TECHNICAL SOLUTIONS FOR THE IMPROVEMENT OF LEVELISED COST OF WIND ENERGY OFFSHORE

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SUMMARY

The next generation of large offshore wind energy generators and tidal power generators needs improvements to solve challenges related to materials, coatings and multi-material architectures to increase operational performance and allow an appreciable reduction of the overall cost: capital expenditure, running and maintenance costs.

Corrosion and fatigue are the main mechanisms of deterioration in offshore structures affected by severe environmental factors such as extended periods of wetness, UV-radiation, abrasion and erosion, which eventually accelerate corrosion rates.

Figure 1 Corrosion on tubular tower and on flanges.

Source: MAREWIND project, KOSHKIL.

Figure 2 Crack issues on concrete structures and biofouling issues.

Source: MAREWIND project, PNO and EDF.

In addition to productivity loss from repair operations, maintenance costs are extremely high due to several factors, including the logistics of getting technicians and materials to the job site, along with limited access to the structures and a difficult working environment influenced by harsh offshore weather conditions. Operations and Maintenance (O&M) account for approximately 25% of the costs of offshore wind farms.

The MAREWIND project, funded by Horizon 2020 program of the European Commission, addresses the main aspects related to the durability and maintenance of the different materials used in offshore wind power plants. Long term problems derived from material degradation include plant failures, additional resources required for maintenance and a loss of energy efficiency, which lowers their economic efficiency. Moreover, by enhancing the materials' durability, recyclability and reduce maintenance in offshore structures, the project will contribute to a more sustainable model for the offshore wind sector.

The main action points related to material development focus on coatings, concrete and composites.

Figure 3 Main action points related to material development within MAREWIND project.

Source: MAREWIND project, LUREDERRA.

On the other hand, the control of material status and evolution for preventive measures and a more accurate maintenance, is developed by Structural Health Monitoring tools, including fiber optic bars, strain sensors, Unmanned Aerial Vehicles (UAVs) and advanced thermographic cameras among others.

Figure 4 Main action points related to Structural Health Monitoring within MAREWIND project.

Source: MAREWIND project, LUREDERRA.

METHOD

MAREWIND has been progressing in accordance with its objectives in the different areas of the project: protection against corrosion with nanocoatings, solutions with repellent properties against the biofouling, superhydrophobic and antierosion coatings for blades, the reinforcement of the composites for blades including the recyclability in its manufacture, as well as new concretes (Ultra High Performance Concrete-UHPC) with more durable properties, resulting in successful floating pilot prototypes. Furthermore, integrated sensors based on fiber optic have been successfully implemented for Structural Health Monitoring (SHM) in novel concrete formulations and blades. In addition, progress has been made obtaining very promising results in multiscale numerical models for resin infusion process and in full field monitoring techniques for blades.

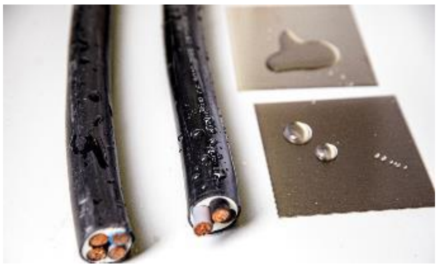
SOME HIGHLIGHTS OF PROJECT RESULTS

Antifouling coated samples show significant delay in fouling cumulation. These results have been partially obtained at PLOCAN-Canarias after obtaining access for 2022-2023.

Figure 5 Relevant results related to antifouling coating, showing delay in accumulation in both polymer (PA) and metal (Stainless steel), after exposure according to ASTM D 3623 standard.

Source: MAREWIND project, ENEROCEAN.

Figure 6 Detail of the repellent effect provided by the one-layer antifouling coating developed by Lurederra (biocide-free).



Source: MAREWIND project, LUREDERRA.

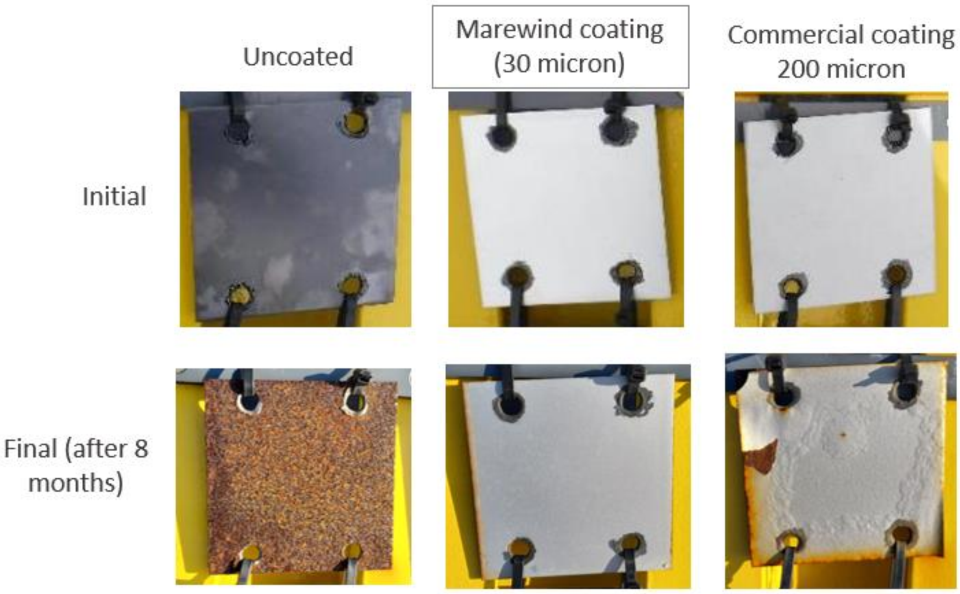
Anticorrosion coating has been validated with no corrosion damage for more than 4200 hours in cycling tests exposure (1800h UV, 600h freezing and 1800h saline mist chamber) based on ISO12944-9. Apart from panels, real carbon steel fastening elements, such as bolts, washers and nuts, were also protected for more than 4000 hours in saline mist chamber.

Figure 7 Direct application by spray gun of the anticorrosion coating as well as relevant results obtained after long-range exposure to saline mist chamber on real fastening elements from TSF.

Source: MAREWIND project, TECNAN and TSF.

Regarding real exposure tests, ISO 8565 standard conditions were followed, showing very good corrosion protection as well as exceptional adherence and hardness after 8 months of atmospheric test.

Figure 8 Relevant results from test carried out by ENEROCEAN in TECNALIA's real exposure facilities HarshLab at BiMEP.



Source: MAREWIND project, ENEROCEAN and LUREDERRA.

Ultra-High Performance Concrete (UHPC) developed by ACCIONA presents 33% reduction in cement used compared to standard. Durability tests according to NT-492 showed after a year of exposure negligible corrosion rate (kΩ·cm) and extremely high chloride penetration resistance (0.008 m^2/s). Freeze and thaw resistance test reflected high durability performance at 200 cycles.

Figure 9 Small prototypes performed in preliminary trials to check production process and buoyancy.

Source: MAREWIND project, ACCIONA.

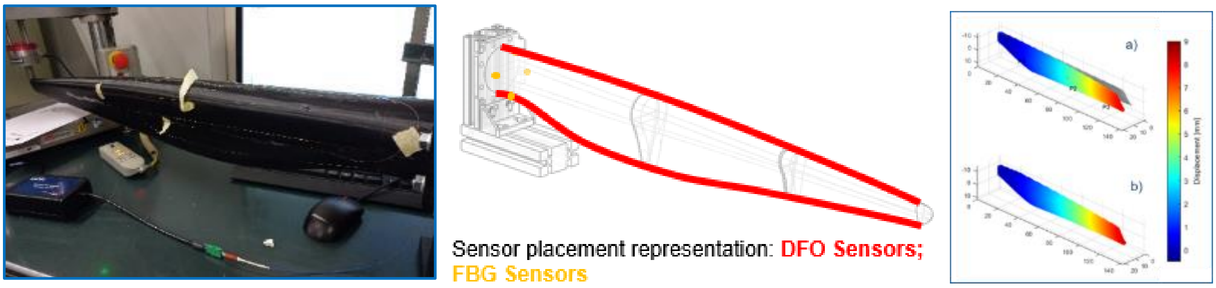
Regarding Structural Health Monitoring activities, on the one hand, integrated sensors have been successfully lab-scale demonstrated in concrete and blades.

Figure 10 Acquired signal from SHM system inside UHPC concrete beam in different instants of loads.

Source: MAREWIND project, CETMA and ACCIONA.

On the other hand, Digital Image Correlation and Thermographic analysis have been used for full-field-measuring techniques of wind blade working conditions.

Figure 11 Different phases of the sensing work from INEGI for preventive monitoring of blade defects

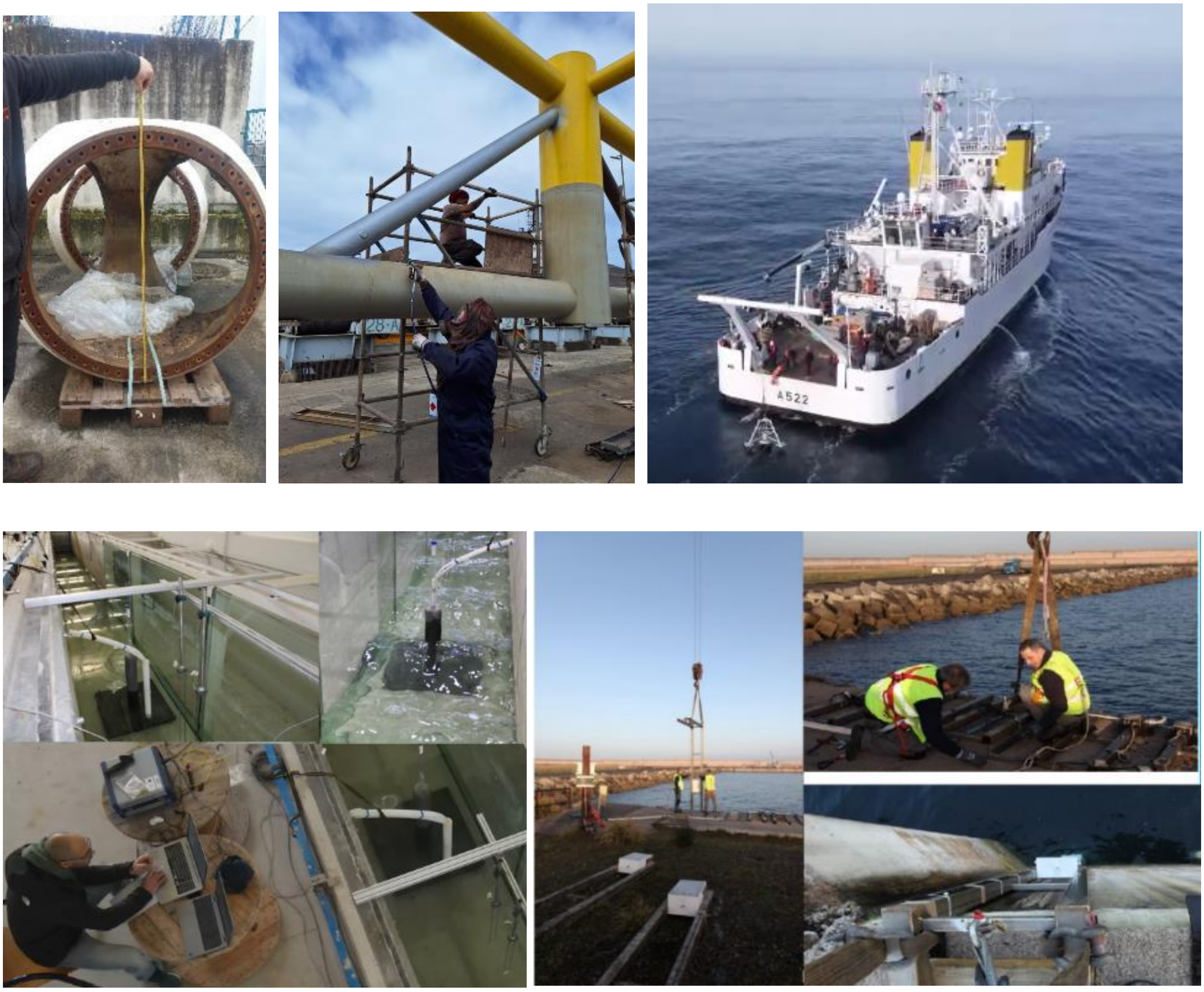


Source: MAREWIND project, INEGI.

Currently, the project is focused on real exposure demonstrations for the different technologies and materials already validated including:

- Repair and maintenance activities on site for corrosion of metallic parts, leaded by KOSHKIL.
- Application of anticorrosion and antifouling coatings on Wind2Power floating platform from ENEROCEAN.
- Construction and deployment of a GBS structure immersed in the Sea by INEGI, including strain sensors, modified concrete ballast (AAM from CETMA) and antifouling coupons for real exposure testing.
- Wave channels tests started at EUMER with optimised concretes (UHPC and AAM) including fiber optic sensors for monitoring.
- UHPC prototypes have been installed by ACCIONA at Gijón Harbour for corrosion test performance at real environment.

Figure 12 Pictures of different demonstrative activities ongoing in the last year of MAREWIND project



Source: MAREWIND project, KOSHKIL, ENEROCEAN, TECNAN, INEGI, CETMA and ACCIONA.

CONCLUSIONS

Among the results obtained in MAREWIND, it is worth mentioning the following which will impact directly on sustainability and reduction on O&M Costs.

- **Antifouling coating**: significant delay in fouling cumulation after several months immersed in the sea. This can reduce the maintenance needs and reduce associated costs.
- **Anticorrosion coating**: the resistance achieved in the laboratory testing would correspond to CX corrosivity category, implying extreme resistance of more than 25 years. Easy and direct application of the coating by spray gun has been demonstrated and the production of 100 L validated its upscaling. An alternative of lower thickness and reduced weight is proposed for easier implementation and reduced investment for application, while keeping the protection.
- **UHPC developed** presents a more sustainable solution than standard UHPC and shows 90% durability improvement compared to a standard C60 at same age. The complex maintenance of concrete structures would be drastically reduced.
- Successful testing of sensors on both concrete (ballast, foundations) and on composite-based blades for **SHM**.

LEARNING OBJECTIVES

People attending the conference will learn about new solutions proposed and developed in the MAREWIND project. MAREWIND addresses the main aspects related with materials durability and maintenance in offshore structures which consequently suppose failures, misfunctioning, loss of efficiency in energy generation and which have a major repercussion in O&M costs and capital costs. With the combined forces of key-players in the current value chain of wind energy, MAREWIND covers a set of ambitious targets focused on: enhancing corrosion protection systems and durability, effective and durable antifouling solutions without using biocides, erosion protection and mechanical reinforcement in wind blades, predictive modelling and monitoring and increasing recyclability. The planned presentation will mainly show results related to anticorrosion and antifouling coatings, new UHPC, SHM and full-field measuring techniques.

ACKNOWLEDGEMENTS

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