Foreword: Materials Research in Reduced Gravity 2023

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https://doi.org/10.1007/s11661-023-07195-6

THE topical collection of papers on materials research in reduced gravity in this journal issue are derived from the symposium by the same title that was held at the occasion of the TMS 152nd Annual Meeting & Exhibition in San Diego, CA, on March 19–23, 2023. This collection features both experimental and modeling approaches relevant to the scope of the symposium as follows.

"The absence of gravitational effects such as thermal and solutal buoyancy enables investigation of a large range of different phenomena in materials science. These reduced-gravity experiments can isolate phenomena otherwise obscured in ground-based experiments, leading to new discoveries that can improve materials and processes here on Earth. Long-term experiments in microgravity have a long history—from the early days of spaceflight to current experiments onboard the International Space Station (ISS). Other platforms for reduced-gravity experiments include drop tubes and towers that provide seconds of reduced gravity, aircraft (parabolic flights) that provide tens of seconds, and sounding rockets that provide hundreds of seconds. Abstracts are solicited in all areas of materials research employing reduced gravity, including crystal growth, containerless processing, materials processing and properties, and experimental facilities for materials research. This symposium continues the series *Experimental Methods for Microgravity Materials Science* and *Materials Research in Reduced Gravity*, which have been recurrently held at the TMS Annual Meeting since the 1980s."

The symposium, which was organized by the authors of this foreword, consisted of four half-day sessions. These included 33 oral presentations on scientific topics such as solidification of metals and transparent analogs, thermophysical properties of metallic and semiconductor materials, as well as on more general topics such as space-agency programs and data-archiving systems to encourage a wider access to experimental data.[1] Notably, presented results were not only on space experiments, but to a large extent also on modeling and simulation activities. Most of the accounts were linked to the American and European materials-science research activities (*e.g.*, NASA, ESA, DLR, and CNES).

The papers in this topical collection demonstrate the variety of research questions that can be addressed with reduced-gravity platforms and by that provide an intriguing exposition of the investigations that are being undertaken to advance the scientific state-of-the-art in solidification physics in particular.

- The article "Gravity-Induced Distortion During Liquid-Phase Sintering" by Randall German *et al.* is reporting on the classical on-orbit processing of samples that are then subjected to post-flight metallographic analysis, in this case to study gravitational effects on pore structures and densification of sintered tungsten-alloy components. For these investigations the ESA/NASA Materials Science Laboratory (MSL-MSRR) onboard the ISS was used. Results show that liquid-phase sintering in a reduced-gravity environment poses a challenge as to achieving complete densification, as well as regarding component distortion.
- The article "Thermophysical Properties Measurement of Al–22.5 wt pctCu in Reduced Gravity Using the ISS-EML" by Quentin Champdoizeau *et al.* is presenting results on experiments with the ESA/

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Accepted August 30, 2023.
Article published online September 11, 2023

DLR electromagnetic levitator onboard the ISS, two major application areas of this facility being to measure thermophysical properties in the liquid and undercooled state and to study solidification mechanisms. This contribution focuses on the latter based on metallographic analyses of the returned sample and notes some particular features in the dendritic microstructure and eutectic morphologies, adding to the scientific insight on the formation of microstructures from the melt for the investigated (intermediary) solidification rates.

- The article "The Transient Evolution of Flow Due to the Excitation Pulse in Oscillating Drop Experiments in Microgravity Electromagnetic Levitation" by Gwendolyn Bracker *et al.* is addressing the flow patterns as they occur in the molten sample during one of the established measuring techniques with the already mentioned electromagnetic levitator onboard the ISS. This so-called oscillating drop method consists of applying an excitation pulse in the electromagnetic field, inducing surface oscillations in the sample that are analyzed to determine the surface tension and viscosity of the melt. Magnetohydrodynamic modeling is used to calculate the flow pattern in the levitated sample, revealing that the excitation pulse leads to very complicated variations in velocity with time. With such simulations, experiments can be finetuned to the specific sample material and conditions that unfavorably affect measuring accuracy can possibly be avoided.
- The article "Relating Cooling Rates in Superheated Liquid During Solidification for Powder Characterization" by Peace Muusha *et al.* is proposing a mathematical model to predict cooling rates during mushy-zone solidification that is validated by experiments with the electromagnetic levitator onboard the ISS using the CoSi and FeCrNi alloy systems. The thermal model, that relates liquid and solid cooling rates as a function of melt thermophysical properties, shows good agreement with the experiment for the studied alloys. It may be used to aid in predicting cooling behavior beyond space environmental conditions such as during spray-forming processes.
- The article "*In Situ* Study of Peritectic Couple Growth Under Purely Diffusive Conditions" by Andreas Ludwig *et al.* is introducing an investigation with the organic TRIS-NPG system using ESA's Transparent Alloys device onboard the ISS. With the liquid phase being (more or less) transparent and the solid phase opaque, the use of such substances enables the time-dependent imaging of the solidification process, in this case in a Bridgman furnace that allows for well-controlled directional solidification in flat samples. The observed growth and pattern formation for the studied near-peritectic compositions and various processing conditions provide scientific insights into the solidification mechanisms in equivalent metallic peritectic alloy systems.
- The article "Nucleation and Growth Dynamics of Equiaxed Dendrites in Thin Metallic Al–Cu and Al–Ge Samples in Microgravity and on Earth" by Maike Becker *et al.* is dealing with near-isothermal solidification experiments performed during DLR sounding-rocket missions and the associated ground experiments. These experiments used X-radiography for the real-time monitoring of crystal nucleation and growth in thin samples. While the latter indicated no differences between the reduced-gravity and the terrestrial condition with horizontal sample orientation, the former appeared notably and distinctly different and is deemed to be attributed to convective flow and buoyancy of grains in the on-ground experiments.

For completeness' sake, it is to be mentioned that yet another presentation at the symposium is accompanied by a manuscript that, however, has already been published in an earlier issue of the journal at hand.[2] This paper is exploring the columnar-to-equiaxed transition (CET) during the solidification of aluminum-based alloys using NASA's SUBSA furnace onboard the ISS. Comparison with ground-reference experiments shows distinct differences in the microstructures and as such the results of these benchmark tests will prove valuable for future modeling efforts, notably to validate advanced solidification models with and without gravity implied.

As mentioned in the scope description, the symposium was the latest in a longstanding series of symposia on materials research in reduced gravity that were held at TMS Annual Meetings. Going back in time, the more recent editions have been at TMS2020 in San Diego, CA (4 sessions, 29 oral presentations and a panel discussion[3]), TMS2016 in Nashville, TN (3 sessions, 26 oral presentations), TMS2013 in San Antonio, TX (3 sessions, 24 oral presentations) and TMS2012 in Orlando, FL (6 sessions, 40 oral presentations). These symposia in turn built on the series *Experimental Methods for Microgravity Materials Science* organized by Robert Schiffman from 1988 to 2003. Encouraged by the continued interest, a next edition of the *Materials Research in Reduced Gravity* symposium is currently in the planning for the TMS2026 Annual Meeting.

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