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Modeling of melting, solidification, and microstructure evolution in laser powder bed fusion process

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Additive manufacturing (AM) processes are receiving widespread attention due to the ability to create or repair precision engineering components without use of any die or mold. Currently, the approach to obtain a specific user defined epitaxial microstructure is a challenging and expensive iterative process. Modeling and validation of solidification microstructure can be leveraged to reduce iteration cost in obtaining a desired microstructure. We developed the combined approach in microstructure prediction during laser powder bed fusion (LPBF) process. Numerical Volume-of-fluid based method incorporating Marangoni convection can accurately predict the resultant melt pool geometry and temperature distribution which can serve as an input in prediction of microstructure evolution in solidifying mushy region. Hence, in the present study, computational fluid dynamics (CFD) analysis is used to predict melt pool characteristics and phase field modeling is employed to simulate microstructure evolution in the as-deposited state for LPBF process. The phase field framework is also modified to incorporate the convection term in scan direction, and it is coupled with the concentration equation to predict segregation of secondary elements and microstructural transition. Different features of LPBF microstructure such as segregation of secondary elements, rapid solidification effect, dendrite sizes, dendritic orientation, dendritic morphology, and surface roughness are investigated and validated through comparison with experimental results. Phase-field Model suggests strong dependency of dendrite orientation on surface roughness and scan speed, and suggests potential of columnar flip or oriented-to-misoriented transition at higher scan speed. Segregation of the secondary elements is found to be the dominant factor in resultant dendrite width in the range of 1 to 3 µm. Furthermore, the developed method is extended to predict the change in orientation of dendrites as new layers are built atop previous layers. Undergoing work is focused to include effects of non-linearity in phase diagram by coupling thermodynamic database with concentration equation for model ternary alloy, as well as extension of the current models to predict grain structure in 3D using HPC clusters with objective of predicting residual stress and fatigue life for as-deposited AM components.