**Machine Learning-Driven Optimization of Cold Spray Process Parameters: A Robust Inverse Analysis for Higher Deposition Efficiency**

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**Abstract:**

Cold spray technology has become essential for industries requiring efficient material deposition, yet achieving optimal deposition efficiency (DE) presents challenges due to complex interactions among process parameters. This study developed a two-stage machine learning (ML) framework incorporating Bayesian optimization to address these challenges. In the first stage, a classification model predicted the occurrence of deposition, while the second stage used a regression model to forecast DE values given deposition presence. The approach was validated on Aluminum 6061 data, demonstrating its capability to accurately predict DE and identify optimal process parameters for target efficiencies. Model interpretability was enhanced with SHAP analysis, which identified gas temperature and gas type as primary factors affecting DE. Scenario-based inverse analysis further validated the framework by comparing model-predicted parameters to literature data, revealing high accuracy in replicating real-world conditions. Notably, substituting hydrogen as the gas carrier reduced the required gas temperature and pressure for high DE values, suggesting economic and operational benefits over helium and nitrogen. This study demonstrates the effectiveness of AI-driven solutions in optimizing cold spray processes, contributing to more efficient and practical approaches in material deposition.

**Keywords:** Cold spray; deposition efficiency; machine learning; Bayesian optimization; explainable AI.