The Transient Dendritic Solidification Experiment (TDSE)

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Dendritic solidification is one of the simplest examples of pattern formation where a structureless melt evolves into a complex crystalline microstructure. Dendrites are known to occur in the solidification of water, salts, organic materials, and most commonly and importantly, in metals and alloys. As most researchers on dendritic growth invariably note, there is considerable engineering interest in dendrites because of the role dendrites play in the determination of physical properties of cast materials. In addition, dendritic solidification has become a well-studied model in non-equilibrium physics, and computational condensed matter material physics.

Current theories of dendrite formation contain two independent components. The first concerns the transport of heat and solute from the solid-liquid interface into the melt. The second involves the interfacial physics that selects the unique growth velocity and tip radius of curvature from a spectrum of combinations that are consistent with the heat transfer and conservation of energy at the solid-melt interface. Until recently, neither aspect of the theory could be tested critically on the earth because of the effects of gravity-induced convection, which modifies the transport processes, and alters the growth kinetics.

Benchmark data were obtained in microgravity from two flights of the Isothermal Dendritic Growth Experiment (IDGE) using succinonitrile (SCN). SCN is an organic material which acts as a BCC metal analog. The data and subsequent analysis on the dendritic tip growth speed and radii of SCN dendrites demonstrated that although the theory yields predictions that are reasonably in agreement with the results of experiment, several significant discrepancies occur. However, some of the discrepancies can be understood by a consideration of the diffusion of heat from three-dimensional dendritic structures. The data and analysis for assessing the pattern selection physics are less definitive.

Current investigations by other researchers are studying, isolated single dendrites, dendritic side-branching, aligned dendritic arrays, and equiaxed dendritic growth. Some of these investigations recognize that in addition to the study of steady-state growth features, where the tip region of the dendrite grows at a constant speed, dendrites also exhibit time-dependent, non-steady features. For example, time-dependent side-branches emerge, amplify, and eventually coarsen.

The Transient Dendritic Solidification Experiment (TDSE) attempts to study fundamental aspects of time-dependent growth, while retaining the advantages of working with a single, isolated dendrite. The TDSE will also attempt to acquire benchmark microgravity data, and provide analyses on transient and time-dependent dendritic growth by employing the effect of the relatively large Clapeyron pressure-mediated melting temperature effect in SCN. A fast change in a sample's hydrostatic pressure quickly changes its liquidus temperature, and thereby provides either more or less free energy or supercooling. With this approach, we plan to observe and measure the kinetics

and morphology of isolated dendrites as they evolves from one well-defined steady-state, at a pre-set supercooling, through a transient stage, to a new well-defined steady-state at the altered pressure/supercooling state.

The major challenge encountered in measuring and analyzing the transient behavior of isothermal dendrites is defining precisely the initial conditions from which or to which the dendrite evolves. Our proposed pressure-mediated TDSE microgravity experiment obviates this difficulty because the transient occurs between two well-characterized steady-states, rather than between an ill-defined initial state and the final steady state. The major results expected are unique data on transient behavior that will extend the scientific bounds from the now well-understood thermal effects, and provide insight into interfacial dynamics where open questions remain.