The Measurement of the Viscosity and Surface Tension of Undercooled Melts Under Microgravity Conditions and Supporting MHD Calculations

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Objectives of the Investigation

The scientific and technical objective of our experiment in the First Materials Science Laboratory (MSL-1) Space Shuttle mission was to utilize the electromagnetic levitation system, TEMPUS, for the experimental determination of the surface tension and the viscosity of metallic melts, in both the superheated and the undercooled state, using the unique attributes of microgravity. This objective was achieved on both the STS-83 and STS-94 Shuttle missions for several different metals.

Necessity of Microgravity

Ground-based experiments introduce an inherent systematic error in the measurement of surface tension. In addition, the perfect symmetry of the samples, possible only in microgravity conditions, eliminates the splitting of oscillation modes that is observed in ground-based experiments. Based on purely theoretical grounds, Cummings and Blackburn have developed a correction for gravitational and electromagnetic effects on the apparent surface tension; one of the accomplishments of the Second International Microgravity Laboratory (IML-2) flight was to provide the first experimental results suggesting the validity of the correction factor. Surface tension data from the MSL-1 flights suggest that this correction factor, while only about 1-3% for microgravity experiments, is still relevant even for these experiments.

The reason for performing measurements of viscosity under microgravity conditions is quite different. Under earthbound conditions, the levitation forces needed are quite high and the associated rotational component of that force (the curl of JxB) gives rise to transitional or turbulent flows, making the measurement of viscosity impossible for normal metals. However, in microgravity, this internal flow velocity may be greatly reduced because much smaller positioning forces (i.e., about 300 times smaller than under earthbound conditions) are needed to contain the sample. These reduced forces allow a laminar flow condition which will not interfere with the droplet oscillations.

Significant Results to Date

Successful containerless measurement of the viscosity of a liquid metal was demonstrated for the first time during these microgravity experiments, both for the superheated and undercooled regimes. Also, high-precision containerless measurements of surface tension were performed as a part of these experiments.

The measurements of viscosity and surface tension were carried out in TEMPUS using the oscillating drop technique. In this technique a sample is positioned, melted, and superheated. Then, it is allowed to cool, and squeezing pulses of the heating field are applied to excite surface

oscillations that are captured by high-speed video. The apparent area of the droplet is calculated for each frame, and the oscillations are analyzed and fit to determine the frequency and damping constant, which are determined by the surface tension and viscosity of the droplet, respectively.

In this presentation, viscosity and surface tension data are presented for a Pd-18Si alloy for a wide range of temperatures (725 - 1425 °C), covering up to 100 °C of undercooling and 650 °C of superheat. These data prove that the oscillation drop technique is capable of providing containerless measurements of viscosity and surface tension. Measurements of viscosity for this alloy may be correlated as a function of temperature, as $\mu = 0.1917 \exp(5754/T)$ for viscosity μ in mPa-s and temperature T in Kelvin. Surface tension data are corrected and fitted as a function of temperature as $\gamma = 1.949 - 1.91 \leftrightarrow 10\text{-}4\ T$ for surface tension γ in N/m and again, T in Kelvin, to a standard error of better than 1%.

The results described above represent a small portion of the data acquired on the MSL-1 missions. Results are forthcoming for:

- PdSi: 53 melting cycles / ~350 pulses
- Zr: 9 melting cycles / ~ 32 pulses
- FeCrNi (2 compositions): 35 melting cycles / ~ 70 pulses
- Zr Ni Cu Al Nb: 2 melting cycles / ~ 5 pulses
- Ti Zr Cu Ni: 6 melting cycles / ~21 pulses

Calculations of the magnetohydrodynamic flow in the droplets allow comparison of flow conditions between different experiments and samples. These calculations were an important part of the planning of these experiments, and contribute significantly to the importance and utility of the results. Details of these calculations are presented in the paper and presentation.