Mesoscale Simulation of Nucleation and Grain Growth of Ti-6Al-4V Alloy in Selective Laser Melting

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ABSTRACT

In selective laser melting (SLM), parts are built by selectively melting metallic powders layer by layer with a high-energy laser beam. It has a variety of applications in aerospace, medical device, and other low-volume manufacturing. Nevertheless, the lack of fundamental understanding of the process-structure-property (P-S-P) relationship for better quality control inhibits wider applications of SLM. Recently, a mesoscale simulation approach, called phase-field and thermal lattice Boltzmann method (PF-TLBM) [1-2], was developed to simulate microstructure evolution of alloys in SLM melt pool with simultaneous consideration of solute transport, heat transfer, phase transition, and latent heat effect.

In this work, a nucleation model based on a Poisson seeding algorithm is introduced in the PF-TLBM model to simulate heterogeneous nucleation at the boundary of melt pool in SLM. A new method is also developed to estimate the thermal flux out of the SLM melt pool given a constant cooling rate. The effects of latent heat and cooling rate on dendritic morphology and solute distribution are studied. The quantitative analyses of thermal history, time evolution of solid phase fraction, and composition distribution are also provided.

The simulation results of Ti-6Al-4V alloy suggest that the inclusion of latent heat is necessary because it reveals the details of the formation of secondary arms, reduces overestimated microsegregation, and provides more accurate kinetics of dendritic growth. The simultaneous considerations of solute transport, heat transfer, nucleation, and dendritic growth are necessary to understand complex rapid solidification in SLM. By considering the release of latent heat, the model is able to predict the temperature field, composition distribution, and dendritic morphology with more detail than models without latent heat.

The PF-TLBM model predicts the microstructure evolution in the SLM process at a reasonable time scale and with tightly coupled multiple physics. The predicted microstructure is the central hinge of the P-S-P relationship, which needs to be investigated for process design and optimization. Classical continuum simulation methods cannot provide fine-grained material phase and composition distribution, whereas atomistic models cannot simulate the time scales which are long enough for manufacturing processes. The proposed mesoscale multi-physics PF-TLBM model is a key component in a multiscale simulation framework for SLM.

REFERENCES

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