Accessing the Effects of Composition and Process Fluctuations on the Quality of Investment Castings

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Abstract: The composition and process fluctuations cause the uncertainty of the quality of investment casting of Ni-based superalloys. This study assesses the influence of fluctuations in alloy composition and process parameters on shrinkage porosity defects in castings based on integrated computation and data-driven approach. Besides, a dynamic correction method for determining boundary condition changes during the shell transfer process is presented. The results show that more accurate shrinkage porosity predictions are obtained with the dynamic temperature corrections, facilitating the quality control of investment casting.

Keywords: investment casting; fluctuations; shrinkage porosity

1 Introduction

Investment casting is a complex manufacturing process. Different parameters have their impact on the casting defects [1]. On one hand, the composition of specific grades of Ni-based casting superalloys is usually a range rather than a fixed value. The composition fluctuation leads to difference in thermodynamic and physical properties, causing the fluctuation in casting defects [2]. On the other hand, some studies rely on historical data and use inverse algorithms to obtain more accurate parameters [3]. However, the actual production process is not fixed, and there are deviations from historical data. Simulation with fixed processing parameters may cause large error. Besides, in some cases, boundary conditions cannot be accurately set in advance.

2 Method

Composition fluctuations

Thermodynamic-finite element integrated computation is applied to quantify the influence of composition fluctuations of K4169 superalloy on shrinkage porosity and feed length. 100 sets of alloy compositions within the boundary limit are designed with optimal Latin hypercube sampling. Thermodynamic calculations are made with Pandat and incorporated into ProCAST software to predict the casting defects.

Processing parameter fluctuations

Stochastic uncertainty is unavoidable in real production, which may cause large error in traditional numerical simulation with fixed processing parameters. To address this challenge, the data-driven approach should be applied. From 20 groups of real production, the fluctuations in processing parameters are collected, which is shown in Table 1. More simulation experiments are designed within the range of process parameter variations.

Table 1. Uncertainty modelling of parameters

Parameters	Fluctuation range
Gating system assembly error	±3 mm
Shell transfer duration	100±25 s
Pouring temperature	1500±30 ℃
Interface HTC	±30%

Boundary condition fluctuation during shell transfer

The shell transfer process is a process in investment casting during which the preheated ceramic shell is transferred from an oven to a pouring furnace prior to casting. During the transfer process, the shell temperature drops rapidly, forming an uneven temperature field that is different from the preheating temperature. In order to real-time capture the fluctuation in boundary condition (ambient temperature), we present a simplified mathematical model of heat transfer based on the finite volume method and a dynamic correction method based on measured data by a thermocouple as shown in Figure 1.

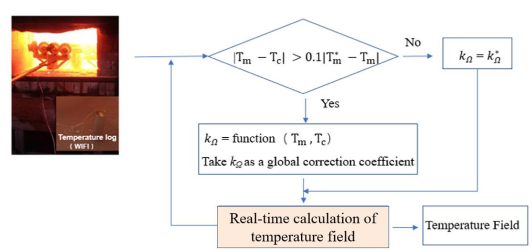

Figure 1 Schematic diagram of dynamic corrections of shell temperature.

Using the dynamically corrected shell temperature at the end of shell transfer as the boundary conditions, the formation of shrinkage porosity defect in the castings is simulated with ProCAST.

Results and discussion

Composition fluctuations

The result of 100 sets of compositions is automatically extracted from integrated computation. Response surfaces shown in Figure 2 are established with machine learning algorithms including RBF and BPNN. The maximum fluctuation due to composition uncertainty is 36% for shrinkage porosity and 21% for feed length.

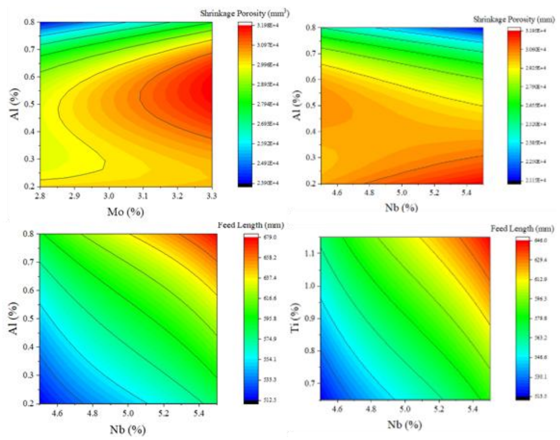

Figure 2 Response surface of shrinkage porosity and feed length.

Processing parameter fluctuations

The impact of parameter fluctuations on the shrinkage porosity is quantified with numerical model. Figure 3 shows the response surface of the shrinkage porosity inside the casting and the safe margin of the porosity above the top of flange for different parameters. Within the limit in Table 1, the contribution of fluctuations is shown in Table 2.

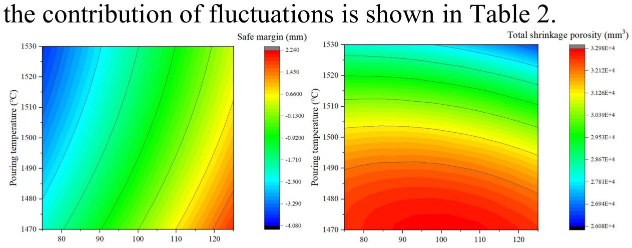

Figure 3 Response surface of safe margin and shrinkage porosity

Table 2. Contribution of process fluctuations

Parameters	Contribution to porosity (%)
Gating system assembly error	32.4
Shell transfer duration	24.5
Alloy composition	22.3
Interface HTC	16.6
Pouring temperature	4.2

Boundary condition fluctuation during shell transfer

Figure 4(a) shows the calculated temperature field of the mold shell after 30 s transfer with dynamic corrections. The trend of the corrected temperature is consistent with the experiment, providing reference values of the process parameters for the subsequent casting process simulation. Castings are more prone to concentrated shrinkage porosity, as indicated in Figure 4(b).

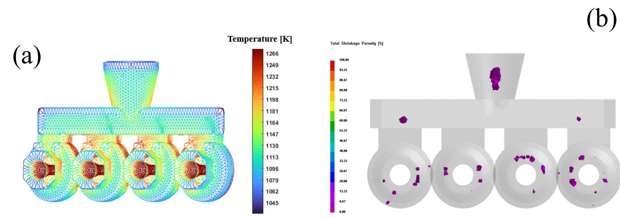

Figure 4 (a) The snapshot of the temperature field of the mold shell with dynamic corrections, (b) Simulation results of the shrinkage porosity in the casting.

Conclusions

In this study, the uncertainty in investment casting from composition and process fluctuations are accessed. The following conclusions can be made:

a) Within the composition boundary limit of K4169 superalloy, the internal shrinkage porosity volume can fluctuate by up to 36%, while the feeding length exhibits a variability of up to 21%.
b) The fluctuations in processing parameters result in different shrinkage porosity defects, among which the gating system assembly error and the shell transfer duration contribute mostly.
c) More accurate shrinkage porosity predictions are obtained with the dynamic temperature corrections during the shell transfer process.

Acknowledgments

This work was financially supported by the National Key Research and Development Program of China (2022YFB3706800), and the National Natural Science Foundation of China (51821001, 52090042).

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