Research for Process on Investment Casting of Impeller Based on 3D Printing

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Abstract. Impellers are widely selected as the research object for its characters of curved surface and high-demanded surface quality. The investment casting of alloy ZL104 impeller with PLA 3D printed pattern is performed. In order to optimizing the process of impeller, CAE analysis software AnyCasting is carried on for the design of gating system. The cross-sharp side gating system is selected as the outstanding one for none defects and uniform filling process. Moreover, the gating system with four uniform distributing risers is established as the prime solution. All the conclusions is checked in the reality experiments that investment casting based on 3D printing, with association of CAE simulation can promote the production efficiency.

1. Introduction

Impeller, as a necessary part in many machines, whose materials range from plastic to metal, according to the working environments. Technique processes of alloy impeller manufacture are welding and casting, but the mechanical properties of former could not satisfied the demands in extended environments[9]. So the casting of impeller is valuable to research[1], especially the impellers with thick blade and complex curved surface.

Investment casting, which is defined as precision casting for its using wax patterns dipped into ceramics to producing the mode cavity. It is characters for the ability that producing castings with smooth surface and high accuracy of expected size[1,3]. Moreover, its excellent adaptability to complex sharp of patterns makes the investment casting becoming the preference for alloy impeller fabrication[4]. Furthermore, as the wax mode manufacture is proofed for its longer time consuming when making assembly mode[2], 3D printing for producing patterns attracts many attention for discussing the probabilities of it[3,5,9].

The detail size of the impeller is shown as Figure 1. Alloy ZL104 is planned as the cast material and PLA is used for 3D printing pattern. Outside diameter of the impeller is 60mm while height of center ring is 8.7mm. Meanwhile, thickness of the blade is decided as 2mm according to the Table 1[1]. The distorting blade will leads to fault casting in forms of shrinkage defects and gas porosity[8]. Thus setting the reasonable process by simulation is necessary.
In this paper, gating systems will be focused. Using CAE analysis software to illustrating the results of top gating system, bottom gating system and two side gating systems. Furthermore, with the assistance of CAE analysis, the gating system will be optimized and the best project of CAE simulation will be practiced.

2. Methodology

Before the practice of manufacture, AnyCasting is applied for design of gating system. The parameters of process are chosen depend on reality fabricate condition of workshop. Thus the results of production will only due to the management of different gating system.

2.1. Modelling

The 3D model is generated according to the setting of size in figure 2. Then the model that including four types of gating system are created. Top gating system, bottom gating system and 2 types of side gating system are added to the impeller as Figure 3.

| Casting Dimensions (mm) | Thickness Range (mm) | Min. | 2.0~2.5 | 2.5~4.0 | 3.0~5.0 | 3.5~6.0 | 5.0~7.0 |
|-------------------------|----------------------|------|---------|---------|---------|---------|---------|
| 10~50                   |                      | 1.5  | 2.0     | 2.5     | 3.0     | 4.0     |         |
| 50~100                  |                      |      |         |         |         |         |         |
| 100~200                 |                      |      |         |         |         |         |         |
| 200~300                 |                      |      |         |         |         |         |         |
| >350                    |                      |      |         |         |         |         |         |

Figure 1. The geometrical dimensions of impeller.
2.2. Simulation of gating system

The software Anycasting bears the simulation. The mesh are created in the preprocessing module called AnyPRE. Taking the top gating system as the example, the account of flexible finite elements is 103488 in Figure 4. Setting the case as the filling analysis and solidification analysis, then the results of preprocessing are saved for later treatments. Solver module is used for calculating the results, as the results will be displayed as image by post-processing module. More settings are as bellowed Table 2.

Combined defected parameter and probabilistic defect parameter are two evidences that for determining the filling results[7].

Figure 3. Four gating system of impeller. Top gating system(a), bottom gating system(b), liner-sharp side gating system(c) and cross-sharp side gating system(d).

Figure 4. Meshing of model with top gating system.
Table 2. Setting process parameters.

| Parameter                  | Method | Casting material          | Casting Temperature | Pre-heated Temperature | Casting Velocity |
|----------------------------|--------|---------------------------|---------------------|------------------------|------------------|
| Value                      | Metal  | AC4C Aluminum Alloy      | 750℃                | 750℃                   | 25cm/s           |

2.3. Reality experiments

After the optimization of gating system, the selected solution will be printed for application in reality experiment. Material for 3D printing is PLA and the final forming metal is ZL104 which the temperature for casting is 750℃. Thermo stability plaster is employed as the material of casting shell due to its advanced liquidity, low thermo conductivity and high accuracy in re-model.

3. Results and discussion

3.1. Filling results of simulation

The results of top gating system are shown in Figure 5. The Fig explains the state of metal fluid that arrive the vault of mode cavity in 1.6sec. On account of the fluid dropping into the cavity directly, speed of fluid is fast as purple area. Thus the surface of fluid is unsmooth which means the appearance of turbulence. The final results of filling can be explained by Figure 5(b) and Figure 5(c). The combined defect parameter analyses the possibility of defect while the probabilistic defect parameter proof that the shrinkage defects and gas porosity will occur between the gating system and the impeller like the zone printed in yellow.

![Figure 5](image)

Figure 5. Results of top gating system. Filling time(a) illustrate the uneven of liquid. Combined defect parameter(b) and Probabilities defect parameter(c) show the location of shrinkage defects or gas porosity.

In bottom gating system, the metal fluid is poured through the bottom of cavity. The solidification time is shown as Figure 6, which means that the solidification of impeller is in an orderless situation. Many defects located in the blades according to the combined defect parameter. Moreover, like the top gating system , the shrinkage defects and gas porosity stay in the similar place. The reason of defect is suspected to be the high speed of filling, which leading to a phenomena that not all the gas escape through the riser on time.
Figure 6. The solidification (a) of model with bottom gating system is unsymmetrical, and the combined defect (b) appears on the blade. Probabilistic defect (c) is forecasted.

The results of linear-sharp side gating system is shown in Figure 7, which indicate that the quality of casting is satisfying and all the defects are inside the gating system that will not affect the impeller.

Figure 7. The solidification (a) is equality, compare with the formers. Defects (b)(c) happens in the gating system.

The same thing also happens in cross-sharp side gating system. As the Figure 8. All the filling and solidification are stable, and effect-free defects in gating system and shrinkage defects in risers, the advance of side gating system is obvious.

However, the solidification in cross-sharp gating system is more stable. As well as defect range in cross-sharp is smaller than the other. So it is worth for further improvements of cross-sharp gating system. The last solidification in cross-sharp gating system is zone in yellow like Figure 8(a), but this area is far away from the riser. This state indicate that the managements of risers can be performed.

Figure 8. The results of model with cross-sharp side gating system. The defects (b)(c) will not affect the casting but the only disadvantage is unstable solidification (a).

The Figure 9 describes the solidifications sequence of mould with more risers. The white zone means the part that solidified lastly. Only in the Figure 9(d), all the white area located in the flow
channel, which means the well sequence of solidification. Therefore, the best solution of gating system is cross-sharp side gating system with four risers.

![Solidification Sequence](image)

(a) ![Solidification Sequence](image) (b) (c) ![Solidification Sequence](image) (d)

Figure 9. The results that solidification of model with different number of risers.

### 3.2 Experiment and confirmation

Mix the thermo stability plaster with water as proportion 100:46 and paint the plaster onto the 3D printed mould. Put it into the casting mold when the plaster is dried. Airing the whole mold for 3 hours and heating them in 400°C for 15min then 600°C for 30min. Make sure that the PLA mould is burned. Finally pour the ZL104 into the mold.

The casting is displayed as Figure 10(e). The impeller is not only full filled with clear appearance, but without any defects. The post machining are cutting the gating system and milling the impellers. The final impeller is in Figure 10(f).
Figure 10. The process of manufacture. The 3D printed model (a) is used as the pattern in the casting shaft (b), after the heating (c) the PLA model is disappeared and pour the ZL104 inside (d). The whole casting (e) is milled for the part (f).

4. Conclusions
In summary, application of 3D printing mold in investment casting is experienced. The CAE analysis for advanced process of impeller is made and proved. In addition, the CAE analysis is also used for further improvements of solutions. The results are bellow.

(1). The 3D printed mold can produce the qualified casting with excellent surface qualification and accurate size.

(2). Cross-sharp side gating system is the best method for investment casting of impeller. On account of its ordered solidification sequence and stable fluid speed.

(3). Increasing the amount of risers can improve the effect of filling in impeller. In this case, four risers are the best way.

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