Simulation and Optimization for Investment Casting of Impeller Based on 3D Printing

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Abstract. Impeller is characterized by complex curved face and extended application environment which cause traditional manufacture methods are unable to satisfy the high requirements for it. Thus investment casting is widely used for manufacturing the impeller on account of the high-accuracy of surface and dimension. Meanwhile, application of 3D printing in casting has been proved for promoting the efficiency. In this paper, the gating system for casting is numerical simulated by software AnyCasting. As the result, side injection system is selected for its smooth filling of the casting cavity and less shrinkage porosity. In the process of manufacture, 3D printing of PLA impeller role is utilized as the rapid tooling(RT) to make excellent castings proceed from effective and economical consideration.

1. Introduction
Investment casting, also called lost-wax casting or precision casting, which is defined as a casting technology that creating the casing made from formed wax patterns which is surrounded by the ceramics. Then wax patterns will be melted and be poured out through the gating system. Finally the cavity will be filled by melted metal again[1]. High dimensional accuracy, excellent surface finish, complicated sharp allowed, flexible production management are the advantages of investment casting, as well as investment casting is unlimited to almost all types of metals including light alloy which is difficult for mechanical treatment[2,5]. Consequently, this technology has been wildly used in producing casting in automotive industry, aircraft, military and medical instruments, etc[5].

The process of investment casting are, firstly making wax model and wax gating system respectively. Then assemble them together. After dipping the assembly into ceramic and dewaxing, the wax pattern is replaced by the metal. Finally, additional machine and heating treatment may be required depend on the condition. However, the more intricate wax models are, the longer period of production and more cost are needed[3]. Except the wax, diverse type of material can be used to make the patterns. Furthermore, the 3D printing is proposed to be applied in the casting.

In order to get the optimized impeller investment casting, gating system is decided depend on CAE analysis results[5]. Top gating system, bottom gating system and side gating system are carried on the simulation by the finite analysis software AnyCasting. At the end of this paper, the properties of different gating system will be illustrated and the best gating system will be chosen to make the reality manufacture using aluminium alloy ZL104. Ploylactic acid(PLA) is chosen as the material for 3D printing as the wax model.
2. Methodology

As is shown in figure 1, the diameter of the impeller is 60mm, thickness of blades are 2mm. The sharp for each blade is anomalous for pushing the fluid. The forming of casting will be influenced by the unstable filling of metal. The mechanical properties and strength will be weakened if exist the defects, such as shrinkage defects and gas porosity. As the CAE analysis can offer the conclusions for production[4], consequently, it is essential to experience CAE analysis for arranging reasonable gating system.

![Image of the impeller model](image1)

**Fig.1.** The model for the impeller, including the Pro/E model (a) and 3D printing model (b).

As one of the practical finite element software, AnyCasting is used for simulating casting effect[5]. Top gating system, bottom gating system and side gating system are compared to avoid the appearance of shrinkage defects and gas porosity. Combined defect parameter and probabilistic defect parameter are two parameters to show the integrity of casting. As is shown in Figure 2, the account of flexible finite elements is 50616. The parameters for simulation are listed in the Table 1.

![Meshing of model with top gating system](image2)

**Fig.2.** Meshing of model with top gating system.

With the design for gating system, the whole model, including the casting and gating system will be printed with PLA. The process of investment casting will be experienced until the impeller made in ZL104 is accepted for proof the effect of simulation. Plaster model is used for its properties that low coefficient of heat conductivity, well fluidity and high accuracy for making model and temperature for filling is 750°C.

| Shell mold | During filling | During filling velocity(cm/s) | Heating insulating material |
|------------|----------------|-----------------------------|---------------------------|

*Table 1. Parameters for simulation*
3. Results and discuss

3.1 Analysis of gating system

The Figure 3 shows the result of the top gating system. It is clear that during the filling period, the liquid level is uneven, which means the appearance of turbulence. The combined defect parameter analysis exhibits the occurrence of defect. Meanwhile, as is observed in figure 3 (c), the shrinkage defect mainly presents in the metal in gating system according to the retained melt modulus, thus the integrity of casting is well.

![Filling Sequence](image1)

![Combined Defect Parameter](image2)

![Proportional Defect Parameter](image3)

Fig.3. Results of simulation, filling sequence (a) is added for prove the uneven of liquid, as well as combined defect parameter (b) shows the defect in the red round. (c) means the retained melt modulus, which reacts the possibility of shrinkage.

When it moved to the side gating system shown in figure 4, the combined defect parameter for any part of the casting is located in the safe range, which proved that there is low probability of defect. Another decisive parameter also certifies no shrinkage.
Fig. 4. The results of simulation with side gating system. Combined defect parameter (a) all painted in blue shows safe and perfect filling without defect and there is no shrinkage according to probabilistic defect parameter (b).

The result of bottom gating system is expressed in the Figure 5. Compare with other two methods, it is clear for the phenomena of defect in figure 5. As well as the obvious shrinkages occur near the bottom corner.

Fig.5. The results of simulation with bottom gating system that purpose parts shows the combined defect parameter (a) while the white part which means probabilistic defect is seen in (b).

To sum up, as the side gating system is obviously perfect with no defects and shrinkages compared with other two simulations, side gating system is finally selected as the conclusion.

3.2 Experiment and confirmation
The complete model is printed by the 3D printer by PLA, a wildly used material for investment casting as the figure 7(a). Mixing the water into plaster with proportion 100:46(plaster: water). Dipping the PLA model into wet plaster like the figure 7(b). After drying 2 hours for getting the plaster mold, the
plaster mold is heated at the temperature 600°C for 1 hour, then arise the temperature into 750°C for 2 hours, which is called dewax as Figure 7(c). After this process, the PLA model will be burned. Finally the melted ZL104 is poured into the plaster model (shown in figure 7(d)). The impeller is presented in figure 7(e) with not only vivid sharp and good quality of surface, but also with no defect and shrinkages.

Fig. 6. The Process of investment casting of impeller.

4. Conclusions
In summary, process of investment is experienced for production the impeller. Technology for casting impeller is improved with the assistant of 3D printing and AnyCasting software. The main results are below.
(1). Side gating system is best solution for reduce the appearance of defects and shrinkages compared with top and bottom gating system in this case.

(2). Application of 3D printing in the investment casting reduce the time of manufacturing assemble wax model. Furthermore, the excellent quality of casting without defects and shrinkages is the proof that 3D printing is valuable in investment casting.

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