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Thermo-fluid Modeling of Influence of Attenuated Laser Beam Intensity Profile on Melt Pool Behavior in Laser-Assisted Powder-Based Direct Energy Deposition

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Abstract

A numerical framework based on Computational Fluid Dynamics (CFD), using the Finite Volume Method (FVM) and Volume of Fluid (VOF) technique is presented to investigate the effect of the laser beam intensity profile on melt pool behavior in Laser-assisted powder-based Directed Energy Deposition (L-DED). L-DED is an Additive Manufacturing (AM) process that utilizes a laser beam to fuse metal powder particles. To assure high-fidelity modeling, it was found that it is crucial to accurately model the interaction between the powder stream and the laser beam in the gas region above the substrate. The proposed model considers various phenomena including laser energy attenuation and absorption, multiple reflections of the laser rays, powder particle stream, particle-fluid interaction, temperature-dependent properties, buoyancy effects, thermal expansion, solidification shrinkage and drag, and Marangoni flow. The latter is induced by temperature and element-dependent surface tension. The model is validated using experimental results, and highlights the importance of considering laser energy attenuation. Furthermore, the study investigates how the laser beam intensity profile affects melt pool size and shape, influencing the solidification microstructure and mechanical properties of deposited material. The proposed model has the potential to optimize the L-DED process for a variety of materials and provides insights into the capability of numerical modeling for additive manufacturing optimization.