Freckle suppression in directional solidification of binary and multicomponent alloys using magnetic fields

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Freckles are formed during directional solidification of alloys and represent areas of higher solute concentrations as compared to the bulk leading to variation in mechanical properties in the final cast alloy. Suppression of thermosolutal convection is necessary for eliminating freckles in solidifying alloys and for improving the final macro-morphology and microstructure of the alloy.

Application of a magnetic field in a solidifying metal alloy in the right direction produces a Lorentz force that opposes the thermosolutal buoyancy force and can be used to control or suppress melt convection. The classic MHD assumptions of non-relativistic flow and quasi-magneto-statics are invoked while coupling the electromagnetic and fluid flow phenomena. The induced electric potential depends on the fluid velocity. The induced magnetic filed is negligible in comparison to the externally applied field for most liquid metal alloys and therefore the galvomagnetic and the thermoelectric effects are neglected. Joule heating effect is neglected in the energy equation because of the high electrical conductivity of most alloys.

Homogeneous solute distribution in the cast alloy is one of our main objectives. The numerical studies described use a single domain, volume-averaged model to simulate binary and multi-component alloy solidification. The mushy zone is characterized as a porous medium with either an isotropic or anisotropic permeability that in turn are functions of the liquid volume fraction. A SUPG (streamline upwind Petrov-Galerkin) based finite element method is used to discretize the thermal and solutal transport subproblems. For the momentum sub-problem, a modified form of the SUPG-PSPG finite element method, incorporating changes due to the Darcy drag force in the mushy zone, is employed. A segregation model incorporating solidification histories is used for closure of the overall numerical model. Advective-diffusive solute transport of a particular species in a multi-component alloy is assumed to be independent of other species present. At each time step, a weakly coupled algorithm is used where the momentum equation is solved only once. This significantly reduces the total simulation time. Parallel iterative solution techniques based on the matrix free GMRES algorithm are used for all our numerical simulations.

Both two- and three-dimensional simulations are presented to demonstrate the effectiveness of the simulator for analyzing the magnetohydrodynamic phenomenon in solidifying alloys resulting in suppression and elimination of macrosegregation and freckle formation.