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Effects of Weld Fume on the Corrosion Protection of Epoxy Coated on Carbon Steel

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Welding was widely used in shipbuilding industries as a joining method. In present study, the effects of welding fume contaminated on steel surface on corrosion protection were examined by water ballast simulation test and condensation chamber test. Pull-off adhesion test, blistering test and cathodic disbondment test were carried out to evaluate the effects of residual welding fume. Consequently, it was clearly indicated that the residual welding fume didn't affect the corrosion protection of epoxy coated on steel when surface was treated by light sweep blasting to heavy sweep blasting which was applied in this study.

Keywords *: welding fume, shop primer, adhesion, blister, cathodic disbondment*

1. Introduction

The shipbuilding consists of many process including welding, cutting, painting, assembling and outfitting, etc. The steels are welded and assembled to block structure which was exposed marine atmosphere more than three months before main paint. In most shipyard, welding method has been used to join the steel structure, and steel surface is apt to be contaminated by welding fume. The steel surface is usually cleaned by blasting before main coating using anticorrosion paint, usually epoxy paint.

Zinc-containing paints are widely used in coating application throughout the world because of their high performance of corrosion protection.[1)-3)] The mechanism by which zinc-containing paints protect steel has been of interest since the early 1940s.[4)] Mayne[4)-5)] established the key factors in corrosion protection performance of zinc-containing paints as the volume concentration of the zinc pigment. Several researchers examined the corrosion protection properties of zinc-containing paints[6)-15)] and they proposed the mechanism on the cathodic protection of zinc-containing paints to metal.

Inorganic zinc silicate primer is most common shop primer used in Shipbuilding Company. Mil scale covered steel plates are delivered to shipyard and mil scale is removed by primary blasting cleaning process finally making surface roughness. Then, inorganic zinc silicate primer is sprayed on blasted steel surface with dry film thickness of 10~15 μm.

After the welding work is carried out, the adjacent parts of the primer surface are contaminated by welding fume. In general, contaminated welding fume has been fully removed by grinding or blasting before main coating. However, how much welding fume is allowed to keep the corrosion protection performance of coating is a matter of concern of industries.

Water ballast tank (Fig. 1) is a compartment within a ship, which holds sea water. A large ship typically have several ballast tanks including double bottom tanks A ballast tank can be filled or emptied in order to adjust the amount of ballast force of ship. Water ballast tanks are the most demanding of effective corrosion protection systems because it experiences severely corrosive environment including sea water immersion, wet and dry, etc. Prior to application of water ballast tank coating, secondary blasting cleaning is required. The shop primer needs to be cleaned properly to remove oil, fat, dirt, dust, rust and salts which degrades adhesion properties and provide an initiating site for blistering

The purpose of present study is to evaluate the effects of extent of residual welding fume after secondary blasting cleaning on corrosion protection of epoxy coated carbon on steel applied to water ballast tank of ship.

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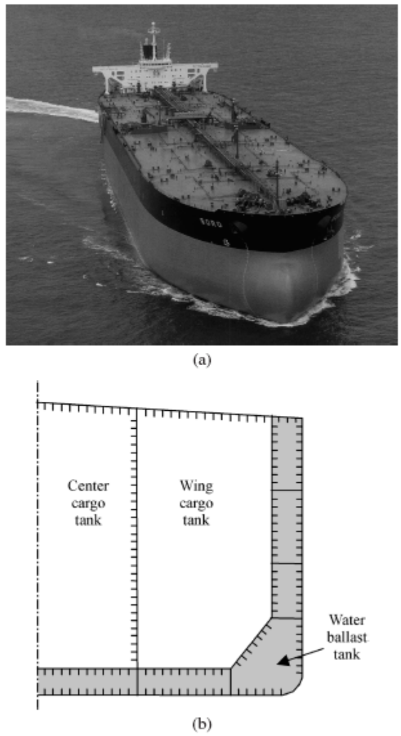


Fig. 1. Water ballast tank structure of commercial ship.

2. Experimental

2.1 Materials and specimen preparation

The shop primer used in this study was inorganic zinc silicate primer. Modified epoxy was used as first and second coating onto shop primed carbon steel. The first epoxy coating was bronze and second epoxy coating was grey color. The carbon steel panels were prepared for water ballast simulation test (200 mm x 400 mm x 3 mm) and condensation chamber test (150 mm x 150 mm x 3 mm). The carbon steel panels were cleaned by primary blasting cleaning with 40~70 μm of surface roughness and then the shop primer was sprayed on blasting cleaned surface by airless pump. The dried shop primed surface was wet and contaminated by water in marine atmospheric environments for 2 months. Then, a flux-cored arc welding device (FCAW) with CO_2 shield-gas was used to generate fumes in a semi-closed space hosting the sample panels. This procedure allowed some of the welding fumes to adhere to surface of the sample panels. The contaminated fume on shop primed surface is as shown in Fig. 2 (a). The secondary sweep blasting cleaning was applied to the weathered shop primed surface by three grades including, light sweep blasting (Fig. 2 (b)), medium sweep blasting (Fig. 2 (c)) and heavy sweep blasting (Fig. 2 (d)), respectively. Then, the main coating was sprayed on sweep blasted surfaces and cured. The dry film thickness (DFT) was measured by thickness gauge (Elcometer 456) and pinhole detection on coated surface also carried out by pinhole detector (Elcometer 269) at 90 volts. Fig. 3 shows the specimen preparation process and table 1 and 2 describe the information of primary and secondary blasting cleaning and coatings.

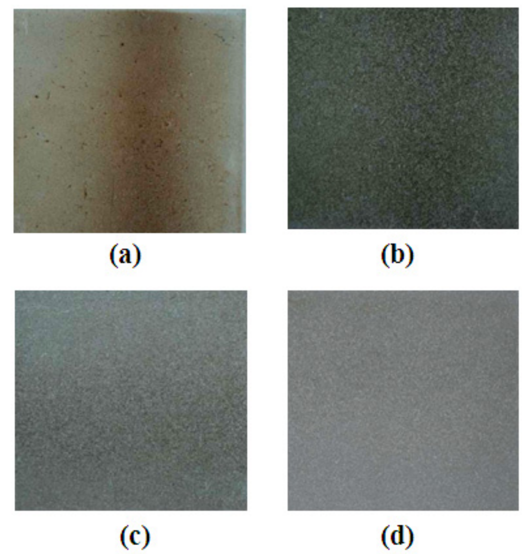


Fig. 2. Sweep blasting treated surface of zinc silicate shop-primed carbon steel: (a) without surface treatment, (b) light sweep blasting treatment, (c) medium sweep blasting treatment and (d) heavy sweep blasting treatment.

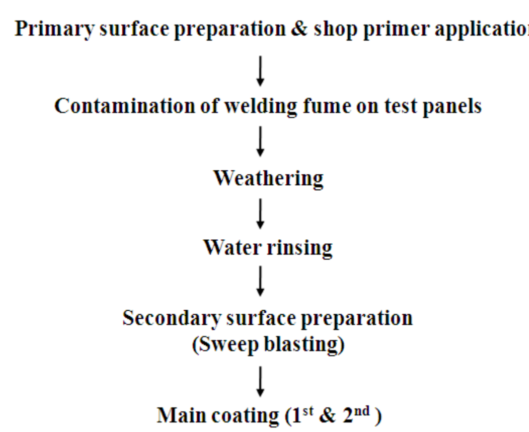


Fig. 3. Specimen preparation process for water ballast simulation and condensation tests.

Table 1. The details of primary and secondary surface treatment for carbon steel

	Surface preparation method	Abrasive (Steel)	Roughness, R_a (μm)
Primary	Full blasting	Grit	80-82
Secondary	Sweep blasting	Grit	35-45

Table 2. The applied coating materials and application methods for specimen preparation

	Shop primer	1st coating	2nd coating
Coating material	Inorganic zinc silicate	Modified epoxy (Bronze)	Modified epoxy (Grey)
Spray equipment	Airless pump	Airless pump	Airless pump
Volume Solid (%)	30	60	60
Thinning (wt %)	30	10	10
Dry film thickness (µm)	15	160	200

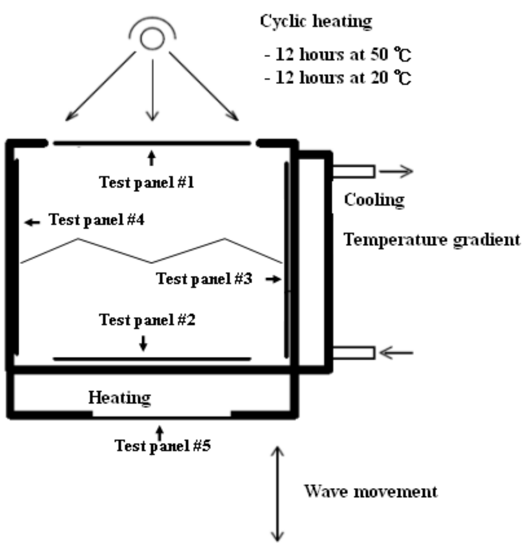


Fig. 4. The configuration of water ballast simulation test.

2.2 Water ballast simulation test

Five carbon steel panels were prepared for water ballast simulation test and total testing periods are 180 days.[16] The reverse side of the test panel was completely painted in order not to affect the test results. In order to simulate the actual ballast tank condition, the test cycle runs for two weeks with seawater and for one week without sea water. The temperature of the seawater was to be kept at about 35 ℃. In order to simulate the corrosion environments of water ballast tanks, the panels were positioned five different locations in water ballast simulation test equipment as shown in Fig. 4 and the explanations of each different positioned panel are described as follows

1. Test panel 1: This panel is to be heated for 12 h at 50 ℃ and cooled for 12 h at 20 ℃ in order to simulate upper deck of ship condition. The test panel is cyclically splashed with seawater in order to simulate a ship's pitching and rolling motion. The interval of splashing is 3 seconds or faster. The panel has a scribe line down to bare steel across width as shown in Fig. 5(a)

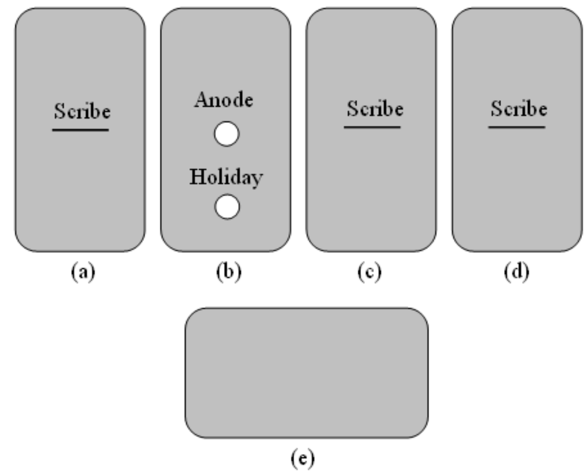


Fig. 5. Each specimen for water ballast tank's condition: (a) conditions of a ship's upper deck, (b) conditions of cathodic protection, (c) conditions of cooled bulkhead in a ballast wing tank, (d) conditions of ship's pitching and rolling motion and (e) conditions of boundary plating.

2. Test panel 2: This panel has a fixed sacrificial zinc anode in order to evaluate the effect of cathodic protection. A circular 8 mm artificial holiday down to bare steel is introduced on the test panel 100 mm from the anode in order to evaluate the effect of the cathodic protection as shown in Fig. 5(b). The test panel is cyclically immersed with seawater.
3. Test panel 3: This panel is to be cooled on the reverse side, in order to give a temperature gradient to simulate a cooled bulkhead in a ballast wing tank, and splashed with seawater in order to simulate a ship's pitching and rolling motion. The gradient of temperature is approximately 20 ℃, and the interval of splashing is 3 seconds or faster. The panel has a scribe line down to bare steel across width as shown in Fig. 5(c)
4. Test panel 4: This panel is to be cyclically splashed with seawater in order to simulate a ship's pitching and rolling motion. The interval of splashing is 3 s or faster. The panel has a scribe line down to bare steel across width as shown in Fig. 5(d)
5. Test panel 5: This panel is to be exposed to dry heat for 180 days at 70 ℃ to simulate boundary plating between heated bunker tank and ballast tank in double bottom as shown in Fig. 5(e)

2.3 Condensation chamber test

In order to evaluate the humidity resistance of coated metal continues condensation chamber test was conducted

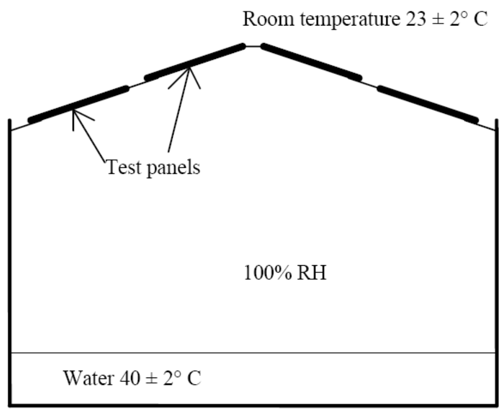


Fig. 6. The configuration of condensation chamber test.

in accordance with ISO 6270-1 standards.[17] The total testing periods are 180 days and two test panels are prepared. The reverse side of the test panel was painted appropriately in order not to affect the test results.

Two test panels were placed on the top of test chamber to evaluate the humidity resistance of coating in condensation test equipment as shown in Fig. 6.

2.4 Evaluation of coating after water ballast simulation test and condensation chamber test

Evaluation of blister and rust formation was carried out according to the ISO standard 4628/2 by evaluation of degradation of coatings including the quantity and size of defects, and the degree of rust on coated surface.[18] The pull-off adhesion tests were performed to investigate the deterioration of the bond strength of epoxy coatings due to moisture absorption according to the ISO standard 4624.[19]

Cathodic protection is widely used in coating industries to protect the metal structures from corrosive attack when the coating is damaged. If bare steel is exposed at breaks in coating, corrosion starts on the exposed metal, with an anode at the defect and cathodic reduction of oxygen on the steel surface beneath the coating at the edge of the defect. In solutions of alkali metal salts, an alkaline environment soon forms at the cathode, which results in disbonding of the coating.[20)-32)] Suggested mechanisms for disbonding include dissolution of the oxide film, degradation of the polymer and the failure of adhesion. If the coated metal is subject to cathodic protection, corrosion at the defect will be avoided, but cathodic disbondment is even more severe.

The current demand was increased with the increase of de-bonded areas. In present study, current demand was calculated from following equation (1).[33]

$$I_c(A) = A_c \times i_c \times f_c \qquad (1)$$

Where, A_c is the individual surface areas of each CP unit, i_c is design current density and f_c is the coating breakdown factor. Cathodic disbondment from artificial holiday was measured by ASTM G95.[34] The undercutting along both sides of the scribe on test panel is measured and the maximum undercutting determined on each panel.

3. Results and discussion

3.1 Effects of welding fume on adhesion strength of coating after water ballast simulation test and condensation chamber test

Good adhesion of coating is very important for corrosion protection. It can suppress corrosion by retarding the development of corrosion products under the coating and suppressing the formation of anode-cathode micro cells in the surface of coated metal.[35]

Pull-off adhesion test was carried out to measure the adhesion strength of the coatings which were exposed to different environmental condition with different extent of welding fume.

The acceptance criteria of pull-off adhesion strength after water ballast simulation test and condensation chamber test was 3 MPa when facture mode shows cohesive failure and 3.5 MPa when facture mode shows adhesive failure, recommended by IMO PSPC.[16] Whether it pass or fail in adhesion strength point of view is very interesting point, however, facture mode also very important because welding fume can affect the adhesion strength negatively with main coating. If it is true, fracture between shop primer and first coating is most likely to occur. Therefore, fracture mode was observed carefully as well as adhesion strength according to the extent of removal of welding fume.

As a result, the various shapes of fracture mode was observed such as fractures in first coating or second coating itself, between first coating and second coating and between steel substrate and shop primer, etc. The observed main fracture mode was fracture of the first coating or second coating and partial fracture between first coating and second coating, fracture of shop primer itself were followed as shown in Fig. 7. However, fracture between shop primer and first coating was not observed for all tested specimens. In addition, adhesion strength of all specimens was higher than 10 MPa and adhesion strength was not decreased with respect to the extent of welding fume by sweep blasting grade as well as the test position of water ballast simulation test and condensation chamber test. Accordingly, it was clearly demonstrated that the adhesion property of epoxy coating was not affected by the

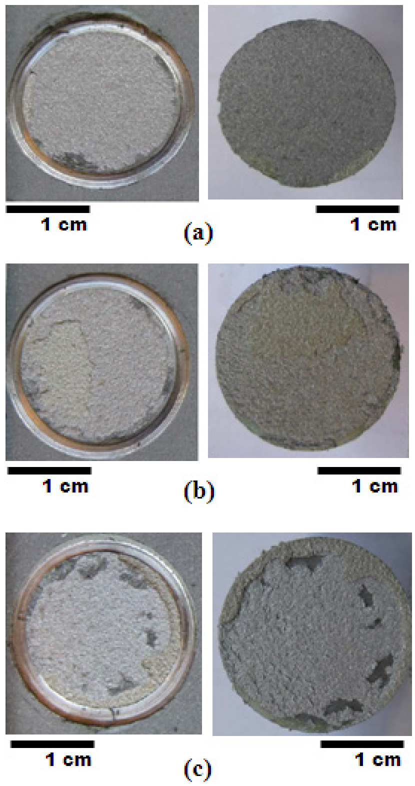


Fig. 7. Photographs of typical fracture modes observed after pull off adhesion test: (a) light sweep blasting, (b) medium sweep blasting and (c) heavy sweep blasting.

residual welding fume after sweep blasting in environmental condition in present study.

3.2 Effects of welding fume on undercutting from scribe for coated steel after water ballast simulation test and condensation chamber test

If a coating is properly applied to a well prepared surface and allowed to cure, then generally corrosion across the intact paint surface is not usually a major concern. However, once the coating is scratched and metal is exposed, the situation is dramatically changed. The metal in the center of the scratch has the best access to oxygen and becomes cathodic. Anodes arise at the sides of the scratch, where paint, metal, and electrolyte meet. Corrosion begins here and can spread outward from the scratch under the coating. The coating's ability to resist this spread of corrosion is major concern. Corrosion that begins in a scratch and spread under the paint is called undercutting. Undercutting refers to corrosion of the metal between metal substrate and paint film at a sheared edge causing blistering of the paint film.

Blistering is not brought by aging of coating. It is sign of failure at the coating and metal interface. Blistering was known to occur when moisture or cations such as sodium penetrates through the coating and accumulate at the coating-metal interface.[36)]

In order to evaluate the effects of welding fume on corrosion protection of epoxy coated carbon steel, undercutting, blister and rust formation of epoxy coating were examined. Fig. 8 shows the results of undercutting for specimens which were taken from water ballast simulation test. Three kinds of secondary surface treatment conditions are shown: (a) light sweep blasting condition; (b) medium sweep blasting condition; (c) heavy sweep blasting condition. The specimens taken from water ballast simulation test were cleaned by water and corrosion product was removed because in many cases corrosion product covered the surface. Once the specimens were cleaned, it was possible to identify surface defects such as blisters or rust. Total 21 test panels were inspected including the 15 test panels of water ballast simulation test with three grades of secondary blasting and the six test panels of

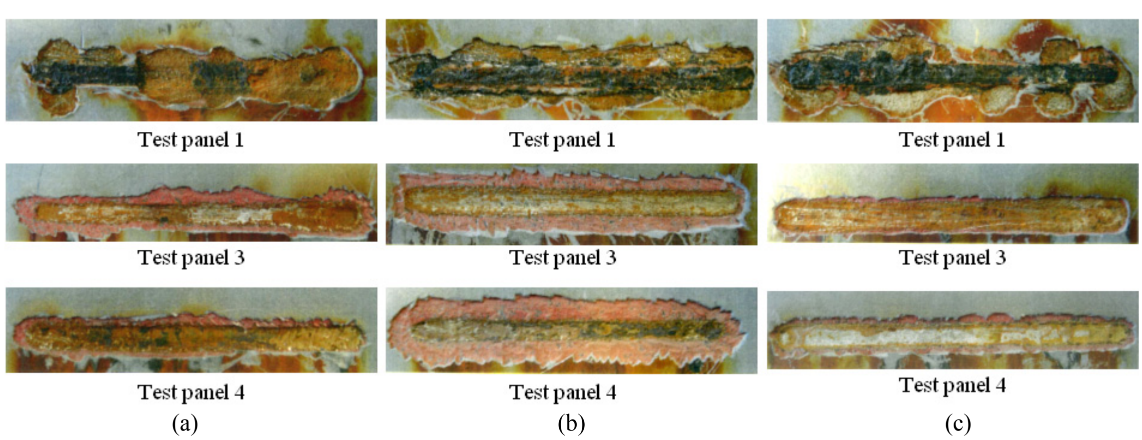


Fig. 8. Photographs of undercutting for specimens taken from the water ballast tank simulation test.: (a) light sweep blasting, (b) medium sweep blasting, and (c) heavy sweep blasting.

Table 3. Undercutting of scribed specimen with respect to position of water ballast simulation test

	Test panel #1(mm)	Test panel #3(mm)	Test panel #4(mm)	Average undercutting (mm)
Low sweep blasting	3	1	2	2
Medium sweep blasting	3	1	3	2.3
Heavy sweep blasting	6	2	2	3.3

condensation chamber test.
Consequently, none of the specimens showed blistering and surface rust

Considering the scribed specimens of position 1, 3 and 4 of water ballast simulation test, the undercutting of position 1 was higher than observed for either the specimen of position 3 or specimen of position 4 independent of sweep blasting grade. This result might be caused by the condensation of water. However, significant differences of undercutting of the coating at the scribed area were not observed depending on sweep blasting grade. The results of undercutting of scribed specimen with respect to position of water ballast simulation test were listed in table 3.

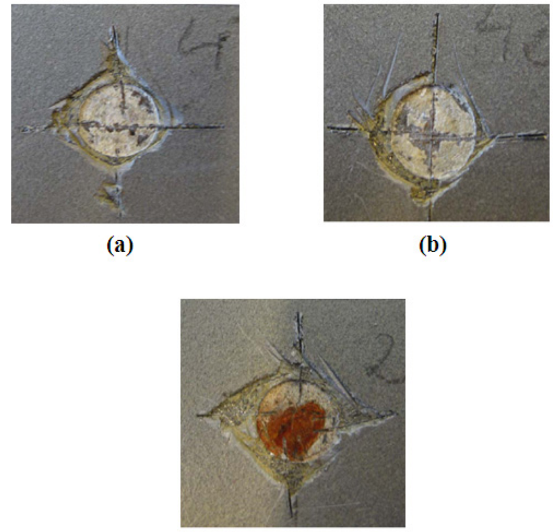
Accordingly, it was clear that occurrence of blister and rust of epoxy coating was not affected by the extent of residual welding fume designed sweep blasting in this study. In addition, it was also confirmed that the degree of undercutting was not related to the extent of residual welding fume but related to the environmental condition.

3.3 Effects of welding fume on cathodic protection for coated steel after water ballast simulation test and condensation chamber test

Cathodic disbondment test provides accelerated adhesion evaluation and determines resistance of the coating to cathodic potential and current flow. The panel has a fixed sacrificial zinc anode in order to evaluate the effect of cathodic protection. A circular 8 mm artificial holiday down to bare steel is introduced on the test panel 100 mm from the anode in order to evaluate the effect of the cathodic protection. The test panel is cyclically immersed with seawater.

Cathodic disbondment test cell was assembled with a DC power supply, platinum wire as anode, high resistance volt/amp meter and a calomel reference electrode. Radius of the disbonded area from the holiday edge was measured and average was obtained.

As a result, cathodic disbondment was measured in 4 mm and blistering and rust was not observed for all specimens as shown in Fig. 9. The weight loss of zinc anode was measured approximately 1gram and calculated current demand was 2.9 to 5.2 mA/m^2 described in table 4.[16)]



(c)

Fig. 9. Photographs of cathodic disbondment taken from the water ballast tank simulation test.: (a) light sweep blasting, (b) medium sweep blasting, and (c) heavy sweep blasting.

Table 4. The results of cathodic disbondment and current demand at position 2

	cathodic disbondment (mm)	current demand (mA/m^2)
Low sweep blasting	4	5.2
Medium sweep blasting	4	3.0
Heavy sweep blasting	4	2.9

Therefore, it was clearly demonstrated that the adhesion property of epoxy coating was not affected by the residual welding fume after sweep blasting in various water ballast corrosive conditions.

4. Conclusions

Water ballast simulation and condensation chamber tests were conducted to evaluate the effects of residual welding fume on corrosion protection of epoxy coated carbon steel. Welding fume was treated by sweep blasting with three grades containing light, medium and heavy sweep blasting Conclusions drawn from the work are as follows:

1) Blistering and rust was not observed in all specimens. It was clear that occurrence of blister and rust of epoxy coating was not affected by the residual welding fume after

designed sweep blasting

2) The results from the adhesion tests also clearly demonstrated that the adhesion of epoxy coating not decreased with respect to the extent of residual welding fume by sweep blasting grade

3) Undercutting measurement has shown that the significant differences of undercutting of the coating at the scribed area were not observed depending on sweep blasting grade.

4) Consequently, corrosion protection performance of epoxy coating in water ballast tank was not affected by extent of residual welding fume of in this study.

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