Study of Interesting Solidification Phenomena on the Ground and in Space (MEPHISTO)

J. Iwan D. Alexander[1], J.-J. Favier[2], and J.-P. Garandet[2]

[1] National Center for Microgravity Research on Fluids and Combustion
Case Western Reserve University
Cleveland, Ohio

[2] Comissariat à l'Energie Atomique
DTA/CEREM/DEM/SPCM
17 Rue des Martyrs
Grenoble Cedex 9, France

Abstract

The rationale for many fluids and crystal growth experiments conducted in low-gravity has been that the near absence of an effective gravitational acceleration would allow the study of these systems under purely diffusive conditions. However, spacecraft vibration, gravity gradient, and atmospheric drag generally result in relative accelerations (g-jitter) that may cause "significant" convective motions that could be detrimental to a given experiment. Consequently, experiment sensitivity to g-jitter has received considerable attention. In general, such work has previously been limited to theoretical studies. Motivated by the lack of quantitative *experimental* g-jitter studies we performed a series of benchmark experiments during the Third United States Microgravity Payload (USMP-3) mission (February 22 - March 6, 1996). In addition, a series of experiments focusing on accurately tracking the morphological stability threshold (i.e., the instability associated with the planar-cellular transition) were also conducted. The goal of the g-jitter experiments was to obtain a quantitative experimental assessment of the effects of microgravity disturbances on directional solidification. Solidification experiments with a tin-bismuth (1.5% at. wt.) alloy were conducted under low gravity conditions in the MEPHISTO furnace facility. MEPHISTO is a directional solidification furnace in which three samples are simultaneously processed. There are two heating/cooling subsystems; one of them is maintained at a fixed position to provide a reference interface, whereas the other is allowed to move for solidification and melting of the alloy. The design of the MEPHISTO system makes it possible to run many experimental cycles on the same sample. This in turn allows us to check the reproducibility of the process. In addition, the simultaneous solidification of three samples means that the experimental conditions are well characterized of the experimental conditions. One sample is dedicated to a measurement of the Seebeck voltage between the two ends. This means that the system acts as its own thermocouple, with a "cold" and a "hot" reference junction (respectively the moving and fixed interfaces). The Seebeck voltage is then a measure of the undercooling at the growth front. The essential feature is that the signal is obtained in real time. On the second sample, the position and the velocity of the moving interface are obtained from a resistance measurement. Peltier pulse marking performed on the third sample allows for the determination of the shape of the interface at given time intervals. Moreover, thermocouples present in the liquid phase in the second and third samples are used to determine the temperature gradient and possible thermal fluctuations. The MEPHISTO facility ran for 312 hours, of which 216 hours were dedicated to scientific operation. During this period, 24 solidification/fusion cycles were carried out. Five growth rates were preprogrammed (1.7, 3.7, 5.7, 12, and 24 mm/h) before the flight, but, thanks to "teleoperation," we were able to use different growth rates to track the morphological stability threshold. Selected experiments focused on the quantitative determination of effects of residual acceleration (or "g-jitter") on transport conditions. To obtain well-characterized g-disturbances, the Shuttle's primary reaction control system (PRCS) thrusters were

activated at specific times during the experiments. We obtained 9 PRCS burns, ranging in duration from 10 to 25 seconds. In addition, an OMS burn and a 360° X-axis roll were also performed. The PRCS "burns" were programmed to produce "square wave" impulse accelerations with specific orientations relative to the crystal-melt interface. The experiment response to the residual acceleration caused by the PRCS activity was characterized in real-time using the instantaneous average interfacial composition, $c_{av}(t)$, (determined from the interfacial temperature measured by the Seebeck signal). Residual accelerations were recorded using the Space Acceleration Measurement System (SAMS).

The Seebeck measurements allowed us to make a direct comparison of numerical simulations with a measured experimental characteristic. This unique opportunity allowed us to quantitatively characterize actual g-jitter effects on an actual crystal growth experiment and to properly calibrate our models of g-jitter effects on crystal growth.