Effect of Retained Pre-construction Primer on the Corrosion Protection Properties of Epoxy Coatings

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Pre-construction primer (PCP), or shopprimer, have been applied to steel plates to control temporary corrosion during ship fabrication. For surface preparation at ship block stage, in common shipyard practices, welding beads, burnt and rusted areas shall be blasted or power tool cleaned and the contamination such as zinc salt shall be removed with blasting or power tool. Whereas, the sound film of PCP needs not to be removed or roughened as the paint having good compatibility with PCP is used for the first coat. In many cases, however, full blasting or sweep blasting on the sound PCP treated block assemblies was requested. There still has been argument about the legitimacy of this practice, thus, it is critical to evaluate the quality of the coating system applied on the sound PCP retained condition, comparing with the one applied on the full blasted or sweep blasted condition. In this study, two different epoxy systems for water ballast tank were applied on the surfaces with sound PCP condition, full blasted condition, and sweep blasted condition. Coating performances such as durability, anti-corrosion, cathodic disbondment resistance were evaluated. The test results clearly indicated that the sound film of PCP needed not to be removed or roughened as the paint having good compatibility with PCP based on inorganic zinc silicate.

Keywords : *Pre-construction primer, shop primer, blasting, protective performance, Sa 2.5, epoxy coating*

1. Introduction

Organic coatings have been widely used to protect steels and other metals in corrosion environments due to their good physical, chemical, mechanical performance, and low cost. Many kinds of organic coatings have been also applied to protect ships in various corrosion environments. As the required life-time of these structures increases lately, the concerns for corrosion protection of ship manufacturer have greatly increased.

In construction of new ships, preconstruction primer (PCP), or shop primer, composed of inorganic zinc silicate is routinely applied to stock steel plates after surface preparation to prevent temporary corrosion from ship's block prior to over-coating. The temporary protection period ranges from 3 to 6 months.

Currently, common painting and inspection practice requires that welding beads, burnt and rusted areas shall be blasted or power tool cleaned and the contamination such as zinc salt shall be removed, but the sound PCP needs not to be removed or roughened as the paint having good compatibility with PCP is used for the first coat[1]. As retention of the sound PCP which alleviates the necessity of second blasting would reduce labor cost and hazardous waste disposal cost and improve productivity, it is desirable for ship manufacturer to retain the sound PCP without reducing coating protective performance. There still has been, however, argument about the legitimacy of this practice, and in many cases full blasting or sweep blasting on the sound PCP treated block assemblies was requested based on the assumption that the higher blasting grade for surface preparation, the higher coating protective performance for ships. So, it is critical to evaluate the quality of the coating system applied on the sound PCP retained condition, comparing with the one applied on the full blasted or sweep blasted condition to eliminate the argument of paint practice.

Therefore, in this study, the effect of retaining sound PCP on the coating performance comparing with sweep-blasted condition and full blasted condition was investigated.

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2. Experimental Methods

Two representative epoxy coating systems which have been typically used for water ballast tank of ships were selected and the coating performance on the PCP conditions was evaluated in the immersion and cyclic wet/dry environments.

2.1 Specimen Preparation and Test Conditions

Dimension and primary surface preparation condition were summarized in Table 1. As substrates, carbon steel plates were used after acetone cleaning. Primary surface preparation was shot-blasted to Grade ISO Sa 2½. The average surface profiles were about 30 μm to 31 μm with a digital gauge (DIAVITE™ DH-5 model) and well met the requirement of shipyard practice.

PCP composed of inorganic Zn silicate (IZ182 JSHTM) was applied to surface prepared specimens using automatic spray machine and dried at room temperature for 2 weeks. Average dry film thickness was approximately 15 μm, meeting shipyard standard which is 15±5 μm. To simulate marine environment of shipyard, shop-primed specimens were exposed to outdoors for 8 weeks which are maximum marine exposure period prior to the first coating in actual ship manufacture process. After marine atmospheric exposure, the shop-primed specimens were grit-blasted, which is called secondary surface preparation.

The secondary surface preparation conditions and designation for the specimens were described in Table 2, along with their appearances. Image analyzer was used to con-

Table 1. Substrate condition and primary surface preparation

Substrate	• Material : carbon steel • Dimension - L : 300mm(L) x 100mm(W) x 1.6mm(T) - S : 150mm(L) x 75mm(W) x 1.6mm(T)
Blasting	• Shot blasting : automatic shot blaster (laboratory) • Grade : ISO Sa 2½
Surface profile	• Ave. 30~31μm (ASTM D4417 B)

* General Shipyard Practice
- shot blasting : ISO Sa 2½, surface profile : Avg. 30~50μm

Table 2. Secondary surface preparation, designation, and appearance

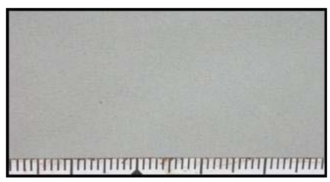
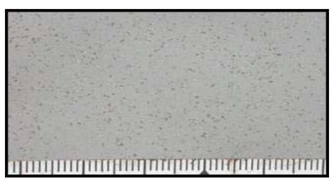
2ndary Surface Preparation	Designation	Surface Appearance
No blasting condition (no PCP removed)	Sound	
Sweep blasted condition (~ 10% PCP removed)	Sweep	
Full blasted condition (~ 100% PCP removed)	Full	

Table 3. Selected coating systems for water ballast tank of ship

Coating system	Tar free Epoxy "H"	Tar free Epoxy "N"
Resin type	Epoxy	Epoxy
Curing agent type	Phenalkamine	Amine adduct
Al pigment content (%)	0	9~10
Color	gray	bronze
Dry film thickness	1st : 150㎛ 2nd : 150㎛	1st : 150㎛ 2nd : 150㎛
Thinning ratio (%)	10	10
2ndary surface preparation	Sound, Sweep, Full	

Table 4. Test methods and conditions

Test Method	Test condition	Test environment	Related standard
Adhesion strength	no scribe	① immersion • natural seawater, 40℃ ② wet(1 wk)/dry(1 wk) • wet(seawater, 40℃) • dry(R.T.)	• Pull off test (ASTM D 4541, ISO 4624)
Flexibility	no scribe		• Erischen cupping test (ISO 1520)
Anti corrosion	"I" type scribe : 50㎜(L)×0.5㎜(W)		• Immersion (ISO 2812 2) • Blistering (ISO 4628 2)
Cathodic disbondment	• holiday : Ψ6㎜ • ICCP type	• Natural seawater • 40℃	Cathodic disbondment test (ISO 15711)

firm removal ratio of retained PCP by sweep blasting and the analysis result was approximately 10%.

After secondary surface preparation, two typical epoxy coating systems for water ballast tank of ship, designated as "H" and "N", were applied to these specimens. Specific information for each coating system was summarized in Table 3.

2.2 Test Method for Coating Performance Evaluation

Test conditions were divided into ① immersion environment (natural seawater, 40℃) ② cyclic wet(immersion, natural seawater, 40℃) and dry(room temp.) environment to simulate the water ballast tank environment. Coating performance evaluation, including adhesion strength, flexibility, anti-corrosion, and cathodic disbondment resistance, was carried out before and after aging coatings under test conditions and compared with each evaluation result. The details of test methods and conditions were shown in Table 4, along with the related standards.

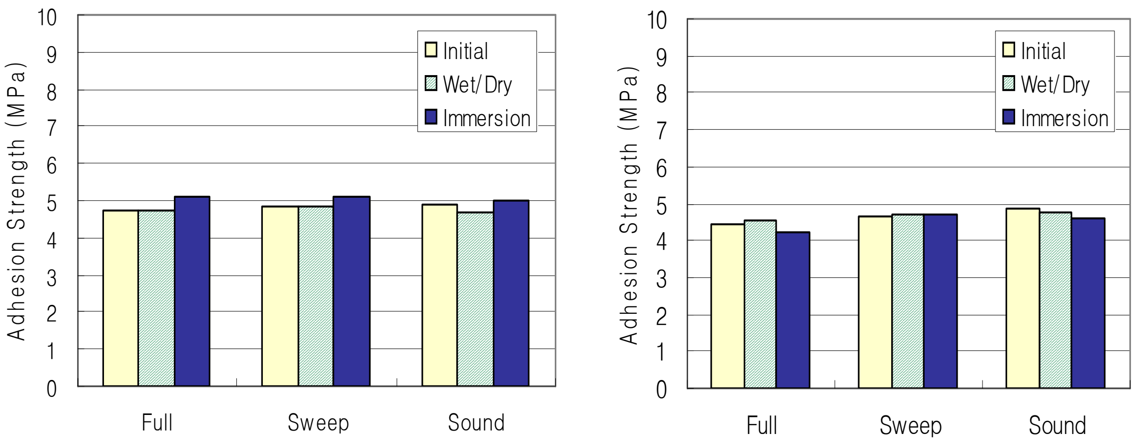
3. Results and Discussion

3.1 Durability Evaluation: Adhesion Strength and Flexibility

Adhesion test was carried out both initial condition and aged condition, as mentioned above Table 4, in ① immersion and ② cyclic wet/dry environment for 6 months. Evaluation results of adhesion strength of coating systems with surface preparation condition and test environment were shown in Fig. 1. Initial coating adhesion strength for coating systems H and N were to be 4.4, 4.9 MPa. After aging coating systems for 6 months, coating adhesion strength were to be 4.5, 4.8 MPa under cyclic wet/dry condition and were to be 4.2, 5.1 MPa in immersion condition, respectively. As a whole, even though adhesion strength of coating system H was a little higher than that of coating system N, the variation of coating adhesion strength with surface preparation condition was little difference. As shown in Table 5, coating failure mode of aged coatings was cohesive in the all conditions, which was the identical with initial condition of specimens.

From these results, it was found that secondary surface preparation conditions such as sound, sweep, and full condition had little effect on coating adhesion property in these environments. In addition, coating adhesion strength and coating failure mode satisfied the requirement of industrial standards, such as ISO standard and IMO Performance Standards for Protective Coatings (PSPC)[2~3].

The flexibility of coating system H and N was evaluated for initial and aged specimens. It is difficult to evaluate

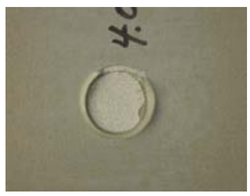
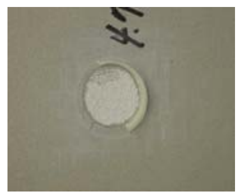
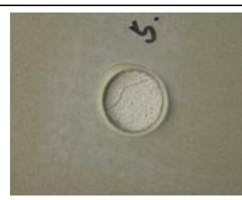
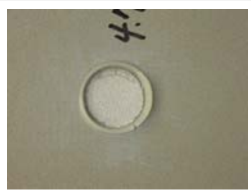


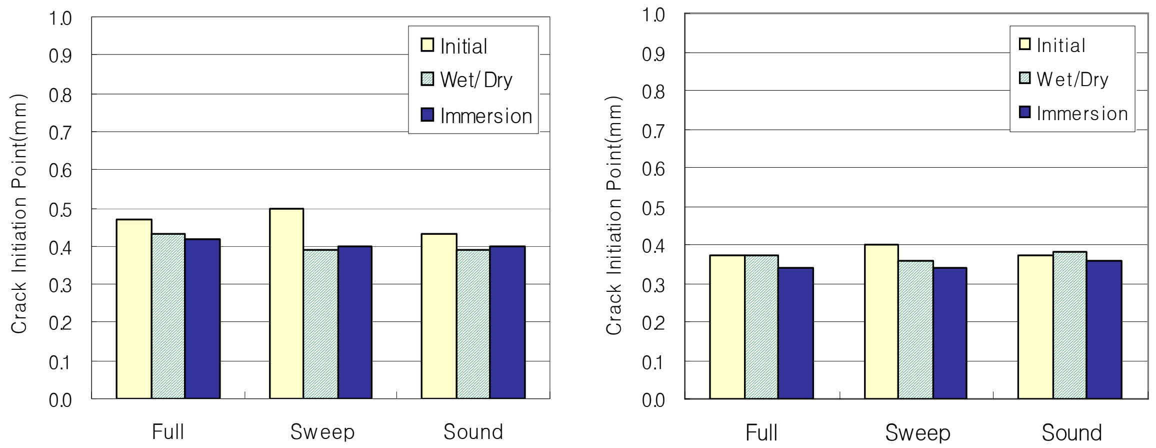
(a) Coating system H (b) Coating system N

Fig. 1. Adhesion strength of coating systems with surface preparation, test conditions

accurate coating flexibility using mandrel bending test method (ASTM D522) due to extensive cracks which result from excessive deformation of steel substrate. On the other hand, Erischen Cupping test (ISO 1520) is generally resulted in gradual deformation by indentation. Therefore, in this study, modified Erischen cupping test method was adopted to evaluate coating flexibility. Since the crack initiation point is the most important in the flexibility evaluation of coatings, the crack initiation depth was measured by visual examination, advancing the indenter into the test specimen to verify the depth of indentation at crack initiation point on the coating surface. The crack initiation points measured in initial coating condition and aged condition for 6 months were shown in Fig. 2, respectively. The coating flexibilities with various surface preparations were similar because the flexibility has been mainly influenced by coating's properties rather than substrate condition. The results also showed the flexibility of coat-

Table 5. Failure mode of 6 month aged coating systems after adhesion strength test

Surface preparation condition	Coating system and test environment			
	H		N	
	immersion	wet/dry	immersion	wet/dry
Full				
Sweep				
Sound				



(a) Coating system H (b) Coating system N

Fig. 2. Crack initiation point of coating systems with surface preparation condition, test condition

ing had a tendency to decrease as aging coating because the coatings became brittle. By evaluating coating flexibility on the basis of crack initiation, it was revealed the surface preparation condition little affected the coating flexibility.

From these durability test results, it was found that adhesion strength and flexibility of coating system H and N before and after ① cyclic wet/dry and ② immersion test are not affected by secondary surface preparation conditions.

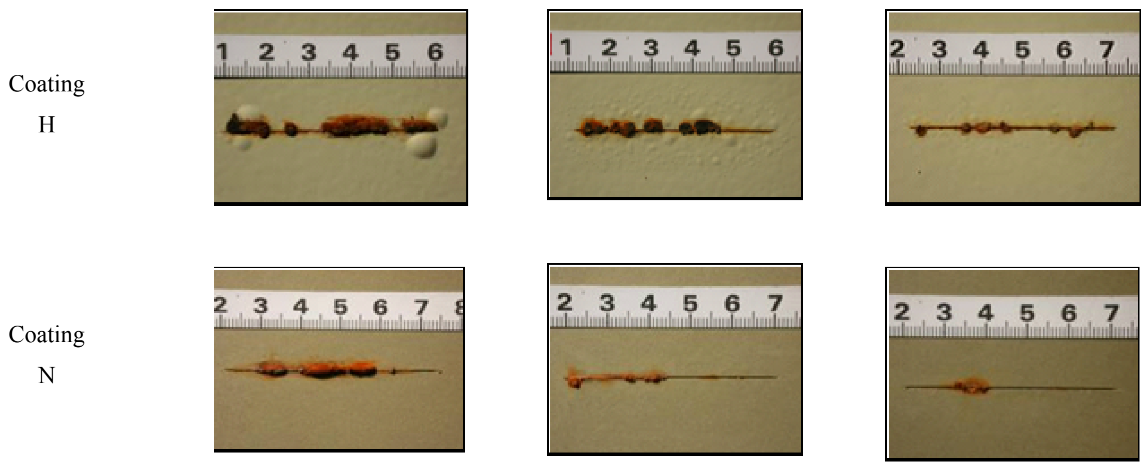
3.2 Coating Protective Performance: Anti-Corrosion Evaluation

Anti-corrosion test results of coating systems with scribed condition were shown in Fig. 3 and Fig. 4. In the case of coating system H, blisters occurred after 6 months regardless of test condition and the blister grade was as higher in the following order;

Full > Sweep > Sound

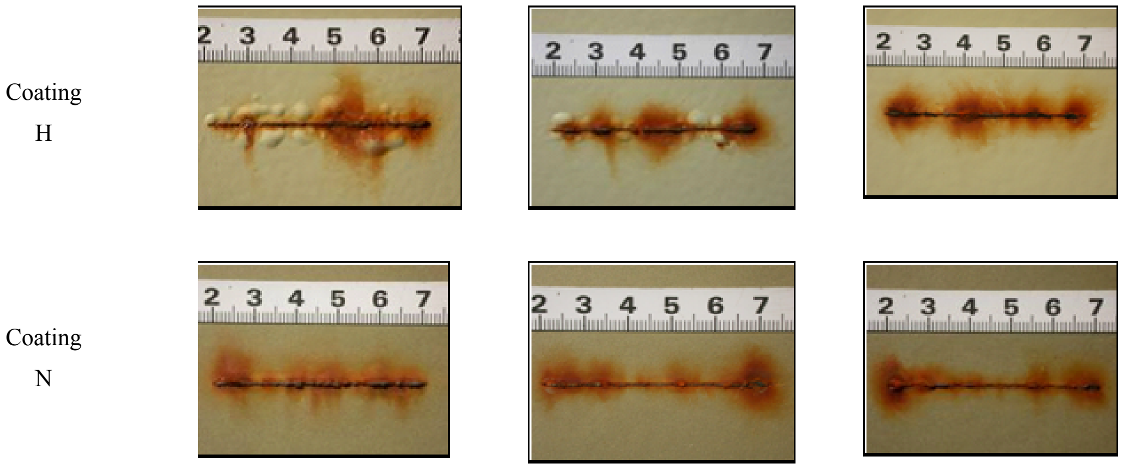
On the other hand, blisters in the coating system N were only observed in the full blasted condition regardless of test conditions.

To quantitatively evaluate protective performance, corrosion creeps (M, mm) were calculated using the following Eq. 1 and the results are shown in Fig. 5 with coating systems and test condition.



(a) Full (b) Sweep (c) Sound

Fig. 3. Specimen appearance after immersion test for 6 months



(a) Full (b) Sweep (c) Sound

Fig. 4. Specimen appearance after cyclic wet/dry test for 6 months

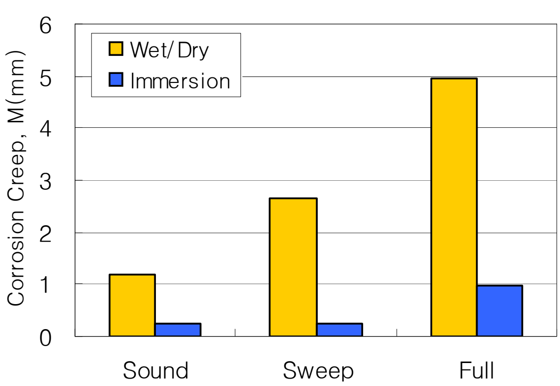
$$M = \frac{C - W}{2} \quad (1)$$

Where C is the measured average corrosion width (mm) at 9 point across the scribe, W is the original width (mm) of the scribe.

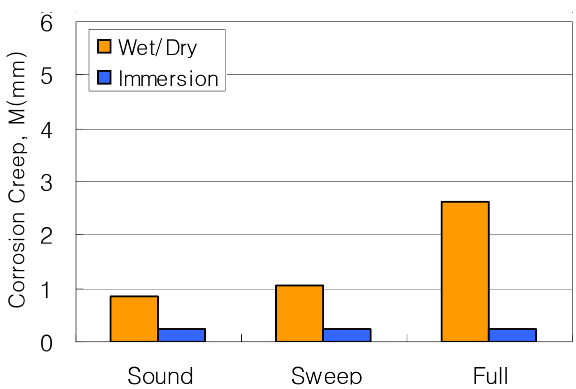
Corrosion creep resistance of coating in cyclic wet/dry condition was inferior to that of coating in immersion condition because corrosion was accelerated by sufficient oxygen during dry cycle. From this result, it was revealed that cyclic wet/dry environment was much more severe than simple immersion environment in terms of corrosion creep. Corrosion creep resistance of coating system N was superior to that of coating system H about from 1.3 times to 2.3 times in cyclic wet/dry condition. Corrosion creep resistance with the secondary surface preparation condition in cyclic wet/dry test was higher in the following order;

Sound > Sweep > Full

This result is due to cathodic protection effect of zinc particle in PCP acting as anode to the steel, which improve corrosion creep resistance.[4] On the other hand, in the immersion test, corrosion resistance of coating system H in full blasted condition was a little inferior to the other conditions. However, corrosion creep except this condition was maximum 0.25 mm which means very excellent anti-corrosion property. Although acceptance criteria of corrosion creep is different with test condition and scribed width, corrosion creep of applied coating systems regardless of coating system and surface preparation condition met acceptance criteria of industrial standard, such as IMO



(a) Coating system H



(b) Coating system N

Fig. 5. Corrosion creep of coating system H and N with surface preparation conditions

PSPC and ISO 20340, for immersion condition well. It is found from these results that it is more beneficial to retain sound PCP with respect to corrosion prevention. The same results were obtained from long period immersion test for 18 months at room temperature.[5)]

3.3 Coating Protective Performance: Cathodic Disbondment Evaluation

Cathodic disbondment test with coating systems and secondary surface conditions was carried out at 40℃ in natural seawater for 6 months. As sacrificial zinc anode is mostly used for water ballast tank, the applied potential was maintained at -1,050 mV(vs. SCE). The artificial holiday of 6 mm diameter on the center of the specimen was made using a flat-ended drill bit.

Cathodic disbondment is one of the principle mechanisms causing coating failure between coatings and metal substrates. When coatings are used in conjunction with cathodic protection, one beneficial effect is that holidays present in the coating and the coating deterioration that inevitably occurs with time do not results in local metal loss, or undercutting of the coatings at these areas. However if the coating system is not properly selected and applied to be compatible with cathodic protection, it is known that some adverse effects, such as deterioration of the coatings attacked by alkaline condition(Eq. 2) or disbanding of coatings due to the generation of hydrogen (Eq. 3), may arise.[6)]

$$O_2 + 2H_2O + 4OH^- \rightarrow 4OH^- \quad (2)$$

$$2H^+ + 2e \rightarrow H_2 \quad (3)$$

Also, since some ship's owner groups had insisted that cathodic disbondment resistance of coatings is deteriorated by aluminum pigment in epoxy resin, coating system N containing Al pigment from 9% to 10% was evaluated.

Representative appearances after cathodic disbondment test for 6 months were shown in Fig 6. For coating system H, blistering happened around the holiday in all surface preparation conditions, whereas blister did not occur on the coating system N regardless of surface preparation condition. These results indicated that cathodic disbondment resistance of coating system N containing approximately 9 % to 10 % Al pigment was much more outstanding than that of coating system H. This result is due to the excellent barrier effect of coating system N against corrosive media such as water, oxygen, and so on comparing with coating system H, as previously reported in the EIS(Electrochemical Impedance Spectroscopy) evaluation results[5)]. In addition, similar results from different coating system and test environment were reported, confirming that cathodic disbondment resistance was improved as increasing Al pigment content.[7)]

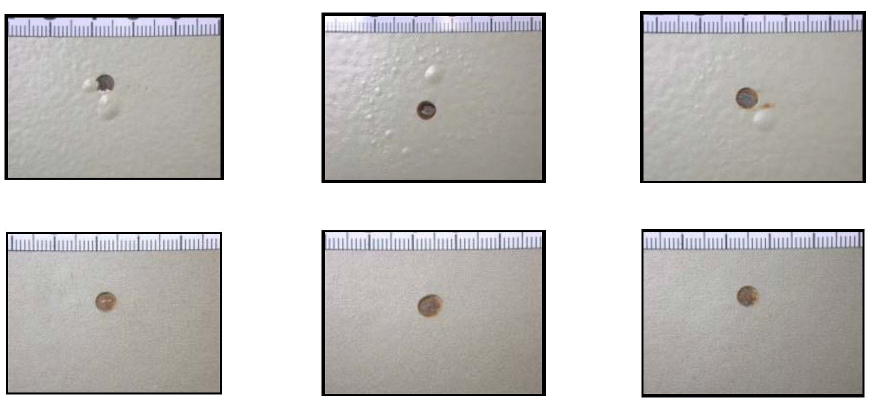
To quantitatively and accurately evaluate the disbondment by cathodic protection, the coating film which had deteriorative adhesion strength caused by cathodic protection was removed around holiday of specimen. Radial cathodic disbondment (R, mm) was calculated by utilizing Eq. 4 and the results were presented in Fig. 7.

$$R = \frac{L - D}{2} \quad (4)$$

R: radial cathodic disbondment(mm),
L: average disbondment length, mm
D: holiday size, mm

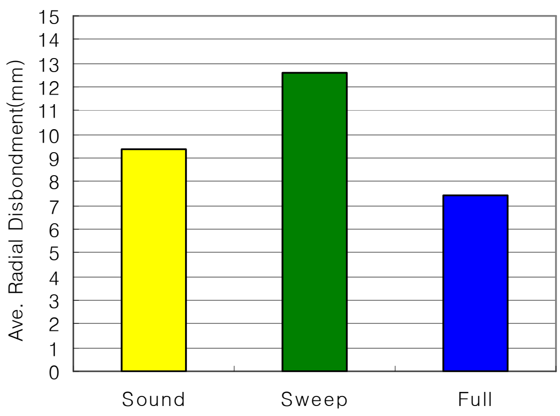
Coating H

Coating N

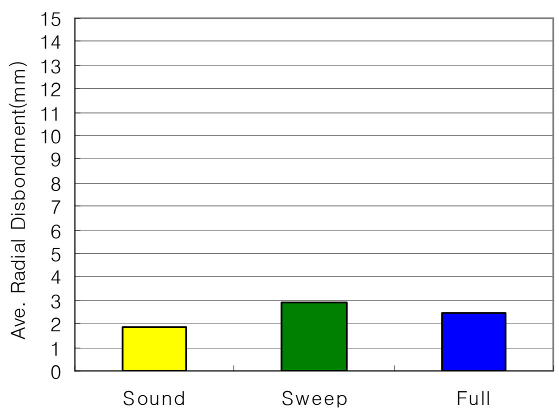


(a) Full (b) Sweep (c) Sound

Fig. 6, Specimen appearance of coating system H and N with surface preparation condition after 6 months test



(a) Coating system H



(b) Coating system N

Fig. 7. Average radial cathodic disbondment(R, mm) of coating system H and N with surface preparation condition

Comparing with R of applied coating systems after cathodic disbondment test for 6 months, it was indicated that cathodic disbondment resistance of coating system N was superior to that of coating system H approximately 3 to 5 times and was little affected by surface preparation condition. However, cathodic disbondment resistance of coating system H in full blasted condition was higher than in sweep blasted condition and sound condition. Even though cathodic disbondment criteria are a little different according to test method, coating system N satisfied well cathodic disbondment criteria of IMO PSPC(<8mm) and ISO 20340(<7mm) regardless of surface preparation condition. These observations confirmed that coating system possessing excellent cathodic disbondment resistance was not affected by surface preparation condition. However, in coating systems H, full blasted condition only met criterion of IMO PSPC and the other conditions did not meet criteria of IMO PSPC and ISO 20340. Though these results may be caused by a little higher test temperature(40℃) than industrial test condition(IMO 35℃, ISO 20340 22±2℃), as known in anti-corrosion test results of the previous clause, it is mainly attributed to relatively low protective performance of the coating system.

From cathodic disbondment test results, it was found that cathodic disbondment resistance is predominantly affected by applied coating system rather than surface preparation condition. Therefore, by selecting coating system having good compatibility with shop primer and excellent cathodic disbondment resistance using CPT(Coating Performance Test) in advance, it is possible to apply various coatings regardless of secondary surface preparation.

4. Conclusions

This study was performed to evaluate coating protective performance on the effect of retaining PCP. Coating performances such as durability, anti-corrosion resistance, cathodic disbondment resistance were evaluated. The following conclusions were obtained from the results;

- Adhesion strength and flexibility before and after aging coating were not affected by blasting condition.
- Anti-corrosion performance in cyclic wet/dry and immersion condition was in the following order;
  Sound condition ≥ Sweep blasted condition
  > Full blasted condition
- Cathodic disbondment results showed that coating performance could be unaffected by surface preparation via selecting good compatible coating system with PCP.

These results clearly indicated that the sound film of PCP needed not to be removed or roughened as long as using the paint having good compatibility with PCP of inorganic zinc silicate type and being applied on to the surface blasted to ISO Sa 2½.

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