Dynamical interaction of fluid flow in the formation of interface microstructure in directional solidification of alloys

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It is the solid microstructure that to a large extent determines the materials properties so that the understanding of microstructure formation at the solid-liquid interface is critical in the elaboration of materials from the melt. Also, those solidification microstructures pertain to pattern formation in dynamical systems far from thermodynamic equilibrium, and thus to non-linear physics. Directional solidification is a "model configuration" well adapted to the investigation of the fundamental mechanisms of microstructure formation in alloys with close control of the growth parameters : pulling rate, temperature gradient, solute concentration(s).

For bulk samples, the limit of diffusive heat and mass transport can be reached in the reduced-gravity environment of space, where the benchmark data needed for the reliable advancement of modelling are obtained. Under terrestrial conditions, fluid flow in the melt is hardly avoided which rises the question of the dynamical interaction of fluid flow in the formation of the interface pattern. This interaction can result in very significant effects spanning from curved front in growth with a smooth interface to clustering and steepling in columnar dendritic solidification with a porous mushy zone and sedimentation in equiaxed growth, going through the localisation of morphological instability and cellular / dendritic array competing with eutectic. By the transport of detached dendrite arms, convection plays also a central role in the columnar to equiaxed transition. Furthermore, the tailoring of fluid flow in the liquid and dendritic mush by the application of an external field (crucible vibration / rotation in our case) has now emerged as a method of choice for the control of the solidification microstructure. On all those topics, only if for the sake of soundness it is of uppermost importance that modelling / numerical simulation and experimental studies are carried out side by side and substantiate each other.