TOWARDS THE DESIGN AND CONTROL OF SOLIDIFICATION PROCESSES WITH DESIRED MICROSTRUCTURES[1]

Professor Nicholas Zabaras
Sibley School of Mechanical and Aerospace Engineering
Cornell University, 188 Frank H.T. Rhodes Hall
Ithaca, NY 14853-3801, USA
Email: zabaras@cornell.edu

The physical mechanisms that influence to a significant degree the obtained microstructures in solidification processes include heat and mass diffusion, natural and solutal convection, thermo-capillary (Marangoni) convection, forced convection (e.g. electromagnetic stirring) and solutal/kinetic/ surface-tension undercooling. To be able to design processes with desired microstructures, one should understand the effects of each of these physical mechanisms on the microstructures and develop mathematical, computational and experimental tools for their control.

The technical means available for such control include mold/furnace cooling/heating conditions, various means of forced convection (electromagnetic stirring, rotation, etc.) and other. Some examples of our work on the design of stable directional solidification processes for binary alloys with desired growth will be presented and the developed computational and mathematical frameworks will be reviewed. Our main design variables are the thermal mold/furnace conditions as well as the strength and orientation of an externally applied electromagnetic field. We select these continuous variables such that a desired growth velocity V and temperature gradient G are achieved near the freezing interface that correspond to desired microstructures. In our preliminary work, we are interested to design processes with spatially uniform growth velocity under stable growth conditions.

These design problems are inverse problems with overspecified thermal conditions (temperature and flux) on one part of the boundary and no-thermal conditions on another part of the boundary. They are posed as functional optimization problems. The exact gradient of the cost functional is obtained via the solution of an adjoint continuum problem. A sensitivity problem is also defined and is used in the implementation of the conjugate gradient method.

The proposed design techniques are important for the development of the next generation of furnaces for controlled crystal growth. In particular, the availability of mathematical models for solidification control via optimally designed thermal boundary fluxes and electromagnetic fields is essential for the development of multiple-zone automated furnaces. Further development of such inverse techniques will enhance our ability to develop new advanced directional solidification process designs for cast microstructure control.

[1] ACCESS e.V., (host: Dr. Gottfried Laschet), Aachen, Germany, August 18, 2000.