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Influence of Forced Convection on Columnar Microstructure during Directional Solidification of Al - Ni alloys

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Abstract. This paper presents a summary of cellular and dendritic morphologies resulting from the upward directional solidification of Al – Ni alloys in a cylindrical crucible. We analysed the coupling of solid-liquid interface morphology with natural and forced convection. The influence of natural convection was first analyzed as a function of growth parameters (solute concentration, growth rate and thermal gradient). In a second step, the influence of axial vibrations on solidification microstructure was investigated by varying vibration parameters (amplitude and frequency). Experimental results were compared to preliminary numerical simulations and a good agreement is found for natural convection. In this study, the critical role of the mushy zone in the interaction between fluid flow and solidification microstructure is pointed out.

Introduction

In Bridgman solidification, even when solidification is performed in a both thermal (i.e. vertical upward solidification) and solutal (i.e. rejected solute denser than solvent) stabilizing configuration, strong convective flow driven by residual radial thermal gradients can be dominant when the growth velocity is slow enough [1]. This convection disrupts uniform solute distribution and promotes radial compositional gradients in the liquid. One consequence of this fluid flow is a severe distortion of the solid-liquid interface, which is harmful for the homogeneity of the grown specimen. For massive sample, the most efficient way to obtain purely diffusive transport in the melt is to carry out solidification in microgravity environment [2].

In order to damp or eliminate the convection, solidification experiments were carried out with axial vibrations. Forced convection induced by mechanical vibration is commonly used in many crystal growth processes to improve crystal quality like in Czochralski or floating-zone methods. In the case of Bridgman solidification, there are very few experimental studies [3,4] considering the effects of longitudinal vibration on the growth process. The second interest of applying vibrations is to tailor fluid flow in the melt and, in particular to control the columnar – equiaxed transition (CET). CET occurs when equiaxed grains grow ahead of the dendrite tips in the undercooled liquid. The origin of these grains could be either refining particles added to the melt or dendrite fragments created by remelting phenomenon and carried out of the mushy zone by fluid flow. If their number and size are large enough, equiaxed grains can stop the columnar growth and form an equiaxed