Influence of Plastic Localization on Fatigue Crack Nucleation and Life Dispersion in Inconel 718 at the Microstructural Scale

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Abstract

Nickel-based superalloys are extensively used in the aerospace industry due to their exceptional high-temperature performance and corrosion resistance. A key characteristic of these materials is their tendency to deform heterogeneously, leading to the formation of slip bands on the material's surface, which are particularly pronounced in the case of Inconel 718. During cyclic loading, intense slip bands play a critical role in the nucleation of fatigue cracks. These bands are strongly dependent on the microstructure, a relationship that may hold the key to understanding the variability in fatigue life. Despite the importance of this phenomenon, existing microstructure-sensitive fatigue models often neglect it in numerical simulations due to computational limitations, as fine meshes are required to accurately represent slip bands.
This study investigates the influence of incorporating slip localization into polycrystalline simulations for predicting fatigue crack nucleation. The objective is to evaluate whether considering plastic localization enhances the accuracy of predictions and, if so, to what extent.

The methodology is as follows: Experimental characterizations are first used to create representative microstructures that replicate key features of Inconel 718 specimens, such as a high number of twin grain boundaries and non-metallic inclusions (NMI)-two known crack nucleation sites. During cyclic loading, slip bands and cracks primarily develop at the surface of samples, so introducing a free surface in the simulation is crucial for accurately capturing this phenomenon. Crystal plasticity simulations are then performed on these microstructures using the spectral solver AMITEX. The resulting fields are analyzed to calculate Fatigue Indicator Parameters (FIP) (1), which quantify the driving force for crack initiation. These FIPs act as a bridge between plasticity and fatigue through a life-prediction model, as in (2). The FIPs in this study incorporate local plastic strain or stress measures to account for cracking mechanisms associated with slip bands and NMI.

To account for plasticity localization in crystal plasticity simulations, two methods are compared to classical crystal plasticity models. The first uses a softening behavior law (3), while

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the second employs a geometrical approach based on weakest link theory (4).

Finally, all models are calibrated using cyclic tests on Inconel 718. Numerical results are compared to experimental micromechanical test data to assess their accuracy. The ultimate goals of this work are twofold: first, to investigate crack nucleation sites and validate the predictions against experimental results; second, to explore the variability in fatigue life predictions and evaluate the ability of the different approaches to capture microstructure-induced fatigue life dispersion.

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