ESRF	**Experiment title:** Crack closure under plane strain and plane stress	**Experiment number**: MA-1123
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Report:

The concept of crack closure (i.e. effects that cause the crack faces to close early during unloading so that the crack tip does not experience the full crack-opening fatigue cycle) have been used to explain many crack retardation effects. Plasticity induced crack closure is one of the most important mechanisms of crack closure, but is still the target of heated debate. Some say that closure does not occur at all, others say that it can only occur under plane stress. To date, experimental measurements of crack closure have been inconclusive and have relied on either (i) measuring some secondary property of the cracked body such as compliance or electrical resistance or (ii) measurement of crack-opening displacements on the surface of the cracked body.

Experimental Results

A series of tests were conducted on compact tension (CT) specimens to measure strain data in the region surrounding the crack tip under plane strain (in the bulk). Energy dispersive mode was utilised, with a fixed 2θ angle of 5˚.Using 2 detectors we could measure the elastic strains in the crack growth and crack opening directions with high spatial resolution.

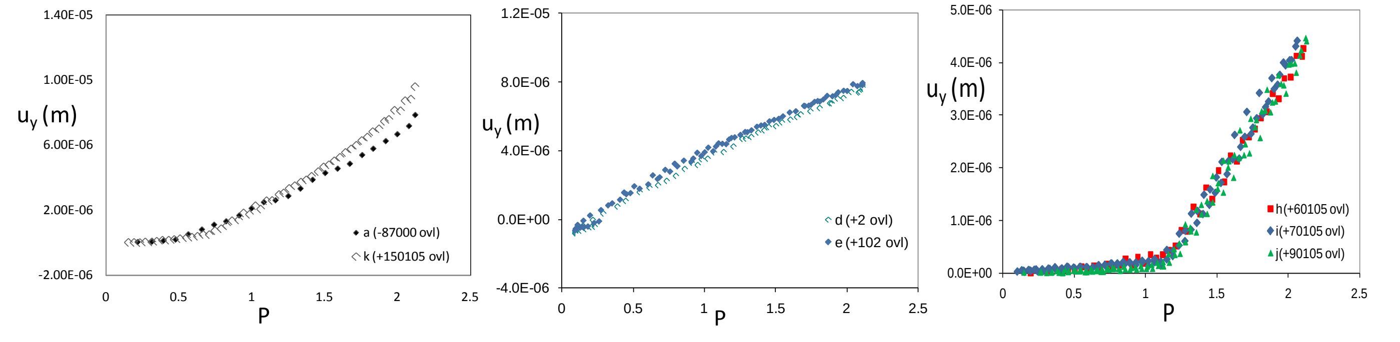

Fig 1: Crack opening displacements (in m) measured by digital image correlation of the free sides of the crack as a function of load, P, (kN) for the sample a) one cycle before overload (OL- 1), b) during and just after overload (OL, OL+1), and c) during retardation (OL+25,000). Conventional thinking suggests that the knee around 1-1.5kN indicates the crack closing . No knee is observed during and immediately after overload.

Regarding the plane stress sample, our surface displacement analysis shows clear evidence of crack closure before and significantly after an overload event (a much higher load than the fatigue load cycle) – see figure 1. In this experiment we were anle to map the crack tip stresses behind and ahead of a fatigue crack in stainless steel prior to and subsequent to an overload event under both plane stress and plane strain.

The primary results are shown in Fig. 2. Here the crack-opening stress field in the plane including the crack is shown for the cyccle immediately before (OL-1), during overload (OL) and after (OL+1). The predictions of a simple model of the fatigue crack stress field are also shown (at max load and at half load and at min load) for each crack loading cycle.

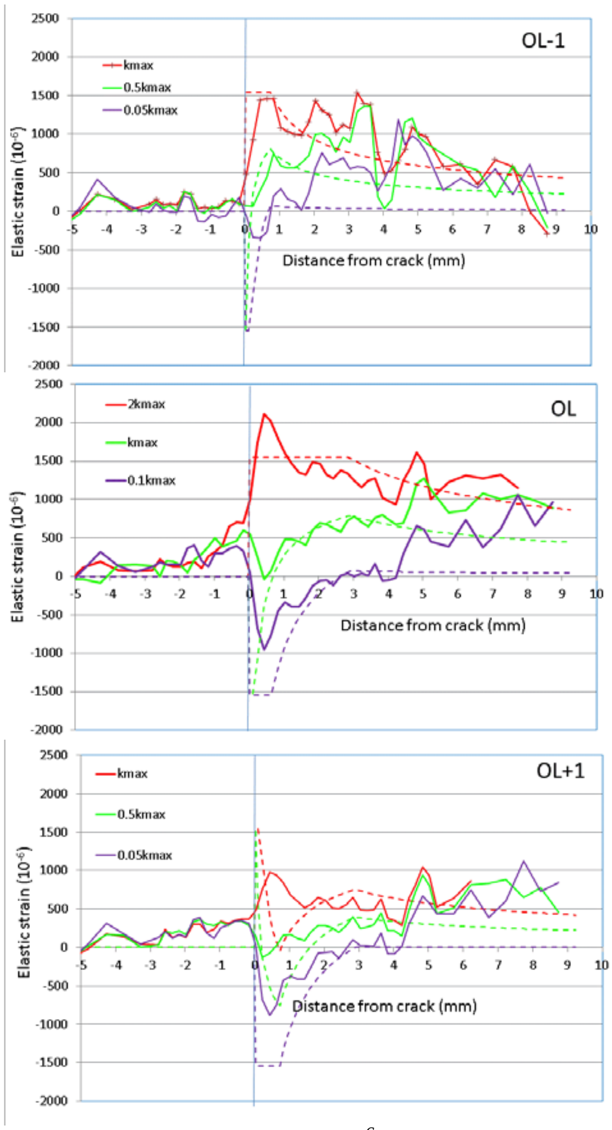

Figure 2: Elastic strain (in 10^{-6}) evolution at the mid plane (t=1.5mm) along a crack. Strain curves measured and predicted by modified Westergaard's solutions (dashed) are shown on all plots. Profiles are shown for the cycle just before the overload (a), during the overload cycle (b) and for the cycle just after the overload (c).

Implications of the results

Conventional plasticity induced crack closure is not evident in the current results. Perhaps somewhat surprising, given the state of almost plane stress and the extensive plasticity, no direct evidence for plasticity induced crack closure is observed for any of the three cycles. This is unusual for the OL-1 case; it may be because closure occurs near the surfaces (as would be recorded by DIC) which causes the centre to be held open remotely; certainly there is no sign of crack face compression. The fact that K is increasing slowly with crack growth may in part explain this – though that would leave the knee in the crack opening recorded by complementary DIC results to explain. Instead, these measurements taken with a relatively large gauge volume appear to show extensive plasticity induced residual stresses which in turn strongly influence the crack-tip stress field.

In a previous publication it was possible to infer the stress intensity factor acting at the crack-tip by fitting the measured strains to analytical solutions [2]. Here the measured strains have been directly compared with Westergaard's analytical solution which was only modified to take into account the plasticity and the associated redistribution of that load. These predictions broadly correspond to the measured strains. The forward and reverse plastic zones are predicted well by this approach if a value of the yield stress intermediate between the initial yield stress and the ultimate tensile stress is used. This suggests that cyclic hardening is important. However the strains within 500µm of the crack-tip appear to be consistently smaller than anticipated, both in tension and compression. This may be due to the extended gauge volume which samples strains over a significant length-scale, potentially smearing out the sharp crack tip. Equally, the crack-tip is not linear across the sample width. To take this investigation further, the experiment will be repeated on finer grained materials where both higher spatial resolution and more accurate strain fields would be obtained.

Publications

[1] P.J. Withers, H. Dai, P. Lopez-Crespo, A. Steuwer, F. Yusof, J.F. Kelleher, T. Buslaps, '*Overload effects on local fatigue crack-tip strain fields in plane stress samples*' in: Characterisation of Crack Tip Stress Fields, Forni di Sopra, Italy, p 8, 2011. (extended paper invited for publication in I. J. Fatigue; in preparation)

[2] A. Steuwer, M. Rahman, A. Shterenlikht, M.E. Fitzpatrick, L. Edwards, P.J. Withers, Acta Materialia, 58 (2010) 4039-4052.

[3] Kelleher, J. F., P. Lopez-Crespo, et al. (2010). "The Use of Diffraction to Study Fatigue Crack Tip Mechanics." Materials Science Forum 652: 216-221.