JOTUN - COATING PERFORMANCE LONG TERM EXPOSURE

Splash Zone Coating Performance Long Term Offshore Exposure

Jotun A/S

Report No.: 2021-3194, Rev. 1
Document No.: 1329576
Date: 2021-12-21

Project name:	Jotun - coating performance long term exposure	DNV AS Oil & Gas
Report title:	Splash Zone Coating Performance Long Term Offshore Exposure	Materials & Structural Int Advisory - Oslo-4100-NO
Customer:	Jotun A/S, Hystadveien 167 3209 SANDEFJORD Norway	Veritasveien 1
Customer contact:	Anders Skilbred	
Date of issue:	2021-12-21	1363 Høvik
Project No.:	10270090	Norway
Organization unit:	Materials & Structural Int Advisory - Oslo-4100-NO	Tel:
Report No.:	2021-3194, Rev. 1	945 748 931
Document No.:	1329576	

Applicable contract(s) governing the provision of this Report:

Objective:

The main objective of the work is to document the coating performance of a specific Jotun coating product after long-term offshore exposure

Prepared by:	Verified by:	Approved by:
Pedersen, Anette — Digitally signed by Pedersen, Anette Date: 2021.12.21 11:20:44 +01'00'	Lønvik, Kari — Digitally signed by Lønvik, Kari Date: 2021.12.21 11:45:43 +01'00'	Digitally signed by Løken, Sondre
Anette Pedersen Principal Engineer	Kari Lønvik Principal Engineer	Sondre Løken Head of Section - Materials Advisory
	Lichtenstein, Lars — Digitally signed by Lichtenstein, Lars Date: 2021.12.21 11:28:58 +01'00'	
	Lars Lichtenstein Principal Specialist	

DNV Distribution:

☐ OPEN. Unrestricted distribution, internal and external.

☐ INTERNAL use only. Internal DNV document.

☒ CONFIDENTIAL. Distribution within DNV according to applicable contract.*

☐ SECRET. Authorized access only.

*Specify distribution:

Keywords:

Glass Flake Polyester, splash zone, Baltoflake

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
0	2021-12-17	First issue	ANEPE	KLOEN, LARLIC	SONLO
1	2021-12-21	Updated based on Client comments	ANEPE	KLOEN, LARLIC	SONLO

Table of contents

1 EXECUTIVE SUMMARY

DNV, Section for Materials Advisory, was requested by Jotun A/S to carry out a study in order to document the long-term performance of use of glass flake reinforced polyester (GFP) coating like Baltoflake in offshore splash zone exposure, with the objective of minimizing or even remove the need for maintenance for a service life up to 20-25 years.

Several operators in the oil and gas industry apparently have good experience with the use of GFP but there is limited information that can be found in the open literature with documented long-term performance. The durability and service life of GFP coating in offshore splash zone environment have in this report been documented after 25-30 years exposure without any maintenance. The experience is mainly documented from inspection of coated decommissioned jacket structures from two fields in the Norwegian sector of the North Sea. One of the structures were coated with Baltoflake in yard with controlled surface preparation in 1998 and was decommissioned after 22 years in offshore service. For the other structure, the surface preparation and coating application was performed offshore in less controlled environment but still showed a good performance after 25-30 years offshore.

Field inspection and laboratory investigation document that the performance of the coating is good after 20-30 years of operation in splash zone, although the adhesion tests show a rather low pull-off strength (1.3-6 MPa). Where some degrees of adhesive failure during pull-off was observed on the coated sample from the oldest structure, some rusting on the steel substrate was observed. These local corrosion products may origin from the offshore surface preparation prior to application of the Baltoflake coating. Cross sections confirm that no active corrosion was taking place at the steel surface and that the coating performance did not appear to be significantly reduced for the offshore applied coating. EIS measurements show values > 10^6 ohm cm^2 @ 0.1 Hz, which indicates that the coating still has a low permeability and provides good corrosion protection. This result is in line with the visual appearance of the coated structures inspected.

Field inspections show that corrosion will take place in areas with mechanical damages in the GFP coating, but the extent of mechanical damages is not very high on any of the structures examined and the corrosion creep underneath the coating is rather limited.

Complete removal of corrosion allowance in the splash zone would most probably not be acceptable by owners for design of offshore wind foundation structures. The design useful coating lifetime may be extended, i.e. corrosion allowance be reduced, beyond the recommendations stated in DNVGL-RP-0416 (of 15 to 20 years), in case an inspection and repair plan (including qualified repair procedure) is specified. The efforts and cost of possible offshore repair works would then need to be accepted by the owner of the assets. The risk and possible costs involved in this may be significantly reduced with the application of a very durable coating system, like the GFP system examined within this documentation.

Based on the documented experience with GFP coating in the oil and gas industry, it may in future update of design codes for offshore wind foundation structures be considered to explicitly define a lower CA in splash zone for GFP coated (minimum 2x600 µm) structures provided some measures to reduce risk of mechanical damage during handling and installation of the structures is implemented.

2 INTRODUCTION

2.1 General

DNV, Section for Materials Advisory, was requested by Jotun A/S to carry out a study in order to document the long-term performance of use of glass flake reinforced polyester coating (GFP) like Baltoflake in offshore splash zone exposure.

Up till now, coating systems applied on structures for wind farms have typically been an epoxy coating system with a 350-600 µm thickness. Such coating systems have been shown to required maintenance and they have not always been able to meet a service life of e.g. 20 years. In that respect, Jotun suggests that the use of a coating system like e.g. Baltoflake, would reduce or possibly eliminate the need for maintenance for a design life up to 25 years or maybe longer. The material cost of GFP with thickness of ~1200 µm, as compared to a coating system with 350-600 µm thickness, is significantly higher and it has been difficult to convince the end user the benefit of using such coating. The aim is therefore to provide documentation showing that an increased CAPEX cost will reduce the risk for corrosion and need for inspections and coating maintenance and thus reduce the overall life cycle cost.

This study for Jotun was initiated in the same period as ConocoPhillips decommissioned Ekofisk 2/4 A (EKOA) that had been in operation since 1972 and Jotun had strong indications that this jacket had been coated with Baltoflake. DNV performed on behalf of ConocoPhillips inspection of the condition of the EKOA structure at the decommissioning yard (coating condition, extent of corrosion etc.). Additionally, laboratory testing on one coated brace that has been exposed in splash zone of EKOA was also performed. ConocoPhillips gave permission for DNV to share these results with Jotun and they also gave permission to retrieve an additional 4 m long length of a coated brace that has been exposed in the splash zone of EKOA for additional testing. DNV has also performed on behalf of Vår Energy inspection of the condition of the decommissioned Jotun B jacket structure. The structure was coated with Baltoflake in the splash and atmospheric zone, and Vår Energi gave permission for DNV to share the results from coating inspection with Jotun.

Jotun see this project as an opportunity to document the durability and service life of the GFP coating (Baltoflake) after long term offshore exposure. It is important for Jotun that the study is performed by an independent party and it is also seen as an advantage that DNV, as a certification body for the wind industry, performs this. The ultimate goal for Jotun is that the GFP type of coating can be implemented as an additional coating category in DNV-RP-0416 and as an option for a coating system having high durability coating with low maintenances needs for long service life.

2.2 Scope of Work

The purpose of the work is to document the durability and service life of one specific splash zone coating system (system to be confirmed in project, but likely a GFP system like Baltoflake), with the objective of minimizing or even remove the need for maintenance for a service life up to 20-25 years. As basis for the work, field experience data collected on decommissioned jacket structures and performance testing of the product after long-term offshore exposure will be used. The work was divided into the following activities:

- Review of documentation from Jotun
- Workshop with Jotun, ConocoPhillips and DNV 3rd June 2021
- DNV laboratory testing (separate laboratory report)
- Reporting

DNV facilitated a half day workshop on Teams with participants from Jotun, ConocoPhillips and DNV. In the workshop Jotun presented results from their testing and experience with use of Baltoflake and DNV presented relevant results from work on decommissioned offshore jacket structures. The purpose of the workshop was to discuss findings from inspection and results from testing. Additional test scope to be carried out on the 4 m long coated brace retrieved from the splash zone of EKOA were discussed in the workshop. A detailed scope of work for laboratory testing to be carried out after the workshop was agreed as a separate activity. Results from these tests are documented in DNV report no. 2021-5504, ref. /1/, and a summary of these results are given in Sec. 7 of this report.

2.3 Abbreviation

Table 2-1 Abbreviations

Abbreviation	Definition
CA	Corrosion allowance
CP	Cathodic protection
DFT	Dry film thickness
DMA	Dynamic mechanical analysis
EIS	Electrochemical impedance spectroscopy
EDX	Energy dispersive x-ray spectroscopy
EKOA	Ekofisk 2/4 A
EL	Elevation
FTIR	Fourier transform infrared spectroscopy
GFP	Glass flake polyester
SEM	Scanning electron microscopy

3 COATING IN SPLASH ZONE

The splash zone is the part of a structure which is intermittently exposed to seawater due to the action of tide or waves or both. The corrosive environment is severe, maintenance of corrosion protection is not practical and cathodic protection (CP) is not effective for parts of this zone.

ISO 12944-2, ref. /2/, specified different corrosivity categories. For splash zone coating both corrosivity category CX and Im4 shall apply, see Figure 3-1, as the coating both must be compatible with CP (lower part of splash zone) and harsh marine atmosphere including UV exposure (upper part of splash zone).

Corrosivity category	Mass loss per unit surface/thickness loss (after first year of exposure)				Examples of typical environments (informative only)	
	Low-carbon steel		Zinc			
	Mass loss g/m²	Thickness loss µm	Mass loss g/m²	Thickness loss µm	Exterior	Interior
CX extreme	>1500 to 5500	>200 to 700	> 60 to 180	>8.4 to 25	Offshore areas with high salinity and industrial areas with extreme humidity and aggressive atmosphere and subtropical and tropical atmospheres	Industrial areas with extreme humidity and aggressive atmosphere

Category	Environment	Examples of environments and structures
Im4	Sea or brackish water	Immersed structures with cathodic protection (e.g. offshore structures)

Figure 3-1 Extract from Table 1 and 2 in ISO 12944-2 definition of corrosivity categories, ref. /2/.

In NORSOK M-501 (ref. /3/), coating system no. 7A is applicable for carbon and stainless steel in the splash zone. Surface preparation requirements are cleanliness SA 2.5 ISO 8501-1, roughness grade Medium G (50-85 µm R_{y5} ISO 8503), dust level 2 ISO 8502-3 and max. 20 mg/m^2 salt. The coating system shall have minimum 2 coats with minimum 600 µm total DFT, ref. /3/. The coating system shall be pre-qualified according to specific requirements in NORSOK M-501 for both splash zone and submerged zone. Pre-qualification of products shall be carried out by an independent laboratory and for system 7A this include the following pre-qualification tests, ref. /3/:

- Seawater immersion according to ISO 20340 (ref. /4/)
- Ageing resistance according to ISO 20340 procedure A with supplementary requirements in Table 1 in NORSOK M-501
- Cathodic disbondment according to ISO 20340

4 BALTOFLAKE COATING SYSTEM

The Baltoflake coating system is a glass flake reinforced unsaturated polyester (GFP) coating, which is applied as one or several layers with typically 600-800 µm thickness in each layer. 2 layers are typically applied for splash zone applications, and the coating is within hours cured to a hard-wearing coating film, having a total thickness >1200 µm. Baltoflake is found in multiple colors and is relatively color stable during exposure.

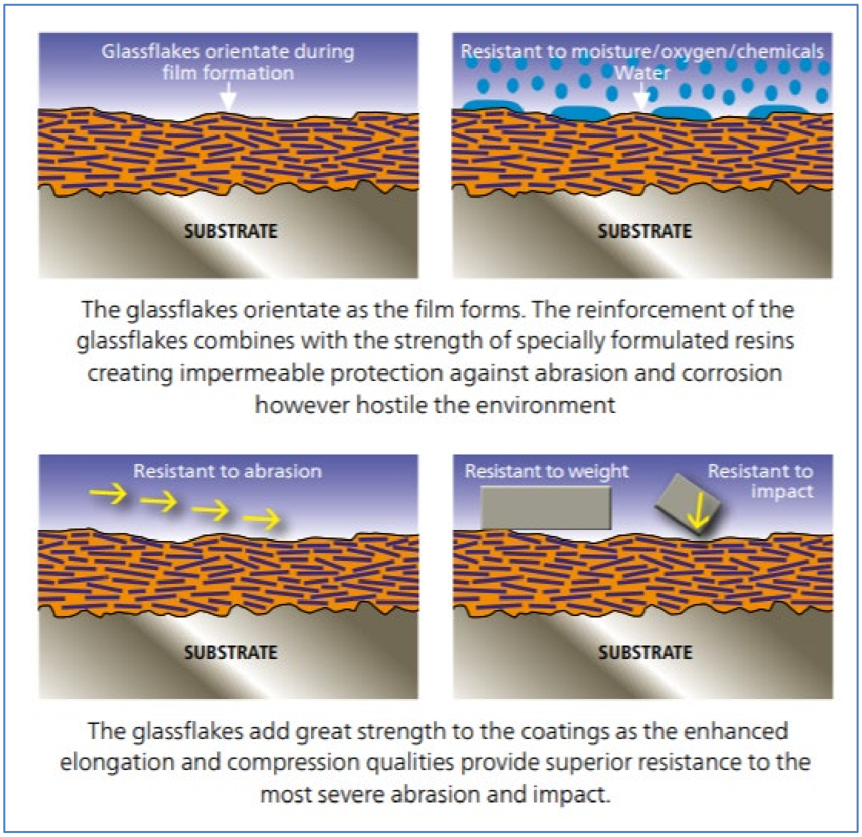


Figure 4-1 Illustration of glassflake coating.

The formulation of the Baltoflake system has been slightly modified since the versions applied in the late 80's/early 90's, mainly on the chemical composition in order to improve the HSE during application of the system. Baltoflake applied in late 80's/early 90's was based on unsaturated polyester in styrene as a binder, containing glass flakes for mechanical strength and barrier properties, as well as additives for application and curing performance, ref. /24/. Ecolife, the latest version of Baltoflake developed in the mid 90s, is a styrene free version of the GFP. Styrene was replaced by vinyl toluene in combination with optimizing the low-emission additives, and development of the curing system with additives and peroxide suitable for faster cure and lower temperature curing, ref. /24/. The binder/polymer and the glassflakes were not changed, so when cured the coating of Baltoflake Ecolife has similar composition and the same properties as Baltoflake from the 80's, ref. /24/.

Baltoflake has been regularly qualified for compliance with System 1 and System 7(A) in NORSOK M-501 edition 3, 4, 5 and 6. Table 4-1 summarize qualification tests carried out on coating systems with Baltoflake, ref. /6/.

Table 4-1 Summary of qualification tests carried out for Baltoflake

Laboratory/ Year	Coating system	Test	Parameters	Results	Ref.
Marintek/ 1996	2 x 750 µm Baltoflake	NORSOK M-501 rev. 3, Salt spray ISO 7253-1984	Sa 2.5, Medium roughness 50-85 µm, 30d curing, Salt spray conditions: NSS, 6000h exposure, DFT 1500 µm	Blistering: 0; Rusting: Ri 0 Cracking: 0; Flaking:0 Creep: Rmax 2.4mm Pull-off: 7.7 MPa Nature of failure: 1of3 samples: 100%B, 2 of 3samples: 20% A/B, 80%B	/7/
		NORSOK M-501 rev. 3, Condensation chamber ISO 6270	Sa 2.5, Medium roughness 50-85 µm, 24d curing, Condensation fresh water, 40ºC, 6000h exposure, DFT 1500 µm	Blistering: 0; Rusting: Ri 0 Cracking: 0; Chalking: 1 Pull-off: 7.3 MPa A/B	
		NORSOK M-501 rev. 3, Cyclic testing	Sa 2.5, Medium roughness 50-85 µm, 36d curing, 4200h exposure, DFT 1500 µm	Blistering: 0; Rusting: Ri 0 Cracking: 0; Chalking: 2; Creep: Rmax 3.1 Pull-off: 11.2MPa Nature of failure: 90-95% C and 5-10% -/Y	
		NORSOK M-501 rev. 3, Cathodic disbondment ASTM G8-90	Sa 2.5, Medium roughness 50-85 µm, 104d curing, Method B (impressed current), 720h exposure, 23ºC, DFT 1500 µm	Radial disbonding: Max. 6.0 mm	
Teknologisk Institutt/2010	2 x 700 µm Baltoflake	NORSOK M-501 rev. 5, Ageing ISO 20340 rev. 2	Sa 2.5, Medium roughness 50-85 µm, 30d curing, 4200h exposure, DFT 1400 µm	Blistering: 0; Rusting: Ri 0 Cracking: 0; Chalking: 1; Creep: Rmax 2.4 Pull-off: 8.2MPa	/8/
		NORSOK M-501 rev. 5, Cathodic Disbondment ISO 20340 rev. 2	Sa 2.5, Medium roughness, 30d curing, Impressed current, 4368h exposure, 23ºC, DFT 1400 µm	Blistering: 0 Radial disbonding: 0 mm	
		NORSOK M-501 rev. 5, Seawater immersion test ISO 20340 rev. 2	Sa 2.5, Medium roughness, 30d curing, Artificial seawater fully immersed, 40ºC, 4200h exposure, DFT 1400 µm	Blistering: 0; Rusting: Ri 0 Cracking: 0; :0 Creep: Ravg 0mm Pull-off: 6.6 MPa	
COT/2011	750 µm Baltoflake	Salt spray test ISO 9227	Sa 2.5, Medium roughness, 21d curing, Salt spray conditions: NSS, 4000h exposure,	Blistering: 0; Rusting: Ri 0 Cracking: 0; Flaking:0 Chalking: 0 Creep: Ravg 0mm Pull-off: 5.2 MPa Nature of failure 100% B	/9/
		Immersion Test ISO 2812-2	Sa 2.5, Medium roughness, 21d curing, demineralized water fully immersed, 40ºC, 1450h exposure	Blistering: 0; Rusting: Ri 0 Cracking: 0; Flaking:0 Pull-off: 5.3 MPa Nature of failure 100% B	
	1500 µm Baltoflake	Cathodic disbondment ASTM G8	Sa 2.5, Medium roughness, 120d curing, 720h exposure, 23ºC	Radial disbonding: 0 mm	
Jotun/2015	2 x 750 µm Baltoflake	ISO 20340	Sa 2.5, Medium roughness, 21d curing, 8832h exposure, DFT 1657 µm	Blistering: 0; Rusting: Ri 0 Cracking: 0; Flaking:0 Chalking: 0; Creep: Ravg 3.4 Pull-off: 5.1MPa Fracture type C,	/10/
			Sa 2.5, Medium roughness, 37d curing, 4200h exposure, DFT 1603 µm	Blistering: 0; Rusting: Ri 0; Cracking: 0; Flaking:0; Chalking: 0; Creep: Ravg 1.6 Pull-off: 6.4MPa Fracture type B (90%B, 10% B/C)	/11/
Norner/2012	2 x 600 µm Baltoflake Ecolife	Cyclic ageing NORSOK M-501 rev. 6, ISO 20340	Sa 2.5, Medium roughness, 38d curing, 4200h exposure, DFT 1221-1355 µm	Blistering: 0; Rusting: Ri 0 Cracking: 0; Creep: Rmax 0.7 Pull-off: 6.1MPa Nature of failure: 100% B one panel, A/B two panels	/26/

Laboratory/ Year	Coating system	Test	Parameters	Results	Ref.
		Seawater immersion NORSOK M-501 rev. 6, ISO 20340		Blistering: 0; Rusting: Ri 0 Cracking: 0; Creep: Ravg 0mm Pull-off: 6.2-6.7 MPa Nature of failure 100%B 7 of 9 samples, A/B 2 samples.	
		Cathodic disbonding NORSOK M-501 rev. 6, ISO 20340	Sa 2.5, Medium roughness, 38d curing, 720h exposure, DFT 1221-1355 µm	Radial disbonding: 0 mm	

5 JOTUN REFERENCE CASES BALTOFLAKE

5.1 General

Baltoflake coating system has been used in splash zones and deck areas on offshore structures for the past 30 years. Table 5-1 summarizes some of the reference cases. More reference cases listed by Jotun are shown in Appendix A. Those reference cases with inspection results made available to DNV is described in more detail in the following sub-sections.

Table 5-1 Reference cases with Baltoflake, ref. /5/.

Name	Component	Coating System	Description
GDF LNG Terminal (France)	Refurbishing 20 years old piles	Baltoflake (thickness not known)	Applied in field in 1992 during low tide. No detailed inspection results available but Jotun states that it was inspected in 1994, 2000 and 2004 and no repair was required
Pampa Melchorita (UK)	Pier piles and platform	Pier piles: 750-1000 µm Baltoflake in 2-4 coats; Pier platform: 750 µm Baltoflake 1 coat	Applied on 550 piles (each 30 m long) and platform structure in year 2007-2009. No information available on performance; e.g. inspection results.
Eldfisk 2/7S (North Sea)	Jacket structure	2 x 600 µm Baltoflake	Applied in Dragados yard in Spain in year 2012-2013.
Sheringham Shoal (UK)	Offshore wind farm	Baltoflake Ecolife	Applied in 2010
DolWin2 (Germany)	Offshore wind turbine convert station	Baltoflake in splash zone	Applied in 2013-2015
Norne FPSO (North Sea)	FPSO	Baltoflake in splash zone?	Applied at yard in Singapore in 1997
Jotun A FPSO (North Sea)	FPSO	2 x 500 µm Baltoflake splash and atmospheric zone	Applied in 1998.
Jotun B	Jacket structure	2 x 750 µm Baltoflake splash and atmospheric zone	Applied in 1998 and decommissioned in 2020 after 22 years in field
Goliat FPSO (Barents Sea)	FPSO	Baltoflake in splash zone	Applied in 2013.
UK Lincs	Offshore windfarm	2x750 µm Baltoflake in splash zone	Applied in 2012

5.2 Jotun field

Baltoflake was applied in the atmospheric and splash zone of both the Jotun A FPSO and the Jotun B jacket. Due to modifications in the field, the Jotun A FPSO went into dock for refurbishment in 2020 (after 22 years in service) and the Jotun B jacket was decommissioned. The Jotun B jacket was coated with 2x750 µm Baltoflake in 1998. Pull off strength testing by Jotun at the decommissioning yard showed strength of 5-6 MPa and with a cohesive break failure, ref. /5/.

Very few mechanical damages were observed on the hull of the Jotun A FPSO, see Figure 5-1. For the atmospheric zone (red colored Baltoflake) significant chalking due to the exposure of the UV radiation was seen. Jotun A/S states however that this is cosmetic and has no detrimental consequence on the protection properties of the coating. 12 pull-off tests were performed on the hull at different elevations, see Table 5-2.

Table 5-2 Pull-off adhesion tests performed at Jotun A FPSO by Jotun A/S, ref. /13/ and /14/. Coating being exposed in the atmospheric and splash zone since 1998.

Zone	Hull portside				Hull starboard			
	Location	**DFT [µm]**	**MPa**	**Nature of fracture**	**Location**	**DFT [µm]**	**MPa**	**Nature of fracture**
Red Baltoflake, atmospheric zone	23m	800	5.87	100%n (topcoat)	22m	900	8.66	100%n (topcoat)
	23m	1400	5.84	100%n (topcoat)	22m	1000	9.37	100%n (topcoat)
	20m	1100	8.48	60%B, 40%n (topcoat)	19m	1300	7.53	100%n (topcoat)
	20m	1300	7.57	100%n (topcoat)	19m	1100	8.94	100%n (topcoat)
	17m (overlap to blue)	1300	6.46	100%n (topcoat)	17m, overlap towards blue	1500	3.84	10% -/Y, 90%n (topcoat)
	17m (overlap to blue)	1500	6.15	10%B, 90%n (topcoat)	17m, overlap towards blue	1200	8.33	20% 80%n (topcoat)
Blue Baltoflake, splash zone	15m	1100	5	30% A/B, 70%B	15m	1500	7.02	100%n (topcoat)
	15m	1000	5.37	100%B	15m	1400	6.05	10%n, 90% A/B
	11m	1200	1.46	100% A/B	11m	1200	1.02	100% A/B
	11m	1300	2.3	100% A/B	9m	1400	3.74	100% A/B
					8m	1300	3.07	100% A/B
					8m	1300	3.65	100% A/B

A/B=adhesive failure between substrate and primer, B=cohesive failure in first coating, n=cohesive failure of the n'th coat of a multicoat system, -/Y=adhesive failure between final coat and adhesive

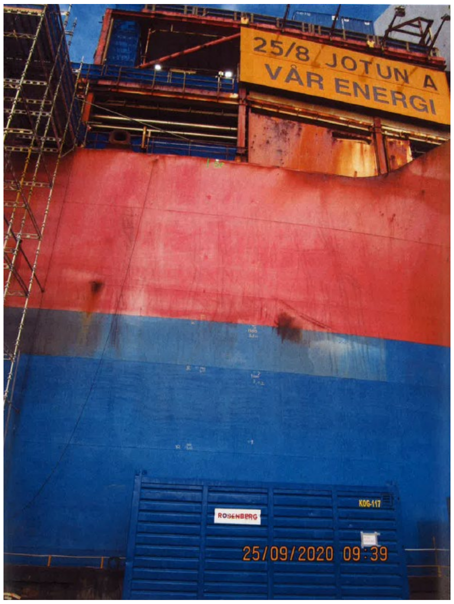


Figure 5-1 Photos of Jotun A hull starboard side, ref. /13/

5.3 Ekofisk 2/4 A

The Ekofisk 2/4 A (EKOA) jacket was decommissioned after 48 years offshore exposure and brought onshore to AF Decom's site at Vats in August 2020. Jotun A/S was able to retrieve a coated sample from the structure, see Figure 5-2. Initially it was assumed that this sample was from the splash zone of the structure, but further investigations have later indicated that this sample is from the atmospheric zone, see Sec. 8.1.

Figure 5-2 Carbon steel sample coated retrieved from atmospheric zone of Ekofisk 2/4A when structure was decommissioned in 2020, ref. /5/. Edges are damaged due to cutting of the sample and center of the sample was used for further examined.

The following tests were carried out by Jotun on the coated sample in Figure 5-2, ref. /5/:

- Dynamic Mechanical Analysis (DMA) and Attenuated Total Reflection-Fourier Transform Infrared Spectroscopy (ATR-FTIR) for characterization of coating system
- Scanning electron microscopy (SEM) and energy dispersive x-ray spectroscopy (EDX)
- Pull-off adhesion as per ISO 4624
- Electrochemical impedance spectroscopy (EIS) measurements as per ISO 16773-2.

The coated sample from EKOA showed a similar spectrum in ATR-FTIR as a new reference sample of Baltoflake and it was concluded that coating from EKOA is a Baltoflake product. DMA analysis showed a glass transition temperature (Tg) of 95ºC for the aged EKOA sample, which is higher than the 85ºC measured on a newly cured Baltoflake sample. This indicate that the exposure has caused a higher level of cross-linking of the aged Baltoflake system.

SEM examination of cross-section of the coating system showed two layers with nominal DFT of 2x600 µm, a base coat (white) and a topcoat (yellow) and good interlay attachment between the layers. Homogeneous distribution of glass flakes within the coating was also in line with the formulation of the reference sample of Baltoflake, ref. /5/.

The pull-off adhesion was measured to 5.1 MPa and all three breaks were classified as 100% c-type fracture (cohesive break in the second coat), ref. /5/.

EIS measurements showed close to 3 x 10^8 Ω cm^2 at low frequencies (i.e. <10 Hz) after 24 and 48 hours conditioning, see Figure 5-3. The data show according to ref. /5/ a response consistent with an intact coating with no presence of subsurface corrosion phenomena.

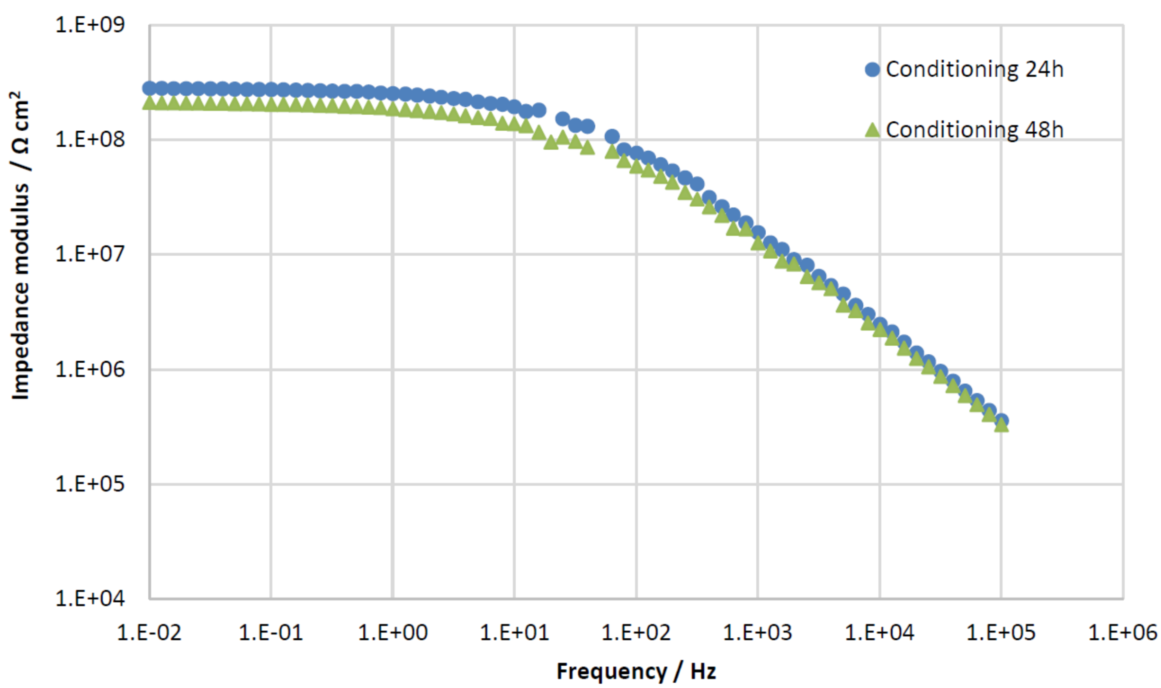


Figure 5-3   Bode representation of the EIS data on EKOA topside coating sample after conditioning for 24 and 48 hours in 5 wt% NaCl. Commonly accepted threshold value for coatings is 10^6 Ω cm^2, ref. /5/.

6 DNV INSPECTION DECOMMISSIONED STRUCTURES COATED WITH GFP

6.1 Jotun B jacket

The Jotun B jacket was installed in 1998 and has been exposed to harsh weather in the North Sea until the structure was decommissioned in 2020. DNV performed, on behalf of Vår Energi, inspection of the condition of the coating on the Jotun B structure' at the decommissioning site, ref. /15/. The Jotun Baltoflake coating (2x750 µm thick) in the atmospheric and splash zone of the structure appeared to be in a good condition and generally had a good coating performance after 22 years in service, see Figure 6-1. Only a few areas of coating damage (flaking) were found just above the splash zone (EL ~+8.0m), see Figure 6-2. It is not known when these coating damages took place. UT examination of one of the horizontal braces with a relatively large area with flaking, indicated a corrosion rate of minimum 0.2 mm/y (assuming 4 mm metal loss since start of operation).

Figure 6-1 Coating appears generally good. a) overview Jotun B at the demolition yard b) conductor frame EL +8 c) node in splash zone, ref. /15/.

a)

b)

Figure 6-2 A few areas with coating damage at EL +8.5. b) Corroded area further examined with UT and up to 4mm wall thickness reduction was found, ref. /15/.

6.2 Ekofisk 2/4 A

6.2.1 General

The Ekofisk 2/4 A (EKOA) was installed in 1972. It was decommissioned during the summer in 2020 after 48 years exposure to harsh North Sea environment. The original design life was 20 years, ref. /16/.

DNV performed on behalf of ConocoPhillips inspection of the's condition of the EKOA structure at the demolition yard, ref. /16/. Based on these inspections, ConocoPhillips also requested more detailed inspection of some parts of the coated structure in order to establish which coating product that was applied on the jacket and more details about the coating performance. Laboratory examination of a 2 m long length of a brace from the splash zone was sent to the DNV materials laboratory in Bergen for further examination, ref. /16/. El +20' (+6.1 m), where the sample was taken from, was the water level at the end of operation in year 2020 (actually EL 0 at that time).

6.2.2 Inspection at demolition yard

The following types of inspection of the coating in the splash zone was carried out by DNV at the demolition yard, ref. /16/:

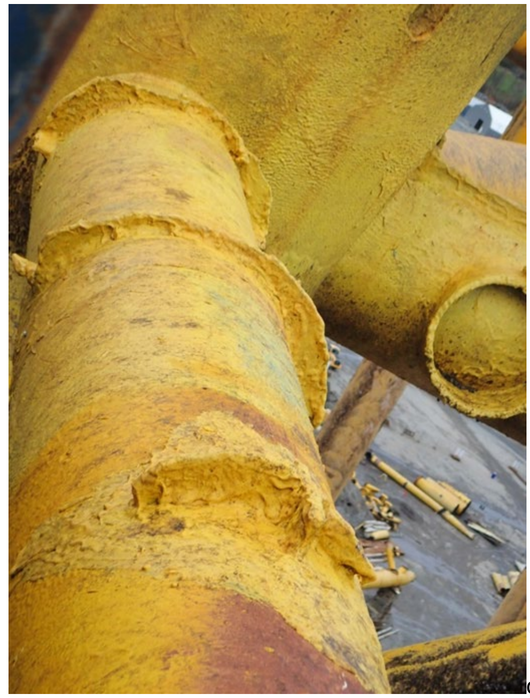
- General visual inspection (GVI)/Close visual inspection (CVI) from basket and lift (prior to toppling of the structure; i.e .while structure was standing on quay)
- CVI of some coated braces after toppling of the structure
- UT of corroded area from splash zone

The major areas of coating applied in the splash zone was still smooth, intact and without sign of delamination, see Figure 6-3. Only a few areas of coating damage were found in the splash zone. A coating damage of one of the horizontal braces at EL +20’ (+6.1 m) were further examined from ground, see Figure 6-4. The coating was relatively easily removed with a knife in the area close to the coating damage. A reduced wall thickness (WT) of approximately 2 mm was found in the corroded area by UT scanning.

Some flaking of the coating took place due to the mechanical forces during toppling of the structure. Inspection from the ground thus revealed that some parts of the braces having been located in splash zone were coated with what appeared to be several layers of coating (2-3 layers) while other braces appeared to have only one layer of ‘yellow’ coating, see Figure 6-5. Samples were sent to Jotun for characterization, see Sec. 7.2.1 for results.

a)

b)



c)

Figure 6-3 Coating appears generally good in splash zone. a) overview El. +20' (+6.1 m) from Row B. b) Close up of node at El. +20' Row 4. c) Close up of node at El. +20' Row A. Some repaired coating on steel inserts (walkway removed in 1993). Ref. /16/.

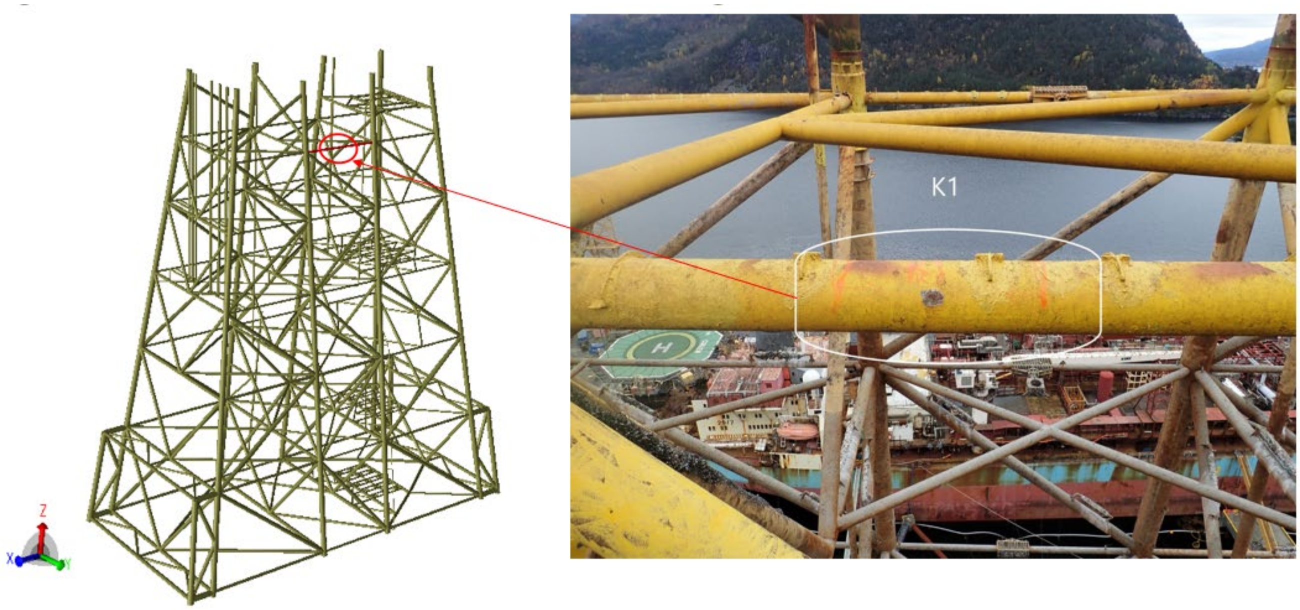


Figure 6-4   Corroded area in splash zone (El. +20’), horizontal brace between leg A2 and leg A3 along Row A, ref. /16/.

a) b)

Figure 6-5   Part of underside of flaked off coating from splash zone at EKOA, ref. /16/. a) Part of coating close to corroded area shown in Figure 6-4. Note light green primer coating. b) Part of coating from another brace in splash zone. No primer seen on this coating.

6.2.3 Laboratory examination

Figure 6-6 shows the 2 m long length from a brace in the splash zone that was further examined in the DNV laboratory in Bergen.

Figure 6-6 2 m length of brace from EL +20' further examined at DNV laboratory in Bergen, ref. /17/.

During the visual inspection of the as-received sample, the coating generally appeared to fit smoothly to a somewhat rugged surface. No blistering, rust, cracks, or other visual defects could be seen in the coated areas without mechanical damage from handling during decommissioning.

The total DFT were measured both with electromagnetic gauge, paint inspection gauge and examination of the cross-cut by microscope. Results from cross section examination of the coating sample in microscope at 10X and 40X magnification is shown in Table 6-1 and Figure 6-7. A yellow top coating (found as single and double layer) appeared to be applied on partly blasted/coated surface. In some parts of the surface a grey primer (100-170 µm) was found between the steel and the yellow top-coating and in other parts both a thin grey and a white coating (~130 µm) was found between the steel and yellow top coating. EDS analysis indicated that the grey coating contains a lot of zinc (e.g. zinc-rich primer), white coating somewhat less zinc than the grey and the yellow top coating appeared to be a glass-fibre reinforced coating.

Table 6-1 Results from cross section inspection in microscope, ref. /17/.

Section	Total DFT [µm]	Number of coats	Comments
A	1800-1900	1 to 3	One layer: ~50% of surface. 2-3 layers: ~50% of surface. White and grey primer layer of thickness 235-351 µm.
B	1300-2000	1 to 2	One layer: ~70% of surface. 2 layers: ~30% of surface. Grey primer layer of thickness ~170 µm.
C	2000-3000	1 to 4	2-4 layers: 2 layers of yellow coating on entire sample. ~70% of surface has a grey primer layer of thickness ~100-170 µm. ~40% of surface has a white primer layer of thickness ~130 µm between grey primer and yellow coating.

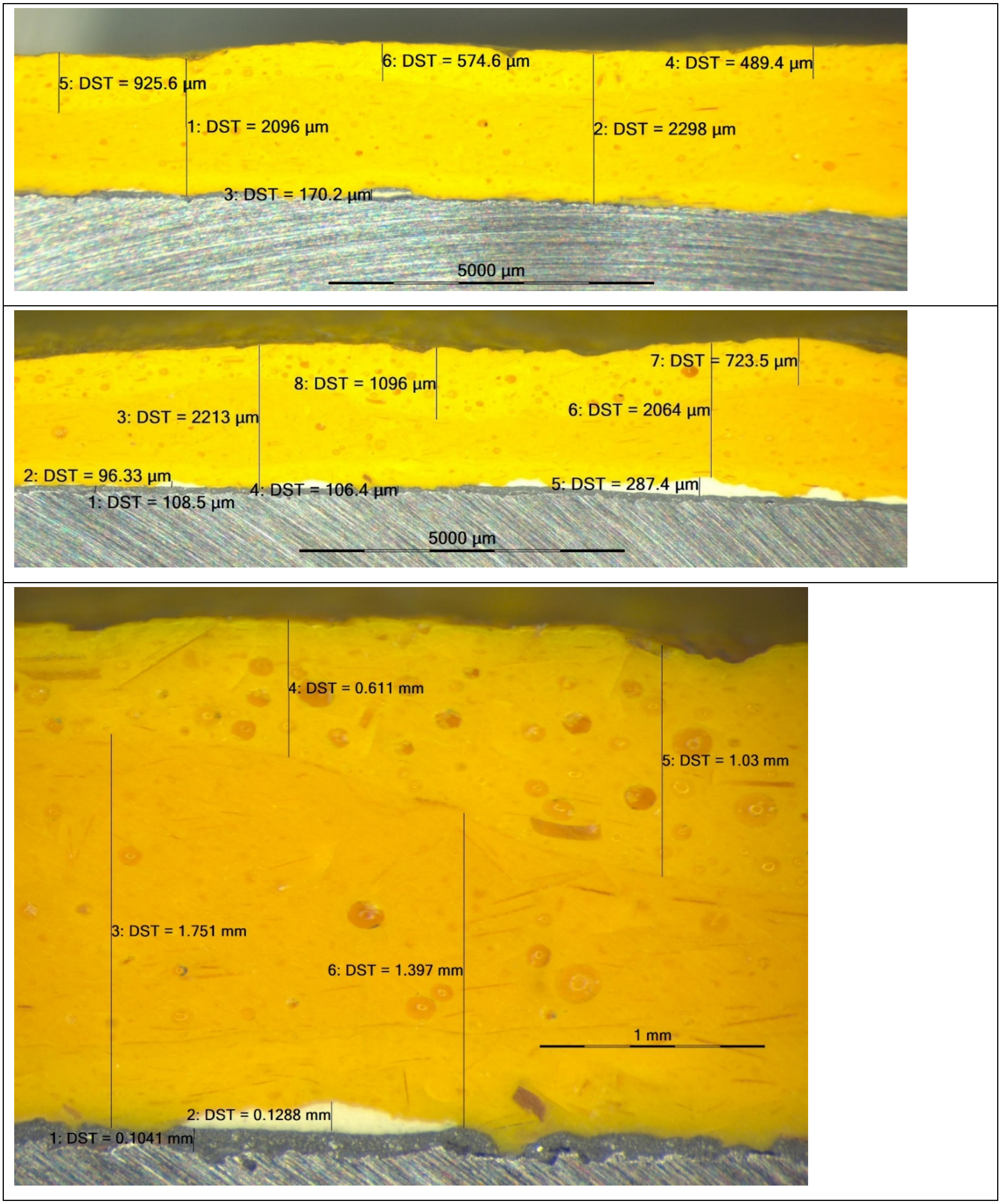


Figure 6-7 Picture of sample 'C' in Table 6-1, taken with 10X and 40X magnification, ref./17/.

Adhesion testing with pull-off and x-cross revealed that the coating did not have a very good adhesion. Adhesion was measured as 0.7-2.8 MPa during pull-off, and during x-cut the coating was removed from most of the area when the knife cut the coating. Area with one layer of coating showed adhesive failure between steel and coating while areas with several layers of coating showed a combined adhesive and cohesive failure in one of the primer layers (white/grey). Some corrosion products could also be seen on some of the surface with adhesive failure between steel and coating, but no significant wall thickness reduction could be seen.

7 LABORATORY EXAMINATION JOTUN PROJECT

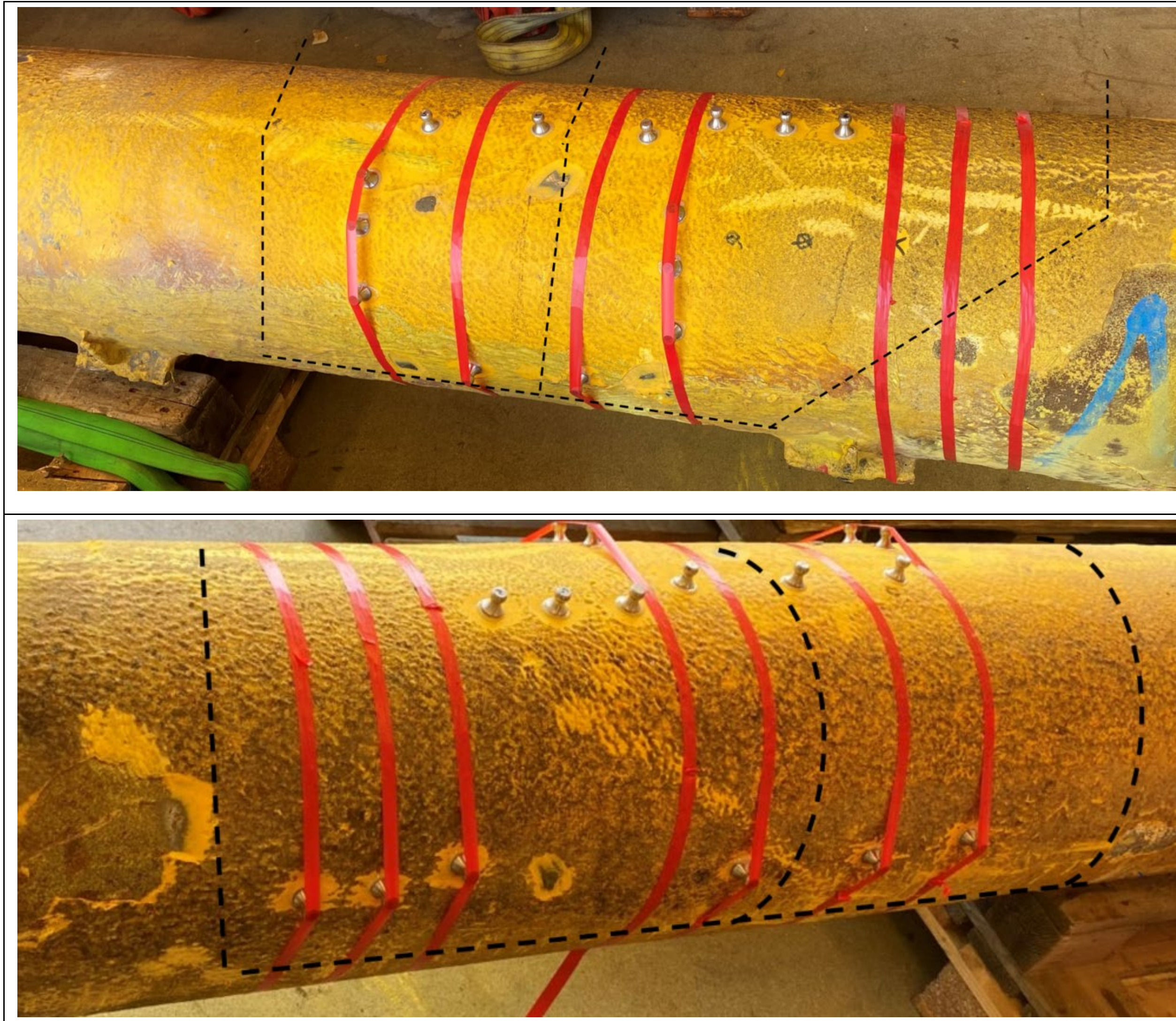
7.1 Work carried out in DNV laboratory

A 4 m long length of a coated brace from the splash zone of EKOA was available for testing after the workshop between ConocoPhillips, Jotun A/S and DNV 3rd June 2021. The brace appeared to have a mix of coatings with some areas with only GFP directly on steel and other areas with remnants of old coating. It was agreed during the workshop that areas with GFP directly on steel is most relevant for further testing as the objective is to document the performance of GFP. The following tests were performed in the DNV laboratory, ref. /1/:

- Identification of areas most likely to have areas without remnant of old coating underneath Baltoflake (e.g. light grinding)
- Pull-off test according to ISO 16276-1 on areas with Baltoflake directly on steel
- Overcoating test according to NORSOK M-501; i.e. overcoat aged coating without mechanical treatment and carry out pull-off
- Cutting and sectioning. One plate to be sent to Jotun in order to carry out EIS and FTIR/DMA
- EIS according to ISO 16773-2. 4 parallels including cross section and examine in light microscope after testing to confirm if sample had a mix of coating systems or only Baltoflake directly on steel. One sample received from Jotun applied with the Baltoflake Ecolife coating system to be tested for comparison.

The general condition of the coating was good. The coating appeared to fit smoothly to a somewhat rugged surface on major parts of the brace. No blistering, rust, cracks or other visual defects could be seen in the coated areas without mechanical damage. A couple of locations showed mechanical damage, assumed to originate from the handling of the jacket structure. In these areas white coloured primer, grey coloured primer and some rust could be found underneath the yellow topcoat.

A section of the brace where only the yellow coating appeared to be applied was selected for further testing, ref. /1/. Figure 7-1 show the part of the brace where further testing was carried out by DNV and Jotun A/S. A total DFT in the range 1.5 mm-3.8 mm was measured along the brace length, ref. /1/.



a)

b)

Figure 7-1 a) Received brace after dollies for pull off adhesion test were attached. Area for cutting is marked by dotted lines (right section was kept at DNV while left section was sent to Jotun A/S). b) Opposite side of brace (left section was kept at DNV while right section was sent to Jotun A/S), ref. /1/.

Results from the pull-off tests showed an adhesion strength of 1.3-6.1 MPa, see Table 7-1. Most of the fractures were cohesive. Some corrosion products could also be seen on some of the surface with adhesive failure partly between steel and the coating, see Figure 7-2. Jotun A/S supplied a sample of Baltoflake Ecolife (todays version of Baltoflake) which was applied on top of the existing coating (to simulate repair). No mechanical preparation was done to the existing coating prior to application. Adhesion testing with pull-off method revealed that the re-coated area had an adhesion strength of 1.2 - 5.7 MPa and most of the fractures were cohesive. Some of the fracture (2 of 6 samples) was also adhesive failure between original coating and the Baltoflake Ecolife.

Table 7-1 Results of pull-off adhesion tests, ref. /1/

Dolly no.	Adhesion [MPa]	Fracture [%]*#							
		A/B	B	B/C	C	C/m	m	-/Y	Y/Z
1	2.7	40	60						
2	3.4	40	60						
3	NA	30	70						
4	1.3	40	60						
5	3.3	40	60						
6	4.0	30	70						
7	4.4	40	60						
8	3.2	40	60						
9	6.1		100						
10	5.5		100						
11	5.7		100						
12	5.4	20	80						
13	4.7		100						
14	4.9		100						
15	5.1	40	60						
16	5.2		100						
17	5.9		100						
18	6.0		100						
19	4.0		100						
20	4.2	30	70						
Min	**1.3**	**Adhesive**	**19.5**						
Max	**6.1**	**Cohesive**	**80.5**						
Average	**4.5**								

*Some of the fracture is rusting of the steel substrate.

#Assuming that the coating is one coat only. Difficult to confirm by visual inspection if more coats are applied.

A/B: adhesive failure between substrate and 1st coat (primer)
B: cohesive failure of 1st coat
B/C: adhesive failure between 1st and 2nd coat
C: cohesive failure of 2nd coat
C/m: adhesive failure between 2nd coat and mth coat of amulticoat system
m: cohesive failure of mth coat of a multicoat system
-/Y: adhesive failure between topcoat and adhesive
Y/Z: adhesive failure between adhesive and dolly

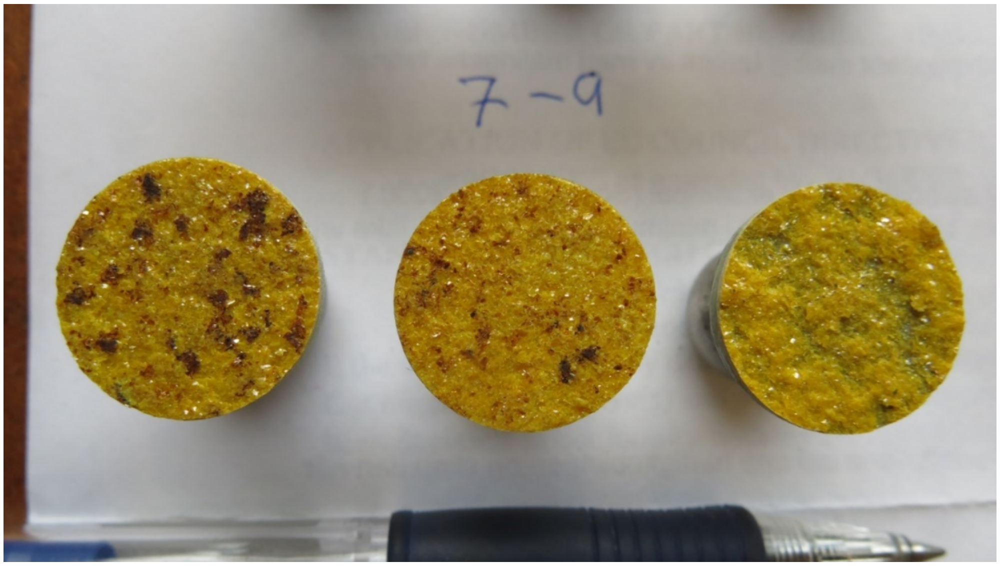


Figure 7-2 Surface of dolly 7, 8 and 9 in Table 7-1 after pull-off, ref. /1/.

EIS based on ISO 16773-2 was carried out at 4 locations on the sample, see Figure 7-3. The samples were conditioned for 24 hours in 5 wt% NaCl prior to measuring. The results were similar on all 4 samples and an impedance of ~10^{10} Ω cm^2 @0.1 Hz was measured after 24 hours conditioning, ref. /1/. For reference, EIS was also tested on a sample coated with 2x600 µm Baltoflake Ecolife (todays version of Baltoflake). 2 parallels were run, and both showed an impedance of ~10^{13} Ω cm^2 @0.1 Hz, ref. /1/. Cross sections of the EIS area were performed in order to confirm that only GFP was applied on the surface (no remnant of old coating), see Figure 7-4.

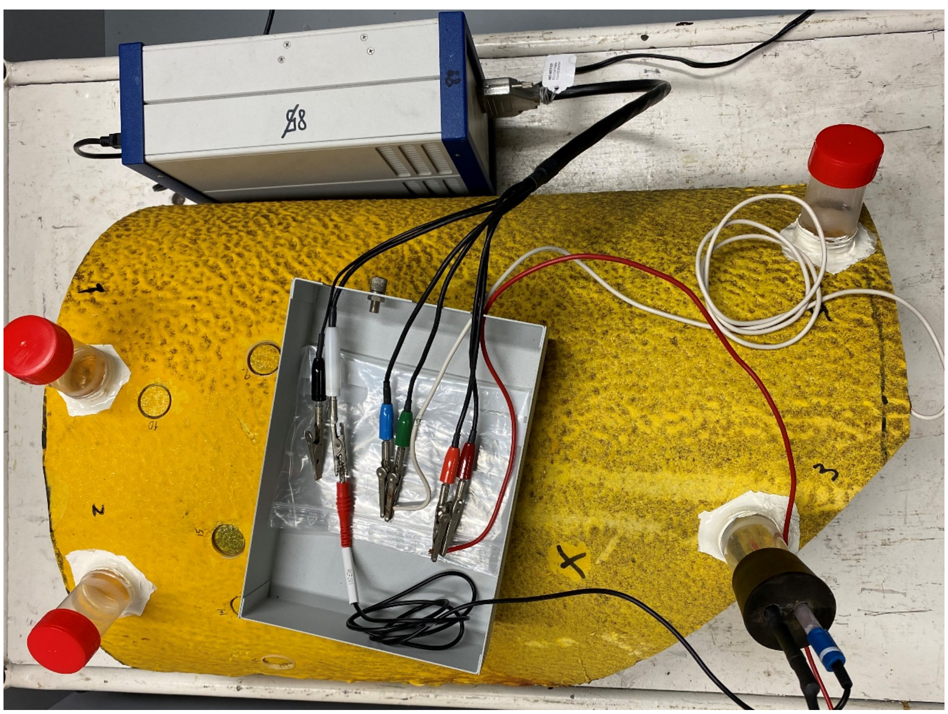
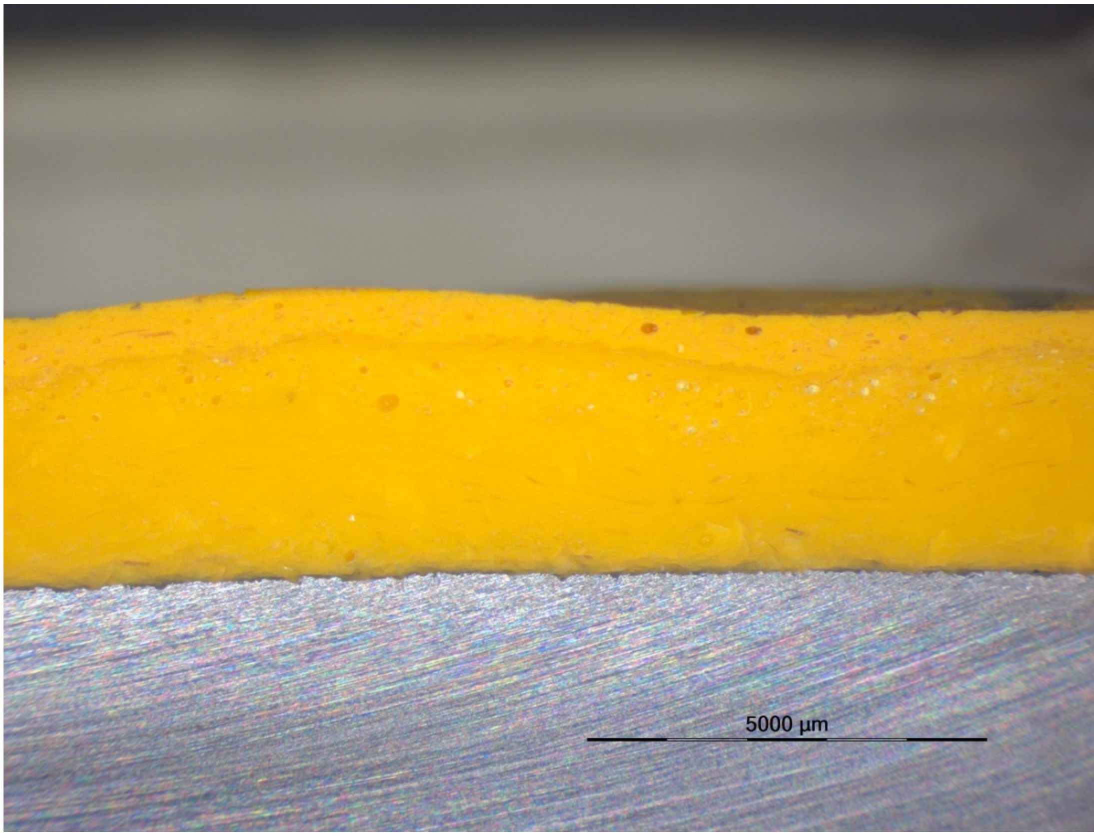
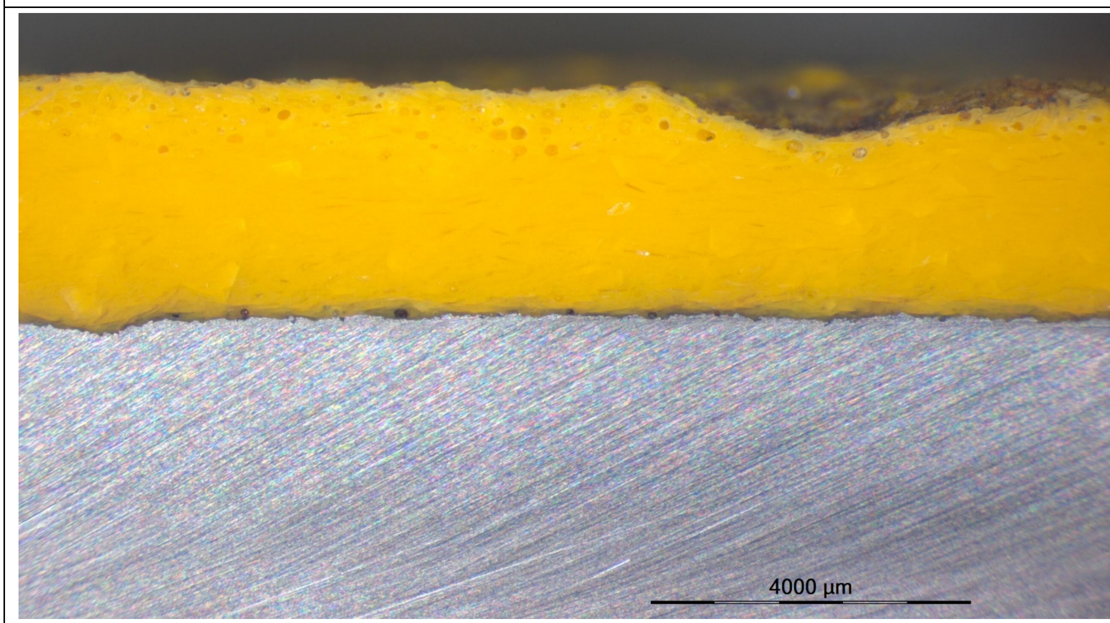


Figure 7-3 Photo of the 4 locations for EIS measurements, ref. /1/



a)



b)

Figure 7-4 a) Cross section of coating at EIS location 1, b) Cross section of coating at EIS location 3, ref. /1/.

7.2 Work carried out at the Jotun laboratory

7.2.1 Analysis of EKOA coating product

The coating samples shown in Figure 6-5 were analyzed by the use of FTIR, GCMS and SEM in order to establish the chemical composition and the corresponding coating product, ref /18/. Samples analyzed and results are shown in Figure 7-5 and Figure 7-6. It was concluded that the samples mainly comprised of a GFP coating corresponding to Baltoflake. The slight shift in FTIR spectra, see Figure 7-6 indicates that the coating has degraded compared to the reference sample, and deemed to be proof that the sample has been exposed to harsh conditions over a long period of time, ref. /18/. No interlayer adhesion failures were found.

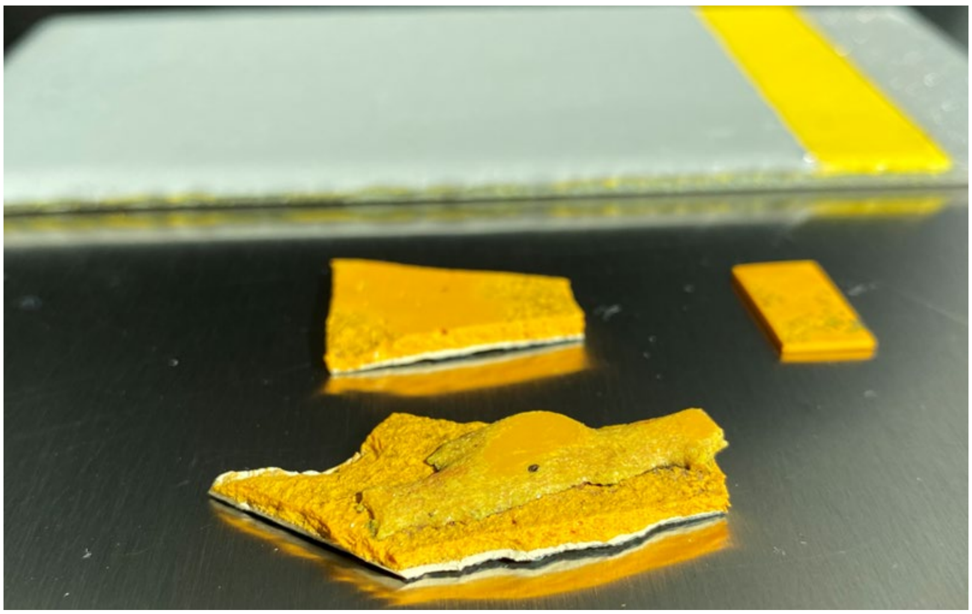


Figure 7-5 Samples for analysis. Yellow rough top layer (with some smooth spillage on one of the samples), white intermediate layer, and a grey primer on some of the samples, ref. /18/.

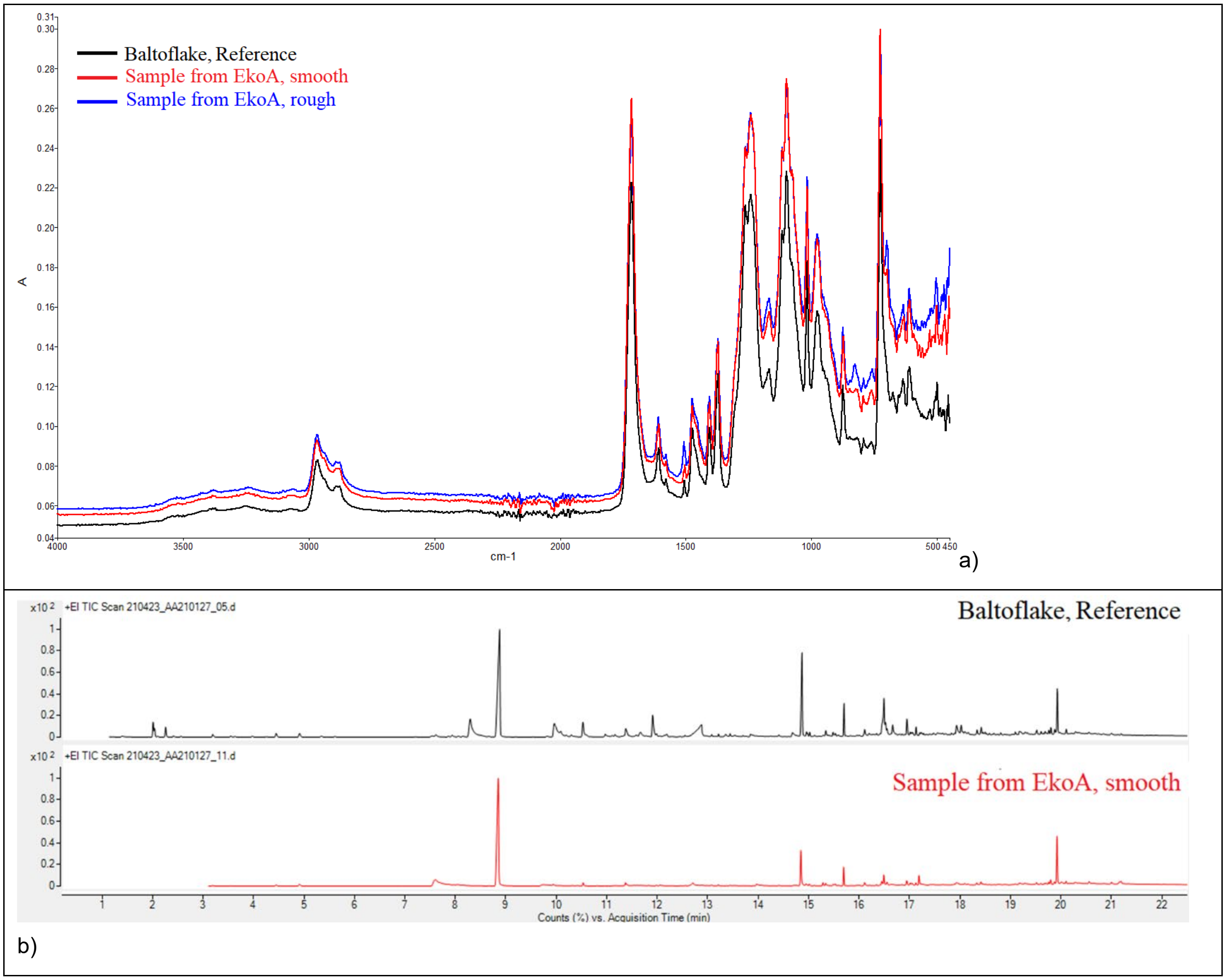


Figure 7-6 a)FTIR spectra of reference Baltoflake and samples from EKOA on two different areas of the yellow outer coating layer. b) GCMS spectra of reference Baltoflake sample and the smooth yellow area of the sample received. Ref. /18/

7.2.2 EIS testing of EKOA sample from splash zone

EIS measurements were performed on the sample from the 4 m long length of the coated brace from splash zone of EKOA, see Figure 7-1 and Figure 7-7. The test was carried out according to ISO 16773-2 and following the same set-up as the DNV EIS testing, see Section 7.1. The result is shown in Figure 7-8. The pore resistance was found as 2.0 x 10^6 Ω cm^2 and the results suggest according to Ref. /25/ that the coating is intact, with no significant coating degradation. The flattening and slight increase in impedance towards the lower frequency signals water uptake. A good fit of the impedance data was found when utilizing a nested Randlers circuit with two constant phase elements, as seen in solid lines (marked “Fit Rpo” and “fit phase angle”) in Figure 7-8.

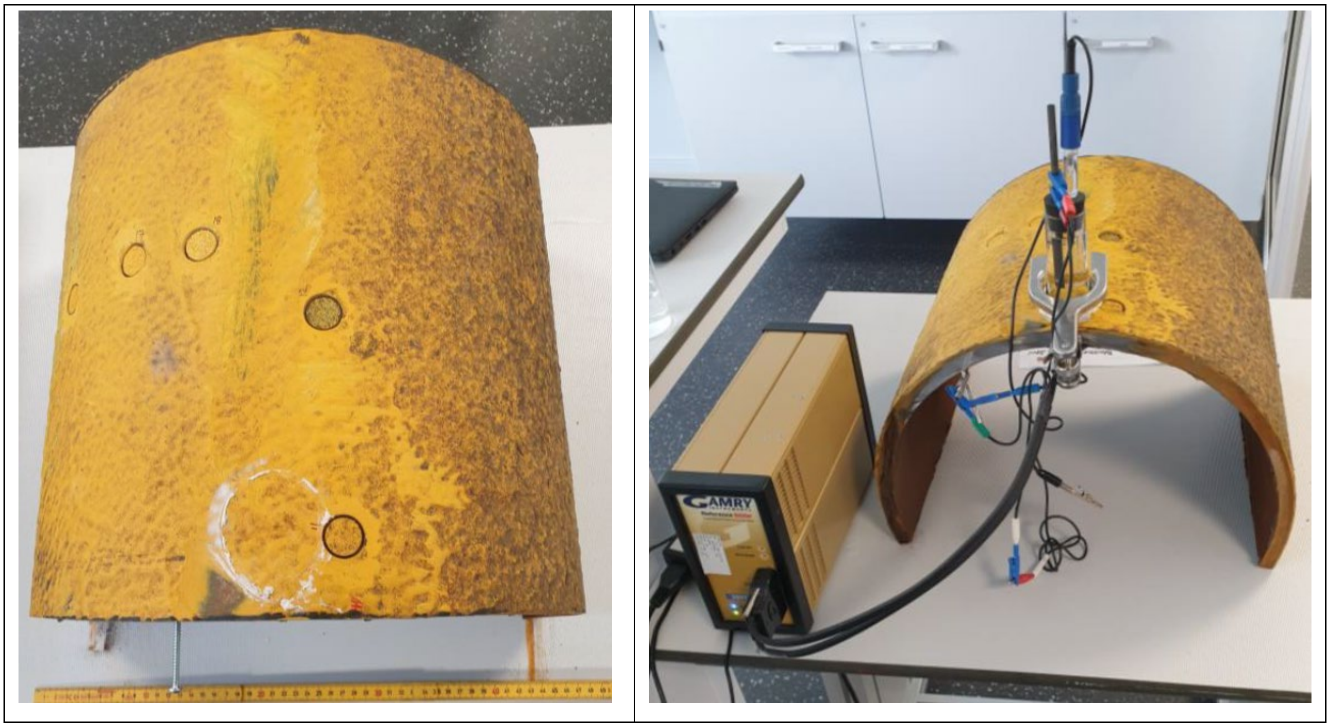


Figure 7-7 As-received sample from 4 m long coated brace in splash zone of EKOA where Jotun A/S carried out EIS measurements. Same sample as shown in Figure 7-1.

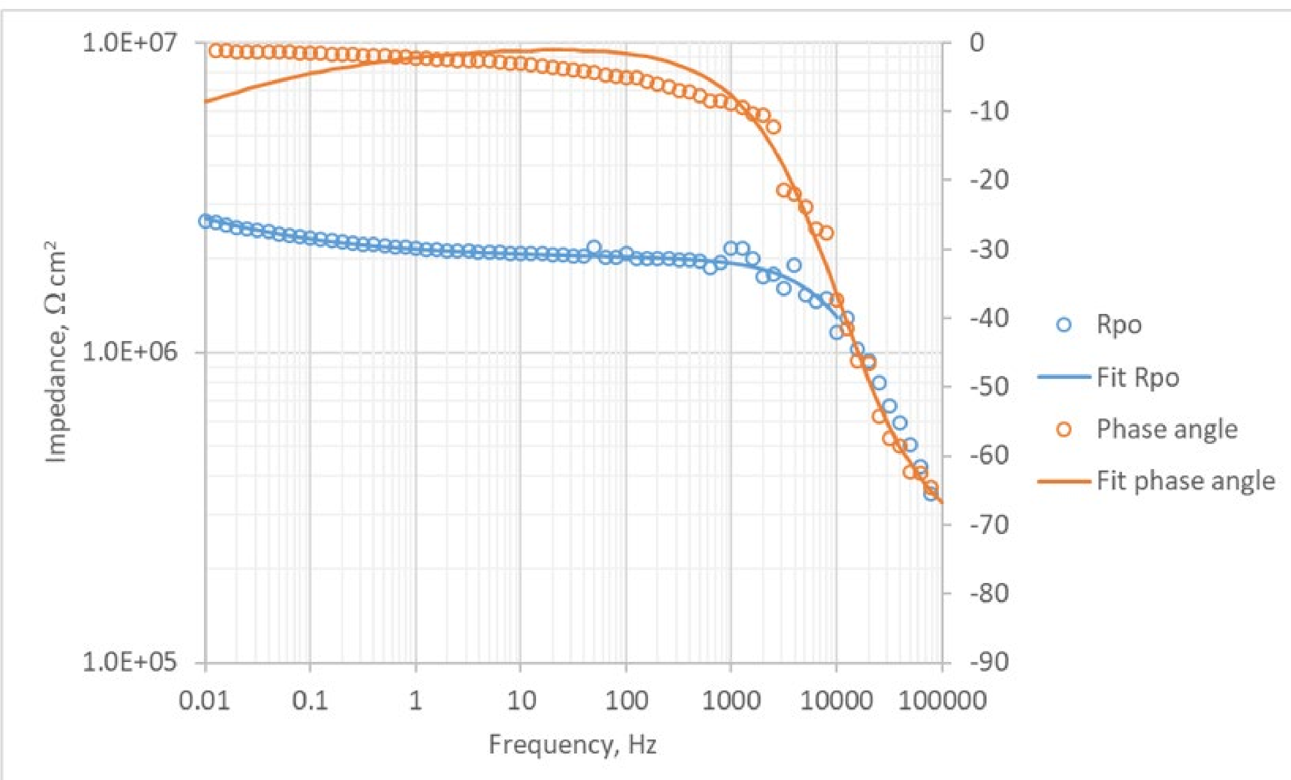


Figure 7-8 Measured impedance and corresponding phase angle as a function of frequency (Bode plot) after 24 hours conditioning in 5% NaCl solution.

8 DISCUSSION

8.1 Coating system at Ekofisk 2/4A

ConocoPhillips did not have detailed information about the coating application and type of coating applied to the structure. It can be concluded that the coating system found on EKOA at the time of decommissioning is a GFP type and FTIR confirm that this is Baltoflake. It is essential for the further assessment of the coating performance that the exposure zone of the coating system (i.e. atmospheric or splash zone) and approximately time of exposure is known.

Baltoflake was not developed in 1972 when EKOA was installed, the coating system must therefore have been applied later in a repair campaign and it was apparent from the inspection at the demolishing yard that recoating of the splash zone had been performed. The Ekofisk field has experienced a general subsidence of 8-9 m in the centre of the field, and the platforms at centre were as a consequence jacked-up and extension pieces installed in 1987. GFP (Baltoflake) was introduced as a new coating system offshore during these modifications. EKOA is located far away from the other installations in the field and was not part of the jack-up project. Dialog with retired personnel from ConocoPhillips indicate that Baltoflake was applied at EKOA in the time period end of 80’s to start of 90’s as several campaigns. There was positive experience with the introduction of the new coating system for maintenance and repair of the platforms at the Ekofisk centre and the same coating system was in general selected for future maintenance. The total subsidence of EKOA has been ~6 m and the braces at +20’ (+6.1 m) was the water level at the end of operation in year 2020 (actually EL 0 at that time). A walkway at EL +20’ (+6.1 m) was removed in 1993 and DNV inspection at demolish yard showed repaired coating in this area, see Figure 6-3. It seems based on this that it is fair to conclude that the coating system examined from EKOA has been exposed to an offshore splash zone environment for 25-30 years.

Jotun A/S was collecting a coated sample from EKOA before the first DNV site visit to the EKOA decommissioning yard in October 2020. The entire structure from EL +35’ (+10.1 m) and down was intact when DNV arrived in October, and DNV inspection of coated structures had to be carried out by cranes (>80 m above ground). Based on this, it was concluded that the Jotun A/S sample described in Sec. 5.3 is likely to be from the atmospheric zone.

The coated sample retrieved by Jotun A/S from atmospheric zone was concluded to exist of two layers Baltoflake (2x 600 µm, white+yellow), see Sec. 5.3. DNV examination from coated braces at EL +20’ (+6.1 m; i.e. water level at end of operation) showed some areas with only yellow Baltoflake and other areas with remnants of 1-2 layers of primer coating (grey+white), see Sec. 6.2. This was discussed in the workshop 3rd of June (ConocoPhillips, Jotun A/S and DNV) and it was concluded that the variation in the coating system is likely due to offshore application of the coating, ref. /23/. All coating examined from EKOA has been applied offshore and not onshore in factory/yard. The surface preparation is not known, but it is considered likely that the structure was re-blasted offshore prior to coating. Re-blasting and coating application are easier to carry out higher up in the structure (Jotun A/S sample from atmospheric zone) than closer to the water line. That is probably the reason for the uneven surface and area with more remnant of old coating underneath the Baltoflake coating in some areas at EL +20’ (+6.1 m).

The laboratory examination carried out after the workshop (Sec. 7) was carried out in areas of the coated brace without any remnants of older coating; i.e. Baltoflake applied directly on steel.

8.2 Literature data and other references to GFP performance

Shell introduced the use of "one coat" GFP coating system for maintenance in 1988 and it has been the maintenance coating system selected for all primary and secondary structures, conductor pipes, helidecks, and decks, ref. /20/. Since 1994/1995 it was extended also to new constructions. In 2004 "one coat" GFP has been applied on 25 platforms. Type of GFP product is not mentioned but the "one coat" GFP is specified with a DFT of ~800 µm, ref. /20/. According to ref. /20/ salt spray testing of the GFP system showed no physical change after 20 000 hours and no cathodic disbondment was observed after a 48 days test. Moisture vapour transmission rate of the coating was commented to be one of the lowest (0.0006 perm inches) when compared to other general epoxy systems. After 5 years in service the coating condition was reported as satisfactory with minor coating breakdown on isolated and in areas where the application of coating was difficult. It was commented that for localised damages, the surrounding coating integrity and adhesion was not affected and no "undercutting was observed", ref. /20/.

750 µm of GFP (product not specified) was also part of a test program with 4 years seawater exposure in natural seawater with cathodic protection (CP), ref. /21/. No loss of adhesion was found and no random blistering found on the plate coated with GFP.

According to Jotun, Equinor has specified Baltoflake for the Johan Castberg having a 50 years design life, ref. /23/. ConocoPhillips confirmed in the workshop 3rd of June 2021 that they in general have good experience with use of GFP in splash zone on their jacket structures. It has for many years been the preferred choice and 2x600 µm is in their company specification. Most of the jacket structures still operating in the Ekofisk field has this coating system. It is generally recognised as a robust system also towards mechanical damage if it is applied directly on steel. Some mechanical damages in splash zone does occur and these are repaired with sand blasting/sweep blasting and a polyester repair coating system.

In the new revision of NORSOK M-501 that at present is on hearing, it is specified in a note for system 7A "*Glass flake epoxy is limited to design life <25 years. Glass flake polyester is also suitable for design lives exceeding 25 years*".

8.3 Coating performance GFP

There is limited information that can be found in the open literature with documented long-term performance of GFP. However, several operators in the oil and gas industry apparently have good experience with the use of GFP. Jotun also have a long track record of deliverance of Baltoflake to the offshore structures.

The coating performance of GFP in the splash zone from two fields in the Norwegian sector of the North Sea have been documented in the present report. For the Jotun field, where the exposure time has been 22 years, the coating application was performed onshore at a yard with controlled surface preparation. For EKOA, where exposure time has been 25-30 years, the coating application was performed offshore and hence, both the surface preparation and coating application are less controlled as compared with Jotun B.

Field inspection and laboratory investigation document that the performance of the coating is good after 20-30 years of operation in splash zone, although the adhesion tests show a rather low pull-off strength (1.3-6 MPa, see Table 5-2 and Table 7-1). The adhesion strength of the coating varied on the component and the highest values were found where the fracture was 100% cohesive. Where some degrees of adhesive failure were observed on the EKOA sample during pull-off testing, some rusting on the steel substrate was observed, see Sec. 7.1. As the rust was seen rather locally, it is considered likely that this may origin from the offshore surface preparation prior to application of the Baltoflake coating. The offshore surface preparation may have left some rustgrade on the surface prior to re-coating. Cross sections after EIS confirm that no active corrosion was taking place at the steel surface and that the coating performance did not appear to be significantly reduced for the offshore applied coating, see Figure 7-4.

Impedance can be regarded as a measure of barrier properties. For coatings, it is common in the literature to compare results in the low frequency range e.g. @ 0.1 Hz, see Figure 8-1, and high impedance indicate low permeability to water and thus good corrosion protection. For a metal sample with a coating in good condition, it is difficult to obtain a stable value of the open-circuit potential, and this is likely to be the reason for the difference between the DNV result (>10^{10} ohm cm^2) and Jotun result (2x10^6 ohm cm^2) of the sample from EKOA. For a newly applied Baltoflake Ecolife system the impedance is very high (>10^{12} ohm cm^2 @ 0.1 Hz). The impedance measured on samples from EKOA is reduced but still measured to > 10^6 ohm cm^2 @ 0.1 Hz by both DNV and Jotun, see Sec. 7. The EIS results indicate that the coating after 25-30 years exposure in splash zone still have a low permeability and provides a good corrosion protection. The result is in line with the visual appearance of the coated parts of the structures inspected.

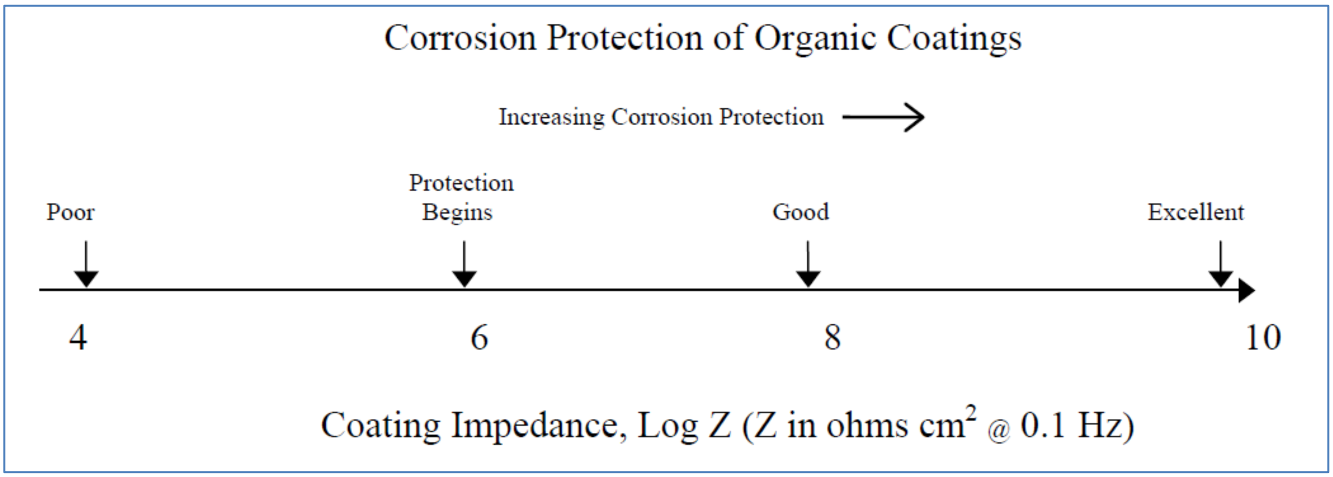


Figure 8-1 Interpretation of coating impedance data, ref. /19/.

The formulation of the Baltoflake system has been slightly modified since the versions applied in the 80’s/90’s, mainly on the chemical composition in order to improve the HSE during application of the system. This is shown in the FTIR analysis of the EKOA samples. The latest version of Baltoflake, Ecolife, is a styrene free version of the GFP. There is no indication that the change of solvent has an impact on the performance of the coating based on long term qualification testing, ref. /23/.

For Baltoflake the recommendation on thickness is minimum 2x600 µm in order to ensure proper curing and performance, ref. /23/. During curing, which is an exothermic reaction, it is important to ensure that there are no glass flakes penetrating the coating layer. It is rather common to specify 2 x 750 µm to have some extra thickness. This thickness also corresponds with the reference cases with Baltoflake presented to DNV where minimum 2 coats with min. 600 µm DFT per layer is found/specified. For the offshore application of EKOA the total thickness was measured to vary between 1500 µm and 3800µm.

Provided no mechanical damages, the GFP system has documented a good performance for 25-30 years in offshore splash zone environment. Field inspection showed that corrosion will take place in areas with mechanical damages in the coating, but the extent of mechanical damages is not very high on any of the structures examined and the corrosion creep underneath the coating is rather limited.

8.4 Corrosion Allowance

For the oil and gas industry a combined coating and corrosion allowance (CA) is required as corrosion protection in the splash zone. In present codes (e.g. ISO 21457) for material selection, it is a requirement that a corrosion allowance is used on carbon steel of "*6 mm unless otherwise specified*", while NORSOK M-001 with GFP coating of min. total DFT >1000 µm requires minimum CA of:

$$CA = (\text{Design life} - 10) \times 0.4 \text{ mm/y}$$

For 30 years design life this would correspond to minimum 8 mm CA. For the major part of the structures inspected there was no indication of reduced wall thickness as the coating was intact in the splash zone. However, locally a wall thickness reduction of maximum 4mm for Jotun B and maximum 2 mm for EKOA was found in an area with mechanical damage in the coating.

For offshore oil and gas platforms there is a generally high risk for mechanical damages from contact during e.g. lifting of containers, scaffolding, dropped object but also small damages from debris in the water from different sources. Wind turbine structures are typically unmanned and coating damages from activities related to lifting, scaffolding and dropped objects is less likely after the structures have been installed. Some damages from debris in the water from different sources must however be expected and may be more likely on structures installed closer to shore.

There are today already some requirements to both coating system and corrosion allowance in codes applicable for corrosion protection for wind turbines. According to DNV-RP-0416 it is stated that, the coating system to be applied in the splash zone shall be based on manufacturer specific material that have been qualified for the actual coating system by proven experience or relevant testing (e.g. according to NORSOK M-501, EN ISO 12944). Maintenance of coating systems in the splash zone is not practical and coating of primary structures shall therefore be combined with a corrosion allowance. The corrosion allowance (CA) shall be calculated as:

$$CA = V_{corr} * (T_D - T_C)$$

Where CA is the corrosion allowance

V_{corr} is the expected maximum corrosion rate (0.30 mm/y in temperate climate and 0.40 mm/y in subtropical and tropical climate)

T_D is the design life of the structure including time between installation of structure and installation of wind turbine.

T_C is the design useful life of the coating, see below

Paragraph 4.3.4 specifies that Tc may be assumed as 20 for GFP. For a design life of 30 years, the present requirements in DNV-RP-0416 would thus require minimum 3 mm corrosion allowance in the splash zone:

4.3.4

For coating systems based on epoxy and meeting the requirements for coating materials and quality control of surface preparation and coating application in NORSOK M-501 Coating System No. 7A (min. DFT 600 µm) with a useful life of up to 15 years may be assumed in the splash zone. For an equivalent system based on glass-flake reinforced epoxy or polyester (min. DFT 700 µm), the useful life may be assumed to be up to 20 years in the splash zone. Pre-qualification of these coating systems in accordance with a recognized standard (i.e. NORSOK M-501, ISO 12944, ISO 20340) is mandatory in order to design for the proposed design useful life T_c.

The inspection of the jacket structures in the North Sea confirm that the CA required in design codes for the oil and gas industry may be very conservative for GFP coated structures. It should be noted that the corrosion rate in splash zone of warmer water (e.g. tropical areas) is expected to be higher than in the North Sea. Unmanned structures and no risk for oil/gas leakage are contributing factors that support a reduction in the CA requirements from design for wind structures. However, complete removal of CA would most probably not be acceptable for end users. For structural design of offshore wind foundation structures some reduced thickness locally in the splash zone should be taken into account and for fatigue design it is important that a possible corroded surface in the splash zone is considered in the selection of applicable S-N curves. For design today it is common to apply S-N curves “in air” for some parts of the lifetime and “free corrosion” in the splash zone for end of life period. It is important that the assumed conditions of the design calculation are met during the corresponding life of the structure, i.e. for the application of a S-N curve “in air” the coating has to be intact without relevant damage, especially at all fatigue critical locations.

Mechanical damage of wind turbine structures is most likely prior to and during installation. It may be considered to define a low CA in splash zone for GFP coated structures provided e.g.:

- measures to reduce risk of mechanical damage during handling and installation of the structures are in place
- as-installed inspection of the structures with repair of mechanical damaged GFP coating (qualified repair procedure)

For oil and gas offshore structures in the North Sea boat impact would be considered as a severe accident and is generally not acceptable. Offshore wind structures are however designed with boating landing areas. Such areas will require a mechanically more robust coating system than 2x600 μm GFP.

9 CONCLUSIONS

Several operators in the oil and gas industry apparently have good experience with the use of GFP but there is limited information that can be found in the open literature with documented long-term performance. The durability and service life of GFP coating in offshore splash zone environment have in this report been documented after 25-30 years exposure without any maintenance. The experience is mainly documented from inspection of coated decommissioned jacket structures from two fields in the Norwegian sector of the North Sea. One of the structures were coated with Baltoflake in yard with controlled surface preparation in 1998 and was decommissioned after 22 years in offshore service. For the other structure, the surface preparation and coating application was performed offshore in less controlled environment but still showed a good performance after 25-30 years offshore.

Field inspection and laboratory investigation document that the performance of the coating is good after 20-30 years of operation in splash zone, although the adhesion tests show a rather low pull-off strength (1.3-6 MPa). Where some degrees of adhesive failure during pull-off was observed on the coated sample from the oldest structure, some rusting on the steel substrate was observed. These local corrosion products may origin from the offshore surface preparation prior to application of the Baltoflake coating. Cross sections confirm that no active corrosion was taking place at the steel surface and that the coating performance did not appear to be significantly reduced for the offshore applied coating. EIS measurements show values > 10^6 ohm cm^2 @ 0.1 Hz, which indicates that the coating still has a low permeability and provides good corrosion protection. This result is in line with the visual appearance of the coated structures inspected.

Field inspections show that corrosion will take place in areas with mechanical damages in the GFP coating, but the extent of mechanical damages is not very high on any of the structures examined and the corrosion creep underneath the coating is rather limited.

Complete removal of corrosion allowance in the splash zone would most probably not be acceptable by owners for design of offshore wind foundation structures. The design useful coating lifetime may be extended, i.e. corrosion allowance be reduced, beyond the recommendations stated in DNVGL-RP-0416 (of 15 to 20 years), in case an inspection and repair plan (including qualified repair procedure) is specified. The efforts and cost of possible offshore repair works would then need to be accepted by the owner of the assets. The risk and possible costs involved in this may be significantly reduced with the application of a very durable coating system, like the GFP system examined within this documentation.

Based on the documented experience with GFP coating in the oil and gas industry, it may in future update of design codes for offshore wind foundation structures be considered to explicitly define a lower CA in splash zone for GFP coated (minimum 2x600 μm) structures provided some measures to reduce risk of mechanical damage during handling and installation of the structures is implemented.

10 REFERENCES

/1/ DNV report no. 2021-5504, *Coating performance long term exposure – Laboratory tests*, DNV 2021

/2/ ISO 12944 (9 parts), *Paints and varnishes – Corrosion protection of steel structures by protective paint systems*, Ed. 1 ISO 2018

/3/ NORSOK M-501, *Surface preparation and protective coating*, Ed. 6, NORSOK February 2012

/4/ ISO 20340 (withdrawn and replaced by ISO 12944-9 in 2018), *Paints and varnishes – Performance requirements for protective paint systems for offshore and related structures*, ISO 2009

/5/ *The use of polyester coatings for offshore wind structures*, Jotun 18.11.2020

/6/ *Baltoflake – list of exposure test reports*, Jotun

/7/ Report.no. 78.1021.10, *Pre-qualification of the coating system: Baltoflake 2 x 750 µm*, Marintek 1998

/8/ Report no. 3410-10-0014 Mt03, *Pre-qualification testing in accordance with NORSOK M-501 System no. 7 in the splash zone area of Jotun on. J-01/N7 2010*, Teknologisk Institutt 2011

/9/ Report no. LAB12-0488-REP rev. 1, *Stand alone test of Baltoflake*, COT 2012

/10/ 2016-00397, *ISO 20340-2009 Cyclic ageing test*, Jotun 2016

/11/ 2016-00115, *ISO 20340-2009 Cyclic ageing test*, Jotun 2016

/12/ Jotun presentation, *References and Cases, Baltoflake "Exceptional lifetime in extreme exposure"*,

/13/ Adhesion Inspection report Jotun A hull portside, 24.09.2020

/14/ Adhesion inspection report Jotun A FPSO Hull starboard side, 24.09.2020

/15/ DNV report no. 2021-0295, *Inspection report Jotun B*, Rev. 1, DNV 19.04.2021

/16/ DNV Report no. 2020-1097, *Inspection of Ekofisk 2/4-A jacket at AF Decom's Decommissioning yard in Vats Rogaland*, Rev. 0, DNV 21.05.2021

/17/ DNV GL report no. 2021-5081*, EKOA - Laboratory Examination of Coating*, rev. 0, DNV GL 15.02.2021

/18/ Jotun report AA210127, *Analysis report – Samples from Ekofisk 2/4 Alpha*, Jotun 12.05.2021

/19/ L.S. Gray, B. Drader, M. O'Donoghue, R. Garrett, J. Garrett, *Using EIS to better understand tank lining performance in laboratory and field evaluation*, NACE 2003

/20/ D. K-K Tiong, M. Ismail; *Experiences on "one coat" glassflake filled polyester (GFP) coating on offshore structures*", Paper no. 04009, NACE 2004

/21/ U. Steinsmo, M. Bjordal, O.Ø, Knudsen, T. Solem, *Coating quality in CP/coating systems – comparison of accelerated test and long time exposure*, Paper no. 00680, NACE 2000

/22/ DNVGL-RP-0416, *Corrosion Protection for Wind Turbines*, DNVGL 2016

/23/ Workshop with Jotun, ConocoPhillips and DNV, *Coating Performance – Splash Zone - Workshop*, Teams-meeting 3rd of June 2021.

/24/ E-mail from A. Skilbred, Jotun, to A. Pedersen, DNV, *«RE: Baltoflake – rapport input?»,* 25.11.2021

/25/ R&D report number RDR-21-0454, *EIS analysis report – Samples from Ekofisk 2/4 Alpha*, Jotun 24.11.2021.

/26/ Report no. SL 13633, *Testing according to NORSOK M-501, rev. 6, System 7A, Baltoflake Ecolife 1200 μm*, Norner 12.12.2013

APPENDIX A
Jotun list of reference cases with Baltoflake

A.1 Offshore references

S/N	Owner	Type	Fabrication / Docking Yard	Yard Country	Baltoflake	Completed
Sakalin 1 SPM					x	2005
Offshore Fish Farm	Salmar	Fish Farm	Qingdao Wuchuan Heavy Industry Co.,Ltd.	China	x	2017
Ekofisk 2/4 A	ConocoPhillips	Jacket	Kvarner	Norway	x	1972
Ekofisk 2/4X	ConocoPhillips	Jacket	Kvarner	Norway	x	1996
Ekofisk 2/4J	ConocoPhillips	Jacket	Kvarner	Norway	x	1997
Ekofisk 2/4M	ConocoPhillips	Jacket	Kvarner	Norway	x	2004
BP Clear Ridge Jacket DP	BP UK	Jacket	Aker Verdal	Norway	x	2011
BP Clear Ridge Jacket QU	BP UK	Jacket	Aker Verdal	Norway	x	2011
ConocoPhillips 2/4 L Jacket	ConocoPhillips	Jacket	Aker Verdal	Norway	x	2012
ConocoPhillips 2/4 Zulu Jacket	ConocoPhillips	Jacket	Aker Verdal	Norway	x	2012
Njord A	Norsk Hydro	Semi-Sub.	Aker Group	Norway	x	1996
Norne	Statoil	FPSO	KeppelFels, Singapore	Singapore	x	1996
Jotun A	Esso Norge	FPSO	Kværner Masa, Lewis Offshore	Finland	x	1997
Schiehallion FPSO	BP	FPSO	Harland & Wolff, Amec, Barmac	UK	x	1998
Aasgard B	Statoil	Semi-Sub.	DSME, Korea	Korea	x	1999
Girassol	Total Fina ELF	FPSO	Hundai Heavy Industry, Korea	Korea	x	1999
Kristin FPU	Statoil	Semi-Sub	Samsung Shipyard, Korea	Korea	x	2004
Goliat	ENI Norge	FPSO	Hundai Heavy Industry, Korea	Korea	x	2013
Glen Lyon (Quad 204)	BP Exploration	FPSO	Hyundai Heavy Industry, Korea	Korea	x	2016
Aker Barents	Aker Drilling	Semi-sub	Dubai Dry Dock - Aker Stord	Dubai - Norway	x	2007
Aker Spitsberg	Aker Drilling	Semi-sub	Dubai Dry Dock - Aker Stord	Dubai - Norway	x	2007
Johan Castberg FPSO	Equinor	FPSO	Sembcorp	Singapore	x	2021

A.2 Offshore wind

Project	Scope	Year	Owner
Nordsee OST Offshore Wind Farm	48 sets of Jack-up foundation	2012- 2014	Kværner + RWE
Sheringham Shoal Offshore Wind Farm	88 transition pieces	2010	Smulders + Statkraft
Gwynt y Môr Offshore Wind Farm	Transition pieces and turbines	2011 - 2013	RWE
Lincs Offshore Wind Farm	75 sets of Transition Pieces	2012	Siemens + Örsted
Walney Offshore Wind Farm	Transformer Platform and jacket	2010 - 2012	Dong Energy, Scottish and southern Energy,
SylWin Alpha offshore wind converter platform	Transformer Platform	2011-2013	Tennet
Dolwin 2 offshore wind converter platform	Transformer Platform	2015	Tennet

A.3 Others

Type of Project	Fabrication Country	Destination Country	Project Name	Owner
New Construction	France	Kuwait	KOTC Shuaiba - LPG Mounded Tanks	Kuwait Oil Tanker Company
New Construction	Qatar	Qatar	NPP/0037-QENFB quay wall & basin revetments.	New Port Project Steering Committee (NPP)
Maintenance	Bahrain	Bahrain	Shaikh Hamad Causeway	Ministry of Works
New Construction	China	Australia	ESC Pile project/Australia/Steel Pipe/China/Ningbo Sanding	ESC Pile
New construction	China	China	Zhongguanghe Rudong Offshore Wind	CGNPC Wind Power Co., Ltd.
New construction	China	Mauritania	Mauritania Friendship Port	Mauritania frendship port
New Construction	China	China	Nantong Detroit Metal Products Co., Ltd.	Nantong Detroit Metal Products Co. Ltd.
New Construction	China	China	Menghua railway cross South-to-North Water Diversion bridge project	West Central Railway Limited by Share Ltd
Maintenance	China	China	GD-China GuoDian Corporation	HANDAN CITY DONGFANG MANUFACTURING Co., Ltd.
New Construction	Indonesia	Indonesia	K. Platform	Total
New Construction	Korea, Republic of	United Arab Emirates	GREEN DIESEL	Abu Dhabi Oil Refining Company
New Construction	Malaysia	Malaysia	Marine Facilities For Ethylene and Polyethylene	BP Malaysia
New Construction	Malaysia	Malaysia	LNG Jetty Extension	Malaysia LNG
New Construction	Norway	Norway	Eikredammen	Oslo Energi
New Construction	Norway	Norway	Storebru	Norwegian Public Road Administration
New Construction	Norway	Norway	Storebru	Norwegian Public Road Administration
Maintenance	Singapore	Singapore	Aeration Basin Tank	PUB
Maintenance	Singapore	Singapore	Bedok STW Contract 3	PUB

About DNV

DNV is the independent expert in risk management and assurance, operating in more than 100 countries. Through its broad experience and deep expertise DNV advances safety and sustainable performance, sets industry benchmarks, and inspires and invents solutions.

Whether assessing a new ship design, optimizing the performance of a wind farm, analyzing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to make critical decisions with confidence.

Driven by its purpose, to safeguard life, property, and the environment, DNV helps tackle the challenges and global transformations facing its customers and the world today and is a trusted voice for many of the world's most successful and forward-thinking companies.