Experimental report

31/05/2019

Proposal: **1-02-223**

Council: 4/2017

Title: Effects of defect and load historyon fracture in the presence of residual stress

Research area: Engineering

This proposal is a resubmission of 1-02-213

Main proposer: **Harry COULES**

Experimental team: Harry COULES
Molly PROBERT
Cui Er SEOW

Local contacts: Thilo PIRLING

Samples: Aluminium alloy 7475-T7351 plate

Instrument	Requested days	Allocated days	From	To
SALSA	7	3	22/06/2018	25/06/2018

Abstract:

In this experiment we will study the effect of residual stress on the elastic-plastic fracture of metals. We aim to demonstrate that the timing of residual stress field formation relative to the introduction of a defect can significantly affect the crack-driving force that occurs. This effect is predicted by computer models of elastic-plastic fracture but has not yet been observed directly in experiments. Understanding of this effect could be used to improve the methods that are used to assess the structural integrity of safety-critical mechanical components.

Effects of defect and load history on fracture in the presence of residual stress.

Molly Probert, Harry Coules, Cui Er Seow

Department of Mechanical Engineering, University of Bristol.

Background

Current defect assessment procedures such as EDF's R6 [1] and BS7910 [2] use the assumption that crack growth history has no effect on the future growth characteristics of a defect. However, it has been shown in Finite Element (FE) analyses that cracks grown under an applied load or residual stress as compared to those grown in unloaded conditions have more favourable crack growth parameters such as the J-integral [3] [4] [5]. It is hypothesised that this is due to the formation of a plastic wake behind the crack tip, allowing for plastic energy dissipation during the crack's growth history. If this conservatism in assessment procedures could be reduced, components that could otherwise be taken out of service prematurely could safely be assessed to continue. Though this effect has been shown to exist within FE analyses, currently there is no direct experimental proof of the benefit of considering the crack growth history of this type in defect assessment. This study aims to provide experimental evidence that the growth of cracks in conditions of large applied load or residual stress can modify a material's subsequent crack growth resistance.

Experiment

Two aluminium alloy 7475-T7351 compact tension (C(T)) specimens had 10 mm fatigue cracks introduced from an initial EDM notch under different loading conditions to reach a final crack length of 25 mm. One specimen had a fatigue crack grown under very low load conditions and the other had a crack introduced under an applied load, the loading regimens used are displayed in Table 1. 10mm of crack growth allowed for fracture test to take place at a/W = 0.5 (final crack length of 25 mm from the load line) after a significant length of plastic wake had been introduced into the specimen.

Table 1:Fatigue loading used to prepare C(T) specimens for neutron measurements of crack tip strain field.

Specimen identifier	a/W at 10 mm fatigue	Maximum K_I (MPa√m)	ΔK_I (MPa√m)	Maximum Load (kN) at 0 mm crack extension
CT36	0.5	8.6	7.7	7.5
CT37	0.5	55	7.7	48.9

The specimens were cut from the same rolled sheet of aluminium with the crack transverse direction orientated in the rolling direction of the plate. The same ΔK_I was used for both specimens and the maximum load of fatigue was reduced at increments of 1 mm crack growth to keep the stress intensity factor, K_I relatively constant during fatigue. The first specimen, with a crack grown in a nominally unloaded condition had an initial K_I of MPa8.6 √ m and the specimen that had a fatigue crack grown in a nominally loaded condition had an initial K_I of 55 MPa √ m, this equates to a maximum fatigue load difference between the two specimens of 41.4 kN.

At the SALSA instrument a wavelength of approximately 1.6 Å was used with a 2 mm × 2 mm primary collimator and a 2 mm secondary collimator. This allowed for a gauge volume of 2 mm^3 to be studied in the central plane of the specimen. A grid of scan locations 20 mm × 8 mm with the final crack tip centred on one side of this area allowed for a full strain map to be taken of the plastic wake forming up to the final crack tip and the plastic zone ahead of the crack tip. This grid has a 2 mm spacing of individual scan locations. A grid of 1 mm spacing was concentrated on the crack tip, this smaller grid spacing allowed a more detailed view of the near-crack-tip stain field in the specimen that had been fatigue cracked under a higher load only. Scan locations and specimen dimensions are shown in Figure 1.

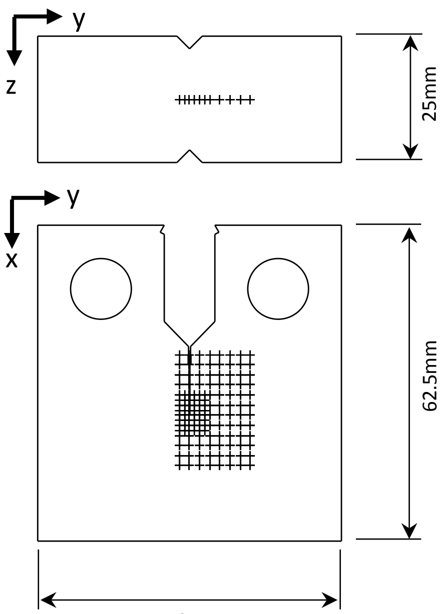

Figure 1: Neutron scan points (+) on C(T) specimen.

Scans were taken with the specimen oriented in three orthogonal directions to allow calculation of stresses. Initial scans were taken on the {200} lattice reflection and further scans were taken on the {311} lattice reflection. A through-thickness scan was completed to quantify the residual stress present in the sheet from the rolling operation used in its manufacture, as shown in Figure 2. Unstrained lattice parameter (d_0) measurements were taken on unstressed comb type specimens of the same material, in all three orientations. The background was calculated using the nominally unloaded specimen in the long transverse and thickness orientations (one in transmission and one in reflection).

Results

Significant crack closure has led to compressive stresses along the crack flanks in the specimen fatigue pre cracked in a higher load condition. As this is not the case in the specimen fatigue cracked in a nominally unloaded condition, it is understood that this is due to the formation of a plastic wake during crack growth. Tensile strain ahead of the crack tip in the specimen fatigue pre cracked at a higher load also indicates that plastic deformation has occurred during the extension of the crack whilst under an applied load.

The calculated stress results are shown in Figure 2 and Figure 3.

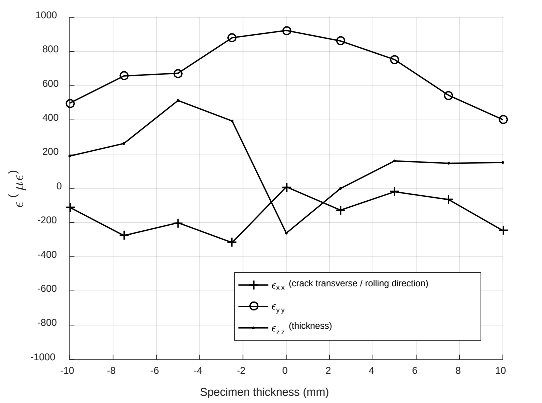

Figure 2: Through-thickness strain values for specimen fatigue pre-cracked in a nominally unloaded condition

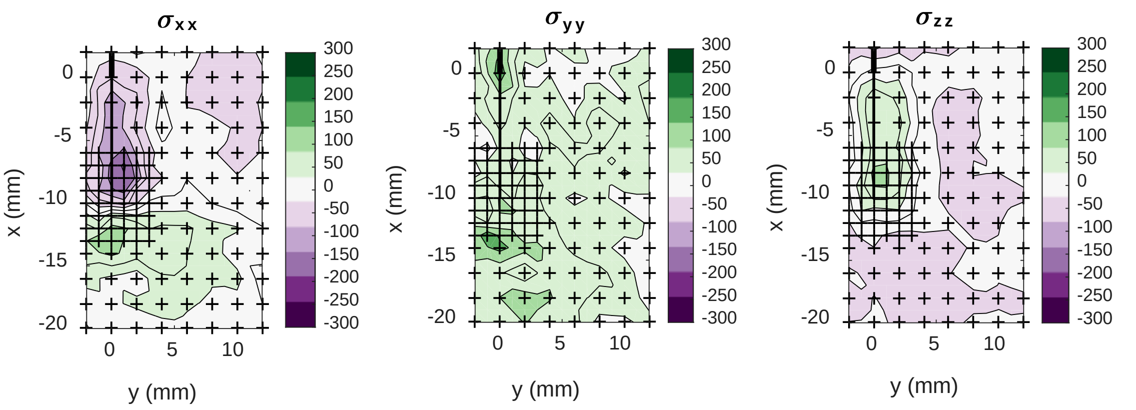

Figure 3: Specimen fatigue pre cracked in loaded condition. Stress calculated from 3 orientations of strain measurements in {311} lattice reflection.

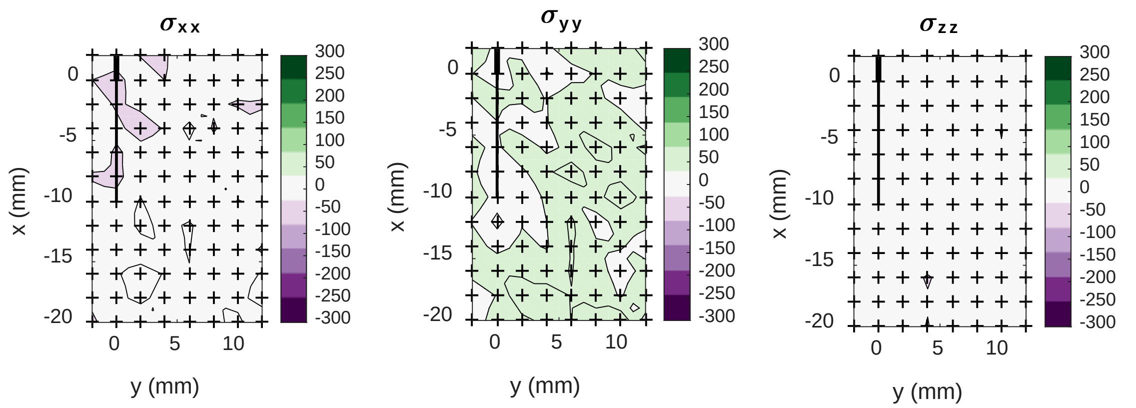

Figure 4: Specimen fatigue pre-cracked in a nominally unloaded condition, stress calculated from 3 orientations of strain measurements in {311} lattice reflection.

References

[1] G. EDF Energy, “R6: assessment of the integrity of structures containing defects, revision 4, Amendment 11.,” 2015.

[2] BSI, “BS 7910:2013 – guide to methods for assessing the acceptability of flaws in metallic structures.,” 2013.

[3] J. R. Willis, D. W. Beardsmore, I. Milne and D. P. G. Lidbury, “Growing cracks with residual stress fields - TAGSI response to question by the MOD,” 2010.

[4] A. H. Sherry, D. a. Q. J. Fonseca, M. R. Goldthorpe and K. Taylor, “Measurement and modelling of residual stress effects on cracks,” *Fatigue \& Fracture of Engineering Materials \& Structures,* vol. 30, pp. 243-257, 2007.

[5] P. J. Bouchard, M. R. Goldthorpe and P. Prottey, “J-integral and local damage fracture analyses for a pump casing containing large weld repairs,” *International Journal of Pressure Vessels and Piping,* vol. 78, pp. 295-305, 2001.