

Numerical Simulation of Solidification Processes

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1. Introduction and Scope

Solidification is a critical step for many manufacturing processes, including casting, welding, and additive manufacturing. While solidification happens during the processing of all types of materials, the solidification of metallic alloys has been of utmost importance to scientists and engineers. This importance comes from the fact that the solidification microstructure has a significant influence on the properties of the solidified materials. The kinetics of solidification also determines the distribution of solute atoms, which eventually leads to micro-segregation, secondary phases, and the formation of various defects, which exert enormous influence on mechanical properties. By combining the bedrock computational physics and informatics with systematic experiments and advanced manufacturing, we can reduce the cost, risk, and cycle time for new product development. Numerical simulation of solidification processes can help scientists gain a better understanding of the kinetics governing the macroscopic, as well as microscopic, features of the solidification process. From an industrial point of view, solidification modeling enables engineers to predict the properties of the material and subsequently modify the process parameters to produce materials of higher quality. Several physical phenomena are involved during solidification processes that, in turn, make the simulations very complex. In the wake of promising progress in the area of solidification modeling, this Special Issue embraces studies on the numerical simulation of solidification phenomena for a variety of applications and processes.

2. Contributions

In this Special Issue, eleven high-quality papers from distinguished researchers are published that cover a wide range of solidification modeling studies including steel casting and solidification, permeability, segregation, cracking and thermal distortion, dendrite growth and grain morphology, welding, and additive manufacturing.

Two of the papers covered topics related to the additive manufacturing of nickel and titanium alloys with studies on 3D modeling of the solidification structure evolution of superalloys in powder bed fusion additive manufacturing processes [1] and in situ X-ray radiography and computational modeling to predict grain morphology in β -Titanium during simulated additive manufacturing [2].

Three of the papers were focused on phase-field modeling of dendritic microstructure evolution and presented studies on permeability measurements of 3D microstructures generated by phase-field simulation of the solidification of an Al-Si alloy during chill casting [3]; a phase-field study on the interaction between grains during columnar-to-equiaxed transition in laser welding [4]; and a two-dimensional phase-field investigation of unidirectionally solidified tip-splitting microstructures [5].

Five papers focused on the casting and solidification of steel, which presented investigations on the optimization of heavy reduction processes on continuous-casting bloom [6]; the effects of alloying elements on solidification structures and macro-segregation in slabs [7]; the prediction of thermal distortion during steel solidification [8]; an analysis of micro-segregation of solute elements on the central cracking of continuously cast



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bloom [9]; and numerical simulation of macro-segregation formation in a 2.45 ton steel ingot using a three-phase equiaxed solidification model [10].

Finally, we provided a review of large-scale simulations of microstructural evolution during alloy solidification [11] featuring the framework and methodologies for achieving scalability in solidification microstructure simulations while highlighting the areas of focus that need more attention.

As Guest Editor of this Special Issue, I hope that the papers included in this collection will be beneficial to scientists and engineering in advancing their research and development endeavors.

3. Conclusions and Outlook

The progression of the numerical models and computational techniques for the simulation of solidification processes has shown that the factors for realistic results are constantly improving. In prediction analysis, the complexity has grown with respect to technological advances. The combination of improved physics models and computational algorithms with thermodynamical databases would enable the calculation of multicomponent phase equilibria, allowing for more reliable simulations for real-world industrial applications. Several manufacturing and material processing applications can take advantage of the prediction capabilities offered by solidification simulations, which include casting, welding, and additive manufacturing processes. The modeling approaches still have many improvements to innovate upon, with promising developments in novel numerical techniques, machine learning, and computing power.

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