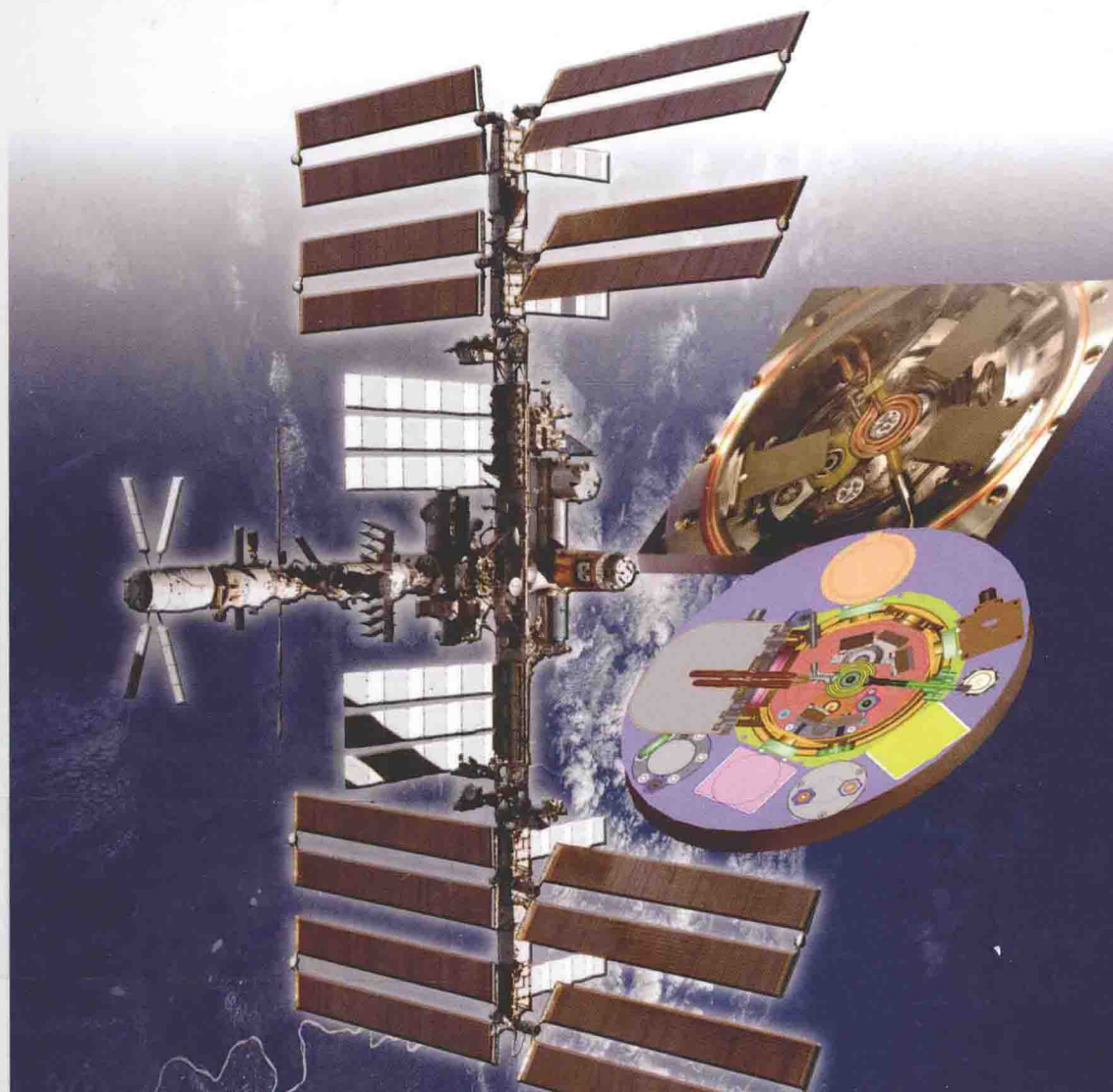


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Solidification of Containerless Undercooled Melts



Edited by Dieter M. Herlach and Douglas M. Matson

Solidification of Containerless Undercooled Melts



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**Solidification of Containerless
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Preface

Metallic materials are prepared from the liquid state as their parent phase. The conditions under which the liquid solidifies determine the physical and chemical properties of the as-solidified material. In most cases time and energy consuming post-solidification treatment of the material is mandatory to obtain the final product with its desired properties and design performance. Therefore, efforts are directed towards virtual material design with computer assisted modelling. This can shorten the entire production chain - ranging from casting the shaped solid from the melt to the final tuning of the product in order to save costs during the production process. The goal is to fabricate novel materials with improved properties for specific applications. To date, metal production is the largest industry worldwide. In the European Union there are 417 700 enterprises with 5.1 Million employees. They correspond to 3.9% of the entire workforce and produce 244.4 billion EUR added value each year (*European business – Facts and figures Eurostat 2007*). Therefore, even small improvements in production efficiency for the metal industry may lead to large economic gains.

Computational materials science from the liquid state requires thermo-physical parameters measured with high accuracy and detailed knowledge of the physical mechanisms involved in the solidification process. In particular, these are crystal nucleation and crystal growth. Both of these processes are driven by an undercooling of the liquid below its equilibrium melting temperature to develop conditions where a driving force for the advancement of a solidification front is created. This gives access to non-equilibrium solidification pathways which can form metastable solids which may differ in their physical and chemical properties from their stable counterparts. Detailed modelling of solidification, both near equilibrium and far away from thermodynamic equilibrium, requires that the solidification process must be investigated in every detail.

In order to achieve the state of an undercooled melt, it is advantageous to remove heterogeneous nucleation sites which otherwise limit the undercoolability. The most efficient way to realize such conditions is containerless processing of melts. In such, the most dominant heterogeneous nucleation process, involving interaction with container walls, is completely avoided. Nowadays, electromagnetic and electrostatic levitation techniques have been developed for containerless undercooling and

solidification of molten metals and alloys. A freely suspended drop gives the extra benefit to directly observe the solidification process by combining the levitation technique with proper diagnostic means. For instance, short range ordering as precursor of crystal nucleation has been investigated by using synchrotron radiation and neutron diffraction on containerless undercooled melts. Additionally, primary phase selection processes for rapid solidification of metastable phases has been observed in situ by energy dispersive X-ray radiation using synchrotron radiation of high intensity. Rapid growth of dendrites is observed on levitation undercooled melts by using video camera techniques characterized by high spatial and temporal resolution.

The application of containerless processing on Earth is limited since large levitation forces are needed to compensate for the gravitational force acting on the samples. The large levitation forces cause undesirable effects like externally induced stirring of the liquid or deformation of the liquid sample from sphere-like geometry. These are overcome when utilizing the special environment of reduced gravity. Here, the forces to compensate for g-jitter, the small random accelerations associated with spacecraft operation, are about three orders of magnitude less than levitation forces on Earth. Based upon such consideration a facility for containerless electro-magnetic processing in space called TEMPUS (Tiegelfreies Elektro-Magnetisches Prozessieren Unter Schwerelosigkeit) has been developed by DLR, the German Space Agency. It was constructed by the German aerospace industry and tested during several parabolic flight campaigns to demonstrate technical functionality. In a cooperation between DLR Space Agency and the US National Aeronautics and Space Administration (NASA), TEMPUS had its maiden flight under real space conditions on board the shuttle Columbia during the NASA Spacelab mission International Microgravity Laboratory IML 2 in 1994. The German – USA cooperation was handled on the principle “no exchange of funds” meaning that the facility was provided by DLR and flight opportunity was offered by NASA. The total experiment time during the 14 days mission was shared between US and German investigator teams. The mission was successful not only by demonstrating technical functionality of TEMPUS in Space but also obtaining interesting scientific results including high accuracy measurements of thermophysical properties and investigations of gravity related phenomena in solidification of undercooled metals and alloys. Later on, TEMPUS was flown again on Columbia during NASA spacelab missions Microgravity Space Laboratory 1 (MSL-1) and Microgravity Space Laboratory 1 reflight (MSL-1R) in 1997. A broad spectrum of science return from the TEMPUS spacelab missions are published in *Materials and Fluids Under Microgravity*, Lecture Notes in Physics, eds.: L. Ratke, H. Walter, B. Feuerbacher (1995) and *Solidification 1999*, Proceedings of symposia at the TMS Fall Meeting 1998, eds.: W. H. Hofmeister, J. R. Rogers, N.B. Singh, S. P. Marsh, P. W. Voorhees (1999).

At present, an advanced Electro-Magnetic Levitator (EML) facility is under development by a common effort between the DLR Space Agency and the European Space Agency ESA. The EML is constructed by ASTRIUM and is scheduled for accommodation on board the International Space Station ISS in 2013. Meanwhile, several international investigator teams of scientists from the member states of ESA, USA

and Japan are preparing experiments dedicated to be performed in Space using the EML multi-user facility on the ISS. In parallel to the experimental work, modelling and theoretical evaluation of solidification processes are planned. In particular, understanding the importance of gravity-driven phenomena like changes in heat and mass transport by forced convection is a central part of these solidification investigations.

These developments both on the experimental and on the theoretical side stimulated the editors of the present book to collect the state of solidification research as far as it is directly correlates to solidification of containerless undercooled melts. These attempts were supported by our colleagues who contributed to the scientific content of the present book. We appreciate their efforts and cooperation in delivering high quality articles to this book. Most of the authors of the book are members of an international Topical Team on Containerless Undercooling and Solidification of Melts (SOL-EML) sponsored by the European Space Agency. We thank ESA for this support and for their vision to bring together experts in this field from all over the world - with membership coming from Europe, North America, Japan and also from China and India. In these latter countries, enormous efforts are undertaken at present to set up a materials science programme in space. In particular, German partners and colleagues benefitted from priority programmes focused on solidification research on undercooled melts in the Earth laboratory, which were financed by the German Research Foundation DFG. This support is greatly appreciated as well. Last but not least the editors are very grateful to Dr. Martin Graf from WILEY – VCH for pleasant and efficient cooperation during the entire course of preparing and editing the present book.

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