# Durability of coating repair systems for offshore service

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## Summary

The aim of this study has been to evaluate the effect of pre-treatment quality, number of coating layers and paint type on the durability of coating repairs on offshore structures under ambient offshore application conditions. In total three different pre-treatment methods, three paint types and two painting systems have been evaluated through laboratory performance test methods, including neutral salt spray and water immersion tests.

The tests show that it may be possible to reduce the requirements for offshore coating repairs without compromising the durability of the coating systems significantly. Good durability can be obtained by coating systems from all three manufactures on abrasive blasted substrates with increased soluble salt concentrations, even with systems with a total DFT of 326-571 µm. Further the study has shown that a reduced pre-treatment quality may provide good results depending on the coating type. Especially one coating type shows remarkably good results on power tool prepared substrates (St2 and Bristle Blasting Grinder) with results comparable to Sa2½.

## 1 Introduction

It is well-known that coating damage may occur on offshore wind structures during their structural lifetime due to climatic breakdown since the offshore location exposes the structures to heavy stresses and a marine corrosive environment. Construction and installation actions may also induce mechanical damage of the protective coating. Furthermore, structures may even be installed offshore without any proper coating protection in local areas due to e.g. production delay.

For damage to the immersed surfaces, good repair is not possible, and it must be relied upon that the cathodic protection is effective. For the atmospheric zone and the upper part of the splash zone, coating repairs are possible.

Change in the weather offshore is a challenge to reliable surface preparation and paint application. Consequently, versatile preparation methods and paints are mandatory to offshore coating repair.

Greater knowledge of the durability of coating repair systems under realistic application conditions may provide valuable information to wind farm owners when specifying coating repair procedures. Optimised paintwork specifications may reduce the number of offshore working days and thus provide significant savings in operating costs.

## 2 Offshore coating repair challenges

It is well-known that coating failures occur on offshore structures due to general climatic breakdown. E.g. for oil and gas installations in the Norwegian sector coating maintenance intervals in the atmospheric zone have been reported to about 12 years for systems consisting of a zinc rich primer, an epoxy intermediate coat and a UV resistant topcoat [1].

The offshore location however entails that potential repair of the applied coating on unmanned wind structures poses a challenge with repair costs of potentially more than 100 times, compared to similar jobs in onshore paint shops. In the case of damages to the coating system occurring early in the service lifetime, the contractor may be obliged to carry out repairs in accordance with the full coating specification. For offshore wind foundations a typical coating system consists of [2]:

| | | |
|---|---|---|
| Specialised epoxy coating | 2-3x | 200-250 µm |
| Polyurethane top coat | | 50-70 µm |

In case small spot repairs are to be carried out by brush application to the full specification above (DFT 800-820 µm), multi-coat applications are necessary to give the specified film build resulting in numerous offshore working days and increased costs.

In general the service lifetime of a coating system depends on five factors [3]:
- Quality of surface preparation
- Actual obtained coating thickness
- Quality of workmanship
- Quality of the coatings
- Conditions at location

For this study the factors surface preparation, coating thickness (number of coating layers) and quality of the coating (coating type) have been selected as test variables in order to investigate the impact of each factor on the durability of coating repairs.

## 3 Experimental setup

### 3.1 Test panels

In total 90 test panels, 200x300x5 mm, hot rolled C-steel, were prepared and blast cleaned to Sa 2½ according to ISO 8501-1. After blasting the panels were covered by 50 mm tape centred on the front side.

The coating system applied on the front side (test side) was similar to a typical applied coating system for offshore wind foundations:

<u>Front side and edges:</u>
2 x 375 µm epoxy coating
1 x 60 µm polyurethane topcoat, RAL 1023

<u>Backside:</u>
2 x epoxy to a total DFT of 450 – 500 µm.

The panels were left for at least 7 day to fully cure.

In order to simulate a coating damage offshore, the panels were pre-corroded in the uncoated area, 50x200 mm, in a neutral salt spray chamber according to ISO 7253 for 3 days until rust grade C according to ISO 8501-1 was achieved (slight pitting). In order to simulate realistic application conditions offshore the panels were fresh water rinsed only once after salt spray exposure in order to remove soluble salts.

Figure 1: Panels in neutral salt spray chamber during pre-rusting.

The pre-treatment qualities tested were:

- Mechanical power tool cleaning to St2 according to ISO 8501-1.
- Bristle Blasting Grinder to SSPC-SP11 (power tool cleaning to bare metal).
- Vacuum abrasive blasting to Sa2½ according to ISO 8501-1.

The conditions of the panels after pre-treatment and before coating application were:

| Pre-treatment | Surface roughness (1) | Soluble salts (2) |
|---|---|---|
| Power tool - St2 | 90-110 µm, ISO 8503-5 (Testex) | 40, 73 |
| Power tool - Bristle Blasting Grinder | 80-100 µm, ISO 8503-5 (Testex) | 37, 40, 60 |
| Abrasive blasting - Sa2½ | M(G), ISO 8503-3 | 38, 43 |

Table 1: Surface preparation test results.

(1): 6 panels tested each preparation grade.

(2): 2-3 panels tested each preparation grade. Result in mg/m$^2$ according to ISO 8502-6.

After pre-treatment and before coating application all edges to existing coating were feathered to a smooth transition and dust removed.

(a) St2 (b) Bristle Blasting Grinder (c) Sa2½

Figure 2: Examples on pre-treatment qualities before coating application.

6 maintenance coating systems were tested:

| Coating system | Primer | Topcoat | Total DFT, µm | |
|---|---|---|---|---|
| | | | Spec. | Actual* |
| A1 | 2 X glassflake reinforced epoxy coating | 1 X polyurethane | 350 | 514 |
| A2 | 3 X glassflake reinforced epoxy coating | 1 X polyurethane | 500 | 571 |
| B1 | 2 X epoxy coating | 1 X polyurethane | 350 | 326 |
| B2 | 3 X epoxy coating | 1 X polyurethane | 500 | 549 |
| C1 | 2 X epoxy coating | 1 X polyurethane | 350 | 535 |
| C2 | 3 X epoxy coating | 1 X polyurethane | 500 | 713 |

Table 2: Coating systems overview.

*): Average of 15 test panels, Minimum 2 readings per test panel.

All 3 three primer types (A, B, C) and topcoats have been recommended by the manufactures for use in offshore splashzone maintenance. The coating systems were applied by brush in our laboratory under controlled environmental conditions. After application the plates were left for curing for at least 7days.

In comparison to the systems above, ISO 12944-5 recommends the following systems:

C5-M, High durability, system A5M.02: 3-4 coats (epoxy, PU), NDFT 320 µm
Im2, High durability, system A6.04: 3 coats (Epoxy (glassflake), PU), NDFT 500 µm

Hence the tested systems correspond well with the systems recommended by ISO 12944-5.

### 3.2 Laboratory test setup

The test variables were:

Coating type: 3 (Manufactures A, B and C).
Pre-treatment: 3 (St2, Bristle Blasting Grinder, Sa2½)
Coating layers: 2 (2 x primer + topcoat, 3 x primer + topcoat).

Total scenarios: 18

The accelerated laboratory tests performed were:

Neutral Salt Spray test, ISO 7253 for 1440 hours: 36 panels (duplicate determination)
Water Immersion test, ISO 2812-2 for 3000 hours: 36 panels (duplicate determination)
Adhesion strength, ISO 4624: All 72 panels after test plus 18 reference panels.

The test durations correspond to C5-M, high durability (Neutral Salt Spray) and Im2, high durability (Water Immersion) as described in ISO 12944-6.

<u>Neutral salt spray test:</u>
The test panels were scribed with a 0.5 mm milling cutter. Due to the hardness of the coating the scribe was produced in several actions following a customised guide. The scribe length was 60 mm, located horizontally in the middle of the repair area.

<u>Water Immersion test:</u>
The test panels were scribed with a 0.5 mm milling cutter. Due to the hardness of the coating the scribe was produced in several actions following a customized guide. The scribe length was 120 mm, located vertically. Due to feathering of the edges to the repair area, the scribe penetrated approximately 20 mm into the original coating system on each side of the 80 mm wide repair area.

The test temperature was 40 °C and the test solution was artificial seawater. The water level was maintained in the middle of the repair area ±15 mm in order to simulate water level conditions.
The test panels were placed vertically and not at an angle of 15-20 ° to the vertical as described in the standard.

## 4 Experimental results

### 4.1 Neutral salt spray

The test panels were fresh water rinsed after test and evaluated immediately for coating defects according to ISO 4628-2, 3, 4 and 5 (blistering, rusting, cracking and flaking). The panels were evaluated in stereo microscope at 10X magnification. No rusting, cracking or flaking was observed. The results for blistering as well as rust from the scribe evaluated according to ISO 7253, are summarised in the table below:

| Coating system | Pre-treatment | Blistering, ISO 4628-2 | Rust from scribe, mm (1) |
|---|---|---|---|
| A1 | St2 | 3(S4) | 7.5 |
| | Bristle Blasting Grinder | 2(S4) | 6.5 |
| | Sa2½ | 0 | 5.0 |
| A2 | St2 | 3(S4) | 6.3 |
| | Bristle Blasting Grinder | 1-2(S4) | 4.3 |
| | Sa2½ | 0 | 3.3 |
| B1 | St2 | 0 | 2.0 |
| | Bristle Blasting Grinder | 0 | 5.5 |
| | Sa2½ | 0 | 3.0 |
| B2 | St2 | 0 | 1.8 |
| | Bristle Blasting Grinder | 0 | 4.0 |
| | Sa2½ | 0 | 2.8 |
| C1 | St2 | 2(S4) | 2.5 |
| | Bristle Blasting Grinder | 2(S4) | 3.8 |
| | Sa2½ | 0 | 3.3 |
| C2 | St2 | 3(S4) | 8.8 |
| | Bristle Blasting Grinder | 2(S4) | 6.0 |
| | Sa2½ | 0 | 0.8 |

Table 3: Visual evaluation of test panels after neutral salt spray test.
(1): Maximum rust creepage, average of two duplicate samples.

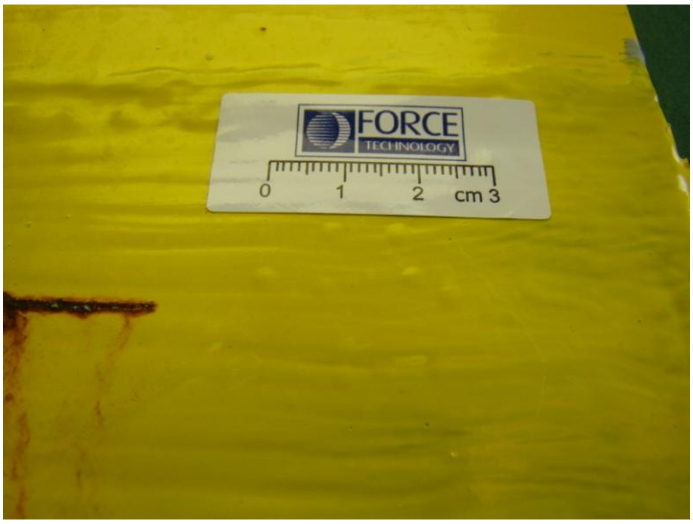
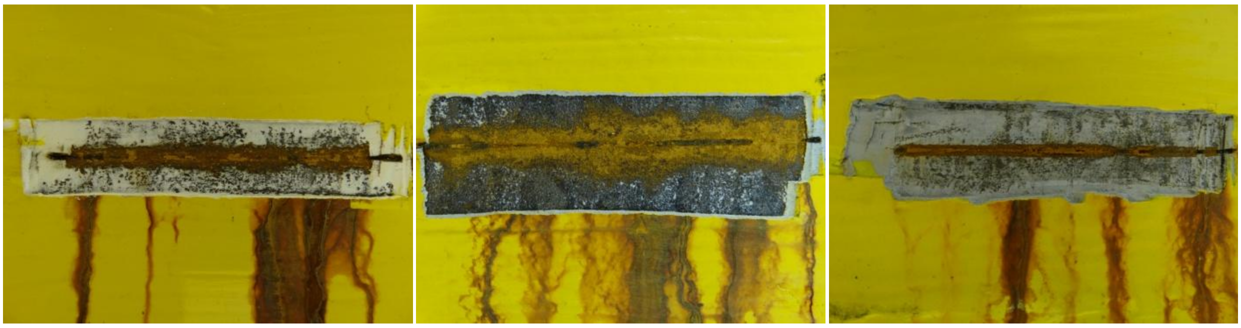



Figure 3: Example of blistering after neutral salt spray test. Result: 3(S4) (St2, System C2).



(a) St2, System B2 (b) Bristle, System A2 (c) Sa2½, System C2

Figure 4: Examples of rust from scribe after neutral salt spray test.

The adhesion strength was tested according to ISO 4624 and compared to tests performed on the reference panels. The results are summarised in the table below.

| Coating system | Pre-treatment | Before test | | After test | | |
|---|---|---|---|---|---|---|
| | | Average value, MPa | Primary break | Average value, MPa | Primary break | Adhesion Retention |
| A1 | St2 | 11.1 | Topcoat | 4.5 | Steel/primer | 0.41 |
| A1 | Bristle | 12.7 | Primer/topcoat | 5.6 | Steel/primer | 0.44 |
| A1 | Sa2½ | 14.9 | Primer/topcoat | 11.5 | Primer/topcoat | 0.77 |
| A2 | St2 | 11.5 | Topcoat | 5.6 | Steel/primer | 0.49 |
| A2 | Bristle | 12.9 | Topcoat | 5.9 | Steel/primer | 0.46 |
| A2 | Sa2½ | 12.6 | Topcoat | 10.7 | Primer/topcoat | 0.85 |
| B1 | St2 | 11.9 | Topcoat (primer) | 10.3 | Steel/primer | 0.87 |
| B1 | Bristle | 11.6 | Primer | 9.3 | Steel/primer | 0.80 |
| B1 | Sa2½ | 12.1 | Topcoat (primer) | 9.9 | Steel/primer (glue) | 0.82 |

| | | | | | | |
|---|---|---|---|---|---|---|
| B2 | St2 | 11.4 | Primer (glue) | 10.8 | Steel/primer | 0.95 |
| B2 | Bristle | 10.7 | Topcoat (glue) | 8.6 | Steel/primer | 0.80 |
| B2 | Sa2½ | 13.6 | Primer | 10.6 | Steel/primer (glue) | 0.78 |

| | | | | | | |
|---|---|---|---|---|---|---|
| C1 | St2 | 11.1 | Topcoat | 6.7 | Steel/primer | 0.60 |
| C1 | Bristle | 8.0 | Topcoat (glue) | 9.1 | Steel/primer | 1.14* |
| C1 | Sa2½ | 8.2 | Topcoat (glue) | 11.7 | Topcoat | 1.43* |
| C2 | St2 | 10.1 | Topcoat | 6.0 | Steel/primer | 0.59 |
| C2 | Bristle | 9.3 | Topcoat (glue) | 7.9 | Steel/primer | 0.85 |
| C2 | Sa2½ | 8.1 | Topcoat (glue) | 11.1 | Topcoat | 1.37* |

Table 4: Test results according to ISO 4624. The values for the reference panels (before test) are the average of up to 3 individual tests. The values for the test panels are the average of up to 6 individual tests (on duplicate samples). Glue: Unitite 2-pack epoxy.

*): Retention values above 1 are obtained due to glue failure up to 30 % in the results before test.


St2, System A2 | Bristle, System B2 | Sa2½, System C1

Figure 5: Examples of adhesion test results including dollys after neutral salt spray test.

## 4.2 Water Immersion test

The test panels were fresh water rinsed after test and evaluated immediately for coating defects according to ISO 4628-2, 3, 4 and 5 (blistering, rusting, cracking and flaking).  No rusting, cracking or flaking was observed. The results for blistering as well as rust from the scribe are summarised in the table below.

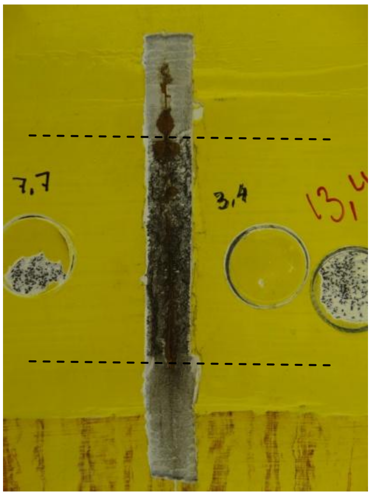
The panels were evaluated in stereo microscope at 10X magnification. The rust from the scribe was evaluated as the maximum rust creepage in the 80 mm repair area. Only areas with red rust were included in the evaluation.

| Coating system | Pre-treatment | Blistering, ISO 4628-2 | Rust from scribe, mm (1) |
|---|---|---|---|
| A1 | St2 | 2(S4) | 0.9* |
| | Bristle Blasting Grinder | 2(S4) | 0.5* |
| | Sa2½ | 0 | 0.5 |
| A2 | St2 | 0-2(S4) | 2.8* |
| | Bristle Blasting Grinder | 0-1(S2) | 2.0* |
| | Sa2½ | 0 | 1.3 |
| B1 | St2 | 0 | 3.3 |
| | Bristle Blasting Grinder | 0 | 2.5 |
| | Sa2½ | 0 | 0.5 |
| B2 | St2 | 0 | 1.0 |
| | Bristle Blasting Grinder | 0 | 1.5 |
| | Sa2½ | 0 | 0.4 |
| C1 | St2 | 1-3(S4) | 0.8 |
| | Bristle Blasting Grinder | 5(S3)-2(S4) | 0.5 |
| | Sa2½ | 0-1(S3) | 1.0 |
| C2 | St2 | 1-2(S4) | 2.5 |
| | Bristle Blasting Grinder | 1-2(S4) | 1.9 |
| | Sa2½ | 0 | 0.1 |

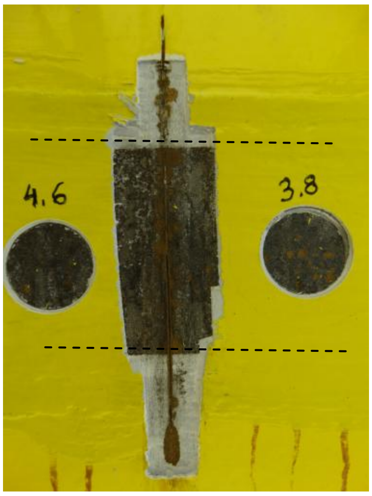
Table 5: Visual evaluation of test panels after water immersion test.

(1): Average of two duplicate samples.

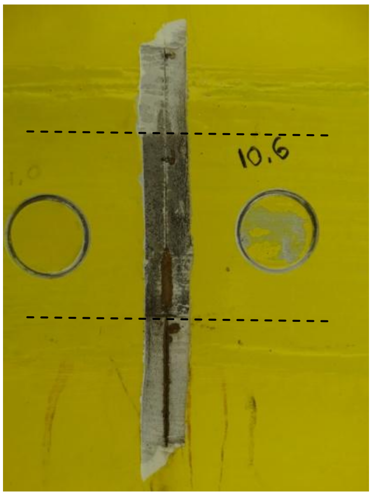
*): Repair area corroded in general - including pull off areas, cf. figure 6(b). Hence the interface steel/primer appeared degraded in the entire test repair area.




(a) St2, System B1*




(b) Bristle, System A2**




(c) Sa2½, System A2

Figure 6: Examples of rust from scribe and adhesion tests after water immersion test. The repair areas are indicated by the stipulated lines. The water level was located in the middle of the repair area ±15 mm.

*): The adhesion values of 3.4 and 7.7 MPa were discharged due to glue failure > 30 %.

**): The repair area shows spot rust on the substrate in the entire repair area, including the adhesion test sites.

As seen from figure 6 there are corrosion attacks of varying width from the scribes above and below the repair areas on some panels. The corrosion most probably occurs due to atmospheric corrosion above the continuous water film or below the water level due to water line corrosion. Hence the rust from scribe may be influenced from especially the water line corrosion (due to macro galvanic effects).

The adhesion strength was tested according to ISO 4624 and compared to tests performed on the reference panels. The results are summarised in the table below.

| Coating system | Pre-treatment | Before test | | After test | | |
|---|---|---|---|---|---|---|
| | | Average value, MPa | Primary break | Average value, MPa | Primary break | Adhesion Retention |
| A (1) | St2 | 11.1 | Topcoat | 5.3 | Steel/primer | 0.48 |
| A (1) | Bristle blaster | 12.7 | Primer/topcoat | 4.8 | Steel/primer | 0.38 |
| A (1) | Sa2½ | 14.9 | Primer/topcoat | 10.3 | Primer/topcoat | 0.69 |
| A (2) | St2 | 11.5 | Topcoat | 4.0 | Steel/primer | 0.35 |
| A (2) | Bristle blaster | 12.9 | Topcoat | 4.5 | Steel/primer | 0.35 |
| A (2) | Sa2½ | 12.6 | Topcoat | 12.5 | Topcoat | 0.99 |
| B (1) | St2 | 11.9 | Topcoat (primer) | 11.3 | Steel/primer | 0.95 |
| B (1) | Bristle blaster | 11.6 | Primer | 7.5 | Steel/primer (glue) | 0.65 |
| B (1) | Sa2½ | 12.1 | Topcoat (primer) | 9.0 | Steel/primer (glue) | 0.74 |
| B (2) | St2 | 11.4 | Primer (glue) | 12.9 | Steel/primer | 1.13* |
| B (2) | Bristle blaster | 10.7 | Topcoat (glue) | 8.3 | Steel/primer | 0.78 |
| B (2) | Sa2½ | 13.6 | Primer | 12.4 | Steel/primer | 0.91 |
| C (1) | St2 | 11.1 | Topcoat | 9.6 | Steel/primer | 0.86 |
| C (1) | Bristle blaster | 8.0 | Topcoat (glue) | 10.7 | Steel/primer Primer/topcoat | 1.34 |
| C (1) | Sa2½ | 8.2 | Topcoat (glue) | 13.8 | Topcoat (glue) | 1.68* |
| C (2) | St2 | 10.1 | Topcoat | 7.0 | Steel/primer | 0.69 |
| C (2) | Bristle blaster | 9.3 | Topcoat (glue) | 10.5 | Steel/primer Topcoat | 1.13* |
| C (2) | Sa2½ | 8.1 | Topcoat (glue) | 11.4 | Topcoat | 1.41* |

Table 6: Test results according to ISO 4624. The values for the reference panels (before test) are the average of up to 3 individual tests. The values for the test panels are the average of up to 6 individual tests (on duplicate samples) performed centred in the repair areas (water level zone). Glue: Unitite 2-pack epoxy.

*): Retention values above 1 are obtained due to glue failure up to 30 % in the results before test.

## 5 Discussion of results

This study has evaluated the influence of the factors surface preparation, actual coating thickness and the quality of the coatings (coating type) on the durability of off-shore coating repairs through accelerated laboratory performance tests.

According to ISO 12944-6 the requirements after test are:

- Adhesion strength: No adhesion failure to the substrate (unless >5 MPa).
- No blistering, rusting, cracking or flaking.
- Corrosion from scratch shall not exceed 1 mm.

The neutral salt spray test has been performed according to the standard, whereas minor adoptions were made to the water immersion test (test angle, scribe location, water level location). Hence the above is only applicable for the neutral salt spray test.

No systems pass due to rust from scribe <1mm, however it must be taken into consideration that the standard prescribes that the paint is preferably to be applied by spraying. In this case the application was by brush which may have had impact on the results. Further the soluble salt content on the panels before test was higher than usually found in onshore coating shops. Most probably the higher salt content has had a significant impact on the rust from the scribe results.

Only system A1 (St2) failed the adhesion strength requirement (4.5 MPa). All other systems passed.

As regards visual performance the following coating systems passed the neutral salt spray test:

- A1 and A2 (Sa2½)
- B1 and B2 (St2, Bristle Blasting Grinder, Sa2½)
- C2 (Sa2½).

Below the impact of the tested factors is discussed in more detail:

Surface preparation:

The repair systems have been applied under realistic application conditions. Hence the panels have been fresh water rinsed only once after pre-rusting resulting in a soluble salt content above the usual acceptance criteria´s for offshore coating work[1].

The resulting soluble salt content on the test panels before coating application was 37-73 mg NaCl/m2. No significant difference in salt content between the preparation grades was present.

The test panels from manufactures A and C, pretreatment qualities St2 and Bristle Blasting Grinder all show significant blistering after neutral salt spray and water immersion tests. Manufactures A and C, pretreatment Sa2½, do not show blisters except for one panel C1 in the water immersion test.

None of the test panels from manufacture B show blistering for any pretreatment qualities.

The rust from scribe results was 0.8-8.8 mm in the neutral salt spray test and 0.1-3.3 mm in the water immersion test. The results show that St2 and Bristle Blasting Grinder show more rust creepage compared to Sa2½. Further St2 in general show slightly more rust creepage than Bristle Blasting Grinder although there are exceptions.

From the adhesion test results it is evident that Sa2½ gives the highest strength with adhesion retention values of 0.77-1.43 in neutral salt spray and 0.69-1.68 in water immersion test. Absolute values after test are minimum 9.0 MPa for the abrasive blasted panels. Further the main break after test is primer/topcoat or topcoat from manufactures A and C which is the same as before test. However for manufacture B, the main break shifts from the coating system to the steel interface.

For manufactures A and C the adhesion test values after salt spray test show the general trend Sa2½>Bristle Blasting Grinder>St2 for both tests. For manufacture B the adhesion strength for all pretreatment qualities is comparable in the in neutral salt spray test. In the water immersion test the range is Sa2½=St2>Bristle Blasting Grinder. Hence it is remarkable that St2 for manufacture B results in adhesion strength values comparable to Sa2½.

In summary the following may be stated from the test results:

- Sa2½ is the best pretreatment quality for all coating manufactures.
- For manufactures A and C it is clear that the range Sa2½>>Bristle Blasting Grinder>St2 is applicable

[1] Acceptance criteria in NORSOK M-501 which is commonly used for offshore coating application: 20 mg $NaCl/m^2$.

- For manufacture B however the results for Sa2½ and St2 are comparable for all test parameters (rust from scribe, blistering, adhesion strength). The bristle blasting grinder further provides almost the same results but the rust from scribe is slightly higher in neutral salt spray test and the adhesion strength slightly lower in general.
- For manufacture B the range Sa2½= St2>Bristle Blasting Grinder is applicable.
- The presence of salts in the range 37-73 mg NaCl/m2 does not cause blistering in general since the Sa2½ panels, manufacture A and C (except C1) plus all panels from manufacture B do not show blistering after test. However the salt content may have contributed to formation of blisters on the remaining panels. In order to verify the significance of the salt concentration on blistering, reference samples with maximum 20 mg NaCl/m2 should be tested for comparison.

<u>Coating type:</u>
In summary the following may be stated from the test results:

- No clear distinction between the coating manufactures can be made from the test results on the Sa2½ abrasive blasted panels. Hence the coating type appears of lesser importance when abrasive blasting is prescribed as pre-treatment.
- Manufacture B is much more tolerant compared to manufactures A and C on St2 substrates. For manufacture B the results for Sa2½ and St2 are comparable for all test parameters, while manufacture C and especially manufacture A show significantly reduced properties on St2 substrates.
- Manufacture B is also more tolerant compared to manufactures A and C on Bristle Blasting ground substrates. Manufacture A shows reduced properties on this substrate (blistering and lower adhesion strength). Manufacture C shows comparable adhesion strength compared to manufacture B, but shows blistering after test (manufacture B does not).

Below the three coating types are ranked according to performance:

Sa2½ substrate: Manufacture A=B≥C (system C1 shows minor blistering in water immersion test).
Bristle Blasting substrate: Manufacture B > Manufacture C > Manufacture A.
St2 substrate: Manufacture B >> Manufacture C > Manufacture A

The technical datasheets for the paints all state that the coating performance will depend upon the surface preparation degree and recommend abrasive blasting for new painting. For maintenance painting the stated minimum surface preparation requirements are power tool cleaning and/or hydrojetting. Hence from the technical datasheets it is not possible to derive with certainty the coating performance on e.g.

power tool cleaned substrates. Only tests as the ones conducted may quantify the difference in durability between the various coating types.

Actual coating thickness:
The number of coating layers was strictly adhered to during application meaning that only 2 or 3 primer layers were applied by brush no matter the total specified DFT. Hence the DFT of system B1 is 326 µm (average) compared to specified 350 µm. All other systems met the specified thicknesses of 350 µm and 500 µm respectively.

From the tests results the following may be derived:
Visual assessment:
- For manufacture A there is a very minor tendency towards system A2 showing less blistering than system A1.
- For manufacture B there is no difference between systems B1 and B2.
- For manufacture C there are very minor differences between the results for systems C1 and C2. No clear direction in the results.

Rust from scribe:
- In general there is only minor difference between the systems in the test results. No clear correlation between coating DFT and rust from scribe can be made.

Adhesion strength:
- In general there are only minor differences between the systems in the test results. No clear correlation between coating DFT and adhesion strength can be made.

In summary the actual coating thickness does not appear to have impact on the test results. There is only very minor difference in test results between systems 1 and 2 for all three manufactures. Further system B1 has the lowest DFT of all the tested systems (326 µm in average) but shows some of the best test results. This shows that the surface preparation and the coating type is of greater importance that the actual obtained DFT.

## 6 General discussion

Presently abrasive blasting to Sa2½ and a maximum soluble salt content of 20 mg NaCl/m$^2$ often is prescribed as pre-treatment for offshore coating repairs. The coating system may subsequently be specified to 800-820 µm in total DFT, resulting in numerous strokes if applied by brush in small repair areas.

This study has shown that good durability can be obtained by coating systems from all three manufactures (A, B and C) on abrasive blasted substrates with increased soluble salt concentrations, even with systems with lower total DFT (326-571 µm).

Further the study has shown that a reduced pre-treatment quality may provide good results depending on coating type. Especially manufacture B shows remarkably good results on substrates St2 and Bristle Blasting ground with results comparable to Sa2½.
Further manufacture C shows acceptable results on Bristle Blasting ground substrate, however also blistering was observed on this substrate, which may question the long term durability of this system.

In summary the surface pre-treatment quality and number of coats (and total DFT) may be reduced for offshore coating repairs without compromising the long term durability of the systems significantly. However optimal choice of coating system is essential.

In this connection it is relevant to discuss the requirements some offshore contractors may request for offshore repairs. E.g. NORSOK M-501 approved coating systems may be requested for repair systems. However since all pre-qualified coating systems through NORSOK (and other laboratory tests) to our knowledge have been tested on abrasive blasted test panels with low soluble salts content, the request for qualified systems may be irrelevant if these conditions cannot be met offshore.

This study shows that it may be more important to choose the most surface tolerant primer if abrasive blasted substrate cannot (or will not) be achieved.

## 7 Conclusion

The effect of pre-treatment quality, number of coating layers and paint type on the durability of coating repairs under realistic application conditions has been evaluated through laboratory performance test methods, including neutral salt spray and water immersion tests to C5-M and Im2, high durability according to ISO 12944-6.

The three tested coating systems (Manufactures A, B, C) and topcoats have been recommended by the manufacturers for use in offshore splashzone maintenance.

The main conclusions from the tests are:

- Sa2½ is the best pretreatment quality for all coating manufactures.
- No clear distinction between the coating manufactures can be made from the test results on the Sa2½ abrasive blasted panels. Hence the coating type appears of lesser importance when abrasive blasting is prescribed as pretreatment.
- For manufactures A and C it is clear that the range Sa2½>>Bristle Blasting Grinder>St2 is applicable

- For manufacture B the range Sa2½= St2>Bristle Blasting Grinder is applicable. Hence manufacture B is much more tolerant compared to manufactures A and C on St2 substrates.
- Manufacture B is also more tolerant compared to manufactures A and C on Bristle Blasting ground substrates.
- The actual coating thickness does not appear to have impact on the test results. There is only very minor difference in test results between systems 1 (3 layers, specified DFT 350 µm) and 2 (4 layers, specified DFT 500 µm) for all three manufactures. Further system B1 has the lowest DFT of all tested systems but shows some of the best test results.
- The surface preparation and the coating type is of greater importance that the actual obtained DFT.

In conclusion the conducted tests show that it may be possible to reduce the requirements for offshore coating repairs without compromising the durability of the coating systems significantly. A good durability can be obtained by coating systems from all three manufactures (A, B and C) on abrasive blasted substrates with increased soluble salt concentrations, even with systems with a total DFT of 326-571 µm. Further the study has shown that a reduced pre-treatment quality may provide good results depending on coating type. Especially manufacture B shows remarkably good results on substrates St2 and Bristle Blasting ground with results comparable to Sa2½.

The repair systems tested were applied under realistic application conditions, including increased soluble salt concentrations. The salt content may have contributed to the formation of blisters on some of the panels and may have promoted increased rust from the scribes. In order to verify the significance of the salt concentration on blistering and rust from the scribes, reference samples with lower soluble salts concentrations should be tested for comparison.

Further the coating application was carried out on horizontal test panels. However offshore repairs are mostly conducted on vertical surfaces where the paint application is more difficult. Hence test of repair systems applied to vertical surfaces may be an area of further investigation.

Investigations by e.g. Momber et. Al. [4] have shown that results obtained through accelerated cyclic tests such as ISO 20340 in general agree with those of the long-term site tests in the splash zone for coating systems intended for wind towers. However it is recommended that the results and trends obtained from this study be verified by actual site tests offshore before the conclusions are implemented in future projects.

# 7 References

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