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Improved Numerical Methods for Accuracy of Filling and Shrinkage Prediction in Cast Iron and Steel Castings

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A hybrid method incorporating cut-cell and porous media approaches is proposed to improve the filling accuracy of castings made using sand casting process. The retained melt modulus and surface methods were coupled with the probability distribution model for the prediction of shrinkage positions and area sizes, and the evaluation of the accuracy of shrinkage prediction. They highly depend upon the shrinkage prediction model and the critical solidification fraction.

Keywords: *hybrid method, filling accuracy, shrinkage model, critical solidification fraction, accuracy of shrinkage prediction*

1. Introduction

Effective numerical algorithms are very crucial both for the mold filling at between cavity and mold interface and for the calculation of shrinkage defects in solidification stage. A hybrid method incorporating cut-cell[1-2] and porous media approaches[3-4] is proposed to improve the filling accuracy of castings made using sand casting process. The method was verified using a Plexiglas-water model and compared with a simulation using the general finite difference method(FDM).

Lots of efforts have been made for the prediction of solidification shrinkage defects by numerical approaches[5-7], and they can be divided into two groups, the tracing of retained melts during solidification for gravity and macro porosity prediction, and appropriate criterion by the balance of temperature gradient and solidification speed in mushy zone for micro porosity. The retained melt modulus(RMM) and surface(RMS) methods in the first group were coupled with the probability distribution model for the prediction of shrinkage positions and area sizes with the variation of critical solidification fraction(CSF).

2. Filling Accuracy

As shown in Fig. 1, an appropriate number of sub-mesh was used to trace the curved boundary of the mold and cavity using the cut-cell method. With this sub-mesh structure, the information for the interface cell, including the volume, advection area, and direction of fluid, was calculated. The fluid volume and advection area of the interface cell were integrated into the momentum, pressure, and free surface transport equations (equations (1), (2) and (3), respectively).

$$V_f \frac{\partial \phi}{\partial t} + u_j \frac{\partial (A_j \phi)}{\partial x_j} = \frac{\mu}{\rho} \frac{\partial}{\partial x_j}\left(A_j \frac{\partial \phi}{\partial x_j} \right) - \frac{V_f}{\rho} \frac{\partial p}{\partial x_j} + V_f g_j \quad (1)$$

$$\frac{\partial}{\partial x}\left(A_j \frac{1}{\rho} \frac{\partial p^{n+1}}{\partial x_j} \right) = \frac{D^n}{\Delta t} = \frac{1}{\Delta t} \cdot \frac{\partial}{\partial x_j}(A_j u_j) \quad (2)$$

$$\frac{\partial}{\partial t}(V_f F) + \frac{\partial}{\partial x_j}(A_j u_j F) = 0 \quad (3)$$

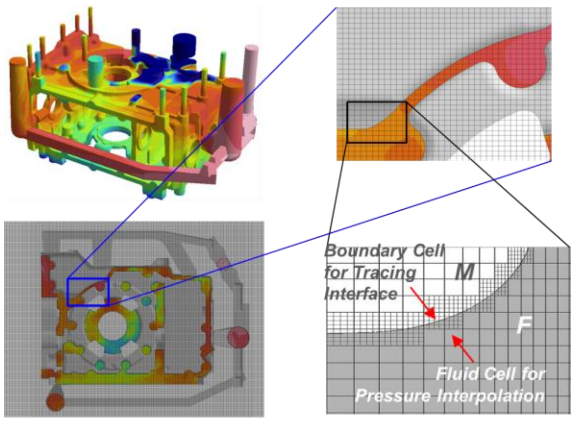

Fig. 1 Trace of the curved boundary of mold and cavity interface using sub-mesh.

As shown in Fig. 2, the Plexiglas-water experiment and simulation results using the FDM and hybrid methods were compared for a sand casting process. The simulation using the hybrid method resulted in a filling pattern similar to that shown in Fig. 2(c).

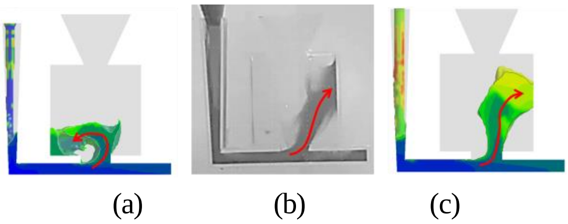

Fig. 2 Filling accuracy in comparison with the Plexiglas-water experiment.

3. Shrinkage Prediction Accuracy

A probabilistic model has been developed for the prediction of shrinkage area size based upon total shrinkage contraction during solidification, and considering both micro and macro feeding by riser and cast as shown in Fig. 3. Two shrinkage models, retained melt surface and modulus have been compared for the accurate prediction of shrinkages with real castings of ductile cast iron diffuser case housing(33 kg) and cast steel barrel(4.6 ton). The accuracy of shrinkage defects prediction was highly depend upon the selection of these shrinkage models and the critical solidificiton fraction, as show in Fig .4 and 5.

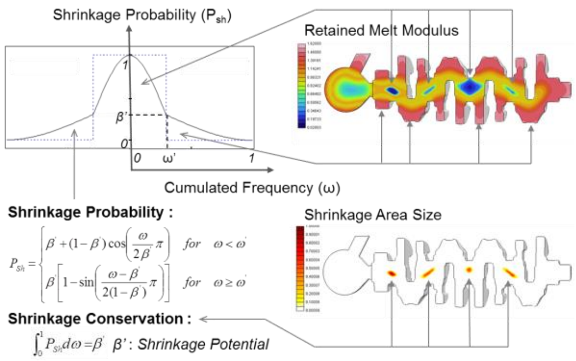

Fig. 3 Prediction of size for shrinkage area using probabilistic model.

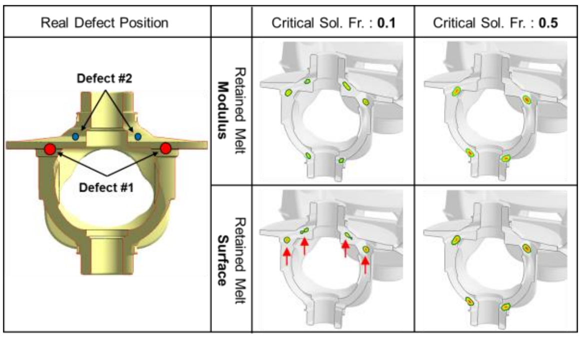

Fig. 4 Shrinkage prediction accuracy according to model and CSF in ductile cast iron casting.

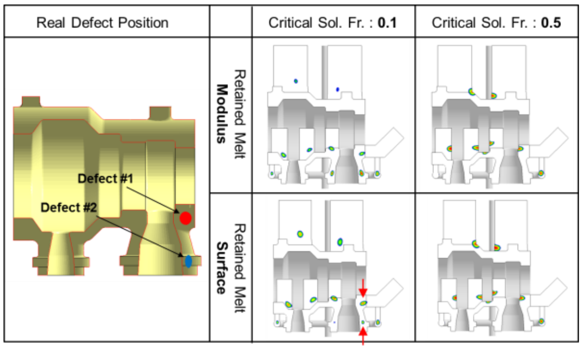

Fig. 5 Shrinkage prediction accuracy according to model and CSF in cast steel casting.

4. Concluding Remarks

For the improvement of shrinkage prediction in the castings of cast iron and steel, three kinds of researches were performed as follows.

a. improve the filling accuracy by the hybrid method

b. propose a probabilistic model for the prediction of shrinkage area size.

c. effect of the selection of shrinkgae prediction model and criticial solidification fraction upon the accuracy for the analysis of shrinkage positions and sizes

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