Freckle Defect Prediction for Single Crystal solidification of Superalloys

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Abstract: Defects in high performance aerospace investment castings can reduce mechanical properties and consequently degrade both component life and durability. It is critical to understand the mechanism of defects formation so that an effective tool can be developed to prevent defects. Those defects are dependent on the chemistry of alloys, casting design, and casting processes. Casting engineers must be able to both accurate predict and reduce or even completely remove casting defects. In the present study, qualitative models were applied to predict the location-specific freckles during single crystal (SC) solidification of superalloy castings. These predictions are validated by comparing predicted results against several special designed superalloy castings as well as production castings. The simulation results agree well with experimental measurements.

Keywords: Freckle; Superalloy; Directional solidification; Single crystal casting

1 Introduction

There are many kinds of casting defects in SC components, such spray grains, freckles and slivers. Freckle is a detrimental defect in superalloy castings, especially in high generation SC superalloy blades. Researchers have found that freckle formation mainly depends on the chemistry of the alloy, casting processing parameters, and the geometry variation of the castings[1-4]. Special designed simple shape castings have been performed experimentally to assess the formation and severity of freckles previously to study the effect of the geometric variation comprehensively [1-2]. In addition to those extensive experimental works, some researchers[3-4] built fluid dynamics models to deeply analyze the convection phenomenon of liquid in the mushy zone during directional solidification, and proposed Ra criteria for the formation of freckles. However, those criteria are mostly based on simplified and ideal conditions, and the simulation results are often inconsistent with the actual castings. Recently, a new mathematical model based on Ra was proposed [5], which takes into account the geometric effect of castings, and the prediction results of freckle defects in complex castings are relatively consistent with the experiments. In this paper, the directional solidification process of a third-generation nickel-based superalloy SC casting is simulated based on an inhouse code which takes into account of the chemistry, casting processing parameters as well as the geometry effect. In order to evaluate the accuracy of the prediction, the area of the freckle on the casting surface was measured and compared with the simulation. The prediction is rather accurate with the error of less than 10%, which proves the accuracy of the current prediction method.

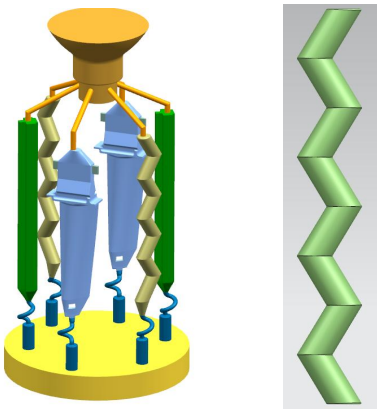
2 Experimental procedure

A third-generation SC superalloy WZ30 was used in the experiment, and its chemical composition is shown in Table 1.

Table 1. Nominal composition of the alloy WZ30 (wt.%)

Cr	Co	W	Mo	Al	Ti	Ta	Re	Nb	Ni
3.5	6.0	6.5	0.4	5.8	0.15	8.0	4.95	0.1	base

The castings designed in this experiment have 3 different cross-section shapes, and the casting wax molds were arranged around the center to assemble a circular wax mold model. Figure 1 shows the casting cluster arrangement and detail of one zigzag casting bar. This paper presents the detail experimental results and simulation results of the zigzag casting only.



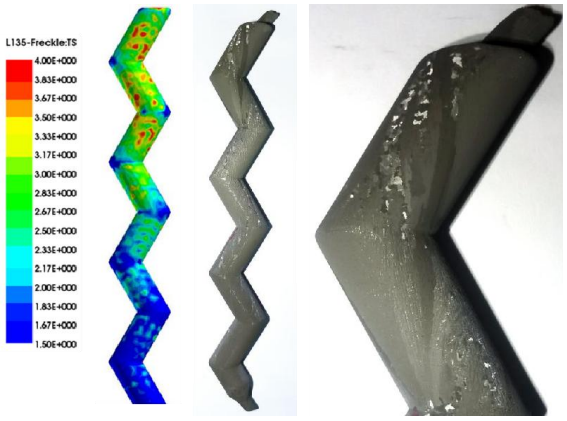
(a) (b)

Fig. 1 Casting cluster arrangement (a) and zigzag casting (b)

The pouring temperature was 1500 °C, and the withdraw rate was 1.5 mm/min. The location of freckles in the casting was identified by visually inspection on the macroscopically etched casting surface. The freckle defect area of the actual casting was marked and measured using Image Pro Plus, to characterize the freckling severity in the investigated casting.

3 Result and discussion

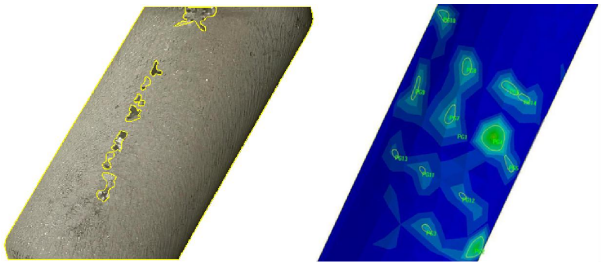
Fig. 2 shows the comparison between the simulated and experimental observed freckle results of the studied casting. In order to quantitatively assesses the prediction, the castings were segmented, and the freckle areas in each section of castings were measured and analyzed in detail along the height of the casting.



(a) (b)

Fig. 2 Comparison of the whole zigzag casting freckles between simulation and experiment (a), and local zoom view of top part of the casting (b)

The comparison between the measured freckle defect and the simulated results in one section of the casting is shown in Figure 3. The predicted freckle area was defined by the area of Ra greater than a critical value which can be determined by experiments or theory calculation.



(a) (b)

Fig. 3 Freckle defect area map of one Section of the casting from experiment (a) and simulation (b)

The freckle defect in the zigzag casting from experiment and simulation along the height of the casting were statistically analyzed, and the comparison results were shown in Figure 4. The error between simulation and measurement is less than 10% .

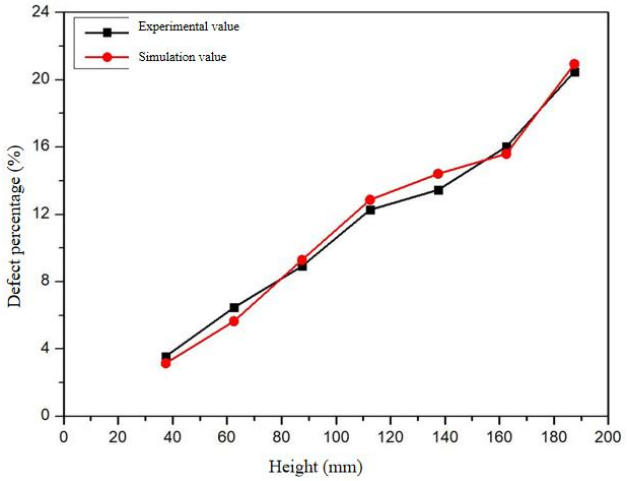


Fig. 4 The freckle area with the height of the casting by experiment and simulation

4 Conclusion

With the increase in casting height, both simulated and measured freckle area on the casting surface shows an increasing trend. This is because during conventional directional solidification process, the temperature gradient becomes normally weaker, leading to the continually coarsening of dendrite structure and the increasing tendency of freckle formation. Simulation results agree well with the experimental observation.

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