BEYOND VALIDATION: PREDICTIVE RELIABILITY OF METAL AM MODELS ACROSS SCALES

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ABSTRACT

Computational modelling in metal additive manufacturing has advanced significantly, with established approaches for melt-pool dynamics, solidification, microstructure evolution, residual stresses and distortion. Reduced-order, surrogate and data-driven models complement these approaches and increasingly contribute to integrated computational materials engineering (ICME). However, a model that performs well for one prediction may not necessarily be reliable for another. Models are usually calibrated or validated against selected experimental observations, but agreement with these measurements does not guarantee the accuracy of other outputs. For instance, thermal models that reproduce similar melt-pool dimensions may predict different temperature gradients, solidification velocities and cooling rates, which are subsequently used in microstructure simulations. Similarly, inherent-strain and other reduced thermo-mechanical approaches can predict distortion efficiently, but their applicability to residual stress prediction or different geometries and processing conditions needs to be examined.

This becomes particularly important when results from one model are used in another or when simulations are used to optimize process conditions. Assumptions about the physics, numerical resolution, material data and model simplifications affect the information available for subsequent predictions. Uncertainties in these quantities may also influence the results at other scales. Furthermore, optimizing process parameters for one response, such as melt-pool geometry, does not necessarily lead to favourable microstructure, residual stress or component performance. These limitations become more relevant with developments such as beam shaping, multi-beam processing, new alloys and complex industrial applications, where models are often extended beyond the conditions for which they were originally assessed. An important question is therefore how much physical detail is needed, which information can be transferred reliably and whether the resulting predictions are adequate for their intended engineering application.

This invited session welcomes contributions examining the predictive capabilities and limitations of computational models used in metal additive manufacturing. Topics include model fidelity and reduction, reliability of information transferred between scales, uncertainty and sensitivity propagation, transferability across processes, materials and geometries, and single- or multi-objective optimization. Studies using high-fidelity, reduced-order, multiscale and data-driven approaches are encouraged, particularly those comparing modelling strategies or demonstrating where existing approaches become less reliable. The session aims to bring together researchers working at different modelling scales to exchange perspectives on predictive capabilities and limitations, with the broader goal of improving the applicability of simulation to process and material development and engineering decisions in metal additive manufacturing.