Experimental Report

24/07/2013

Proposal: **1-02-122** **Council:** 4/2012

Title: Determination of Residual Stressesin Electron Beam Welded Compact Tension Specimens

This proposal is a new proposal

Researh Area: Engineering

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Samples: 316H Austenitic Stainless Steel

Instrument	Req. Days	All. Days	From	To
SALSA	3	4	12/11/2012	16/11/2012

Abstract:

Welding can generate considerable residual stresses in components. These stresses will drive creep strain accumulation at high temperatures, and are generally superimposed by stresses generated from an applied (primary) load (e.g. pressure loading). It is greatly important that the influence of residual stresses is understood. A novel approach to introduce residual stresses in a Compact Tension C(T) specimen using strategically placed Electron Beam (EB) welds is proposed to perform Creep Crack Growth (CCG) tests. C(T) specimens with EB welds have been fabricated, for which the the residual stresses are to be measured. A numerical model of the welding and specimen fabrication has been developed, using Finite Element Analysis (FEA) to predict the residual stresses. The Neutron Diffraction (ND) measurements are to be used to validate the model.

Experimental Report: Determination of Residual Stresses in Electron Beam Welded Fracture Specimens (SALSA Proposal: 1-02-122)

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Introduction

Power plants currently operating in the UK contain welded components that have not been stress relieved. Residual stresses (RS) are generated within welded components to accommodate incompatible strains. 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) using non-uniformly pre-compressed compact tension C(T) specimens [1, 2]. However plasticity generated ahead of the notch reduces the creep ductility of the material and the influence of RS alone on CCG cannot be distinguished from that caused by material properties alteration.

A novel fracture mechanics specimen design has been developed to investigate Creep Crack Growth (CCG) due the relaxation of RS. Compact tension, C(T), specimens have been fabricated from Electron Beam (EB) welded blocks made from ex-service 316H austenitic stainless steel. EB welding generates tensile longitudinal residual stresses in excess of yield magnitude surrounding the weld whilst inducing local plastic deformation only. A pre-crack is machined in the C(T) specimen such that crack growth begins in a region of the material with tensile RS and limited plasticity.

Samples of 316H stainless steel have been EB welded whilst instrumented with thermocouples to enable a numerical simulation of the weld process to be developed. Neutron Diffraction (ND) measurements made using the instrument SALSA at the ILL are used to quantify the RS in the specimen to validate the numerical simulations. This report presents measurements made to continue the previous study presented in [3].

Specimen Geometry and Measurement Details

RS have been measured on 3 specimens, two of which were previously tested using the instrument SALSA, at ILL [3]. ND measurements on specimens EBW3 and EBW4 were previously made following EB welding. The run on, run off and backing blocks were removed using Electric Discharge Machining (EDM) for both of these specimens. Specimen EBW3 also has a pre-crack machined to 3 mm beyond the weld centre. The geometry of both specimens are shown in Figures 2 and 3. Repeat ND measurements have been made to determine the extent of residual stress redistribution during the machining process.

Specimen EBW5 has been tested in the as welded configuration as shown in Figure 1. This specimen is made from uniformly pre-compressed ex-service 316H austenitic stainless steel. The specimen is made from uniformly pre-compressed ex-service austenitic type 316H 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 [4]. 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 along lines A-B as show in Figures 1 to 3, which are in the expected plane of crack growth for the C(T) specimen to be manufactured. Measurements were made in 1 mm increments close to the weld and in 2 mm increments far from the weld. A total of 22, 43 and 43 points were measured in specimens EBW3, EBW4 and EBW5 respectively 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 until a specified number of neutrons were counted as shown in Table 1.

The elastic strain response of the {311} lattice plane was measured in these tests. With an incident neutron beam wavelength of 1.648 nm, the sample was set up with an angle, 2θ, of 98.7° between the incident and scattering beam.

ND measurements were made across a toothcomb specimen containing the EB weld at the centre to determine the variation of d_0 through the parent material, HAZ and the fused material.

Residual Stress Distributions

Strains measured in three orthogonal directions have been used to calculate residual stresses in the longitudinal, transverse and normal directions to the weld, which are shown in Figure . Stress components for both of the specimens are compared to residual stresses predicted from numerical simulations.

Peak tensile residual stresses of approximately 600 MPa have been measured in the longitudinal direction near the weld. The tensile residual stress region extends approximately 12 mm from the centre of the weld in the transverse direction.

Specimen EBW3 has one weld pass and specimen EBW4 has two; the second pass is made directly over the first hence the HAZ has undergone two thermal cycles. It was expected EBW4 would have higher residual stresses as a result of the material becoming hardened during the multiple weld passes, however the results do not show this. The residual stresses for both of the specimens are similar.

The residual stresses predicted by the numerical simulation show a similar distribution to that measured by ND. The FE model accurately predicts the magnitude of the tensile residual stresses. However the compressive stresses measured in the longitudinal and normal directions are less than that predicted by the numerical simulation. This is likely to be due to the assumptions made in selecting boundary conditions in the numerical simulation.

In the longitudinal direction, the compressive stresses measured using ND far from the weld have a small magnitude. A large compressive region far from the weld was expected which balances the tensile residual stresses to achieve force equilibrium. As the results do not show this to be the case, equilibrium must be achieved across the normal-transverse plane upon which line A-B lies and therefore it is likely compressive regions near the top and bottom surfaces of the specimen exist. Residual stress measurements using the contour and slitting method are to be performed on specimen EBW4 to investigate this.

References

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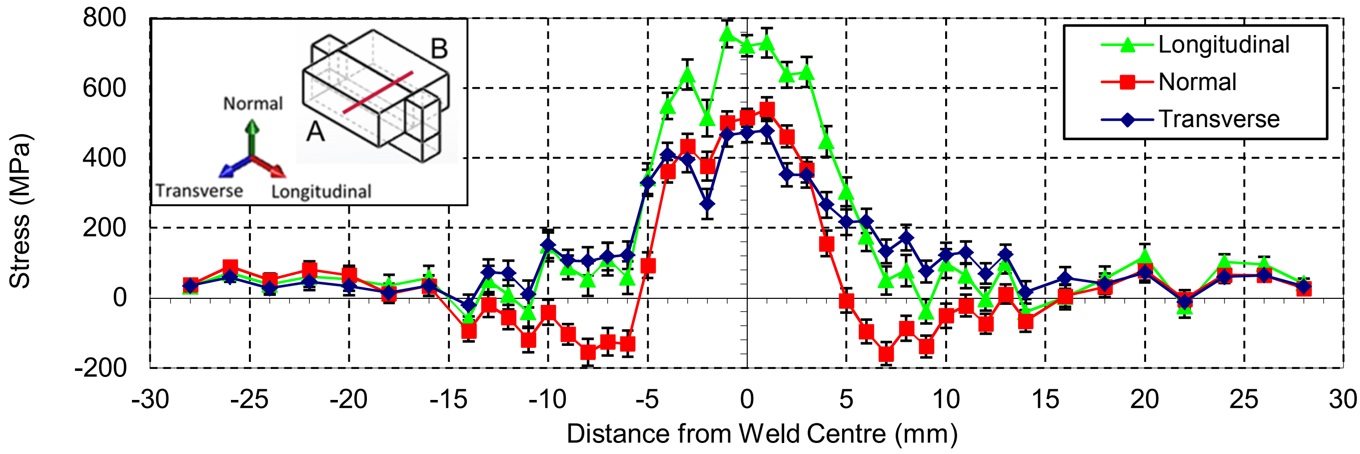

Figure 1 Residual stresses measured along line A-B in specimen EBW5 after welding

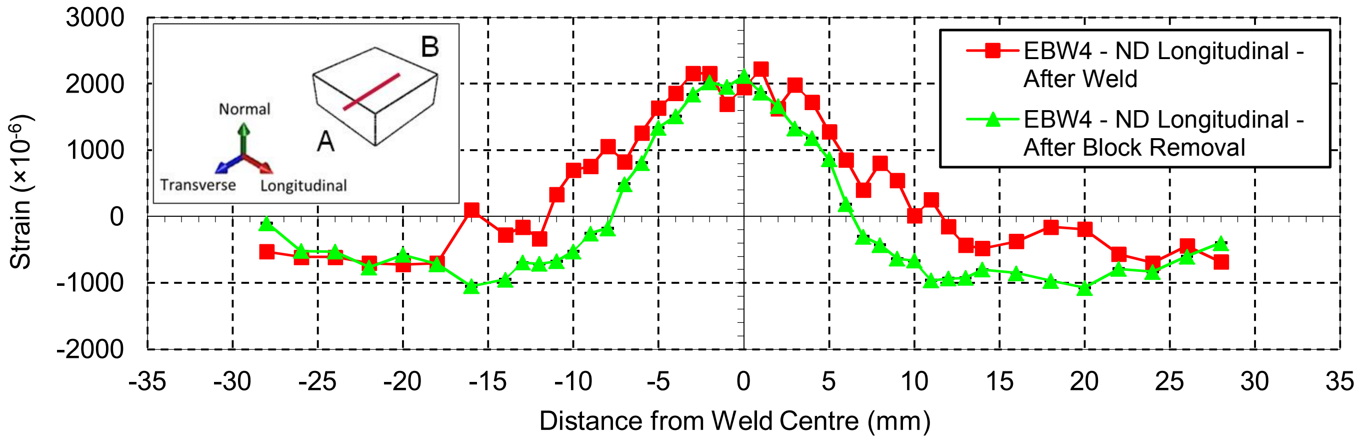

Figure 2 Comparison of longitudinal residual strains measured along line A-B in EBW4 after welding and after machining off run on, run off and backing blocks

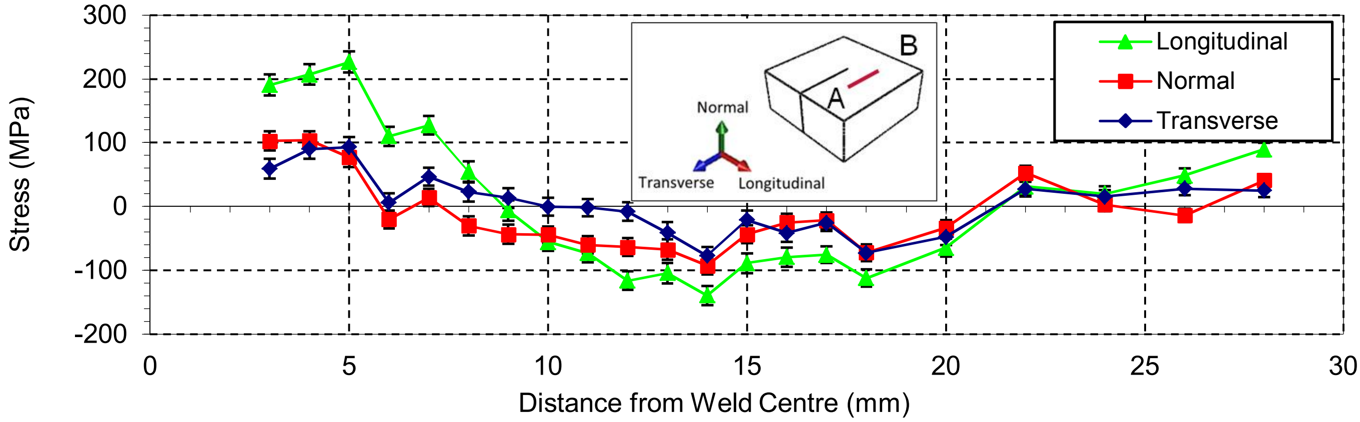

Figure 3 Residual stresses measured along line A-B in specimen EBW3 after machining into a fracture specimen

Table 1 Number of neutrons counted for the three strain components in the three specimens

Specimen	Number of Neutrons Counted		
	Longitudinal	Transverse	Normal
EBW3	10 500	10 500	10 500
EBW4	5 600	Not Measured	Not Measured
EBW5	5 600	5 600	5 600