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Original Article

Simulation of unconstrained solidification of A356 aluminum alloy on distribution of micro/macro shrinkage

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ABSTRACT

In the condition of Newtonian heat transfer, A356 aluminum alloy is solidified with randomly distributed equiaxed dendrites. Ability of interdendritic liquid flow is described by permeability parameter using Darcy's law and this parameter is used to predict the micro-shrinkages. In this study the interdendritic liquid flow during nucleation and grain growth are simulated in a 1 mm × 1 mm domain. Temperature gradient is zero in the initial condition of the unconstrained solidification. The numerical simulation procedure includes two stages; first, numerical evolution of the shape, number, size, and distribution of dendrites during solidification using a novel Cellular Automation Finite Volume (CA-FV) method, and second, numerical determination of the micro-permeability by a Computational Fluid Dynamics (CFD) technique. Subsequently, the effect of Reynolds number, cooling rate and solidification rate on a critical permeability range was investigated in order to predict the micro/macro shrinkage distribution. Results showed that it is possible to propose a mathematical model to relate the Reynolds number and liquid flow rate, in the creeping flow range, on the micro-permeability during unconstrained solidification.

1. Introduction

Nucleation and grain growth occur successively during solidification of alloys and consequently the number, size, distribution and morphology of the grains are determined during this process. In the case of rapid solidification the effect is more pronounced. During solidification, micro-defects such as micro-segregation, micro-porosities and micro-shrinkage form a porous medium (mushy zone) located in interdendritic spaces. The ability of the liquid to flow into the mushy zone is known as permeability of interdendritic liquid. Therefore, micro-defects formation is affected by the permeability factor. In a number of studies, micro/macro solidification models have been simulated based on the permeability factor using Darcy's law [1–4].

To obtain an expression for the permeability as a function of the porosity of the porous medium, one generally considers flow through an idealized medium geometry, since it is impractical to solve the flow equations for the complex flow between the particles [5–7]. Analysis of permeability for Stokes flow through periodic arrays of cylinders was done by Sangani and Acrivos [8], Sparrow and Loefler [9], and Larson and Higdon [10].

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