20th European Mechanics of Materials Conference - EMMC20
Florence, Italy | May 27th-29th, 2026
www.emmc20.unifi.it

4D Characterization of the relationship between the microstructure, deformation mechanisms and the fatigue cracking of a nickel-based superalloy

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Paper ID: 338
Symposium S9: Fatigue evaluation: modelling and characterisation at different length scales
Extended Abstract

Abstract

The initiation and propagation mechanisms of microstructurally short fatigue cracks (MSFCs) are still not fully understood. This limited understanding arises because, at the grain scale, fatigue damage is primarily governed, among other, by local microstructural variability. To improve insight into MSFC behavior, in situ observations of fatigue damage must be correlated with characterization of the local microstructure and local mechanical state. MSFC initiation and propagation are most often characterized using 2D electron microscopy techniques. However, such observations provide partial information and do not capture the 3D nature of fatigue damage evolution or its time-dependent behavior. Significant progress has been achieved with synchrotron X-ray imaging techniques, which enable separate non-destructive 3D in situ observation of fatigue damage, microstructure, and local mechanical fields. But no studies have correlated all of these 3 observations within a single experimental framework. In this work, we propose a new characterization protocol for MSFCs based on synchrotron techniques with in situ fatigue loading. This approach enables direct correlation between fatigue damage evolution, microstructural features and local mechanical state. Conducted on Inconel 718 (IN718), this study aims a better understanding of MSFC initiation and propagation mechanisms. For this study, the NANOX device was developed by the “Centre des Matériaux” and the European Synchrotron Radiation Facility (ESRF) to perform in situ fatigue loading. Each tested IN718 sample was loaded with a targeted HCF behavior. During fatigue loading, 3 different X-ray imaging techniques were used at the ESRF. Phase contrast tomography (PCT) to describe fatigue damaging. Diffraction contrast tomography (DCT) to describe grain morphology and orientation. And 3D X-ray diffraction (3DXRD) to describe internal mean elastic strain. Multiple DCT, PCT and 3DXRD scans were performed throughout fatigue testing. Each technique relies on a specific reconstruction algorithm and data formats. To enable correlation between these measurements, dedicated 3D field alignment procedures were developed, combining image processing for damage detection and volumetric digital correlation for geometric registration. Fatigue testing combined with data reconstruction highlight the presence of short cracks with lengths of 1 to 2 µm. These observations enable quantification of crack initiation time and identification of initiation sites. They also reveal the existence of different crack initiation mechanisms, even within the same specimen. Tracking MSFCs propagation within the IN718 microstructure revealed significant variability in crack growth rates from one crack to another. Moreover, it shows that crack growth rate was not necessarily correlated with the crack initiation time. This work enabled correlation of MSFCs propagation data with several microstructural and mechanical features. Crack growth rates and propagation directions were extracted from and related to the distance to grain boundaries, grain-to-grain misorientation, crystallographic grain orientation, and internal stresses within individual grains. The nature of the MSFC initiation and propagation mechanisms will be discussed in light of these comparisons.

Keywords:

Fatigue Synchrotron 4D characterization Short cracks IN718.