Experimental report

02/10/2019

Proposal: 1-02-258

Council: 10/2018

Title: How does the load ratio in fatigueaffect fracture initiation?

Research area: Engineering

This proposal is a resubmission of 1-01-162

Main proposer: Harry COULES

Experimental team: Cui Er SEOW
Harry COULES
Molly PROBERT

Local contacts: Thilo PIRLING
Sandra CABEZA

Samples: Aluminium alloy 7475

Instrument	Requested days	Allocated days	From	To
SALSA	6	5	23/07/2019	28/07/2019

Abstract:

In metals subjected to fatigue, the ratio of constant to cyclic loading affects the crack growth rate and the development of a plastic wake which forms around the crack tip. During the transition from fatigue crack growth to unstable fracture, this difference in prior plastic deformation affects the material's apparent initiation fracture toughness. We will use SALSA to observe elastic strains during high-cycle fatigue loading and infer the plastic wake development from the measured data via reconstructive finite element analysis. By relating this to fracture toughness measurements, we will determine the cause of observed differences in the toughness of metals after fatiguing at different stress ratios.

ILL Experimental Report 1-02-258

How does the load ratio in fatigue affect fracture initiation?

H. E. Coules, M. A. Probert and C. E. Seow

Background

Cracks in structural components subject to progressive crack growth mechanisms may reach a critical size, after which sudden fracture occurs. In particular, the mechanism of transition between fatigue crack growth and fast fracture is of interest to many industries. Systems which experience cyclic loading include aeroplane landing gear, oil platform supports subjected to wave action or pressure vessels which are cyclically pressurised and de-pressurised.

Fatigue cracking is driven by stresses which often have both fluctuating and constant components. The ratio between the magnitude of these two loading components affects the crack growth rate, as well as the critical load that leads to fast fracture. Higher stresses in fatigue lead to the growth of a plastic wake along the crack flanks and alter the plastic zone ahead of the crack tip.

Aim

We aim to demonstrate that observed differences in (apparent) fracture toughness of materials subjected to high-cycle fatigue at different load ratios results from plastic wake development. We will also determine whether this is caused via strain-hardening of the crack tip material by the wake, by the development of a crack tip residual stress field, or by combination of factors.

Experiment

Stroboscoptic diffraction measurements were performed during fatigue cycling of fracture specimens. SALSA's list mode functionality was used to take continuous neutron diffraction measurements during in situ fatigue loading of aluminium alloy 7475-T7351 compact tension specimens. The {311} lattice reflection was studied as this has previously been shown to give a good bulk average of this material. This required a wavelength of approximately 1.7 Å. A gauge volume of 2×2×2 mm was created by use of the 2 mm primary slit and 2 mm secondary collimator, this was positioned 1.88 mm +/- 0.125 mm ahead of the crack tip. During fatiguing, the crack length was continuously monitored and by incrementally moving the hexapod the position of the gauge volume was kept at a constant position relative to the moving crack tip.

The SALSA Instron 50 kN load rig was programmed to perform sinusoidal fatigue cycles in load control with periodic reduction in load magnitude to keep the crack tip conditions constant throughout the 10mm of crack growth. Continuous monitoring of the specimen Crack Mouth Opening Displacement (CMOD) using a clip gauge allowed for compliance measurements of the specimen to be used to monitor the crack length.

Analogue outputs from the Instron control software were connected to the high-speed analogue inputs for Nomad. By monitoring the load and CMOD through Nomad the Instron data could then be used to facilitate binning of individual neutron detection events according to the phase of the sinusoidal fatigue loading. A digital output from the Instron was also utilised. This output was monitored by the Nomad 'watchdog' to allow automatic movement of the hexapod at specified times within the Instron program and corresponding break in collection of diffraction data that could have been distorted by the movement of the specimen. A set of functions written in MATLAB was used to analyse the data. This first split the list mode data into arrays of load and corresponding time stamps, and neutron diffraction events with corresponding times stamps. A sine fit was applied to the loading data and manually assigned phase widows allowed time windows to be determined. Each neutron diffraction count was then assigned to the corresponding time window and recombined into LAMP readable files to be fitted in the usual way. A gaussian fit with a flat background was used to determine the peak parameters of each et of neutron counts.

Grid scans were also taken centred about the crack tip to determine the extent of the compressive residual strain ahead of the crack tip after fatigue crack growth. The specimens were then loaded to failure in situ, and further grid scans were taken during loading. Comb-type d0 specimens were used for unstrained lattice measurement.

Results

The three different frequencies of fatigue load studied are shown in Figure 1. Lower elastic strains are measured in the specimens subjected to lower frequency loading, which suggests that material viscoplasticity affects the fatigue process. These measurements are believed to be the first stroboscopic data taken using SALSA.

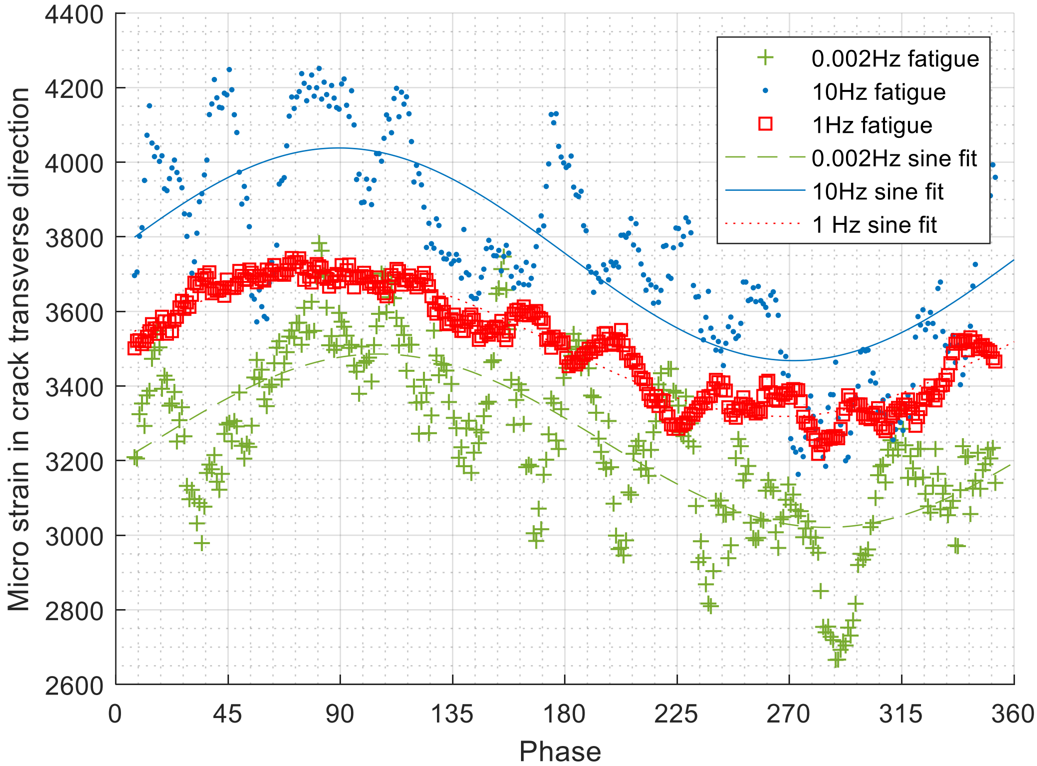

Figure 1: Elastic strain calculated from stroboscopic neutron diffraction measurements during fatigue loading at 10Hz, 1Hz and 0.002Hz (quasi-static). Neutron counts have been binned in 15°-wide phase bins with a 1° offset between bins.

The residual strain in the crack-transverse direction after the full length of crack growth is shown in Figures 2 & 3. The green area shown in Figure 2 indicates a tensile region ahead of the crack tip. A comparison between these grid scans and a finite element model (using a material model based on rate-dependent uniaxial cyclic hardening tests performed at Bristol) will allow the quantification of the plastic deformation that has occurred by the different frequencies of fatigue crack growth.

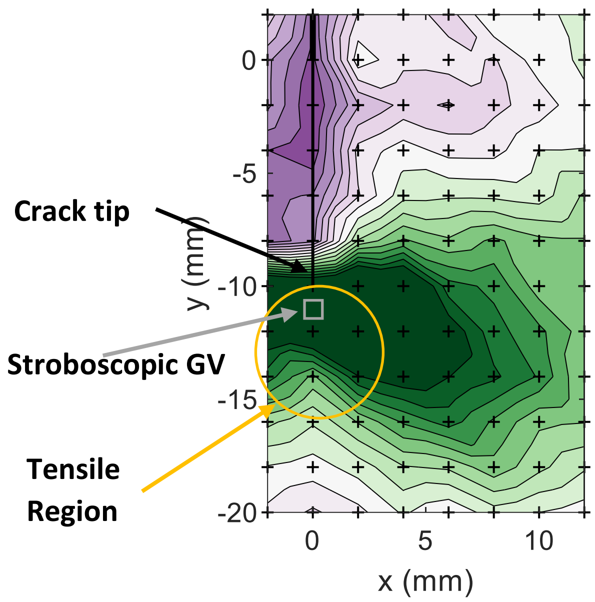

Figure 2: Elastic strain (in µε) in crack-transverse direction after 10 mm of fatigue crack growth at 10Hz. Specimen held at 26 kN load. (+) markers indicate measurement locations.

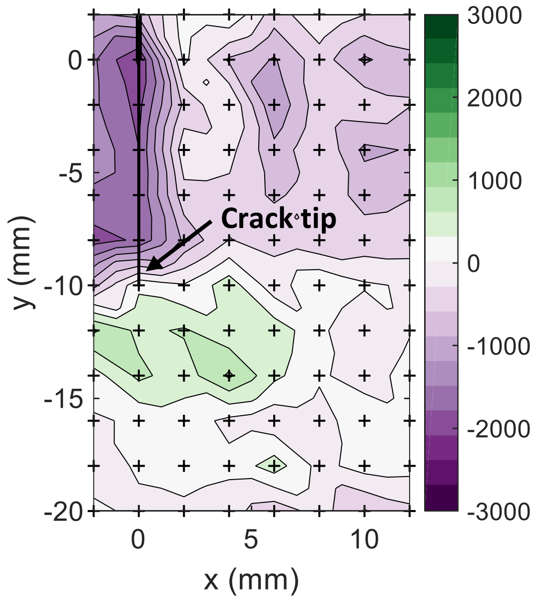

Figure 3: Elastic strain (in µε) in the crack-transverse direction after 10 mm of fatigue crack growth at 10Hz. Specimen held at 0 kN load. (+) markers indicate measurement locations.