Mapping of Residual Stress in Ship Hull Structure

S.Y. Kenno,[1] S. Das,[1] J.B. Kennedy,[1] R. Rogge,[2] and M. Gharghouri[2]

[1] University of Windsor, Windsor, Windsor, ON, Canada N9B 3P4

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

Failure of ship hulls is often a product of numerous causes. One contributing factor that has often been overlooked or overdesigned for are the residual stresses created during the welding process. This study was designed to achieve a detailed understanding of the residual stress distribution associated with welds typically found on ship hulls. The first phase of this study focused on the stress field created by one and two stiffeners and also due to the stop and start in the welding process. Additional information was collected on the parent plate and the residual stresses caused by the manufacturing rolling process. The second phase of the study looked at the effect of spacing of the stiffeners and altering the welding heat input. Properly scaled and constructed specimens were created to obtain results that provide the best representation to those found in an actual ship hull. The neutron diffraction method was chosen to non-destructively map strain data at locations within the volume of the specimens.

The specimens were constructed from 9.53 mm thick plates stiffened by L127x76x9.53 stiffeners all of 350 WT grade [1] structural steel. The steel plate material was found to have a yield stress of 405 MPa. The plates were cut using water-jet cutting to avoid additional stresses induced by most cutting processes. The fillet welds were produced using metal-core arc welding (MCAW). The specimens were fully restrained during the welding and the cooling process. The first phase welds were created manually and had some inconsistencies. To reduce the inconsistencies in the welds of Phase II, an automatic trolley system was used. The test matrix for Phases I and II is shown below in Tables 1 and 2, respectively.

Only key findings and results will be presented here.

Specimen 3 was a stiffened plate which was 400 mm wide (T) x 600 mm long (L) x 9.5 mm thick (N). It had two stiffeners and the primary objective was to study the effects of welding a second stiffener on the stress distribution of the first welded stiffener. Measurements were taken at seven depths through the thickness and transversely across the weld.

Table 1: Phase I test matrix

Specimen	Base Plate (L x W x D)	Stiffener Details	Welding Method	Heat Input
1	400 mm x 400 mm x 9.5 mm	No stiffener	No welding	N/A
2	600 mm x 400 mm x 9.5 mm	One 600 mm long stiffener at 150 mm from one edge	MCAW	High (2.5 kJ/mm)
3		Two 600 mm stiffeners spaced 250 mm apart (75 mm from both edges)		

Table 2: Phase II test matrix

Specimen	Base Plate (L x W x D)	Stiffener Details	Welding Method	Heat Input
4	600 mm x 400 mm x 9.5 mm	One 400 mm long stiffener at 150 mm from edge along 600 mm direction	MCAW on speed controlled trolley	High (2.5 kJ/mm)
5	400 mm x 600 mm x 9.5 mm	Two 400 mm long stiffeners spaced 400 mm apart (100 mm from both edges)		
6				Moderate (1.75 kJ/mm)

Figure 1 details the one-dimensional distribution for the longitudinal stress for the transverse line across the weld for Specimen 3. The figure shows the expected stress distribution [2] and exhibits a minimal change in stress levels as the depth through the plate changes. The peak tensile stress at the first and second welded stiffeners was 430 MPa and 386 MPa, respectively, with a plateau of roughly -150 MPa compressive stresses between the two stiffeners. The higher stress value at the first weld indicates that the second weld affects the stress levels of the first weld and is a stress value higher than the yield stress at 405 MPa. The majority of the stress values at the weld centreline are about 400 MPa, just below the yield stress level.

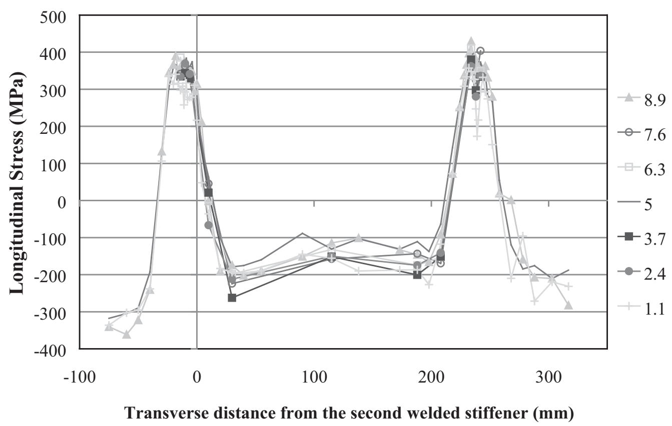

Fig 1. Specimen 3 - Longitudinal stress through the depth in the transverse direction

Specimen 5 was a plate with dimensions of 600 mm wide (T) x 400 mm long (L) x 9.5 mm thick (N). Two 400 mm long stiffeners were welded and spaced at 400 mm on centre. The objective was to determine the effect of stiffener spacing on residual stress distributions compared with Specimen 3 in Phase I. The measurements were taken in the transverse direction across the weld and along both welds to check for consistency and at five depths through the plate. Measurements were not collected at the weld and stiffener connection due to time constraints and complicated test set-ups. However, the results from Phase I demonstrated that the strain values were constant through the weld.

The longitudinal stress distribution transversely across the weld is shown in Figure 2. The pattern of stress distribution agrees with that which was obtained from Specimen 3 and previous work [2]. At the second welded stiffener, the maximum stresses were observed near the welded surface of the plate (at depths of 8.4 mm and 6.6 mm) and the value is about 525 MPa, which is well above the first yield stress of the plate, which was measured as 405 MPa. The maximum longitudinal stress at the stiffener welded first is 410 MPa, which is close to the yield stress value and similar to the value observed from Specimen 3 of Phase I. Therefore, the higher value of stress at the second welded stiffener may be due to the effect of welding the first stiffener or some inconsistencies in the weld itself.

The Specimen 5 stress values drop from the maximum tensile peak down to a compressive value of roughly -200 MPa, which are roughly the same values as found in Specimen 3. From this low point directly next to the stiffener-weld connection the stress values increase back up to near zero (ranging from -35 MPa to 45 MPa) for the plateau between the stiffeners.

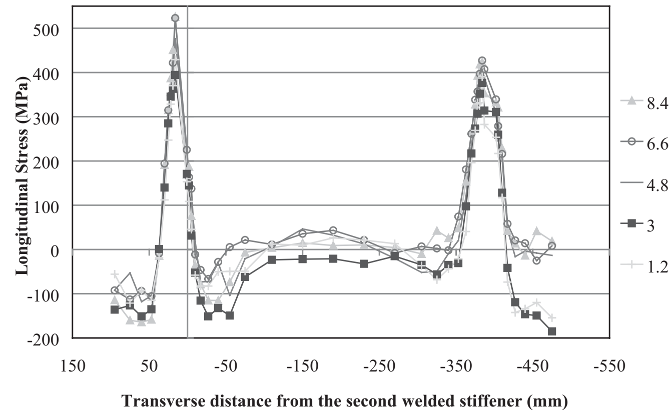

Fig 2. Specimen 5 - Longitudinal stress through the depth in the transverse direction

Specimen 6 was constructed identically to Specimen 5 however; the heat input during welding for Specimen 6 was significantly less (1.75 kJ/mm) compared to the average heat input (2.5 kJ/mm) used for all other specimens. Measurements were only taken around the second welded stiffener due to time constraints and a complicated test set-up. It was assumed that the stress pattern found in Specimen 5 would be similar to the pattern found in Specimen 6 with a change in magnitude.

Figure 3 shows the longitudinal stress collected for Specimen 6 transversely across weld at the second welded stiffener and does not include any extrapolated data. The longitudinal stress component had a 25% increase from Specimen 5 to Specimen 6 with the 30% drop in welding heat input. Based on literature reviewed the increase in maximum stress values were expected when using a lower heat input during the welding process.

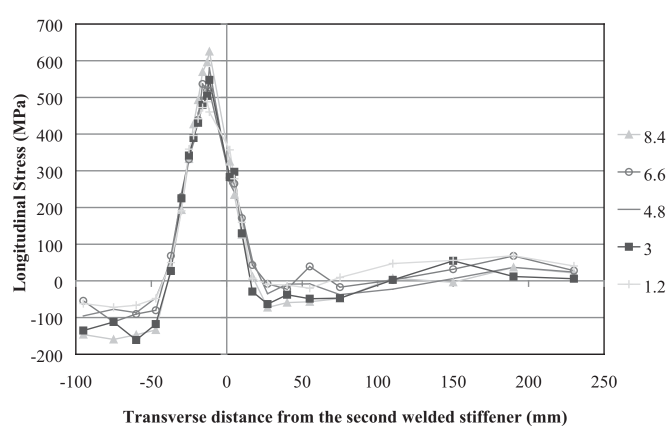

Fig 3. Specimen 6 - Longitudinal stress through the depth in the transverse direction

This is a result of a faster cooling rate with a lower heat input since the welding temperature is closer to the ambient temperature than if a higher heat input was utilized. The increased rate of cooling allows for shrinkage and additional phase transformations, ultimately leading to higher residual stress values. ([3], [4])

Summary and Conclusions

The testing completed shows detailed information on the residual stress distribution through the thickness of a plate. All three strain components were collected to calculate the actual residual stress distributions in the specimens. Most previous work focused only on surface stresses due to the limitations of testing methods and only focused on collecting one or two strain components and assuming a plane strain problem.

Specimen 2 and Specimen 3 are the benchmark specimens for comparing stress distributions in Phase II and for future studies. Specimen 2 provided a look at the one stiffener stress distribution and weld inconsistencies that were not presented here. Specimen 3 presented a first look at the effect of welding a second stiffener on the stress distribution. The maximum stress values of the first welded stiffener were found to be slightly higher than those of the second welded stiffener and near the yield stress of the plate.

The results from Specimen 5 showed that the increased stiffener spacing allowed for the stress levels between the stiffeners to reduce down to near zero but the peak tensile stresses to increase above yield. Specimen 6 was created physically identical to Specimen 5 except for a difference in welding heat input. The results for Specimen 6 showed the expected stress distribution with higher peak tensile values due to the lower welding heat input.

The data collected and analyzed here will be beneficial in the planning and execution of any future testing. A more in depth look may also be taken at the effects of inconsistencies in the welding process, expanding on the minimal data that was collected in these experiments. A semi-destructive method, such as hole-drilling, may be implemented to verify the results found here. As well, computer modelling may be used for a detailed parametric study.

References

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