3D study of overload effects on fatigue crack growth through X-ray tomography and image correlation

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Abstract. By examining fatigue crack growth with 3D computed tomography, and computing corresponding displacement fields with digital volume correlation, the effects of a single tensile overload on crack growth and behaviour are investigated. The experimental procedure consists in subjecting corner-notched AlSi dogbone type samples to cyclic tensile loading *in-situ* at a synchrotron X-ray tomography beamline.

Introduction

The largest part of the fatigue failure proces in metals consists in the stage of development of small nonthrough fatigue cracks after initiation[1]. These cracks are characterized by an irregular geometry and a highly tridimensional mechanical behaviour [2]. Overloads (OL), i.e. a one-time increase in the maximum load within a cycle, were shown to slow down or stop fatigue crack growth for a number of cycles in the case of tensile-tensile cylic fatigue loading[3].

Because real load histories applied to actual working mechanical components almost always stray far from simple tensile-tensile cyclic load and feature variations, quantifying overload effects is of primary interest to mechanical design . Understanding the relationship between 2D and 3D behaviour of small fatigue cracks is also criticla, since the evaluation of the extent and severity of a crakc is only available on the surface in most real-life applications.

Procedure

For this study, AlSi dog-bone samples were manufactured before being subjected *in-situ to* cyclic tensile loading at a synchrotron X-ray tomography beamline. A laser notch is applied on the corner of the central square cross section of size 1.6x1.6mm. Across the loading sequence, 3D reconstructions of the samples (scans) were regularly acquired with an intensification of the number of scans at points of interest within the load history (near OLs). When nominal crack growth is achieved, a single OL was applied and its effects were observed.

Characteristic periods of crack retardation after OLs have been observed, with crack growth recovery occurring preferentially in the bulk of the sample, rather than close to the free surfaces as it had been previously observed in [2]. This phenomenon indicates the difference of behaviour between the surface and the core of the sample that emerge from the conditions of 3D crack growth. Loading continued until nominal crack growth has been achieved once more, or when the crack reached the opposite end of the sample. These observations are summarised on an example on Fig. 1.

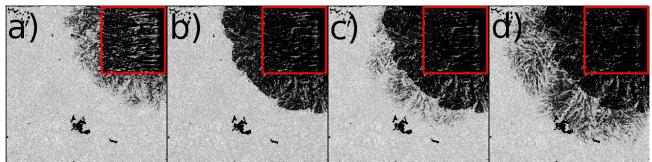


Figure 1: Projection of the crack on the sample cross section (detail) at different points in the loading sequence. a) At N_1 =215kc, crack has grown from the initial notch (shown in red) under nominal fatigue loading, b) At $N_2 = N_1$ +1 after the application of an OL, the crack remain arrested at this position for 85kcycles, c) at N_3 =490kc, crack has resumed growing after OL through the core of the sample (centre) but remains mostly blocked close to the free surfaces (top and right side), d) at N_4 =560kcycles, crack growth as resumed all throughout the sample.

Results

The alloy designed for this study features a 3D speckle pattern of eutectic Si particles, facilitating the use of digital volume correlation (DVC) for displacement field reonstruction.

Extracting crack opening displacement maps from displacement fields allows the crack closure phenomenon to be studied qualitatively and quantitatively. This value can be linked to local plasticity effects and correlated to local crack growth rates.

Crack growth rates can be measured locally by comparing the position of the crack front between two scans of the sample at different steps of the load, allowing the quantification of the "core-preferential" effect of crack growth resumption mentioned previously.

In order to quantify crack growth behaviour, crkack growth rates and stress intensity factor ranges are computed. The systematic study of these parameters is expected to yield quantitative insight into the retardation phenomenon.

Conclusion

This study showcases the interest of synchrotron X-ray tomography to get a complete grasp on the 3D aspects of fatigue crack growth and of digital image correlation to gather quantitative data and provide insight on the phenomenon.

References

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