Offshore wind foundations
Long term corrosion protection, … fiction?

November 2015, Jo van Montfort
Main Topics

- General introduction
- Current situation offshore wind
- Differences with O&G
- Background Coatings
- Standards State of the art and current needs
- Proposed new approach
- Conclusions
Current situation

**Global impact**
Estimated at US$ 2.2 trillion, the annual global cost of corrosion is over 3% of the world’s GDP

**Challenges**
WCO:” All studies estimate that 25 to 30% of annual corrosion costs could be saved if optimum corrosion management practices were employed
Implement knowledge into practice!

**Fact**
You can never kill it, you can only fight/manage it!
Offshore wind foundations

- Work platform
- Tower
- Shaft
- Boat landing
- External J tubes
- Grouted connection
- Transitional piece
- Seabed
- Monopile
# Classification environment

<table>
<thead>
<tr>
<th>ISO 9223</th>
<th>Typical environment</th>
<th>Corrosion rate for the first year of exposure (μm/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mild steel</td>
</tr>
<tr>
<td>Category</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>Very low</td>
<td>Dry indoors</td>
</tr>
<tr>
<td>C2</td>
<td>Low</td>
<td>Arid/Urban inland</td>
</tr>
<tr>
<td>C3</td>
<td>Medium</td>
<td>Coastal or industrial</td>
</tr>
<tr>
<td>C4</td>
<td>High</td>
<td>Calm sea-shore</td>
</tr>
<tr>
<td>C5</td>
<td>Very High</td>
<td>Surf sea-shore</td>
</tr>
<tr>
<td>CX</td>
<td>Extreme</td>
<td>Ocean/Off-shore</td>
</tr>
</tbody>
</table>
## Relevant types of corrosion

<table>
<thead>
<tr>
<th>Type</th>
<th>Corrosion rate/y in sea water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric</td>
<td>0.1 – 1 mm</td>
</tr>
<tr>
<td>Galvanic</td>
<td>1-3 mm</td>
</tr>
<tr>
<td>Crevice and pitting</td>
<td>1-3 mm</td>
</tr>
<tr>
<td>ALWC (MIC)</td>
<td>1-3 mm</td>
</tr>
<tr>
<td>Stress corrosion cracking</td>
<td>N.a.</td>
</tr>
<tr>
<td>HIC</td>
<td>N.a.</td>
</tr>
</tbody>
</table>
SRB heavy fouling biomat scare

patchy distribution of biomats and scars creates

- differential aeration
- open circuit potential (noble shift to + 400mV)
- increasing cathode reaction rate (exceeding pitting potential)

Johan Mertens
Johan.mertens@UGent.be
Offshore wind farms

Corrosion challenge

- Corrosion is a top three failure mechanism, due to atmospheric, marine and bio-corrosion.
- Extremely high repair costs (up to €3000/m2), due to offshore circumstances
- Different from O&G; complex dynamical loads, mass production, maintenance free approach

Splash zone
Monopile / transition piece
Monopile internal
Secondary structures
Offshore wind farms

System challenge

- **Minimal** part of budget allocated to maintenance, resulting in extreme OPEX overspending
- **Mass** produced substructures require **quick** curing systems
- Current procurement focus is **NOT** on complete lifetime of an asset
- Current standards and guidelines focus on lifetimes < 15 years
- Trend is working towards further offshore and deeper installations, resulting in **even higher** repair costs
Facts

Typical corrosion damage on foundations:

- splash zone,
- internal monopile,
- secondary structures (boat landing, J-tubes, railings, platforms, stairs).
Different from O&G

- **Cost** aspect Offshore Wind *initial phase* versus O&G focus on the complete lifetime of asset.

- Large offshore wind farms (500 MW and more) means mass production resulting in high pressure on the fabrication (limited curing time of coating systems), O&G uses single structures specific designed and more time for curing and fabrication is usually calculated in the fabrication process.

- The operational phase in offshore wind is based on minimal maintenance or even *maintenance free* for the sub structure, O&G has depending on the individual standard practises more actions and budget reserved for maintenance offshore.

- Offshore wind applies strictly the *general* specifications, in O&G the owner usually applies *specific standard practises* in which an additional safety factor is calculated such as an additional coating layer in the splash zone or prevention of bio-corrosion in confined spaces.
State of the art not sufficient

State of the art guidelines

DNV-OS-J101: Design of Offshore Wind Turbine Structures

The DNV-OS-J101 standard provides principles, technical requirements and guidance for design, construction and in-service inspection of offshore wind turbine foundation structures. Corrosion protection is mentioned, but the document refers to other standards and recommended practices, like NOROSK M-501, ISO 12944 and DNV-RP-B401.

NORSOK M-501: Surface preparation and protective Coating

NORSOK M-501 is specifically developed for the offshore oil and gas industry. A pre-qualification regime for coatings in atmospheric-, splash- and submerged zone may be applicable to offshore wind as well, but due to differences with respect to maintainability and access to surfaces, copying NORSOK M-501 uncritically may be a dangerous strategy for the offshore wind industry.
ISO 12944: Paints and varnishes - Corrosion protection of steel structures by protective paint systems
ISO 12944 describes selection of protective coatings for steel constructions in all environments. Lifetimes are estimated in three groups: low < 5 years, medium 5-15 years and long > 15 years. For constructions with lifetimes longer than 20 years one can discuss whether this standard is helpful.

DNV-RP-B401: Cathodic Protection Design
DNV-RP-B-401 describes design of cathodic protection of marine constructions.
Current situation Selecting Coatings

Testing Coating systems (off shore, bridges, etc.) C5-M and C4

- ISO 12944-6
  - Preferably experience (similar cases)
  - Artificial test result used with caution
- Required Tests C5-M and C4
  - Water condensation (ISO 6270)
  - Salt spray (ISO 7253)
  - On flat panels
  - New materials
  - Applied under lab. conditions

- Although it is in the ISO do not do this.
- We need materials fit for purpose ≠ passing lab. Tests!
State of the art not sufficient

Guideline for the Certification of Offshore Wind Turbines, GL Wind 2005

“Offshore wind turbine components are exposed to aggressive environmental conditions and not easily accessible. Because of the operational conditions, in many cases repeated protective coating is not possible. Special importance therefore attaches to the design, choice of material and corrosion protection measures“.

- Germanischer Lloyd WindEnergie
Coatings, PAIN(t)?

Main Function

- Shield steel (metal) from environment during > 20 years?

How?

- Prepare surface (“if you fail to prepare you prepare to…”)
- Mix wet (2) components
- Apply wet components on substrate
- Multi layers
Current solutions

- Multi layer systems
- >8-24h waiting between layers
- Passing tests but lack of proven track records
- Strict application circumstances required:
  - Maximum surface prep. required
  - Expensive and long term shielding
  - T and/or RH control
- Maximum 15 years lifetime
- Containing VOC’s (10-30%)
- Not under water (influences) curable

<table>
<thead>
<tr>
<th>#</th>
<th>Coating</th>
<th>Pro</th>
<th>Con</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi (3-4) layer EP-PU systems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Primer epoxy (zinc-phosphates)</td>
<td>• Adhesion to steel</td>
<td>• Strict application circumstances (T/RH)</td>
</tr>
<tr>
<td>1-2</td>
<td>Mid coats: Epoxy 20-30% VOC (optional with glass flakes)</td>
<td>• Chemical resistance</td>
<td>• Curing time each layer &gt; 8 h</td>
</tr>
<tr>
<td>1</td>
<td>Top coat: PU finish</td>
<td></td>
<td>• Emission of 10-30% VOC</td>
</tr>
<tr>
<td>Polyurea (1-2) systems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-1</td>
<td>Primer epoxy (zinc-phosphates)</td>
<td>• Chemical, abrasion, thermal resistance</td>
<td>• Surface preparation and special application equipment are crucial</td>
</tr>
<tr>
<td></td>
<td>Top coat</td>
<td>• Curing time</td>
<td>• Bad intercoat and steel adhesion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 20 yrs (in shop coat)</td>
<td>• Poor surface quality, due to low flowability</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Not repairable, no overpainting</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• High costs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Hazardous components (isocyanates)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• VOCs 10-15%</td>
</tr>
</tbody>
</table>
## Offshore wind farms

### Current Coating systems

<table>
<thead>
<tr>
<th>System 1</th>
<th>Common coating system</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Metallization (e.g. Zn/Al 85/15)</td>
<td>60-100 μm</td>
</tr>
<tr>
<td></td>
<td>2 layers Epoxy</td>
<td>2x 150 μm</td>
</tr>
<tr>
<td></td>
<td>1 layer Polyurethane (aliphatic)</td>
<td>50-80 μm</td>
</tr>
<tr>
<td>System 2</td>
<td>1 layer Epoxy Zinc dust primer</td>
<td>60 μm</td>
</tr>
<tr>
<td></td>
<td>2-3 layers Epoxy</td>
<td>2x 150 μm</td>
</tr>
<tr>
<td></td>
<td>1 layer Polyurethane (aliphatic)</td>
<td>50-80 μm</td>
</tr>
</tbody>
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Coatings, PAIN(t)?

What happens?

- Multilayers (3-4)
- Chemical reaction **simultaneous** release of solvents, induce:
  - Internal stress (“cross linking”)
  - Internal voids/defects (“holidays”)

![Chemical reaction diagram](image)

![Polymer chains](image)
What is (not) controlled?

- Temperature and RH (dew point)
- Thickness
- Adhesion (to steel and intercoat)

- Temperature substrate
- Curing
- Solvent retention
- Internal stress
Currently “accepted” Risks

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation</td>
<td>Adhesion</td>
</tr>
<tr>
<td>Temperature, RH</td>
<td>Adhesion, curing, solvent retention</td>
</tr>
<tr>
<td>Thickness</td>
<td>Insufficient cover, vs high internal stress</td>
</tr>
<tr>
<td>Waiting in between</td>
<td>Solvent retention vs bad intercoat adh.</td>
</tr>
<tr>
<td>Water (rain, moist)</td>
<td>Insufficient curing</td>
</tr>
</tbody>
</table>

Crack formation
On welded edge

Stress

Displacement
Cause of Multi million € damages

The Truth!
- Time and Cost savings
- Deadlines
- Practical impossibilities (Hinder Traffic, Safety, Accessibility, etc.)

Main cause of paint material failure = early (micro) cracking of the paint
Main cause of paint system failure = low tolerance to application window (surface prep., T / RH)

Corrosion = Result of 50% coating material and 50% system failure
Main root cause

Problem is "Unawareness of Incompetence"

**Product**
- Designed for passing tests
- Insufficient verifiable, relevant track records
- Purchase on liter price (not performance)

**Application**
- Strict application circumstances required
- Multi layers
- VOC's (10-30%)

Result = **illusion** reducing risks

Unpredictable performance and (maybe) unforeseen early damage
Offshore wind farms NEEDS

- **Lower** initial costs and **lower** Life Cycle Cost
- **Workability** under poor conditions
- **Low** environmental impact (0% VOCs, no leaching)
- **Broad** application window (T / RH)
- **Rapid** application (exposing wet paint to water)
- Maintenance free **(25+ years)**
- Easy **repair** (over coat-able) under offshore conditions
- Insurance on full package PPP
Current approach

“If you fail to prepare, you prepare to..”

- Passing lab. tests=
  - Demonstrate performance
  - On flat panels
  - Applied under perfect conditions
  - New material in Cor-test
  - Ageing test related to aesthetics
  - Materials properties not known

- Limited data review on track records

- Product (liter/kg) Price

New approach

- Demonstrate tolerance for application circumstances by:
  - Testing not only on “perfect” substrates under “perfect” circumstances. Accept that a perfect substrate is a myth but a more tolerant coating materials are needed.
  - Data from Track records proves real performance outdoor (EIS)
  - Understanding materials behavior will reduce risks and costs (modelling)
  - Saving LCC
Offshore wind farms NEEDS

Fit for purpose tests, EIS
Grooved panels versus flat

<table>
<thead>
<tr>
<th>gleuf 1</th>
<th>gleuf 2</th>
<th>gleuf 3</th>
</tr>
</thead>
</table>

Gleuf 1: 0,8 mm diep
Gleuf 2: 1,4 mm diep
Gleuf 3: 2,0 mm diep
Mechanical properties

- **Massa-afname**
  - 0 uur
  - 500 uur
  - 1000 uur
  - 1500 uur

- **Krimp**
  - 0 uur
  - 500 uur
  - 1000 uur
  - 1500 uur

- **Relaxatie**
  - 0 uur
  - 500 uur
  - 1000 uur
  - 1500 uur

- **E-modulus**
  - 0 uur
  - 500 uur
  - 1000 uur
  - 1500 uur

- **Treksterkte**
  - 0 uur
  - 500 uur
  - 1000 uur
  - 1500 uur

### Glas transition temperature
- Before WOM: 31°C
- After WOM: 57°C

### Adhesion strength
- Before WOM: 7,4 Mpa
- After WOM: 9,6 Mpa
Problem definition
Defects in the existing coating resulting in corrosion affecting structural integrity in due time.
Repairs with existing coating systems are nearly impossible or extremely costly because of the offshore circumstances

Solution
Application of a single layer system which is tolerant for offshore circumstances because of:
- High tolerance against insufficient surface preparation
- High tolerance against water immediately after application.
- 10 years warranty.

Benefits
Fast and cost effective durable solution.
Conclusions

- Be critical and reluctant about “conventional” tests
- Propose together with expert fit for purpose testing
- “Coatings really do have mechanical properties”
- Most valuable test is (validated) outdoor experience
- Assess TOLERANCE of coating
- Product Price is irrelevant, assess project price
- Innovation is not always new
- Cost savings (initial and LCC) of more than 20% are possible (Acotec)
Questions?

Email: jvm@bjond.be
M: +31 629 70 51 79