A Digital Twin for Residual Stress and Porosity Estimation in Cold Spray Additive Manufacturing

Abdoolah Badaloo[1,2], Muhammad Faizan-Ur-Rab[2], Saden H. Zahiri[2], Syed. H. Masood[1], Suresh Palanisamy[1]*

**abadaloo@swin.edu.au*

[1,] School of Engineering and Technology, Swinburne University of Technology, Hawthorn, Melbourne, Australia 3122

[2,] CSIRO Manufacturing, Commonwealth Scientific and Industrial Research Organization, Clayton, VIC 3168, Australia

Abstract

Cold Spray Additive Manufacturing (CSAM) is a promising solid-state deposition process capable of producing high-performance metallic components without inducing thermal degradation. However, two critical challenges residual stress and porosity formation significantly affect the mechanical integrity and functional reliability of CSAM parts. This study introduces a digital twin framework designed to reliably predict residual stresses and porosity distributions during the cold spray process.

A large-scale, high-fidelity simulation involving 10,000 particles has been successfully executed using a Lagrangian finite element method within ABAQUS/Explicit. Unlike conventional models that rely heavily on assumed upstream parameters, this framework is empowered by a validated cold spray digital twin (CSDT), which provides accurate boundary conditions, including particle velocity, temperature, and impact dynamics derived from computational fluid dynamics (CFD) simulations. The digital twin bridges experimental calibration and computational modelling, ensuring realistic representation of the physical process.

The model outputs demonstrate excellent agreement with experimental data, particularly in predicting the average residual stress and porosity across multiple material systems. The study also captures localised stress concentrations and microstructural heterogeneities with enhanced resolution, supporting better process control and optimisation.

This digital twin approach not only improves simulation accuracy but also significantly advances the predictive capability of CSAM, offering a scalable and adaptable tool for future industrial applications. By coupling data-driven input conditions with advanced numerical techniques, this study sets a new benchmark for multi-scale modelling in additive manufacturing and opens new avenues for design, optimisation, and qualification of cold spray components.

Biography

Abdoolah Badaloo is a researcher in Advanced Manufacturing with a focus on Cold Spray Additive Manufacturing (CSAM). He is currently completing his PhD in collaboration with CSIRO, where his research integrates high-fidelity finite element modelling and digital twin frameworks to predict residual stress and porosity in CSAM components. Abdoolah combines deep technical expertise in numerical simulation (using Abaqus/Explicit) with experimental validation to drive innovation in solid-state manufacturing. Passionate about bridging computational science with real-world applications, his work contributes to the development of high-performance, sustainable manufacturing solutions for aerospace, defence, and biomedical industries.