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A Bayesian-Calibrated Multiscale Framework for Predicting Texture Evolution in Laser Beam Powder Bed Fusion

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Abstract

Laser beam powder bed fusion (PBF-LB) offers a transformative pathway for tailoring the crystallographic texture and mechanical properties of metal components[1]; however, the predictive reliability of numerical models is often hindered by parametric uncertainty and simplified physics. This study addresses these limitations by integrating a coupled computational fluid dynamics–phase-field (CFD–PF) model with a surrogate-assisted Bayesian calibration framework to quantitatively predict microstructural evolution in austenitic stainless steel. The framework is subsequently extended to Ti-6Al-4V titanium alloy to verify its robust applicability in predicting melt pool morphology across different material systems. The CFD component, implemented via the OpenFoam based laserbeamFoam framework[2], accounts for complex laser–powder interactions, recoil pressure, and Marangoni convection, while the phase-field model resolves competitive grain growth at grain envelope scale by incorporating temperature-dependent mobility and anisotropic grain boundary energy. To bridge the gap between simulation and reality, Bayesian inference was employed to calibrate critical parameters, such as effective absorptivity and surface tension gradients, using experimental melt pool geometries and microstructural features[3]. The calibrated model is quantitatively compared with experimental data, highlighting the transition between <100>//BD and <101>//BD textures and the emergence of stray grains under varying hatch spacings. Sensitivity analysis further reveals that hatch spacing is a primary determinant of texture outcomes compared to power or scan speed. By providing quantitative confidence intervals for microstructural predictions, this research establishes a robust, uncertainty-aware methodology that facilitates process optimization and inverse design of additively manufactured materials. Reference

Keywords:

Additive manufacuring Laser beam powder bed fusion Bayesian calibration Melt pool dynamic Phase field modeling Microsturcture evolution

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