The Study of Titanium Alloy Precision Casting Turbine Blades Based On Procast

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Abstract. The software ProCAST which is based the Finite Elements Method is used to simulate the process of TiAl casting. Ti-47Al-2Cr-2Nb alloys will be used in the casting. As a result, we have known the characteristic of the alloys, flowage and solidification, and we also have forecast the quantity and distributing of defect in the casting.

1. Introduction
With the continuous development of aerospace industry, the requirement for material properties is higher and higher. TiAl alloy is considered as a material with great potential for development because of its low density, high specific strength, non-magnetic, high melting point, low thermal expansion coefficient and strong corrosion resistance and oxidation resistance [1-2]. The main processing methods of TiAl alloys are casting, forging and powder metallurgy, among which precision casting is considered to be the most successful and widely used near-final processing technology of TiAl alloys. However, TiAl alloys are prone to defects such as shrinkage porosity and porosity in casting process because of their high melting point, low melting superheat and poor liquidity of alloy solution, and because of their low density, difficulty in gravity feeding and strong growth trend of columnar crystals [3-6]. In this paper, the flow field and temperature field of TiAl alloy during filling and solidification process are simulated by commercial casting simulation finite element software ProCAST, and the shrinkage defects are predicted. The results are compared with the actual casting results. The results show that the process optimized by simulation can effectively guide actual production, improve product quality and reduce casting defects.

2. Test Method
Pro-Egineer software is used to model the blade entity, and the three-dimensional files of Pro-Egineer modeling are exported to IGS files. Then mesh cast, the mesh generation tool of Pro-CAST, is used to read and divide the surface grids. The finite element model is shown in Figure 1. According to the thickness of different parts of the blade, the nonuniform surface mesh is used. The edge length of the surface mesh at the wall thickness is 2.2 mm, and the edge length of the surface mesh at the wall thickness is 0.8 mm, so as to ensure that there are at least two meshes at the thinnest part of the castings. At the same time, the “SHELL” command of Mesh cast automatically generates a 15 mm thick die shell. Subsequently, volume meshes are generated, the total number of meshes is 354263, and then the volume meshes are checked and optimized. After that, the pre-processing program includes the setting of geometry (including symmetry, virtual die, checking geometry), material distribution, heat transfer coefficient between material surfaces, boundary conditions and operation parameters.
The thermophysical parameters used for casting and shell materials are as follows:

TiAl alloy: density 3.9g/cm$^3$, specific heat 400-1000 kJ/kg $^\circ$C, heat conductivity 12-53W/m $^\circ$C, latent heat 375kJ/kg, liquidus 1522$^\circ$C, solid phase 1457$^\circ$C, initial temperature 25$^\circ$C.

Mold shell material: density 2.78 kg/cm$^3$, specific heat 440-850 kJ/kg $^\circ$C, heat conductivity 0.97 W/m $^\circ$C, initial temperature 25$^\circ$C.

The composition of Ti-47Al-2Cr-2Nb in this study is Ti-47Al-2Cr-2Nb. By mixing raw materials, vacuum induction melting (Y2O3 crucible) method is used to melt the Ti-47Al-2Cr-2Nb. Four blades with a weight of 300 g were designed and cast. Titanium and aluminium are easy to be oxidized, so it is necessary to remove the oxide layer by surface polishing before weighing, and then add the weighed material to acetone solvent and place it in the ultrasonic cleaning instrument for cleaning, so as to remove the oil contamination and other impurities attached to the material. At the same time, in order to ensure the removal of moisture in the material, it is also necessary to put the cleaned material into the resistance oven for drying.
3. Analysis of simulation results

3.1. Simulation results and analysis of filling process

The simulation results of filling process of Ti-Al alloy are shown in Fig. 2. The filling characteristics of the alloy are analyzed.

In Fig. 3, a, b, c and d are filled with t=0.69s, 1.57s, 2.11s and 2.5s respectively. From the analysis of filling simulation results, it is concluded that after the liquid metal enters the sprue, the crown of the blade is filled first, and the liquid metal enters the blade body. Because the cross-section area of the blade is very small, the flow rate of the liquid metal into the blade body is less than that into the sprue, so the liquid level in the sprue rises. When the liquid metal fills the blade crown, cooling begins at the corner of the blade tip. When the metal liquid fills the die shell at 2.58 s, the blade tip has been partially solidified. At the same time, the root of the blade is partly solidified. It is also found that the preheating temperature of the shell has a great influence on the flow of liquid. Generally speaking, the higher the casting temperature is, the better the flow of liquid metal and the shorter the filling time.

TiAl alloy liquid metal filling under gravity has poor fluidity, and filling speed slows down obviously at the thin-walled position and tip of blade, which is prone to defects such as insufficient pouring. Turbulence also occurs when the liquid metal reaches the bottom of the shell and backfills in the opposite direction. Therefore, shrinkage and stomatal defects are easy to occur at the center line and tip of the blade. The defects such as shrinkage and porosity will be alleviated at the position near the riser due to the sufficient metal liquid supplement at the upper blade crown.

3.2. Simulation results and analysis of solidification process

Fig. 3 is the simulation result of the solidification process. The analysis shows that the thin-walled section of the blade begins to solidify first, and the solid-liquid interface advances from the thin-walled end to the center. Because there is a wall thickness in the crown and root of the blade, the solidification speed of the adjacent region slows down, and the heat dissipation in the middle of the blade is difficult, and the cooling speed is the slowest. Because of the existence of a straight runner in the blade canopy, the hot spot will be compensated, while the bottom of the blade will not, so shrinkage holes will occur. Locations A and B (Fig. 3c) are the hot spot locations of the blades. At the same time, the local hot spot locations also exist (Fig. b, c) because the blade body can not completely uniformly heat dissipation and meshing. The solid-liquid interface presents an irregular curve. These reasons lead to shrinkage and loosening of blade body.
In Fig 4, a, b, c and d solidify at t = 0.25s, 3.34s, 5.23s and 6.73s, respectively. Because the blade is thinner, it is easy to produce edge effect. Often the thin wall of the blade and the tip of the blade far from the gate solidify first. If there is no external temperature gradient, the liquid solidifies under the condition of its own temperature gradient, its solid-liquid interface curve will be very sharp, that is, the expansion angle of the feeding is very small, and it is easy to block the metal feeding channel. If a longitudinal temperature gradient is applied to the shell, the tendency of solidification of the alloy liquid from the tip of the blade far away from the gate riser will increase, and sequential solidification will be realized. As a result, the curve of the solid-liquid interface becomes blunt, that is, the expansion angle of the feeding increases, which is beneficial to the feeding of the liquid metal and reduces the shrinkage defects [7].

From the simulation results of solidification solid fraction, it is more intuitive to show the mechanism of shrinkage and porosity of castings. During the solidification process, the solid fraction decreases gradually from the thin-walled edge of the blade and the tip of the blade to the center of the blade. The solid fraction at the tip of blade with t = 6.23s reached 0.93 at the die shell temperature of 30°C, while it was only 0.73 near the center line of blade and 0.46 at the gate and riser. So the final solidified area often produces defects.

3.3. Simulation results of the effect of shell temperature on solidification process

The solidification process of liquid metal at different shell temperatures is simulated. The simulation results are shown in Fig. 4. a is the solidification of shell temperature T = 30°C and time T = 4.59s, b is the solidification of the shell temperature T = 700°C and time T = 6.66s. The temperature gradient of the die shell is 40°C/cm, and the solidification time is 4.59s, d is the temperature gradient of the die shell at 40°C/cm, and the bottom of the die shell is lined with copper plate, and the solidification time t = 6.66s. Because the casting is thin, the solidification is very fast. When the die shell is at room temperature, the blade body solidifies completely at 9.8s. The complete solidification time of leaves was prolonged to 18 s when the shell temperature was increased to 700°C. At the same solid fraction, the solid-liquid interface morphology of blade blades of castings with different shell temperature and shell temperature gradient did not change significantly, and the expansion angle did not expand significantly.
3.4. Prediction of Shrinkage and Porosity Defects in Castings

In Fig.5, a shows that the temperature of the die shell is 30 °C; b shows that the die shell is preheated to 700 °C; and c shows the temperature gradient of the die shell belt. From the results of numerical simulation, the shrinkage and porosity of castings are mainly distributed on the central line near the thick wall part of the blade. By comparing and analyzing the number of defects under different shell temperature conditions, it can be found that the addition of a longitudinal temperature gradient does not significantly reduce the defects. The defect is slightly improved when the bottom of the die shell is padded with copper plate. Therefore, in the casting process of thin-walled blades, the temperature gradient has little significance to reduce shrinkage and porosity.

The defect distributes along the center line of the thick wall side of the blade, mainly because the center line of the casting is mostly in the hot spot position. The temperature at this position is relatively high, the cooling rate is relatively slow, and it often solidifies at last. It is easy to produce defects such as shrinkage cavity and porosity due to insufficient liquid metal feeding during solidification [8].

4. Test result

According to the technological parameters of the simulation process, Y2O3 mold shell was poured into the vacuum induction furnace, and the blades shown in Fig. 6 (a) were obtained. It can be seen that the casting fills well, the surface is relatively flat, there is no flash burr, no shrinkage hole. X-ray non-destructive testing was used to detect the shrinkage and porosity of blades, and the content and distribution of shrinkage and porosity were observed by photography. The negative is shown in Figure 6 (b). The film analysis shows that the shrinkage porosity of blade castings mainly distributes along the central line near the thick wall, and the tip and thin wall central line are more serious. The experimental results are consistent with the simulation.
5. Conclusion
(1) Under vacuum condition, the liquid titanium alloy is well-filled, and the blade with smooth surface and no burr can be obtained. In the thin-walled position of the blade and away from the riser, the solid-liquid interface curve will be very sharp, the expansion angle of feeding is very small, and the metal feeding channel will be easily blocked.
(2) Shrinkage and porosity of castings are mainly distributed on the central line of the blade near the thick wall part. The temperature of this position is relatively high, the cooling rate is relatively slow, and it often solidifies at last. The defects such as shrinkage and porosity are easily formed due to insufficient liquid metal feeding during solidification.

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