Key Analysis of Design and Numerical Simulation for Aluminum Alloy Impeller Low-pressure Casting Mold

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Abstract: It is of great practical value to complete the low-pressure casting of aluminum alloy impeller in the current development of low-pressure casting process. In the research, it is necessary to focus on factory realization and use low-pressure casting to produce aluminum alloy impellers, so that impeller castings with compact structure and meeting performance requirements can be obtained. Compared with other casting methods, low-pressure casting itself, as a precision casting method, can be cast on the metal solution with lower pressure in the application process. The castings can be filled and solidified under certain pressure, and the castings with compact structure can be obtained. In the research, Pro/Engineer is used to design the low-pressure casting mold for aluminum alloy impeller, and MAGMASOFT is used to carry out the filling and solidification process of aluminum alloy impeller. Through numerical simulation, we can accurately predict the defects of impeller castings, and optimize the mold scheme and pressure-time parameters according to the prediction results.

1. Introduction
In the process of aluminum alloy impeller casting in modern society, it is necessary to master the advantages and performance of aluminum alloy impeller. From the principle and characteristics of low pressure casting process, master the application advantages and low pressure casting process of aluminum alloy impeller casting process. In addition, it is necessary to fully grasp the key points of mold design in the process of low-pressure casting of aluminum alloy impeller, carry out the mold design control work with the actual demand of aluminum alloy impeller as the core, and optimize the design scheme through numerical simulation to improve the level of aluminum alloy impeller casting process.

2. Principle and Characteristics of Low-pressure Casting Process
Low-pressure casting is a manufacturing process between pressure manufacturing and gravity manufacturing. In the process of low-pressure casting, it is necessary to exert relatively low pressure on the metal solution, the pressure value is generally 0.02~0.07 MPa. After the pressure is applied, the metal solution is pressed into the mold, and the castings can be filled and solidified under pressure to obtain the castings with compact structure. The specific principle of low-pressure casting process is shown in Figure 1.
During the operation of low-pressure casting process, it is necessary to open the air inlet valve of the crucible air inlet pipe first, and the gas enters the crucible, forming pressure on the molten metal. Under the influence of the pressure, the molten metal can rise from the liquid riser, enter the mold through the gating system, and be filled, crystallized and solidified. After the casting is solidified, open the air outlet valve of the crucible air outlet pipe, so that the pressure on the molten metal can drop, and the molten metal in the gating system and liquid riser can reflux[1]. This is the process of low-pressure casting. In the process of low-pressure casting, it mainly includes different links, such as liquid lifting by liquid riser, pressurization and mold filling, solidification and pressure relief, casting cooling and so on.

3. Low-pressure Casting Process of Aluminum Alloy Impeller

When using low-pressure casting technology to complete the casting production process of aluminum alloy impeller, it mainly includes the following steps: First, complete the preparation of molten metal and prepare the mold. Second, carry out the preparation of low-pressure casting equipment and complete the mold assembly. Thirdly, the mold is filled by pressurizing and metal solution pouring, and then the mold is opened and the parts are taken out. Finally, it is necessary to complete the casting cleaning and subsequent treatment [2].

It should be noted that in the process of low-pressure casting of aluminum alloy impeller, it is necessary to effectively control every link to ensure the stability of the low-pressure casting process. First, in the process of preparing molten metal and mold, it is necessary to finish the melting and refining of aluminum alloy A357 in strict accordance with relevant operation requirements, and prepare molten metal. At the same time, the finished metal mold and manufactured gypsum core should be effectively combined to prepare for low-pressure casting.

Second, during the preparation of low-pressure casting equipment, we should pay attention to the different characteristics and service conditions of different low-pressure casting machines, which need reasonable selection. Aluminum, magnesium and zinc alloy are cast by low-pressure casting machine with holding furnace, and copper alloy, cast iron and cast steel are mainly cast by pressure tank. In this research process, we mainly finish the casting of aluminum parts, so we need to use the low-pressure casting machine with holding furnace to finish the casting work [3].

Third, in the process of mold assembly, asbestos rope or asbestos board sealing layer should be placed around the liquid riser, so as to ensure the tightness of the connection position between the liquid riser and the inner gate and prevent air leakage. At the same time, the preheated metal mold assembly should be placed on the low-pressure casting machine to ensure the alignment of liquid riser and mold gating system. After each part of the mold is fastened with the template of the low-pressure casting machine, it is necessary to open the low-pressure casting machine to check whether the mold is opened and closed smoothly. If the mold is opened and closed successfully, the mold can be purged of impurities, and then the mold is closed for subsequent pouring operations.
Fourth, the step of pressure casting and mold filling. In this link, it is necessary to control the outlet temperature of the liquid riser and the preheating temperature of the metal mold and the pouring temperature. During the research, the pouring temperature of aluminum alloy solution is 700℃, the preheating temperature of metal mold is 250℃, and the preheating temperature of liquid riser is 550℃. After opening the button of the page pressure control system, the pouring air valve is also opened. At this time, the pressure control system can be adjusted, and the liquid level pressure of molten metal can be adjusted, so that different operations such as boosting, filling, boosting, maintaining pressure, relieving pressure and venting can be completed.

Fifth, it is necessary to open the air outlet valve of the crucible to complete the deflation and pressure relief before opening the metal mold to take out the castings after the metal castings are completely cooled and not deformed. Usually, small and medium-sized castings in aluminum alloy can be opened and taken out within 1~4 minutes after pressure relief. After the casting is taken out, it is necessary to clean up the impurities in the metal mold, and re-spray the paint falling off the inner surface of the mold. After pressing, the next casting casting production process can be carried out. In the process of casting cleaning and post-processing, it is necessary to cut off the gating and riser system to ensure that mechanical processing or numerical control processing can effectively cut off the gating and riser system of impeller castings, and the surface of castings should be polished and cleaned by mechanical and manual methods to remove burrs. In the process of heat treatment of impeller castings, T61 solution aging heat treatment can be completed to ensure that the mechanical properties of impeller castings can meet the specific application requirements [4].

4. Key points of low-pressure casting mold design

4.1 Select mold material
In the process of low-pressure casting mold design, the mold materials must be reasonably selected. Whether the mold materials are used properly will affect the service life of the mold and the molding quality of castings. In this research, H13 was used as the mold material when developing the low-pressure casting process of aluminum alloy impeller.

4.2 Casting design
In the process of mold design, it is necessary to ensure the effectiveness of mold design from the following two aspects: First, the mold wall thickness should be fully considered. The wall thickness of the mold has a crucial influence on the molding quality of castings. Usually, in the process of disposable mold design, the mold wall thickness is proportional to the heat absorption capacity. The thicker the mold wall, the stronger the heat absorption capacity. On the contrary, the worse the heat absorption capacity. However, when designing the repeatedly used mold, the thicker the mold wall, the lower the thermal conductivity, and conversely, the stronger the thermal conductivity. According to the empirical value, H13 steel is selected as the aluminum alloy impeller material. When it is used as a mold, the rear of the mold wall is kept at about 20~30 mm. Second, give full consideration to the mold structure. In the process of casting mold design of impeller castings, the parting surface can be designed by horizontal and vertical mixed parting [5].

4.3 Gate system design
Gate system design is also the key content in the design process of low-pressure casting die. In the process of gate system design, we need to proceed from the following aspects to ensure the design level of gate system: first, the design of filter screen. The main function of the filter screen is to stabilize the flow and filter residue. The material of the filter should be considered when designing the filter. Generally speaking, the filter includes heat-resistant chemical fiber filter, ceramic filter, iron filter and steel filter. Among them, the metal filter is generally semi-circular and the ceramic filter is generally flat. The filter screen made of chemical fiber is barrel-shaped. However, the pore size of the filter screen will also have an impact on its use effect. The filter screen is selected among 12~20 meshes, and the best
wire diameter is generally between 0.5~1 mm. In the actual production process, the aperture is 20 mesh, and the mesh diameter is about 0.3~0.4 mm. The material of the filter screen is iron filter screen. Second, the liquid riser. The function of the liquid riser in the crucible is to introduce the molten aluminum from the crucible into the channel of the mold cavity. The flange on the upper part of the liquid riser lies in the low-pressure casting machine, and the lower part can enter the molten aluminum in the crucible. The inner diameter of the pipe channel is generally more than 35mm. Usually, the distance between the lower end face of the riser and the bottom of the liquid pool in the crucible is about 50~100 mm, and the diameter of the liquid riser is 8 mm, which is made of seamless steel pipe [6].

5. Numerical simulation points

5.1 Mold scheme design
In this research process, the mold design work is carried out to ensure that the castings can realize top-down sequential solidification, and the mold scheme can be designed as shown in Figure 2.

![Figure 2 Mold design scheme](image1)

Figure 2 Mold design scheme

In actual design, it is only necessary to apply a cooling device to the top of the upper cover plate of the impeller casting. According to the mold scheme of assembly design, the horizontal and vertical mixed parting includes upper, lower, left, right, core and liquid riser. The mold opening diagram is shown in Figure 3.

![Figure 3 Mold opening drawing of mold design scheme](image2)

Figure 3 Mold opening drawing of mold design scheme
The molded aluminum alloy impeller parts are the main parts, and the upper metal mold is divided
into upper mold and workpiece from the bottom surface to form the lower mold entity. In the design, the top of the upper cover plate of the impeller casting needs to be cooled. Therefore, it is necessary to use the upper part of the impeller profile to cut the upper mold and workpiece to form the lower mold entity. The structure of impeller castings is complex, and the overall diameter generally increases gradually from top to bottom. In order to facilitate the impeller castings to be taken out effectively, the left and right parts of the remaining workpieces can be divided in the middle parting surface during design to form left and right halves. In order to reduce casting defects, exhaust measures should be set on the mold [7]. Because the last mold filling position of the impeller casting is on the top of the upper cover plate, it is necessary to set six exhaust holes with a diameter of 8mm in the upper mold to place the exhaust plugs. Through numerical simulation, the exhaust effect can be observed, and liquid riser are placed on the upper and lower molds to manufacture impeller castings, and molten metal is poured in. After assembly, the working core and the metal mold can be placed on the low-pressure casting machine to prepare for the casting of aluminum alloy metal solution. In order to accurately position the core, the diameter of the core is 20mm larger than that of the impeller in design, and the bottom of the core is convex, which can be matched with the depression of the lower mold to accurately position the core during assembly. In addition, the diameter of the liquid riser is designed according to the corresponding empirical value, and the diameter is determined to be 80 mm, the distance from the bottom of the liquid riser to the bottom of the crucible is generally more than 50 mm, and the height of the liquid riser is 300 mm. In this case, when the top of the cover plate is cooled, the larger the wall thickness of the metal mold is, the stronger the heat storage capacity is, and the cooling effect on the castings will be constantly improved normally.

5.2 Mold scheme simulation
After the mold scheme design is completed, it is necessary to simulate the mold scheme, which mainly includes the following links: First, the project establishment. In order to ensure the effectiveness of numerical simulation of filling and solidification process of aluminum alloy in low-pressure casting, it is necessary to use software MAGMASOFT for analysis. Second, complete the geometric construction. In MAGMASOFT software, Preprocessor can be used to complete geometry construction or import, and Pro/Engineer software can store and import the designed mold components into the software. In this research process, the geometric figure and oblique view of the mold scheme can be adjusted by processing tools, and the mold components imported in the pre-processing process should be in different material groups according to different functions, such as upper mold, lower mold, side mold, castings, cores, etc. Different materials need to be displayed in different colors, as shown in Figure 4.
The color of the metal is reddish brown, the casting is red, the core is green, and the vent is light yellow. In the pre-processing process of software, it is necessary to adhere to the principle of covering, and then the imported components have the priority to import components before automatic cutting. Therefore, in the process of lead-in, the mold lead-in should be completed in a certain order, and then the castings, cores, inner gates, runners, etc. should be introduced. In this way, the imported components can be presented according to the expected shape [8]. Third, grid division. In the application of finite element analysis software, in order to ensure the effectiveness of numerical simulation, it is necessary to carry out gridding. Grid division includes automatic division and advanced division. Usually, automatic division can meet the requirements. The more grids are divided, the higher the calculation accuracy. However, if the number of grids is too large, the computer will occupy more memory and the calculation time will be prolonged. Therefore, in the process of grid division, we can pre-divide, check the number of defects, and finally determine the specific number of grid division.

In the process of mold scheme design, the material parameter is that A357 is used as the material for aluminum alloy impeller castings. In actual production, the core uses gypsum core, but because there is no gypsum material in the material library, in order to ensure the convenience of operation, the material with heat transfer performance close to that of gypsum core can be selected as the core material. In the actual simulation, H13 steel is used as a metal mold, and there is no such material in the material library, so it is necessary to select a material with similar heat transfer performance to H13 steel as a metal mold material. The upper mold can achieve the cooling effect on the top of the upper cover plate of impeller casting by using lower preheating temperature [8].
5.3 Simulation result
After calculation and simulation by MAGMASOFT software system, filling simulation results and solidification simulation results can be observed in post-processing, mainly including filling time, speed, pressure, solidification time, etc. By analyzing the simulation results of mold scheme, it can be determined that top-down sequential solidification in low-pressure casting process can ensure feeding at the gate, thus reducing defects. In the process of mold scheme research, we mainly look at the solidification time to judge the solidification sequence of castings. The solidification time of the mold scheme is shown in Figure 5.

![Figure 5 Cooling time of the mold scheme](image)

It can be seen from the figure that the solidification time at the top of the impeller casting hub is longer than that at the entrance of the liquid riser, which means that the top of the impeller casting hub has not solidified after the solidification at the entrance of the liquid riser, so it is difficult to capture the inner defects of the impeller casting in this case. In the design process of aluminum alloy low-pressure casting die, the positioning of the die and the setting of vent holes are very important to the quality of castings. In the process of low-pressure manufacturing, the mold positioning device is not appropriate, and when molten metal fills the mold under the pressure, it may shift, resulting in the casting not meeting the shape requirements. Therefore, in the process of low-pressure casting, mold positioning is very important. In the design process of low-pressure casting model, the setting of mold exhaust is also an important factor that must be considered. If the exhaust device is unreasonable, the body in the mold can't be discharged, which will lead to the entrainment of molten metal when filling the mold, and the gas can't be discharged from the mold, which will lead to the shrinkage cavity in the solidified casting and affect the microstructure and properties of the casting. Therefore, in the process of low-pressure casting mold design, the mold positioning and exhaust device design must be considered.

According to the numerical simulation results, it is necessary to improve and optimize the mold design scheme, and optimize the mold design scheme to complete the mold positioning and exhaust device optimization. Like the previous mold design scheme, the optimization process of mold design scheme also includes upper mold, lower mold, working mold half, right mold half, core and liquid riser. The specific optimization contents are as follows: First, the upper mold should be divided into the upper left mold and the upper right mold, and vent holes should be opened on the parting surface, and the gas in the mold can be effectively exhausted by the vent holes and parting surface. Secondly, the left mold half is provided with an exhaust hole, and the exhaust hole is exhausted through the parting surface between the left mold half and the right mold half, so that the gas inside the mold can be completely exhausted by the parting surface exhaust hole and the upper mold exhaust groove, and the molding quality and service performance of the mold can be improved. Thirdly, flange devices can be designed at the joint of the left and right halves, and threaded holes can be designed on the flange to complete the connection and positioning of the left and right halves. Through the design of this positioning device, the mold can be well positioned, and displacement can be effectively avoided in the casting process, so as to ensure the structural compactness and molding quality of the casting [10].
6. Conclusion
In a word, based on the best process parameters obtained by numerical simulation, the sample casting molding can be completed under factory conditions. After heat treatment of T61, we observed the microstructure of the sample and found that the microstructure was compact. By testing the mechanical properties, the following results can be obtained: the tensile strength and yield strength are 270MPa and 220MPa respectively, and the elongation is 3%, which can meet the actual production and application requirements of aluminum alloy castings.

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Reference:
[1] Yu Baoyi, Zhao Xizhu, Wang Sai, et al. Cas Technology and Mold Design of Aluminum Alloy Shell under Low Pressure Cas Based on Numerical Simulation[C]. 2012 China Casting Activity Week. 2012.
[2] Dong Shuai, Zhao Zhongxing, Fu Hefeng, et al. Design and Optimization of Low Pressure Casting Process for Turbocharger Impeller[J]. Journal of Shenyang Ligong University, 2014, 33(3):4.
[3] Duan Jingying, Fu Changjing. Study on Optimization of Low Pressure Casting Process and Mold Design Scheme of Impeller[J]. Foundry Technology, 2013, 34(7):3.
[4] Dai Zhigong, Bi Junxi, Tang Qingrui. Influence of Sprue Size in Low Pressure Casting on Casting Quality[J]. Foundry Technology, 2018, 39(2):4.
[5] Xie Fuzhi, Huang Daji. Study on Low Pressure Casting Process of Impeller of Hydraulic Coupling[J]. Hydraulics Pneumatics & Seals, 2010(3):3.
[6] Han Taidong, Ji Zhongxue, Zhang Dechao, et al. A Low-pressure Casting Method for Aluminum Alloy fan blades:, CN112775414A[P]. 2021.
[7] Wang Yingying. Design and Numerical Simulation of Low Pressure Casting Mold for Aluminum Alloy Impeller[D]. Shandong University, 2013.
[8] Huang Yuxiang. Numerical Simulation Study on Low Pressure Casting of Automobile Aluminum Alloy Parts[D]. Nanochang University, 2015.
[9] Yu Baoyi, Jiao Fuchuan, Li Qingfeng, et al. Process Optimization of Low Pressure Casting Aluminum Alloy Flanges Based on Numerical Simulation[C]. National Foundry Annual Meeting and China Foundry Week. 2011.
[10] Guan Guohua. Study on Numerical Simulation Technology and Mold Design Optimization of Low Pressure Casting of Large Aluminum Alloy Oil Pan[D]. Chongqing University of Technology, 2015.