Advances in Solidification Processing

FOREWORD

Solidification phenomena are the heart of most of the product manufacturing processes. From conventional manufacturing processes like foundry casting, arc welding, ingot casting etc. to the latest technologies like crystal growth, near-net shape processing, laser processing, and plasma processing, solidification phenomena play a dominant role in process as well as product optimization. Over the last couple of decades, there has been significant progress in the fundamental understanding as well as in the modelling approaches to solidification phenomena. This has led to better product quality and higher productivity of conventional processing. Besides these, the new advances in the understanding of the process have led to the development of several new technologies.

With this background, an International Workshop was organised by Tata Research Development & Design Centre, Pune, in association with the Indian Society of Heat & Mass Transfer (ISHMT) and the American Society of Mechanical Engineers (ASME), on January 10 and 11, 2000 in Pune, India to review the latest developments on several aspects of solidification processing, namely, fundamental understanding and modelling, control and optimization, new technologies and challenges for the next millennium. This volume of *Sādhanā* documents some of the issues that were presented and discussed in the workshop.

The paper by A Ghosh presents a critical review of segregation during solidification processing. Control of segregation (both macro and micro) is one of the most challenging tasks in the quest to improve product quality. The paper discusses fundamental aspects of segregation, and presents the state-of-the-art in experimental and modelling studies of segregation analysis and control. The author briefly discusses centre-line segregation in continuous casting of steel and its control.

G Phanikumar and K Chattopadhyay provide an overview of evolution of microstructure. Solidification microstructure is governed by interfacial instability together with transport at different length scales. The paper discusses different scaling parameters as well as pattern formation leading to different types of microstructures.

The paper by Guo-Xiang Wang, V Prasad and S Sampat presents a mathematical model of rapid solidification during thermal spray coating, which has been validated with experimental data for alumina, yttria and partially stabilised zirconia. Together with careful experiments, growth conditions for different types of microstructure have been identified using the model. The paper finally discusses the effect of some of the process parameters on the solidified microstructure.

Solidification in microgravity has opened up a challenging area in materials processing with possibilities of new microstructures and materials, and the paper by B K Dhindaw presents an overview of this subject. Several fundamental aspects like nucleation, grain growth, pattern formation, particle engulfment and macrosegregation are discussed with respect to microgravity solidification. Solidification experiments carried out on board space shuttles are also discussed.

S Pendurti *et al* present in their paper the mathematical modelling of transport and defect phenomena during growth of single crystals by both Czochralski and Bridgman techniques. Different techniques of crystal growth are also discussed. Dislocation is a major defect in crystal growth and the paper discusses both nucleation and propagation of dislocation. Based on an adaptive grid to represent free boundaries, a comprehensive numerical model to simulate fluid flow, solute and thermal transport is presented.

The paper by K N Seetharamu *et al* presents finite element modelling of the solidification process. Based on visco-plastic material behaviour, a thermo-mechanical model of solidification is discussed, including metal/mould contact and material shrinkage. The prediction of the model is compared with experiment to note good agreement. Several key issues of finite element application in solidification process are also reviewed.

Thermo-solutal convection plays a key role in controlling macrosegregation patterns in solidification of alloys and Suresh V Garimella and James E Simpson carry out detailed numerical simulation to study its impact during directional solidification. Comparative studies of macrosegregation are carried out between solidification in a differential cavity in gravity and Bridgman crystal growth in microgravity and the role of thermo-solutal convection on segregation is discussed.

Using a continuum mixture model of solidification, the paper by A K Singh *et al* presents a number of studies to highlight different important roles of convection. The predicted macrosegregation data are compared with the measured one and the importance of appropriate modelling of flow in mush is demonstrated. Need for accurate representation of mush is further strengthened through some careful numerical simulations. Finally, the characteristics of thermo-solutal convection during solidification for different materials are reported and macrosegregation patterns are compared.

Continuous casting of steel is one of the most challenging application of solidification phenomena and the paper by Amit Chatterjee and Sanjay Chandra presents a critical overview of different technical developments in continuous casting. The main focus of the paper is on one of the recent technological innovations in the steel industry, the thin-slab casting machine, to produce thin slabs which are hot-charged in the tunnel furnace and directly rolled. The paper further discusses the several advantages of the thin-slab caster and presents a techno-economic analysis clearly stating the benefits accruing from thin-slab caster installation.

S Mazumdar and S K Ray present a critical analysis of several operational and fundamental parameters which affect the solidification process during the continuous casting of steel. Detailed analyses are presented on the effect of mould friction/lubrication, mould oscillation and initial shell formation on caster productivity and quality. The role of steel chemistry on the thermo-mechanical state of solidifying strands is discussed. Finally, control of continuous casting of stainless steel slabs is presented based on these principles.

G Ravichandran in his paper describes a thermal analysis of plasma arc welding using a finite element-based model, which is rigorously validated by carrying out experiments. Based on this model, the paper presents a comprehensive analysis on the effect of different process parameters (like welding current and speed) on weld pool characteristics including solidification characteristics.

This special issue thus presents a wide range of interesting research work on the fundamentals (like segregation, microstructure, convection) and applications (thermal sprays, crystal growth, welding and continuous casting) of solidification phenomena. It is

hoped that this issue will be useful to researchers and practising engineers in their respective fields of application.

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Guest Editor