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Strain-controlled low cycle fatigue loading of single-cell lattice structures using digital image correlation and finite element simulations

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Abstract

Cellular structures produced by additive manufacturing (AM) can be effectively employed to produce components with tailored mechanical performance by engineering the unit-cell shape and its relative density at the mesoscale. Nevertheless, their attractiveness is questioned by the intrinsic structural weakness of such intricate geometries, which makes it challenging to reliably predict the failure behaviour, especially in cyclic loading applications, i.e. fatigue. Understanding the mechanisms underlying failure events is crucial for predicting fatigue performance. From the experimental perspective, techniques such as current potential drop, acoustic emission, and thermal field measurements are proven to offer global insights into damage. Nevertheless, these methods lack localised failure detection. To shed some light on the local material cyclic response and failure behaviour of these structures, the study relies on an in situ digital image correlation (DIC) investigation on small-scale specimens, each consisting of a single cell, tested under low-cycle fatigue conditions. The imposed macroscopic strain amplitude was controlled by a dedicated online DIC-based controller. Two lattice cell types with differing mechanical responses (FBCCZ and gyroid) were selected for fatigue tests. The specimens were fabricated from 316L steel by laser powder bed fusion (L-PBF). Both the macroscopic cyclic elastoplastic response and the local strain field were analysed, enabling detection of strain concentrations at weak points. This approach allowed monitoring of damage evolution at global and local scales and finding a correlation between the two. Concurrently, finite element (FE) models for both lattice specimens were created and validated by comparing simulated and experimental stress-strain responses. Fatigue failure was then estimated using a volume-averaged strain-energy-density criterion implemented in an FE framework. The obtained experimental and numerical data for a single cell provide a crucial foundation for advancing both the understanding of damage mechanisms and the multiscale modelling of lattice structures consisting of multiple cells.

Keywords:

Cellular structures Low cycle fatigue Cyclic elastoplastic behaviour Digital image correlation Finite element simulations