Physics-Informed Machine Learning of Thermal Stress Evolution in Laser Metal Deposition

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Abstract Rapid laser scanning generates a complex heat-affected zone with steep temperature gradients in laser additive manufacturing, including laser metal deposition (LMD) and laser powder bed fusion process (LPBF). The complex thermal history and severe gradients lead to very high thermal stresses that evolve into residual stresses after the component cools down. Data-driven methods, such as machine learning (ML), offer an alternative to traditional physics-based simulations for calculating the thermal stress evolution. However, ML often requires a large, labeled training dataset, which is computationally inefficient. In addition, the "black box" nature of data-driven ML methods makes it difficult to interpret the results. Additionally, data-driven ML methods do not use governing physical laws underpinning laser additive manufacturing to make them data-efficient. This study aims to develop a physics-informed ML (PIML) model that can predict thermal stresses during laser scanning without requiring any labeled training dataset. A case study has been conducted to demonstrate the predictive capability of the PIML method and examine the evolution of thermal stresses in an LMD process.

Keywords Metal additive manufacturing · Thermal stress · Physics-informed machine learning

Introduction

Coupled partial differential equations (PDEs) are widely used to model complex phenomena in various scientific and engineering fields. A growing area of research

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