Experimental Report

15/06/2013

Proposal: **1-02-130** **Council:** 4/2012

Title: Residual stress measurements in stainless steel pipe girth welds withdifferent heat inputs for validation of a neural network approach

This proposal is a new proposal

Researh Area: Engineering

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Samples: Austenitic stainless steel

Instrument	Req. Days	All. Days	From	To
SALSA	4	4	22/11/2012	26/11/2012

Abstract:

Through-wall profiles of residual stress will be measured in three stainless steel pipe girth welds of thickness 12.7 mm made using low, medium and high heat input welding processes. These will be followed by destructive Contour method measurements, providing complementary maps of the hoop residual stresses. The welds have been selected based on gaps in an existing data set for stainless steel girth welds and will be used to validate a novel neural network based approach for weld residual stress characterisation, aimed at providing more accurate input to structural integrity assessment of industrial components.

Residual stress measurements in low, medium and high heat input stainless steel pipe girth welds for validation of a neural network

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1 INTRODUCTION

Accurate quantification of the magnitude and distribution of residual stresses in a welded joint is a challenging task due to the complex interaction of many variables and its non-linear nature. Structural integrity assessment codes simplify the three dimensional residual stress field at a welded joint by selecting an idealised one dimensional stress distribution along a line through the wall thickness. The bounding profiles in these procedures have been based on examination of residual stress measurements and expert judgment. This approach suffers from the drawback that the upper bound curve can increase as more measurements and data scatter are obtained. The consequence of this is that structural integrity assessments of defective plant can be over-conservative by a large margin, and may lead to unnecessary and costly repair or inspection. PhD student Jino Mathew at The Open University is re-examining methods for measuring and estimating more realistic through thickness residual stress profiles in stainless steel pipe girth welds, including refinement of the statistical approach based on Bayes theorem developed by Nadri [1], a novel approach based on neural network modelling and measurements focused on Neutron diffraction and the contour method. His work is supported by Lloyd’s Register Educational Foundation, EDF Energy and Amec. In order to increase the experimental database of residual stress profiles in welded pipes that are relatively thin (< 20 mm), the Open University is undertaking residual stress measurements in three similar thin section stainless steel austenitic stainless steel pipe girth welds made using different welding heat inputs.

2 TEST COMPONENTS

A set of 3 butt-welded pipe specimens were fabricated from AISI Type 316L austenitic stainless steel under carefully controlled conditions with dimensions 300 mm long, 265 mm OD and 12.7 mm thick. The specimens were solution heat treated prior to welding at a temperature of 1060° C for one hour and air cooled to remove stresses induced due to the manufacturing processes. The welds had a single V-type side-wall preparation with an included angle of 75° and were made using a manual TIG process with 316L filler wire. Three pipe welds were made using different electrical heat inputs of 0.7 KJ/mm (low), 1.0 KJ/mm (medium) and 1.2 KJ/mm (high). The interpass temperature was kept below 150° C. An access window of dimensions 35 mm x 50 mm was machined in each pipe using a die sink EDM process in preparation for neutron diffraction residual stress measurements. The stresses were measured at approximately 90° offset to the start-stop location. Stress free reference pins of dimensions 5 mm × 5 mm × 17 mm were extracted from the machined window of each pipe using a wire EDM process.

3 EXPERIMENTAL PROCEDURE

The through-wall distributions of as-welded residual stresses in the three welded pipes were calculated using a monochromatic beam in the present neutron diffraction experiment. Neutrons with wavelength 1.648 Å were collimated to a nominal gauge volume of (2.3 x 2.3 x 2.3) mm^3 and for analysis of the {311} reflection a diffraction angle of approximately 99° was obtained. To enable the hoop component of strain to be measured with little attenuation, an access window was created by removing a “plug” of material located in the path of the diffracted beam. The strain components in the radial, axial and hoop directions were calculated from the peak positions measured at eleven points along radial lines at the weld centre-line (WCL) and heat affected zone (HAZ) and at six points on radial lines at a distance of 2, 4.5, 10 and 14 mm away from the weld centre line. Pins of weld and HAZ metal with dimensions 5 mm x 5 mm x 12.7 mm were extracted from the removed plug of material to measure the reference stress-free lattice parameter (d_0). A schematic diagram of the pipe geometry the array of all the measurement points is shown in Figure 1. In determining stresses it was assumed that the material was isotropic. The diffraction elastic Young’s modulus and Poisson’s ratio were calculated using the Kröner model implemented in the DECcalc software [2] as 187 GPa and 0.303 respectively. Position dependent values for the stress free parameter were used for measurement points along the weld centre line and HAZ by interpolating between fifteen stress free sample measurements on each pin using a polynomial function. Position dependent values were also used to calculate the through wall stresses at locations between the WCL and HAZ (2 mm and 4.5 mm away from the weld centre-line) and HAZ stress free values for points further away from HAZ (10 mm and 14 mm away from the weld centre-line). The average counting time for each measurement point was about 15 min. The measured {311} diffraction peaks were fitted to a Gaussian superposed on a linear background and the scattering angle θ, was determined for each measurement point.

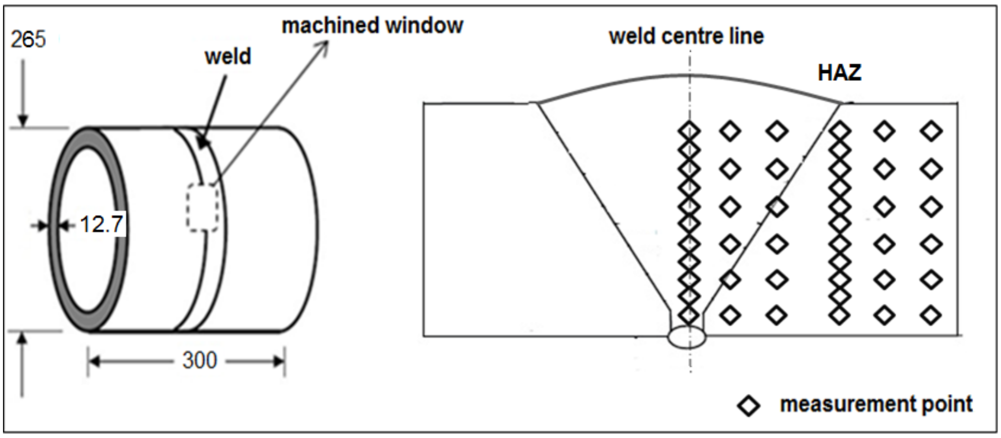

Figure 1: Schematic diagram of pipe girth weld showing the measurement array of points

4 RESULTS AND DISCUSSION

A complex pattern tensile and compressive stresses are seen moving from the inner surface to outer surface and away from the weld centre-line in each weldment. Overall, peak tensile stresses are observed away from the WCL in all three pipes with the WCL being in a relative state of compression. The hoop stress maps exhibit a similar trend with high magnitude compressive stresses along the WCL and peak tensile stresses occurring at a distance of 3 mm away from the WCL. Substantially lower magnitude stresses are generally evident in the medium weld heat input pipe. Interestingly, the consistent pattern in all three pipe welds of high tensile stresses in the HAZ with the WCL predominantly in a state of compression has never been reported before in austenitic stainless steel welds.

Further investigation revealed that substantial radial stresses were present in all three components and the axial and hoop stresses at the WCL were in compression; this result is judged to be unrealistic. The reason could be that the d0 measured in the welds and at a different location are not uniform. Therefore a different data analysis strategy was implemented where the radial stresses were forced to zero representing a plane state of stress condition. This was judged to be a reasonable approach for the relatively thin (~ 12 mm) pipes. Moreover the variation of d0 required to force radial stress to 0 MPa have a similar pattern to the actual measurement, but without much scatter. The resulting (corrected) axial and hoop stress profiles for the WCL are illustrated in Figures 2 and 3. A specific pattern is evident in all the stress profiles in accordance with the variation in heat input. The low heat input pipe has significantly lower stresses at the inner diameter and peaks near the outside surface thereby displaying the maximum stress range out of the three pipes. The high heat input pipe has higher stresses at the ID but a minimal change in the magnitude progressing towards the OD. As expected, the medium heat input pipe has an intermediate profile when compared with the low and high heat input pipe results.

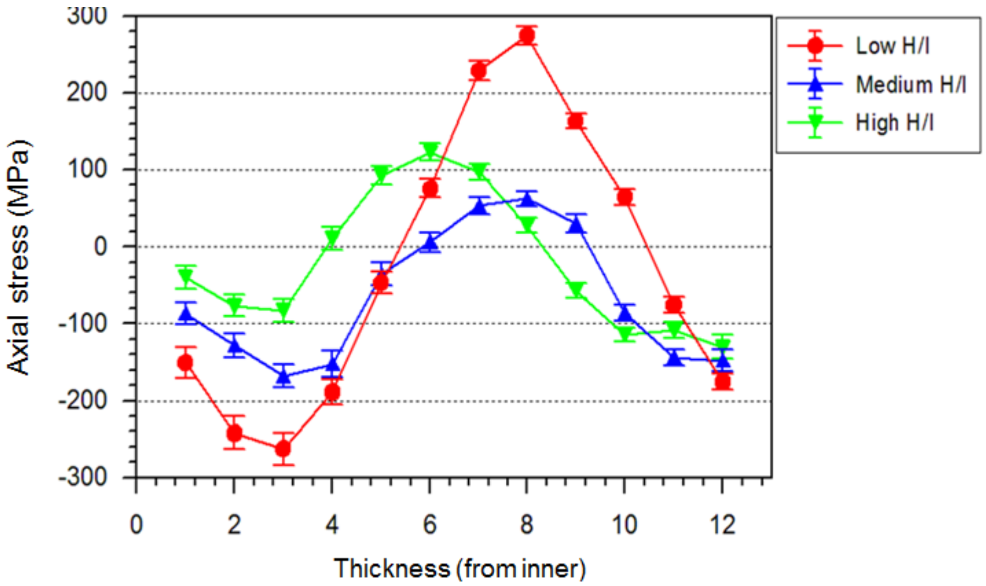

Figure 2: Corrected axial stress profiles at the weld centre line

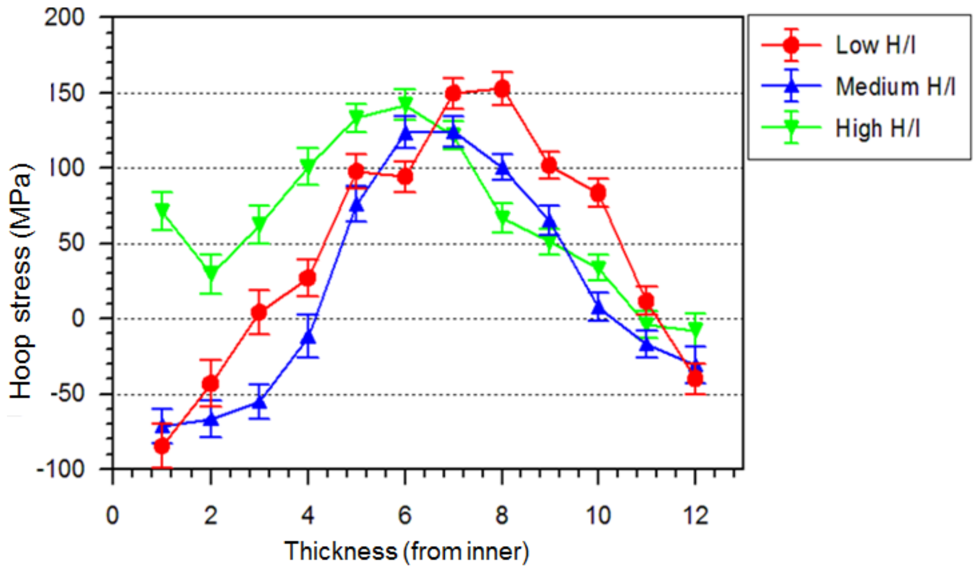

Figure 3: Corrected hoop stress profiles at the weld centre line

5 CONCLUSIONS

The distributions of residual stress in stainless steel pipe girth welds made using three different heat inputs have been successfully measured by neutron diffraction using the SALSA neutron diffractometer at the ILL. A consistent pattern was observed in all three pipe welds of high axial and hoop tensile stresses in the HAZ with the WCL predominantly in a state of compression. A different data analysis strategy was implemented where the radial stresses were forced to zero assuming plane state of stress condition as the pipes are relatively thin (~ 12 mm).

6 REFERENCES

1. Nadri, B., Bouchard, P.J., Truman, C.E., Smith, M.C. and Smith, D.J. Statistical analysis of pipe girth weld experimental residual stress data. ASME Pressure vessels & Piping division Conference. Prague, Czech Republic. PVP2009-77571. 2009.
2. Manns, T. and Scholtes, B. Eine Software zur Berechnung diffraktionselastischer Konstanten aus Einkristalldaten. HTMJ.