International Scientific Colloquium
Modelling for Material Processing
Riga, June 8-9, 2006

Influence of Forced/natural Convection on Segregation During the Directional Solidification of Binary Alloys

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In metallurgy macrosegregation, which describes the gradual change in composition, is a very important and well-known phenomenon during solute rich alloy solidification process. It is often observed at the scale of the product, deteriorating the properties of the material. Segregations may occur at the various scales of the ingot. Microsegregations are linked to composition variations at the scale of the lowest solid structure, whilst macrosegregations concerns the scale of the product. At the intermediate scales, one particularly striking form is the "channel segregation". Typical dimensions are several centimeters in length, a few millimeters in cross section, so that they appear as "freckles" on transverse sections. They were observed in different solidification processes (forge ingots, vacuum arc remelted ingots, directionally solidified turbine blades). A typical condition of occurrence is a relatively slow solidification rate (nickel base alloys, high alloy steels, and also Pb-Sn alloys or ammonium chloride solutions for laboratory studies). Apart from the normal segregation linked to the partition of solute at the liquid-solid interface, it is admitted that convection in the mushy zone can produce such segregations. Such convection may originated from thermo-solutal buoyancy forces but also from any forced flows, for example electromagnetic stirring or volume changes due to the shrinkage. It has been shown that the fluid flow, especially electromagnetically driven flows, could produce significant macrosegregations but also that the configuration was able to control the segregation pattern.

In the present paper, we shall focus our attention on the effect of various types of electromagnetically driven flows on solidification. Attention is restricted to simple situation which consists of analyzing the directional solidification a binary alloy. Electromagnetically-forced convection can be created from single –phase magnetic fields or polyphase magnetic fields, such as traveling or rotating magnetic fields (referred hereafter to as TMF or RMF respectively). More complex situations can also be achieved by slow modulation of the AC magnetic fields (MTMF). Such tailored flows may exert subtle effects such as segregation suppression. The solidification has been analyzed both from different experiments and from numerical modeling. We shall review the effect of RMF or TMF with three different types of alloys Al-7wt%Si, Al-3.5wt%Ni and Pb-10wt%Sn in comparison with buoyancy forces. Indeed to Each alloy will correspond a different situation of buoyancy forces. The first alloy is constituted by two components having almost the same density. Thus the importance of buoyancy forces generated by solutal effects is negligible. In the second alloy, the presence of the heavier nickel solute will tend to stabilize the flow due to its stratification. Finally, the third alloy is well-known to produce a significant solutal natural convection since the tin solute is less dense than the lead.

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