d) $H = 0.67H_0$

Fig. 3 Deformed meshes at different forging stages

by the billet R(150− 40) mm × 80mm. It could be seen that the inner ring forms little indention at early stage due to slight small relative contacting length but becomes smooth gradually. The outer verge of the billet does not contact the die at the beginning, but the outer ring significantly indents and has the inclination to form lap defect because of the small relative contacting length at early stage at this location.

Choosing different sizes of ring-like billets to calculate, we could determine the plausible range not to form the lap defects or the inclination. So the relative contacting length has decisive effect on whether the lap defects occur or not when using the ring-like billets to deform disk-shape forging. For special billet height, outer diameter and forming condition (fixed velocity of die, friction, material, shape of die etc.), the inner diameter design should satisfy one critical value or range for contacting length to avoid the lap defects. The outer diameter design should also satisfy the similar demand to avoid such defects unless the outer edge is a bulged one like a pancaking after upsetting. Certainly, the size of the billet should firstly guarantee to fully fill the die to avoid underfill defect.

REFERENCES

1 Peng Yinghong, Zhou Fei and Ruan Xueyu. Journal of Shanghai Jiao Tong University, (in Chinese), 1996, 30(9): 122.

2 Oh S I, Wu W T and Tang J P. J Mater Processing Tech, 1991, 27: 25.

3 Peng Yinghong, Ruan Xueyu and Zuo Tieyong. J of Mater Processing Tech, (in Chinese), 1994, 45: 539.

4 Oh S I, Wu W T and Tang J P. J Mater Processing Tech, 1992, 35: 357 .

5 Peng Yinghong and Ruan Xueyu. Journal of Shanghai Jiao Tong University, (in Chinese), 1994, 28(4): 83.

6 Kobayashi S, Oh S I and Altan T. Metal Forming and the Finite Element Method. Oxford: Oxford University Press, 1989.

7 Li Yuanchun, Fen Zhaohui, Cui Jian *et al*. Metal Forming Technology, (in Chinese), 1997, 15(6): 49.

(Edited by Peng Chaoqun)