Investigation of the Relationship Between Undercooling and Solidification Velocity

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The study of solidification velocity is important for two reasons. First, the manner in which the degree of undercooling and solidification velocity affect the microstructure of the solid is fundamental. Second, there is disagreement between theoretical predictions of the relationship between degree of undercooling of the liquid and solidification velocity and experimental results.

Thus, the objective of this work is to accurately and systematically quantify the solidification velocity as a function of undercooling for pure metals and alloys. The key theoretical parameters of interface temperature, thermal gradient, and solutal gradient will be extracted through modeling. The results will be examined in order to gain an understanding of the mechanisms controlling interface movement. They will be compared to solidification theory and possible improvements on existing theories will be sought. The primary hypothesis to be examined is that present theories on solidification velocity do not predict the behavior at high undercoolings.

The measurement of the solidification velocity as a function of undercooling, with an emphasis on high undercoolings (>10% T_M), requires containerless processing techniques to limit heterogeneous nucleation sites and to directly observe the interfacial movement. Electromagnetic levitation and electrostatic levitation are the ground-based methods of containerless processing that are best suited for experiments in which the solidification velocity is determined by imaging techniques.

From examination of prior experimental results for the solidification velocity as a function of undercooling, it is clear that in all of the systems there is a discontinuity in the growth rate with increasing undercooling. It is this phenomena and the mechanisms causing it that will be the primary focus of this research. Presently accepted theory (e.g., Boettinger, Coriell, and Trivedi Theory) and the desire to examine single phase solidification provide the basis for the selection of the specific metals and alloys to be examined in this work.

To date, the solidification velocity of electromagnetically levitated metals has been measured using ultra high speed imaging. A ten-by-ten square array of photodiodes, in conjunction with a data acquisition system, was employed to observe the progression of the solid/liquid interface during solidification. The output of each photodiode in the array was sampled simultaneously at rates ranging from 2 ms per frame (500 frames per second) to 1 ms per frame (1,000,000 frames per second). The movement of the solidification front was followed by monitoring the progression of the thermal field developed by recalescence. As the solidification front proceeded across the surface of the sample, an image of the lower hemisphere of a levitated and undercooled drop was projected onto the array of photodiodes. Then, as the interface moved across the surface of a sample, its bright/dim nature caused an increase in output in each photodiode that it crossed. This allowed the position of the interface to be monitored with the photodiode array as it progressed across the drop's surface. From the data, which was collected as a succession of frames in time, the velocity of the interface was determined. This was done by measuring the distance that the interface moved between frames and dividing by the time between frames.

The surface temperature of the drop was measured during solidification, simultaneously with ultra high speed imaging, by a narrow band pass pyrometer. The output from the pyrometer was recorded at 1 kilohertz using standard data acquisition techniques. The pyrometer was exposed to

the same view of the levitated sample as the imaging system via a beam splitter in order to precisely measure the surface temperature of the samples during each experiment.

Comparison of dendritic growth theories to experimental measurements of the solidification velocity as a function of undercooling indicates both the strengths and weaknesses of the theories and the measurements. Qualitative agreement to experimental results is exhibited for low undercoolings and low solute concentrations. However, the theories do not correctly predict the behavior of these materials at large undercoolings. For higher solute concentration alloys there are no areas of agreement between theory and experimental results.