Process Optimization of Water Chamber Based on Numerical Simulation

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ABSTRACT

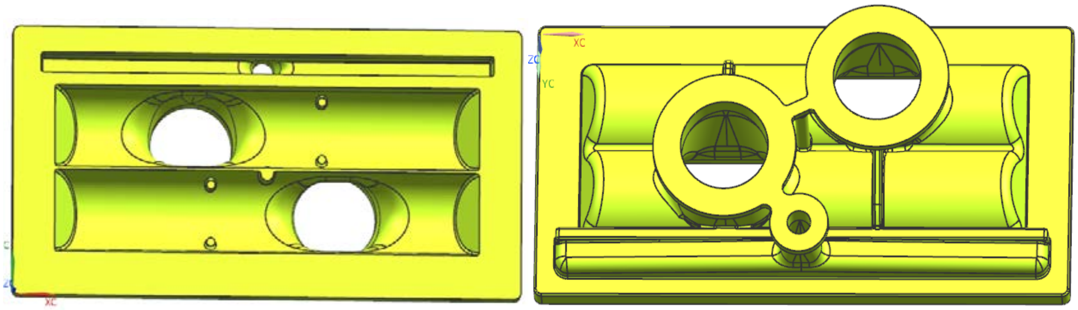
In order to prevent the formation of inclusion and pores in the water-chamber casting, numerical simulation was used to determine an optimized casting process based upon the characteristics of the water chamber. The structure of the water chamber was first analyzed and found to have complex structures with a large difference in wall thickness. The optimized casting process was designed after careful inspection of the defects within the original casting. A new gating system with incorporation of insulting risers, graphite chills, and ceramic filters was then used in the new casting process. Simulation was carried out and the result shows no defect was produced using the new gating system.

Keywords: Water-Chamber; Structural Analysis; Defect Analysis; Gating System Design; Numerical Simulation

1 INTRODUCTION

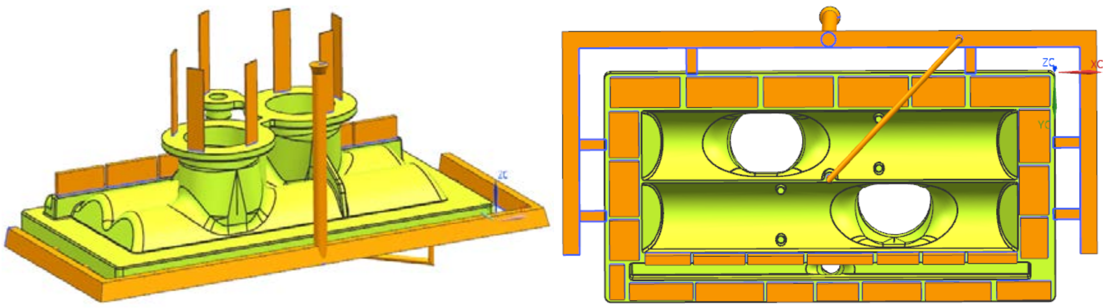
The casting process design is essential to the quality of the casting. At present traditional casting process is designed largely depending on the practical experience. However, when it comes to castings with complex structures, optimized gating systems are usually obtained based upon the casting practices and the cycle of the process is time consuming and usually high cost will be incurred. It is therefore very challenging to successfully produce large parts just with the traditional casting methods[1]. The emerging finite element method provides an easy and fast alternative to achieve the production of casting without defects. Various numerical simulation approaches or softwares in recent years were used to optimize the casting process in a very economical way and shorten the development time for an improved casting process[2].

Water-chamber is an important part of the air separation and its surface needs to withstand a certain pressure under working conditions. For the purpose of avoiding internal stress and casting deformation, the performance of different parts should be not too large. In particular, surface defects can not appear in order to avoid galvanic corrosion [3] and the compactness of casting is required in order to prevent leaking. The technical requirement for the casting is such that no cracks, shrinkage, cold shuts and other casting defects are present after magnetic and ultrasonic inspection. The geometry of the water chamber with dimension of 1600 mm × 930 ㎜ × 390 ㎜ is shown in Figure 1. The mass and the materials for the casting are 690 ㎏ and QT400-18 respectively.



Figs1 3D modeling of intermediate cabinet

2 ORIGINAL PROCESS



Figs.2 the original process

Tab1: Casting parameters of Water Chamber

Sprue		runner		ingate		Pouring temperature/^{0}C	Pouring time/s
Height /mm	diameter /mm	quantity/ind.	size/mm	quantity/ind.	size/mm		
300	60	1	40/50×65	6	40/44×9	1380	35
				1	φ25		

The gating system designed is shown in Figure 2. Ingates with multi-channel and a flattened structure were used to ensure the smooth filling of the liquid metal[4]. Sprue cross-sectional area and the ratio of each section were determined based upon the total mass of the casting according to the empirical formula. Since cold shuts are likely to be formed around the intermediate bottom rib with a small thickness, ingates of ceramics were employed to connect to this part. The utilization of the ceramics can help avoid the impurity during the filling process and produce casting with good quality[5]. Six flat outlets at the top of the flange were used to aid the discharge of the gas and reduce the pressure during the filling process. Cross-sectional area of the sprue of semi-enclosed gating system is less than the sum of the cross-sectional area of the runner, but greater than the sum of the cross-sectional area of the runner gating system, the erosion of the gating system is much smaller than the erosion of closed-gating system, slag effect of semi-enclosed gating system is better than the slag effect of opened-gating system, so this casting system is widely used in iron castings [6]. To prevent Shrinkage cold irons of HT200 are placed on the both sides of the thickest part.

3 CASTING QUALITY TESTING RESULTS AND ANALYSIS

The production test results based upon the original design indicates many defects are within the final casting, as shown by the magnetic test (Fig.3). The morphologies of the casting defects were examined by SEM and EDS and the results are shown in Figure 4.

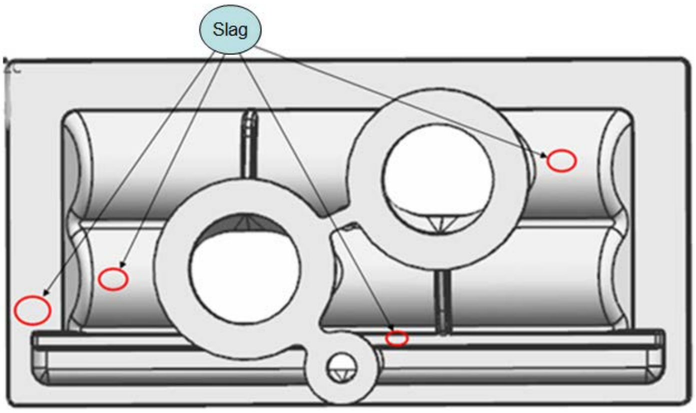
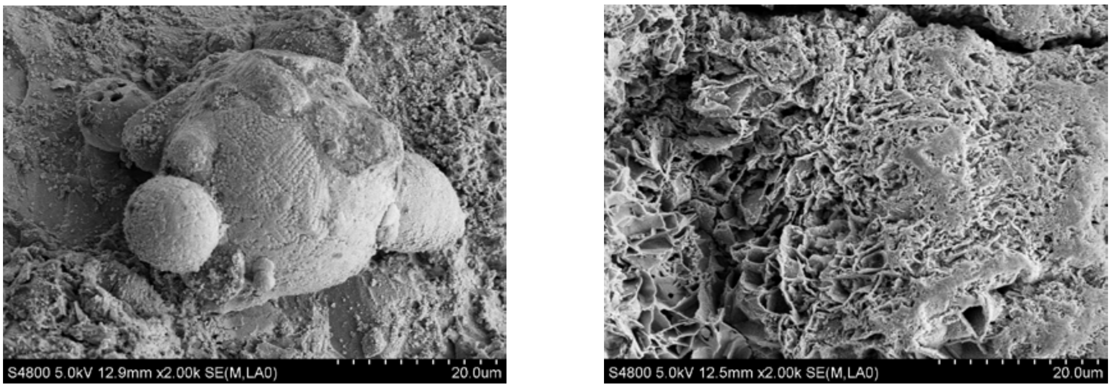


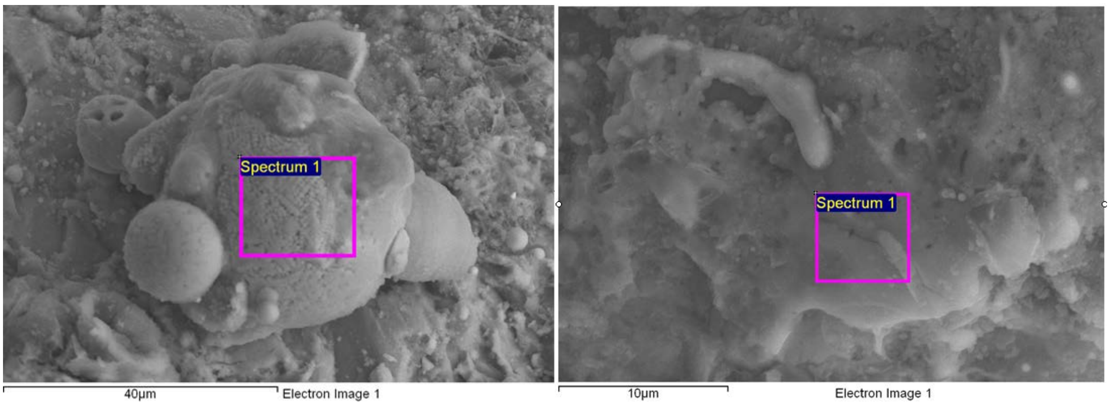
Fig.3 Magnetic Flaws map



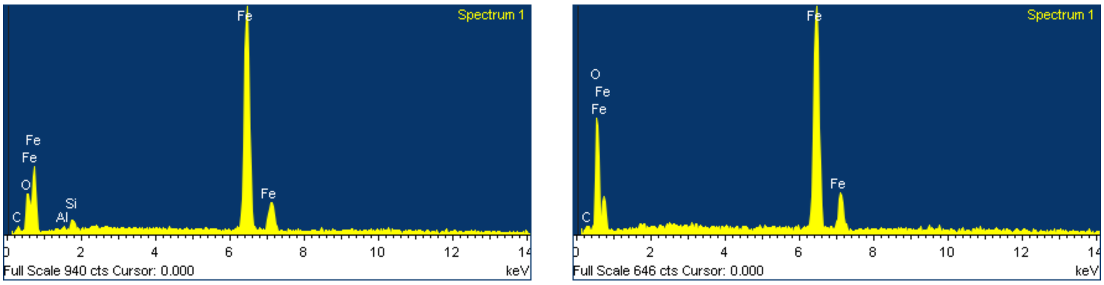
(a) (b)

Fig.4 Morphology of different parts of the defect

It is expected that turbulence would be likely to occur during the filling process and the liquid might encounter cold air inside the cavity, leading to the chilling of the liquid and formation of iron beans (Fig.4a) while insufficient feeding cause the shrinkage cavity during the late solidification (Fig.4b). A further analysis was made by EDS and the results are given in Figure 5 and Table 1. It can be observed that oxygen elements are found within the casting defects, implying oxidation takes place during the filling process. The oxidation is attributed to the occurrence of the turbulence which leads to the formation of slags within the casting[7]. Inclusions or slags can also be affected by some chilling areas, where rapid cooling prevents them from flowing up to the risers[8].



（a） (b)



(c) (d)

Fig.5 Microanalysis defect site and Element content distribution

Tab2: the average content of the casting defect sites

elements	C	O	AL	S	P	Si	Mg
Contents (wt %)	3.6	11.78	0.77	0.012	0.047	1.51	0.4

Tab3: Casting element content range

elements	C	Si	Mn	S	P	Mg	RE
Contents (wt %)	3.45~3.64	2.47~3.00	0.45~0.57	0.012	0.047	0.3~0.5	0.1~0.25

4 NEW PROCESSES AND SIMULATION

Based upon the analysis of the original process, new design has been made. A open-gating system was utilized to increase the cross-sectional area and reduce the inflow of molten iron. The gate was opened only on one side to avoid a collision of molten iron inside. The position and orientation of the ingate were carefully selected to ensure a stable filling process. Filters of ceramic foam were used to prevent slags from entering and live risers were employed to facilitate feeding and discharge the gas. The size of the rises was determined by calculating the effective modulus. Graphite chills were placed on hot spots to help cool the molten iron and shift the defects to desired positions[9].

The three-dimensional model of the casting and the gating system designed was shown in Figure 6. After the gating system is designed, the simulation work was carried out to assess the quality of the casting.

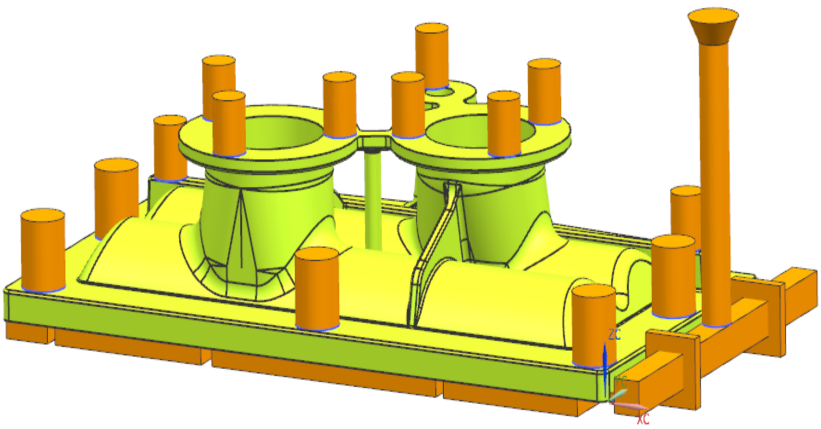
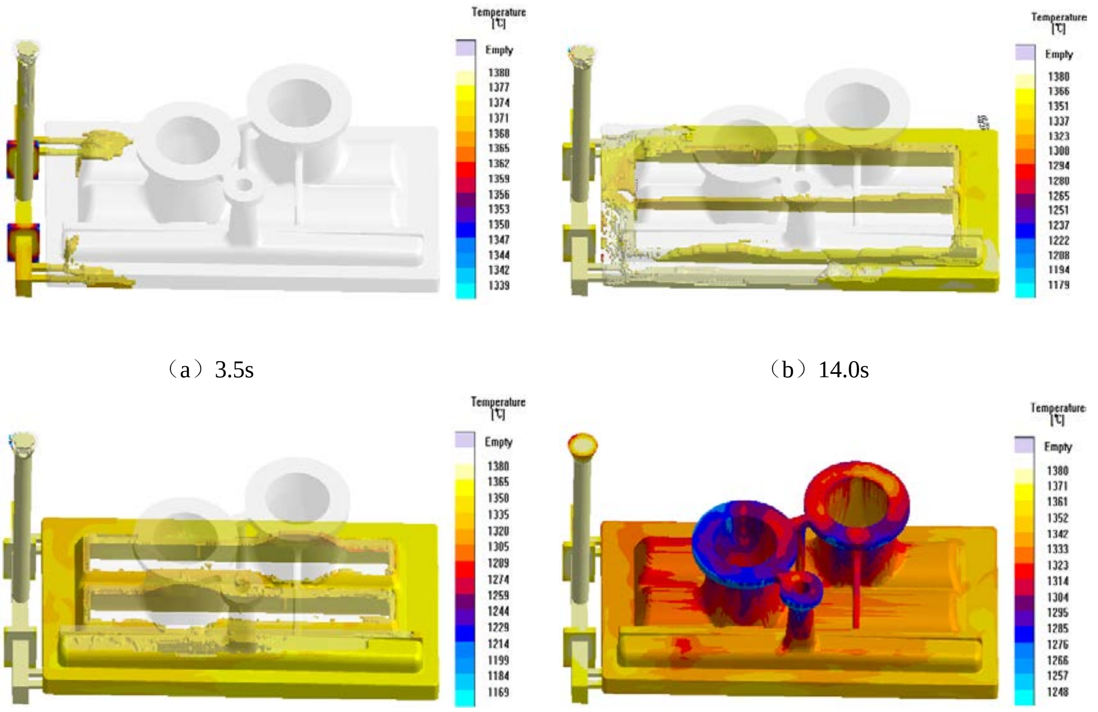


Fig.6 the new process

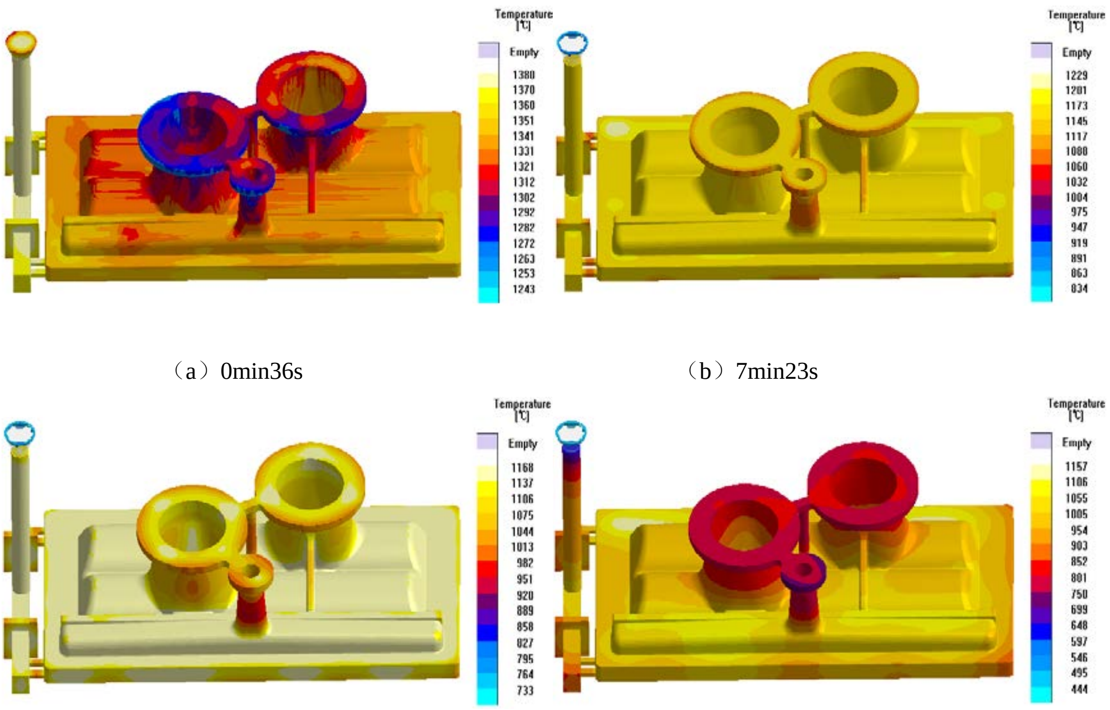
The three-dimensional model of castings and gating system are exported in STL format, adjust the position, and then sequentially introduced into MAGMASOFT software for data definition and meshing. Afterwards, processing parameters are set. In particular, the casting pouring temperature is set to be 1380℃. The filling process is shown in Fig.7. It can be seen that metallic liquid fills the runners slowly and smoothly and the temperature is uniformly distributed. In addition, no turbulence is noted, indicating the design is reasonable. The solidification process is shown in Figure 8. Even temperature distribution is noticed during the solidification process.



（a）3.5s （b）14.0s

（c）24.5s （d）35.0s

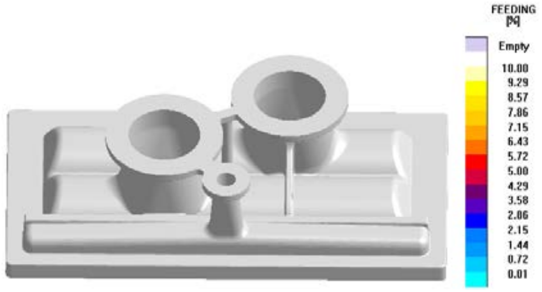
Fig.7 filling process of the casting process



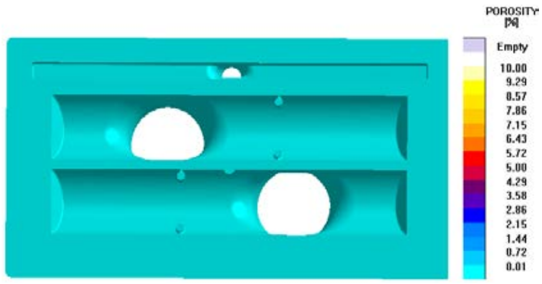
（a）0min36s （b）7min23s

（c）13min16s （d）48min49s

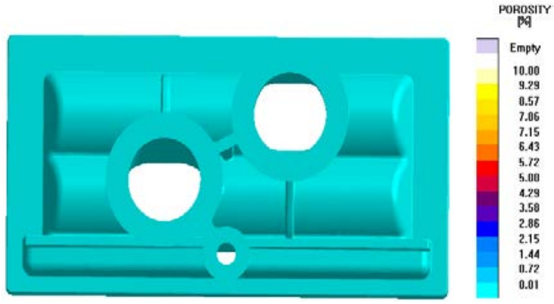
Fig.8 the solidification process of the casting



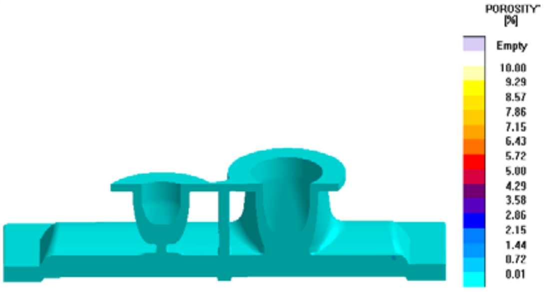
（a）Feeding criterion



（b）Porosity



（c）Flanges internal defects



（d）internal defects

Fig.9 Shrinkage criterion

Feeding criterion is given in Fig.9. It can be seen that overall casting feeding effect is very good and shrinkage cavities do not exist in the casting surface and the internal. The results indicate use of the design gating system and the pouring temperature of 1380℃ can produce castings with improved quality.

5 CONCLUSIONS

In present study, an optimized gating system is designed and the simulation was later carried out to assess the casting process. It is found the new gating system avoids the occurrence of the turbulence and lead to a even temperature distribution during the casting process. No slag or shrinkage defect was found in the final casting, indicating the new gating system is of a reasonable design.

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