Experimental Report

24/02/2014

Proposal: **1-02-135** **Council:** 10/2012

Title: Residual Stress Measurements in Fracture Specimens used for Stress Relaxation Tests

This proposal is continuation of: 1-02-106

Researh Area: Engineering

Main proposer: **KAPADIA Priyesh**

Experimental Team: KAPADIA Priyesh

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Samples: 316H Austenitic Stainless Steel

Instrument	Req. Days	All. Days	From	To
SALSA	4	4	28/02/2013	04/03/2013

Abstract:

Residual stresses induced by non-stress relieved welds in steel pipework within power plants drive creep strain accumulation at high temperatures. To assess cracking due to strain relaxation of secondary loads, residual stresses need to be induced in fracture specimens. Residual stresses have been induced in compact tension, C(T), type specimens using the insertion of an oversized wedge and electron beam welding. The specimens are made from uniformly pre-compressed austenitic stainless steel. Work hardening the material increases its yield strength and thus allows larger magnitudes of residual stresses to be generated within the components. Following the neutron diffraction measurements, these components shall be placed in a furnace to perform Creep Crack Growth (CCG) tests.

Experimental Report: Determination of Residual Stresses in Electron Beam Welded Fracture Specimens (SALSA Proposal: 1-02-135)

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Introduction

Power plants currently operating in the UK contain welded components that have not been post weld heat treated and contain residual stresses (RS). Cracks have been found in the Heat Affected Zones (HAZ) of some of these components which have been caused by the relaxation of RS during service at high temperature. Studies have been carried out to investigate the effect of RS on Creep Crack Growth (CCG).

Novel fracture mechanics specimen designs have been developed to investigate Creep Crack Growth (CCG) due the relaxation of RS. The design of these Electron Beam (EB) welded C(T) specimens and wedge-loaded C(T) specimens are detailed in [1] and [2]. RS measurements are being made during the manufacturing of these samples to determine the residual stresses that will drive crack growth in future CCG tests and to validate numerical simulations of the fabrication process.

Specimen Geometry and Measurement Details

Compact tension, C(T), specimens have been fabricated from Electron Beam (EB) welded blocks made from ex-service 316H austenitic stainless steel such that the weld induced RS drive crack growth. The residual stresses following welding were previously measured using SALSA, at ILL. A C(T) blank has been machined out of the welded sample (EBW5). The RS stresses in this C(T) blank is presented and compared to the as-welded RS to determine the extent of stress redistribution during machining.

Wedges have been inserted into the mouth of C(T) specimens such that the misfit generates residual stresses ahead of the crack tip. Two specimens, WC(T)3 and WC(T)4, have been created with various wedge insertion depths which will have different magnitudes of RS.

All samples are made from uniformly pre-compressed ex-service 316H austenitic stainless steel. Uniform pre-compression at room temperature to 8% plastic strain results in a hardened material with creep ductility's and crack growth properties similar to those of weldment samples where the crack tip is located and grows within the Heat Affected Zone (HAZ). Uniform 8% pre-strain is therefore a suitable material to simulate the behaviour of welded samples [3]. The increased yield stress of the work hardened material allows greater tensile residual stresses to be generated in comparison to un-compressed material.

Measurements were made using a 2 x 2 x 2 mm^3 gauge volume. The material has a relatively large grain size, hence the gauge volume was rotated by ± 2.4° in 0.8° steps in the ω-plane to increase the number of grains orientated in the measurement direction.

Measurements were made along lines A-B as show in Figures 1 to 3, which are in the expected plane of crack growth for the C(T) specimens. In specimen EBW5, measurements were made in 1 mm interval up to 10 mm from the weld plane and every 2 mm further away from the weld. Both sides of the weld were measured in the longitudinal direction (39 points), which is the direction of interest in this study. The strain distribution was proved to be symmetric in previous measurements and therefore only one side of the weld was measure in the longitudinal and normal directions (20 points in each direction). In WC(T)3 and WC(T)4 measurements in three directions were made in 1 mm intervals up to 10 mm from the pre-crack and in 2 mm increments for the rest of the ligament (19 points)

The elastic strain response of the {311} lattice plane was measured in these tests. Reference, d_0, measurements were on a separate piece of ex-service 316H stainless steel and also on the corner of each specimen which were considered to have low stresses from numerical simulations of the manufacturing of the specimens. As the material had been pre-compressed, measurements were made in multiple directions to test for variations in d_0 measurements however significant differences were not observed.

Residual Stress Distributions

Strains measured in three orthogonal directions (longitudinal, transverse and normal directions to the weld) in specimen EBW5 are shown in Figure 1. These strains are compared to measurements made after welding using the instrument SALSA, at the ILL. In general the shape of the profiles match closely where the magnitudes of residual strains have relaxed slightly due to machining processes which is expected. The magnitudes of the tensile longitudinal residual strains near the weld have reduced by approximately 300 με. This is small compared to the large magnitude of tensile residual strain measured in this region. The longitudinal residual stress is calculated to be 740 MPa near the weld region. In the regions from 5 mm to 10 mm away from the weld the tensile longitudinal residual strains have reduced significantly to become compressive during machining of the C(T) blank. When this specimen is machined into a C(T) specimen and tested at high temperature, the compressive stresses will arrest any crack growth.

The residual strains in the wedge-loaded C(T) specimens, WC(T)3 and WC(T)4 are shown in Figure 2 and Figure 3 respectively. The strain profiles for both specimens are similar. Specimen WC(T)4 has a larger wedge insertion depth and therefore the magnitudes of strains are larger than specimen WC(T)3 as expected. The residual strains are used to validate Finite Element (FE) models of the wedge insertion process. The simulations provide close predictions for both specimens along the ligament of both specimens except close to the notch. Large strain gradients exist in this region which cannot be accurately measured using the 2×2×2 mm^3 gauge volume used in the experiment. Therefore the simulation is judges to give the correct predictions.

References

1. Kapadia, P., Davies, C. M., Dean, D. W. and Nikbin, K. M., *Numerical Simulation of Residual Stresses Induced in Compact Tension Specimens using Electron Beam Welding*, in *ASME 2012 Pressure Vessels & Piping Division Conference*. 2012, ASME: Toronto, Ontario, Canada
2. Kapadia, P., Zhou, H., Davies, C. M., Wimpory, R. C. and Nikbin, K. M., *Simulating Residual Stresses using a Modified Wedge-Loaded Compact Tension Specimen*, in *ASME 2013 Pressure Vessels & Piping Division Conference*. 2013, ASME: Paris, France
3. Mehmanparast, A. N. D., C.M., Dean, D. W. and Nikbin, K. M., *Material Pre-Conditioning Effects on the Creep Behaviour of 316H Stainless Steel, in 13th International Conference on Pressure Vessel Technology* in *ICPVT-13*. 2012: London

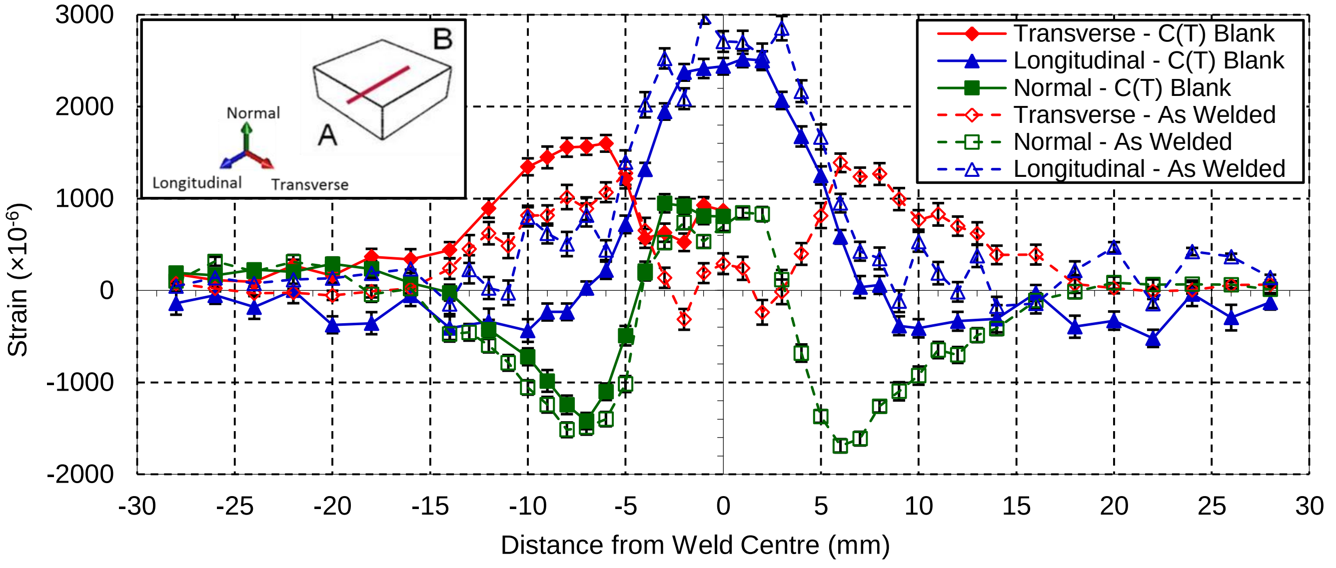

Figure 1 Comparison of residual stresses measured along line A-B in specimen EBW5 after welding and in C(T) blank

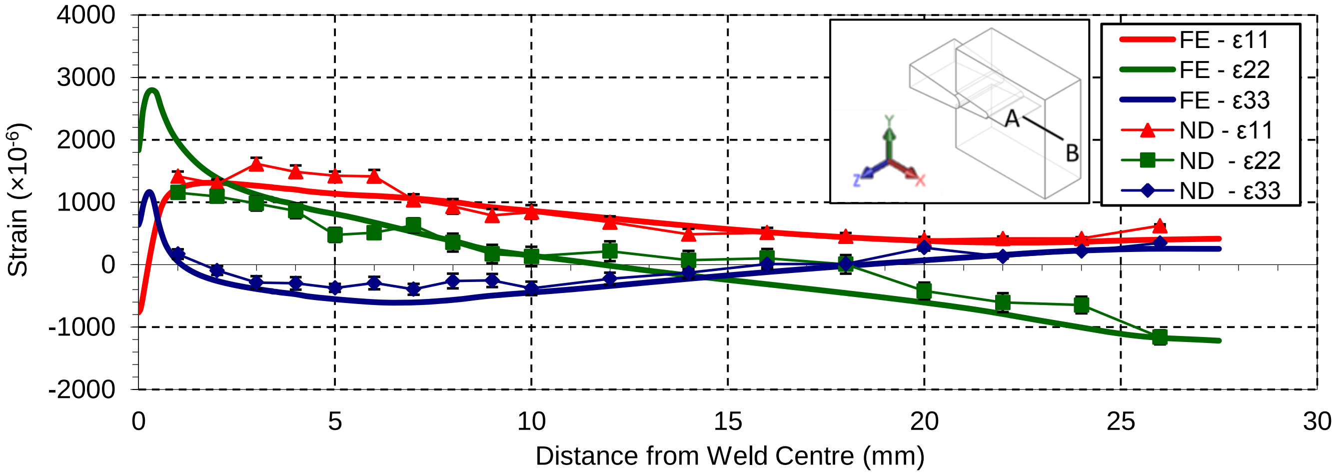

Figure 2 Comparison of residual strains measured along line A-B in WC(T)3 with FE predictions

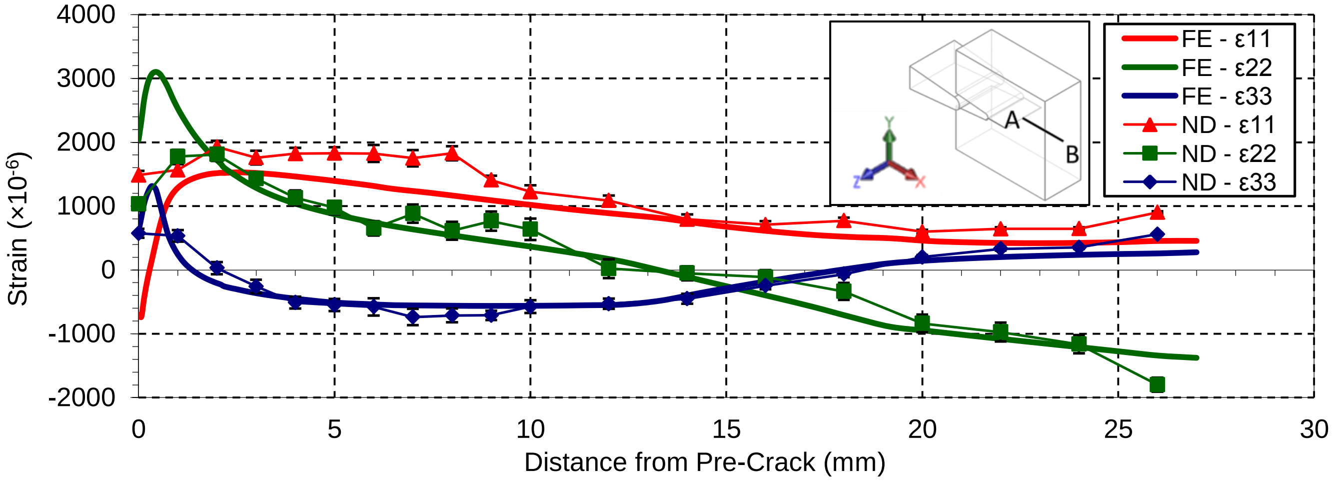

Figure 3 Comparison of residual strains measured along line A-B in WC(T)4 with FE predictions