A Unified Physics-Based Framework for Incremental Modelling of Residual Stress in History-Dependent Manufacturing Processes

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ABSTRACT: Residual stress plays a fundamental role in determining the structural integrity, dimensional accuracy, and fatigue performance of manufactured components. Depending on the manufacturing process, it evolves under thermal loading, mechanical loading, or their coupled interaction, making its prediction a major challenge in manufacturing science. While experimental characterization is costly and finite element analysis is computationally expensive for predictive applications, this keynote lecture presents an incremental physics-based analytical framework for predicting residual stress evolution by accounting for the entire loading history through sequential thermo-mechanical analysis. Owing to its general formulation, the framework is applicable to a broad range of manufacturing processes, including laser powder bed fusion, machining, burnishing, shot peening, and laser shock peening. The proposed methodology is demonstrated and verified through pulsed laser powder bed fusion as a representative case study, where the predicted residual stresses show good agreement with X-ray diffraction measurements.

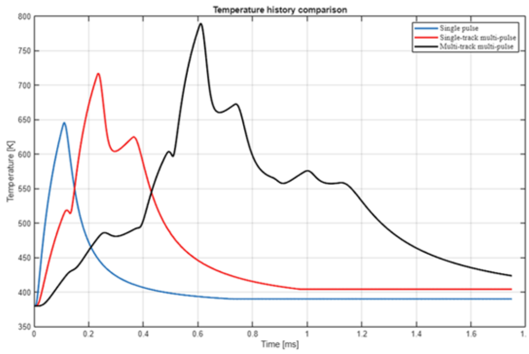

Figure 1: Temperature history as load path for single-pulse, multi-pulse single track and multi-pulse multi-track pulsed laser powder bed fusion

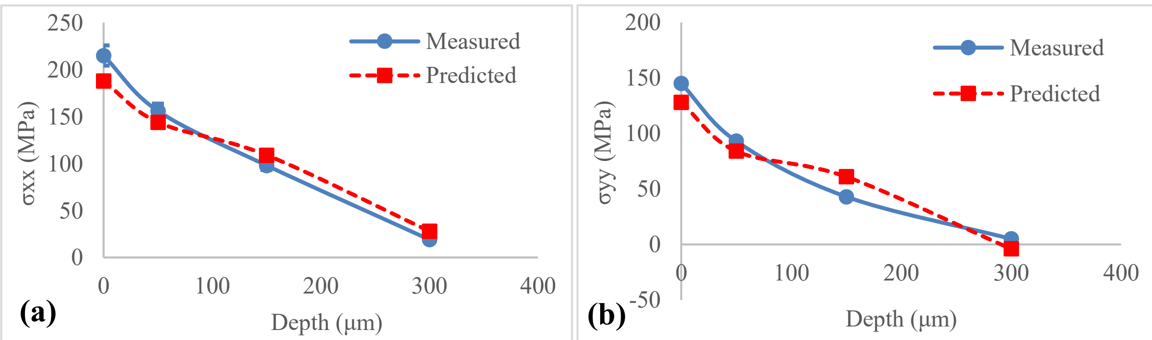

Figure 2: Distribution of residual stress in (a) track direction (b) hatch direction

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