Residual Stress Characterization of a Fabrication Weld from the Victoria-Class Submarine Pressure-Hull

R. McGregor [1], R. Rogge [2]

[1] Defence R&D Canada Atlantic, Dockyard Laboratory Pacific, Victoria, BC, Canada, V9A 3E9

[2] Canadian Neutron Beam Centre, National Research Council, Chalk River Laboratories, Chalk River, ON, Canada K0J 1J0

Background

The operational demands of naval platforms can benefit from explicit understanding of the structural impact of fabrication residual stresses. Such accounting supports full exploitation of the operational envelope in emergency or combat situations and design-life extension initiatives.

A length of circumferential-seam closure-weld was contained within a section of hull-plate recently removed from the HMCS Victoria submarine during refit operations. This plate was given to DRDC Atlantic, Dockyard Laboratory Pacific for metallurgical research and has provided a rare opportunity for detailed study of the thru-thickness as-received condition of this common weld-type from original vessel assembly, using techniques not otherwise possible. The results can be considered representative of all legacy circ-seam welds, and can be exploited within numerical models supporting operational limits such as diving depth for Canada's new VICTORIA Class fleet. [1]

Objectives

The plan was to first survey the through-thickness residual strain gradient in an as-rolled plate section (not welded or otherwise cold or hot-worked) to characterize the plate fabrication residual stress effects and provide a comparative baseline for the primary study of the circ-seam weld; and second to characterize the through-thickness residual stress distribution in the vicinity of the circ-seam weld and an adjacent fit-up discontinuity (potential bounding case of pressure-hull cold-work). A grid pattern strain survey in the three principal stress directions would allow one and two-dimensional presentation of interpreted stress data.

The residual stress character within the weld was surveyed with the L3 Neutron Diffractometer. The experiment was performed over a four-week period around October 2007, with DRDC personnel supporting on-site.

Results

The neutron diffraction survey has provided the residual stress distribution shown in Figure 1 for the circ-seam weld transverse direction. Results indicate that OD surface tensile stress peaks exist in the weld transverse direction at levels around 80% of material tensile yield. Longitudinal direction tensile surface stresses are lower in magnitude but similarly fall off to compressive levels at the weld centre line before increasing to higher tensile levels again toward the ID. Measurements are consistent with distributions from numerical analysis and 'surface-only' X-ray diffraction studies on similar weldments from other studies. [2,3,4,5]

From the trend apparent in the through-thickness stress distribution, weld finishing by flush grinding may have served to mechanically remove the highest tensile weld stresses which tend toward the OD surface (Figure 1, note that the micrograph X and Y axes do not have the same scale). Also, the evidence of the back gouge in the Figure 1 micrograph may be attenuating tensile magnitudes on the ID. Flame cutting or the cold work of the dent - both in the vicinity of the test plane - appear to have insignificant polluting effect on the weld stress data. There is little evidence of the effect on the residual stress distribution of the fit-up undulation that runs parallel and immediately adjacent to the circ-seam weld. It seems, therefore, that whatever stresses may have resulted from the fit-up deformation have either been relieved in the welding process or are at least dominated by the weld stresses.

Summary

Data has been obtained to enhance the validity of DRDC's pressure-hull numerical models, metallurgical experimentation initiatives, and X-ray diffraction residual-stress techniques. This will support design enhancement or operational envelope analysis and evaluation for emergency and combat operations including ultimate diving depth determination, structural "weak link" isolation (incipient buckling), and design-life limit assessment and extension (fatigue margin, stress corrosion cracking resistance).

Results can also serve to renew relevance to the existing body of "surface-only" work that has been conducted on actual submarine hulls. Results are available to DRDC for use in other research areas such as submarine hull numerical modeling, X-ray diffraction validation, and fracture mechanics experimentation.

Chalk River has a history of support to DRDC submarine scientific programs for the Oberon Class fleet. [6] This current study has provided a very successful initial interface between NRC-CNBC and the new Submarine Scientific Support Service Level Arrangement that DRDC maintains with Department of National Defence for the recently acquired Victoria-Class fleet. This SLA program is presently engaged in various pressure-hull R & D activities; the NRC's unique residual stress characterisation capabilities have been anticipated as solutions to some of the challenges within these programs. DRDC expects to apply for similar residual stress characterization support in the near future.

This work is a component of the DRDC Atlantic, Submarine Scientific Support Service Level Arrangement. The project was conducted in collaboration with NRC Canadian Neutron Beam Centre with the support of Dr. Ronald Rogge.

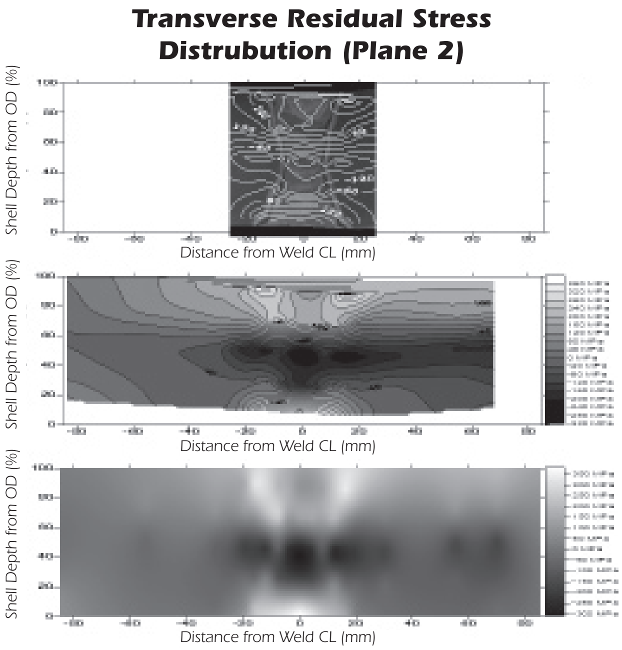

Fig. 1 Distribution of transverse-direction residual stress over the hull circ-seam weld using different visualization approaches.

References

[1] Smith, M., Structural Modelling and Strength Assessment of the Victoria-class Submarine Pressure Hull. Maritime Engineering Journal, Fall 2005.

[2] Porter, J. F. Residual Stress Evaluation of HMCS Onandaga Pressure Hull Weldments, Canadian Forces / CRAD Meeting, DREA – Halifax, May 1985.

[3] Porter, J.F., Brauss, M. F., Pineault, James. X-ray Diffraction Determination of Residential Strain for Marine Platforms, 2nd Canadian Forces / CRAD Meeting on Naval Applications of Materials Technology, DREA-Halifax, May 1985.

[4] Brauss, M. Wong, H., Holt, R.A., Fryzuk, P. Non-Destructive Evaluation of Oberon Submarine Pressure Hull Residual Stress. 2nd Canadian Forces /CRAD Meeting on Research In Fabrication and Inspection of Submarine Pressure Hulls, DREA-Halifax, May 1987.

[5] Farrell, S., Bayley, C. Assessment of Residual Stress Proximal to the Dent Repair Area of HMCS Victoria. DRDC-Atlantic Technical Memorandum TM2006-275, November 2006

[6] Clark, Percy., Holden, Tom., Porter, John., Yee, Richard., Diffraction Measurements on CPF Steel Fatigue Samples. Canadian Forces / CRAD-Meeting, DREA – Halifax.