MARE WIND

MAterials solutions for cost **R**eduction and **E**xtended service life on **WIND** off-shore facilities

EU H2020 PROJECT

GENERAL PRESENTATION

The project has received funding from the European Union's Horizon 2020 research and innovation program under Grant Agreement N° 952960

Project overview

MARE WIND

Materials solutions for cost Reduction and Extended service life on WIND off-shore facilities

H2020-NMBP-ST-IND-2020 (Industrial Sustainability)
LC-NMBP-31-2020 Materials for off shore energy (IA)

Materials improvement → Monitoring - Predictive → Manufacturing and testing elements → VALIDATION AND DEMONSTRATION IN RELEVANT ENVIRONMENT Standardisation and regulation

Participants: 17 partners from 7 countries (Belgium, Ireland, Italy, France, Portugal, Spain, United Kingdom)

Project Information

MAREWIND
Grant agreement ID: 952960

DOI
10.3030/952960

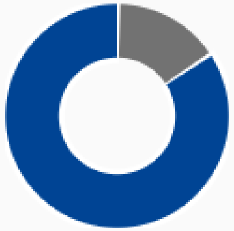
EC signature date
6 November 2020

Start date 1 December 2020
End date 30 November 2024

Funded under
INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies - Advanced materials

Total cost
€ 7 953 783,75

EU contribution
€ 6 706 969,38



Coordinated by
L'UREDERRA, FUNDACION PARA EL DESARROLLO TECNOLOGICO Y SOCIAL
Spain

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Importance and challenges of offshore wind energy

European wind energy sector:

- 2020-scenario: Installed capacity 220 GW (onshore + offshore), 16% electricity demand.
- 2025-scenario: +105 GW installations.
- **Offshore** wind energy:
    - Only 11% of the installed power capacity meeting only 3% of electricity demand;
    - Challenges: Damage on materials and coatings due to wetness, UV-radiation, abrasion, erosion and corrosion, and lack on efficient predictive modelling and monitoring system;
    - Consequences: 4-20% reduction in energy production, O&M costs up to 25% of total.
- *End-of-life* stage: Expected 800 kt/year of waste wind turbine blades by 2050.

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The MAREWIND concept

Goal: Provide vital solutions to help building a next generation of large offshore wind energy- and tidal power generators by solving the current challenges related to materials, coatings and multi-material architectural performance.

How will MAREWIND work?

- By enhancing the materials' durability, recyclability, and reduce maintenance in offshore structures, the project will contribute to a more economic and sustainable model of the offshore wind sector.
- Develop durable materials and recyclable solutions for the offshore wind industry, while extending the service life of the wind facilities.
- Contribute to meeting the EU climate targets and create new job opportunities within the wind industry.

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Concept

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Expected Impact

The MAREWIND results will have industrial, economic, ecological, energy and social benefits:

- maintaining/improving performance;
- improved durability of materials at optimized costs:
  - improved durability of corrosion protective coatings (> 25 years);
  - improved durability of reinforced structural concrete; (> 50% durability increase);
  - improved durability of antifouling coatings (> 5 years);
  - improved durability of antierosion blade paints (>10 years);
- significant reduction of life cycle costs;
- cost reduction for offshore energy production of about 40% of the *levelized cost of energy*, with cost values produced by wind energy systems below 10 ct€/kWh;
- reduction of environmental impact by 35%;
- reducing CO_2 emissions and fuel dependency: 3,5 ktoe in short term and 13,6 ktoe at mid/long term;
- creating growth and jobs in Europe by strengthening the European industrial technology base.

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ACTION POINTS IN THE STRUCTURES → Material development

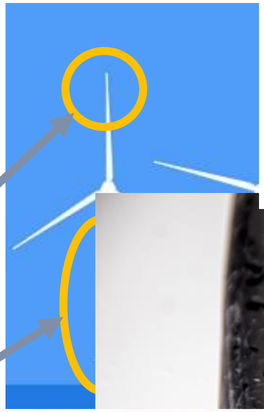
MAREWIND project is focused on **WIND** … cretely, addresses **material development** in **different action points of the structures, improving durability a** … **levelized cost of electricity.**

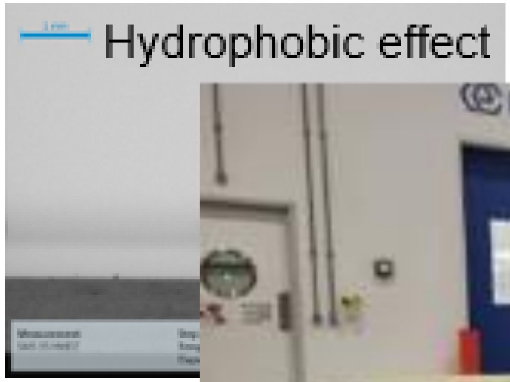
The global perspective of the project cons … es.

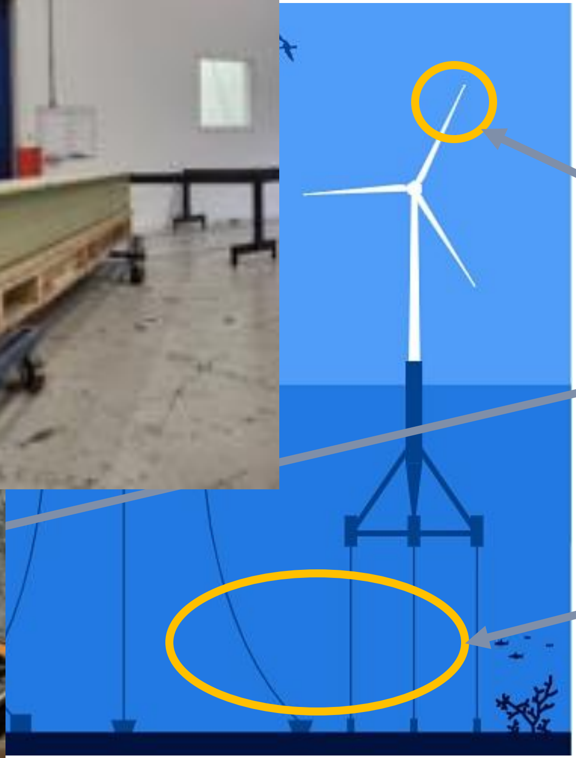
Antierosion hydrophobic coating for blades

Anticorrosion coating for towers and fastening el…

Alkali Activate… (balla…







New reinforced composites for blades

Ultra High Performance Concrete (floating)

Antifouling coating for mooring lines and inter-array cables.

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ACTION POINTS IN THE STRUCTURES → Structural Health Monitoring

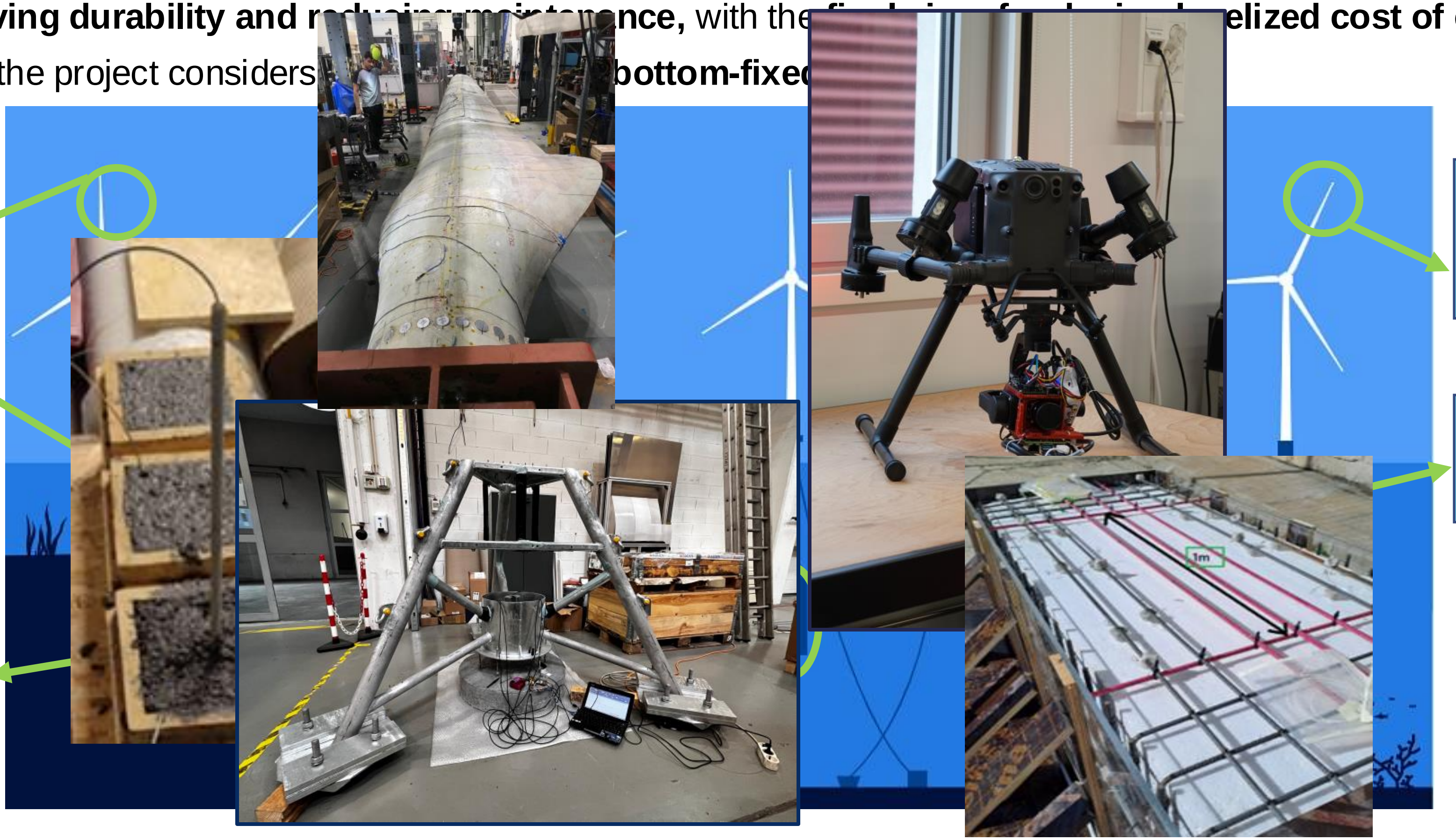
MAREWIND project is focused on **WIND TURBINES** in **OFFSHORE.** Concretely, addresses **material development** in **different action points of the structures, improving durability and r**… **…nce,** with the **fi…** …**elized cost of electricity.**

The global perspective of the project considers … **bottom-fixed** …

Fiber Optic Sensing System (FBGs + DFOs) for the Blade monitoring system

AAM concrete ballast. **Fiber Optic bars and sensors**

GBS. **Strain sensors**



UAVs (drones) with cameras for blade surface monitorisation

UHPC (floating). **Fiber Optic bars and sensors**

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ANTICORROSION COATING DEVELOPMENTS

EFFICIENCY OF THE MAREWIND ANTICORROSION SOLUTION IN REAL FASTENING ELEMENTS, manufactured by TSF

The anticorrosion system developed has been tested based on specific conditions from **ISO 12944-9** (*Protective paint systems and laboratory performance test methods for offshore and marine related structures*)

Easy and direct application of the coating by spray gun

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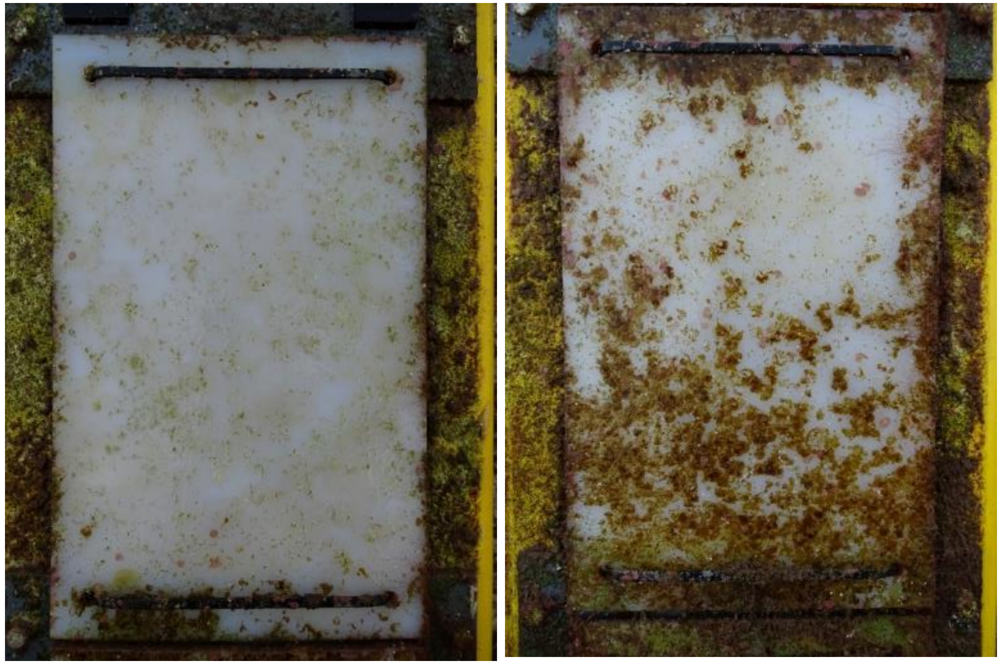
ANTIFOULING COATING DEVELOPMENTS

MAREWIND ANTIFOULING SOLUTION SUCCESSFULLY TESTED IN REAL EXPOSURE IMMERSED IN THE SEA

Nylon coated – non coated



Stainless steel coated – non coated

These experiments have been performed in the facilities of Consorcio Plataforma Oceánica de Canarias (PLOCAN) by EnerOcean according to ASTM3623 regulation in conditions of full immersion during 2 months

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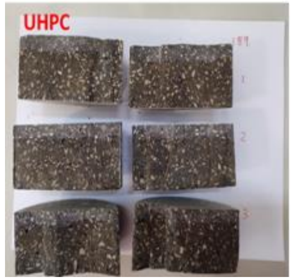
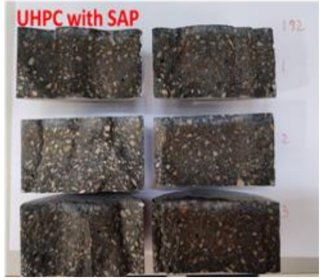
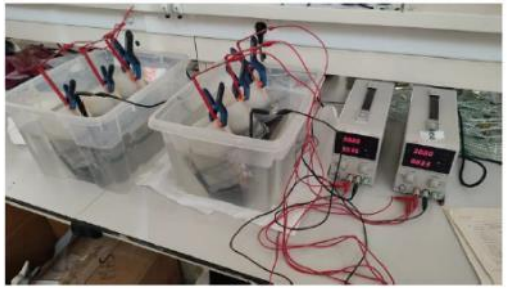
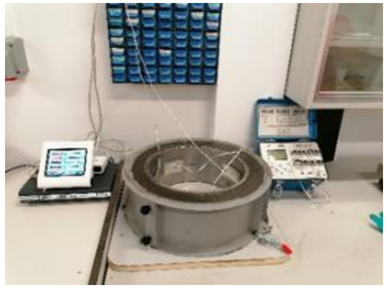
NEW CONCRETE DEVELOPMENTS

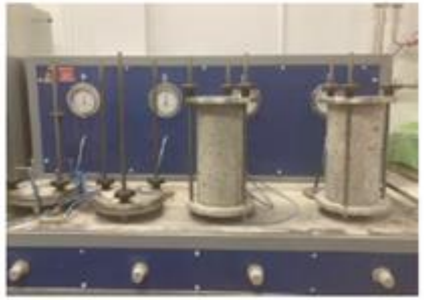
MAREWIND HIGH AND ULTRA-HIGH CONCRETE SOLUTION SUCCESSFULLY REACHED PROJECT OBJECTIVES











Mechanical and durability characterization tests at ACCIONA and CETMA facilities according to the corresponding standards

- **Greener solutions with CO2 footprint reduction.**
- **Improved durability performace than tradictional solution.**
- **Raw material consumption reduction.**

Ballast Prototype

Sensor integration tests at lab scale

Floating Prototype

Buoyancy tests at lab scale for design purposes

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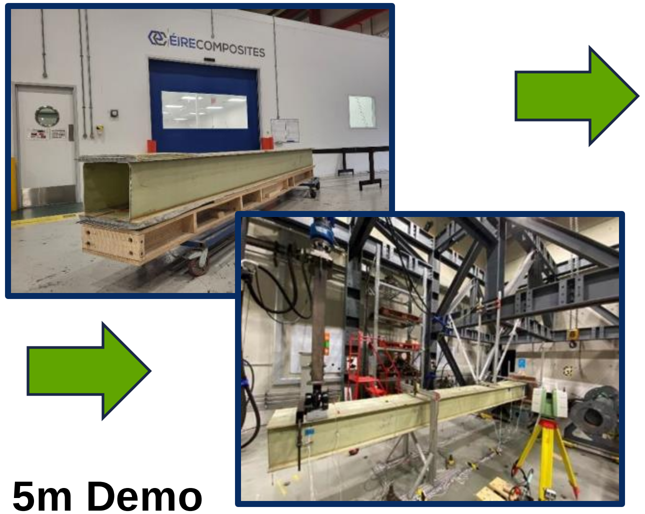
NEW COMPOSITES for BLADES

13-meter WIND BLADE PROTOTYPE was manufactured WITH NEW RECYCLABLE RESIN FOR BLADE COMPOSITES

Coupon manufacture & Test



5m Demo Manufacture & Test

Mould manufacture

13 m prototype

Test Property	Test Method	UD GF/Elium 191 XO/SA	UD GF/epoxy
0° tensile strength (MPa)	ASTM D 3039	770,53	782,00
0° tensile modulus (GPa)		45,20	39
0° compression modulus (GPa)	ASTM D6641	53.96	45.13
In-plane shear modulus (GPa)	ASTM D3518	3.5	3.67

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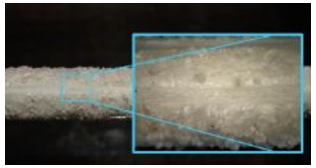
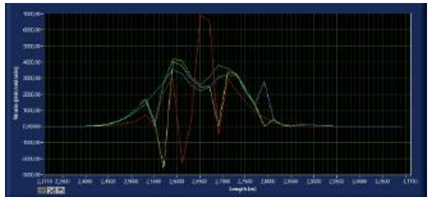
STRUCTURAL HEALTH MONITORING

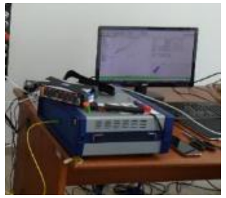
INTEGRATED SENSOR TECHNIQUES SUCCESSFULLY DEMONSTRATED AT LAB SCALE

Implementation and evaluation of FBGS/DFOS for composite technologies and for High and Ultra-High performance concretes and Alkaline Active concretes (AAC)

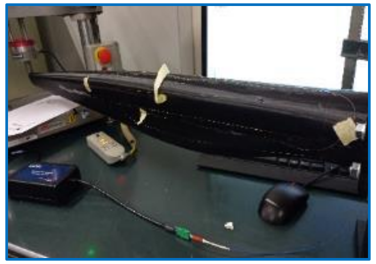
Acquired signal from the SHM system inside the UHPC concrete beam in four different instants of loads

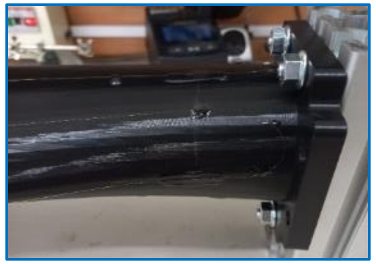




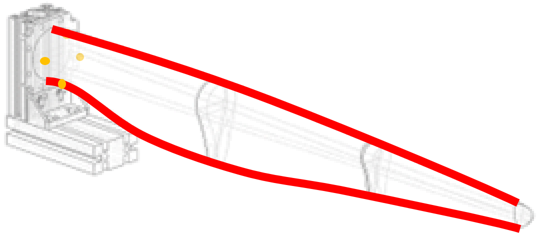


SHM System in Blades

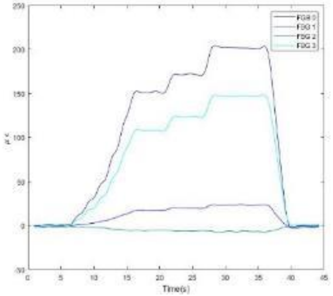




Scaled geometry SHM setup with FBG Strain gauge placement



Sensor placement representation: **DFO Sensors; FBG Sensors**



Material compatibility test

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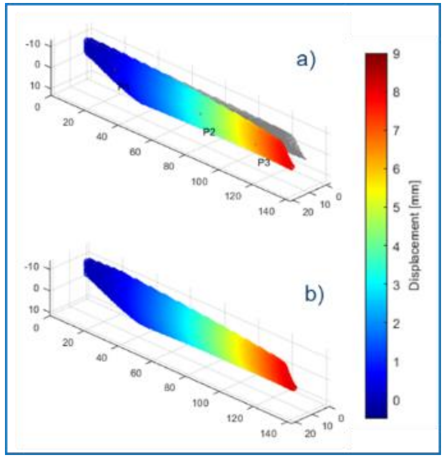
FULL-FIELD TECHNIQUES

FULL-FIELD TECHNIQUES SUCCESSFULLY DEMONSTRATED AT LAB SCALE

Full-field measuring techniques of wind blade working conditions: hardware, measurements and algorithms

Digital Image Correlation

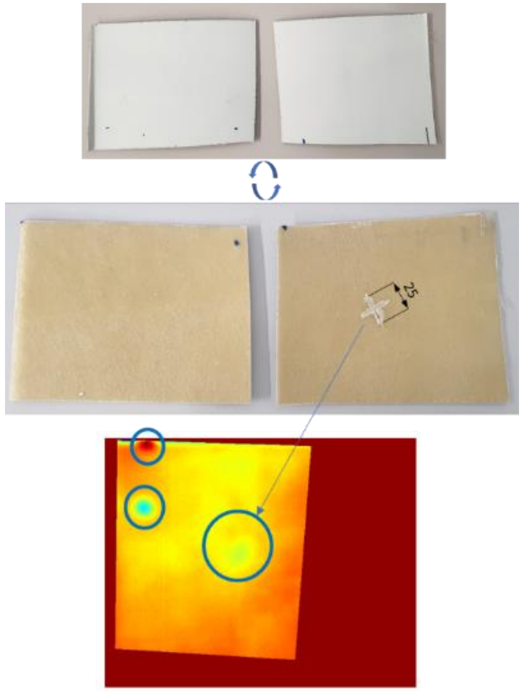
- GNSS Trigger and Synchronized Control solution development
- Moving camera and blade laboratorial setup execution
- DIC displacement measurements with rotating blade was performed



DIC displacement measurements

Thermographic Analysis

- IR Defect detection algorithm development and optimization
- Performance of thermographic analyses on a damaged composite plates used for testing - Glass fibre wind turbine sections



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REAL EXPOSURE OVERVIEW for COATINGS

ANTICORROSION COATING

- North sea (Teesside) EDF
- Northern Spain KOSHKIL
- Atlantic sea (Canary Islands) ENEROCEAN

ANTIFOULING COATING

- North sea (Teesside) EDF
- Mediterranean sea (Banyuls) EDF
- Atlantic sea (Sines Portugal) INEGI
- Atlantic sea (Canary Islands) ENEROCEAN

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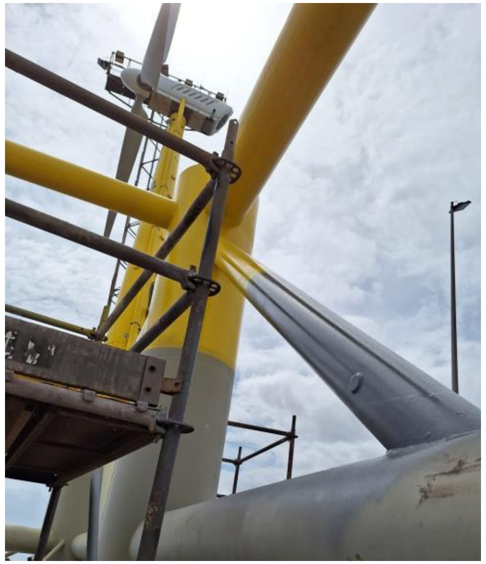
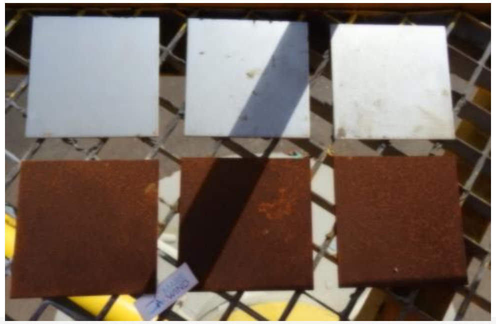
Testing sites: ENEROCEAN -> **Wind2Power floating platform**

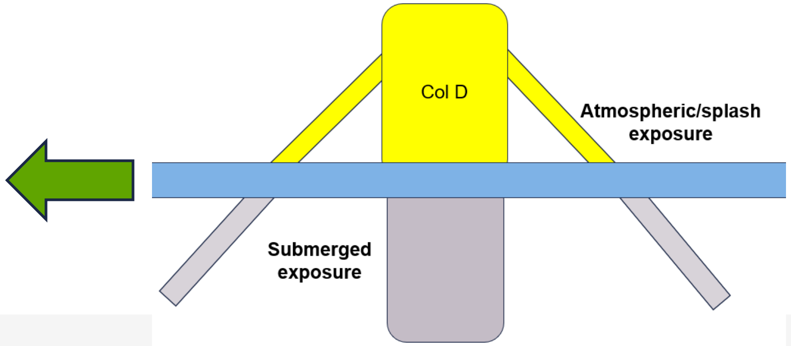
Oblique braces in W2Power platform were coated with the <u>Anticorrosion solution</u>



Canary Islands, South Atlantic Ocean

Coupons coated by TECNAN





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Testing sites: EDF -> **Teesside windfarm**

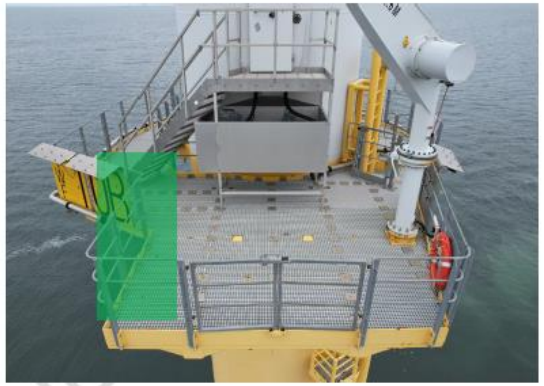
Redcar North Yorkshire (UK)/ North sea

Comparisons including:

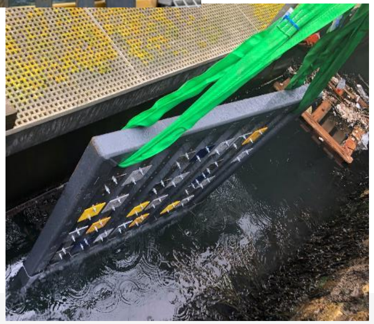
- Coated (MAREWIND)
- Uncoated
- Commercial references

Coupons and fastening elements (TSF) coated by TECNAN

Teesside Externa
Working Platform
Above Water –
‘**Atmospheric’**



Hartlepool Pontoon
(on deck level):
Above Water –
‘**Splash Zone**’



Hartlepool
Pontoon
(suspended in
water): **Subsea**

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Testing sites: KOSHKIL -> Corrosion repair of real wind turbine elements

Direct application systems: electric spray gun and aerosol

VIDEO VIDEO

IN MAINTENANCE AREA, DISSASEMBLED PART (ROTOR HUB)

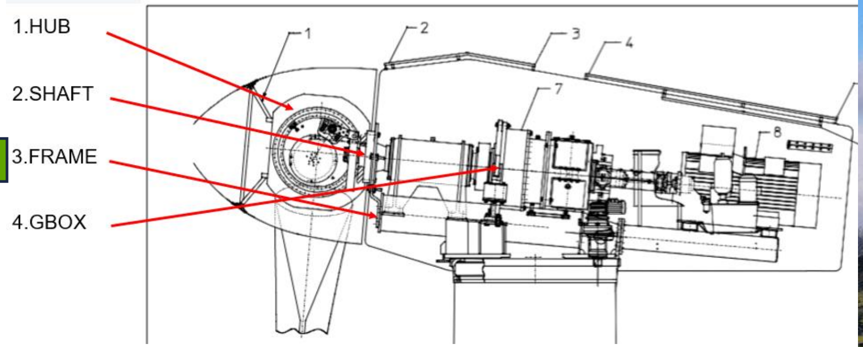
Exposed outdoors in Pamplona Area (North of Spain)

Repair and maintenance operations were carried out in with the new anticorrosion coating

SHAFT

FRAME

GBOX



ARITZ Windfarm in Leitza Area (North of Spain)

INSIDE WINDMILL, IN SITU APPLICATION, ASSEMBLED PARTS

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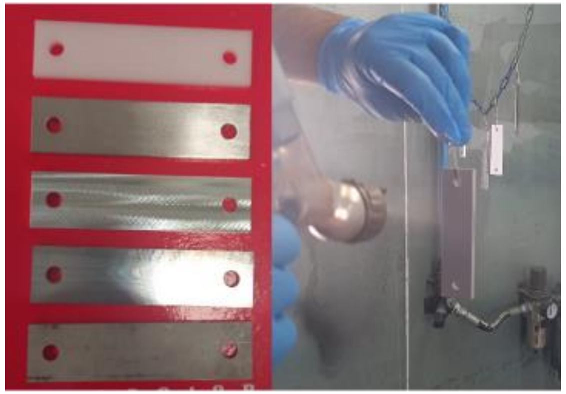
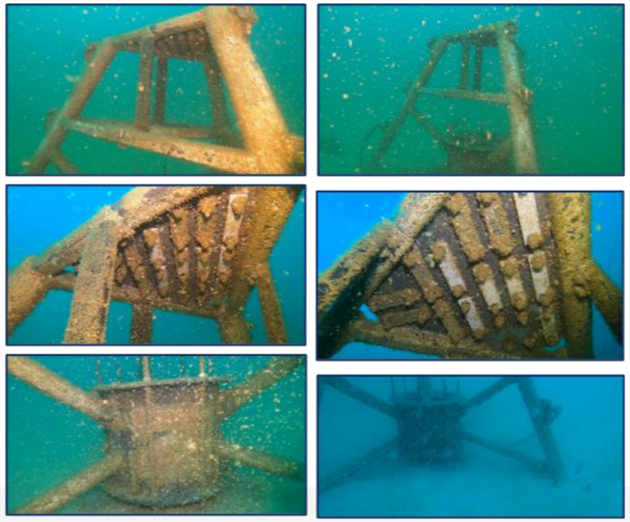
Testing sites: INEGI -> GBS subsea in Sines

North Atlantic Ocean, PORTUGAL



Coupons coated with antifouling (TECNAN) in GBS structure (INEGI)

VIDEO



Comparisons including:
- ❑ Coated (MAREWIND)
- ❑ Uncoated
- ❑ Commercial references

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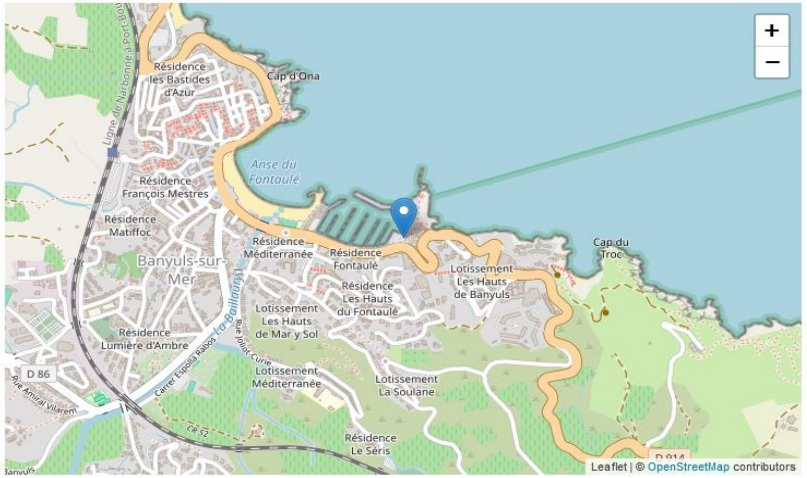
Testing sites: EDF -> Test in Banyuls-sur-Mer

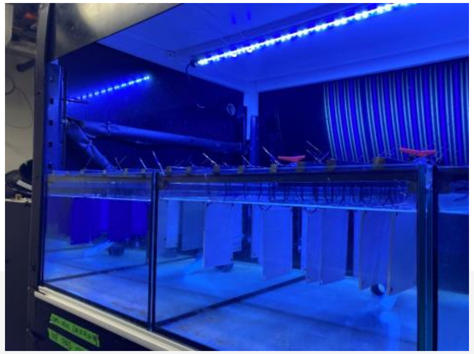
Comparisons including:
- ❑ Coated (MAREWIND)
- ❑ Uncoated
- ❑ Commercial references

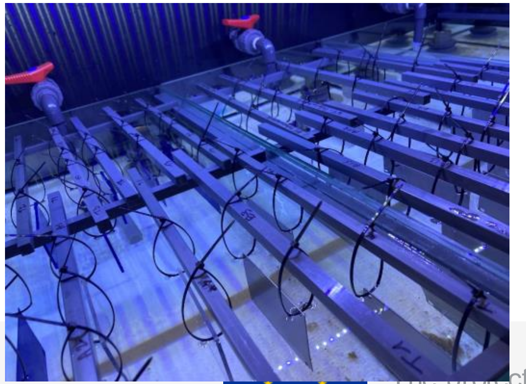
Mediterranean sea, FRANCE

- Banyuls (France) Laboratoire de Biodiversité et Biotechnologies Microbiennes
- Real sea water is used for the essay



Treatment	Substrate	Coupon 1	Coupon 2	Coupon 3	Mean
T1: Transparent antifouling (Marewind)	Polycarbonate (PC)	2	2	2	2.0
	Inox	2	3	2	2.3
T2: Coloured antifouling (Marewind)	Polycarbonate (PC)	1	2	2	1.7
	Inox	1.5	1.5	1.5	1.5
T3: Coloured higher hydrophobicity antifouling (Marewind)	Polycarbonate (PC)	2.5	2	2.5	2.3
	Inox	2.5	2.5	2	2.3
T4: Epoxy primer + antifouling (Marewind)	Polycarbonate (PC)	4	4	4	4.0
	Inox	4	4	4	4.0
T5 : Commercial	Polycarbonate (PC)	3	3	3	3.0
	Inox	4	3	4	3.7
UN: Untreated (controls)	Polycarbonate (PC)	5	5	5	5.0
	Inox	5	5	5	5.0

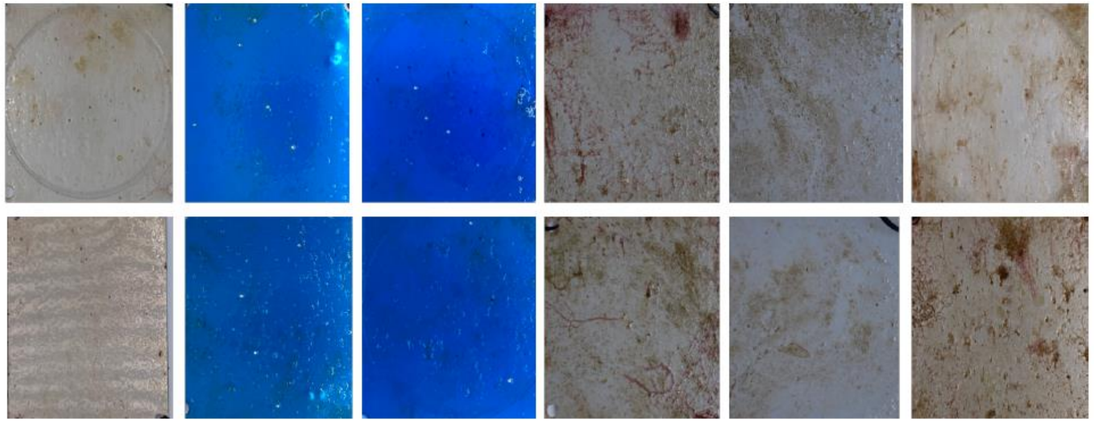




T1 T2 T3 T4 T5 NT

Polycarbonate (PC)

Inox



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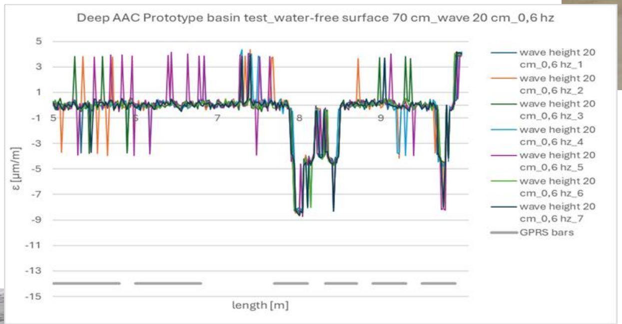
Testing sites: ACCIONA AND CETMA (1/2)-> Validation of CONCRETES at EUMER wave simulation facilities

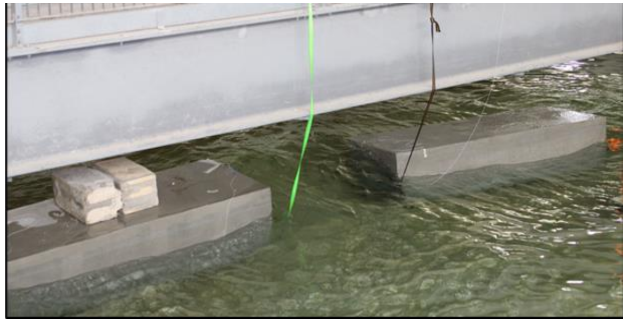
Alkali Activated materials (AAM)

Test conditions 2D Wave flume:
- Water frequencies from 0.5 to 0.8 Hz.
-Wave heights of 0.1m and 0.2m.

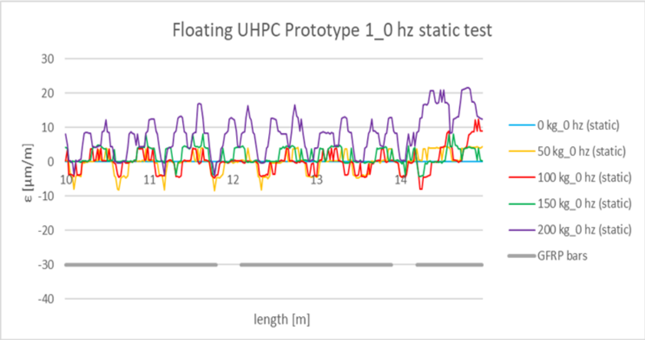


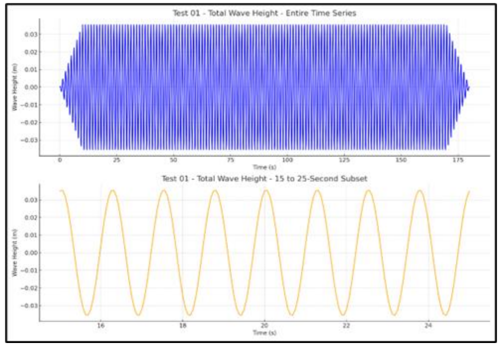
VIDEO

Ultra High Performance Concrete (UHPC)



Test conditions 3D wave basin:
- Water frequencies from 0.5 to 0.8 Hz.
-Wave heights of 0.07m.
-Loads from 0kg to 200kg to analyze the dynamic response of the model under wave influence.



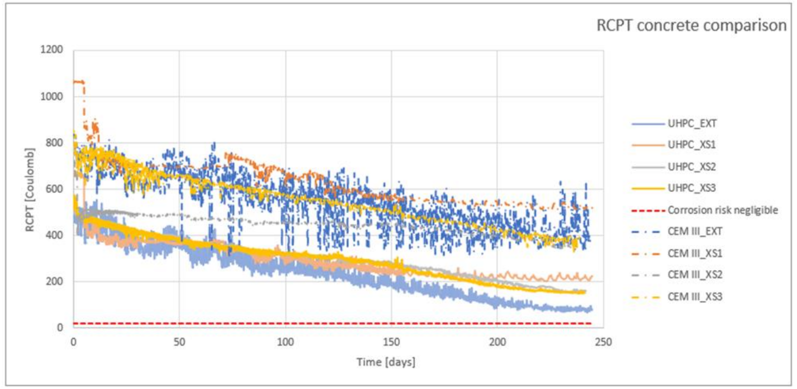


UHPC: all acquisitions were found to be consistent with each other and significant in relation to the expected data. Floating prototypes showed a progressive increase in peak strains as wave frequencies decreased and applied loads increased.

AAC: Present a maximun deformation consistently at the pier reinforcing bars. Channel testing: by varying the test conditions, increases in each of these three quantities caused the peak strain to rise. This resulted in more than a tenfold increase under unfavourable loading conditions Basin testing, the increase in peak strain was solely due to the increase in wave height, wave frequency did not affect strain, which remained almost constant.

Testing sites: ACCIONA AND CETMA (2/2)-> Validation of CONCRETES in REAL EXPOSURE

UHPC **Gijón Harbour,** SPAIN

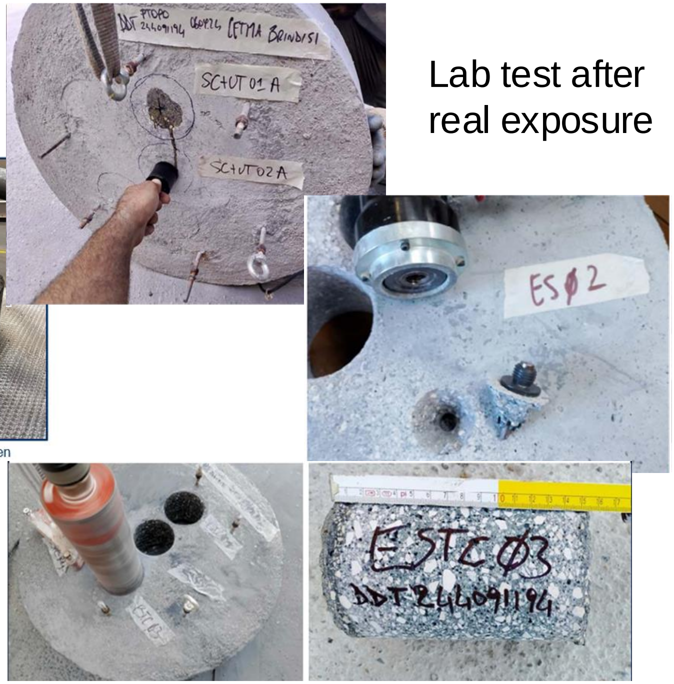


AAM **GBS, Portugal**

Alkali Activated Material concrete ballast specimen

6 months exposure

Lab test after real exposure



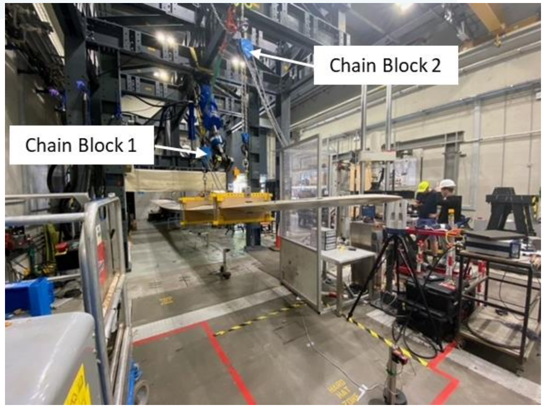
AAC: after 6months exposure in the sea, the **mechanical performance did not decrease**. When the specimens were subjected to accelerated ageing cycles, **no weight loss** was observed, indicating that the specimen did not degrade but, contrary to expectations, <u>losses in compressive strength</u> were found.

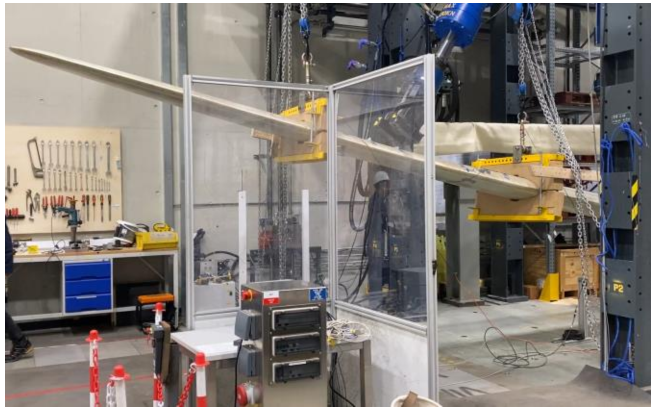
UHPC corrosion: tests are still on-going and will be left on place for longer ages performance analysis. During these months, monitoring results from real environment, concluded that this solution presents a **more durable** concrete solution and presents <u>3 times lower</u> penetrability to chlorides than the standard solution.

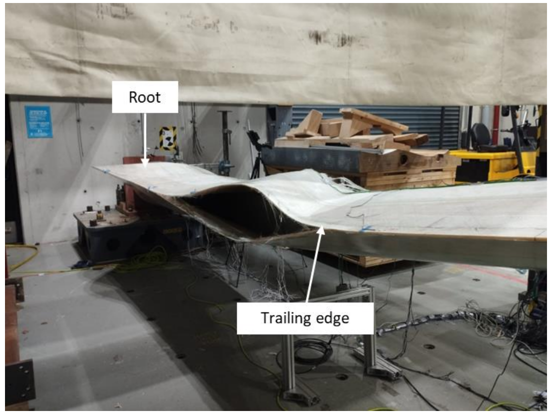
MARE WIND

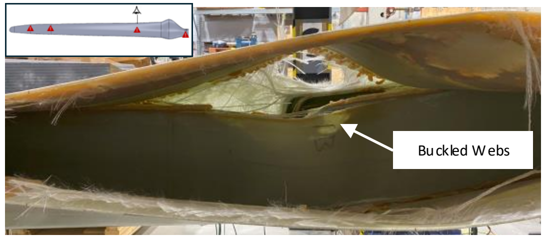
Testing sites: EIRE -> Recyclable blade manufacture validation

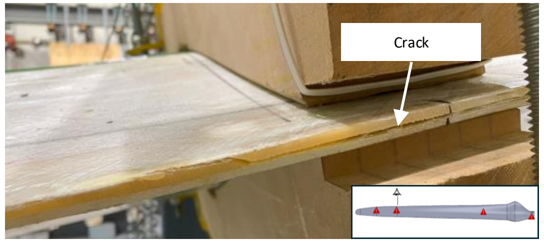
Specific mechanical tests carried out in the Large Structures Testing Laboratory at the University of Galway

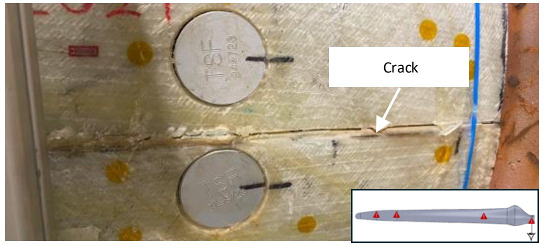




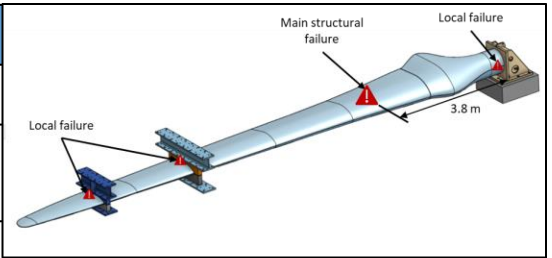








Test	Result	Purpose/Outcome
Static test	Tested up to **70%** of design load	Validate Finite Element Model (FEM)
Fatigue test	Tested up to **500k** cumulative fatigue cycles	Validate fatigue prediction model
Residual static strength test	Blade failed at **165%** of design load.	Identified failure mode and manufacturing defects prone to damage initiation: Increased blade weight and inconsistent bond line caused by cure ply thickness error during manufacture, which ultimately led to bond line failure and web buckling. Also, dry patch repair resulted in a weakened zone with delamination in the skin component around failure zone.



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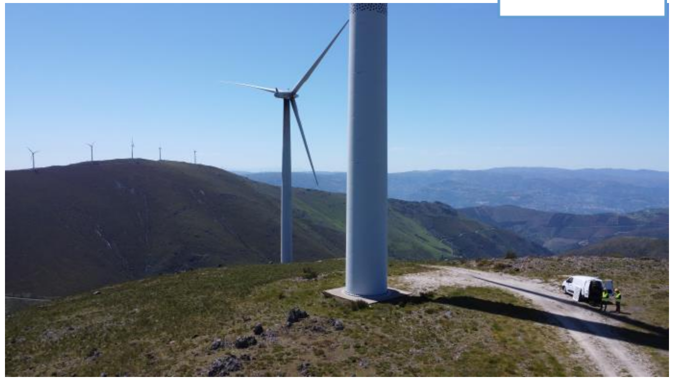
Testing sites: INEGI -> SHM for blades with UAVs

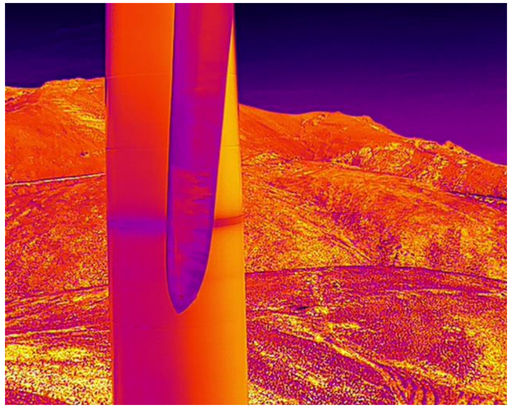
Serra do Marão, Portugal

(Parque Penedo Ruivo no Marão)

VIDEO

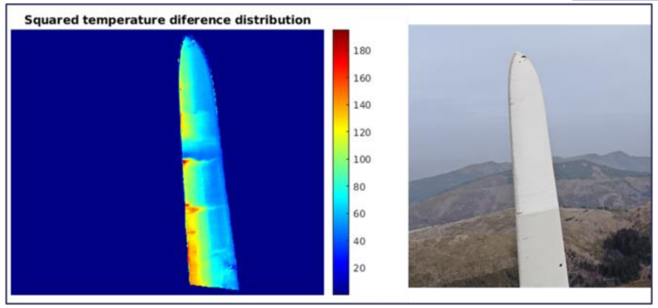


VIDEO

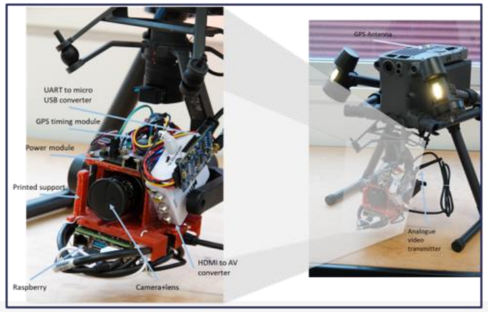


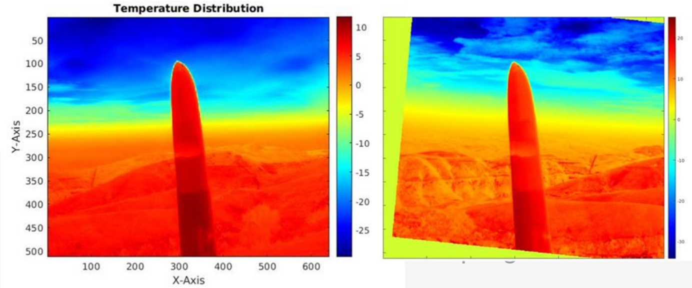
Defined Test Site Location:41°14'05.2"N 7°54'25.4"W

VIDEO



Drone photo taken by INEGI in pre-trials at the defined Test Site Location





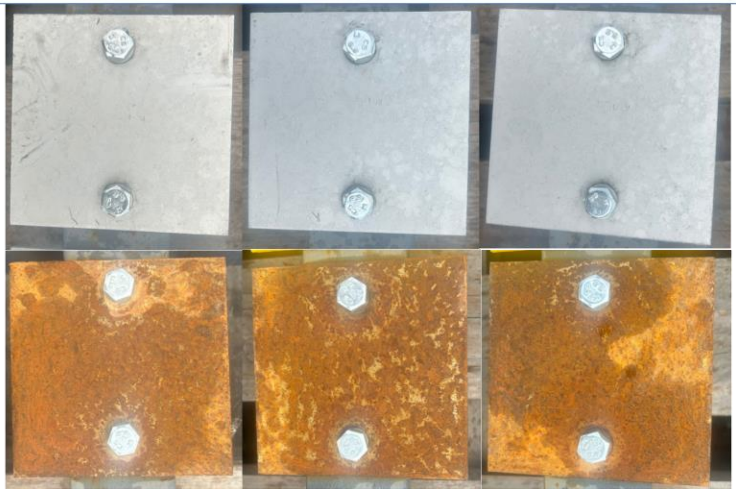
rom the European Union's Horizon 2020 research
nt Agreement N° 952960

Highlights from results - COATINGS

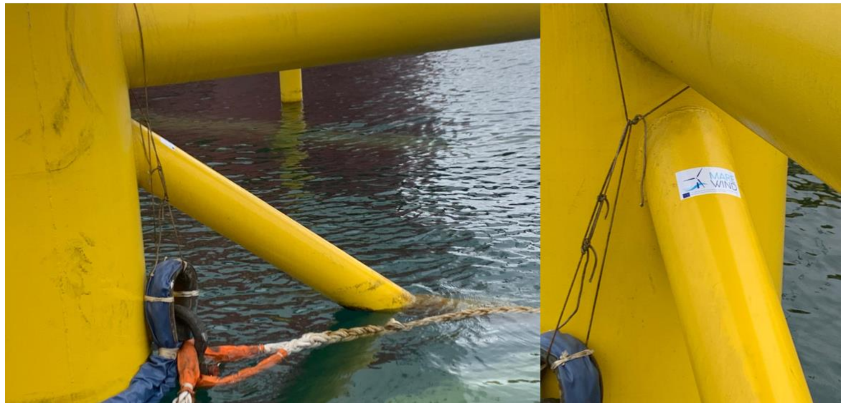
ANTICORROSION COATING:

- Good performance under **real marine exposure** for more than 8 months in different sea locations. Treated parts or coupons coated with the novel low thickness anticorrosion coatings, are not damaged by corrosion.
- The anticorrosion coating shows good **compatibility with other commercial coatings**, for instance with the yellow paint in compliance with current maritime regulations for platforms.
- In the case of **repair and maintenance actions**, the coating demonstrated versatility during application, offering both an aerosol format option as well as other portable spray techniques, which provided good surface coverage with the novel coating.

3 LAYER SYSTEM VS NON TREATED SAMPLES (Teesside Windfarm) Atmospheric Exposure



COMPATIBILITY OF ANTICORRSION COATING UNDER COMMERCIAL PAINTS



PORTABLE SPRAY GUN APPLICATION

START

AFTER 4 MONTHS EXPOSURE

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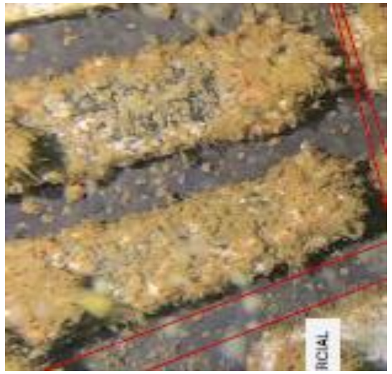
Highlights from results - COATINGS

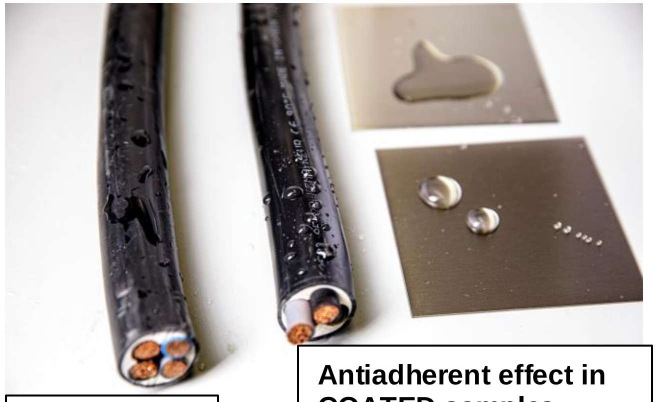
ANTIFOULING COATING:

- Significant **delay in biofouling growth** in treated samples both in metal and polymeric material compared to uncoated.
- The one-layer low thickness coating from MAREWIND has the advantage over commercial solutions of providing **good adhesion** to various substrates, whether metallic or polymeric.
- The anti-adherent coating, offers versatility for incorporating **colour** in case is needed by potential end users.
- This coating shows **good compatibility** for application over commercial epoxy-based primers, according to the latest tests conducted in real environments.

COATED

UNCOATED





UNCOATED

Antiadherent effect in COATED samples

COLOURED MAREWIND ANTIFOULING TREATMENT

POM

UNCOATED

BIOCLEAN ECO

MAREWIND ANTIFOULING (cross cut test)

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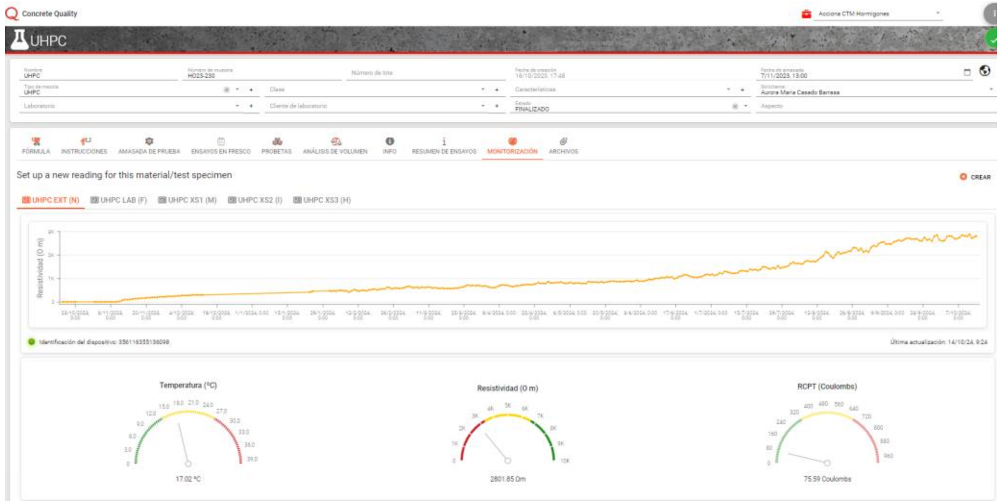
Highlights from real exposure results - CONCRETE

UHPC Corrosion test

- **UHPC**: presents 33% reduction in cement used compared to standard leading to a more sustainable solution than the commercially available solution. 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.



AAM Ballast semi-destructive and destructive tests

- After 6 months of immersion real condition exposure no reduction in compressive strength was observed

- After a further 200 freeze-thaw cycles in a climate chamber, No loss in weight was observed, indicating that the structure of the samples was not compromised

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Highlights from results - COMPOSITES

NEW RECYCLABLE COMPOSITES:

- Low viscosity Elium resin demonstrated ability to infuse 70 mm thick root sections.
- Successfully manufactured 13 m recyclable wind blade prototype.
- Negligible fatigue damage observed after 500k cycles
- Achieved 165% of design load at failure, despite 34% extra blade mass.

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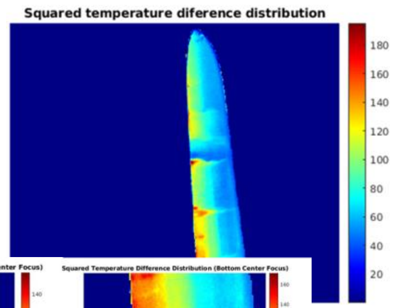
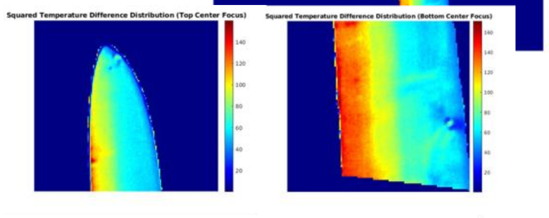
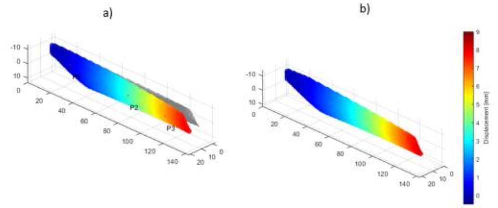
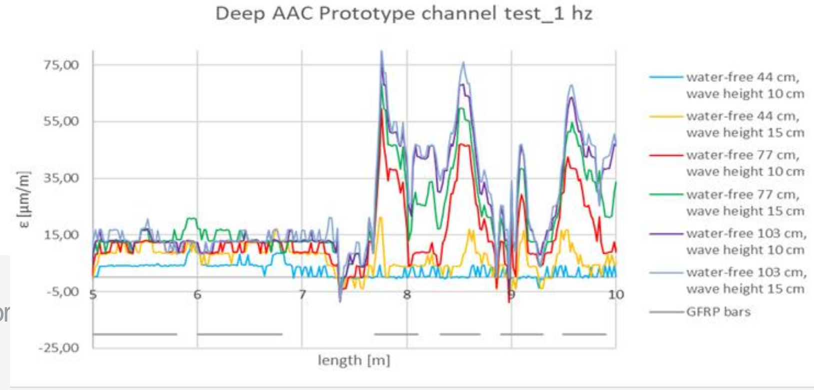
Highlights from results - SHM









UAV Conclusions:

- Experimental tests in the field have shown promising results, confirming the reliability of the DIC method, which effectively monitors turbine blade displacement and geometric changes during operation using UAVs.
- Thermography tests successfully detected heat transfer variations caused by defects, showcasing its capability to identify potential blade damage.
- Both methods yielded positive results and require further validation and optimization for broader application in wind turbine monitoring.

Blade FBGs/DFOs Conclusion:

- The structural health monitoring system utilizing Distributed Fiber Optic Sensors (DFOs) and Fiber Bragg Gratings (FBGs) has been successfully implemented in the developed wind turbine blade.
- The results obtained from the fiber optic SHM are consistent with those from the conventional sensing system, demonstrating strong system performance.
- Both sensor types have shown positive results and are regarded as suitable solutions for integration into wind turbine blade monitoring

Concrete/ Structures:

- Fiber-optic monitoring system provided a lot of useful information to understand the state/behaviour of the structures under different loading conditions.

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Get in touch with us for more information!

CONTACT US

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Partners

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Thank you!

MAREWIND CONSORTIUM

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