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Isothermal precision forging of complex-shape rotating disk of aluminum alloy based on processing map and digitized technology

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ABSTRACT

Isothermal precision forging of complex-shape aluminum alloy rotating disk of airplane was systematically investigated by means of digitized technology based on computer-aided design (CAD), computer-aided engineering (CAE) and computer-aided manufacturing (CAM). The constitutive equation of 7A09 aluminum alloy under hot compression was established in order to understand the flow behavior of the metal material during isothermal precision forging. 7A09 aluminum alloy frequently exhibits dynamic recovery in the case of low strain rate, while it can also be characterized by dynamic recrystallization in the case of high strain rate. According to dynamic material model, the hot processing map of 7A09 aluminum alloy was obtained to optimize the process parameters which lead to the stable flow of the metal material during isothermal precision forging. Based on the different preforms, finite element method (FEM) was used to simulate the metal flow and predict the forming defects during isothermal precision forging of rotating disk. By controlling the metal flow, the high-quality rotating disk forging was manufactured on the basis of the proper preform through digitized technology. The simulated results are in good accordance with the experimental ones.

1. Introduction

For the purpose of meeting the requirements for light weight in the aerospace field, aluminum alloy forgings are usually designed based on the integral structure with complex shape. Furthermore, they are characterized by high dimension accuracy, good mechanical properties and perfect flow line distribution. In general, the complex-shape aluminum alloy forgings possess the lightening structures, such as high rib, long ear, thin web, thin wall and so on. The lightening structures lead to the rapid dissipation of heat quantity during forging and thus have an adverse influence on the formability of the forgings. In addition, aluminum alloy usually have a narrow forging temperature interval of about 70 °C. Therefore, too low forging temperature or too long forging time leads to the rapid drop of the temperature in the forging preform and thus results in the increase in the deformation resistance as well as the decrease in the material plasticity. Consequently, the finished forgings frequently possess some defects, such as coarse grains, cracks, folding, underfilling and so on [1–3].

Isothermal precision forging is an advanced plastic forming process, in which the dies are heated to the approximately same temperature as the forging and the forging temperature is almost constant in the process of forging. As a candidate for producing a net shape or at least a near-net shape workpiece, isothermal precision forging has been increasingly used to form light materials such as aluminum, magnesium and titanium alloys with small forging temperature range. As compared to conventional bulk forging, isothermal precision forging has many advantages, such as uniform temperature distribution, low deformation load, high material plasticity, small machining allowance and so on [4–8]. However, the optimization of the process parameters plays an important role in obtaining the high-quality forgings during isothermal precision forging. In general, the digitized technology becomes a candidate for cost reducing and time saving during isothermal precision forging. The digitized technology deals with the integration of computer-aided design (CAD), computer-aided engineering (CAE) and computer-aided manufacturing (CAM). In particular, as an important simulation and prediction instrument, finite element method (FEM) plays a significant role in the digitized technology [9–13]. In addition, the knowledge for flow behavior and hot workability of metal materials lays the foundations for optimizing the isothermal precision forging process. The constitutive equation is an important approach to understanding the flow behavior of the metal materials during hot working. On the one hand, the constitutive behavior of the metal materials during hot deformation can be used for understanding dynamic recovery and dynamic recrystallization. On the other hand, the constitutive equation can become a material model for finite

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element simulation. The hot processing map is another important approach to describing the hot workability of the metal materials. At present, the processing maps are mainly based on atomic model and dynamic material model (DMM) [14]. So far, DMM has been increasingly used in the hot working field because of its practical utility. DMM was first put forward on the basis of continuum mechanics of large plastic deformation, physical system modeling and extremum principle of irreversible thermodynamics by Prasad et al. [15]. The hot processing map can be used for determining the unstable flow zone of the metal materials during hot deformation in order to optimize the process parameters. So far, it has been widely applied to titanium alloy, magnesium alloy, metal matrix composite and so on [16–22].

In the present study, the constitutive equation and the processing map of 7A09 aluminum alloy were established during hot deformation. Furthermore, isothermal precision forging of complex-shape rotating disk of airplane was systematically investigated by means of digitized technology based on CAD, CAE and CAM.

2. Experimental procedures

2.1. Typical forging

Rotating disk of aluminum alloy is an important load-bearing part and is located in the principal shaft of lifting system of airplane. The rotating disk has two inner ears and five outer ears, in which four outer ears have the concaves, as shown in Fig. 1 (a) and (b). In addition, the rotating disk forging must meet the distribution of flow line along the profile in order to guarantee the appropriate load-bearing ability, as shown in Fig. 1(c) and (d).

2.2. Material

7A09 aluminum alloy bar was used as the experimental material, which belongs to T6 state and possesses the diameter of 200 mm. The chemical composition of 7A09 aluminum alloy is shown in Table 1.

2.3. Compression test

Hot compression test was carried out on the thermal analog test machine of Gleeble-1500 type. The compression samples with the height of 12 mm and the diameter of 8 mm were derived from the 7A09 aluminum alloy bar. The compression samples were covered with the graphitic lubricant before compression test in order to avoid the inhomogeneous plastic deformation due to friction. During compression test, the compression samples were heated to a certain temperature at the heating rate of 1 °C s^{-1} and then were held for 3 min. Then, the compression samples were compressed by the deformation degree of 60% at the temperatures ranging from 300 °C to 460 °C and at the strain rates ranging from 0.01 s^{-1} to 10 s^{-1}, and subsequently were quenched into the water at room temperature in order to keep the original microstructures of the compressed samples. All the compressed aluminum alloy samples were cut along the longitudinal direction by means of electro-discharge machining (EDM) and then were made into the metallographic specimens. All the metallographic specimens were etched in a solution containing 1.3% HNO_3, 0.4% HCl, 0.3% HF and 98% H_2O by volume fraction and subsequently were characterized by XJG-05 optical microscope.

3. Digitized design and manufacturing

Digitized design and manufacturing of isothermal precision forging of rotating disk mainly deals with establishment of constitutive equation, construction of hot processing map, computer-aided design (CAD), computer-aided engineering (CAE) and computer-aided manufacturing (CAM), and the flow chart

Table 1
Chemical composition of 7A09 aluminum alloy (%, mass fraction).

Cr	Mn	Si	Cu	Zn	Mg	Ti	Fe	Al
0.23	0.081	0.063	1.49	5.8	2.8	0.024	0.45	Balance

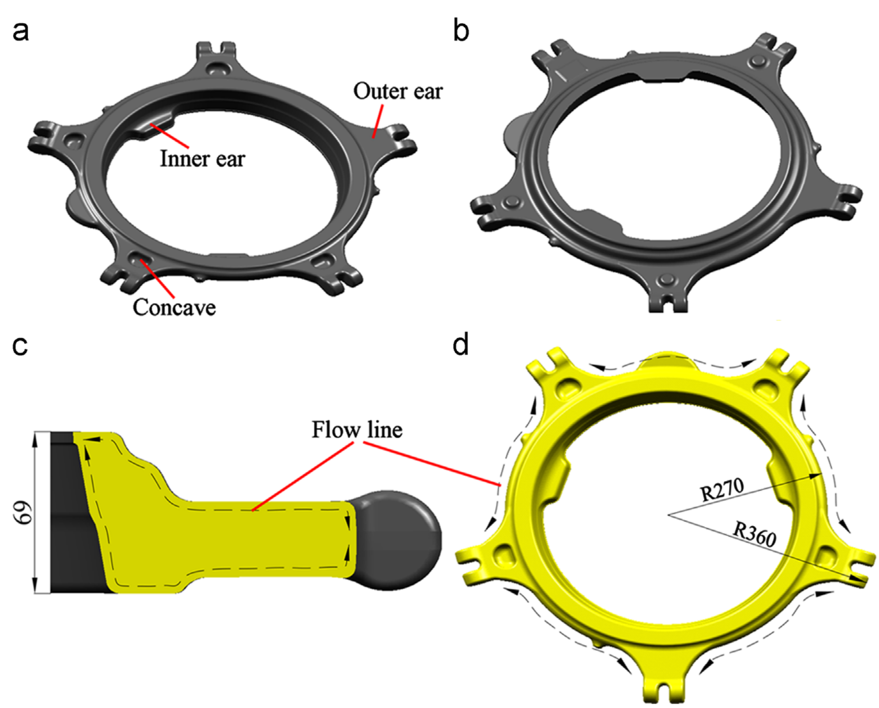

Fig. 1. Model of aluminum alloy rotating disk forging: (a) forward face; (b) backward face; (c) radial flow line and (d) circumferential flow line.