NUMERICAL SIMULATION ON FORMING PROCESS OF EAR PORTION OF UPPER CASE①

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ABSTRACT Upper case is a key part in the driving system of a helicopter, the ear portion of the upper case is difficult to be formed owing to its complex geometry and high demands for microstructure and mechanical property. The forming of the ear is simulated by rigid plastic finite element method. According to the simulation result, it was found that, during the ear forming, the metal fulfills the axial ring first, then the ear, at the last stage of the ear forming, the metal flows inversely, which causes the generation of the lap defect. To avoid the generation of the lap, the pre-forming procedure, which gathers sufficient metal round the ear, was adopted to make sure the ear and the rib fulfills simultaneously.

Key words die forging finite element method upper case

1 INTRODUCTION

Upper case is a key part in the driving system of a helicopter. The upper case forging is shown in Fig. 1 and its material is MB15 magnesium alloy. As the four ears transfer the driving torque when the upper case is in use, the metal flow line in the ear portion is requested to be distributed along the ear's contour and the existence of flow line defects such as turbulence, vortex and shearing are not allowable. On the other hand, the shape of ear is wide and spread out. A hollow for weight reduction is located in the ear's center which causes the uneven volume distribution. Those mentioned above make the ear difficult to be formed. If the metal fulfills the die cavity with unsuitable sequence, various defects will present during forging.

Though the rigid plastic finite element method was developed by Lee and Kobayashi in 1973[1], park and Kobayashi conducted the three dimensional analysis firstly in 1984[2], up to now, the examples of three dimensional simulation on the forming process of complex geometry forging are still relatively rare, due to the complex boundary condition, huge computation

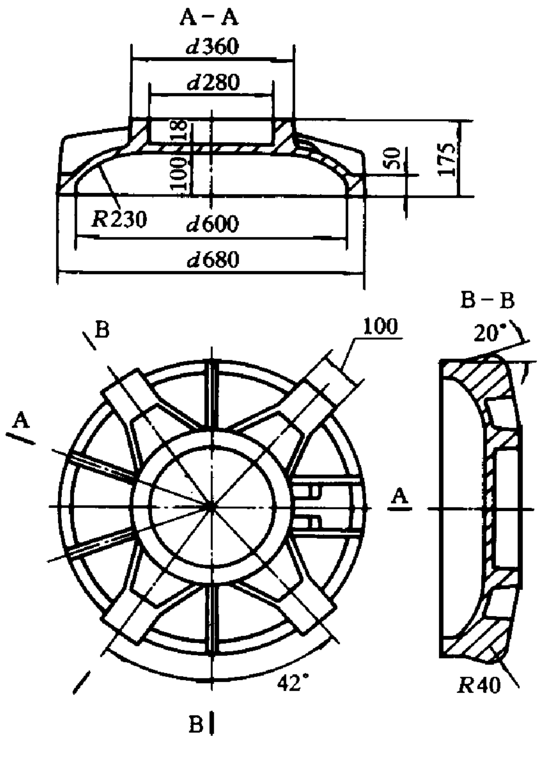

Fig. 1 Drawing of upper case forging

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time and unperfected technology for automatic mesh generation[3-5]. In the present study, to obtain necessary information for designing the forging process, the forming process of the ear portion of upper case is simulated by rigid plastic finite element method.

2 FINITE ELEMENT FORMULAR

The variational equation of the rigid plastic material model is given by the following[6]:

$$\int_V \bar{\sigma}\delta\dot{\bar{\varepsilon}}\,\mathrm{d}V + K\int_V \dot{\varepsilon}_v \delta\dot{\varepsilon}_v\,\mathrm{d}V - \int_{S_f} f_i \delta v_i \mathrm{d}S = 0 \qquad (1)$$

where

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

$\dot{\varepsilon}_v = \dot{\varepsilon}_{ii}$;

K, σ'_{ii} and $\dot{\varepsilon}_{ii}$ are the penalty constant, deviatoric stress and strain rate, respectively.

The friction force between workpiece and die is given by the following vector form:

$$\boldsymbol{f} = -\frac{2}{\pi} mk \cdot \tan^{-1}\frac{|\boldsymbol{V}_s|}{u_0} \cdot \boldsymbol{t} \qquad (2)$$

where m is the friction factor, k is the local flow stress in shear and u_0 is a very small positive number compared to $|\boldsymbol{V}_s|$. $\boldsymbol{V}_s$ is the velocity vector of the workpiece related to the die and $\boldsymbol{t}$ is the unit vector in the direction of $\boldsymbol{V}_s$.

Eqn. (1) is discretized at the element level which yields a set of nonlinear algebraic equations.

$$G(\tilde{u}) = \tilde{0} \qquad (3)$$

The Newton-Raphson iteration method is introduced to obtain the solution of eqn. (3):

$$\frac{\partial G(\tilde{u})}{\partial \tilde{u}}\Big|_n \Delta\tilde{u}_{n+1} = -G(\tilde{u})\Big|_n \qquad (4)$$

$$\tilde{u}_{n+1} = \tilde{u}_n + \beta\Delta\tilde{u}_{n+1} \qquad (5)$$

where β is the relaxation factor, $0 < \beta \leqslant 1$.

3 SIMULATION METHOD

For simplification of simulation, a sectorial brick in which the ear locates is chosen as the simulation objective. The side planes of the sectorial brick are assumed to be separate flow planes in circular direction and the displacement in normal direction of the plane is restricted. The geometry of the simplified die is schematically shown in Fig. 2. Half of the model is analyzed due to the symmetry. The dimension of the initial billet is d 680 mm × 100 mm.

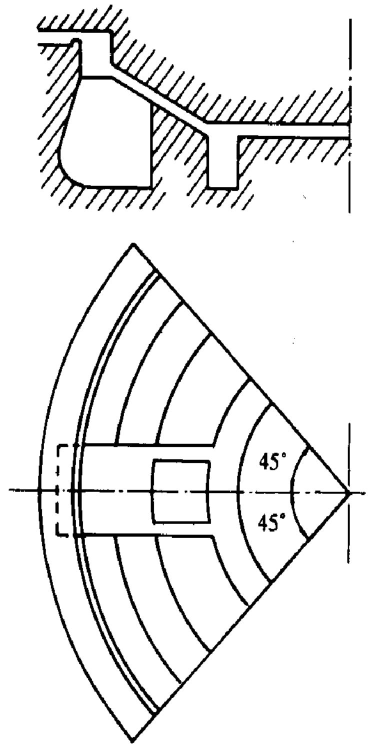

Fig. 2 Die geometry

The flow stress of MB15 magnesium alloy at an elevated temperature is 25 MPa[7]. The lubricant used in forging is water-based graphite and the friction factor is 0.2[8].

In the initial stage of forging, i. e., from the beginning of upper die contacting with billet to the moment the whole surface of upper die contacting with the billet, the deformation of the billet could be assumed as a pure bending because there are few materials fulfilling the die cavity in this stage. In the present simulation, the initial stage of forging is neglected and the bended billet is assumed to be the initial billet.

In the simulation the lower die is fixed and the upper die depresses with a velocity of 1 mm/s. The time step in simulation is taken as 0.6 s.

4 SIMPLIFICATION ON FLASH

In die forging, the deformed metals not only fulfill the die cavity, but also flow outside to form the flash. If the flash is taken as a portion of workpiece, the simulation will be more complex due to increase of calculation time and difficulty in describing the geometry of the flash. In the present study, the flash is trimmed along the exit of flash bridge to simplify the simulation. For cylindric forging such as upper case, the trimmed flash is thought to be a ring subjected to internal force (Fig. 3), calculating as[9]:

$$p = 1.1\sigma_s \ln \frac{D}{d} \qquad (6)$$

where σ_s is the material flow stress, D and d the outer and inner diameter of the ring.

The reacting force p is applied to the exit of flash bridge, thus the simulation would be simple (Fig. 4).

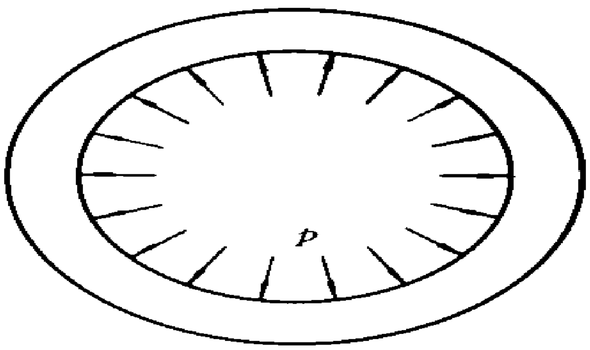

Fig. 3 Ring subjected to internal force

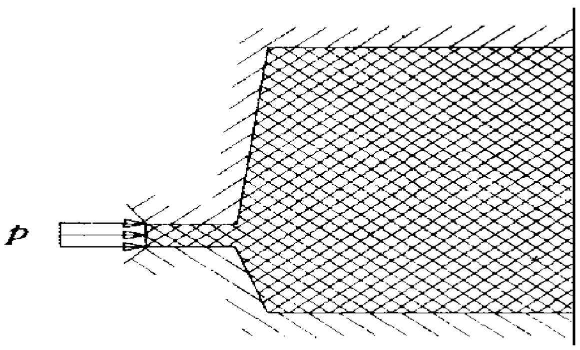

Fig. 4 Simplified calculation on flash

5 SIMULATION RESULTS

The FEM meshes in different reductions of die forging are shown in Fig. 5. For easy to observe, all meshes in Fig. 5 is in inverse. Due to the severe deformation in forging, a total of nineteen remeshings are triggered to complete the simulation[10]. From the simulation results,

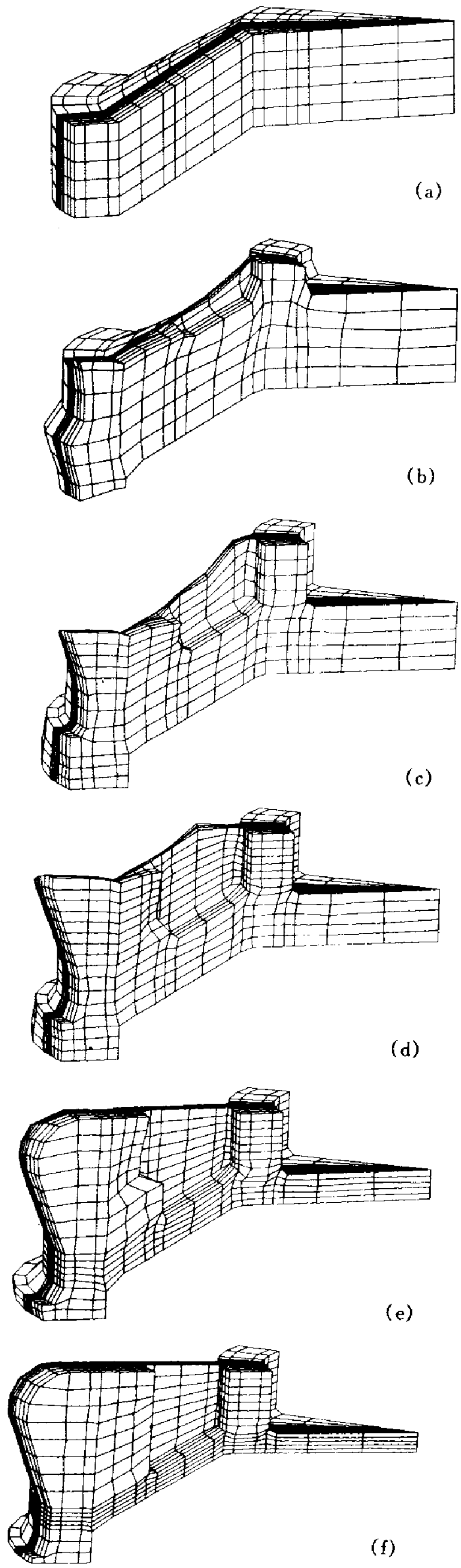

Fig. 5 FEM meshes with different reductions
(a) —0 mm; (b) —16.0 mm; (c) —40.0 mm; (d) —52.0 mm; (e) —73.0 mm; (f) —82.0 mm

it can be seen that, in the initial stage of forming, the metal fulfills the axial ring and flows outside to form the flash simultaneously. As soon as the axial ring is fulfilled completely, the metal begins to fulfill the ear. It should be noticed that the fulfilling of the ear is not in full area pattern. The metal flows along the outer surface of die cavity, which yields a gap between the metal and the die piston until the metal contacts the bottom of the die cavity. Then the metal flows inversely to minimize the gap till the die cavity is fulfilled completely.

According to the simulation results, if the forging is conducted directly with the cake-type billet, the metal in the ear portion will flow inversely. It should be noticed that, as the lateral rib is formed already, the inverse metal flow will generate the lap defect at the connect portion of ear and lateral rib.

For avoiding the generation of the lap, a preforming procedure is added to the forging sequence. Fig. 6 is the geometry of preforming. As the preforming gathers sufficient metal round the ear previously, the metal will fulfill the ear and the lateral rib simultaneously in later forging and the lap could be eliminated.

The upper case has been forged successfully with the improved forging process. The mechanical properties, microstructure and the accuracy of forging satisfied the requirements of the user[11]. Fig. 7 is the photo of upper case forged.

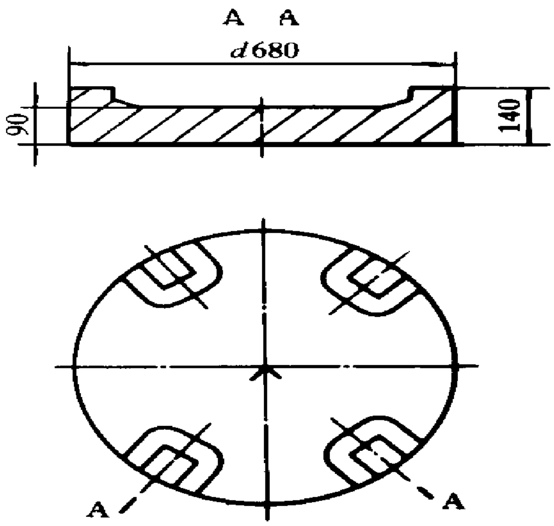

Fig. 6 Geometry of pre-forming

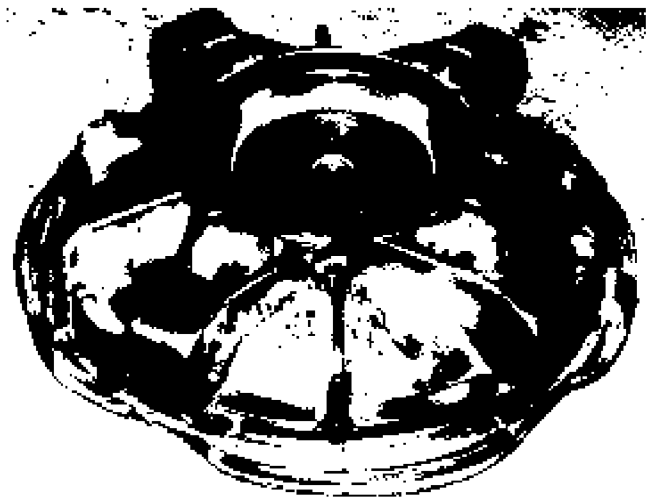

Fig. 7 Photo of upper case forged

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