Influence of overload on the propagation of 3D short fatigue cracks

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Abstract

Short abstract

The influence of tensile overload on fatigue crack growth of a short 3D crack has been monitored in 3D using X-ray tomography, and displacement fields computation with digital volume correlation.

Introduction

Structural components, *e.g.* aircraft, railways, or automotive applications, are inevitably

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submitted to Variable Amplitude fatigue (Schijve, 2001). Even when components are designed for constant amplitude loading, occurrence of overloads or underloads in service is frequent and affect the fatigue crack growth rate. In most metallic alloys a few cycles of crack acceleration followed by FCG retardation are usually observed after a tensile overload. Since the early seventies, the study and modelling of overload has been focused on long through cracks. However fatigue cracks are inherently 3D objects that remain part-through short cracks during a large fraction of the fatigue life (Schijve, 2001). Due to a lack of experimental data, the fundamental mechanisms of the propagation of 3D cracks under non-constant amplitude loading have not received enough attention yet. The goal of this study is thus to understand overload effects on physically small 3D fatigue cracks in order to build predictive models.

Methodology

The material of the study, an AlSi7Mg0.6 cast aluminium alloy, was specifically designed by the CETIM to provide a fine speckle pattern of eutectic Silicon particles for Digital Volume Correlation (DVC). Besides it has a grain size (@150μm) small enough to ensure a smooth crack plane. The experimental procedure consisted in subjecting corner-notched dog-bone type samples to cyclic tensile loading (frequency=20Hz, R=0.27) in-situ at PSICHÉ X-ray tomography beamline of SOLEIL synchrotron. When the crack has propagated away from the previous overload, another overload was applied until the unbroken ligament became too small. Up to 4 overloads, at decreasing load ratio (FOL/Fmax from 1.8 to 1.3), could be applied on one specimen. During the loading sequence, 3D tomography scans of the sample were regularly acquired before, during and after a single overload. On some key cycles, several acquisitions were obtained at intermediate load steps between the extremums to study crack opening and closure.

Results

Analysis of the raw tomographic volumes allows the crack fronts, hence crack growth rates, to be obtained while analysis of the displacement fields from DVC allows extracting Stress Intensity Factors (SIF) and crack opening displacement along the crack front. DVC was performed with UFreckles software (Réthoré, 2018) using a size of element of 8 pixels (20.8μm) and SIF were computed by projecting the 3D displacement field onto Williams series solutions (Lachambre et al., 2015). Characteristic periods of crack retardation after overloads are observed, with crack growth recovery occurring first in the bulk of the sample, then later close to the free surfaces.

Interestingly, no correlation between the measured Stress Intensity Factors (SIF) and crack growth rates after the overload is evidenced. The SIF range of post-overload cycles are unaffected by the overload. Although the crack is effectively blocked after the overload, the value of KI remains the same. Finite Element calculation using DVC as boundary conditions corroborates the SIF values obtained with DVC and allows to characterize the evolution of the plastic zone along the crack front to confirm the larger plastic zone close to the free surfaces in relation with a larger closure effect.

If the SIF parameter is no more an appropriate driving force after the overload, the analysis of the crack opening displacement from measured displacement fields allows to understand what happens at the crack tip during the overload cycle with plastic deformation, crack tip blunting and residual effect of the overload. Finally, the evolution of crack tip opening after the overload seems a more promising parameter to correlate with fatigue crack growth delay and crack recovery than the SIF.

Conclusion

This study allows to characterize the effect of tensile overloads on a 3D short fatigue crack evidencing strong differences between the free surfaces and the bulk that could not have been observed and quantified without x-ray tomography and digital volume correlation.

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