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Thermomechanical fatigue behaviour monitoring of additively manufactured AISI 316L via temperature Harmonic Analysis

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Laser-based Powder Bed Fusion of Metals (LPBF) is an advanced additive manufacturing technology that enables the production of geometrically complex components using metallic alloys, such as AISI 316L steel. However, LPBF-processed materials typically exhibit higher porosity and microdefect densities compared to those produced by more traditional fabrication methods. Consequently, while static mechanical properties may still meet design specifications, fatigue reliability is often compromised. Furthermore, fatigue optimisation is challenged by the limitations of standard fatigue characterization procedures, which are time-consuming, costly, and frequently yield highly dispersed results. These limitations stem from factors such as microdefect-induced brittleness and residual stresses resulting from suboptimal post-processing thermal treatments.

This study investigates the application of thermographic methods as a potentially efficient approach to assess the intrinsic fatigue behaviour of LPBF materials. Thermographic methods, as employed herein, involve monitoring thermomechanical metrics derived from surface temperature measurements during cyclic fatigue loading. The capacity to effectively capture these temperature-based metrics during stepwise tests with incrementally increasing load amplitudes enables the early detection of intrinsic heat dissipation. The stress amplitude associated with a significant increase of dissipation rate correlates with the onset of irreversible microdamage accumulation, ultimately resulting in fatigue failure. Therefore, thermographic methods offer the potential to determine material-intrinsic fatigue stress thresholds in a relatively rapid and effective manner.

The extension of thermographic methodologies to the evaluation of LPBF metals is particularly relevant for industries that may benefit most from this technology, e.g. the biomedical and aerospace sectors. These sectors, characterized by stringent regulatory requirements for material qualification in fatigue-prone applications, stand to benefit significantly from the enhanced efficiency that the thermographic fatigue assessment may offer.

Specifically, this study explores the feasibility of a stepwise Thermographic-Method approach based on the evaluation of temperature harmonic metrics. These have the advantage to be obtainable at early stages of each stepwise loading block, by high-frequency sampling of the temperature signal over a few seconds. The acquired dataset is then fully post-processed within seconds, yielding near-real-time full-field maps of the amplitude and phase of the first and second temperature harmonics. These harmonics are subsequently employed to monitor both the development of localized damage, via thermoelastic signal maps, and the local/average level of intrinsic dissipation associated with each loading block.

The results demonstrate that the chosen thermographic metrics effectively monitor the structural health evolution of the test coupons during the incremental stepped fatigue tests. Each metric correlates with the material status through distinct mechanisms, which are presented and discussed.

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