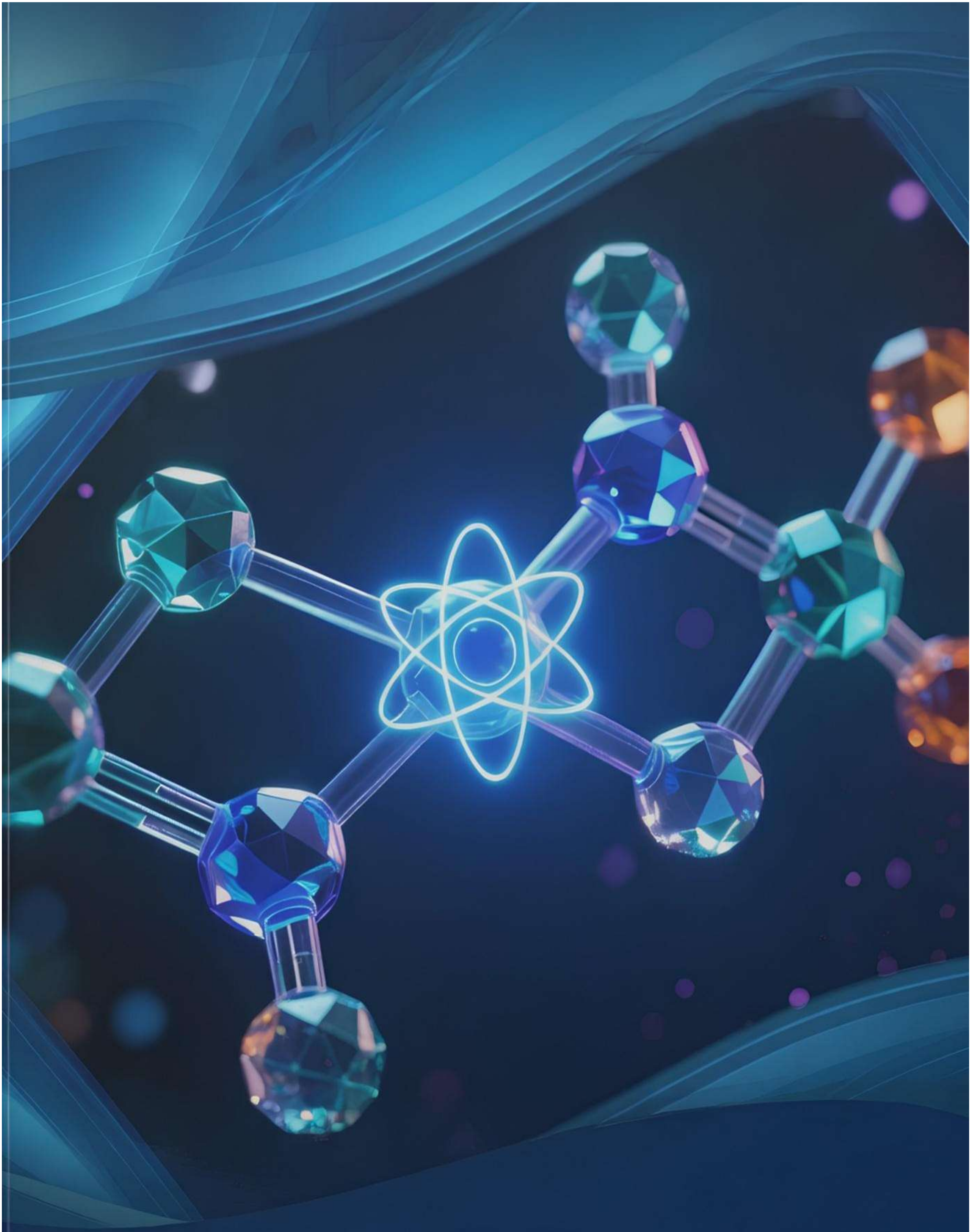

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From Thermal History to Properties: Experimental and Numerical Studies of Micrometallurgical Processes in Direct Energy Deposition Additive Manufacturing

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Abstract

Additive manufacturing (AM) involves layer-by-layer material deposition to produce fully functional components. The thermal history during processing strongly affects microstructure evolution, mechanical properties, and residual stress development. These characteristics depend on process parameters and local thermal conditions. Improper parameter selection may lead to excessive residual stresses, distortion, cracking, reduced corrosion resistance, and non-uniform material performance. Therefore, understanding and controlling thermal history is essential for obtaining reliable component properties.
This work investigates the relationship between thermal history, microstructure evolution, mechanical properties, and residual stresses in Direct Energy Deposition (DED) manufactured components. The study evaluates the possibility of predicting these characteristics using temperature measurements acquired during processing. Initial experiments performed with a custom thermal imaging system revealed significant challenges related to temperature acquisition and data processing, leading to discrepancies between measured and expected results. Experimental observations were therefore correlated with numerical simulations.
The developed numerical model enables faster parameter selection to achieve the desired microstructure while minimizing residual stresses. Model validation was performed using temperature measurements and substrate displacement recorded during manufacturing. Temperature evolution was monitored with thermocouples and pyrometers, whereas displacement was measured using Digital Image Correlation. Good agreement between simulations and experiments was achieved.
The results demonstrate that additively manufactured components cannot be considered fully homogeneous at the macroscopic scale. Local thermal variations produce measurable differences in microstructure, mechanical response, and residual stress distribution, which should be considered in process optimization.

Keywords: additive manufacturing, direct energy deposition, thermal history, numerical simulations