COATING SYSTEMS FOR VERY LONG TIME IN SERVICE IN HARSH ENVIRONMENTS – REDUCING THE AMOUNT OF STEEL NECESSARY

Horns Reef 1

2022–inspection

– together with

Hempel



PER GRUMSEN



Originally educated as marine engineer

1983 - 2012:
THE DANISH CORROSION CENTRE/FORCE TECHNOLOGY

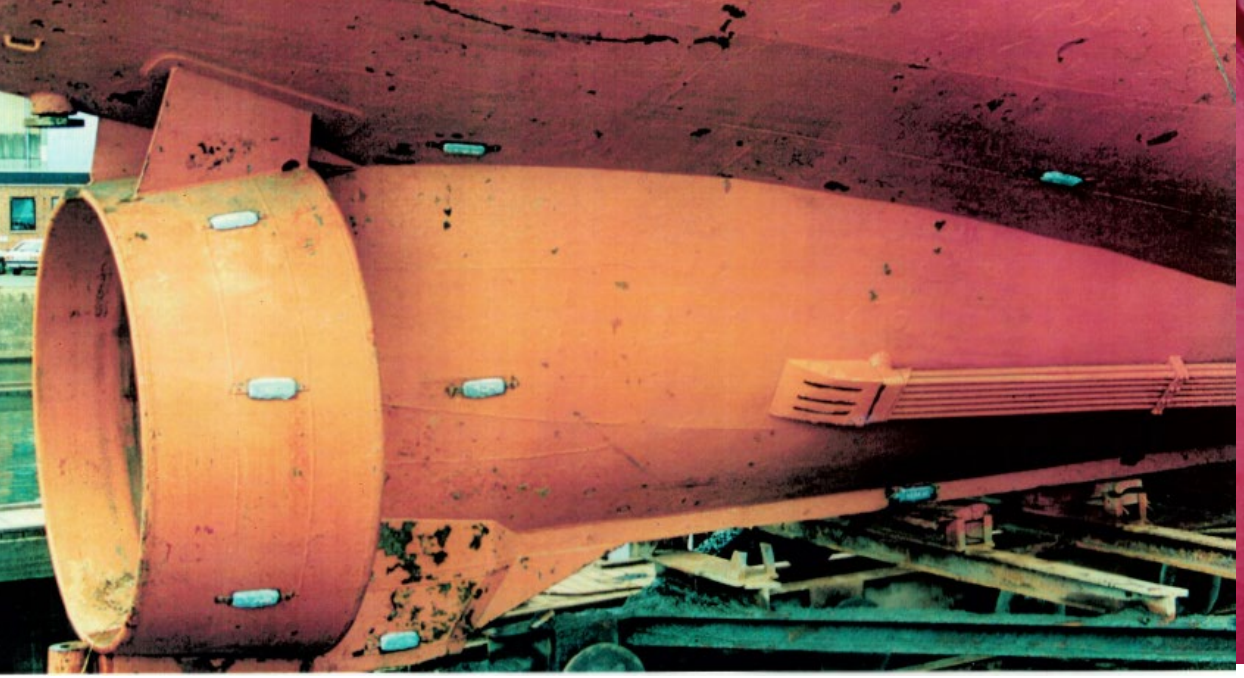
MATERIALS AND ANALYSIS/CORROSION AND METALLURGY, ESBJERG

2012 - 2025:
RAMBOLL ENERGY, ESBJERG

PIPING, MECHANICAL AND LAYOUT

2025 - ??:
PG TECH

TECHNICAL ADVICE REGARDING MATERIALS AND MATERIAL PROBLEMS





PG TECH – ESBJERG TECHNICAL ADVICE

CONTACT INFORMATION

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PG TECH - WORKING AREAS

- Material selection
- Failure investigation and analysis (corrosion, wear etc.) and breakdowns (e.g. diesel engines, gears, pumps, leaking pipes and hoses etc.)
- Examination of defects originating from manufacturing and fabrication (casting defects, forging defects, welding defects etc.)
- Metallurgical examinations
- Cracks/fractures
- NDE-methods
- Corrosion problems and –prevention
- Surface treatment spec. (painting systems, hot galvanizing etc., inspection of surface treatment)
- Jobs as expert appointed by the courts
- Seminars/courses

STEEL PRODUCTION => HEAVY CO_2 EMISSION

- Global warming is the rapid increase in the Earth's surface temperature
  - This is primarily caused by CO_2 released from fossil fuels
- The steel industry accounts for 7% of global CO_2 emissions
  - Making it one of the biggest single industrial CO_2 emitters
- The growing world population leads to demand for new infrastructure
  - And resource scarcity



STEEL PRODUCTION => HEAVY CO_2 EMISSION – THEREFORE – LET'S TALK ABOUT:



SuSTEELability !



STEEL PRODUCTION => HEAVY CO_2 EMISSION –

Huge amounts of steel used by the wind industry –

building new wind farms all over the world –

not least at sea – windy conditions – but harsh environment.



Long lifetime expected today

(approx. 32 years)



Corrosion – a great problem

which might, however,

be resolved.

FROM 15 TO 30 YEARS COATING LIFETIME

FOLLOW-UP INSPECTION – HORNS REEF 1 – JUNE 2022





INSPECTION AT HORNS REEF 1

Hornsreef 1:

- 14-20 km from Danish west coast
- 80 Monopiles
- 2.0 MW turbines
- Operative since 2002
- 5 TP's inspected, coated with
  - Hempel High Protect 3565 coating:
  - Solvent-free, two-component, high-build amine adduct cured epoxy
  - 2 x 500 µm, without any topcoat.
- Inspected 2016 and 2022 and by Hempel only also in 2004
- The 75 other TP's are coated with another product (CeRam-Kote)

Follow up inspection of coating on wind turbine TPs – Horns Reef 1 – offshore wind farm



INSPECTION AT HORNS REEF 1

According to NORSOK M-501 only 15 years of lifetime can be expected for this coating type – also in the new revision of M-501 from 2021.

Hundreds of tonnes of extra steel used to have the right fatigue strength – calculations based on ”free corrosion” after only 15 years in service.

Much better performance is obtained at Horns Reef 1.

Steel is expensive !!

Follow up inspection of coating on wind turbine TPs – Horns Reef 1 – offshore wind farm



HORNS REEF 1, THICKNESS MEASUREMENTS

	2022/2016	2022/2016	2022/2016	2022/2016	2004	2004
Wind turbine No	**Number of measure-ments**	**Min. thickness recorded µm**	**Max. thickness recorded µm**	**Average thickness recorded µm**	**Min. thickness recorded µm**	**Max. thickness recorded µm**
93	76 / 50	695 / 801	1578 / 1578	1186 / 1123	-	-
94	75 / 42	688 / 707	1448 / 1590	1063 / 1069	1031	>1300
95	66 / 27	823 / 797	1491 / 1581	1195 / 1199	-	-
96	62 / 29	808 / 1133	1585 / 1593	1244 / 1344	-	-
97	61 / 22	770 / 987	1535 / 1563	1143 / 1190	1112	>1300

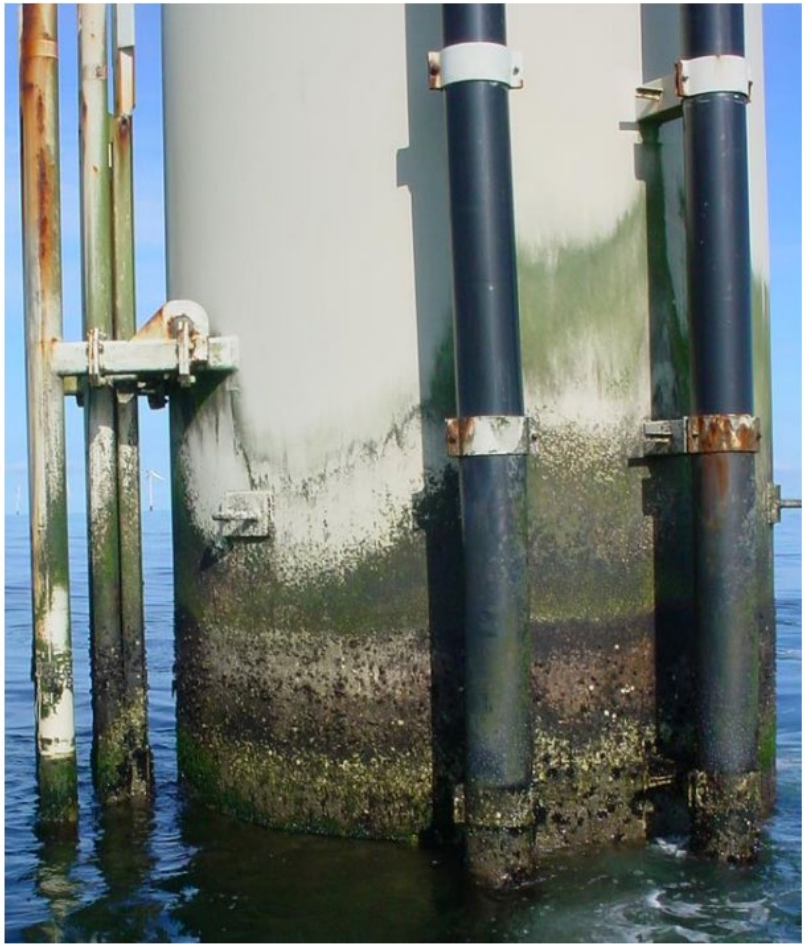
Table 2-1: Coating thickness results, 2022, 2016 and 2004

- Only small reductions of coating thickness during 20 years of exposure was measured
- Coating system is without topcoat which is expected to increase thickness reduction
- No significant influence from orientation, was measured, i.e. the reductions at severely exposed west side was not significantly higher than at the other sides.



GENERAL, VISUALLY DEEMED CONDITION

WT 93



WT 94



GENERAL, VISUALLY DEEMED CONDITION

WT 94



Coating generally in excellent condition after 20 years.



Close-up of localized mechanical damage.

GENERAL, VISUALLY DEEMED CONDITION

WT 94





2016



2022

Comparison of extent of damage – 2016 and 2022. Except the already in 2016 loosened coating marked by a red arrow at the 2016-photo only relatively insignificant extent of under-rusting and loss of coating along the edges of the damage have occurred over a period of 6 years in the splash zone.

GENERAL, VISUALLY DEEMED CONDITION

WT 95



WT 96



GENERAL, VISUALLY DEEMED CONDITION

WT 97



Concluded general condition after 20 years:

- Generally - quite excellent condition
- No signs of coating degradation (except insignificant loss of gloss) observed
- No signs of peeling, flanking, cracking or blistering observed.

CONCLUSION REGARDING THE HEMPEL COATING

It is concluded that:

- Coating is in excellent condition after 20 years
- Very little development during the last 6 years
- A service life of more than 30 years is most likely

Regarding recommended new coatings:

- To minimize thickness loss and loss of gloss the system should be supplemented by a topcoat, e.g., Hempathane HS 55610 – thickness 60 µm

CONDITION OF THE OTHER 75 TP'S





All the other foundations are corroding freely -

380 µm total thickness specified

Blisters observed in 2004



CONDITION OF THE 75 OTHER TP'S

(2 MILL DKK SAVED IN 2002 – 140 MILL DKK USED IN 2016 FOR INSPECTION FOR CORROSION FATIGUE CRACKS)



Looking closer:

- The TP's were originally coated but the coating failed after a few years
- Trials (e.g., using a cofferdam) showed that re-coating was almost impossible
- Re-calculation using newer, more refined methods showed that free corrosion of the TP's could be allowed.
- Re-coating was not performed due to the robustness of the earlier structural design methods.

For new projects it is unlikely that free corrosion can be accepted

CONCLUSIONS MADE IN 2022

- As no significant signs of degradation of the original coating (Hempel High Protect 3565) after 20 years in service have been recorded – and as no significant, measurable reduction of the coating thickness could be recorded after this service period - it can be concluded that the actual type of a relatively "simple" paint/coating type is highly suitable for future wind farms, where a lifetime of up to 30 + 2 years is expected.
- Glass flake reinforced epoxy products might be the preferred choice of coating for some owners of wind farms.
- 1000 µm glass flake coatings are accepted in standards for >25y but due to cost and application (might cause problems resulting in poor quality of coating) glass flake coatings are not used very much on offshore wind installations. Reduced production costs very important.
- With the actual type of solvent-free epoxy coating system applied - a very long lifetime might be expected which might – if accepted by the clients - lead to a reduction in the amount of steel necessary for future wind turbine constructions as use of "free corrosion SN-curves" during the design of the constructions will only be necessary after e.g., 25 or 30 years in service.

That is sustainability – good for the environment!!

FURTHER DEVELOPMENT OF COATING PRODUCTS AT THE TIME OF INSPECTION IN 2022

Further development of coatings of same generic type - even better properties regarding general abrasion resistance and corrosion protection and also, regarding drying time/over-coating intervals during application.

Coating / Product	Specification thickness µm	Min. overcoat interval
HEMPADUR 35620	2 X 500 or 3 x 300	Approx. 6 hours
HEMPADUR 35560	2 X 500 or 3 x 300	Approx. 10 hours
HEMPADUR MULTI-STRENGTH 35840	2 X 500 or 3 x 300	Approx. 8 hours
HEMPADUR MULTI-STRENGTH 35842	2 X 500 or 3 x 300	Approx. 8 hours

Hempadur Multi-strength products 35840 and 35842 presented in table above are epoxy products – reinforced with glass flakes.

TWO TYPES OF NEW COATING PRODUCT – HEMPAPRIME STRENGTH 530 - ACCEPTED BY DNV FOR LONG SERVICE TIME

Further development of a coating of same generic type - Hempaprime Strength 530 - a **self-priming, hi-build epoxy** designed for offshore use – splash zones and permanent immersion.

Abrasion resistance and corrosion protection – e.g. at:

- Offshore wind turbines
- Offshore oil and gas platforms
- Bridges, piers and jetties
- Solar power foundation
- Mining
- Marine boats
- FPSO (floating production storage and offloading)



TWO TYPES OF NEW COATING PRODUCT – HEMPAPRIME STRENGTH 530 - ACCEPTED BY DNV FOR LONG SERVICE TIME

DNV

Conclusion:

The field experience, qualification testing and comparative laboratory results provide a technical basis for considering the following design useful life objectives in accordance with DNV-RP-0416, section 4.5.2:

- **Hempaprime Strength 530, 2 × 500 µm:** up to **25 years**; and
- **Hempaprime Strength 530, glass-flake reinforced, 2 × 600 µm:** up to **30 years**.

Results of an inspection carried out at HR1 in March 2026 by C-Cube international bv also considered regarding this conclusion

(HR1 coating still in excellent condition in 2026)

POLYURETHANE LAYER ON TOP OF EPOXY

To obtain max. gloss and colour retention (most often yellow colour), a final coat of e.g. Hempathane HS 55610 – thickness 60 µm – can be applied on top of the epoxy paint selected for the job.



NEW COATING SYSTEMS FOR VERY LONG TIME IN SERVICE – REDUCING THE AMOUNT OF STEEL

