

# Numerical simulation and optimization of casting process for complex pump

Xueqin Liu<sup>1</sup>, Anping Dong<sup>1\*</sup>, Donghong Wang<sup>1</sup>, Yanling Lu<sup>2</sup> and Guoliang Zhu<sup>1</sup>

<sup>1</sup>Shanghai Key Lab of Advanced High-temperature Materials and Precision Forming, Shanghai Jiao Tong University, China

<sup>2</sup>Shanghai Institute of Applied Physics, China academy of sciences, China

\*Corresponding author: apdong@sjtu.edu.cn

**Abstract.** The complex shape of the casting pump body has large complicated structure and uniform wall thickness, which easy give rise to casting defects. The numerical simulation software ProCAST is used to simulate the initial top gating process, after analysis of the material and structure characteristics of the high-pressure pump. The filling process was overall smooth, not there the water shortage phenomenon. But the circular shrinkage defects appear at the bottom of casting during solidification process. Then, the casting parameters were optimized and adding cold iron in the bottom. The shrinkage weight was reduced from 0.00167g to 0.0005g. The porosity volume was reduced from 1.39cm<sup>3</sup> to 0.41cm<sup>3</sup>. The optimization scheme is simulated and actual experimented. The defect has been significantly improved.

## 1. Introduction

High pressure pump is pressure casting, which has enough strength, compact structure, stable size, but also has good performance of thermal heat pump, to prevent leakage of body and produce rose. Investment casting is a near net forming process, including wax molding, composite casting system, system shell, dewaxing, finally pouring complete casting manufacturing [1]. In the traditional casting process, the actual experience mainly depends on the workers. The casting pressure type design, gating system design and pouring parameter establishment was the lack of theoretical basis and the optimization of the scientific method. The quality is difficult to control of the casting. Especially for complex parts, workers need to optimize the gating system structure, modify the casting parameters in order to meet the requirements of the ideal process technology. The experiment result of experience of casting long development cycle [2]. This high quality is not reliable due to drawbacks. The rate of finished products is not high especially for the thin-walled parts with complex shapes in actual production process, which has been unable to meet the demand of the industrial development. Therefore, casting process simulation is an effective scientific method with the help of numerical simulation technology.

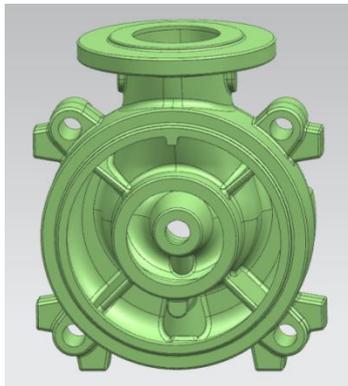
Commercial casting simulation software technology is increasingly being applied to design of gating system and simulation of mold filling and solidification process for different structural characteristics of casting. It can reduce the design cycle of product, improve product quality. Many researchers studied the shrinkage and misrun defects in the casting process by using the ProCAST software [3-5]. Guo et al. predicted the volume fraction of macroscopic shrinkage and microscopic pore defects during the solidification of nickel-based alloys [3]. Bahmani et al. proposed a FDM based model to predict the micro-porosity distributions in A356 Al alloy casting [4]. The casting defects can



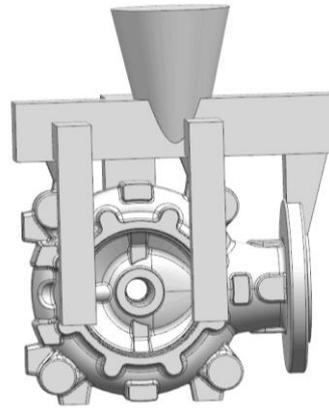
significantly be reduced through optimization of process parameters [5]. The casting CAE technology uses the finite analysis technology to carry on the mold filling process, the solidification process simulation. It can provide the powerful instruction for the formulation reasonable casting craft, is one kind of typical multi discipline frontier field.

## 2. Process design and analysis

The 3D structure of pump body is shown in Figure 1. From the whole point of view, the maximum height is 339mm. The maximum diameter of pump is 254mm. The thin wall thickness of the impeller is 3mm. The 304 stainless steel alloy was used to pour pump body by gravity casting in this study. The chemical composition is shown in Table 1. In order to ensure the smooth flow of metal liquid cavity, the initial setting time is 29s. Note the relationship of time to calculate the pouring speed for 233mm/s. The pouring temperature is 1560°C. The shell preheating temperature is 1000°C. The mold heat transfer coefficient is 1000W/m<sup>2</sup>K). The mold surface heat transfer method is air cooling. The original gating system was shown in Figure 2. The shell used in this study had a primary chemistry of 33 wt% mullite, 33 wt% silica (SiO<sub>2</sub>), 16 wt% zircon (ZrO<sub>2</sub>), and 18% alumina (Al<sub>2</sub>O<sub>3</sub>).



**Figure1.** The shapes of the complex pump



**Figure 2.** The original pouring system

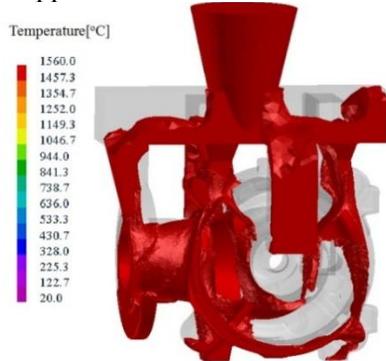
**Table 1.** Chemical composition of 304 stainless.

Elements	C	Si	Mn	Cr	Ni	P	Fe
Content (wt.%)	0.058	0.76	1.14	19	9	0.035	Bal.

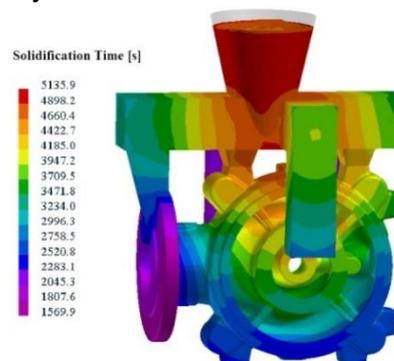
## 3. Numerical simulation and process optimization

The alloys melt flow path in the shell under gravity casting was shown in Figure 3, the filling time is 1.03s. The flow rate of the molten alloy is slow, and the side wall of the pump body is first filled with the melt. Then the alloys melt flow to the bottom of the pump. The liquid metal fill to the casting cavity from bottom to top, flow smoothly, have no obvious splash and turbulence. The simulation results prove that the design of gating system for existing riser is reasonable, the number and size of open meet the design requirements, can ensure the casting surface no obvious flow mark Cold insulation defect, light smooth surface. Figure 4 shows the overall solidification time of the casting. The solidification sequence of the casting is the outer flange of the pump body, the bottom and the upper part of the pump body. This is the final solidification sequence should be the ideal solidification sequence. The casting process can be achieved to the maximum extent feeding, so as to ensure the compactness of the product. Figure 5 is the solidification shrinkage defects after the casting solidification was finished. It is shown that the shrinkage mainly in the lateral sprue, runner cup. There is a little shrinkage at flange and the bottom of the. A large number of porosity was located at the thick wall part of the pump body. This part of melt is the last solidification which has no metal melt to feed. The shrinkage weight was 0.00167g and the porosity volume was 0.41cm<sup>3</sup> after quantitative calculation of the number of defects. It can be seen that the feeding effect of top pouring scheme is

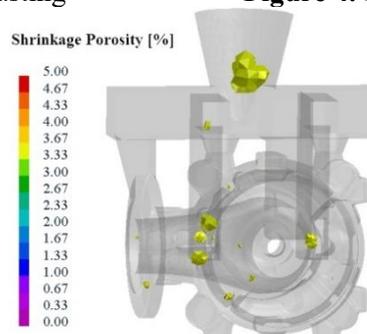
obvious poor through the numerical simulation for the structure of pump. A significant shrinkage defects will appear at the bottom and center of the pump body. So the scheme is not reasonable.



**Figure 3.** Filling field of casting

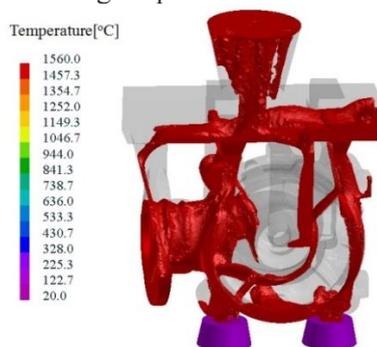


**Figure 4.** Solidification time of casting

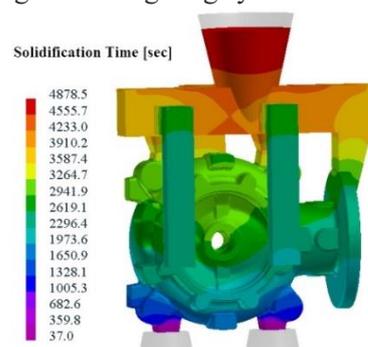


**Figure 5.** The predicted solidification shrinkage defects

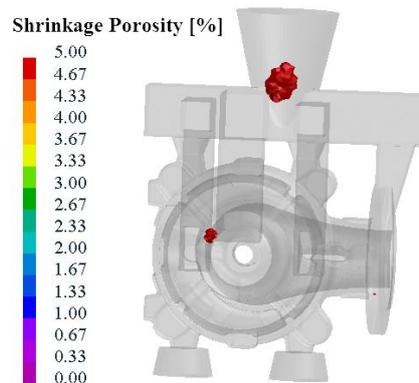
Because of the casting shrinkage was emerged at the bottom of pump, the improved design scheme was adding cold iron at the bottom, as shown in Figure 6. The casting pouring speed is 350mm/s, the alloy melt flow path is shown in Figure 6. The molten metal firstly flow from the cross runner to the outer flange. And then the shell was filling from both sides of the casting to the middle. Figure 7 is the solidification time map for the casting. As we can see that the first visible solidifying location in contact with the cold iron parts, the maximum coagulation time was shortened from 5136s to 4879s. The difference of cast solidification time was reduced. The final distribution of shrinkage porosity defect of the pump with the cold iron added is shown in Figure 8. There is only litter shrinkage in the body of the pump. Cold iron is set at the lower part of pump with the temperature is 25°C. The cooling rates were increased at the bottom part of the casting. The fastest temperature drop is no longer part of the outer flange and the outer part of the circle, but the bottom part of the casting, after the end of the filling time of 40s, the site has been basically completed solidification. The shrinkage weight was 0.0005g. The porosity volume was 0.41cm<sup>3</sup>. The filling process is stable, without the occurrence of turbulence, and the region prone to defects can get feeding from the gating system.



**Figure 6.** The optimized pouring system



**Figure 7.** Solidification time after modification



**Figure 8.** Prediction of porosity for investment casting products with cold iron.

#### 4. Conalusion

The numerical simulation software ProCAST is used to simulate the initial top gating process scheme, after analysis of the material and structure characteristics of the high-pressure pump. It can be seen that the feeding effect of top pouring scheme is obvious poor through the numerical simulation for the structure of pump. The shrinkage weight was 0.00167g and the porosity volume was 0.41cm<sup>3</sup> after quantitative calculation of the number of defects. For the bottom part of the casting was not feeding phenomenon, cold iron was added. The simulation results show that the modified scheme of solidification sequence is reasonable, which has good feeding effect. The shrinkage weight was reduced from 0.00167g to 0.0005g. The porosity volume was reduced from 1.39cm<sup>3</sup> to 0.41cm<sup>3</sup>. The experimental results show that the casting process simulation technology can optimize the scheme and process parameters based on ProCAST. The effective numerical method provides a reliable and scientific guidance for the casting production process.

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