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Variational Methods

Quantitative variational phase-field modeling and simulation of powder bed fusion additive manufacturing

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Abstract

Powder bed fusion additive manufacturing offers unique opportunity for materials design through process regulated microstructure.
To fully exploit the potential, a reliable process simulation tool linking the process parameters and the resultant microstructure is indispensable, and variable phase-field models are promising.
However, the underlying physical processes during powder bed fusion are complex.
This requires the consideration of thermal and/or chemical diffusive phenomena arising across various interfaces, including the solid-melt interface, free surfaces of grains, as well as the grain boundaries. A main issue thereby is the quantitative validity of conventional variational phase-field models when they are coupled with diffusive phenomena with asymmetric transport properties across the interfaces.

In the first funding period, we derived successfully a quantitative variational phase-field model for sintering processes with the grain-pore interface as key feature, and considerable progress was achieved towards non-isothermal models and including cross-coupling in the kinetics.
To further achieve a quantitative and variational description of the full non-isothermal model of the powder bed process, including melting, resolidification, melt flow, and structural relaxation of pore and grain structure in direct coupling to heat transfer, the solid-melt interface will be mostly regarded in the second funding period.
Even though there are quantitative variational non-isothermal phase-field solidification models, the fluid dynamics induced mass transport and the strong viscosity asymmetry across the melt-solid interface have not treated thereby. This will be regarded in the proposed phase-field model.

More importantly, we aim also at the mathematical analysis of asymptotic regimes of the proposed phase-field model with focus on quantitativeness at the sharp-interface limit of the developed quantitative variational phase-field models.
Last but not least, a unified and systematic analysis and numerical approximation of the aimed model via variational methods in space and time as well as the numerical analysis will be considered. The obtained model will be applied to simulate powder bed fusion and the resultant microstructure of model material systems like stainless steel 316L and the yttria-stabilized zirconia. In the long run, the simulation data will be used to extract the process-microstructure correlation and process optimization.