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

L. Sanciet--Munier[1a], N. Limodin[1] J.-Y. Buffière[2], J.-F. Witz[1], J. Réthoré[3], M. Coret[3], G. Bahaj Filali[3], Y. Gaillard[4], M. Fleuriot[4], A. Bonnin[5], G. Lovric[5], A. King[6], J. Lachambre[2] and A. Weck[7]

[1]LaMcube – Laboratoire de Mécanique Multiphysique Multiéchelles, Villeneuve d'Ascq, France, [2]MATEIS, INSA Lyon – Villeurbanne, France, [3]GeM - Institut de Recherche en Génie Civil et Mécanique, Centrale Nantes, Nantes, France, [4]CTIF – Centre Technique des Industries de la Fonderie, Sèvres, France, [5]TOMCAT beamline, Swiss Light Source, Paul Scherrer Institut, Villigen, Switzerland, [6]Synchrotron SOLEIL, Saint-Aubin, France, [7]Department of Mechanical Engineering, University of Ottawa, Ottawa, Canada

[a]lucas.sanciet-munier@centralelille.fr

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 aluminium silicon dog-bone type samples to cyclic tensile loading *in-situ* at a synchrotron X-ray tomography beamline.

Introduction

The largest part of the fatigue failure process in metals consists in the stage of development of small part-through fatigue cracks after initiation [1]. These cracks are characterized by an irregular geometry and a highly three-dimensional 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 cyclic fatigue loading [3].
Because real load histories applied to actual working mechanical components almost always stray far from simple tensile-tensile cyclic load, quantifying overload effects is of primary interest to mechanical design. Understanding the relationship between 2D and 3D behaviour of small fatigue cracks is also critical, since the evaluation of the extent and severity of a crack 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. Throughout the course of the loading sequence, 3D reconstructions of the samples (scans) were regularly. Near OLs, the frequency of acquisitions was increased. 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 emerges from the conditions of 3D crack growth. Loading continued until nominal crack growth rate has been recovered, or when the crack reached the opposite end of the sample. These observations are summarised on an example in Fig. 1.

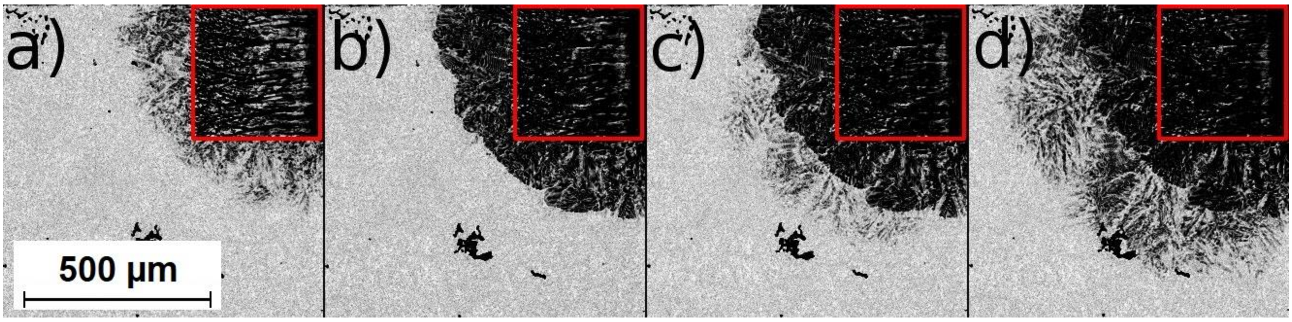

Figure 1: Projection of the crack on the sample cross section (detail) at different cycles. a) At N_1=215k cycles, crack has grown from the initial notch (shown in red) under nominal fatigue loading, b) At $N_2 = N_1+1$ after the application of an OL, the crack remains arrested at this position for 85k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

Results

In order to quantify crack growth behaviour, crack 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.

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 reconstruction.

Crack growth rates can be measured locally by comparing the position of the crack front between two scans of the sample at cycles. The effect of preferential post-OL growth towards the core of the sample can thus be studied quantitatively.

Extracting crack opening displacement maps from displacement fields allows the crack closure phenomenon to be studied qualitatively and quantitatively. Comparing all measured values to variations in the local crack growth rate gives way to the understanding of crack growth behaviour in relation with local plasticity effects.

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 volume correlation to gather quantitative data and provide insight on the phenomenon.

Acknowledgments

The authors wish to acknowledge the French National Research Agency (ANR) for funding this research as part of the ADVENTURE project (ANR-20-CE08-0017). The authors also thank the staff of the TOMCAT beamline at SLS and the staff of the PSICHÉ beamline at SOLEIL for providing access to their respective facilities for our experiments.

References

[1] Schijve, J., 2009. Fatigue of Structures and Materials

[2] Proudhon et al. 2012. https://doi.org/10.1016/j.crhy.2011.12.005

[3] Suresh, S., 1998. Fatigue of Materials,