Investment Casting Simulation and Analysis of Shell AlSi11 Alloy Part

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Abstract. Shell investment casting of AlSi11 alloy was stimulated in this paper. The shell model of AlSi11 alloy casting was established using UG three-dimensional drawing software, and the solidification process of the inner material of the shell was numerically simulated based on the ProCAST software. The final analysis shows that the entire solidification process is solidified layer by layer, and the filling time of the material inside the shell is 14.70 s. After solidification and cooling, the shrinkage volume of the internal defects of the material is 7.80 square centimeters, the average shrinkage rate is 17.90%, and the pore volume is 1.70 square centimeters. Through the simulation and analysis of the solidification process, not only can we find out the shrinkage cavities generated in the solidification process, but also can effectively reduce production costs and improve efficiency.

Keywords: AlSi11 alloy; Shrinkage rate; Solidification process; Investment casting

1. Introduction

AlSi11 alloy is a eutectic alloy, and Si is one of the most important elements that make the aluminum alloy have good casting properties [1]. AlSi11 alloy has excellent processability, thermoplasticity and extrudability, as well as good corrosion resistance and toughness. The surface finish after processing is high, and the anode is easy to oxidize and color. Because AlSi11 alloy has the above advantages, it is widely used in building profiles, irrigation pipes, furniture, elevators, etc.

Traditional casting production is mainly based on the experience of casting designers to design the production process, which makes the trial production cycle of casting products longer, higher production costs, lower efficiency, and cannot guarantee the quality of casting [2]. With the continuous development of informatization, in order to solve the problems of long trial production cycle, high production cost and low efficiency, domestic and foreign foundry simulation software has begun to be researched, there are mainly Magma from Germany, ProCast from the United States, FT-STAR from Tsinghua University, InterCAST/Huazhu CAE from Huazhong University of Science and Technology and other software. These softwares can not only optimize the casting process and ensure the quality of castings, but also shorten the product trial production cycle, reduce production costs, and improve efficiency [3].

ProCAST software is suitable for a variety of casting processes, including investment casting, sand casting, lost foam casting, high-pressure casting, low-pressure casting, etc., and it can perform casting simulation for a variety of materials [4]. Jia Lu et al. [5] used the centrifugal casting method in the
ProCAST software to simulate the casting of 42CrMo rings and determined that the casting temperature was 1520°C and the mold ejection temperature was 1050°C. Li Yunshuai et al. [6] used ProCAST software to numerically simulate the filling and solidification process of magnesium alloy wheels. The simulation results show that the increase of the riser and the external cooling iron can help reduce the shrinkage cavity and porosity defects in the casting process, and improve the quality of the castings. Jia Xianzhen et al. [7] used ProCAST software to numerically simulate the solidification process of RHT explosives, and compared with the test results to verify that ProCAST software can accurately calculate the location of internal defects during the solidification of molten cast explosives, which can be used for the simulation design of molten cast explosives. Sun Xinhuan et al. [8] used ProCAST software to numerically simulate the solidification process of modified B explosive, they found that ProCAST software can simulate the overall solidification process of the explosive. Cui Xinpeng et al. [9] simulated the stress of the titanium alloy skeleton based on the ProCAST software. The simulation results showed that the casting will produce stress when it is cooled in the shell, and the residual stress will be formed after the shell is removed. Due to its own shrinkage and the hindrance of the mold shell, the corners of the periphery of the casting are the parts with the largest residual stress. Verify the accuracy of the simulation results. Su-Ling Lu et al. [10] performed centrifugal casting on the wet cylinder liner (WTCL) model based on ProCAST software, and optimized the casting process through simulation results. Results show that the simulated temperature field is in accordance with the actual process and the casting defects appear in the final solidification zone and inside the sub-surface near the thick-wall side.

2. Composition Analysis and Alloy Phase Diagram of Casting Material

2.1. Casting Material Composition

The casting material is AlSi11 alloy (EN AC 44000). The relevant information of this material can be found in the ProCAST software material library. Its chemical composition and mass fraction are shown in table 1.

| Element | Si  | Mg  | Ti  | Fe  | Mn  | Cu  | Zn  | Al    |
|---------|-----|-----|-----|-----|-----|-----|-----|-------|
| Content | 11  | 0.25| 0.2 | 0.1 | 0.1 | 0.05| 0.05| Balance|

3. Simulation and Emulation of Material Solidification Process

3.1. Establishment of 3D Model

Use the 3D modeling software UG to draw the three-dimensional model of the shell. The structure is a hollow structure with a maximum diameter of φ100mm and a height of 100mm. A cone with a height of 30mm is removed from the bottom, and the wall thickness is about 3mm, as shown in figure 1.

![Figure 1. 3D model of the shell.](image)

3.2. Meshing and Inspection

In order to ensure that the calculation accuracy is high enough, the number of discrete units must be large enough. On the premise of ensuring the calculation accuracy and increasing the calculation speed, the 2D mesh size of the shell and runner is set to 3mm, and a 1mm thick investment mold is generated.
Check the obtained 2D mesh. After the check is correct, perform 3D volume meshing and check. The number of 2D grids obtained by the simulation is 117030, the number of 3D grids is 536468, and the total number of grids is 653498. After the 3D mesh is divided, check and repair the mesh, and perform pre-simulation processing after the check is correct.

3.3. Pre-simulation Processing Settings
The pre-processing settings of the simulation mainly include the settings of gravity vector selection, material selection, heat exchange conditions, and operating parameters. For the solidification simulation process, the main setting process is as follows:

1) Gravity vector selection
When pouring, the gravity of the melt is used to make it flow into the shell for solidification, so the shell needs to select the direction of the gravity vector. According to the stretching direction of the model during modeling, select the direction of the gravity vector as the -Z axis direction.

2) Material selection
In the material setting, furan molding sand is selected as the investment material, AlSi11 alloy (EN AC 44000) is selected as the casting material, the initial filling rate of the runner and the shell is 0. The initial temperature of the liquid was 750°C, and the initial temperature of the investment mold was 500°C.

3) Boundary heat transfer conditions
First, set the heat exchange conditions. During the solidification and cooling process of the melt, the heat exchange of the entire system mainly includes: the interface heat exchange between the investment mold and the shell, and the interface heat exchange between the investment mold and the runner, the heat transfer coefficient Both are taken as 500W/m2 · K. Next, set the boundary conditions. The investment mold is cooled by air cooling and cooled to room temperature 20°C; the molten liquid pouring time is set to 15s, the pouring temperature is set to 750°C, and the flow rate during filling is calculated.

4) Operating parameters
The operating parameters include the time step of the simulation calculation, the termination temperature of the simulation, the simulation save frequency, etc. In this experimental simulation, the calculation is terminated when the model temperature is lower than 300°C, and the number of steps calculated for the actual simulation duration of 1s is set to 2 (that is, the time step is 0.5s).

4. Simulation Results and Analysis
It can be seen from the filling time chart in the filling time and defect distribution chart (figure 2) that filling is completed in 14.70s, which is very close to the calculation result, and the error is small. From the defect distribution map, it can be seen that the parts prone to shrinkage cavities are mainly concentrated in and near the center of the shell.

(a) Filling time chart
According to the total shrinkage porosity analysis chart (figure 3), the shrinkage volume at the internal defects of the material is 7.80 square centimeters, the average shrinkage is 17.90%, the pore volume is 1.70 square centimeters, the pore density is 0.0012 g/square centimeter, and the pore weight 0.002039 grams.

It can be obtained from the filling speed diagram (figure 4) that the maximum casting speed does not exceed 1.4m/s. At the beginning of pouring, due to the raised bottom of the shell, the pouring is not stable and serious air entrainment occurs. With the continuous injection of molten metal, the pouring process gradually stabilizes, but there is a problem of lagging in filling at the top of the shell, this may result in unsmooth gas discharge, resulting in shrinkage cavities defects.
From the solid phase fraction change graph (figure 5), it can be seen that the solidification speed of the molten alloy in the middle part of the shell is slower than the solidification speed of the surroundings, therefore, when the middle part is still liquid, the surrounding has solidified into a solid state. In this way, when the molten metal in the middle part begins to solidify, the surrounding solid metal cannot be fed, so that the slow solidification middle part is prone to shrinkage cavities. Therefore, it can be inferred from the change in fraction solid percentage in figure 5 that the middle position of the shell is very likely to produce shrinkage cavities defects [11].

Figure 5. Solid phase fraction change graph.

During the solidification process, heat exchange and heat convection have a great influence on the solidification rate and solidification quality. During the solidification process, the molten alloy in contact with the metal shell only has heat conduction with the metal shell. Therefore, its thermal conductivity is better than other parts, and it has a stable thermal conductivity. The heat exchange and heat convection during the solidification process of the molten alloy in other parts are more complicated, including not only the heat exchange between the molten alloy and the shell, but also the heat convection between the molten alloy and the heat exchange in the high and low temperature areas. Therefore, this part of the molten alloy has the obvious characteristics of complex heat exchange, low
thermal conductivity, and slow cooling rate during the solidification process, which makes this part of the molten alloy easy to deposit solid phase components during the solidification process. From the perspective of the entire solidification process, it is a layer-by-layer solidification process. To reduce shrinkage porosity and other problems after solidification, it is necessary to feed the solidification process in a timely manner [8].

5. Conclusion
(1) During the solidification process, heat exchange and heat convection have a great influence on the solidification rate and solidification quality, and shrinkage cavities are prone to occur in the central part. The whole solidification process is a layer-by-layer solidification process. To reduce the shrinkage porosity and other problems after solidification, it is necessary to feed in the solidification process in a timely manner.
(2) The filling time of the material inside the shell is 14.70s, which is very close to the calculated filling time, and the error is small. After solidification and cooling, the shrinkage volume of the internal defects of the material is 7.80 square centimeters, the average shrinkage rate is 17.90%, and the pore volume is 1.70 square centimeters, further confirm that the central part is prone to shrinkage cavities.
(3) The maximum speed of the pouring does not exceed 1.4m/s, but the pouring is not stable at the beginning, and serious air entrainment occurs. At the end of the pouring, there is a problem of lagging in the top of the shell.

References
[1] Brodarac Z Z, Grgurić T H, Burja J 2017 Thermodynamic stability of AlSi11 alloy microconstituents Journal of Thermal Analysis and Calorimetry 127(1).
[2] Li W J, Huang Y G, Lu Zh J, Qiu G 2020 Casting simulation of aluminum alloy suction valve housing based on ProCAST Chemical Management (32): 137-139.
[3] Yang L W 2015 Present status and future development trend of casting CAE technology First Heavy Technology (03): 62-66.
[4] Li K Y 2019 Study on Casting Process and Compressive Property for Aluminum Honeycomb Dalian University of Technology.
[5] Jia L, Li Y T, Wu Y H, Qi H P 2014 Research on the temperature parameters in casting-rolling continuously forming of ring parts Chinese Journal of Mechanical Engineering 50(16): 119-125.
[6] Li Y Sh, Zhu X Q, Lin W H, Shen M J 2020 Casting simulation of automobile wheel hub based on ProCAST Casting 69(05): 547-551.
[7] Jia X Zh, Wang X F, Wang J L 2013 Numerical simulation of temperature field and defects during the solidification process of casting explosive Ordnance Industry Automation 32(09): 42-43+46.
[8] Sun X H, Cui Q Zh, Xiong B, Zhang Y, Xu Y, Huang Y P 2020 Solidification simulation and verification of modified explosive Ordnance Industry Automation 39(01): 77-81.
[9] Cui X P, Liu J W, Wang H, Nan H, Zhang A B 2020 Shell mechanical parameters and stress simulation of titanium alloy investment casting Ordnance Industry Automation 39(05): 506-509.
[10] Lu S L, Xiao F R, Zhang S J, et al. 2014 Simulation study on the centrifugal casting wet-type cylinder liner based on ProCAST Applied Thermal Engineering 73(1): 510-519.
[11] Zhang Sh Q 2018 Study on Investment Casting Shell Deformability of TiAl Alloy Shenyang University of Technology.