Experimental Report

Proposal: **1-02-148** **Council:** 4/2014

Title: Experimental verification of a newmethod for determining maximum crack driving force for components containing residual stresses

This proposal is a new proposal

Researh Area: Engineering

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Samples: Aluminium alloy 7075

Instrument	Req. Days	All. Days	From	To
SALSA	9	9	02/10/2014	11/10/2014

Abstract:

In this experiment we will measure the residual stress fields around two crack tips in 7xxx series aluminium alloy fracture specimens, along with the corresponding stress field prior to introduction of the cracks. The measurements will be used to verify a numerical method for calculating an upper bound for the stress intensity at a crack in an object containing an unknown distribution of residual stress. This method enables more accurate prediction of fracture for internally-loaded structures, and is broadly applicable in structural integrity assessment. The measurements made using SALSA will be compared with upper bound estimates of the stress intensity factor for this specimen geometry, which should provide experimental verification for the upper bound method.

Experimental verification of a new method for determining maximum crack driving force for components containing residual stresses

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Introduction

Residual stresses can have a significant effect on the fracture of metallic materials. Consequently, most current structural integrity assessment procedures require the consideration of residual stress in the component or structure being assessed. However, generating the residual stress information required for such an assessment is often difficult and time-consuming, requiring detailed experiments and/or complicated finite element simulations. Our previous work has suggested that for any given defect in a component, there exists a maximum Mode I stress intensity factor (K_I) which can be applied by any residual stress field. We have developed a numerical method to calculate this stress intensity upper bound. In this experiment, we performed a detailed characterisation of the residual stress field in three test specimens, two of which contain introduced notches. The results will be used to validate the stress intensity upper bound calculation method.

Method

Three oblong bar specimens of aluminium alloy 7075-T6 were manufactured, and then compressed at a known location using a pair of cylindrical punches, in a similar manner to that used by Mahmoudi et al.[1]. Wire Electrical Discharge Machining (EDM) was then used to introduce notches of well-defined length into two of the specimens: one of 7.5 mm length and one of 15 mm. The specimen geometry is shown in Figure 1.

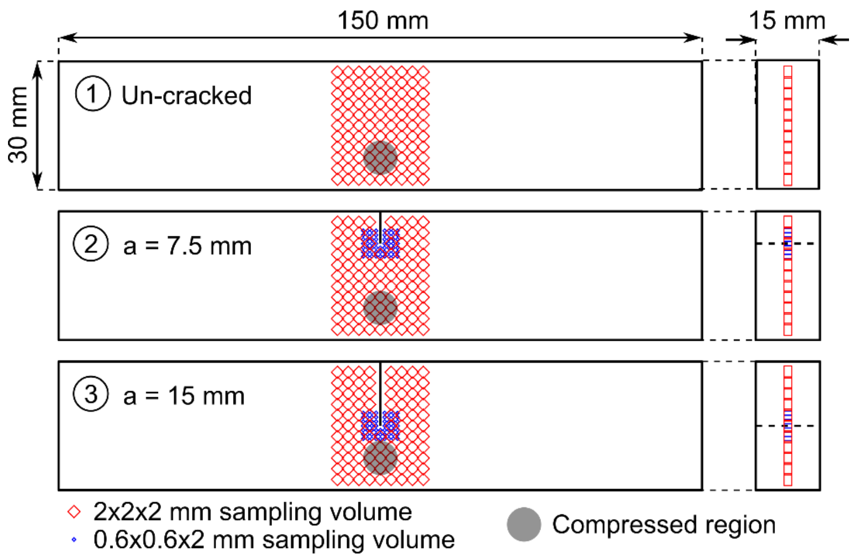

Figure 1: Geometry of the compressed bar specimens.

Measurements of residual elastic strain in three orthogonal directions (longitudinal to the crack, transverse to the crack and out-of-plane) were made using SALSA. An incoming neutron wavelength of 1.644 Å was used for all measurements. Measurements were made using two sets of gauge volume dimensions: 2x2x2 mm for a relatively coarse grid of measurements (shown in red in Figure 1) and

0.6x0.6x2 mm for a finer grid (shown in blue). In the majority of measurements the Al {311} reflection was observed; however the specimens were found to be quite strongly textured and for measurement in the transverse direction with the 0.6x0.6x2 mm gauge volume it was necessary to instead use the Al {222} reflection to improve the neutron count rate. However both of these lattice plane families are known to have a low sensitivity to intergranular strains[2], and in this material have very similar diffraction elastic constants[3]. Measurements of the material's unstrained {311} and {222} lattice spacings were taken from comb samples machined from nominally identical specimens using wire EDM.

Results

Residual stress in the crack-transverse direction, calculated from the measurements made using a 2x2x2 mm sampling volume, is shown in Figure 2. As expected, a strongly compressive region has been created in the indented region, and this is balanced by a region of tensile stress adjacent to it. The introduction of the EDM notches results in partial relaxation of the stress field, as seen in Figure 2b & c.

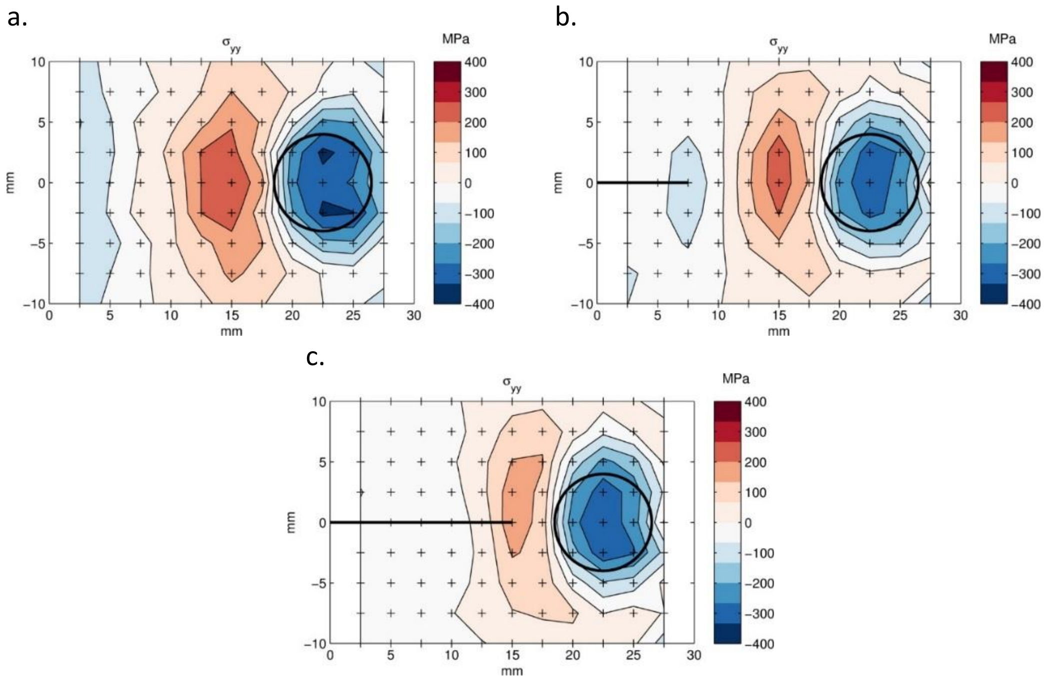

Figure 2: Residual stress in the crack-transverse direction measured at 2.5mm spatial resolution on the mid-plane of the specimen. a.) No notch, b.) 7.5 mm notch, c.) 15 mm notch. Circle indicates the indenter location.

Residual elastic strain around the tips of the two notches, measured using the 0.6x0.6x2 mm gauge volume, is shown in Figure 3. From these results, it is possible to calculate the Mode I stress intensity factor via two methods:

1. By the weight function method[4], using the measurements of the overall stress field in the un-notched specimen on the prospective crack plane (shown in Figure 2a).
2. By fitting a modified Westergaard stress function[5] to the near-tip measurements from the notched specimens (shown in Figure 3).

For the 15 mm crack this gives $K_I = 21.04\, MPa\sqrt{m}$ (weight function method) and $K_I = 19.37\, MPa\sqrt{m}$ (crack tip field fit). For the 7.5 mm crack it gives $K_I = -13.86\, MPa\sqrt{m}$ (weight function method) and $K_I = -11.55\, MPa\sqrt{m}$ (crack tip stress field). Each notch has a finite width and for the 7.5 mm slit the notch faces are non-contacting, so a negative value of K_I is expected given that the crack is in a region of mainly compressive transverse stress.

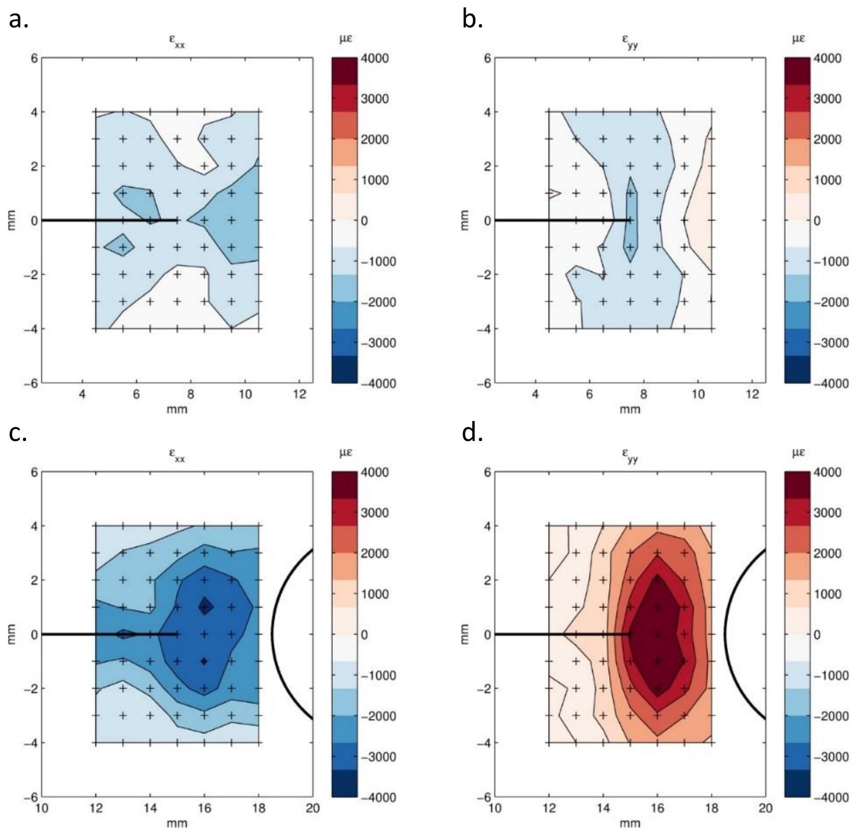

Figure 3: Residual elastic strain in the crack growth (xx) and crack-transverse (yy) directions on the mid-plane of the specimen, measured at 1 mm spatial resolution. a, b.) 7.5 mm slit, c, d.) 15 mm slit.

These results are currently being used to validate methods for calculating a stress intensity upper bound for a given crack. Our formulation of this problem allows it to be additionally constrained (and the upper bound hence reduced) using any available experimental residual stress or strain data. Therefore, to test the accuracy of the method we will run analyses with increasing levels of constraint, i.e. using an increasing proportion of the measured strain data. The upper bound result should converge to the K_I given above when all available data is used.

References

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3. Hutchings, M. T., Withers, P. J., Holden, T. M. & Lorentzen, T. *Introduction to the characterization of residual stress by neutron diffraction*. (Taylor and Francis: 2005).
4. Tada, H., Paris, P. C. & Irwin, G. R. *The Stress Analysis of Cracks Handbook*. (Professional Engineering Publishing: 2000).
5. Sanford, R. J. A critical re-examination of the Westergaard method for solving opening-mode crack problems. *Mechanics Research Communications* **6**, 289–294 (1979).