

Investigating Corrosion Protection of Offshore Wind Towers

Part 1: Background and Test Program

Andreas W. Momber, Muehlhan AG,
Hamburg, Germany;

Peter Plagemann, Volkmar Stenzel;
Fraunhofer Institute for Manufacturing
and Applied Materials Research,

Bremen, Germany; and

Michael Schneider, Fraunhofer Institute
for Ceramic Technologies and Systems,
Dresden, Germany

The installation of offshore wind energy mills in both the North Sea and the Baltic Sea is one of the most recent approaches for alternative production of energy. A number of offshore wind energy parks have already been established in these areas, and others are under consideration. An offshore wind energy mill basically consists of a foundation, the actual tower, and the turbine rotor construction (Fig. 1).

The tower is usually mounted on the foundation by a bolted flange. This article deals with the corrosion protection of the towers and part of the foundation. These towers are ambitious engineering constructions. They can be as high as 80 meters for offshore installation; the diameter can be as large as 7 meters; and the wall thickness can be in the range of several centimeters (Fig. 2).

Offshore wind energy towers are exposed to harsh and complex stresses, including the following:

- corrosive stress,
- physical load, and
- biological stress.

Editor's note: This article is based on an earlier version given at PACE 2008, January 27–30, in Los Angeles, CA. PACE is the joint conference of SSPC: The Society for Protective Coatings and the Painting and Decorating Contractors of America (PDCA).

*Burbo Bank Offshore Wind Farm (Liverpool Bay)
Courtesy of Siemens Wind Power*

This article deals mainly with the corrosive stress, although researchers found that biological stress may also play a role in the conditions offshore. The corrosive stress includes features such as seawater exposure, wet-dry cycles, temperature variations, construction details (joints, bolts, welds), and construction materials (material combinations).

The location of steel structures several miles offshore is not a new situation. Oil and gas exploration and extraction platforms have performed in such areas for decades. The coating industry has, over the years, developed special coating systems, to protect offshore structures from corrosion. A simple approach for protecting offshore wind energy towers could be to adapt coating systems for offshore platforms to the wind towers. This approach would also allow for the use of standard assessment schemes developed by the industry and regulatory bodies.^{1,2} There are, however, critical differences between platforms and towers, the most significant being that offshore wind energy towers are unmanned structures with highly restricted access. On oil and gas platforms, corrosion protection systems are generally under permanent inspection, which is not the case on offshore wind energy towers. Thus, whereas on oil and gas platforms, areas of deteriorated coating can be recognised and repaired comparatively easily, such repairs are not feasible on offshore wind energy towers.

In this article, the authors discuss a nationally funded project on the performance testing of different corrosion protection methods under site and laboratory conditions. This first part deals with the rationale behind, and the setting-up of, the test program. A second article will discuss the test results.

Corrosive Stress and Corrosivity Category

Corrosive stress depends largely on the location of a structure. An offshore wind energy tower, as a sea-based construction, has significant exposure in several zones, including the following:^{2,3}

- underwater zone (UZ), the area permanently exposed to water;
- intermediate zone (IZ), the area where the water level changes due to natural or artificial effects, and the combined impact of water and atmosphere increase corrosion;
- splash zone (SZ), the area wetted by wave and spray action, which can cause exceptionally high corrosion stresses, especially with seawater.

The environmental zones above can be classified as per Fig. 1. Corrosion zones considered in this study are marked. The corrosion rate of steel in these environments can be greater than 2.5 mm per year.⁴ It is already known that corrosion rates of steel are highest in the splash zone.⁴ Table 1 lists results reported in reference 4. In Table 1, the splash zone, which features the flange connection between foundation and

tower, seems to require particular attention for corrosion protection. However, using the values in Table 1 requires caution, because they are based on the corrosion of unprotected steel, whereas the present investigation deals with the performance of protective coating systems over steel.

Two corrosivity categories must be considered for offshore wind energy mills:³

- C5-M: very high, marine; coastal and offshore areas with high salinity, and
- Im2: seawater or brackish water (including offshore structures).

Selection of Corrosion Protection

Systems for Wind Energy Towers

The specification for a corrosion protection system for wind energy towers should address the following demands:

- high corrosive stress due to elevated salt concentration in both water and air,
- mechanical load due to ice drift or floating objects,
- biological stress, namely under water,
- notable variations in temperature of both water and air,

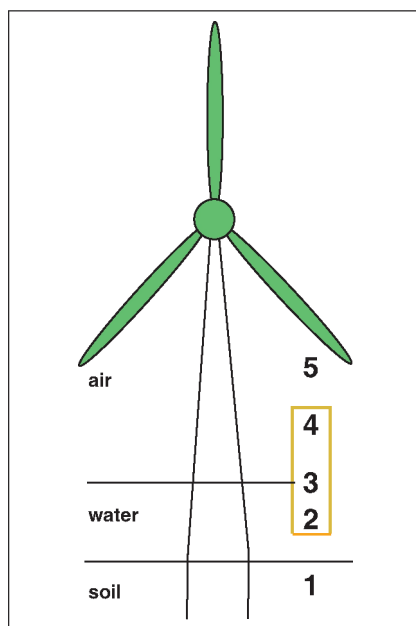


Fig. 1 (Left): Corrosion zones on offshore wind energy towers. 1= buried in soil; 2 = underwater zone (UZ); 3 = intermediate zone (IZ); 4 = splash zone (SZ); 5 = atmospheric zone
Courtesy of the authors

Table 1: Corrosion Rates of Steel in Offshore Service⁴

Environmental zone	Corrosion rate (mm/year)
Buried in soil	0.1
Underwater zone (UZ)	0.2
Intermediate zone (IZ)	0.25
Splash zone (SZ)	0.4

- long and irregular inspection intervals because of reduced accessibility, and
- high maintenance and repair costs in case of coating failure.

The formal way to select a system is to consider the corrosivity categories according to reference 3. If the categories are combined with a given durability range, general coating system schemes can be pre-selected.⁵ The general scheme covers the following coating parameters: binder, primer type, number of coats, and nominal dry film thickness. A typical system that meets the corrosivity categories C5-M and Im2 would include a zinc-rich, epoxy-based priming coat (60 µm); three subsequent epoxy mid-coats, and one polyurethane topcoat, with a total nominal dry film thickness of 400 µm. However, this selection process considers only organic coating systems, not the detailed application of metal coatings, which are quite common on wind energy towers. Coating systems, typically applied to traditional offshore structures, are specified in reference 2, where hot-dip galvanized and metallized steel substrates are included.

Reference 6 reviews coating systems applied to offshore wind energy towers in the past. The systems basically consisted of a Zn/Al-metallization, organic pore filler, several intermediate epoxy-based coats and a polyurethane-based topcoat. A typical total dry film thickness was about 400 µm. Reference 7 describes a coating system on offshore wind energy towers that provides high abrasion resistance.

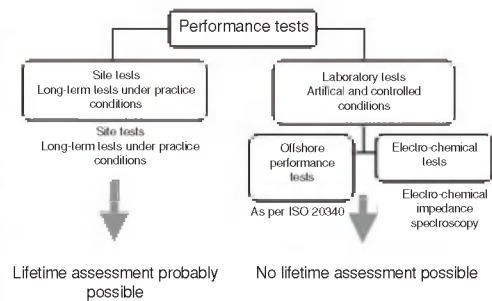
Table 2: Qualification Tests for Offshore Coating Systems (ISO 20340)

Test	Artificial scribe	Testing duration for Im2		
		SZ	IZ	UZ
Ageing resistance*	Yes	4,200 h	4,200 h	-
Cathodic disbondment	ISO 15711	-	6 months	6 months
Seawater immersion (ISO 2812-2)	Yes	-	4,200 h	4,200 h

*See written text, pp. 34-35.



*Fig. 2: Dimension of a typical wind tower construction
Courtesy of Muehlhan A/S, Vissenbjerg*



*Fig. 3 (Above): Summary of performance tests
Courtesy of the authors*

Test Procedures

Testing and assessment methods for corrosion protection systems may be subdivided into laboratory tests under defined artificial stress conditions and site tests under real stress conditions. Figure 3 summarizes all tests for the present study.

The site tests included long term exposure tests in a real corrosion environment. They were performed at the seawater test site at the island of Helgoland, 70 km off the German coast. The test site featured three galleries: one for the underwater zone (UZ) environment; one for the intermediate zone (IZ) environment; and one

Table 3: Parameters of the Cathodic Disbonding Tests

Parameter	Test A, based on (9)	Test B, based on (8)
Exposure time	30 days	180 days
Applied cathodic potential	-1,450 mV _{SCE}	-1,050 mV _{SCE}
Electrolyte	Potable water; added: 10 g/l sodium chloride 10 g/l sodium sulphate 10 g/l sodium carbonate	Demineralized water; added: 23.8 g/l sodium chloride 9.8 g/l magnesium chloride 8.9 g/l sodium sulfate 1.2 g/l calcium chloride

What do you do when the surface you need to paint is *never dry*?

No Sweat!



In Here, You Need the Proven Power of Polyurethane Coatings Built on Bayer Technology

Ever-present condensation on the piping caused by cold water being piped into the plant. **Flash-rusting** on surfaces that were next to impossible to get clean enough and moisture-free during preparation. These conditions made a **moisture-cure urethane system built on Bayer technology** the only way to go to coat more than 35,000 square feet of sweating steel piping and valves in the **Hammond Water Filtration Plant in Hammond, Indiana**.

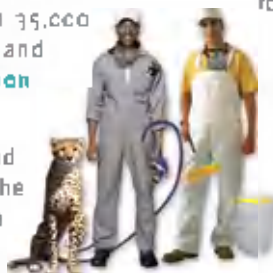
The moisture cure urethane primer and aliphatic topcoat took advantage of the moisture and humidity in the plant to dry and cure.

Plus they will remain elastic and resistant to UV radiation so the job will last and look good for 15 to 20 years.

Get the whole story on this application and how well the power of polyurethane coatings can work for you. See examples of applications where polyurethane coatings are providing enduring protection and exceptional, long-term great looks. And, how easy they are to apply.

Visit www.bayermaterialsciencenafia.com/a

Or call 412-777-3983 and get your copy of **The Proven Power of Polyurethane Coatings**.



Helping make our customers' vision a reality. Bayer MaterialScience. Where VisionWorks.

Phone: 412-777-3983 • www.bayermaterialsciencenafia.com/a

Copyright © 2002, Bayer MaterialScience LLC

Click on Reader's Card at printsquare.com/r/c



Fig. 4 (Left): Outdoor test stand at Heigoland with specimens. Courtesy of the authors

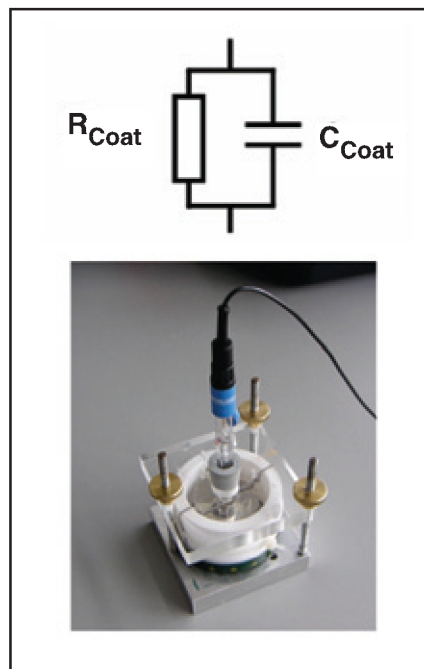


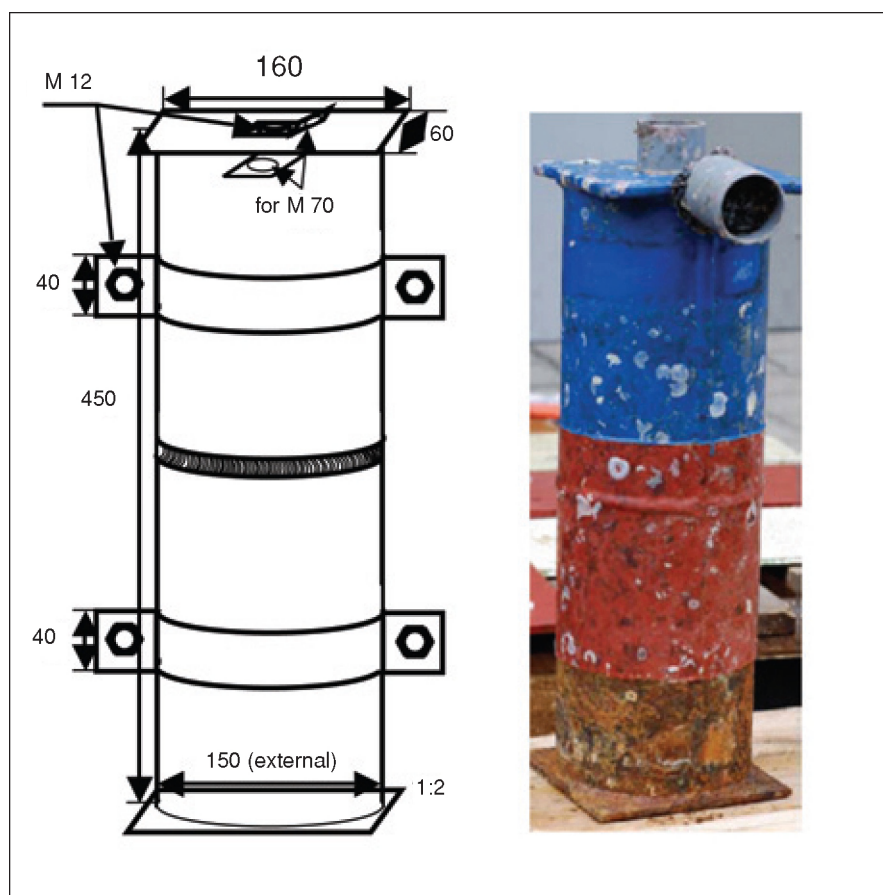
Fig. 5 (Left): Set-up for electrochemical impedance spectroscopy measurements, and equivalent circuit
Courtesy of the authors

Fig. 6 (Below): Specimen design for underwater zone (UZ); dimensions in mm
Courtesy of the authors

for the splash zone (SZ) environment. Figure 4 shows the test site, where the specimens for the SZ and the IZ can be recognized. The specimens for UZ, which are submerged, can be seen as discoloration of the water surface. All specimens were tested for three years. Part of the site test procedure was cathodic protection, consisting of an impressed current system. The applied potential was controlled to $-880 \text{ mV}_{\text{Ag}/\text{AgCl}}$

The laboratory tests were subdivided into ageing tests according to ISO 20340,² cathodic disbonding tests,^{8,9} and tests based on electrochemical impedance spectroscopy (EIS). All tests were performed in the laboratory at IFAM, Bremen. The procedure prescribed in reference 2 includes a combination of UV/condensation, salt spray, and low-temperature exposure cycles. The exposure cycle in the procedure lasts a week (168 hours) and includes the following stresses (see also Table 2):

- 72 hours (3 days) of exposure to UV (UV [B] lamps) and water,





VersaFlex
INCORPORATED

“The Polyurea People”®

We make our money selling the best polyurea systems available. We earn our money providing technical service and contractor training second to none.



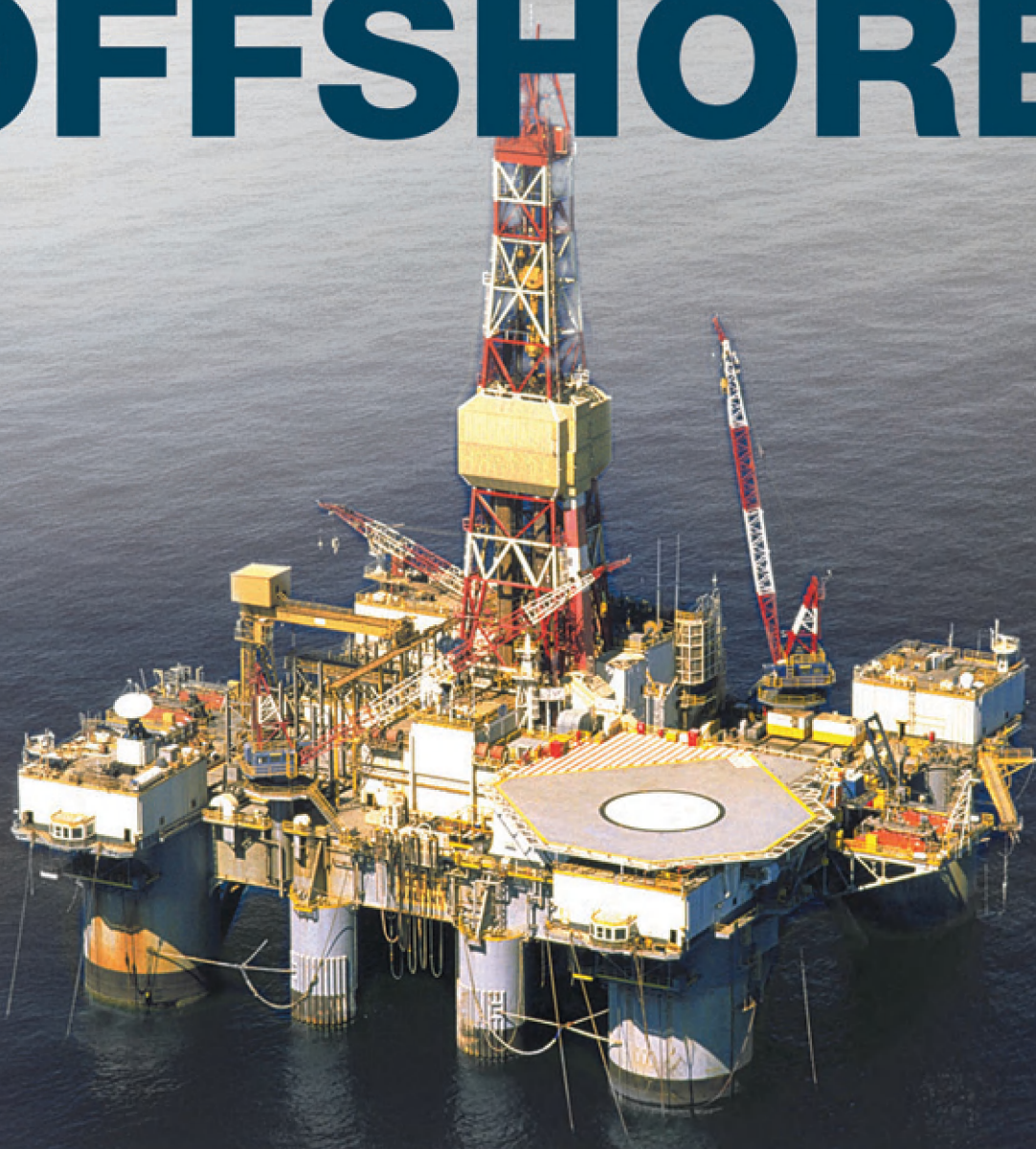
VersaFlex is pleased to announce that Cullen Ryan has joined our staff, furthering our commitment to provide the best technical service to our customers.

VersaFlex Incorporated
www.versaflex.com

87 Shawnee Avenue
Kansas City, KS 66105

Click our Reader e-Card at paintsquare.com/ric

WE KNOW... OFFSHORE



AMERCOAT



PPG's Protective & Marine Coatings (PMC) protect customer assets in some of the world's most demanding conditions and environments. Our research and product development teams understand what the offshore industry is up against in the most extreme operating conditions. In partnership with industry experts, our teams work tirelessly to develop new and innovative systems for the offshore industry around the globe.

Many of our coatings systems are NORSOK approved as well as meeting local requirements. A number of our developments are unique and set the standard for the entire offshore industry.

The result is a wide range of protective coatings ideal for use in offshore.

Contact a PMC specialist or visit PPGPMC.COM for more information.

Click our Reader e-Card at paintsquare.com/ric

+1 800 441 9695 |



PPG Protective & Marine Coatings
WE KNOW...

| www.ppgpmc.com

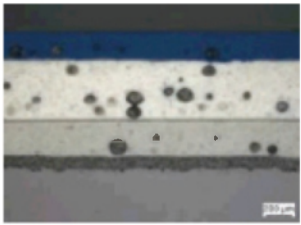
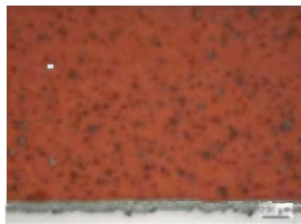
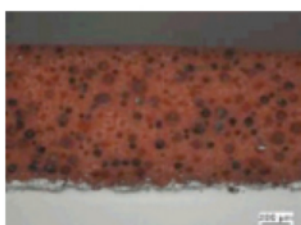
- 72 hours (3 days) of exposure to salt spray, and
- 24 hours (1 day) of exposure to low temperature ($-20\text{ C} \pm 2\text{ C}$).

A total of 25 cycles (25 weeks) were run. Part of the assessment procedure was cathodic disbonding according to references 8 and 9. For these tests, specimens with the design shown in Fig. 10 (p. 49) were used. Holes were drilled through the coating down to the substrate, and the samples were exposed to synthetic seawater. Table 3 lists details on the test parameters.

However, these tests are plain pass/fail tests. Although they allow for a comparative evaluation of different paint systems, they do not provide information on the paint degradation processes or on corrosion progress. A promising method for gathering degradation and corrosion information on coatings for wind energy towers is EIS.^{10,11} Therefore, additional EIS tests were performed on a number of laboratory samples. EIS was carried out on coated steel specimens, which had been stored in a 3% NaCl solution for up to 62 days. The measurements were performed according to the three-electrode method with an onset cell of 8 cm diameter. The testing device is shown in Fig. 5. The spectra were measured from 100 kHz to 0.01 Hz; with a potential amplitude of 20 mV_{Ag/AgCl}. From the obtained spectra, barrier resistances were determined by fitting a simple RC (ohmic resistance/capacitor) equivalent circuit (Fig. 5).

In addition, probable contact corrosion between dissimilar metals was investigated. These investigations were applied to the contact between the bolt material in the flange area and construction steels. The contact areas were assessed visually.

Table 4: Coating Systems

System number	SEM cross section	System composition (DFT)				Total DFT in μm
		Primer	2. Layer	3. Layer	4. Layer	
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	No image available	EP ⁵⁾ (1,000 μm)	-	-	-	1,000
6		Al/Mg (95/05) ²⁾ (350 μm)	EP ⁶⁾ (40 μm)	-	-	390

1) topcoat; 2) metallization; 3) primer + pore filler; 4) particle reinforced; 5) applied in one layer; 6) (pore filler); SEM - scanning electron microscopy

Test Samples

Outdoor Test Samples

Design rules for offshore wind energy tower follow the function of the tower. Low-corrosion design is a secondary issue. Therefore, the towers are complex structures with construction details such as bore holes, bolted connections, flanges, weld seams, bracings, steel sections, and coating overlap. Few approaches have been made in the past to consider these details. Bailey et al.¹² were probably the first to simulate construction details of offshore structures. Their specimen featured a plate with bore holes, I-beams, a pipe section, edges, weld seams, and bolts. Wilds¹³ manufactured specimens containing a welded pipe section, angled parts, weld seams and I beam, and he investigated the performance of organic repair coating systems. The author found a notable effect

at the weld seams.

For the present study, researchers designed and manufactured three types of special specimens: for the UZ, for the IZ, and for the SZ (Figs. 6 to 8). The use of the specimens embodying on a small scale the typical structural features of a real offshore wind energy tower is considered a new approach in testing. All outdoor samples were made from high-strength, weldable construction steel, S-355.

The samples for the UZ were steel pipes. The pipes were filled with seawater and then sealed. These specimens contained weld seams at the uncoated and coated sections. They also featured a connection for cathodic protection (see Figs. 6 and 8). About 60% of the surface was coated. The specimens for the IZ zone were simple steel plates (Fig. 8). After an exposure for 13 months, researchers scribed the IZ samples to promote corrosion.

The specimens for the SZ consisted of two parts bolted together (Figs. 7 and 8). The lower part embodied the end of the foundation structure where the actual tower construction, embodied by the upper part of the specimen, rests. Both parts of the specimen featured a flange end, which was welded to the main body. The flange sections were metallized but not coated. Made from high-alloyed steel (AISI 304), the bolts represented the contact between dissimilar metals. The SZ specimens also contained an angled steel panel welded to the lower part. This construction detail may characterize design that promotes corrosion (Fig. 8).

Laboratory Test Samples

Three types of laboratory samples were manufactured. The first type covered the specimens for the degradation tests according to ISO 20340.² The dimensions were slightly modified (Fig. 9). The coated specimens were provided with two artificial scribes to simulate localized mechanical damage. Position and dimensions of the scribes

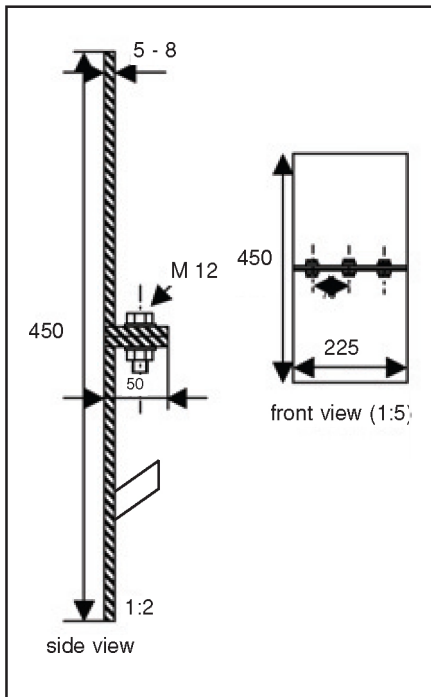


Fig. 7: Specimen design for splash zone (SZ); dimensions in mm
Courtesy of the authors



Fig. 8: Coated specimens for outdoor testing. Upper: Splash zone (SZ) specimens. Center: Intermediate zone (IZ) (originally without scribe, no effect after 13 months; scribe added after 13 months to produce mechanical damage to the systems.) Bottom: Underwater (UZ) specimens
Courtesy of the authors

THE PROVEN LEADER

IN WASTE WATER CONTAINMENT PROTECTION

ITW Devcon Futura Coatings is the proven leader in protecting waste water facilities against leaks and corrosion with specifically designed liquid applied polyurea and polyurethane coating systems.

Approved by most of the major national water and waste engineering firms in North America, our applications have been successful for over 25 years. We are the preferred coatings supplier for elastomeric polyurethane and polyurea coatings by many of the largest water and waste water application firms in North America.

Our systems are VOC compliant, offer protection for H₂S environments and our coating specialists are NACE certified. In addition, our single coat DTM flexible polyurethane's are NSF approved systems for steel potable water tanks.

**ITW Devcon Futura Coatings,
protecting your assets in the toughest
environments.**

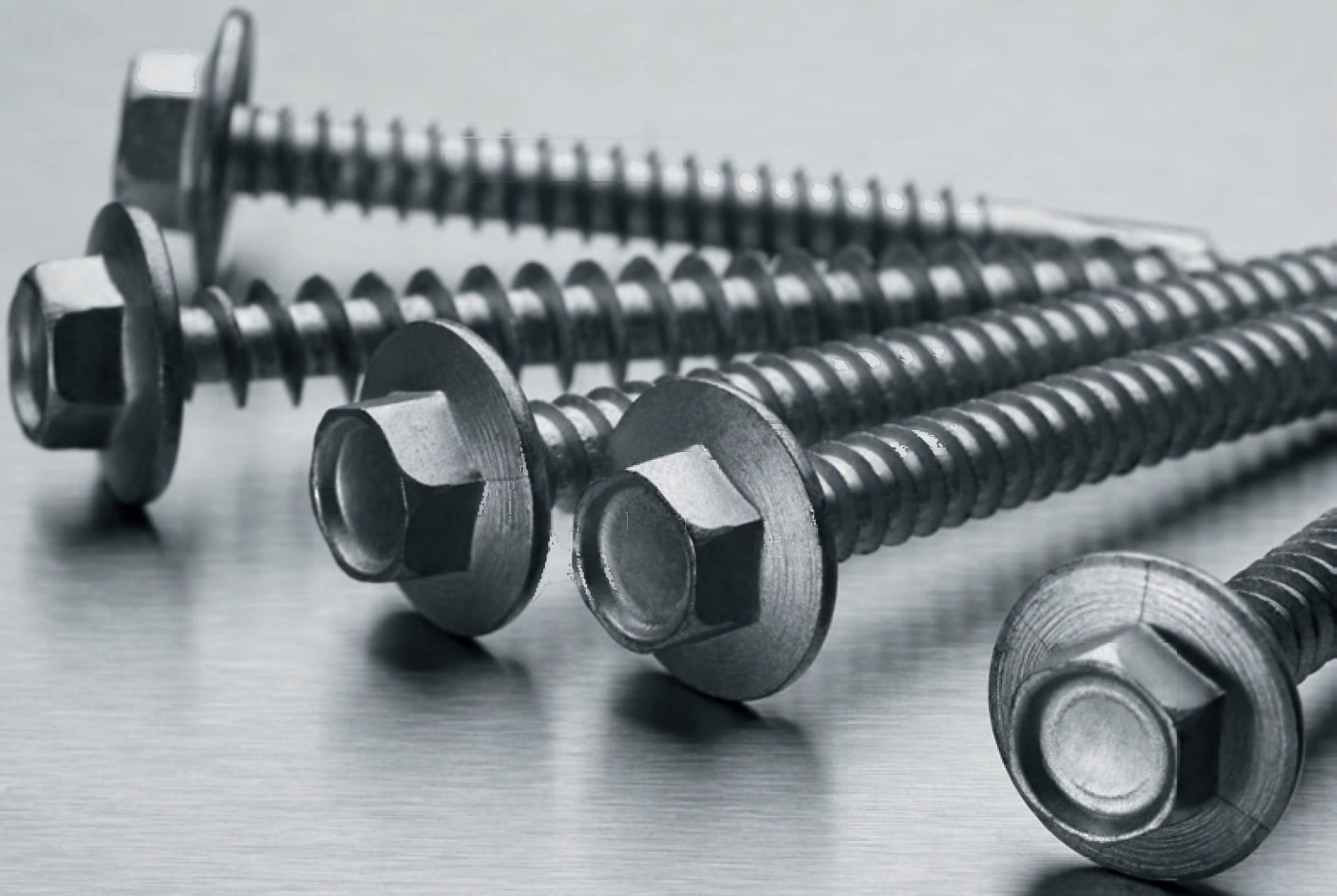


ITW Devcon Futura Coatings

1685 Galt Industrial Boulevard
St. Louis, MO 63132-1021
314-733-1110 • FAX: 314-733-1164
877-347-5730
www.futura coatings.com

Click our Reader e-Card at paintsquare.com/ric





The ECKART effect – makes strong stronger.

The Eckart effect maintains the value of investments. Unlike conventional zinc dust primers which often tend to shatter, especially when applied in thick coats, ECKART zinc flakes virtually eliminate this risk. Zinc flakes unite the anti-corrosive properties of zinc with the barrier effect created by pigments in the form of flakes, transforming a priming coat into sustained anti-corrosion protection, and turning necessity into a long-term benefit. That is the Eckart effect.

ECKART is the world's leading manufacturer of effect pigments for the plastics industry. Innovation, research & our continuous process of product development ensure ECKART's leadership position. www.eckart.net

ECKART Switzerland . Case Postale . CH-1963 Vétroz . Switzerland . Tel: 41 27 346 4727 . Fax: 41 27 346 5261 . info.eckart.switzerland@altana.com
ECKART America Corporation . 4101 Camp Ground Road . Louisville . Kentucky 40211 . USA . Tel: 1 502 775 4241 . Fax: 1 502 775 4249 .
Toll-free: 877-754-0001 . info.eckart.america.ky@altana.com . www.eckart.net

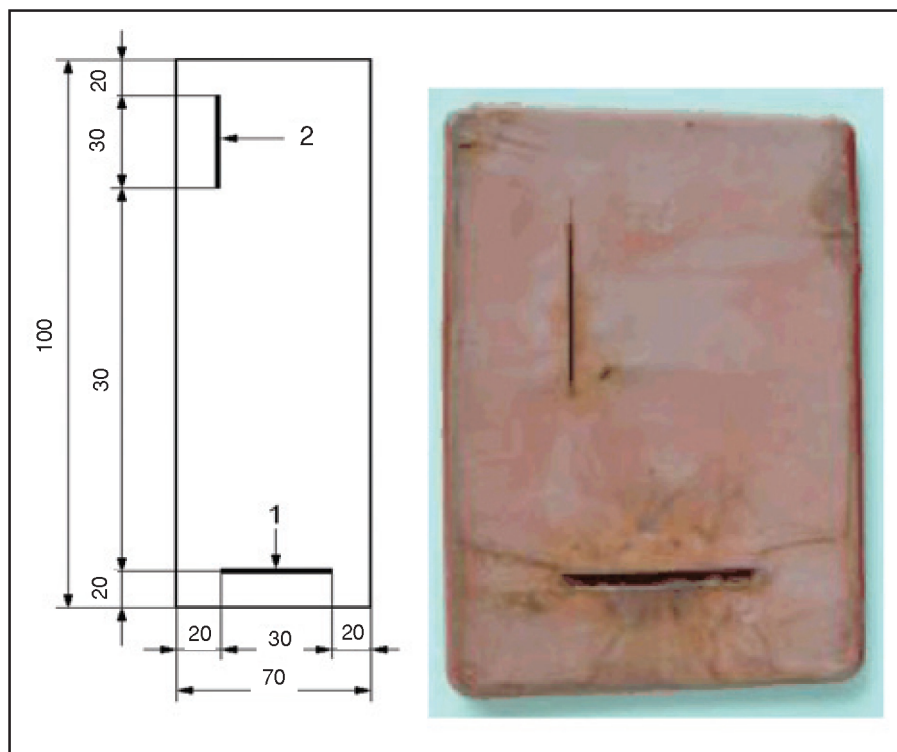


Fig. 9: Specimen design for the tests according to ISO 20340 (2); dimensions in mm
 "1" = 2-mm-wide scribe; "2" = 0.05-mm-wide scribe
 Courtesy of the authors

- cathodic corrosion protection of unpainted steel;
- thick, single-layer organic coating,
- multi layer organic coating system,
- duplex system: metal-sprayed coating with organic top coat, and
- metal-sprayed coating with organic sealer.

Details of these protection methods can be found in Table 4. Systems 1 and 2 are basic inexpensive versions, whereas the systems 3 and 4 represent more advanced versions. Systems 5 and 6 were applied to the samples for the UZ only.

The systems differed not only in terms of composition and thickness, but also in terms of primer coat and type of intermediate coat. The organic coating materials with particle reinforcement were non-commercial products. Duplex systems are routinely used for onshore wind energy towers, and they have been applied to offshore wind energy towers at places⁶. Duplex systems are high-level systems because the protection of steel against corrosion can be ensured even if the organic coating fails. Multi-layer organic coating systems are standard solutions, but their performance depends on the details of the systems. Therefore, multi-layer systems with different intermediate layers have been tested. Single-layer organic coating systems are not common in the offshore industry, but they could offer advantages in terms of application. Their performance under offshore conditions has not yet been investigated systematically. The system

"Al/Mg metallization + pore filler" is an uncommon variant for offshore constructions, but it would allow for a comparison between different metallization systems, Zn/Al and Al/Mg.¹⁴

All samples were blast cleaned according to ISO 8504-2.¹⁵ Abrasive material was steel grit with a particle size between 0.2 and 2 mm. Fine cleaning was performed. The surface profile was measured with a stylus instrument according to ISO 8503-4.¹⁶ The average

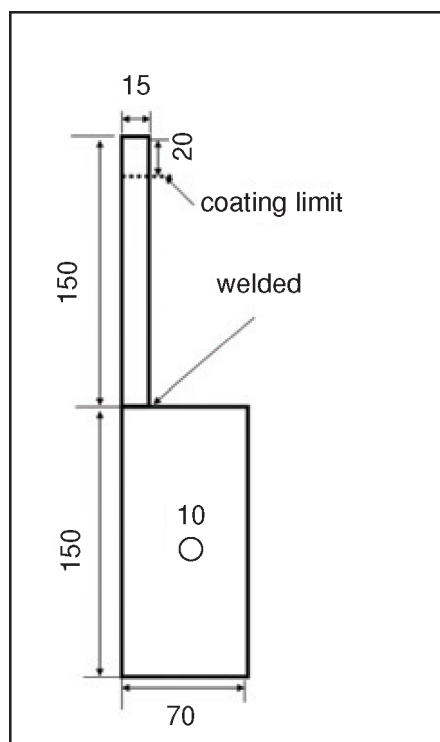


Fig. 10: Specimen design for the cathodic disbonding tests; dimensions in mm
 Courtesy of the authors

can be read from Fig. 9. The second type covered the specimens for the cathodic disbonding tests (Fig. 10). The specimen consisted of a lower primary section and an upper, smaller secondary section, whereas the top part of the upper section remained uncoated. A hole with a controlled cross section (\varnothing 10 mm) was drilled through the coating down to the plain steel in the center of the specimen. The third specimen, used for EIS measurements, was a simple, coated plate 30 mm x 30 mm.

Coating Systems and Coating Materials

Corrosion protection scenarios can be subdivided into three categories: active methods, passive methods, and temporary methods. Active methods include the selection of corrosion-resistant materials, designs reducing the risk of corrosion, and cathodic protection. Passive methods include applying coatings or linings to protect the steel. The methods investigated in this project included the following:

maximum roughness had a value of $R_{y5}=69\text{ }\mu\text{m}$, with a standard deviation of $6\text{ }\mu\text{m}$. The surface preparation grade was Sa 2½ (for the organic systems) and Sa 2½ to Sa 3 (for the metallized systems). The weld seams were ground and cleaned to a P3-quality according to ISO 8501-3.¹⁷ All coatings were applied in accordance with the manufacturers'

specifications. The organic systems were applied with airless spray systems. The metallized coatings were applied with a special metallizing technique¹⁸ with the sample preparation and test program this described.

The second part of this article, to be published in an upcoming issue, will discuss the results of this testing.

References

1. M. Mitchell, "An update and review: offshore systems and current test scenarios," *Protect. Coatings Europe*, Vol. 11, No. 4, pp. 36-41 (2006).
2. ISO 20340, "Performance requirements for protective paint systems for offshore and related structures", International Organization for Standardisation, Geneva (2005).
3. ISO 12944-2, "Paints and varnishes—Corrosion protection of steel structures by protective paint systems—Part 2: Classification of environments," International Organisation for Standardisation, Geneva (1989).
4. P. Ault, "The use of coatings for corrosion control on offshore oil structures," *Protect. Coatings Europe*, Vol. 11, No. 4, pp. 42-46 (2006).
5. ISO 12944-5, "Paints and varnishes - Corrosion protection of steel structures by protective paint systems—Part 5: Protective paint systems," International Organisation for Standardisation, Geneva (2007).
6. K. Mühlberg, "Corrosion protection for windmills on-shore and off shore," *Protect. Coatings Europe*, Vol. 9, No. 4, pp. 30-35 (2004).
7. D. Levie, M. Roehl, "Anforderungen und Erfahrungen bei der Beschichtung von Fundamenten bei Offshore-Windenergieanlagen," *Korrosionsschutz in der maritimen Technik*, Tagungsband zur 2. Tagung, Hamburg, pp 87-94 (2003).
8. ISO 15711, "Paints and varnishes—Determination of resistance to cathodic disbonding of coatings exposed to seawater," International Organisation for Standardisation, Geneva (2003).
9. ASTM G8, "Standard testing methods for cathodic disbonding of pipeline coatings," ASTM

Total Containment Systems, L.P.

Respectability & Dependability Since 1993

Talk with companies who have used the TCS patented platform. Ask them the tough questions: "Does the TCS platform save on labor costs and does it increase productivity as much as they say? How responsive and professional are they? Does TCS care about the success of your project? If you had to do it again, would you choose the TCS platform?" We think you will be impressed with the positive responses.

We look forward to the opportunity to demonstrate our quality "state of the art" working platform and debris shielding systems. No other system available in today's marketplace offers contractors as much versatility and cost effectiveness. One platform serves a variety of functions and allows you to concentrate on the most important items of your business; ...

...WORKING SAFELY AND MAKING MONEY!



- COMPLIES WITH OSHA REQUIREMENTS
- FITS ANY BRIDGE PROFILE
- COST EFFECTIVE
- LIGHTWEIGHT
- SIMPLICITY IN USE
- NATIONWIDE RECOGNITION
- MATERIALS ARE REUSEABLE
- UNPRECEDENTED SAFETY RECORD

TOTAL CONTAINMENT SYSTEMS, L.P.

28 1/2 Alice Street Binghamton, NY 13904
(607) 723-3066 Phone (607) 723-4514 Fax
www.tcsplatform.com—Website

- International, West Conshohocken (2003).
10. Y. Korobov, P.D. Moore, "Performance testing methods for offshore coatings: cyclic, EIS and stress," *Corrosion* 2004, New Orleans, March/April 2004, Paper 04005.
 11. M. O'Donoghue, R. Garrett, V.J. Datta, S. Osborne, and P. Roberts, "Windmills—fast production schedules with novel zinc primers and polyaspartic ester topcoats," *Proc. PACE* 2005, Las Vegas, Conference-CD (2005).
 12. G. Bailey, D.H. Deacon, and W.R. King, "Results of offshore tests of selected coating systems," *Trans Inst. Mar. Eng. (C)*, Vol. 91, Conf. No. 1, pp. 43-50 (1979).
 13. N. Wilds, "Surface tolerant coatings for offshore maintenance," *PACE Conference and Exhibition* 2006, Tampa, February, Conference-CD (2006).
 14. Y. Li, J. Liu, J. Duan, and B. Hou, "Thermally sprayed aluminium and zinc coatings for tidal zone cathodic protection of offshore platform legs," *Materials Performance*, No. 12, pp. 16-19 (2006).
 15. ISO 8504-2, "Preparation of steel substrates before application of paints and related products—Surface preparation methods—Part 2: Abrasive blast cleaning," International Organisation for Standardisation, Geneva (2002).
 16. ISO 8503-4, "Preparation of steel substrates before application of paints and related products—Surface roughness characteristics of blast-cleaned steel substrates—Part 4: Method for the calibration of ISO surface profile comparators and for the determination of surface profile—Stylus instrument procedure," International Organisation for Standardisation, Geneva (1995).
 17. ISO 8501-3, "Preparation of steel substrates before application of paints and related products—Visual assessment of surface cleanliness—Part 3: Preparation grades of welds, edges and other areas with surface imperfections," International Organisation for Standardisation, Geneva (2007).
 18. ISO 2063, "Thermal spraying—Metallic and other inorganic coatings—Zinc, aluminium and their alloys," International Organisation for Standardisation, Geneva (2005).

The authors can be contacted through
Dr. Andreas Momber,
momber@muehlhan.com

PosiTector® 6000

COATING THICKNESS GAGES

New

***Tougher,
Smarter
features
and still...***

***Simple.
Durable.
Accurate.***



Separate Probe Available

- Tough probes, robust housing, strong warranty
- Automatic Ferrous/Non-Ferrous substrate recognition
- Free Certificate of Calibration traceable to NIST
- High resolution and accuracy



MADE IN THE USA



DeFelsko®

40 Years of Quality

1-800-448-3835

www.defelsko.com

DeFelsko Corporation • Ogdensburg, NY • Phone: 315-393-4450 • techsale@defelsko.com