Investigation of Residual Stress in Multi-Bead on Plates

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The neutron diffraction technique is used to investigate and compare the residual stress characteristics in fully restrained samples with different numbers of beads. The aim of the research was to characterize the residual stress distribution which arises in a welded component with increasing the number of passes or beads. These results support the concept that welding integrity can be increased as additional layers of welding are added.

1. Introduction

Welding residual stresses are formed in the structure as the result of differential contractions which occur as the weld metal solidifies and cools to ambient temperature [1,2]. The magnitude of stress is a function of the weld deposit size and the effect of shrinkage [3]. Moreover the distribution of residual stress (RS) along the weld can be influenced by the heat input and by phase transformation [4]. Imposed mechanical stresses have a significant effect on corrosion, fracture resistance, creep and corrosion/fatigue performance [5] and a reduction of these stresses is normally desirable. RS in weld joints can be reduced by heat treatment [6] or by mechanical stress relieving [7].

There are various ways of measuring or estimating RS. The direct measurements can be either semi-destructive (e.g., hole drilling and indenting [8]) or non-destructive (x-ray (laboratory or synchrotron) or neutron diffraction (ND) [9] and ultrasonic [10]).

Finite element approaches have been used for welding but a major review still determined that there remains an “urgent need” [11] to develop the required knowledge. The residual stresses in weld repairs are much more complex and difficult to understand and predict [12].

This paper reports experimental ND measurements of weld stresses generated by multi-beads-on-plate. The focus is on the value of line scans of the stress variation in the middle of the weldments. The changes in RS distribution after deposition of additional beads are discussed.

2. Experimental Procedure

2.1 Welding procedure

The parent material used in this study was a low-carbon steel plate of dimensions 200x100x12mm^3, fully restrained during welding. Sample I had three beads on the plate with 50% overlapping from both sides (Fig. 1a). Sample II had four beads on the plate, three in the first layer with 50% overlap and the fourth in a second layer over the top of three (Fig. 1b).

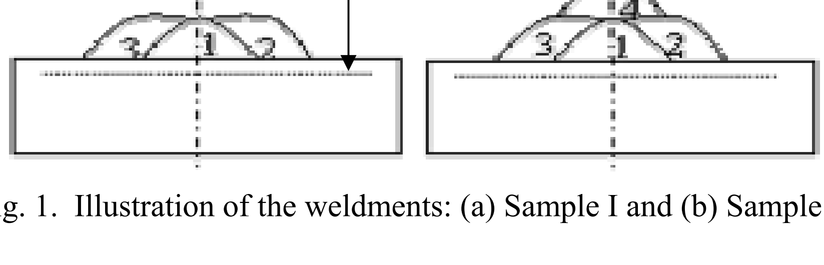

Fig. 1. Illustration of the weldments: (a) Sample I and (b) Sample II

The welds were produced using a flux-cored arc welding (FCAW) process. The specimens were mounted under an automatic-speed-controlled welding torch. The inter-run temperature was 50°C. There was no pre- or post-weld heat treatment (PWHT).

2.2 Residual stress determination

The use of elastic diffraction techniques to determine changes in lattice parameter or d-spacing, (and thus elastic strains) is well established [1,2]. Components of strain are measured directly from changes in crystal lattice spacing. The angle at which any given diffraction peak occurs can be established using Bragg's law.

ND measurements were undertaken on The Australian Strain Scanner (TASS) at ANSTO, Australia. The neutron wavelength used was 1.40Å. Measurements were made using the αFe (112) reflection, at the detector angle, 2θ, of approximately 73.5°**.** Measurements were made with the scattering vector parallel to three axes defined as follows: longitudinal (parallel to the weld); transverse (perpendicular to the weld and parallel to the plate surface); and normal (perpendicular to the weld and the surface).

Scans were made along the measurement line (Fig. 1) from x = 0 (the centre of the weld) to x = 32mm. The centre of the gauge volume was 1.5mm below the top surface of the plate. The stress-free parameters for the steel were measured on eight of 2x2x2mm^3 cuboids which had been cut and glued together (the d_o specimen). The d_o specimen required three measurements for accuracy and yielded a stress-free diffraction angle, 2θ = 73.36°.

3. Results and Discussion

The residual stresses were derived from the elastic strain measurements using a Young's modulus of 207GPa, and a Poisson's ratio of 0.3. The comparisons of the RS in three directions for Samples I and II are shown in Fig. 2. Error bars based on uncertainty in the value of the peak diffraction angle have been shown .

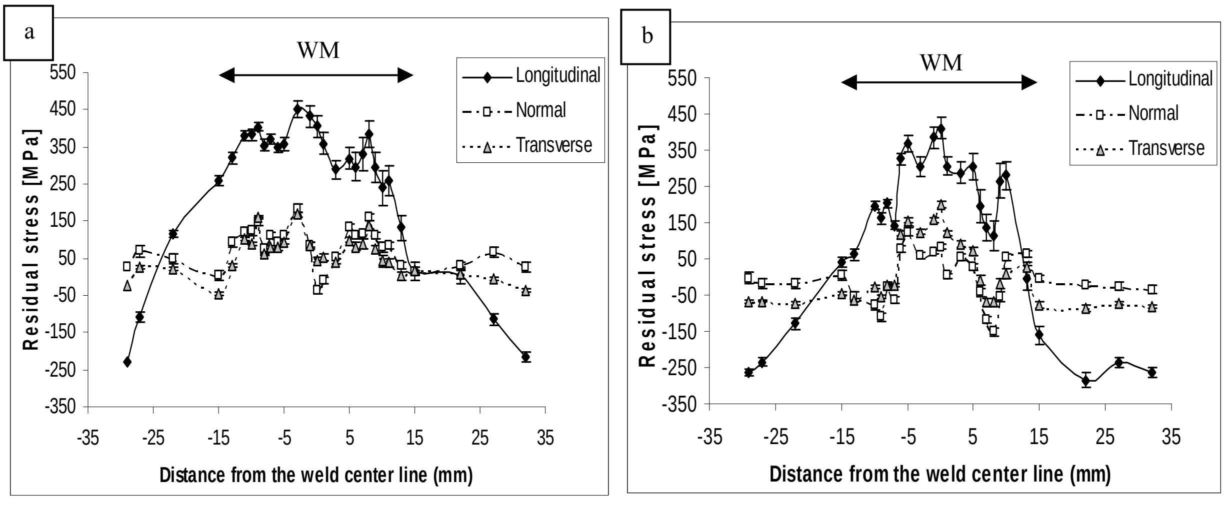

Fig. 2. The longitudinal, transverse and normal components of RS for (a) Sample I and (b) Sample II, measured by ND against distance from the weld center line.

The detailed RS distributions measured by ND for up to three beads-on-plate are described in the authors' previous work [13]. The results show that after deposition of the third bead (Sample I) an increase under the last bead was observed, as well as a decrease on opposite side of the weld. The value of the stress at the toe where the third bead deposited was 260±25MPa but on the opposite side was much less, only 15±15MPa (Fig.2a).

The deposition of the fourth bead which is in fact a new layer (Sample II) made a significant change in residual stress distribution of the weldment (Fig. 2b). The RS increased slightly in the transverse and normal directions under the deposited fourth bead however the longitudinal direction seems to be not affected. Decreases in all directions in heat-affected zone (HAZ) and parent metal (PM) were observed. The RS at the toe of the weld (= 15mm from centre line) reduced in the longitudinal direction from 260±25MPa (Fig. 2a) to 65 ±25 (Fig. 2b) on the side of third bead and from 15±15MPa to compression -140MPa on the side of second bead. The normal stress decreased to 0MPa and the transverse to -50MPa (Fig. 2b).

4. Conclusions

The use of a neutron beam as a non-destructive method of measuring RS due to welding has been explored. Key findings are:

- The peak stress in all samples (which is in the longitudinal direction) exceeded the minimum yield stress in the PM and occurred in the HAZ below the weld bead (where the yield stress is higher).
- With additional weld bead (in a second layer) deposited on to the preceding three beads, the narrowing of the peak and a shift of the peak stresses into the last bead (the last point of solidification) was observed.
- The fourth bead tended to reduce the RS in all components resulting from the previous beads in the HAZ and PM. In particular, significant reduction of the tensile residual stress at the toe of the weldment was observed, which is where most of the service cracks happen.

Acknowledgements

This work was conducted with the assistance of an Australian Research Council grant supported by the Welding Technology Institute of Australia (WTIA). The authors also thank the Australian Institute of Nuclear Science and Engineering (AINSE) for financial assistance (Award Nos. 04050, 04198 and 05053) to enable measurements on TASS to be conducted. A.P. acknowledges the receipt of an AINSE Postgraduate Research Award.

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