Experimental report

21/03/2017

Proposal: **1-02-185** **Council:** 4/2016

Title: Residual stress relaxation and itseffect on elastic-plastic fracturestability

Research area: Engineering

This proposal is a new proposal

Main proposer: **Harry COULES**

Experimental team: Graeme HORNE
Harry COULES
Kiranmayi ABBURI VENKATA

Local contacts: Thilo PIRLING

Samples: Aluminium alloy 7075

Instrument	Requested days	Allocated days	From	To
SALSA	8	8	21/11/2016	29/11/2016

Abstract:

This experiment will study how residual stresses influence the initiation and propagation of elastic-plastic fractures. Specifically, we want to determine how the partial relaxation of a residual stress field during elastic-plastic fracture affects the fracture process. Using SALSA, we will produce 3D maps of the elastic strain transverse to a crack in aluminium alloy specimens as they are fractured in the presence of residual stress, and take digital image correlation measurements of total strain at the surface of the specimens. These measurements will indicate how the stress field changes under conditions of stable crack extension and will allow us to validate a generalised analytical model of residual stress relaxation. This work will help to enable more accurate methods of structural integrity assessment, benefitting both the safety and the economics of high-dependability engineering structures including nuclear pressure systems and aerospace components.

Residual stress relaxation and its effect on elastic-plastic fracture stability

Experimental team: Harry Coules, Graeme Horne, Kiranmayi Abburi Venkata

Department of Mechanical Engineering, University of Bristol

Introduction

Residual stresses are known to influence both brittle and elastic-plastic fracture, and this has wide-ranging implications for the structural integrity of mechanical components [1], [2]. However, in quasi-ductile materials residual stress relaxation occurs during a fracture event. Typically, this is the result of two processes happening simultaneously. As the fracture propagates through the object, it changes the boundary conditions that the residual stress field is subject to and hence changes the stress field itself. Also, plasticity occurs in the region of the crack tip and this further modifies the original residual stress distribution. In this experiment, we mapped the elastic strains in the vicinity of a propagating crack using SALSA. We are now using this information along with Digital Image Correlation data and finite element modelling of the fracture process to relate the residual stress field to the crack growth stability.

Method

The experiment used four Compact Tension specimens of aluminium alloy 7475-T7351. All of the specimens were cut from the same plate of material and in the same orientation, with the longitudinal direction of rolling in the direction transverse to the crack. Two specimens were indented ahead of the crack tip using a pair of cylindrical indenters to introduce a residual stress field. The other two specimens had no significant residual stress at the beginning of the experiment (and this was verified upon arrival using neutron diffraction). All specimens were fatigue pre-cracked to ensure an initially sharp crack tip.

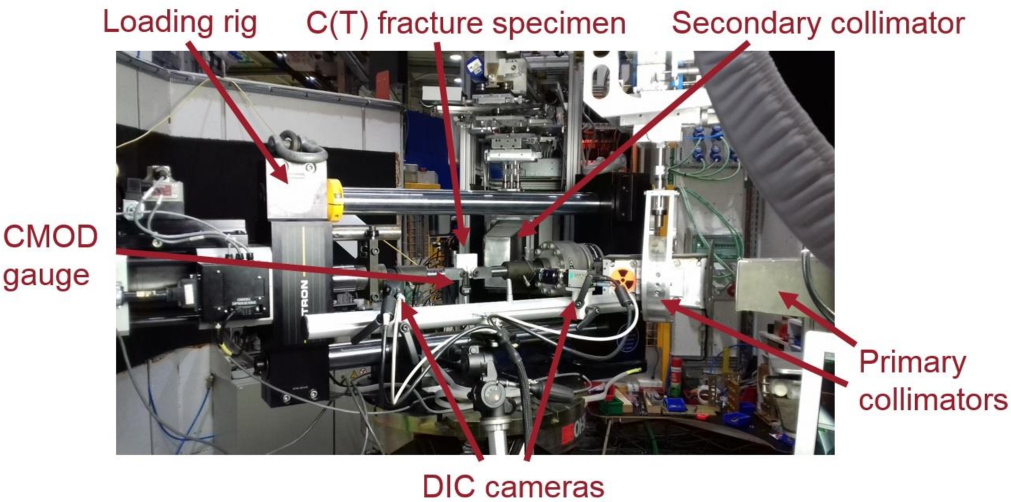

Figure 1: Experimental setup showing loading rig, C(T) specimen and DIC cameras.

The specimens were loaded to failure on the beamline using SALSA's Instron loading rig (see Figure 1). Loading was carried out under displacement control. The load, crosshead position, and Crack Mouth Opening Displacement (CMOD) were recorded continuously. The CMOD was measured using an extensometer. At set intervals of displacement, small unload-reload cycles were performed in order to measure the specimen's compliance, from which the crack length was inferred using the method of ASTM E1820-13 [3]. One surface of each specimen was painted with a speckle pattern. This surface was observed using a binocular camera setup during loading. Digital Image Correlation was later used to determine the displacement field and hence the total strain at the specimen's surface.

Two types of neutron diffraction measurements were taken. For one indented specimen and one non-indented specimen, measurements were taken in large grids of points by pausing the loading of the specimen at set increments of CMOD (0, 0.5, 1.0, 1.5 and 2.0 mm). This was designed to determine the overall elastic strain field. The other two specimens were used for list-mode scans. For these specimens, the gauge volume was positioned approximately 7.5 mm ahead of the initial crack tip and measurements were taken continuously as the specimen was loaded. For all the measurements, a gauge volume of 2x2x2 mm was used and only the crack-transverse strain direction was interrogated. A neutron wavelength of 1.64 Å was to resolve the peak corresponding to {311} lattice reflection only. Unstrained lattice parameter measurements were taken from comb-type specimens of the same material and orientation.

Results

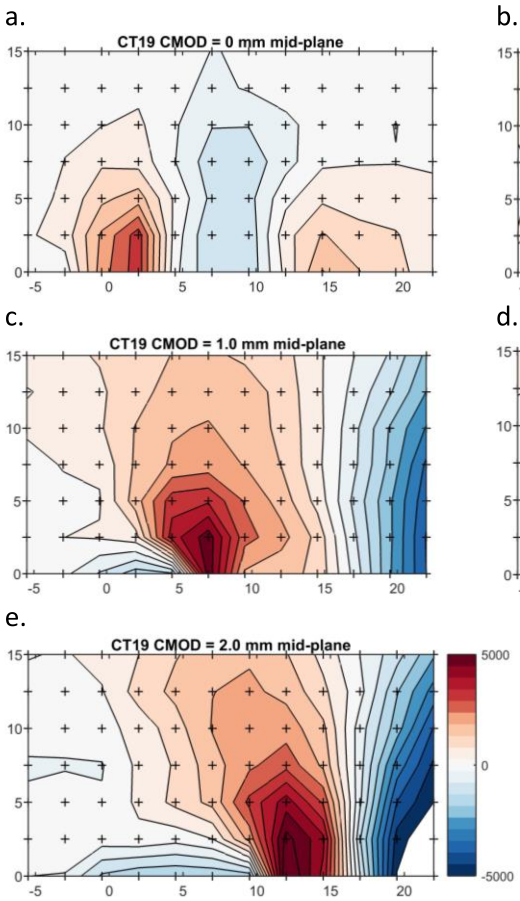

Figure 2: Elastic strain field (crack-transverse component) at the mid-thickness plane of a residually-stressed C(T) specimen during loading. The crack propagates from left to right along the y = 0 mm plane, starting at x = 2 mm when CMOD = 0 mm. Only one side of the specimen is shown. Black crosses indicate gauge volume centroids. Colour scale is in microstrain.

The results of the grid-type measurements were used to plot contour maps of crack-transverse elastic strain. A typical sequence is shown in Figure 2 for 0.5 mm increments of CMOD. The effect of crack extension can clearly be seen as the stress concentration at the crack-tip (coloured red) moves from left to right. The list-mode scans have not yet been analysed, as there is not yet a procedure for analysing SALSA data taken in this mode. However we are liaising with the beamline scientist to develop this.

Figure 3 shows the load vs CMOD curves for one non-indented specimen and one indented specimen. The clear difference in the maximum load was found to be very repeatable, and consistent with the results of other tests performed at Bristol after the beamline experiment. The compliance of the specimen was determined from the gradient of the unload-reload cycles visible in Figure 3. From this it was shown that the crack growth as a function of CMOD was different for the two types of specimen. This conclusion was consistent with the elastic strain maps for the different specimens and with subsequent off-beamline tests, both of which showed the same variations in crack growth rate. Currently, we are consolidating the experimental results with finite element modelling in order to determine the level of residual stress relaxation and quantitatively separate out the effect that this has on fracture propagation.

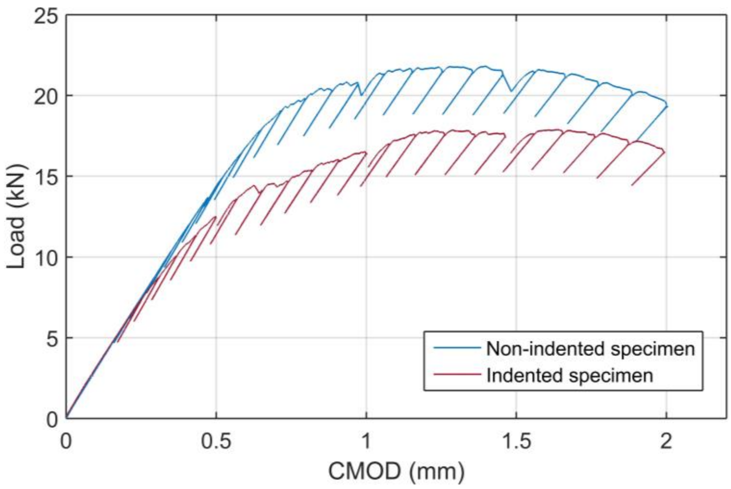

Figure 3: Load vs Crack Mouth Opening Displacement curves for two aluminium C(T) specimens.

References

[1] P. J. Budden and J. K. Sharples, “Treatment of secondary stresses,” in *Comprehensive Structural Integrity, Volume 7*, 1st ed., R. A. Ainsworth and K.-H. Schwalbe, Eds. Elsevier-Pergamon, 2003, pp. 245–288.

[2] P. J. Withers, “Residual stress and its role in failure,” *Reports on Progress in Physics*, vol. 70, no. 12, pp. 2211–2264, 2007.

[3] ASTM, *Standard test method for measurement of fracture toughness*, no. E1820–13. ASTM, 2013.