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As-Built CAD Models: A Tool for Fatigue Life Prediction of Additively Manufactured Strut-Based Lattices

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Abstract

Despite the remarkable advantages of metal additive manufacturing (MAM) in enabling the efficient fabrication of complex and multifunctional geometrical architectures, such as lattice structures, the printing process inherently introduces a certain degree of defects. These imperfections, often associated with surface roughness, parasitic masses, dross formation, and internal flaws, critically degrade the fatigue performance of additively manufactured components. Nevertheless, such detrimental effects are frequently overlooked during the design phase, where structural optimization typically neglects the actual as-built morphology. Consequently, full-scale testing of MAM lattice structures often fails to capture the true local failure mechanisms ruled by the interplay among geometry, surface features, and internal defects.

To address these limitations, recent research has increasingly focused on miniaturized specimens that reproduce the fundamental sub-unital features of strut-based lattices, such as individual struts and junctions, thereby enabling accurate microscale mechanical characterization while reducing experimental cost and time. In this work, we propose a novel and cost-effective methodology for predicting the fatigue behavior of such sub-unital elements without resorting to expensive monitoring techniques like X-ray Computed Tomography (CT). The approach integrates stereo-optical surface reconstruction with CAD and implicit modeling workflows to accurately reproduce three-dimensional strut geometries. Finite Element (FE) analyses of these reconstructed models are evaluated using the average strain energy density (ASED) criterion and validated against both CT-based FE models and experimental results, establishing correlations through an ASED–Nf relationship derived from bulk Ti-6Al-4V L-PBF specimens. This framework represents an initial step toward defining a robust pathway to bridge microscale and macroscale mechanical behavior, ultimately enabling fatigue-tolerant and cost-efficient lattice designs that can accelerate the industrial adoption of MAM technologies.

Keywords: metal additive manufcaturing; fatigue life prediction; strut-based lattices; finite element analysis