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Towards effective production in DED: linking process parameters to the properties of the deposition

By

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The rapidly advancing field of Additive Manufacturing (AM) has ushered in a myriad of technological innovations, among which Direct Energy Deposition with Laser Beam and Powder Feedstock Material (DED-LB/Powder) shows remarkable potential for efficient material deposition in industrial applications. However, optimizing these systems demands an interdisciplinary methodology supported by robust process parameters. This study employs the Design of Experiments (DoE) to navigate this complex landscape, offering a systematic approach to establishing reliable, data-driven process parameters.

This work is structured into two main parts. The first focuses on characterizing the powder feeder system and narrowing down the variables that interact during the fabrication process. This phase is critical for isolating key parameters and laying the groundwork for subsequent optimization. The second part is devoted to the experimental development and testing of a method for establishing a linkage between the three typical physical processes in DED: powder stream dynamics, melt pool formation, and track solidification. By comprehensively examining these interrelated phenomena, the study aims to create a cohesive framework that enhances the predictability and robustness of DED-LB/Powder systems, thereby advancing their readiness for broader industrial applications.

The first segment of this study focuses on the comprehensive characterization of the powder stream process within a powder feeder system. Utilizing a combination of experimental techniques, statistical analyses, and regression methods, response surfaces were derived. These surfaces not only delineate the operational boundaries and ranges but also enable the precise setting of factors to achieve a specified powder mass flow rate. The subsequent phase optimizes the carrier gas level, essential for adequate powder transportation. By tuning this variable, the study establishes the optimal gas level required for consistent and accurate deposition, thereby minimizing variability.

The second segment of this study is dedicated to the formulation of mathematical models that serve as a bridge between three core physical processes involved in DED.

Through hypothesis testing and multifactorial experimentation, the efficacy and robustness of the developed methodology were rigorously evaluated. Specifically, three physical properties of the specimens—density, porosity, and micro-hardness—and one geometric property, the target height growth, were examined. A single experiment was conducted to assess both the robustness and sensitivity of the method. Utilizing regression analyses, relationships among these variables were established. In the final phase, a computational code was developed that provides end-users with the necessary process parameters tailored to varying input conditions.

The meticulous analyses conducted in this study validate the initial hypotheses and generalize the findings, making them both applicable and adaptable to a wide array of DED-LB/Powder systems. This work comprehensively addresses the initial research questions and provides a nuanced understanding of the DED-LB process, laying the groundwork for future research in this rapidly evolving field. Through the systematic exploration and validation of key process parameters and their interactions, the study establishes a rigorous mathematical framework that facilitates optimized material deposition. The contributions of this research stand as a seminal effort in bridging the knowledge gaps in DED-LB systems and offer a robust foundation for subsequent investigations.