Surface preparation for residual stress measurement of an accelerated corrosion tested welded marine steel

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Surface Preparation for Residual Stress Measurement of an Accelerated Corrosion Tested Welded Marine Steel

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Abstract:

Residual stress measurement is often required for the assessment of structural integrity of components. Measurement of residual stress in corrosion tested specimens is challenging owing to the difficulty of accessing the surface because of the rust layer. This study explored the potential methods for the surface preparation of an ultrasonically-peened and accelerated corrosion tested DH36 marine steel fillet welded specimen to ease the way for subsequent residual stress measurement using neutron diffraction and the contour method. We find that hydroblasting introduces compressive residual stress at the surface that will alter the surface stress to be measured.

Keywords: Rust; X-ray diffraction; Steel.

1. Introduction

Corrosion affects the performance and overall appearance of structures, and causes reduction in component strength. Accelerated corrosion tests are designed and conducted to assess protection against corrosion and to predict service life. Temperature is the most common accelerating factor during accelerated corrosion testing.

Ultrasonic peening (UP) is a post-weld treatment method to increase the fatigue life of welded joints by imparting compressive residual stress. For the specimen used in this study ultrasonic peening was applied at the weld toe of fillet weld attachments. The broad scope was to determine the distribution of residual stresses in the ultrasonically peened region after accelerated corrosion exposure. Samples were studied as-welded, following ultrasonic peening, and after accelerated corrosion exposure. Following accelerated corrosion exposure the sample was covered with a thick coating of rust, that prevents the application of residual stress measurement techniques. For example, X-ray diffraction cannot penetrate more than a few tens of microns [1]; incremental hole drilling requires accurate knowledge of the surface location of the underlying metal [2]; neutron diffraction requires knowledge of the surface location in order to define internal measurement positions [3]; and for the contour method of residual stress measurement the specimen is cut using wire electric discharge machine (WEDM), and it is essential that the specimen be free from any rust so that it may not affect the quality of cut by causing wire breakage or an irregular cut.

Mechanical cleaning procedures are undesirable in the preparation of samples for residual stress measurement, as they change the existing residual stress state within the near surface layer. In this paper, we report results of a study that was carried out to examine the feasibility of the application of the hydro-blasting process to DH36 steel.

A particular application of hydro-blasting, known as water jet peening, has been used previously to induce compressive stress for resistance against fatigue and stress corrosion cracking failures [4, 5]. The method has been noted as leading to surface roughening [6], which may be undesirable in some applications.

2. Specimen details

A fillet welded marine DH36 steel specimen was used in this study, which was ultrasonically peened at the weld toe locations around the attachment corners. The specimen comprised a 25-mm-thick base plate with 15 mm thick attachments welded manually on both sides of the plate using flux cored arc welding (136/FCAW). The material was carbon manganese DH36 ship structural steel, with nominal composition as in Table 1. Ultrasonic peening was carried out by Daewoo Ship Building and Marine Engineering (DSME). The depth and width of the peened groove were 0.5 and 3 mm respectively.

Following peening the specimen was accelerated corrosion tested as per ASTM standard D1141 [7]. The composition of synthetic sea water as per ASTM D1141 is shown in Table 2. The corrosion rate of synthetic sea water is close to natural sea water [8].

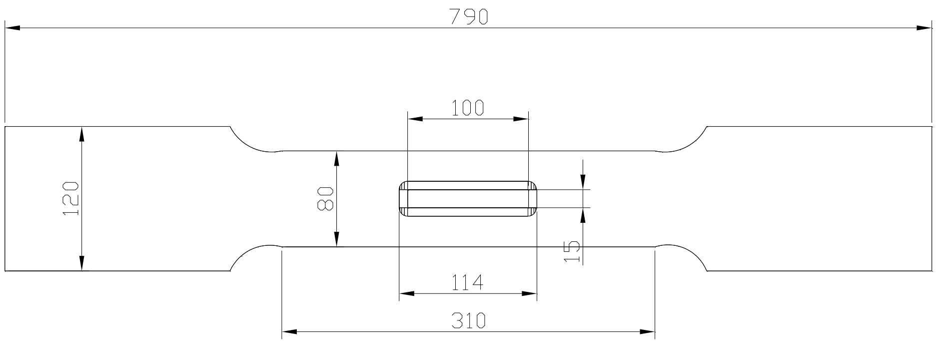
Element	C	Mn	Si	P	S	Al	Nb	V	Ti	Cu	Cr	Ni	Mo	Fe
Wt%	0.18	0.9-1.6	0.5	0.035	0.035	0.035	0.02-0.05	0.02-0.05	0.02-0.05	0.02-0.05	0.2	0.4	0.08	bal

Table 1: DH36 steel composition

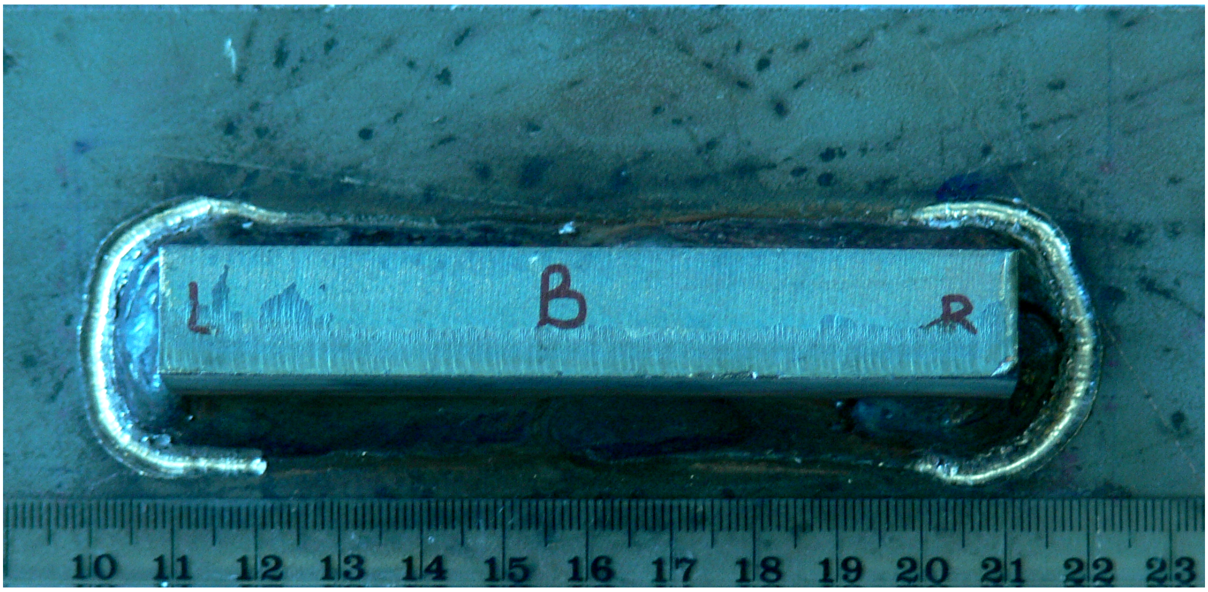
Percentage chemical composition of synthetic sea water / g l^{-1}		
Sodium chloride	NaCl	24.53
Magnesium chloride	$MgCl_2$	5.20
Calcium chloride	$CaCl_2$	1.16
Potassium chloride	KCl	0.70
Sodium sulphate	Na_2SO_4	4.09
Sodium hydro-carbonate	$NaHCO_3$	0.20
Potassium bromide	KBr	0.10

Table 2: Chemical composition of synthetic sea water

A cycle of half hour of artificial sea water spray followed by half hour drying at temperatures of 60°C and 90°C was used for the accelerated corrosion testing, and was undertaken by Lloyd's Register, UK. Specimens were rotated from time to time for uniform exposure to salt spray. The exposure rate simulated the service life of 7.5 years and the corrosion duration was 324 days. Figure 1 shows the specimen details, and figure 2 shows the salt bath used for corrosion exposure.



(a)



(b)

Fig. 1: (a) Schematic of the specimen; (b) Detail of the weld, showing the peened areas at both ends.

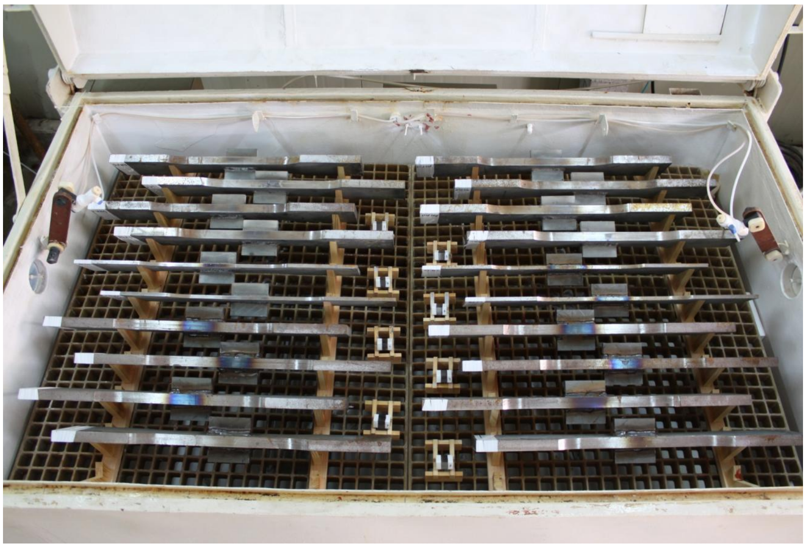


Figure 2: Salt bath used for corrosion exposure. A number of specimens were placed in a single test chamber and were rotated from time to time to ensure uniform exposure to salt spray

3. Experimental details

The general practice for removing the corrosion products after a corrosion test is prescribed in ASTM standard G1–90 [9], wherein procedures for mechanical, chemical and electrolytic cleaning of corrosion products are described. It is generally desired that corrosion removing products only remove the corrosion and should not affect the base metal. Mechanical cleaning procedures such as grit blasting, scraping, brushing etc. also remove some of the base metal and can induce residual stresses to the specimen.

Hydro-blasting is a surface preparation/cleaning technique that depends upon high-pressure water to produce the cleaning effect. A small strip of 120 × 120 mm^2 was extracted from DH36 steel using electro-discharge machining and the hydro-blasting was performed by RGL Hampshire with a pressure of 248 MPa. Surface roughness (R_a) was measured before and after hydro-blasting using a Taylor Hobson Surtronic 3+ roughness tester and was found to be was 8 μm and 12 μm respectively. Surface X-ray diffraction measurements were performed using a Stresstech X-Ray diffractometer using the $\sin^2\psi$ technique with Cr K-α radiation diffracting from the Fe {210} planes. The diffraction angle $2\theta = 156.4$, the material modulus of elasticity $E = 210$ GPa and Poisson's ratio $\nu = 0.3$. The residual stress measurement results are shown in section 4, performed at various locations before and after hydro-blasting.

As an alternative, a chemical method was selected for cleaning of the sample. Cleaning solutions typically use hydrochloric acid (HCl), sodium hydroxide (NaOH), and hexamethylenetetramine as corrosion removing products. Since all these products are in liquid form, their application to large specimens make them difficult to handle or require specialized arrangements wherein specimens can be dipped into a reservoir containing solution from time to time until the desired surface has been achieved. For the accelerated corrosion tested specimen a more practical way of removing the corrosion product was to apply rust remover gel, which can stay on specimen for some time and also does not require specialist arrangements. Hammerite rust remover gel (HAM RRG) part no.11336 was selected. According to the manufacturer this gel is composed of hydroxyl propane tricarboxylic acid, sodium heptonate, solvent naphtha (petroleum) with an overall pH of 2.05-2.45. The gel was applied with a plastic wire brush on the specimen for 20-30 minutes as recommended by the manufacturer, followed by removing the products with a plastic wire brush followed by water rinsing. The process was repeated until a suitably clean surface was achieved that could afterwards be used for residual stress measurement. The stress state is to be determined in the base metal underlying the rust, therefore it is necessary that the datum surface be clearly visible and clean.

4. Results and discussion

The surface residual stress measured using X-ray diffraction at five points on the surface of the specimen before and after the application of hydro-blasting is shown in Table 3. The results are derived from the slope of the measured d vs $\sin^2\psi$ plots from the {210} planes. The shift in the diffraction peak with ψ-angle was determined within the machine software by use of a cross-correlation technique.The hydro-blasting process has introduced compressive residual stresses on the surface of specimen for all measurement points. The induced residual stresses range from –58 to –77 MPa in the longitudinal direction relative to the original rolling direction of the plate material, and –16 to –131 MPa in the transverse direction. These stresses are in addition to those stresses that already existed in the specimen due to specimen manufacturing. The objective of using the hydro-blasting was to clean the surface without modifying the existing stress state, and as the results showed that this process induces compressive residual stress thus it was decided not to use this process for surface preparation of the corrosion tested specimen.

Measurement point no.	**Residual stress before hydro-blasting / MPa**			**Residual stress after hydro-blasting / MPa**		
	Longitudinal	Transverse	Average	Longitudinal	Transverse	Average
1	–156 ± 15	–229 ± 14	–195 ± 14	–234 ± 10	–246 ± 12	–240 ± 11
2	–183 ± 10	–156 ± 14	–170 ± 12	–241 ± 10	–240 ± 13	–241 ± 11
3	–128 ± 12	–160 ± 18	–144 ± 15	–195 ± 9	–193 ± 12	–194 ± 11
4	–158 ± 14	–129 ± 20	–144 ± 17	–242 ± 11	–246 ± 12	–244 ± 12
5	–186 ± 22	–119 ± 19	–193 ± 14	–256 ± 11	–251 ± 10	–240 ± 11
	Average		**–160 ± 16**	Average		**–234 ± 11**

Table 3: Surface residual stress measured by X-Ray diffraction before and after hydro-blasting

Figure 3 shows the ultrasonically peened fillet welded specimen subjected to accelerated corrosion test after preparing its surface with Hammerite rust remover gel.

Fig. 3: Close-up of area of interest of ultrasonically peened fillet welded specimen after removal of rust

After the surface preparation of specimen with rust removal gel it was used for residual stress measurement using neutron diffraction and the contour method.

5. Conclusions

A DH36 marine steel was prepared with fillet weld attachments, and subjected to accelerated corrosion exposure following ultrasonic peening of the welds. Corrosion exposure was to an equivalent of 7.5 years, in artificial sea water. A thick layer of rust was present on the surface following corrosion, which was required to be removed in order to effect measurement of the residual stress in the sample. Hydroblasting was trialled for the cleaning, and was found to induce compressive residual stress that would alter the residual stress profile at the specimen surface.

Acknowledgement

The authors are grateful for funding from the Lloyd's Register Foundation, a charitable foundation helping to protect life and property by supporting engineering-related education, public engagement and the application of research. We wish to thank RGL Hampshire for performing the hydro-blasting of the test coupon.

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