The Effect of Convection on Morphological Stability During Couple Growth in Immiscibles

Barry Andrews
University of Alabama at Birmingham
Department of Materials and Mechanical Engineering
Birmingham, AL 35294
Phone: (205) 934-8452
Fax: (205) 934-8485
E-mail: bandrews@eng.uab.edu

Sam Coriell
National Institute of Standards and Technology
Metallurgy Division
Gaithersburg, MD 20899
Phone: (301) 975-6169
E-mail: corell@coral.nist.gov

Objective

This study is designed to investigate the influence of convection on morphological stability of the solid-liquid interface during directional solidification in immiscible systems. Ground-based experimentation by the investigators indicates that variations in microstructure occur as a result of fluid flow at the solid-liquid interface. The flow generated appears to be capable of disrupting the coupled growth process necessary for the development of desired fibrous microstructures.

This study will combine observations made utilizing transparent metal-analog systems with a detailed analysis of fluid flow on a microscopic and macroscopic scale. The first step involves a theoretical analysis to determine the anticipated fluid flow at the solidification front. The analysis will then move into a combined experimental/theoretical stage where experimentation will be carried out either to verify or disclose weakness in the theoretical portion of the analysis. The findings will make a significant contribution to a better understanding of the role of fluid flow on steady state solidification and coupled growth in immiscible alloys.

Relationship to Microgravity Research

Coupled growth during directional solidification in immiscible systems should be possible due to the presence of the monotectic reaction, $L_1 \rightarrow S_1 + L_2$. In fact, coupled growth of alloys of monotectic composition to produce an aligned fibrous microstructure has been demonstrated in several alloy systems. However, little is known about the solidification process in alloys which are off of monotectic composition (particularly hypermonotectic alloys) because of difficulties encountered when processing these alloys under one-g conditions. It should be possible to process a hypermonotectic alloy under conditions that would result in coupled growth between the L_2 and S_1 phases. Solidification under these conditions would result in an aligned fibrous microstructure consisting of fibers of the L_2 phase in a matrix of S_1. In this case, the L_2 phase would be present in a higher volume fraction than that found at the monotectic composition.

Unfortunately, a simple analysis reveals that steady-state directional solidification in a hypermonotectic alloy results in a composition profile that is convectively unstable. The

convection resulting from the unfavorable density gradient appears to influence the stability of the coupled growth process.

Approach

The approach taken in this study first involves modeling of the density variations in the liquid adjacent to the solidification front. The density variation due to the thermal and solutal fields are calculated to determine the magnitude of the buoyancy force involved with each. Anticipated flows resulting from the above density variations are then calculated and experimentation is carried out to verify the model.

A transparent metal-model system is being utilized in order to facilitate flow visualization. Very small cell wall spacings are being used initially in this study (10 µm) to provide significant damping of buoyancy driven fluid flow. This damping may be sufficient to result in convective stability for very thin sample cells. The sample cell thickness is being varied in order to control fluid velocities ahead of the solidification front. Cell spacings from 10 µm to 1.0 mm will be utilized in order to vary the flow velocities. Non-reactive tracer particles will be utilized to track flow patterns that develop in the cells and to determine flow velocities.

Results to Date

Significant progress has been made in modeling the flow in advance of the solidification front. Since the monotectic reaction involves the decomposition of a liquid into a solid and new liquid phase, analysis is somewhat different than for a eutectic system. Because one of the phases is a liquid, the normal assumption of “no diffusion in the product phases” is not expected to be valid. Analysis has been carried out assuming an infinite diffusion coefficient for the liquid product phase and indicates a much smaller effect than first anticipated. Work has also been carried out on the anticipated effect of surface tension driven flows at the liquid-liquid interface at the tips of the liquid fibers at the solidification front. Work is continuing on the development of the model and is anticipated to continue for some time. Experimentation has begun using two alloy compositions and two cell spacings. These initial experiments are primarily intended to monitor differences in flow rates for the two cell spacings and to determine the influence of this flow on interface stability.