Orbital Processing of Eutectic Rod-like Arrays (OPERA)

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Task Objective

The objective of this program is to utilize the orbital microgravity environment to conduct unique experiments to evaluate process models that describe convective influences on solidification of regular, low volume fraction, eutectic alloys. These models include a generic model of lamellar and rod-like eutectic solidification and complementary models that concern current interface demarcation and the influences of Soret transport on eutectic and off-eutectic solidification.

Experimentally, we will directionally solidify regular eutectic structures in orbit (microgravity) and terrestrially (1-g) under magnetically damped and undamped conditions. We will simultaneously apply *in-situ* diagnostics to monitor and perturb the solidification interface velocity using current interface demarcation and to precisely monitor the temperature at the solidification interface using Seebeck measurements or subminiature thermocouple arrays. Comparative quantitative sample and data analyses will determine the relations between the velocity, interface temperature (undercooling), and structural parameters (rod diameter and interrod spacing) in microgravity (µg) and in unit gravity (1-g) under magnetically damped and undamped conditions.

Microgravity Rationale

Prior analytical convective sensitivity testing of eutectic solidification theory predicted insensitivity and prior experimental testing of this theory offered broad-based agreement, although mostly for high volume fraction lamellar eutectics that solidified without faceting at the solidification interface. Directional solidification experiments of low volume fraction eutectics under damped (microgravity or magnetic field) conditions, however, have demonstrated significant sensitivity, challenging this fundamental theory. More recent theories have been proposed which introduce: kinetic undercooling, faceting, velocity sensitivity, fluid velocity, and the possibility that the interface composition is not the same as the bulk liquid composition in order to explain the observed sensitivity. This program tests the established and proposed analytical theories and addresses the origins of the discrepancies between the experimental and analytical results. New process model(s) will be developed that will include all of the above possibilities as well as the influence(s) of the diagnostic techniques that will be employed.

Significant Results

The dominant theory that describes eutectic solidification, Jackson and Hunt, was derived for diffusion-controlled growth of alloys where both solid phases solidify metallically (i.e., without faceting at the solidification interface) and with minimum interface undercooling. Both high volume fraction (lamellar) and low volume fraction (rod-like) regular metallic arrays are treated by this theory. Many of the useful solders and brazements, however, and most of the *in-situ* composites are characterized by solidification reactions that are faceted/non-faceted in nature, rather than doubly non-faceted (metallic). Further, diffusion-controlled growth conditions are atypical terrestrially since gravitationally-driven convection is pervasive. As a consequence, it is important

to determine whether these faceted/non-faceted composites behave in the same manner as their doubly non-faceted counterparts. We have selected the regular, faceted/non-faceted, low volume fraction case for investigation because of the potential for process control using directional solidification and the near-isothermality of the interface.

As a critical part of this task, a directional solidification model has been developed and validated experimentally with concomitant thermo-electric interface demarcation. This full transient model includes all of the thermo-electric contributions (Peltier, Thomson, Joule, and Seebeck) and calculates the interface shape and location as a function of time. The eutectic rod-like structure within the pulsed region and within the post-pulse transient is then approximated using the known relationship between velocity and microstructure. This model also incorporates Soret diffusion, induced and applied magnetic fields, and gravitationally-dependent convective contributions.

A separate effort has developed a generalized Jackson-Hunt theory that includes either lamellar or rod-like microstructures, asymmetric phase relations (volume fraction and redistribution coefficients), significant interface undercooling, the full Peclet (velocity) regime, surface energies, and the possibility that the interfacial composition is not the same as the bulk liquid composition.

The above models will be merged, and when completed they will provide a full model of the influences of transient and steady-state experimental conditions, as well as convective influences on directional eutectic solidification.

Experimentally, the need for homogeneous eutectic alloys is obvious. These alloys are being fabricated using rocking furnace technology and directional solidification experiments are being conducted in the Bridgman-Stockbarger geometry. The possibility of macrosegregation being introduced due to Soret Transport is being quantitatively evaluated using the process model, ground experiments, and prior off-eutectic flight results. The terrestrial experiments will continue, and a precursor μg flight experiment has been approved to precisely measure the Soret Coefficient.

The application of current pulses to the directionally solidifying sample is being developed using programmable power supplies and experiment control using Lab-View. Ampoule design is complete and preliminary experiments have been conducted. Process model validation is being pursued under one-g magnetically damped and undamped conditions.

Preliminary evaluation of interface temperature measurement has been initiated using sub-miniature thermocouple, sub-micron thermocouple, and Seebeck technologies. The compatibility of the Seebeck technique with applied magnetic fields will be evaluated and the system requirements will be quantitatively ascertained. Preliminary measurements suggest that Seebeck signals on the order of 10 μV must be processed.

Lastly, the empirical relations between microstructure, interface velocity, and interface solidification temperature are being refined under damped and undamped conditions. Improved techniques are under development for polishing the samples and quantitatively analyzing the microstructures, pattern formations and particle morphology and distribution.