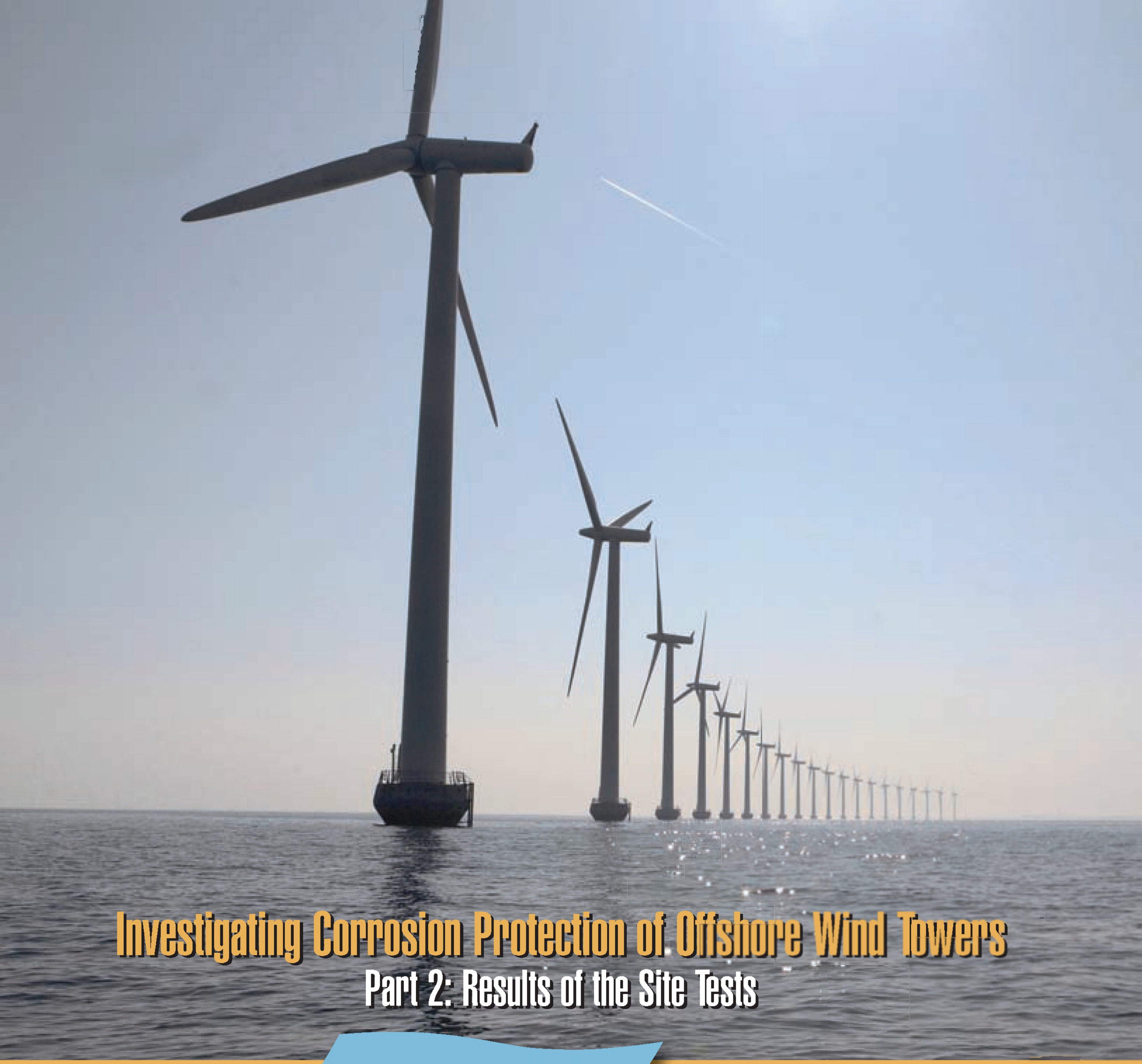

Investigating Corrosion Protection of Offshore Wind Towers

Part 2: Results of the Site Tests

Editor's Note: This article is the second part of the authors' report on testing coating performance on offshore wind towers. The first part, "Investigating Corrosion Protection of Offshore Wind Towers," was published in the April 2008 *JPCL* (pp. 30–43) and won SSPC's highest editorial honor, the Outstanding Paper Award, which was announced at PACE 2009, held February 15-18, 2009, in New Orleans. (See also "Awards" story, pp. 57–59, of this issue.) Part 1 described the rationale behind the authors' test program as well as its setup. In addition to appearing in the print edition of the April 2008 *JPCL*, Part 1 can also be accessed in the online edition of the April 2008 *JPCL*, found in the "Publications" section of *JPCL*'s electronic home, www.paintsquare.com. Part 3 of the report will be published in an upcoming issue of *JPCL*.

This article is the second part of a report on a nationally funded project on the performance testing of different corrosion protection methods for offshore wind towers under site and laboratory conditions. Part 1, published in the April 2008 *JPCL*, reported on the rationale behind, and setting up of, the test program. The present article discusses the test results.

Background

Testing was conducted for performance of coatings in the underwater, intermediate, and splash zones. Six coating systems were tested, although not all systems were tested in all three zones. The coatings were applied over steel blast cleaned with steel grit and in accordance with ISO 8504-2. Uncoated steel with cathodic protection was also tested. The systems tested are shown in the box on the opposite page.

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Coating Systems Tested (Composition and dft)*

System	Primer	2. Layer	3. Layer	4. Layer	Total dft
1	Zn-EP (80 µm)	EP (300 µm)	EP (300 µm)	PUR[1)] (70 µm)	750
2	Zn-EP (80 µm)	EP (450 µm)	EP (450 µm)	-	980
3	Zn/Al (85/15)[2)] (100 µm)	EP[3)] (20 µm)	EP (450 µm)	EP (450 µm)	1,020
4	Zn/Al (85/15)[2)] (100 µm)	EP[3)] (20 µm)	EP[4)] (450 µm)	EP[4)] (450 µm)	1,020
5	EP[5)] (1,000 µm)	-	-	-	1,000
6	Al/Mg (95/05)[2)] (350 µm)	EP[6)] (40 µm)	-	-	390

*µm÷25.4=mils [1)] topcoat; [2)] metallization; [3)] primer + pore filler; [4)] particle reinforced; [5)] applied in one layer; [6)] (pore filler)

Fouling and Biological Growth

Fouling on offshore structures is a well-known phenomenon. In the sector of offshore gas and oil extraction, various studies have been performed.[1,2,3] Some studies on the fouling on offshore wind energy towers have also been reported.[4,5,6]

The type and quantity of fouling species will depend on certain environmental conditions, namely, temperature, water composition, and the kinematics of the water. Nutrient concentration, in particular, is affected by the season.[3]

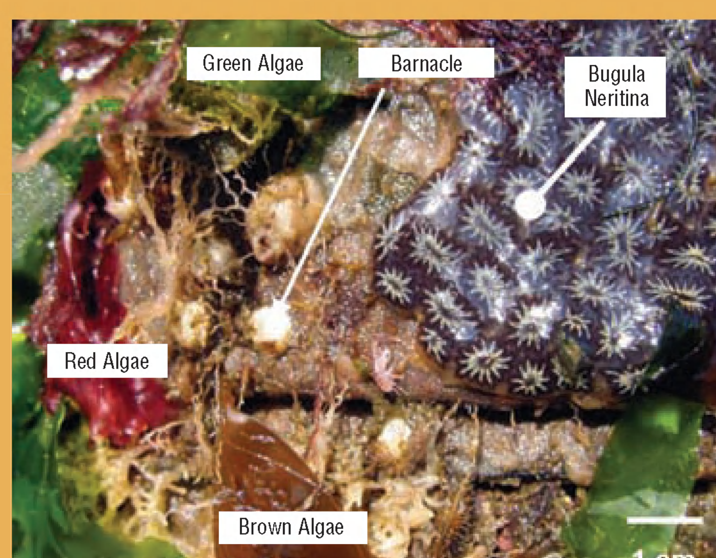


Fig. 1: Fouling at an underwater zone (UZ) specimen
Photos and figures courtesy of the authors

Therefore, results of fouling assessment may to some extent depend on the season.

The samples in this study were released in the summer season (July). Some environmental conditions applying to the test site are listed in Table 1.

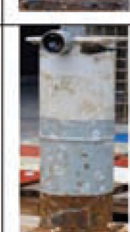
Fouling can affect the corrosion of

Table 1: Site-Specific Environmental Conditions (Ref. 3)

Parameter	Range
Salinity	29 – 33 PSU
Turbidity	Low – moderate
Light (PAR)	100 – 2,000 $mol/m^2 \cdot s$
Wave exposure	Exposed
Flow velocity	0.3 – 1.5m/s
Specific wave Height	0.5 – 4m
Temperature	2 – 20 C

Fig. 2: Great crab, domiciliated in the underwater zone (UZ)

Table 2: Visual Appearance of Underwater (UZ) Specimens under Various Conditions

Condition	System				
	3 (+ 5)[1)]	4 (+ 5)[1)]	1 (+ 5)[1)]	2 (+ 5)[1)]	6
After 5 months (total fouling)					
After 13 months (total fouling)					
After 36 months (total fouling)					
After 36 months (first cleaning)					
After 36 months (final clea-ning for assessment)					

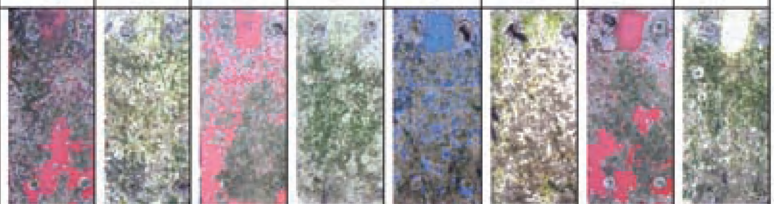
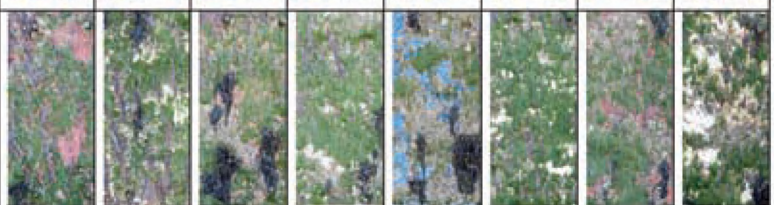
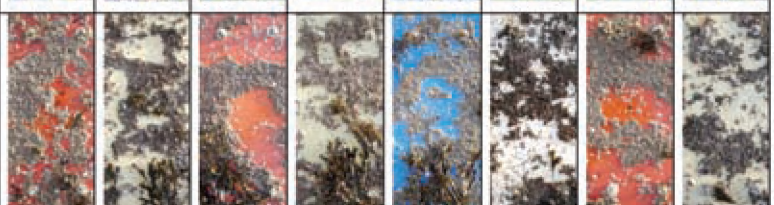
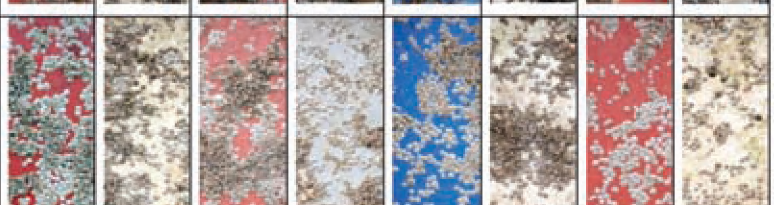
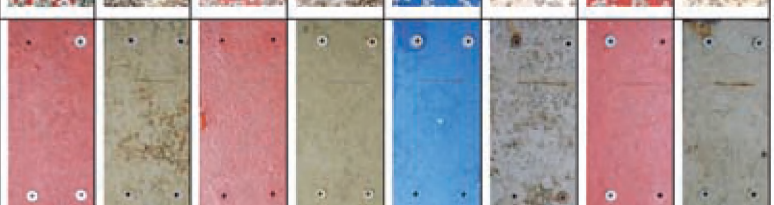
[1)] Lower section of the specimen is System 5 (red, respectively gray)

steel in several ways: creation of areas of trapped water; oxygen concentration cells; sites for aerobic bacteria; removal of metal.[7] It is, however, not clear if fouling and marine growth can affect the performance of protective coatings.

Fouling in the Underwater Zone (UZ)
All UZ samples were heavily fouled (as shown in the upper three rows of Table 2). Species found on the test specimens included brown algae (*Laminaria*) with large brown leafs up to 2 m long. They appeared predominantly in the upper region of the UZ. Further on, green algae (*Ulva*) were found, as were at least three species of red algae, which were not classified (Fig. 1). Moreover, the following types of species were identified: sponges, mussels (common mussel, oyster-type mussel), anemones, bryozoan (very striking was the species *Bugula neritina*) and sea firs. One special kind of barnacle (*Balanus crenatus*) could be found in the UZ only. This species features a calcareous basal plate, which could not be dislodged completely, even when the barnacles were removed from the specimens (Table 2). This species was reported to likely occur in the UZ of wind towers in the North Sea.[4] Vagile (mobile) species were detected as well, among them worms, some crabs (Fig. 2), and small fish (up to 20 cm long). The settling of numerous species of crabs and fish at submerged wind tower sections in the North Sea was also reported.[6] Algae could not be detected at the rear side of the sample plates because of lack of sunlight in that area.

Fouling in the Intermediate Zone (IZ)
All IZ samples were heavily fouled (see the upper two rows of Table 3). Species detected included green algae (*Enteromorpha*) and brown algae (among others, *Ventricaria ventricosa*). Algae could not be detected at the rear side of the sample plates because of lack of sunlight in that area. Two species of barna-

Table 3: Visual Appearance of Intermediate Zone (IZ) Specimens under Various Conditions

Condition	System 3		System 4		System 1		System 2	
	3a	3b	4a	4b	1a	1b	2a	2b
After 5 months (front area with total fouling)								
After 36 months (front area with total fouling)								
After 36 months (front area; algae removed)								
After 36 months (Rear side)								
After 36 months (front area cleaned for assessment)								

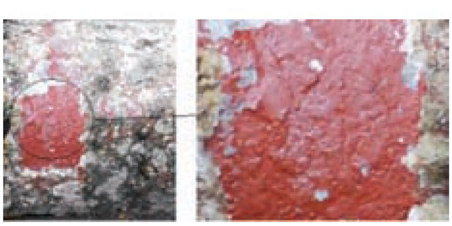


Fig. 3: Coating delamination at System 5 after 36 months of UZ exposure

cles also grew intensely over the samples (row 3, Table 3). One species was *Elminius modestus* (small species), which is known to attach to artificial structures. This species was reported to likely occur in the intermediate zone of wind towers in the North Sea.[4] The other species was *Semi balanus* (larger, well-adhering). This species is known to be very well aligned to tides, but it cannot survive very well under permanently submerged conditions. In contrast to the barnacles found in the UZ, these species feature a membranous basal plate. Some vagile species (worms, crabs) were also found. There was no relationship between fouling and generic paint type. For System 1, which has a PU top layer, the sample 1a exhibited the least fouling, whereas the sample 1b was as heavily fouled as the systems with an EP-based upper coat. It was noted, however, that the rear areas of the panels were much less populated compared to the front. Basically, only barnacles settled in the rear areas (row 4, Table 3), most likely because of the lack of UV light.

Coating Performance in the Underwater Zone

Performance after 5 and 13 Months

The samples were assessed after 5 months and after 13 months. Results of these surveys are reported elsewhere.[8,9] The results obtained after 13 months are briefly recapitulated here. A striking, and rather unexpected, feature was heavy fouling on the underwater samples (upper two rows, Table 2). The fouling consisted of small barnacles and a dark biofilm (algae, sponges). The severity of the fouling differed notably. The sample with System 6 showed the most severe fouling; it was almost completely covered with barnacles. System 5 exhibited the least severe coverage with barnacles but was covered extensively with biofilms. The coating performance could not be assessed in detail. At a few small areas, the fouling was carefully removed, and the coatings were visually inspected. No signs of deterioration were detected.

Performance after 36 Months

The samples were mechanically cleaned with a wood scraper and subsequent high-pressure water washing to visually assess the conditions of the coatings (Table 2).

System 3 showed slight delamination at the front after cleaning, perhaps due to mechanical damage and subsequent deterioration. The steel/primer interface exhibited initial delamination. System 4 did not show any damage to the surface. Slight initial delamination at the steel/primer interface was noted.

Table 4: Assessment of Bond between Steel (Weld Seam) and Applied Coating Systems, Based on Polished Cross Sections

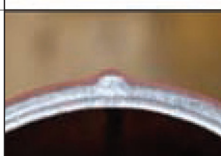
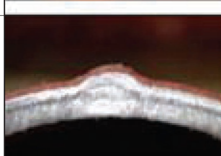
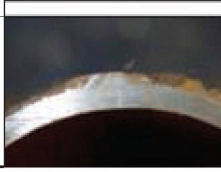
System	Image	Remarks
1	No image available	Excellent bond over the entire length.
2		Excellent bond over the entire length. Reduction in DFT at the right weld section.
3		Excellent bond over the entire length.
4		Excellent bond over the entire length. Reduction in DFT at the right weld section.
5		Excellent bond over the entire length. Coating partly broken due to cutting.
6		Coating failed.

Table 5: Assessment Scheme for Underwater Zone (UZ) Specimens after 36 Months of Exposure

Assessment						
System	Coating general (blisters, defects)	Coating at weld seam[1)]	Delamination steel / primer	Delamination primer / topcoat	Adhesion (pull-off test)[2)]	Remarks
1a	+++	+++	++	+++	4.18 MPa B/C 70% C 30%	Steel/primer interface: very preliminary delamination Transition to single coat: no delamination No damage to surface
2b	+++	+++	++	+++	7.41 MPa A/B 100%	Steel/primer interface: slight intial delamination Transition to single coat: no delamination No damage to surface
3a	+++	+++	++	+++	6.31 MPa A/B 70% B 30%	Delamination at the front surface after cleaning (maybe due to mechanical damage with subsequent corrosion and delamination) Steel/primer interface: initial delamination Transition to single coat: no delamination
4b	+++	+++	++	+++	9.41 MPa A/B 80% Y/Z 20%	Steel/primer interface: no delamination Transition to single coat: no delamination No damage to surface
5	+++	+++	++	Does not apply	Not measured	Steel/coating interface: slight initial delamination No damage to surface
6	–	–	–	–	Not measured	Assessment was performed at fixing points only Large-scale blistering and coating delamination[3)]

Conditions: –bad; +acceptable; ++good; +++very good [1)] See Table 4; [2)] Average of three measurements (ISO 4624); [3)] See Fig. 3

Systems 1 and 2 performed the same as System 4.

System 6 exhibited large-scale blistering and severe coating delamination. This sample could not be cleaned properly because high-pressure washing would have removed the deteriorated coating. The sample showed white corrosion products, which were identified as the corrosion product of the metallization. The total system could be removed by scratching it slightly with a fingernail (Fig. 3). Because metallization with adequate sealers (at least Al/Zn metallization) is usually an effective and proven method for protecting offshore steel structures,[10,11,12] the result was surprising. No conclusive explanation can be delivered at the moment, and this issue will be the topic of a subsequent study. It is not clear whether fouling effects contributed to that failure. The compatibility of this coating system with cathodic protection under laboratory conditions was good (See Part 3 of this series, to be published in an upcoming issue).

The UZ specimens were cut into two pieces, and the cross sections of the cuts were inspected in terms of coating. Examples of the cross cuts are shown in Table 4. Even in the critical range over the weld seam, shown in the images in Table 4, most of the coatings featured good, tight adhesion to the steel substrate. The exception was System 6, which failed totally.

Table 5 lists results of pull-off tests. The pull-off strength values were between 4.18 MPa and 9.41 MPa. With the exception of System 1, the values are still well above the value of 6.0 MPa, which is recommended in ISO 20340 for newly applied coatings for immersion service.[13] On the other hand, only System 1 showed fractures in the coating system alone, not in the steel-primer interface.

The internal areas, originally filled with seawater, were inspected as well. They showed signs of oxidation, but, in general, the corrosion was not severe, and pitting was not detected. Signs of more severe oxidation were recognized along a stripe that ran exactly along the weld seam (see image for System 4, Table 4). This feature was interesting because the weld seam was attached only to the external surface. Metallurgical changes in the steel, originating from the welding process, might have caused this phenomenon.

The results of the assessment procedure are listed in Table 5, which shows that they did not allow for a reliable ranking of the systems in terms of coating performance (except for

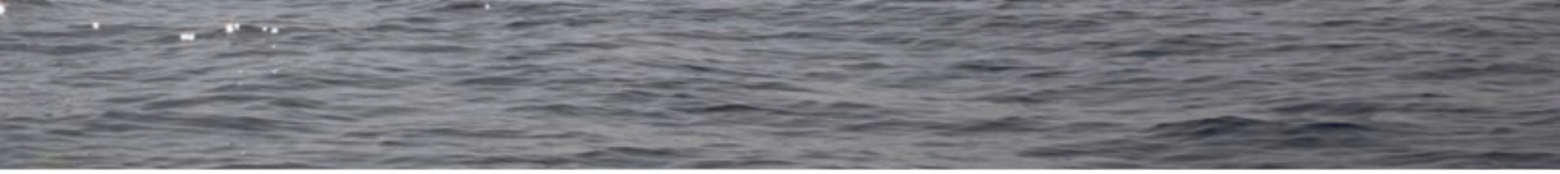


Table 6: Assessment Scheme for Intermediate Zone (IZ) Specimens after 36 Months of Exposure

Assessment					
System	Coating general	Scribe: corrosion[1]	Scribe: delamination[1]	Adhesion (pull-off test)[2]	Remarks [1]
1a	++	–	–	9.78 MPa B/C, C, C/Y	Neither delamination nor blistering at the area. Notable corrosion and delamination at the scribe and blistering (up to 10mm away from the scribe).
1b	++	+	+	6.70 MPa A/B 20% B 80%	Neither delamination nor blistering at the area. Notable corrosion and delamination (ca. 1mm) at the scribe.
2a	++	+	+	11.9 MPa B 30% C/Y 70%	Neither delamination nor blistering at the area. Limited corrosion and delamination (ca. 2mm) at the scribe.
2b	++	+	+	Not measured	Neither delamination nor blistering at the area. Limited corrosion and notable delamination (ca. 3mm) at the scribe.
3a	++	+++	+++	8.99 MPa B 80% B/Y 20%	Neither delamination nor blistering at all.
3b	++	+++	+++	11.6 MPa B 10% B/Y 90%	Neither delamination nor blistering at all.
4a	++	+++	+++	2.35 MPa B/C 100%	Neither delamination nor blistering at all. Compared to SZ, no chalking and less metallic appearance.
4b	++	+++	+++	Not measured	Neither delamination nor blistering at all.

Conditions: –bad; +acceptable; ++good; +++very good [1] See Table 7; [2] Average of three measurements (ISO 4624)

System 6).

Coating Performance in the Intermediate Zone (IZ)

Performance after 5 and 13 Months

The samples were assessed after 5 months and after 13 months. Results of these surveys are reported elsewhere.[8,9] The results obtained after 13 months are briefly recapitulated here. Similar to the UZ samples, the samples exposed to alternate immersion showed strong deposition of, and fouling with, biological species such as algae, barnacles, and other species (first row, Table 3). The intensity and kind of species differed notably, depending on the coating system and the immersion period. Explanations for the latter effect are the influence of the season in which the specimens were assessed and the individual life and growth cycles of the species. The coating performance could not be assessed in detail. At a few small areas, the fouling was carefully removed, and the coatings were visually inspected. No signs of deterioration were detected.

Performance after 36 Months

The samples were mechanically cleaned with a wood scraper and subsequent high-pressure water washing to visually assess the conditions of the coatings. Table 6 lists the results of the assessment procedure. Generally, the coated areas of the specimens were in good condition, with no signs of severe corrosion, degradation, or delamination. Corrosion and degradation effects were observed only in the sections around the artificial scribes. The delamination from the artificial scribe was measured with high-resolution optical microscope images, taken from polished cross sections (e.g., lower images, Table 7).

Notable effects were found for Systems 1 and 2. The scribe delamination was about 2 mm for sample 1a and about 1 mm for sample 1b. The sample 1a exhibited severe corrosion at the scribe (Table 7). Scribe delamination was about 2 mm for sample 2a and about 3 mm for sample 2b. Both samples for System 2 showed limited corrosion at the artificial scribe. Sample 1a exhibited blistering up to a distance of 10 mm from the scribe.

As shown in Table 6, values for pull-off strength varied between 2.35 MPa and 11.9 MPa. With the exception of System 4a, the values were higher than the values estimated for the UZ specimens (Table 5), and are well above the value of 4 MPa, which is recommended in ISO 20340 for newly applied coating systems in C5-M service.[13] Typical fracture types were fractures in the paint system and in the glue. These fractures are in contrast to the observations of the UZ specimens, where the fracture was primarily adhesive.

According to the results of the assessment, summarized in Table 6, coating performance among the systems could be ranked as follows: 3, 4, 2, 1.

Coating Performance in the Splash Zone (SZ)

Performance after 5 and 13 Months

After 13 months of immersion, the splash zone samples were in good condition in terms of degradation and corrosion (second row, Table 8). The front of the metallized surface of the flanges appeared grayish due to the development of a protective oxide layer, typical for zinc. Generally, the metallization at the rear section of the flanges was in good condition. No negative interaction with the high-alloyed screws was observed. Also, the angled steel panels did not contribute to any

Table 7: Corrosion (upper image) in, and Paint Delamination (lower image; cross section view) at, the Artificial Scribe at the IZ Specimens

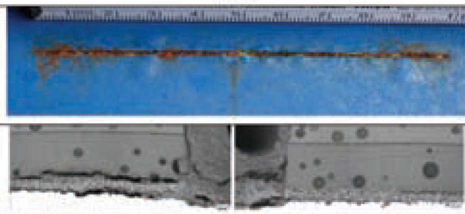
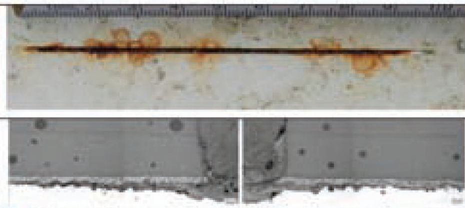
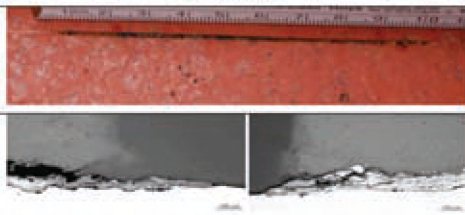
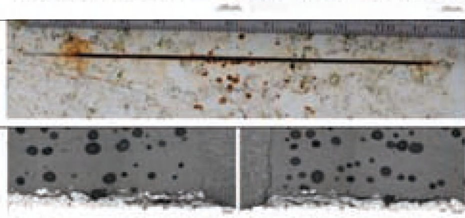
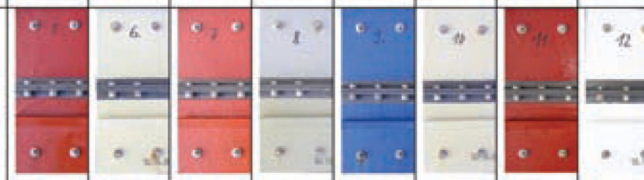
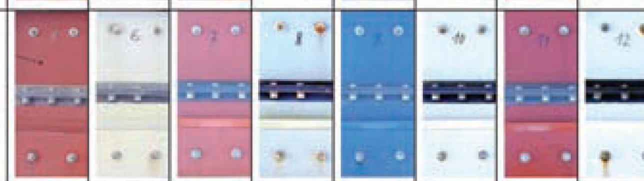
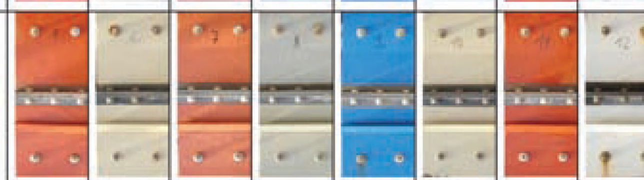
Sample	Image
1a	
2b	
3a	
4b	

Table 8: Visual Appearance of Splash Zone (SZ) Specimens under Various Conditions

Condition	System 3		System 4		System 1		System 2	
	3a	3b	4a	4b	1a	1b	2a	2b
After 5 months								
After 13 months								
After 36 months								
Flanges rear section (lower part)								No image available

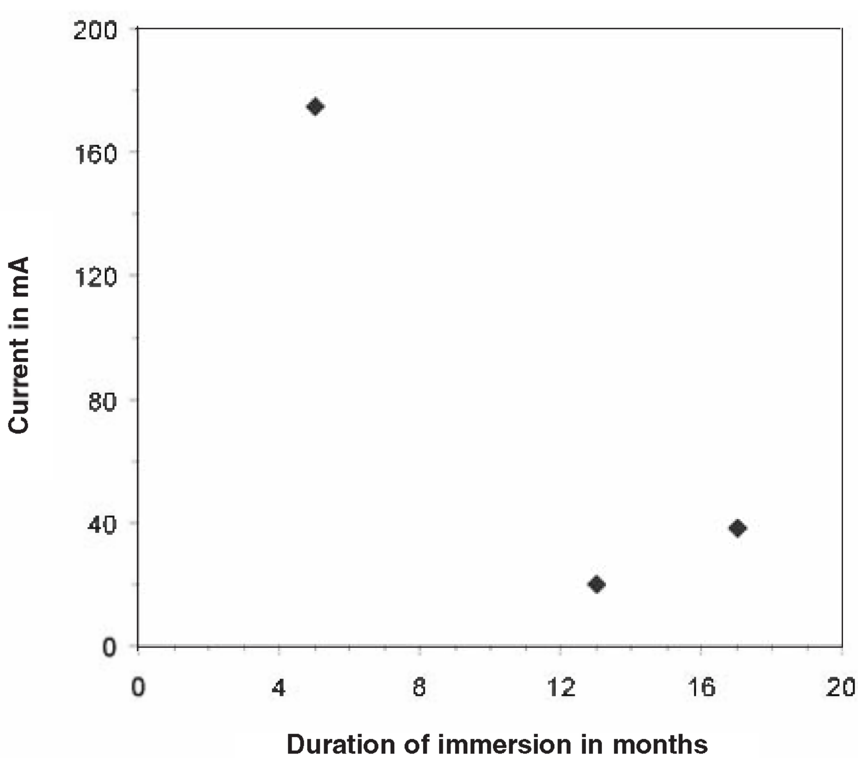


Fig. 4: Current consumption of cathodic protection of UZ samples

notable negative effects.

Performance after 36 Months

Table 8 lists the results of the visual assessment. All coating systems were generally in good condition. Chalking was observed on almost all samples, with the exception of System 1, which featured a PU-based topcoat. Chalking was most pronounced for System 4. Yellowing of the topcoat was observed for two samples. Sample 1a showed some gloss loss.

No severe corrosion or degradation effects could be detected. Delamination was not observed in the organic coating or in the transition zone between organic coating and sprayed metal. Only some slight white rust formation on the metal-sprayed layer was observed. As the results of the assessment for the coatings in Table 9 show, the systems could not be distinguished in terms of a clear ranking.

The rear sides of the metallized flange sections exhibited corrosion (Table 8). The way the flanges were affixed to the structure promoted crevice corrosion.

Table 9: Assessment Scheme for Splash Zone (SZ) Specimens after 36 Months of Exposure

Assessment						
System	Coating	Zinc metalization front section of flange	Screws	Flange areas	Zinc metalization rear section of flange[1)]	Remarks
1a	+++	+++	+++	++	–	Gloss loss No chalking
1b	++	+++	+++	++	–	Yellowing of the coating Good adhesion in the range of paint chippings
2a	++	+++	+++	++	–	Slight chalking
2b	+++	+++	+++	++	–	No chalking; slight yellowing Good adhesion in the range of paint chippings
3a	++	+++	+++	++	–	Slight chalking
3b	++	+++	+++	++	–	Slight chalking
4a	++	+++	+++	++	–	Notable chalking
4b	++	+++	+++	++	–	Notable chalking

Conditions: –bad; +acceptable; ++good; +++very good [1)] See lower two rows in Table 8

The corrosion was mainly characterized by the formation of white rust, but the formation of red rust on the substrate was also observed at places. It could be shown that the amount of corrosion depended on the location on the flanges and on the system. Critical areas were the slits between the individual flange sections, across from the weld seams, where the most severe corrosion was observed at all specimens. Again, crevice corrosion might have caused this phenomenon. Corrosion was always more severe at the lower part of the flange, where thick, loose layers of white rust as well as partial red rust developed (Table 8, lowest row). The two abutting faces with inserted nuts did not show severe corrosion. Slight white rust formation was observed at places.

The AISI 304 steel screws showed good compatibility with the metal-sprayed layers. The boreholes for the screws were usually in good condition, although white rust formation occurred at a few locations. Grommets and screw nuts were in good condition.

Cathodic Protection of Uncoated Sections

Figure 4 shows results from the cathodic protection measurements. During the first months, the sample remained unprotected for technical reasons. The current had rather high values, which may have been caused by initial corrosion of the unprotected samples. After the cathodic protection was introduced, the value for the current dropped, and it seemed to be constant for the entire exposure phase. Coverage by fouling and the precipitate of alkaline earth salts are two probable reasons for the continuously low values for the protective current. Unfortunately, part of the cathodic protection device was destroyed due to heavy wave load after 17 months, and it did not work properly. Therefore, the cathodic protection failed, and the uncoated sections of the specimens started to corrode.

Fig. 5: Unprotected section of a UZ specimen after 36 months of exposure

The uncoated sections featured two layers of corrosion products (Fig. 5). The layer next to the steel was a black, loosely adherent layer, which was identified as Fe-oxide, more specifically, Fe-hydroxide with a low oxidation number. The top layer was the typical red rust, also loosely adherent. Figure 6 provides an SEM image and an EDX spectrum taken from the external corroded wall of the uncoated section of an UZ specimen. It can be seen that the rust was already cracked. Crack lengths ranged from 0.25 to 1.5 mm. Rust flakes were partly separated and only loosely adhering to the steel. The honeycomb structure in the far right region of the photograph is residue of fouling, and may be the origin of Si and partly of S and Na, occurring in the

Fig. 6: SEM image (upper image; image width: 5 mm) and EDX plot (lower diagram) of the corroded external wall of UZ specimen 2 after 36 months exposure

EDX spectrum. The Fe-peaks in the spectrum originate from the corrosion products formed at the surface. The elements Al, Cl, Ca, Mg, S, and Na are constituents of the seawater.

Summary

• Fouling did not seem to affect the corrosion protection performance of the coating systems. From the point of view of effects on the habitat in the vicinity of the towers, fouling in the UZ and the IZ may become an issue in running off-shore wind energy towers in the North Sea.

• The results of the long-term site tests gave the following ranking of the protection capability of the coating systems: 3, 4, 2, 1. Thus, Zn/Al metallization, followed by two intermediate layers of EP-based paint, is a good choice. The assessment is based mainly on the results obtained from the artificially damaged IZ samples.

• In the SZ, the flange connection was a critical structural part in terms of corrosion. Notable crevice corrosion was observed at places. Therefore, a suitable sealant between abutting faces may be considered for additional protection against corrosion.

• The corrosion zones showed no effect on the performance of the coating systems. In contrast to plain steel, which showed accelerated corrosion in the SZ of offshore structures,[14,15] the coatings performed equally well, as long as the undamaged areas of the samples were considered.

• Mechanical damage to the coating initiates paint delamination and corrosion. A recommended coating system, therefore, should be either very resistant to impact or able to compensate for corrosion of the steel.

• Cathodic protection of uncoated sections in the UZ is an interesting alternative to passive coating systems.

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References

1. A. Wolfson, G. van Blaricom, N. Davis, G.S. Lewbel, "The marine life on an offshore oil platform," *Marine Ecology*, Vol. 1, pp. 81-89 (1979).
2. P. Whomersley, G.B. Picken, "Long-term dynamics of fouling communities found on offshore installations in the North Sea," *J. of the Marine Biological Assn. of the UK*, Vol. 83, pp. 897-901 (2003).
3. B.H. Buck, C.M. Buchholz, "The off shore-rig: a new system design for the open ocean aquaculture of macroalgae," *J. of Appl. Phycology*, Vol. 16, pp. 355-368 (2004).
4. K. Hiscock, H. Tayler-Walters, H. Jones, "High level environmental screening study for offshore wind farm developments – marine habitats and species project," Project Report W/35/00632/00/00, AEA Technology, Harwell, UK (2002).
5. J. Birklund, A.H. Petersen, "Development of the fouling community on turbine foundations and scour protections in Nysted off shore wind farm," Survey Report, Energi E2 A/S, Copenhagen, Denmark (2004).
6. R. Frederiksen, M. Bech, S.B. Leonhard, "Hard bottom substrate monitoring Horns Rev offshore wind farm," Survey Report No. 1, Elsam Engineering A/S, Fredericia, Denmark (2004).
7. R.G. Edyvean, "The influence of marine macrofouling on corrosion," *Bioextraction and Biodeterioration of Metals* (Eds.: C.C. Gaylarde, H.A. Videla), Cambridge University Press, pp. 169-196 (1995).
8. M. Schneider, V. Stenzel, A.W. Momber, "Vergleichende Untersuchungen von Korrosionsschutzkonzepten für Offshore-Windenergieanlagen," Proc. Workshop Korrelation von Labortests mit Praxisbedingungen im schweren Korrosionsschutz, DECHEMA, Frankfurt, pp. 81-97 (2005).
9. A.W. Momber, V. Stenzel, P. Plagemann, M. Schneider, "Combined field-laboratory studies on corrosion protection conceptions for offshore wind energy towers," *Proc. 4th International Symposium on Protective Coatings*, Mumbai, pp. 62-70 (2006).
10. M. Cornago, "Improving performance using thermal spray coatings for off shore structures," *Protect. Coatings Europe*, Vol. 4, No. 9, pp. 28-32 (1999).
11. Li, Y., Liu, J., Duan, J., Hou, B., "Thermally sprayed aluminium and zinc coatings for tidal zone cathodic protection of offshore platform pile legs," *Materials Perform.*, Vol. 45, No. 12, pp. 16-19 (2006).
12. K.P. Fischer, W.H. Thomason, T. Rosbrook, J. Murali, "Performance history of thermal sprayed aluminium coatings in offshore service," *Materials Perform.*, Vol. 34, No. 4, pp. 27-35 (1995).
13. ISO 20340, "Performance requirements for protective paint systems for offshore and related structures," International Organisation for Standardisation, Geneve (2005).
14. M. Smith, C. Bowley, L. Williams, "In situ protection of splash zones," *Materials Perform.*, Vol. 41, No. 10, pp. 30-33 (2002).
15. P. Ault, "The use of coatings for corrosion control on offshore oil structures," *Protect. Coatings Europe*, Vol. 11, No. 4, pp. 42-46 (2006).

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