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The Investigation of Performance Properties of the Epoxy/Glass Flake Composite Coating on Steel Pile Pipes

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ABSTRACT

Steel pile pipes used for offshore applications and port construction are subject to high levels of corrosion. To protect the top end of the steel pile pipe against aggressive corrosion conditions, the splash zone of the steel pile pipe is coated with epoxy. For a high strength offshore system applications, the requirement of the long term durability of coating was specified as C5(H)Im2 according to ISO 12944. The coated specimens with glass flake reinforced epoxy were exposed to neutral salt spray (NSS) for 1440 hours according to EN ISO 9227 and examined adhesion strength of the coatings. The corrosion and adhesion results of the samples which are coated in single and 2 layers with a dry film thickness of 600 microns, were found to be suitable and the painting operation was applied on the pipe to specify application condition. When the application results were examined, it was seen that the sample with a dry film thickness of 600 microns, coated in 2 layers, met the desired requirements.

Çelik Kazık Borular Üzerindeki Cam Pulcuk Takviyeli Epoksi Kompozit Kaplamanın Performans Özelliklerinin Araştırılması

MAKALE BİLGİSİ

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Anahtar Kelimeler:
Çelik kazık boru
Korozyon
Sıçrantı bölgesi
Cam pulcuk takviyeli epoksi

ÖZET

Açık deniz uygulamaları ve liman inşaasında kullanılan çelik kazık boruları yüksek düzeyde korozyona maruz kalır. Çelik kazık borunun üst ucunu saldırgan korozyon koşullarına karşı korumak için çelik kazık borusunun sıçrama bölgesi epoksi ile kaplanmıştır. Yüksek mukavemetli açık deniz sistem uygulamaları için, kaplamanın uzun süreli dayanıklılık şartı ISO 12944'e göre C5(H)Im2 olarak belirtilmiştir. Cam pulcuk takviyeli epoksi ile kaplanmış numuneler 1440 saat boyunca EN ISO 9227'ye göre nötr tuz spreyine (NSS) maruz bırakılmış ve kaplamaların yapışma mukavemeti incelenmiştir. Korozyon ve yapışma test sonuçları uygun bulunan tek kat ve iki katlı 600 mikron kuru film kalınlığına sahip boyama sistemi ile uygulama koşullarının belirlenmesi için boru üzerine boyama uygulaması yapılmıştır. Uygulama sonuçları incelendiğinde 600 mikron kuru film kalınlığına sahip ve 2 katta kaplanmış numunenin istenilen şartları sağladığı görülmüştür.

1. INTRODUCTION (GİRİŞ)

Steel pile pipes are widely used in the construction of onshore and offshore foundations. The low transportation damages, high material strength and high vibration absorption during driving are among the most important advantages of steel pile pipes [1-4]. The corrosion zones of port structures generally consist of atmospheric, splash, tidal, seawater and mud & backfill parts. Fig. 1 schematizes an example of corrosion environments for a steel pile pipe. The corrosion rate in the splash zone is approximately 0.3 mm/year, while the rate of the atmospheric zone is less than 0.1 mm/year. The steel surface exhibits wet and dry cycles in the splash zone. Thus, the conditions at the splash zone are generally more aggressive than at the full immersion zone since compared to the latter, the steel surface is exposed to a thin layer of water which can easily carry dissolved oxygen. For that reason, a coating is applied to the splash zone to avoid the corrosion of the steel pipe [5, 6].

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Organic coatings are a coating commonly used to protect metallic surfaces from corrosion. Compared to other organic coatings, glass flake filled epoxy coatings are preferred in the marine atmosphere due to their abrasion resistance, low water vapor permeability, chemical stability and excellent cathodic disbondment properties. In recent years, paints containing glass flakes have been investigated for metal protection in extremely corrosive environments, with the expectation that composite coatings will significantly inhibit water penetration in the polymeric matrix [7-9]. The improved barrier properties of glass flakes in the coating have attracted the interest of researchers to study composite coatings containing glass flakes for corrosion resistance. In addition to corrosion resistance, the use of glass flakes to improve some properties such as thermal and viscoelastic properties is among some studies [10].

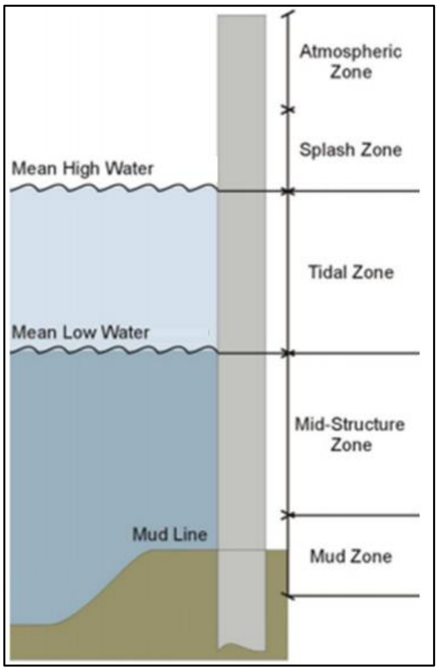


Figure 1. Corrosion zones of steel pile pipe (Çelik kazık boruların korozyon bölgeleri)

Salt spray testing is among the common methods for accelerated corrosion testing. Salt spray test results have been associated with results obtained from atmospheric interaction in subtropical environments, increasing its validity [11]. In addition, the accelerated non-electrochemical test is the salt spray test, which is widely used for coating evaluation [12].

In this study, the corrosion properties of the steel coated with glass flake reinforced epoxy under different conditions and the adhesion strength properties of the coatings were investigated.

2. MATERIAL AND METHOD (MATERYAL VE YÖNTEM)

In this study, three samples were prepared for each condition to be used in the experiments. Two of them were used for the salt spray test and the remaining sample was used for the adhesion strength test. For surface preparation of steel plates having dimensions of 150x50x3 mm, blasted by using grit/shot steel mix. The grit/shot ratio was 1/1. The surface roughness values of all steel plates were measured between 60 µm and 90 µm. The surface roughness was analysed by the Mitutoyo surface roughness tester. In addition, the surface quality level was found to be at Sa 2.5 according to the ISO 8501-1 standard and the surface was cleaned from visible oil and dirt.

After blasting, the paint mixing denoted as components A and B was prepared according to the product technical data sheet. The paint application was performed on blasted steel plates by the airless spraying technique. The theoretical dry film thickness (DFT) of coating types is given in Table 1. The DFT measurements of coatings were performed by Elcometer 456 coating thickness gauge. After the painting application, the curing temperature was selected as room temperature (23±2º C) for all specimens. For the two-layer coating types, the painting of the second layer was applied after the first layer had dried.

Table 1. Coating condition (Kaplama şartları)

Coating Type	Number of coating layer	DFT of first layer	DFT of second layer	Total nominal DFT on plates
1	Single layer	300 µm	-	300 µm
2	Two-layer	300 µm	300 µm	600 µm
3	Single layer	600 µm	-	600 µm

The test samples were prepared for neutral salt spray (NSS) test. This test was performed according to ISO 9227 [13]. Atmospheric corrosivity and immersion categories were specified as C5(H)Im2 according to ISO 12944-6 [14].

During the test process, the samples are placed into the chamber and a solution of 50 ± 5 g of sodium chloride (NaCl) per litre of deionized water is evaporated at a test temperature of 35 °C. The conductivity of the used deionized water was measured as 4.64 µS/ cm. The PH level of the salt-rich solution was specified as 7.0. The salt-rich NaCl vapor performs a corrosive attack on the samples. In order to determine the long-term durability for C5(H)Im2 requirement, the samples were kept in a salt spray cabinet (5% NaCl) up to 1440 hours and the tests were carried out under the same aggressive conditions for all samples. After neutral salt spray test (NSS), the examination of the coated specimens was performed according to ISO 4628-1 [15] standard requirements. Pull-off tests of the coatings were performed according to ISO 4624 standard. The adhesion strengths of coatings were measured by Positest AT-M digital pull-off adhesion tester.

3. EXPERIMENT AND OPTIMIZATION RESULTS (DENEY VE OPTİMİZASYON SONUÇLARI)

The dry film thickness (DFT) of the coated specimens were measured. Fifteen gage readings were made on each plate and their average DFT values were calculated. For coating type 1, the average DFT of coating was measured as 311 µm. For the two-layer type 2, the average DFT of the first layer was 309 and the average of the top layer was 612 µm.

Table 2. The scale for designating the size and quantity of defects (Kusurların boyutunu ve miktarını belirlemek için ölçek)

Rating	**Quantity of defects**	**Size of defects**
0	none, i.e. no detectable defects	not visible under ×10 magnification
1	very few, i.e. small, barely significant number of defects	visible under magnification up to ×10
2	few, i.e. small but significant number of defects	just visible with normal corrected vision (< 0.2 mm)
3	moderate number of defects	clearly visible with normal corrected vision (between 0,2 mm and 0.5 mm)
4	considerable number of defects	between 0.5 mm and 5 mm
5	dense pattern of defects	> 5 mm

For single-layer type 3, the average thickness was measured as 610 µm. The accelerated neutral salt spray (NSS) test provides valuable information regarding the protective performance of coatings for the assessment of coating defects. This evaluation was carried out by following a numerical scale (0-5) in accordance with ISO 4628-1 [15] standard, where “0” means no degradation and “5” points out the maximum degradation. The details of these information are given in Table 2. The type of defect, the quantity and its size, is expressed as indicated in the following examples: blistering; degree of blistering 2(S2), i.e. quantity 2/size 2.

Table 3. Data of the coating performance after NSS test (NSS testi sonrası kaplama performansı verileri)

Evaluation Criteria	Acceptance Criteria	Coating Type		
		1	2	3
Blistering (Acc. to ISO 4628-2)	Max. 0 (S0)	0 (S0)	0 (S0)	0 (S0)
Rusting (Acc. to ISO 4628-3)	Max. Ri0	Ri 1	Ri 0	Ri 0
Cracking (Acc. to ISO 4628-4)	Max. 0 (S0)	0 (S0)	0 (S0)	0 (S0)
Flaking (Acc. to ISO 4628-5)	Max. 0 (S0)	0 (S0)	0 (S0)	0 (S0)
Corrosion around a scribe (Acc. to ISO 4628-8)	Max. Grade 1 (Max 1.5 mm as average of the nine values)	Grade 3	Grade 1	Grade 1

The results of the NSS tests are given in Table 3. When the test results were examined, it was seen that the NSS results of coating type 2 and type 3 were within acceptable limits. Sample images after 1440 NSS tests are given in Figure 3. The sample images support the results in Table 3. The increase in coating thickness positively affected the corrosion resistance. The type-1 sample with a dry film thickness of 300 microns showed unsatisfactory results compared to coating type 2 and type 3.

In figure 2, the adhesion test results of coating types are given. It is seen that the adhesion results of all coating types are close to each other. In a study of coating application on steel, Altuncu et al. [16] stated that the surface roughness value between 60µm-90µm is the most appropriate range for corrosion resistance. In another study [17], examining the effect of surface roughness on the adhesion between steel and coating, it was reported that the increased surface area caused by surface roughening positively affected the adhesion. The increase in surface roughness of the samples used in this study was limited in order to keep the paint consumption at an optimum level and to prevent corrosion problems. The adhesion test results of coatings 2 and 3 are above the minimum requirement of 5 MPa [14].

For type 2 and type 3 coatings that are suitable for NSS and adhesion tests, the application was made on the pipe. After applying the type 3 coating system, sagging occurred on the paint. On the other hand, no visual defect was observed on the type 2 coating.

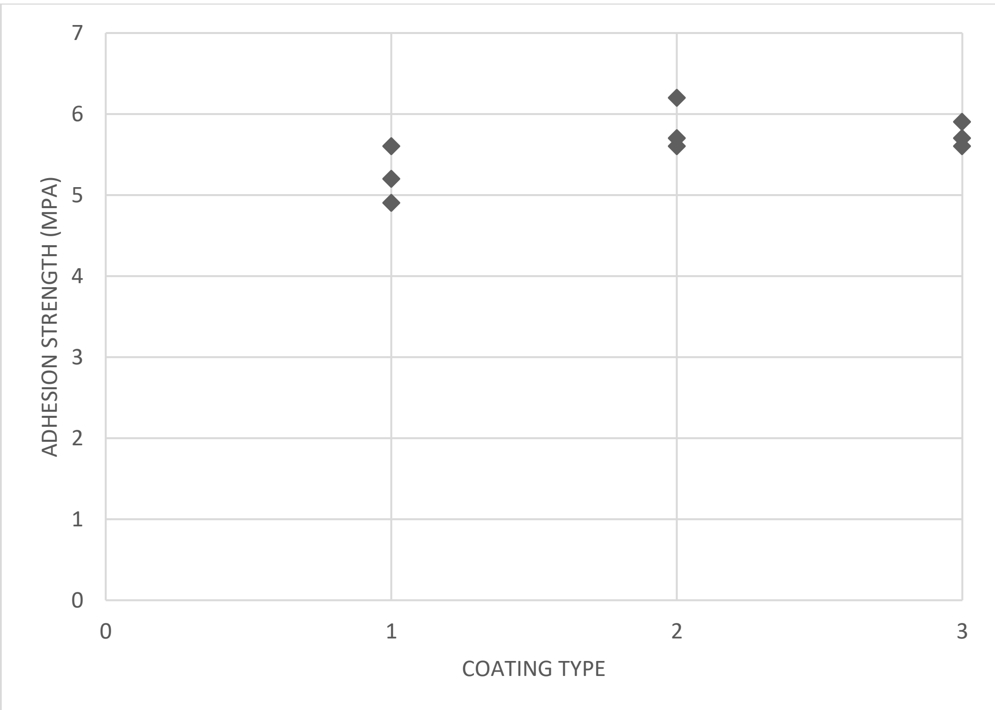


Figure 2. The adhesion test results of the coating types (Kaplama tiplerinin yapışma test sonuçları)

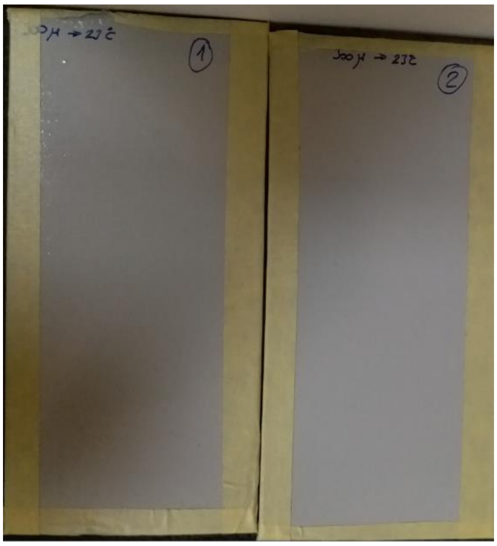
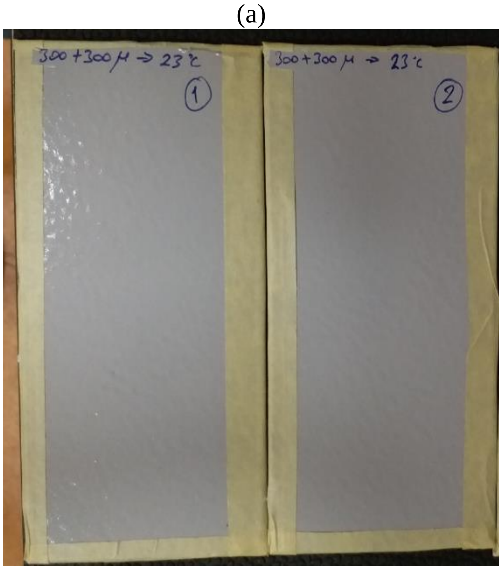
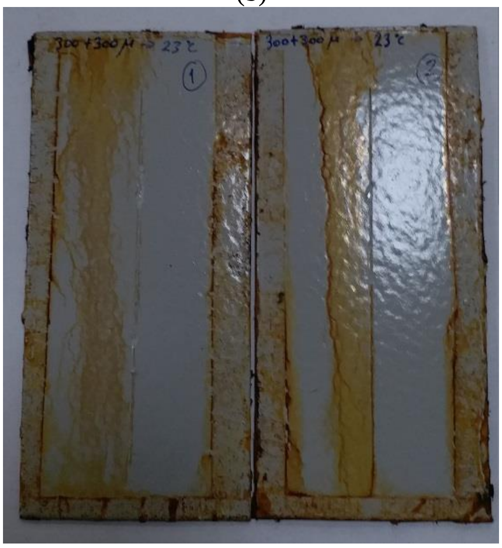
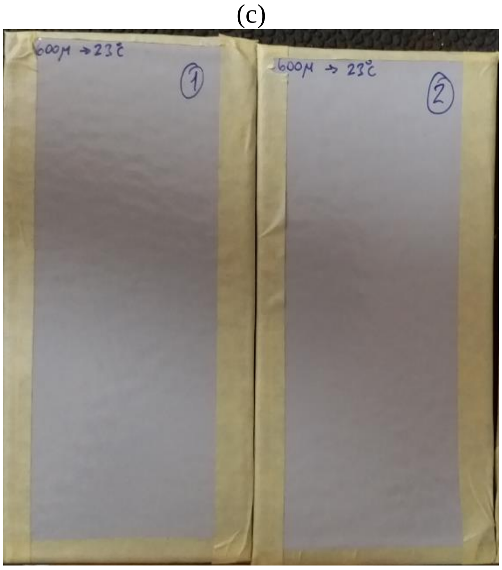
Condition	**Before NSS test**	**After NSS test for 1440 hours**
Type 1	 (a)	 (b)
Type 2	 (c)	 (d)
Type 3	 (e)	 (f)

Figure 3. (a), (b) Type 1, (c), (d) Type 2, (e), (f) Type 3, Neutral salt spray test for coating conditions ((a), (b) Tip 1, (c), (d) Tip 2, (e), (f) Tip 3, Kaplama koşulları için nötral tuz püskürtme testi)

Figure 4. Coated pipe with coating type 2 on splash zone (Tip 2 kaplama ile kaplanan borunun sıçrantı bölgesi)

4. CONCLUSIONS (SONUÇLAR)

The results obtained from the experiments are listed below;

1. Corrosion resistance of the coating decreased depending on the decrease in the coating thickness. The type 1 coating system could not meet the desired corrosion conditions.
2. The surface roughness value between 60µm-90µm is sufficient to provide C5(H)Im2 requirement.
3. The type 2 and type 3 system coatings with glass flake reinforced epoxy meet the C5(H)Im2 requirement in accordance with ISO 12944.
4. The type-2 coating system is more applicable and has a high visual quality during the pipe coating application.

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