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Research on Suction Casting Defects of Al Based Alloy Linkage

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Abstract: The filling process and solidification of Al based alloy linkage by suction casting was studied via numerical simulation. The shrinkage defect of Al based alloy linkage casting was predicted by using FEM software ProCAST. The results indicate the cold shut will be decreased with the increase of graphite suction opening diameter and the pouring temperature. With the decrease of the coefficient of heat transfer, the cold shut is reduced. The Al based alloy linkage are obtained by this method. The simulated result tallies well with the actual cast experiment, and lays down a foundation for improving the cast technology of the Al based alloy casting.

Key words: FEM simulation; ProCAST software; suction casting; shrinkage defect

I. INTRODUCTION

Aluminum alloy with low density, high specific strength and high elastic modulus ratio, at high temperatures can still maintain a high enough intensity and rigidity, and at the same time, it also has anti creep and good oxidation resistance ability. So it is widely concerned in the aerospace, aviation and other fields [1-2]. Currently, the ingot metallurgy [3]、powder metallurgy technology [4]、investment casting [5] and many other forming methods have been applied to the aluminum alloy, but these are still some problems in forming technology, such as ingot metallurgy complex process, organization thick, powder metallurgy alloy composition is difficult to control, investment casting interfacial reactions is serious, and it is difficult to solve these problems.

Aluminum alloy cast metal type vacuum manifold method is filling under vacuum to avoid oxidation of aluminum alloys in the filling process and generate the involvement of the stomatal；Alloy melt mold filling in the joint action of gravity and gas pressure to overcome the complexity of thin-walled aluminum alloy components in the filling process due to lead to faster solidification problem can not be completely filled. In recent years, the simulation of liquid metal flow and heat transfer phenomena through a variety of commercial software [6-11]. Finite element software ProCAST is a successful example, which uses the finite element method to achieve the metal flow field, temperature field calculation and prediction [12-14]. Process design provides a theoretical which guide the production of high quality castings. In this study, using ProCAST software to simulate the forming technology of filling and solidification process, the use of mobile computers for the formation process of casting, and heat transfer coupling computational analysis. Studying the dynamic of the whole process of mold filling and the changes of temperature. Shrinkage porosity, shrinkage and other casting defects were predicted.

II. Principle of bottom drain vacuum suction casting

Metal-bottom-drain vacuum suction casting principle shown in Figure1. Metal smelting in the melting chamber, melting chamber is surrounded by high purity argon, there is a certain pressure (P2). Suction casting mold in the chamber, suction casting chamber in a vacuum state (P1), when the metal is molten, and has a certain degree of superheat, the molten metal in the melting chamber and the suction pressure casting chamber difference (P2-P1≈P) and under its own gravity, suction through the graphite filling. Molten metal in the mold under the action of the solidification, thereby obtaining the casting.

A. *Mathematical model and meshing*

High temperature liquid metal as an incompressible viscous fluid, which uses the following equations [15] :

Mass conservation equations (continuity equation)

$$\frac{\partial_u}{\partial_x}+\frac{\partial_v}{\partial_y}+\frac{\partial_w}{\partial_z}=0 \qquad (1)$$

Momentum conservation equation（Navier-stokes）

$$\frac{\partial_u}{\partial_t}+u\frac{\partial_u}{\partial_x}+v\frac{\partial_u}{\partial_y}+w\frac{\partial_u}{\partial_z}=-\frac{1}{\rho}\frac{\partial_p}{\partial_x}+g_x+u\left(\frac{\partial^2_u}{\partial_{x^2}}+v\frac{\partial^2_u}{\partial_{y^2}}+w\frac{\partial^2_u}{\partial_{z^2}}\right) \qquad (2)$$

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$$\frac{\partial_v}{\partial_t}+u\frac{\partial_v}{\partial_x}+v\frac{\partial_v}{\partial_y}+w\frac{\partial_v}{\partial_z}=-\frac{1}{\rho}\frac{\partial_p}{\partial_x}+g_x+u\left(\frac{\partial^2_v}{\partial_{x^2}}+v\frac{\partial^2_v}{\partial_{y^2}}+w\frac{\partial^2_v}{\partial_{z^2}}\right) \quad (3)$$

$$\frac{\partial_w}{\partial_t}+u\frac{\partial_w}{\partial_x}+v\frac{\partial_w}{\partial_y}+w\frac{\partial_w}{\partial_z}=-\frac{1}{\rho}\frac{\partial_p}{\partial_x}+g_x+u\left(\frac{\partial^2_w}{\partial_{x^2}}+v\frac{\partial^2_w}{\partial_{y^2}}+w\frac{\partial^2_w}{\partial_{z^2}}\right) \quad (4)$$

Energy conservation equation (heat transfer equations)

$$\rho C_p\left(\frac{\partial T}{\partial_t}+u\frac{\partial T}{\partial_x}+v\frac{\partial T}{\partial_y}+w\frac{\partial T}{\partial_z}\right)=\lambda\left(\frac{\partial^2 T}{\partial_{x^2}}+v\frac{\partial^2 T}{\partial_{y^2}}+w\frac{\partial^2 T}{\partial_{z^2}}\right)+S \quad (5)$$

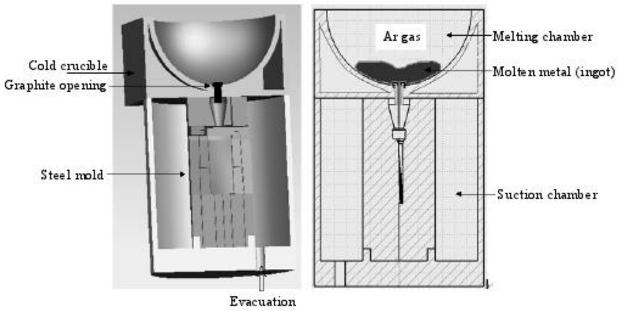

Fig.1 Schematics of suction casting

Wherein u, v, w respectively difference grid point（x, y, z）of the velocity vector, m/s ; t for filling time, s ; μ is the kinematic viscosity of the fluid, m^2/s ; C_p is the specific heat, $J\cdot Kg^{-1}\cdot K^{-1}$; P is the pressur, Pa ; T is the temperature, K ; ρ is the density, Kg/m^3 ; λ is heat transfer coefficient, $W\cdot m^{-2}\cdot K^{-1}$; S is the heat source, W/m^3 ; g_x, g_y, g_z respectively are the gravitational acceleration component.

Using PRO-E software for three-dimensional modeling casting, modeling its link shown in Figure 2, the size is 200mm × 80 mm × 20mm. ProCAST meshing module with the casting and mold to mesh, using unsynchronized long grid cells, smaller than the grid casting mold grid, so shorten the simulation time while maintaining the accuracy of the simulation.

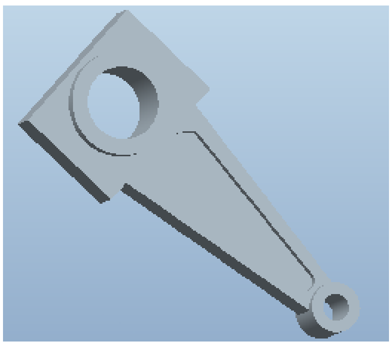

Fig.2 Geometry model of linkage castings

II. Numerical simulation of the impact of process parameters on the defect

The impact of graphite suction diameter on the defect

Select the mold heat transfer coefficient of 1000 $W/\left(m^2\cdot k\right)$, Filling temperature 1200 ℃ , Mold temperature is 20℃, Filling speed is 1 m/s , Suction mouth diameter of graphite were 10, 14, 18mm。

Figure 3 shows the simulation results of Al based alloy linkage casting filling and temperature distribution, it can be seen, which produce heat exchange while filling liquid alloy. In filling process which graphite suction diameter of 10mm, the temperature of molten metal rod Falcon department and gate location has dropped below the melting point, which will lead to produce water shortage。In the filling process of graphite suction diameter at 14mm, when the moment just completed filling, the lowest temperature of molten alloy gate location, and the melting temperature of the same, but does not affect the cast after feeding negative. In graphite suction diameter 18mm of the filling process, when the complete filling of the moment, apart from the surface of the thin-walled alloy liquid and leaves the body has solidified at a temperature higher than the liquid inside the alloy liquid temperature 30~50℃, so it will not occur that casting misrun and cold shut caused due to solidification speed.

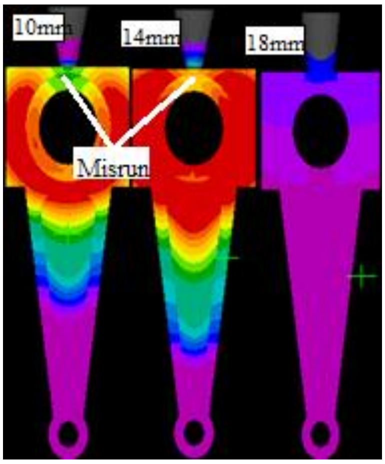

Fig.3 Effect of graphite suction opening diameter on casting defect

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A. Influence on the heat transfer coefficient of defects

Select filling velocity is 1 m/s, Pouring temperature is 1200℃, Graphite suction diameter is 18mm which the simulate object is, Heat transfer coefficients are 500, 1000 $W/\left(m^2 \cdot k\right)$。 Figure 4 shows the coagulation time and coagulation status under different heat transfer coefficient.

As can be seen from Figure 4, with the increase of heat transfer coefficient, the liquid alloy solidification time shorter, solid fraction increases. When the moment had just finished filling, heat transfer coefficient of 500 $W/\left(m^2 \cdot k\right)$, more than 20% of the liquid alloy solidification fraction appeared in the linkage edge, at this time, the local solidification alloy liquid fraction is greater than 20% does not affect the filling process, and 1000 $W/\left(m^2 \cdot k\right)$ mold heat transfer coefficient greater than 20% of the liquid alloy solidification fraction appeared in large numbers of the leaves Falcon department. Now the local solidification alloy liquid fraction is greater than 20% of the linkage Falcon department appeared filling difficult issues, thus resulting in cold traps falcon linkage portion and water shortage.

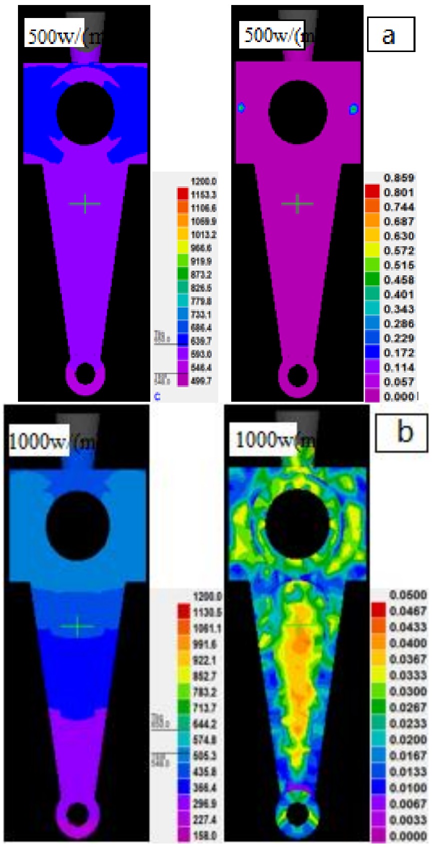

Fig.4 The effect of coefficient of heat transfer on solidification time and state:
(a) 500 $W/\left(m^2 \cdot k\right)$ and (b) 1000 $W/\left(m^2 \cdot k\right)$

Metal casting because the high heat transfer coefficient, fast heat dissipation, especially for complex thin-walled castings, huge heat loss can cause the temperature of the molten metal surface forefront low or fall below the solidus. The casting of filling process can not be successfully completed, allowing the casting to produce cold traps, water shortage and other casting defects. In addition, the temperature of the liquid metal with decline in its flow characteristics will change dramatically, which makes casting filling state change dramatically. Therefore, the study of different heat transfer coefficients have a very significant impact on the filling.

B. Effect of temperature on the casting defects

Selected filling velocity 1 m/s, graphite suction diameter is 18mm, heat transfer coefficient is 500 $W/\left(m^2 \cdot k\right)$, as 1200、1250℃ pouring temperature to simulate object。 Figure 5 shows the effects of different pouring temperature of solidification state。 When the moment had just finished filling, pouring temperature of 1200℃ that local solidification fraction greater than 20% liquid alloy in linkage falcon department appeared in large numbers. Which means the local solidification alloy liquid fraction is greater than 20% of the linkage in Falcon department appeared filling difficult problem. Resulting in a cold shut falcon linkage portion and a water shortage. The alloy liquid was not appeared which cast local solidification temperature of 1250℃ fraction greater than 20%. That pouring temperature increased from 1200℃ to 1250℃, only need to raise 20℃, pouring on water shortage can be a good improvement falcon linkage portion, cold shut phenomenon. Fig.6 is obtained under different casting temperatures linkage castings. Description proper pouring temperature conducive to improve defect reduction.

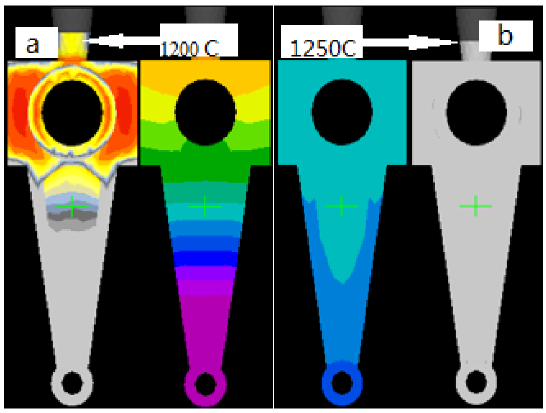

Fig.5 Effect of pouring temperature on solidification state: (a) 1200℃ and (b) 1250℃

D. Shrinkage forecast

In the numerical simulation, it is assumed when the local contraction less than 1.5% called shrinkage porosity, more than 1.5% called shrinkage。In Al alloy, shrinkage can eliminate by use of hot isostatic pressing. Therefore, shrinkage is an important casting defects, must try to eliminate. Figure 6a is a pouring temperature of 1250℃, filling velocity is 1m/s, graphite suction mouth diameter 18mm. Obtained the Fig of shrinkage porosity and

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shrinkage when exchange heat coefficient is 500 $W/\left(m^2 \cdot k\right)$. As can be seen from the figure, shrinkage mainly in the thin wall of the linkage, and shrinkage porosity distributed over the entire linkage. Figure 6b is a shrinkage profile in the casting temperature 1270 ℃ obtained, it can be seen from the diagram, with the increase of the pouring temperature, the shrinkage in thin-walled linkage is reduced. In addition, it can be seen from the figure, the shrinkage porosity in falcon department are more than thin wall, which is mainly during the solidification process, the thin-walled in linkage can be obtained the feeding by alloy liquid. The probability of macro porosity decreases, and linkage falcon department and central gate alloy liquid supplement channels become narrow, feeding difficulties. Therefore the trend of the formation of shrinkage cavity in linkage falcon department became bigger. The liquid alloy in central gate will finally solidify, so the free surface in the middle of the gate appears macroscopic shrinkage.

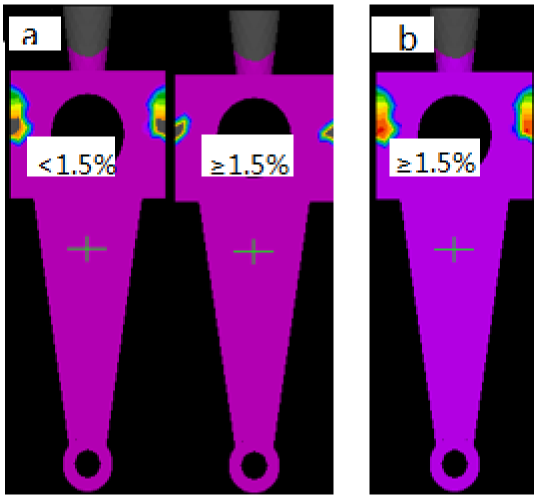

Fig.6 Distribution of casting shrinkage porosity and cavity: (a) 1250℃ and (b) 1270℃

III. CONCLUSION

1) Simulation analysis showed that by increasing graphite suction diameter and the pouring temperature is conducive to cold traps and reduce water shortage defects. Increased the heat transfer coefficient of the linkage making Falcon department cold water shortage defects increasing. Shrinkage cavity produced mainly in the falcon department of linkage. There are a small amount of shrinkage porosity and a large number of shrinkage in the linkage thin-wall.

2) Cold traps, water shortage, loose shrink and shrinkage defects coincide with the actual casting results.

3) Appropriate increasing the diameter of graphite suction mouth. To improve the pouring temperature. Reduced heat transfer coefficient can be obtained good quality castings.

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