

PROCEEDINGS

Numerical Simulation for Microstructure Control in Ultrasonic Assisted Directed Energy Deposition

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ABSTRACT

The controllability and predictability of microstructure are important for high-quality component fabrication in metal additive manufacturing. However, the unstable melt pool flow leads to the microstructure coarsening and anisotropic distribution in directed energy deposition. To address this problem, a numerical method is proposed to establish the relationship between the behavior of melt pool flow and grain nucleation under ultrasonic vibration. The challenge of controlling the microstructure evolution caused by the melt pool flow is solved by this method. The ultrasonic force and particle force are introduced into the modified momentum equation in the developed thermal-fluid-solid-ultrasonic coupling model, with the carrier gas-solid phase interaction incorporated. The intrinsic mechanism is revealed as ultrasonic energy input enhances the nucleation kinetics through controlled melt pool flow behavior. The uniformity of temperature and gradient distribution in the melt pool is significantly improved by the regulation of ultrasonic vibration. The grain coarsening induced by the local overheating and excessive temperature gradients is eliminated, and the solidification rate is enhanced. Compared with traditional directed energy deposition, the nucleation rate is increased by 68.6% and the proportion of equiaxed grains is raised by 51.7% through the specific flow characteristics induced by ultrasonic vibration. Furthermore, this work reveals that the nucleation rate is determined by the cooling rate and melt pool flow velocity. The synergistic control of the laser beam and particle flow rate leads to the melt pool velocity being increased by 23.4%, cooling rate being elevated by 205 K/s, and average grain size being reduced by 20.1%. This work provides a reliable numerical framework and practical guidance for melt pool dynamics prediction and microstructure control in metal additive manufacturing.

KEYWORDS

Additive manufacturing; multi-physics modeling; melt pool dynamics; ultrasonic vibration

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