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Optimization of Investment Casting Process for Valve Body of Air Relief Valve Based on ProCAST

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Abstract

Based on the ProCAST software, a numerical simulation study on the investment casting process of the vent valve body has been carried out in this paper, and a new flange side vertical top pouring scheme has been proposed. Through the analysis and research of the simulation results of the scheme, the structure of the pouring system is analyzed. And the pouring parameters are both optimized and analyzed. The results show that: ①Adding a riser on the side of the valve body flange can effectively transfer the casting defects inside the flange and improve the quality of castings. ②Using a top-pouring pouring scheme, under the working condition of a filling time of 30s and a filling speed of 0.48kg/s, 1110℃ is the best pouring speed.

Keywords

ProCAST;valve body;investment casting;process optimization.

1. Introduction

In the traditional casting industry, the yield of its products and the quality of castings mainly depend on the experience accumulation of casting staff, so there is a great uncertainty in the quality of finished castings [1]. With the development of computer technology, casting simulation technology based on computer computing power has been continuously developed and matured day by day. The casting simulation technology overcomes the problem that the liquid metal flow cannot be visualized in traditional casting. The flow characteristics, heat transfer characteristics and solidification characteristics of the molten metal can be visually observed through the mold software [2]. The simulation of solidification of castings can effectively reduce workshop tests and ensure that the castings are defect-free. The casting simulation method is based on the finite element method (FEM), the finite difference method (FDM), and the finite volume method (FVM) [3]. You can intuitively observe the physical and chemical phenomena of the molten metal, such as the formation of oxides, the impact of the molten metal on the mold, etc., and you can observe the transient flow characteristics of the molten metal, such as the temperature, speed, and solidification state at a certain moment [3-5], by analyzing the temperature field, velocity field, and stress field of the simulation results, engineers can predict the location of shrinkage porosity and shrinkage holes that may appear in the casting, and then design a feeding system or improve the casting process [6,7], Eventually achieve the effect of increasing the yield, shortening the production cycle, reducing energy consumption, and protecting the environment [8]. At present, many mold softwares have been developed and used at home and abroad. The most common ones abroad are ProCAST, MAGMAsoft, Flow-3D, and AnyCasting. There are CAE and FT-STAR in China [9].

Sand casting is one of the most common casting methods, suitable for the production of castings of various shapes, sizes and different purposes. The mold of sand casting is composed of an outer sand mold and a core. Because of its cheap molding materials and simple mold production, sand casting can be suitable for single piece production, batch production and mass production [10]. The sand casting process is simple, the main processes include: sand mixing, modeling,

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drying, box closing and pouring [11]. Based on ProCAST software, this paper conducts simulation research on the investment casting process of the vent valve body, and improves the process according to the simulation results, which has certain guiding significance for practical production.

2. Establishment of numerical model

2.1. 3D model of casting

Figure 1 shows the valve body model of the air release valve established by SolidWorks. The casting material is made of ZCuSn10 alloy, the outline size is 176mm×175mm×185mm, the maximum thickness of the model is the thickness of the top flange, which is about 19.90mm, and the minimum thickness is the thickness of the curved surface connecting the bottom and the two bosses, which is about 4mm. The weight of the valve body is 12.80kg, and the production method is investment casting. The solidus temperature of ZCuSn10 alloy is 830℃, and the liquidus temperature is 1020℃. The width of the solid-liquid temperature interval is 190°C. Table 1 shows the chemical composition of ZCuSn10 copper alloy.

Figure 1 Valve body model of the air release valve

Table 1 Chemical composition of ZCuSn10 copper alloy (%)

Cu	Sn	Others
88.25	10.48	1.27

2.2. Determination of the pouring plan

A good pouring system can ensure the continuity, order, and stability of the molten metal flow, and prevent the molten metal from suffocating, entraining, inclusion and insufficient pouring during the filling process. Reasonable gating system design can prevent shrinkage porosity and shrinkage cavity, and ensure the sequential solidification of castings. For the valve body of the air release valve, the traditional pouring scheme is to place the valve body flange upwards, place it horizontally, and use the bottom pouring scheme for pouring. However, simulation studies have found that when this scheme is used for pouring, shrinkage and looseness of the top flange will occur. Shrinkage and suffocation phenomena. Therefore, a new pouring plan is designed in this article, as shown in Figure 2. The top pouring pouring plan is placed in the vertical direction of the valve body flange, and a riser is set above the flange to feed the solidification shrinkage and shrinkage holes in the valve body. , Divert the casting defects inside the valve body. Two vent holes are provided at both ends of the top runner to remove the gas inside the casting and prevent defects such as pores and entrainment. Using top-pouring pouring process, the metal liquid flows in from top to bottom, and the filling speed is fast, avoiding insufficient pouring and cold barrier defects. In the top-pouring pouring process, at the final solidification, the upper temperature is higher than the lower temperature, and the solidification sequence meets the bottom-up sequential solidification, which is conducive to feeder feeding.

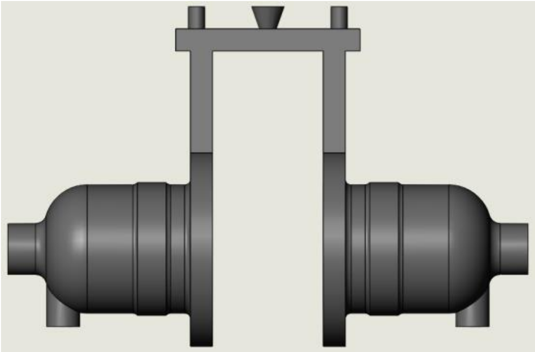
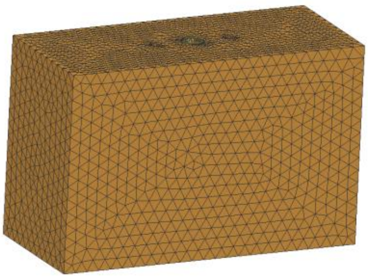


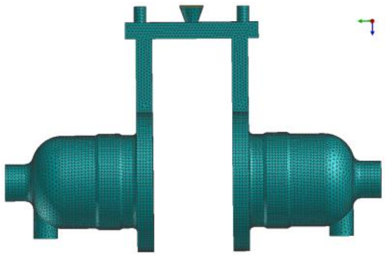
Figure 2 Casting process plan

2.3. ProCAST meshing

After using SolidWorks to establish the casting and gating system model, save it in the igs format and import the ProCAST mesh module for mesh division. When dividing the mesh, the calculation performance of the computer must be fully considered while ensuring the accuracy of the model solution, so 20mm is used for the sand mold. Mesh size, 2mm mesh size is used for the gating system and castings, and finally the number of surface meshes is 53,228 and the volume mesh is 915,246. The meshing model is shown in Figure 3.



(1) Sand meshing



(2) Mesh division of castings and gating system

Figure 3 Meshing model

2.4. Simulation parameter setting

The pouring time τ has a great influence on the filling speed and casting quality, so the pouring time must be accurately calculated, which can be calculated by the following formula (1)[11]:

$$\tau = S_1 \sqrt[3]{\delta G} \tag{1}$$

In the formula: τ is the pouring time; G is the total weight of the pouring system; δ is the wall thickness of the casting; S1 is the coefficient of the cast metal, and S1 is taken as 5. Bring in the data of the air release valve body, and calculate that the pouring time is 31.69s.

The interface heat transfer coefficient h will directly affect the heat exchange capacity between the casting and the mold, and between the mold and the external environment. The expression is shown in formula (2) [12].

$$\mathrm{h} = \frac{q}{\Delta T} \tag{2}$$

Where: is the heat flux density, W/m2; is the temperature difference between the casting and the mold interface, K; the heat transfer coefficient between the sand mold and the tin bronze alloy in this article is 500W/m2·K, and the sand mold boundary condition is air cooling, that is,

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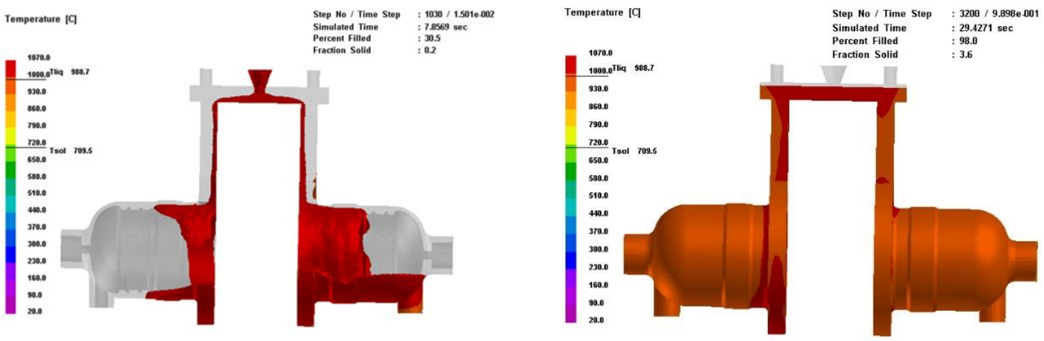
The air heat transfer coefficient is 10 W/m2·K, and the ambient temperature is 20°C. The pouring temperature is generally 50℃~100℃ higher than the liquidus temperature of the casting. The liquidus temperature of ZCuSn10 alloy is 1020 ℃. Therefore, the pouring temperature is set at 1070°C~1120°C, and the sand mold temperature is set at 20°C. The casting method is metallic gravity casting, the gravity acceleration is 9.8m/s2, and the direction is -Y. When the pouring temperature is 1070℃ and the filling rate is 100%, the software solution result is that the filling speed is 0.42kg/s and the filling time is 29.99s, which is close to the theoretical filling time, indicating that the model is established correctly.

3. Filling simulation of castings

3.1. Simulation results and analysis of filling process

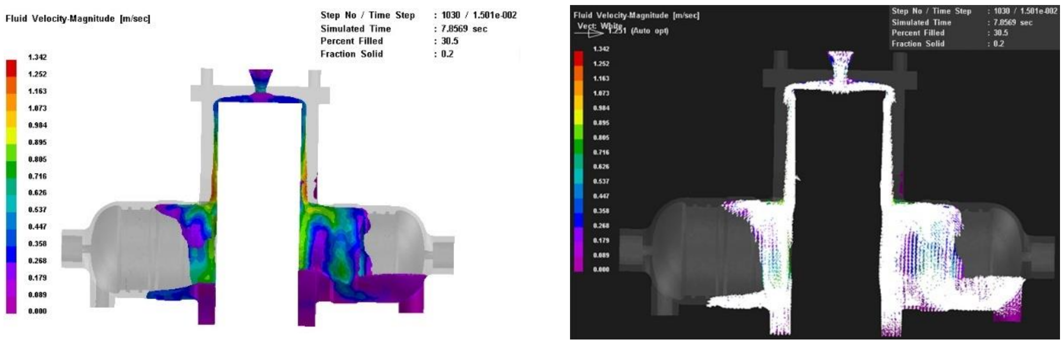
Figure 4 shows the casting simulation process. It can be seen from the figure that the metal level rises relatively steadily during the filling process, and most of the solution temperature is higher than the liquidus temperature of the casting when the casting is filled, and there is no cold separation or pouring. Insufficient, the filling process can be completed smoothly. When the pouring temperature is 1070℃ and the pouring speed is 0.42kg/s, the entire casting is fully filled in 29.42s.



t = 7.8s t=29.42s

Figure 4 Filling simulation of castings

Figure 5 shows the casting flow velocity field. It is not difficult to see from Figure 5(a) that the maximum flow velocity of the metal liquid appears at the connection between the flange and the riser during the filling 7.85s, and the maximum flow velocity does not exceed 1.2m/s. The cavity has little impact. Figure 5(b) shows the particle tracking diagram of the casting at 7.85s. It is not difficult to see from the figure that the molten metal flows smoothly, there is no turbulence, and no entrainment is generated.

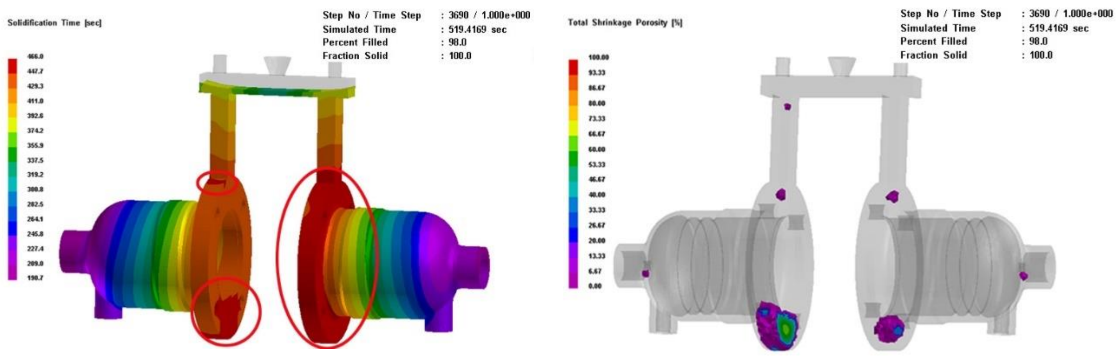


(A) 7.85s velocity field (B) 7.85s casting particle tracking field

Figure 5 Filling flow velocity field of castings

3.2. Simulation results and analysis of the solidification process

For the solidification process of castings, the solidification sequence has a great influence on casting defects such as shrinkage porosity and shrinkage cavities. Liquid shrinkage and solidification shrinkage occur when the metal solidifies. The shrinkage requires liquid feeding from the surrounding molten metal, otherwise it will form Shrinkage and shrinkage defects. The first solidified metal obviously has no fluidity, and therefore has no ability to feed the area to be fed. The characteristic of top-injection pouring is that the temperature of the upper part of the casting is higher than the lower part, the casting solidifies from bottom to top, and the riser solidifies at the end. The formation sequence solidifies. However, in actual simulation or production, the metal temperature of some parts of the lower part of the casting is often higher than that of the upper part. After the metal on the upper part of the casting has solidified, the part is still not solidified. Because the upper metal liquid cannot be fed, it is often in the casting. Shrinkage porosity and shrinkage cavity defects are formed inside. Figure 6(a) shows the solidification time field of the casting when the pouring temperature is 1070 ℃. The red circle mark in the figure shows that the solidification time of this area is longer than the solidification time of the surrounding area, indicating that shrinkage porosity and shrinkage cavities may appear in this area. . Figure 6(b) shows the solidification defect field of the casting. The area circled by the red circle in the figure is the location of the possible shrinkage porosity and shrinkage cavity defects of the casting, which is consistent with the results predicted in Figure 6(a). It is not difficult to see from the solidification field of the casting that there are many defects of shrinkage porosity and shrinkage in the casting. These defects are mainly concentrated in the lower part of the flange. On the one hand, this phenomenon is caused by the large thickness of the flange itself. The solidification speed of the surface layer is higher than that of the inside, which causes the internal liquid to not be fed when it solidifies and shrinks; on the other hand, it is also related to the fact that the bottom of the flange is far from the riser and cannot get enough liquid feeding from the riser.



(A) Freezing time field (B) Solidification defect field

Figure 6 Casting solidification field

4. Process optimization design

Researchers found that 90% of casting defects are caused by design defects of the gating system and feeding system [13]. In view of the shrinkage porosity and shrinkage porosity in the solidification field of the above castings, it is necessary to optimize the pouring process plan to eliminate or reduce the shrinkage porosity and shrinkage porosity and improve the quality of the casting. Process optimization design is mainly carried out from two aspects. One is to improve the structure of the gating system, such as adding risers and chilled iron at specific locations to transfer casting defects. The second is to optimize the pouring parameters. For example, if the pouring temperature is adjusted, if the pouring temperature is too low, the filling

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speed will become slower and a larger temperature gradient will be formed, which will seriously affect the fluidity of the metal liquid, and then cause defects such as insufficient pouring and shrinkage. . If the pouring temperature is too high, the filling speed will be too fast, causing problems such as sputtering, entrainment, and sand washing.

4.1. Structure optimization of gating system

The optimized gating system is shown in Figure 7. After fully studying and analyzing the structure of the original gating system and the causes of casting defects, the gating system is optimized as follows: ①The length of the vertical runner is shortened, and the straight The entrance of the sprue is designed as a funnel shape with a certain inclination angle. The molten metal can first flow down the slope of the funnel-shaped sprue, and then flow down the vertical sprue, reducing the impact on the molding sand during filling and at the same time Helps improve the stability of molten metal flow. ②Two chimney-shaped risers are installed at the lower end of the flange. The metal liquid in the riser can feed the flange, and then transfer the shrinkage and shrinkage defects of the flange to the riser, improve the quality of valve body castings.

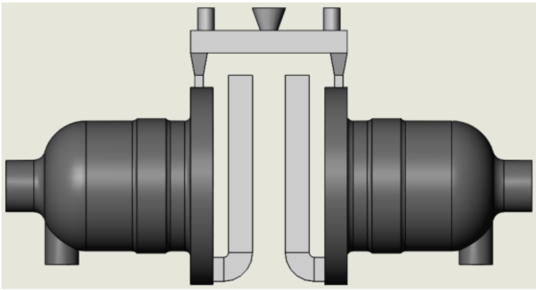
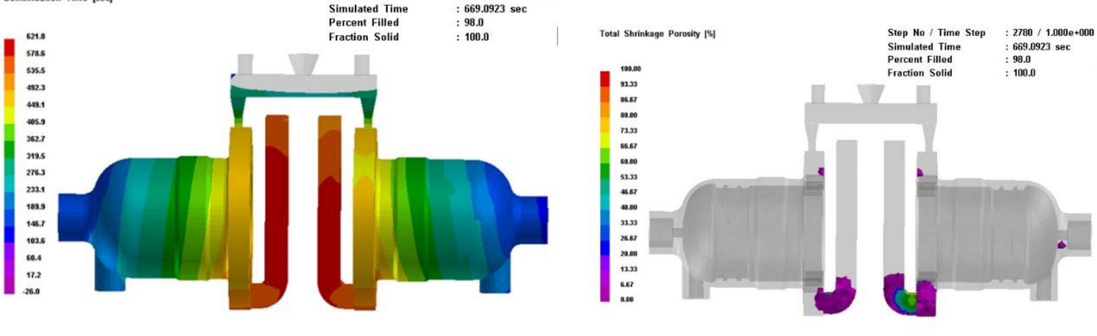


Figure 7 Optimized pouring system

When the pouring temperature is 1070℃ and the pouring speed is 0.48kg/s, the solidification field of the casting obtained by the optimized pouring system is shown in Fig. 8. It can be seen from Fig. 8(a) that the newly added riser The position is the final solidification position, which can provide timely feeding for the flange, reduce or even eliminate the shrinkage and shrinkage defects gathered at the bottom of the flange, and improve the quality of castings. It can be seen from Figure 8(b) that the shrinkage porosity and shrinkage cavity defects of the castings are mainly concentrated at the bottom of the riser, which is consistent with the analysis of the solidification time field. After the optimization of the pouring system structure, the internal shrinkage porosity and shrinkage defects of the casting are greatly reduced compared with the original pouring plan, which fully shows that the structure optimization of the pouring system is reasonable.



(A) Freezing time field (B) Solidification defect field

Figure 8 Casting solidification field

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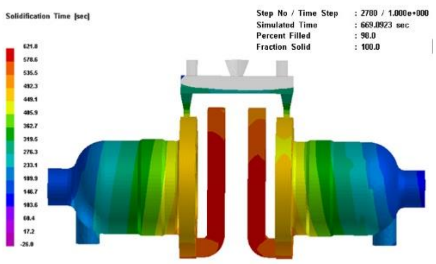
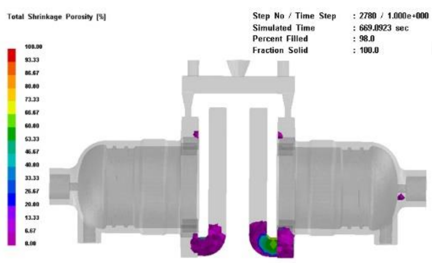
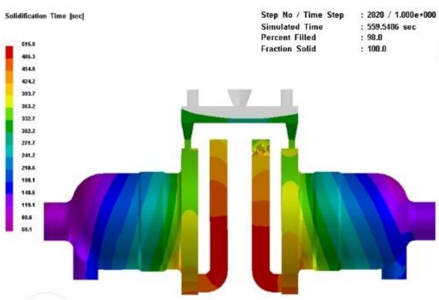
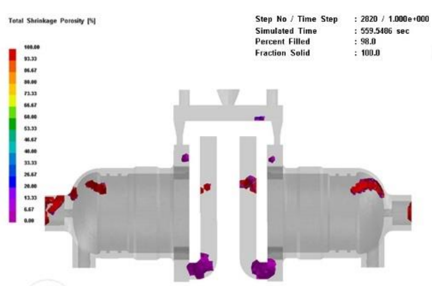
4.2. Optimization of pouring parameters

Pouring process parameters such as pouring temperature, sand mold temperature, ambient temperature, the heat transfer coefficient between the casting and the sand, the heat transfer coefficient between the sand and the air, etc., will all have an impact on the quality of the casting, and the influence of the pouring temperature is particularly significant [14 ,15]. Therefore, based on the optimized gating system, it is very necessary to study the influence of different pouring temperatures on castings based on the controlled variable method. Generally speaking, the pouring temperature is usually 50℃~100℃ higher than the molten metal temperature. The liquidus temperature of the casting material ZCuSn10 this time is 1020℃, so the pouring temperature can be set as 1070℃, 1090℃, 1110℃, respectively. Table 2 shows the comparison between the solidification time field of the casting and the defect field of the casting at different temperatures. It is not difficult to find from Table 2 that at different pouring temperatures, each model basically solidifies at the riser part, and can feed the valve body flange, but the final solidified liquid volume in the riser is obviously different. , The comparison of the riser liquid volume shows: V1110℃>V1070℃>V1090℃. The larger the riser liquid volume, the stronger the feeding capacity, that is, the stronger the ability to transfer shrinkage porosity and shrinkage cavity defects, which is reflected in the casting defect map. The above is the comparison of shrinkage porosity and shrinkage cavity volume in the riser: V1110℃>V1070℃>V1090℃. Comparing the defect maps of castings, it is not difficult to find that the defects of castings at 1070°C and 1110°C are relatively large, and they are mainly concentrated under the riser. However, the casting defects at 1090°C are more scattered, the casting defects below the riser are small in volume, and there is a high probability of casting defects at the position of the valve body boss far away from the riser. After carefully comparing the casting defect field of the casting model at 1070℃ and 1110℃, it is not difficult to find that in terms of the volume of internal defects in the riser, there is little difference between the two, but in terms of the volume of internal defects in the casting, the casting of the 1110℃ model The defect volume is significantly smaller than the casting defect volume at 1070°C. In summary, it is determined that 1110℃ is the best pouring temperature.

temperature /℃	Solidification time field	Casting defect field
1070		
1090		

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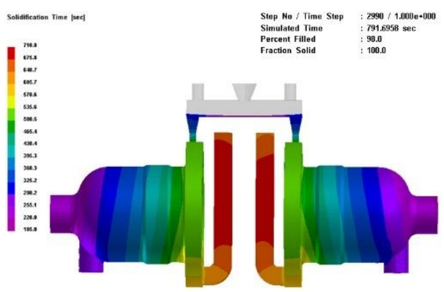
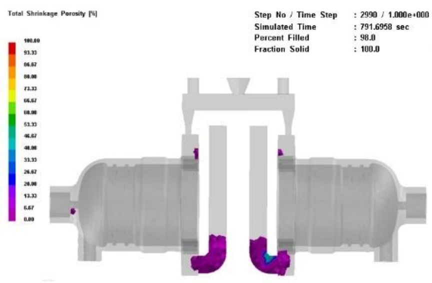
1110		

Table 2 Comparison of casting solidification field at different pouring temperatures

5. Conclusion

1) Add a riser on the side of the flange of the valve body. During the solidification process, the temperature of the riser is the highest, and finally solidifies, which conforms to the principle of sequential solidification. The metal liquid in the riser can be the shrinkage produced by the flange during the liquid solidification and shrinkage process. Loose and shrinkage holes are effectively compensated, the casting defects inside the flange are transferred, and the quality of castings is improved.

2) Using the top-injection pouring method, the filling time is 30s, and the filling speed is 0.48kg/s. The casting solidification field of the 1110℃ model shows that the shrinkage porosity and shrinkage cavity defects of the casting are mainly concentrated at the bottom of the riser. The volume of casting defects inside the riser is the largest, and the volume of casting defects inside the casting is the smallest, which indicates that the feeder has the strongest feeding capacity. Therefore, 1110°C is determined as the best pouring temperature.

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