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Melt Flow Control Using Magnetic Fields and Magnetic Field Gradients

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Abstract

Solidification of materials to near net shape is one of the most commonly used and economical methods of manufacturing. Different industries impose different restrictions and design objectives on the solidification process. For example, single crystal growth requires a planar growth front whereas casting requires homogenous material distribution. There are various techniques to control the flow in the melt to achieve the required objectives. Magnetic field based techniques have become the most popular commercially used methods for solidification control. Unfortunately, these control methods (uniform magnetic field, rotating magnetic field) are restricted to conducting materials. The extension of magnetic control to non-conducting media is explored in this work. The application of a non-uniform magnetic field produces an extra distributed force term in the governing melt flow equations. This body force, along with the Lorenz force (for conducting media) can be used to effectively control solidification. The physics behind the application of a time varying magnetic gradient on the flow is discussed and a coupled set of equations governing the fluid flow, thermal, concentration and magnetic field evolution is determined. A computational method for the design of solidification is developed such that a prescribed characteristic during solidification is achieved. Various design objectives are considered. As an example, the cost functional is taken as the L_2 norm of an expression representing the deviation of the velocity field in the melt region from conditions corresponding to convection-less growth. The adjoint method for the inverse design of continuum processes is adopted in this framework. A continuum adjoint system is derived to calculate the adjoint temperature, concentration and velocity such that the gradient of the cost functional can be expressed analytically. The cost functional is minimized using the conjugate gradient method with a finite element realization of the continuum direct, sensitivity and adjoint problems. The developed methodology has wide applications in crystal growth, directional solidification of metals, organic compounds and biological macromolecules. Different thermal conditions like radiation and boundary heat flux as well as various other effects including surface tension (Marangoni effect) are taken into account. Examples of designing the time history of the magnetic field, for different types of materials, are presented.

REFERENCES

[1] B. Ganapathysubramanian, N. Zabaras, *Using magnetic field gradients to control the directional solidification of alloys and growth of single crystals*, Journal of Crystal Growth, (submitted).

[2] J. W. Evans, C. D. Seybert, F. Leslie, W. K. Jones, *Suppression/reversal of natural convection by exploiting the temperature/composition dependence of magnetic susceptibility*, Journal of Applied Physics, 88(7), (2000), 4347.