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Interface of components with large ratio of altitude to diameter formed by laminated pouring and accumulated liquid forging technology ①

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Abstract: Based on the experiment of laminated pouring and accumulated liquid forging of 2A12 aluminum alloy, interface bonding of formed component with large altitude to dimeter ratio of altitude to diameter was investigated by means of SEM and Instron tensile tester. The results show that the method of laminated pouring and accumulated liquid forging can be used for forming components with large ratio. Pouring temperature, reheated temperature of die, pressure, pouring layers and standing time are all important technique parameters that influence the mechanical properties. When pouring temperature is 740 ℃, reheated temperature of die is 480 ℃, pressure is 500 kN, pouring layers are three and standing time is 5 s, the mechanical properties of interface are the optimum ones, microstructure is equiaxed crystal and tensile fracture has character of dimple. There are three kinds of bonding, which are melting bonding, part melting bonding and mechanical bonding. And the interface of the melting bonding possesses the best mechanical properties.

Key words: laminated pouring; accumulated liquid forging; mechanical properties
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1 INTRODUCTION

Liquid forging technology was developed in the Former Soviet Union in 1937[1]. From then on, this technology has been applied into forming metal components in the fields of military industry in some developed countries, which benefits highly and shows strong vitality. Liquid forging is a kind of technology in which mechanical pressure is applied while the liquid metal is poured into die cavity and components can be obtained by solidification and plastic deformation[1-3]. Mechanical properties of liquid forging components have almost approached their forge pieces[3-6]. However, it is very difficult to determine forging technology parameters because they are related to metallurgy, liquid flow, thermal conductivity and plastic deformation. Moreover, this technology requires the less ratio of altitude to diameter of the forged component. So the components with large ratio of altitude to diameter can't be formed by common liquid forging method.

Rapid prototyping technology is a newly-developed technology in recent years, which includes many subjects, for example, computer technology, information technology, new materials, reverse engineering and CAD/CAM, etc[7, 8]. It is one of fast developed technologies in the world[9, 10]. By RP technology any complicated components can be manufactured because it needn't die and cost isn't related to complication degree. The best merits of RP is rapidity[11]. But the components manufactured by this technology can't be used for structural components because their mechanical properties can't satisfy the demand. In addition, metal components can't be manufactured by this technology because of their low mechanical properties. Based on the advantages of liquid forging and rapid prototyping, a new technology is put forward to solve the difficult problem of large ratio of altitude to diameter. Therefore, the problem of interface of every two layers is very essential to assure the mechanical properties. In this paper we study the technology parameters that influences the mechanical properties and the interface bonding' way by means of SEM and Instron drawing equipment.

2 EXPERIMENTAL

The chemical composition of 2A12 alloy is listed in Table 1. Its melting point is 502 - 638 ℃.

Table 1 Chemical composition of 2A12 alloy (mass fraction, %)

Cu	Mg	Mn	Cr	
3.8 - 4.9	1.2 - 1.8	0.3 - 0.9	≤0.1	
Fe	Zn	Si	Ti	Al
≤0.5	≤0.25	≤0.5	≤0.01	Bal.

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A set of equipment with reheated device is designed, as shown in Fig. 1. The following five techniques are listed in Table 2.

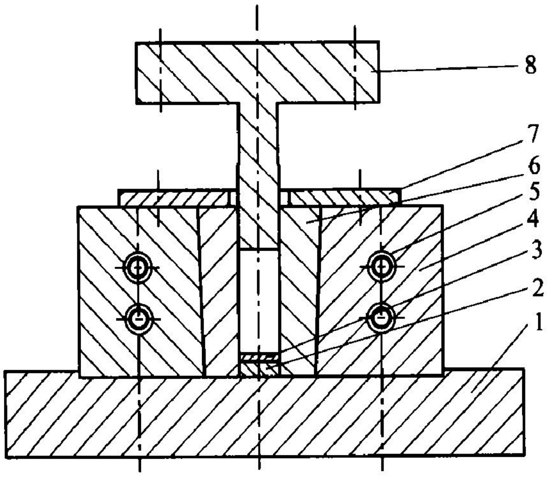

Fig. 1 Schematic of forging die
1 —Supporting plate; 2 —Supporting bracket;
3 —Supporting bracket; 4 —Die carrier;
5 —Resistance wire; 6 —Cavity die;
7 —Press plate circle; 8 —Upper punch

Table 2 Techniques parameters

Pouring temperature/ ℃	Preheated temperature/ ℃	Load/ kN	Pouring layers	Dwell time/ s
710, 720, 740, 760, 780	470	500	3	5
740	450, 460, 470, 480, 490	500	3	5
740	480	400, 500, 600, 700, 800	3	5
740	480	500	1, 2, 3, 4, 5	5
740	480	500	3	1, 2, 3, 4, 5

The forged component is a simple cylinder of 52 mm in diameter and 120 mm in heigth. So its ratio of altitude to diameter is 2. 3, but that ratio of liquid forging component is no more than 0. 5[2]. Therefore, experimental component belongs to large ratio of altitude to diameter. Tensile specimens were obtained along tension direction and they were analyzed by Oringin6. 0 software. Specimens for observing microstructure were obtained from interface. After these specimens were ground, polished and corroded, they were observed under SEM and OM.

3 RESULTS AND ANALYSIS

3. 1 Mechanical properties of interface

The stress—strain curve is shown in Fig. 2. It shows that when pouring temperature is 740 ℃, preheated temperature of die is 480 ℃ and press is 500 kN(pressure is 218. 4 MPa), pouring layers are 3 and standing time before pressing is 5s, the mechanical properties of interface are the best.

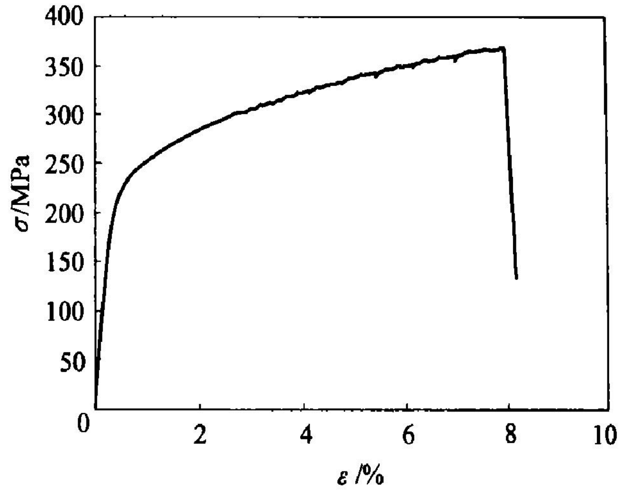

Fig. 2 Stress—strain curve of specimen with the best mechanical properties

Plastic deformation zone in Fig. 2 is relatively long and the strength and elongation are high. Fracture is not completed in a short term and it has the character of elongation. Strength and elongation under different conditions are shown in Fig. 3.

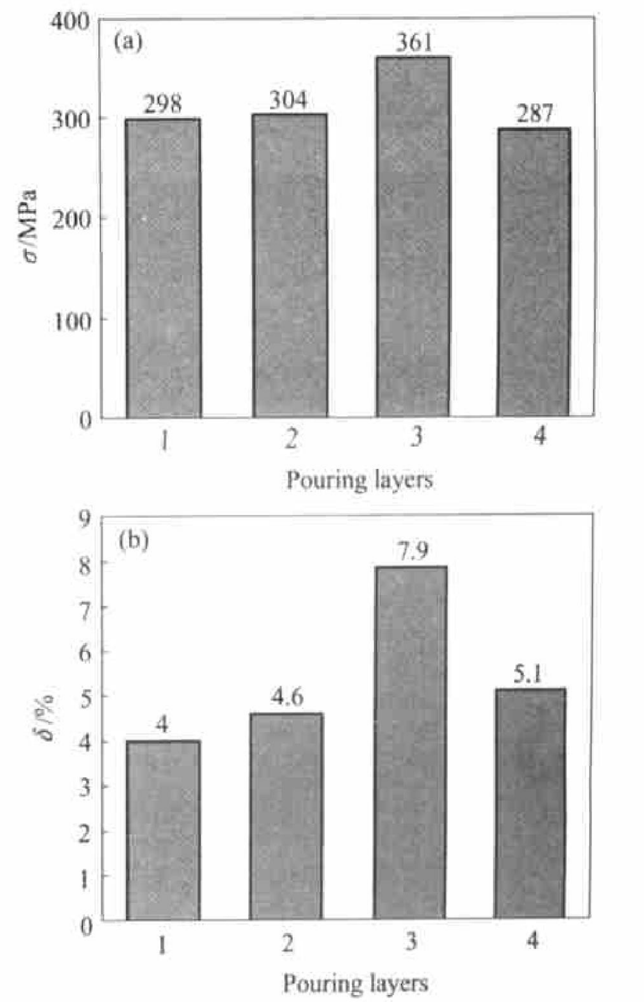

Fig. 3 Strength and elongation under different conditions
(a) —Strength; (b) —Elongation

From Fig. 3 it can be seen that, mechanical properties are influenced greatly by the pouring layers. If the liquid metal was directly poured into a die, its mechanical properties are worse than those by laminated pouring. Because pressure's loss is very large and flaw is much if the ratio of altitude to diameter is relatively large, which makes the mechanical properties worse. It can also illustrate that technology of laminated pouring and accumulated liquid forging is feasible. However, pouring layers influence the mechanical properties of interface under the condition of laminated pouring technology. It is proved that mechanical properties of three layers component are the best and they are better than those of direct pouring. In view of heat distribution, pouring layers should be fewer to make the heat more homogeneous to increase the thickness of interface. If pouring layers become fewer than 3, the ratio of altitude to diameter of one layer becomes large, which makes mechanical properties fall down; but when pouring layers are four layers, mechanical properties become worse because heat quantity becomes little.

3.2 Structure of interface

Macrostructures of formed components are shown in Fig. 4. There are no laminations on the surface of components as shown in Fig. 4(b).

Macrostructure of component is shown in Fig. 5, where we can see that macrostructure of the forged component is very condense and no flaws can be found. There isn't lamination on the interface. If the technological parameters are selected

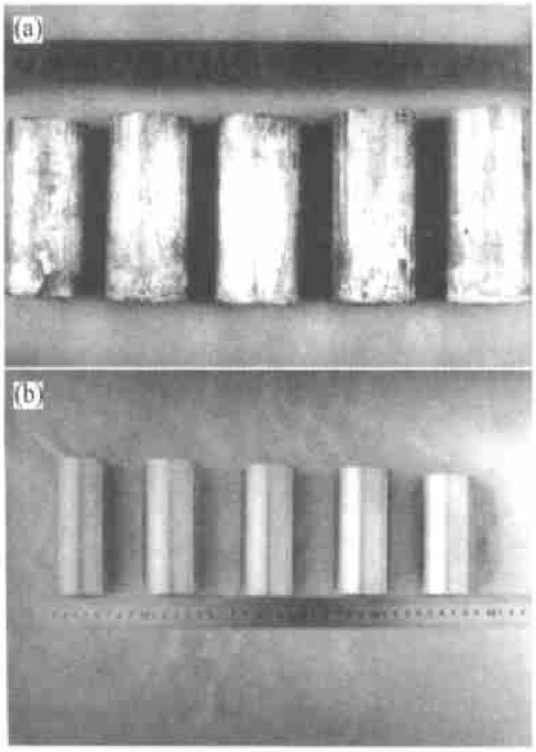

Fig. 4 Macrostructures of formed components
(a) —As-poured; (b) —As-machined

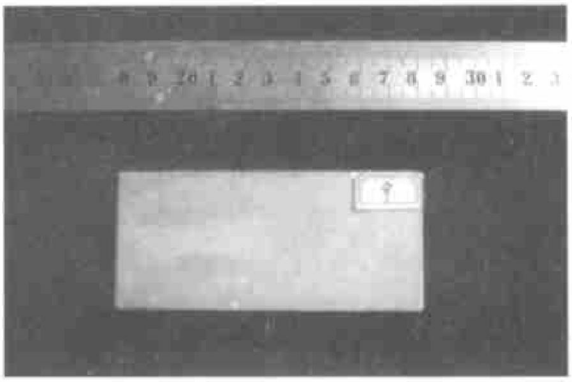

Fig. 5 Macrostructure of component with optimum mechanical properties

well, technology of laminated pouring and accumulated liquid forging is feasible and the bonding of interface is very good.

Microstructure of the component with best properties is shown in Fig. 6. As shown in Fig. 6, the microstructures are composed of equiaxed crystal and the strength of bonding of interface is high. At the same time, grains are distribu-

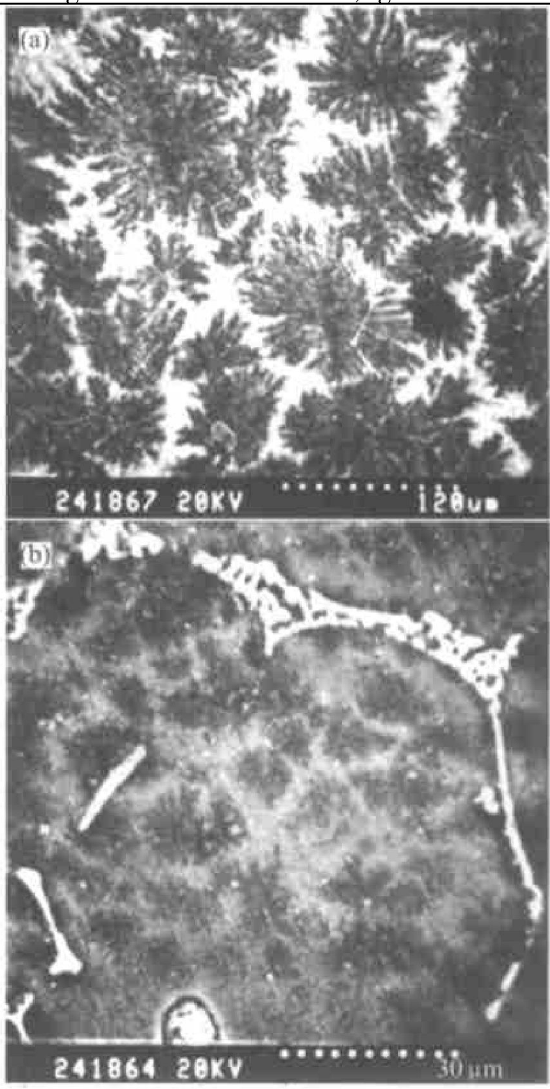

Fig. 6 Microstructures of component with optimum mechanical properties
(a) —Low magnification; (b) —High magnification

ted uniformly and the direction of growth is random. We can see the character of equiaxed crystal in Fig. 6 (a) and subgrains are in inner. As shown in Fig. 6 (b), microstructure is very compact and no deficiency appears. Mechanical properties of this component are the best.

Tensile frctograph of component with optimum mechanical properties is shown in Fig. 7. There are some ridges in Fig. 7(a), which indicates that fracture has character of ductilty. Fiber area can also be found in Fig. 7(a)[12]. Microstructure is shown in Fig. 7(b), which has the character of dimple fracture that is composed of circular or oval ruts[13]. It is because that when tensile force is distributed uniformly on the surface of fracture, micropores can grow in three directions.

3.3 Bonding mode of interface

If the surface of the first solidified layer is melted by the heat of the second liquid metal, a melting layer is formed and the two layers combine under the pressure, which is called melting bonding. If the surface of the first solidified layer can't be melted by the heat of the second liquid metal, the bonding of interface is due to pressure, which is called simple mechanical bonding. If the surface of the first solidified layer is partially melted by the heat of the second liquid metal, the bonding of interface is due to melting and mechanical pressure, which is called partially melting bonding. Generally speaking, if the pouring temperature and preheated temperature are appropriate, the mode of bonding is melting bonding. Based on the experiment and analysis of theory, we generalize three kinds of bondings of interface which are melting bonding, partially melting bonding and mechanical bonding. They are shown in Fig. 8.

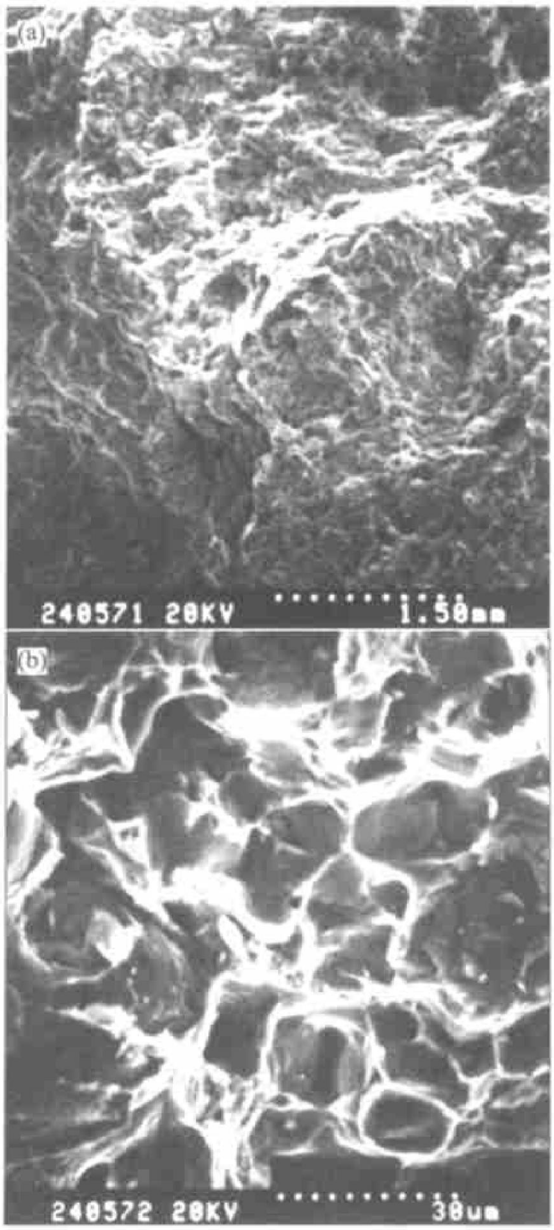

Fig. 7 Fractographs of component with optimum mechanical properties
(a) —Macrostructure; (b) —Microstructure

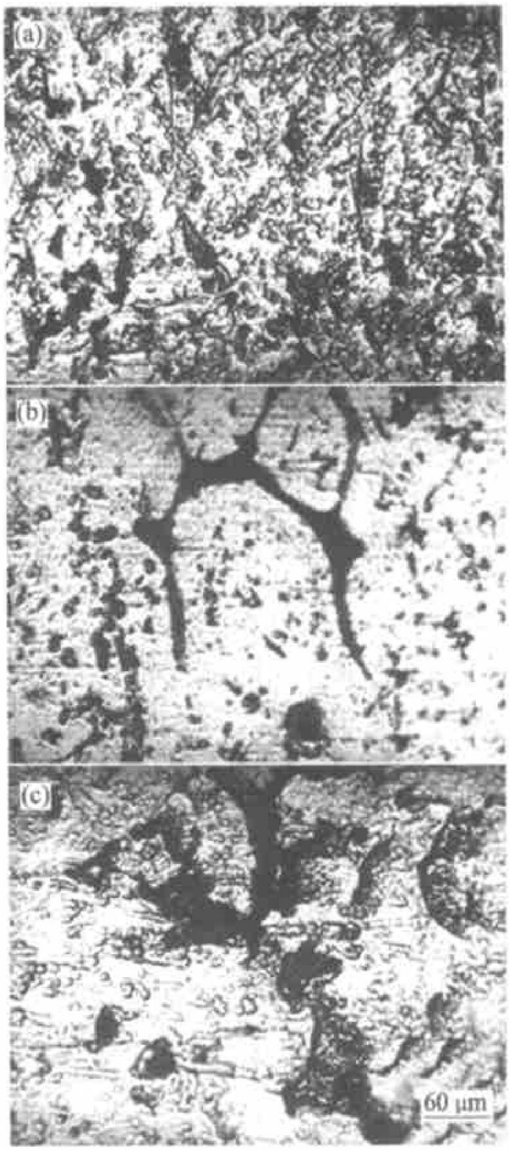

Fig. 8 Schematic of different bondings of interfaces
(a) —Melting bonding; (b) —Partially melting bonding; (c) —Mechanical bonding

4 CONCLUSIONS

1) It is feasible to apply the technology of laminated pouring and accumulated liquid forging to form the components with large ratio of altitude to diameter, which is superior to common liquid forging technology.

2) Pouring temperature, preheated temperature, pressure, pouring layers, and standing time are important parameters that influence mechanical properties.

3) With such technological parameters as pouring temperature of 740 ℃, die's reheated temperature of 480 ℃, pressure of 218.4 MPa, pouring layers of three and standing time of 5 s, the mechanical properties of interface are very good, microstructure is equiaxed crystal and tensile fracture has character of dimple fracture.

4) There are three kinds of bondings, which are melting bonding, part melting bonding and mechanical bonding. And the interface of the melting bonding has good mechanical properties.

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