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Precision Modeling of Directed Energy Deposition for Inconel 625: Advancing Additive Manufacturing and Industrial Applications

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Abstract : Directed energy deposition (DED) is a transformative additive manufacturing technology that enables the fabrication of high-performance components with complex geometries and customized properties. This study focuses on the computational modeling and experimental validation of the DED process for Inconel 625, a nickel-based superalloy recognized for its superior mechanical strength, exceptional corrosion resistance, and high-temperature performance. Leveraging Flow3D software, a CFD-VOF-based model was developed to capture the intricate physics of the DED process, including phase change, thermal gradients, and molten pool dynamics. The model is grounded in solving conservation equations for mass, momentum, and energy, alongside phase transition dynamics, to predict deposition geometry, temperature distribution, and flow behavior with high accuracy. The simulation precisely characterizes the interaction between the laser and material, providing insights into optimizing key parameters such as laser power, scanning velocity, and powder feed rate. Experimental validation was conducted by fabricating single tracks of Inconel 625 under controlled conditions. The results showed remarkable consistency between simulated and experimental outputs, with deviations in wall geometry and thickness well within acceptable limits. These findings underscore the model's robustness and its potential to improve DED process reliability and efficiency. Inconel 625's unique properties position it as a critical material for industries such as aerospace, energy, and automotive, where components must endure extreme conditions and prolonged usage. This research contributes to advancing additive manufacturing by providing a reliable simulation framework that accelerates innovation, enhances process precision, and reduces costs associated with trial-and-error experimentation. The outcomes highlight the strategic role of computational modeling in bridging the gap between research and industrial applications, offering a pathway for developing next-generation manufacturing technologies.

Keywords : additive manufacturing, directed energy deposition, flow 3D, Inconel 625, modeling, simulation
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