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FE simulation and process analysis on forming of aluminum alloy multi-layer cylinder parts with flow control forming①

WANG Xin-yun(王新云), WU You-sheng(吴有生),
XIA Ju-chen(夏巨谌), HU Guo-an(胡国安)
(State Key Laboratory of Die and Mould Technology,
Huazhong University of Science and Technology, Wuhan 430074, China)

Abstract: The aluminum alloy parts used in airbag of car were studied with flow control forming(FCF) method, which was a good way to low forming force and better mechanical properties. The key technology of FCF was the design of control chamber to divide metal flow. So, the design method of FCF was analyzed and two type of control chamber were put forward. According to divisional principle, calculation model of forming force and approximate formula were given. Then forming process of aluminum alloy multi-layer cylinder parts was simulated. The effect of friction factor, die radius and punch velocity on metal flow and forming force was obtained. Finally, the experiment was preformed under the direction of theory and finite element(FE) simulation results. And the qualified parts were manufactured. The simulation data and experimental results show that the forming sequence of inner wall and outer wall, and then the force step, can be controlled by adjusting the process parameters. And the FCF technology proposed has very important application value in precision forging.

Key words: flow control forming; multi-layer cylinder; process analysis; force calculation
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1 INTRODUCTION

Nowadays, especially in auto industry, how to reduce the energy consuming is a hot topic. The basic ways to realize it include adopting light mass materials(aluminum alloy, magnesium alloy, etc), redesigning parts construction and using new precision forming method[1-6]. By means of precision forming method, light mass parts can be manufactured and used widely in auto industry and other fields[7-15]. Recently, a new forming method called as flow control forming (FCF) is introduced to manufacture complex parts[16]. With FCF method, the flow of metal material can be controlled, so the precision forming of those very complex parts can be realized. Accordingly, the defects such as folder and under-filling can be avoided, and the mechanical properties can be improved.

Aluminum alloy multi-layer cylinder parts, such as gland bush, shell and capacitor parts, are used widely in auto and other civilian industry fields today(see Fig. 1). Among these, the gland bush and shell is the key part of car's airbag. Due to the used purity aluminum material has good plastic and lower deformation resistance, the multi-layer capacitor has realized the mass production with cold extrusion method in 1970s. The gland bush and shell usually used with high strength aluminum alloy material, however, are not easy to be manufactured with plastic working method. The reason is that the used aluminum alloy has bad plasticity and high strength, very complex shape, and the severe requirement to mechanical properties like σ_b. So, before new technology is developed, the conventional methods such as pressure casting or cutting methods are adopted to make these kinds of parts. In this paper, the FCF technology will be adopted to make multi-layer cylinder parts. Process analysis and the calculation of force during the experimental process of aluminum alloy multi-layer cylinder will be studied, and then the specimen will be manufactured.

2 TECHNOLOGY ANALYSES AND CONTROL CHAMBER DESIGN

2.1 Technology analysis of FCF

There are two key points during FCF process, the one is to control the metal flow direction and the position, the other is to control the forming force to obtain longer equipment and die life. The key technology of FCF is the design of control chamber to divide metal flow. According to the shape characteristics of multi-lay cylinder parts,

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Correspondence: WANG Xin-yun, PhD, Associate Professor; Tel: + 86-27-87543491; E-mail: bigaxun@263.net

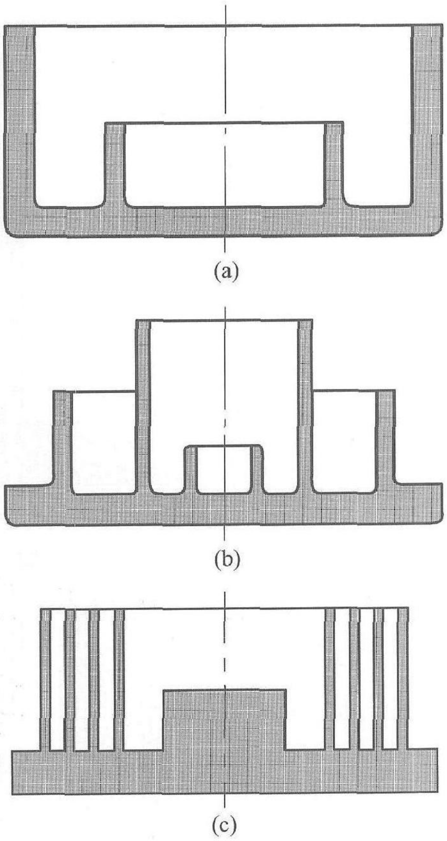

Fig. 1 Multi-layer cylinder parts
(a) —Shell; (b) —Gland bush; (c) —Multi-layer capacitor

the parts can be formed with forward close die forging or backward close die forging (see Fig. 2).

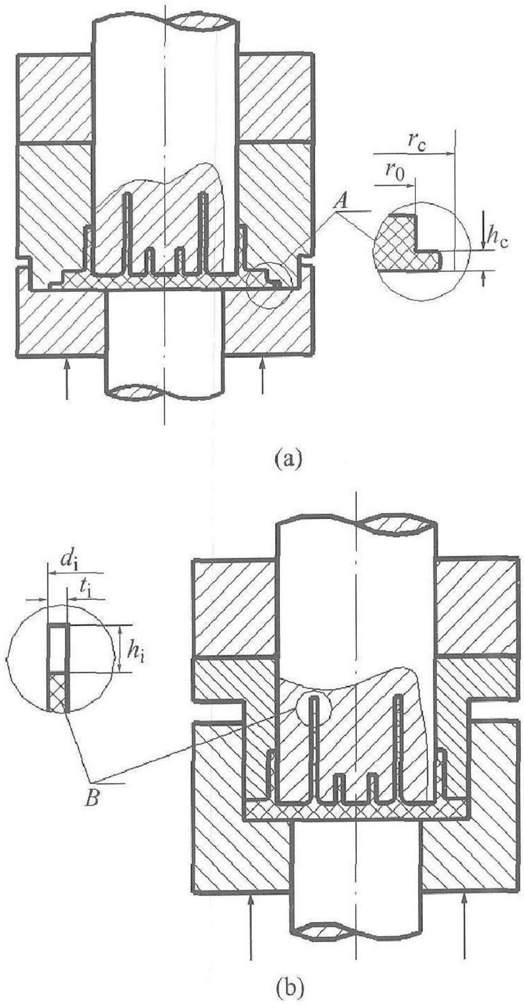

Fig. 2 Backward close die forging
(a) —Transverse direction ring control chamber;
(b) —Longitudinal direction cylinder control chamber

2.2 Design of transverse direction ring shape control chamber

The approximate relationship between the height of ring shape control chamber h_c and the radius of flange of die chamber $r_0(=d_0/2)$ can be expressed as Eqn. (1). The outer radius of ring shape control chamber r_c can be valued as Eqn. (2), and accordingly, the volume of control chamber V_k can be obtained by Eqn. (3) [7]:

$$h_c = 0.082 r_0 \quad (1)$$

$$r_c = (1.1 - 1.15) r_0 \quad (2)$$

$$V_k = 0.06 r_0^3 \quad (3)$$

2.3 Design of longitudinal direction ring shape control chamber

As to multi-layer cylinder parts, Eqn. (4) was proposed to estimate which layer cylinder wall of the part will be formed at last. Eqn. (4) shows that that filling sequence can be determined according to the value of height-thickness ratio, friction factor and radius of cylinder wall root. Obviously, when all the cylinder walls have the same friction condition and radius value, then Eqn. (5) was obtained. The cylinder wall that has the highest value of height-thickness ratio is the cylinder wall that formed last:

$$K_i = f(m_i, r_i) h_i / t_i \quad (4)$$

$$k_i = h_i / t_i \quad (5)$$

where k_i (or K_i) is the height-thickness ratio, h_i is the height of cylinder wall, and t_i is the thickness of cylinder wall ($i = 1, 2, \cdots, n$).

The dimension of control chamber can be obtained by Eqns. (6) and (7):

$$\frac{\pi}{4}[d_i^2 - (d_i - 2t_i)^2] h_i \cong 2V_k \quad (6)$$

$$h_i \cong \frac{2V_k}{\pi t_i (d_i - t_i)} \quad (7)$$

where d_i is the outer radius of cylinder wall.

2.4 Calculation of forming force

If the scheme shown in Fig. 2(a) is adopted, the forming force can be calculated according to Ref. [7]. In this paper, the forming force is studied when the scheme of longitudinal direction cylinder control chamber is adopted (see Fig. 2(b)). The calculation model of forming force of gland bush part (see Fig. 1(a)) is shown in Fig. 3.

So, the total forming force can be expressed as

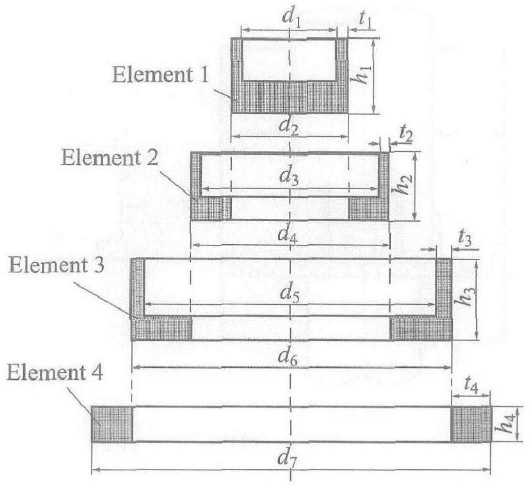

Fig. 3 Calculation model of close die forging force

$$p = p_1 \frac{\pi}{4} d_1^2 + p_2 \frac{\pi}{4}(d_3^2 - d_2^2) + p_3 \frac{\pi}{4}(d_5^2 - d_4^2) + p_4 \frac{\pi}{4}(d_7^2 - d_6^2) \quad (8)$$

where p_1, p_2 and p_3 are the backward extrusion pressure of three cylinder elements respectively, p_4 is the forming pressure of ring shape element, d_1, d_2, …, d_7 are the inner or outer diameters of four elements respectively.

$$p_i = \sigma_s \left[\frac{d_{2i}^2}{d_{2i-1}^2} \ln \frac{d_{2i}^2}{d_{2i}^2 - d_{1i-1}^2} + (1 + 3\mu) \left[1 + \ln \frac{d_{2i-1}^2}{d_{2i}^2 - d_{2i-1}^2} \right] \right] \quad (9)$$

$$p_n = \sigma_s \left[2 + 1.2 \ln \frac{d_{2n-1} - d_{2n-2}}{2 \times 4.2 r} \right] \quad (10)$$

where $i = 1, 2, \ldots, n$. σ_s is yield strength of material, r is the outer round corner radius of element 4.

3 FE SIMULATION AND EXPERIMENT

3.1 Simulation model

The required aluminum alloy double wall cup part is shown in Fig. 4 (a). And the FE model used in simulation is shown in Fig. 4 (b). The velocity of punch v and the friction factor m_1 (between punch and billet) and m_2 (between die and billet) and other parameters (marked in Fig. 4 (a)) will be discussed during simulation process.

3.2 Forming process

During the forming of aluminum alloy double wall cup, inner wall and outer wall can be formed orderly by controlling metal flow. The following figure (see Fig. 5) shows that the inner wall formed first and the outer wall formed subsequently. What's more, the height of outer wall is lower than that of inner wall at that time. Also, by adjusting the value of parameters marked in Fig. 1, the inner wall could be formed later and the outer wall first.

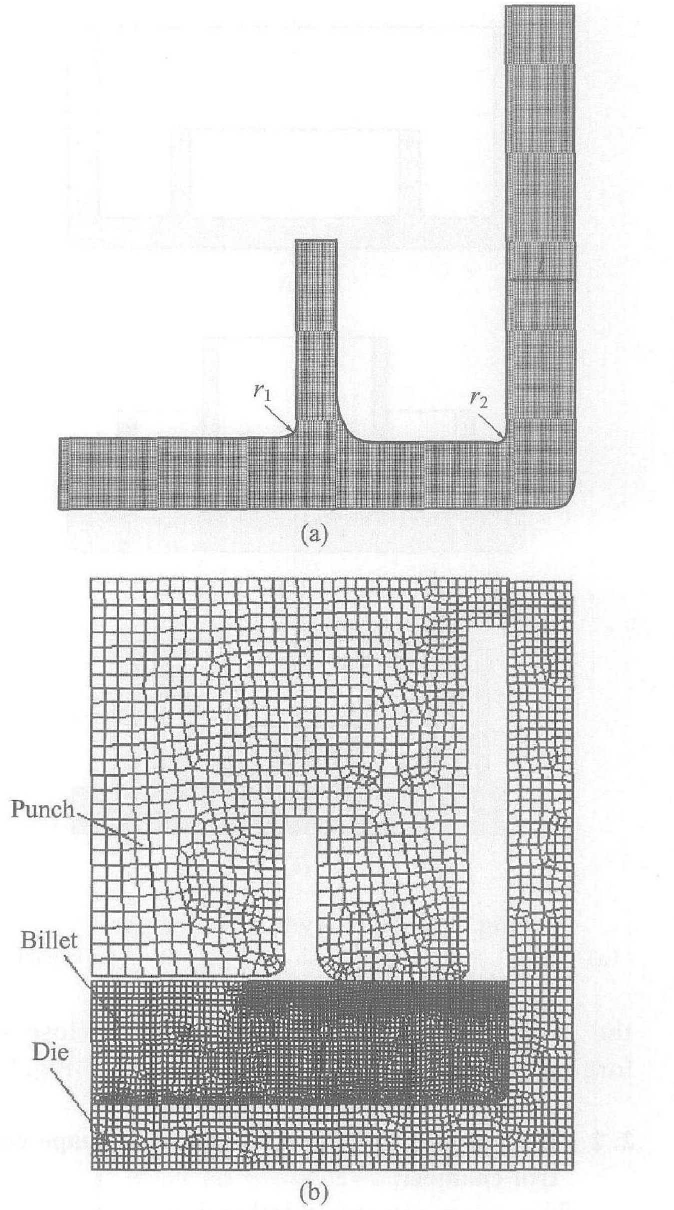

Fig. 4 Simulation model
(a) —Required aluminum alloy double lay cup;
(b) —FE model used in simulation

3.3 Forming force predicted by FE simulation

The buck forming FE software DEFORM™ was employed to forecast the forming process of multi-layer cylinder parts. It is very important to predict the forming force with FE numerical simulation method. The highest force needed in forming can be used to choose proper hydraulic press and design die structure optimally. The effect of process parameters on forming force is shown in Fig. 6.

The friction factor is an important parameter that affects the forming force during bulk metal forming. It can be seen that from Fig. 6(a), the effect degree of m_2 on the increment of load is higher than that of m_1. In Fig. 6(b), the lines marked with ▲ and ■ are obtained by reducing the out wall thickness t from 9 mm to 7 mm and by adjusting the punch velocity from 1 mm/s to 2 mm/

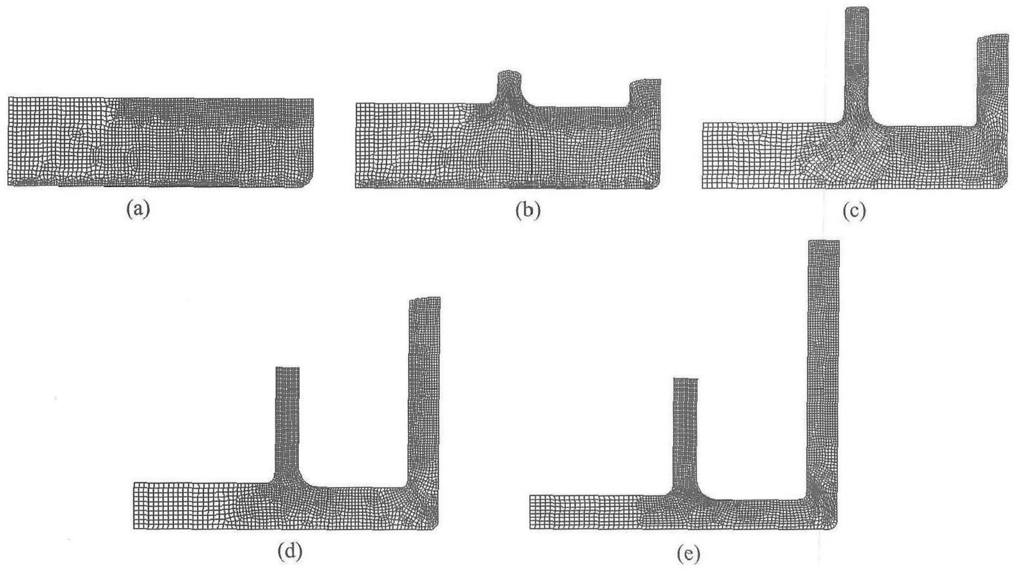

Fig. 5 Simulation process of aluminum alloy double wall cup
(a) —Initial step; (b) —Stroke= 0.2 mm; (c) —Stroke= 0.6 mm; (d) —Stroke= 1.0 mm; (e) —Final step

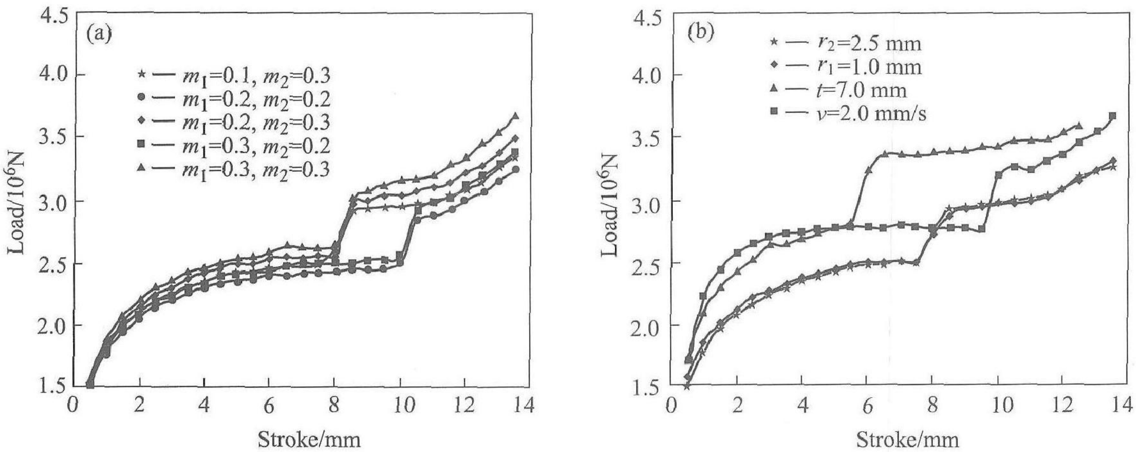

Fig. 6 Effect curves of parameters on forming force
(a) —Friction factor; (b) —Other parameters

s respectively. It is shown that the needed load is improved obviously. By comparing the lines marked with △ and □ in Fig. 6(b) and the line marked with △ in Fig. 6(a), it also can be seen that the variation of punch round radius has little effect on load.

3.4 Formed parts

The total forming force of gland bush is 3 710 kN according to theoretical equation (Eqn. (6)), and the measured force is 4 030 kN in experiment. And the corresponding values of shell are 3 200 kN and 3 420 kN respectively. The difference between theory and experiment only is about 8%. So the values are in good agreement with that of the FE computed results. The formed part is shown in Fig. 7.

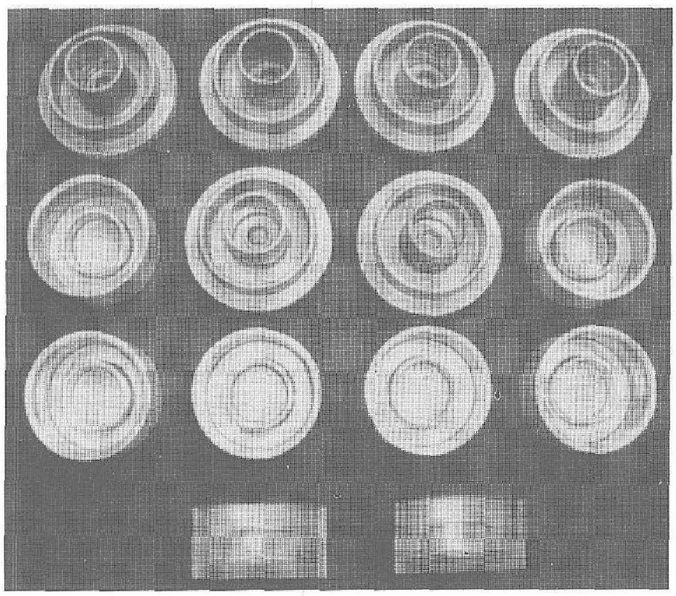

Fig. 7 Some experimental parts

4 CONCLUSIONS

Based on the flow control forming principle, the key technologies of CFC during the forming process of multi-lay cylinder parts were studied. The calculation model and formulation of backward extrusion force was proposed. The results calculated by it show good agreement with that of obtained from experiments and FE simulation. According to the shape characteristics of multi-lay cylinder parts, the reasonable technical scheme and die structure were designed to reduce the forming force and improve mechanical properties. Then the required parts, i. e. gland bush and shell, were manufactured successfully.

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