Sustainable Process Hybridization of Additive Manufacturing for Enhanced Manufacturing Efficiency

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Abstract

This study investigates the hybridization of Powder Bed Fusion using Laser Beam (PBF-LB/M) and Directed Energy Deposition using Arc (DED-Arc) for the efficient manufacturing of stainless-steel components. Benchmark specimens were fabricated to assess dimensional accuracy and mechanical performance, followed by the development and validation of a hybrid manufacturing workflow incorporating DED-Arc deposition, intermediate surface preparation, and PBF-LB/M processing. PBF-LB/M exhibited superior dimensional accuracy and achieved the highest ultimate tensile strength (UTS) of 597 MPa, whereas DED-Arc attained a comparable UTS of 573 MPa with good ductility despite lower geometric precision. The hybrid specimens achieved a UTS of 595 MPa, with fracture occurring in the DED-Arc region adjacent to the interface, indicating a strong metallurgical bond between the two processes. Hardness measurements and metallographic characterization further confirmed a gradual microstructural transition across the DED-Arc/PBF-LB/M interface. A hybrid manufacturing case study successfully validated the proposed workflow, demonstrating the capability of integrating DED-Arc for rapid bulk deposition with PBF-LB/M for high-precision feature fabrication. By leveraging the complementary strengths of both processes, the hybrid approach offers a more sustainable manufacturing strategy through improved material and energy efficiency, reduced production time, and optimized resource utilization while maintaining high component performance.