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# Investigating the accelerated test condition to produce cracking failure of water ballast tank coatings

N. Perera<sup>1</sup>, E. A. Oriaifo<sup>1</sup>, A. Guy<sup>2</sup>, P. S. Leung<sup>1</sup>, K. Tan<sup>1</sup>

<sup>1</sup> Department of Mechanical and Construction Engineering, Faculty of Engineering and Environment, Wynne Jones Building, Northumbria University, Newcastle Upon Tyne, NE1 8ST, England.

<sup>2</sup> Safinah Ltd, 21A Bridge Street, Morpeth, Northumberland NE61 1NT, England.

**Abstract:** The shipping industry and its stakeholders have raised concerns of coating degradation leading to corrosion in water ballast tanks (WBTs) of in-service Double Hull (DH) tankers and bulk carriers. It is extremely challenging to maintain, inspect and repair WBT coatings due to their size and complex structural geometry. Hence there is an increasing demand from the shipping industry for better WBT coating quality and performance to increase the life span of the DH tankers and bulk carriers. Prior to their application WBT coatings are subjected to the Performance Standard for Protective Coatings for Dedicated Sea Water ballast tanks (PSPC) test protocols to assess their performance. When in-service WBT coatings are subjected to hygrothermal cycling which is due to their working condition i.e. change in temperature as a result of the day/night cycle and the ballasted/de-ballasted cycle. Cargo temperature can also add to this cyclical burden. Stresses that are induced in the coating via hygrothermal cycling may contribute to the initiation of cracks in the coating. Therefore there is both academic and industrial interest to better understand and identify the factors that contribute to the cracking phenomena of these coatings. This investigation examined the effectiveness of the accelerated tests consisting of defined environmental factors to produce coating cracking failure at the welded joints under laboratory conditions.

**Key words:** Corrosion, Hygrothermal cycling, Test protocols, Water ballast tanks.

## 1. Introduction

WBTs are an essential part of the ship as they provide stability and propeller immersion when the ship is in the un-laden (unloaded) condition. In the late 19<sup>th</sup> century stone, sand and rock were replaced with seawater as the preferred ballast medium [1]. The introduction of dedicated water ballast tanks (that

were integrated into the ships structure) and the use of seawater as a ballast medium gave rise to corrosion problems. This ultimately led to the use of coatings in WBTs to reduce corrosion. The WBT coating performance and its ability to prevent corrosion was highlighted in the late 20<sup>th</sup> century as a result of considerable losses of bulk carriers and tankers [3]. As a result of this there was increased focus on the effects of corrosion and a greater demand from the shipping industry for better performing protective coatings [3], [4].

The USA Oil Pollution Act of 1990 (OPA 90) was introduced to address the Exxon Valdez accident in 1989. As a consequence of this, tankers had to be built with a DH design to eliminate the potential risk of an oil spill and the resultant pollution of the marine environment in the event of an accident. However the DH design increased the surface area and the geometrical complexity of the WBT as compared to the Single Hull (SH) design [5], it also served to provide a “thermos effect” which tended to increase temperatures in the ballast tanks, resulting in associated accelerated rates of corrosion. The increased quantity of the stiffeners used in the DH design and its complex geometries make it very challenging for the applicators to achieve a good quality WBT surface preparation and coating application. These highlighted issues together with the WBT environmental working conditions have resulted in early coating degradation and increased corrosion rates in the DH as compared to the SH vessels [5], [6]. Modes of coating degradation included cracking, flaking and blistering [7]. Cracking was observed to occur most at the welded sections within the DH WBTs [5], [8], in particular in way of fillet welds and erection butts and seams.

Currently the coating industry and regulatory bodies as well as asset owners apply a range of test protocols to measure coating performance. Some of the common test protocols are ASTM D5894-10, ISO20340:2009 (E), NORSOK M-501, NORDTEST, NACE TM0104-2004, NACE TM0304-2004 and IMO PSPC. Published work [9] demonstrated that these test protocols do not satisfactorily reproduce coating cracking failure as seen in in-service DH WBT coatings. It has also been reported [9] that issues such as changes in coating formulation i.e. compositional and preparation, exposure to severe service conditions and inadequate test and prequalification standards potentially contribute to the DH WBT coating failure.

## 2. Experimental Setup

### 2.1. Test Equipment

The oven used in this investigation was a Memmert UF160 Plus. The oven features were: interior dimension (W X D X H) is 560 mm x 400 mm x 720 mm with a temperature range from a minimum of +30°C to a maximum of +300 °C. Other equipments used were a pico logger, thermocouples, laptop computer and water tank.

### 2.2. Test Specimen Preparation

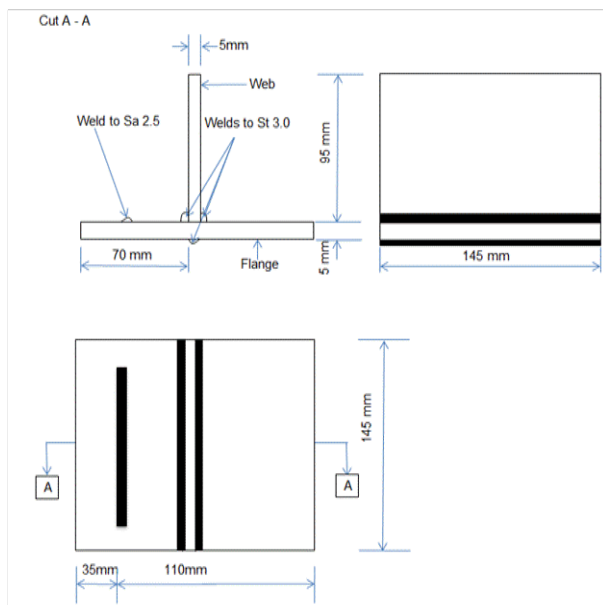


Fig. 1: T girder test specimens

The test specimen used was a mild steel T girder (i.e. a welded web and flange as shown in fig 1 above). The T girder dimensions of the web were 145 mm x 145 mm x 5 mm and the flange were 145 mm x 95 mm x 5 mm. These dimensions were selected to accommodate the maximum number of test specimens within the internal space of the oven. In-service cracking failures of WBT coatings are seen initiated on the welded joints especially at corners that are normally prepared by power tooling. Power tooling leaves a smoother surface which can reduce the adhesion of coatings to the substrate. However it tends to result in coatings having higher dry film thicknesses when applied due to stripe coating. Other areas such as the flat surfaces and welds on the flat surface are mostly prepared by grit blasting. Grit blasting leaves a roughened and clean adhesion surface for coating application. The effect of surface preparation and its perceived contribution to the coating cracking phenomena has been factored into the preparation of the test specimen. This was achieved by having 4 welds on the test specimen to simulate the effect of the in service surface preparation. 2 welds at the intersections of the flange and web, 1 on the underside of the web situated directly under the flange and another situated 35mm away from the edge of the flange. The surfaces on top of the T girder including the weld situated 35mm away from the edge of the flange were prepared by grit blasting to Sa 2.5. The surfaces on the underside of the flange, the welded joints at the intersection of the flange and web together with the weld on the underside of the flange were prepared by power tooling to St 3. The difference between Sa 2.5 and St 3 are shown below in table 1.

Standard	Method	Description of finish
Sa 2.5	Blast cleaning	Near white metal with mill scale, rust and foreign matter completely removed so that only traces remain in the form of spots or stripes
St 3	Hand or power	Mill scale and poorly adhering rust are removed

	tool	leaving the surface contamination that is well adhered and exhibiting a metallic sheen.
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Table 1: Description of the standards

### 2.3. Epoxy coatings

For the purpose of this investigation 4 epoxy coating formulations were applied to the T girder test specimens. Due to a non-disclosure agreement between the university and its industrial partners, details pertaining to the compositions of these 4 epoxy coating formulations were limited to the information shown below in table 2. For explanation purposes the 4 epoxy coating formulations used in this investigation were described as Formulation A, B, C and D. Normally coatings are specified to be applied at 320  $\mu\text{m}$  dry film thickness (dft) in 2 coats. However practical experience in the field have shown that it often results in over application at between 2 and 3 times the dft specified as a result of the complex geometry and design of these stiffeners [10]. To replicate the coating dft as seen in the field, each coating formulation was applied with dfts of 640  $\mu\text{m}$  and 960  $\mu\text{m}$  on 3 T girders respectively. Therefore a total of 24 T girder test specimens were prepared for the 4 epoxy coating formulations consisting of 2 different dfts. The coating application was carried out using airless spray.

For.	Vol. solids %	PVC %	Stoichiometry-Epoxy: Amine	Epoxy resin
A	70.7	27.88	1:0.9	Liquid
B	67.79	26.01	1:0.85	Liquid
C	93	9.19	1:0.87	Liquid
D	87.45	12.91	1:0.85	Liquid

Table 2: Compositional details of the formulations

### 2.4. Accelerated Testing

The accelerated test consisted of cooling and heating cycles. The cycles were as follows: cooling the test specimens in sea water at 23°C and then heating it in the oven at 100°C. A water tank containing artificial sea water (3.5% salt) at 23°C was used to cool the test specimens. A typical accelerated test cycle had the T girder test specimens cooled in sea water at 23°C for 2 hours in a water

tank, then heated in the oven at 100°C for 2 hours. This was followed by cooling it in artificial sea water at 23°C for 2 hours in a water tank then heated again in the oven at 100°C for 18 hours. The accelerated test cycle was then repeated continuously until visible cracks appeared on the coating of the T girder test specimens. The accelerated test cycle was stopped immediately for that particular coating formulation once cracks appeared on the coating of the T girder test specimen.

### 3. Results and Discussion

For formulation A, after just 1 accelerated test cycle, cracks were observed only on the welded joints at the intersection of the flange and web of the T girder as shown in Fig. 2. All 6 T girder test specimens for both dfts for this formulation exhibited cracks at this location.

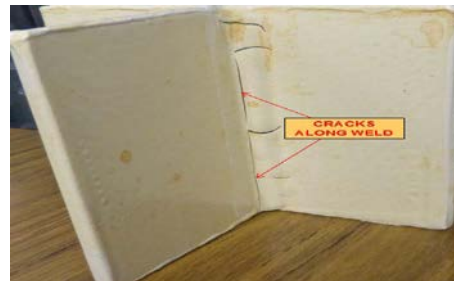


Fig.2: T girder test specimen for formulation A displaying cracks along the welded joint

For formulation B, cracks were observed only on the welded joints at the intersection of the flange and web of the T girder after 42 accelerated test cycles. All 6 T girder test specimens for both dfts for this formulation exhibited cracks at this location.

For formulation C, cracks were observed on the welded joints at the intersection of the flange and web of the T girder after 59 accelerated test cycles. All 6 T girder test specimens for both dfts for this formulation exhibited cracks at this location. Additionally minute cracks have also been observed on all the flat surfaces of the 2 test specimens of 640  $\mu\text{m}$  dft and the same was observed for the 3 test specimens of 960  $\mu\text{m}$  dft.

For formulation D, minute cracks were observed only on the welded joints at the intersection of the flange and web of the T girder after 59 accelerated test

cycles. Cracks at this location were observed on a total of 2 T girder test specimens having 640  $\mu\text{m}$  and 960  $\mu\text{m}$  dfts respectively. The size of cracks that appeared on the welded joints at the intersection of the flange and web of the T girder ranging from largest to smallest has been observed in rank order of Formulation A, B, C and D. The number of accelerated tests cycles that were required to produce cracks on the welded joints at the intersection of the flange and web of the T girder ranging from the lowest (1 cycle) to the highest (59 cycles) were also observed in rank order of Formulation A, B, C and D. From these observations it can be deduced that the coating cracking resistance strength ranging from weakest to strongest is in the rank order of Formulation A, B, C and D.

#### 4. Conclusion

The results have shown that under laboratory conditions for all 4 coating formulations the implemented accelerated test conditions have produced cracks at the welded joints (i.e. corners) as seen in the in-service WBTs. Further validation of this experimental result is required. This is to ensure the validity of the accelerated test conditions used in this investigation before it can be considered as a reliable test protocol to assess the in service performance of the WBT coating. It is acknowledged that currently it would not be possible to draw any conclusive comparison between the performances of the coating formulation used under laboratory conditions with the in-service coatings due to the coating performance being formulation dependent. Therefore in the longer term it would be useful to investigate the performance of coatings having set formulations to enhance the life expectancy of the DH tankers and bulk carriers.

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