ABSTRACT

Martensitic stainless steel 420 (SS 420) is widely used in plastic injection molds and tooling components but exhibits limited surface service reliability under cyclic mechanical contact and thermal loading. To enhance surface performance, this study investigates steady magnetic-field-assisted (MF) laser cladding and powder-fed laser-directed energy deposition (L-DED) of Super Duplex Stainless Steel 2507 (SDSS 2507), selected due to its high strength and balanced ferrite-austenite microstructure, to establish process-structure-property correlations and develop data-driven optimization strategies. Pre-placed powder laser cladding is performed with and without MF (0, 3, and 6 mT) using Taguchi L_{81} design. MF assistance stabilizes molten-pool convection and modifies thermal history, resulting in grain refinement, an increase in high-angle grain boundary fraction, and reduced lattice distortion. X-ray diffraction peak shifts correlate with EBSD observations, showing reduced kernel average misorientation and increased HAGB fraction, indicating improved strain accommodation and solidification stability under MF assistance. These microstructural modifications improve hardness and tribological behaviour, while Raman spectroscopy confirms the formation of a protective Fe-Cr-O tribo-oxide within the wear tracks. Multi-objective optimization (MOBO, NSGA-II, MOPSO, and MODA) identifies Pareto-optimal solutions, and multi-criteria decision-making identifies an experimentally validated condition that achieves controlled dilution with improved hardness and wear resistance. Explainable machine-learning models predict clad geometry and hardness with high accuracy ($R^2 > 0.90$) and quantify parameter contributions. Powder-fed L-DED under MF conditions is investigated using Taguchi L_{48} design, highlighting single-track and multi-layer deposition behaviour. Compared with pre-placed laser cladding, L-DED provides improved deposition stability, enhanced integrity of the overlap zone, and more uniform microstructural characteristics across deposited layers. EBSD reveals improved grain-boundary characteristics, while TEM analysis confirms refined Cr_7C_3 carbide precipitation and stabilized dislocation substructures. These refinements improve hardness, wear resistance, and corrosion resistance in chloride media. Thermal-cycle measurements establish a correlation between MF-modified solidification behaviour and performance enhancement. Overall, MF-assisted laser deposition is an effective surface engineering strategy that improves the performance of SS 420 mold tooling by integrating experimentation, optimization, and explainable artificial intelligence.

keywords: Steady magnetic field; Laser cladding; Laser-directed energy deposition; Super Duplex Stainless Steel 2507; Martensitic Stainless Steel 420; Microstructural evolution; Tribological behaviour; Corrosion resistance; Multi-objective optimization; Explainable machine learning.