TURBO newsletter Jan-2025 (#4)

Towards turbine blade production with zero waste

Welcome to the fourth TURBO project newsletter!

Following the consortium 24M plenary at ARDITEC in Nice (image left), this edition contains technical updates on several TURBO research topics discussed at the meeting:

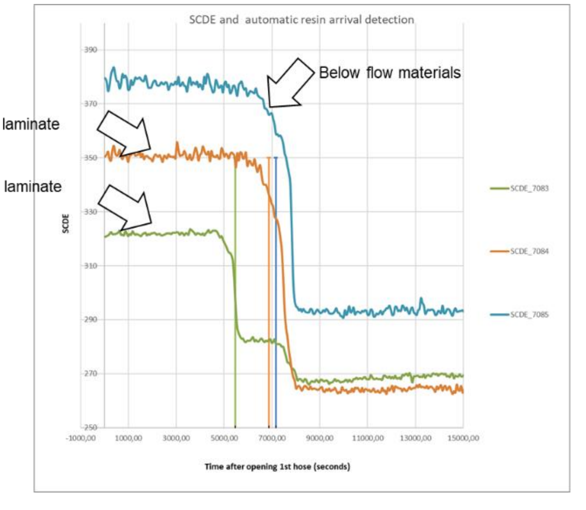
- SGRE progress on the infusion of half shell wind turbine blade cross sections
- ARDITEC Life Cycle Assessment (LCA) analysis of TURBO impacts
- Predictions of the cure shrinkage in blade fabrication and modelling of cure-induced wrinkles from DTU-W
- Defect detection in wind turbine blade coatings using machine learning at UPV.

For more info visit the website: https://turboproject.eu

Or join the TURBO LinkedIn group: https://www.linkedin.com/company/turbo-project

Infusion of half shell wind turbine blade cross sections

Two infusions have been performed on a section representing a cross-section at 10 m from the wind turbine blade (WTB) root. The first infusion was performed using a standard Siemens Gamesa Renewable Energy (SGRE) infusion strategy. The second trial was modified incorporating new approaches to reduce errors and repairs. The progress of the infusions was recorded by multiple methods (including visible light image inspection, thermocouples and flow front detection) and the data was fed to large-scale infusion models in PAM RTM to validate the initial assumptions. This concerns *e.g.* the timing of inlets and placement of auxiliaries *etc.*



SGRE plot of the flow front detection

Consortium

DTU, SIEMENS Gamesa, NORBLIS, National Composites Centre, synthesites, ARDITEC, Universitat Politècnica de València, esi get it right, cpi, VIVID Components

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Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or UKRI. The European Union or UKRI cannot be held responsible for them.

Casting of the first specimen

De-moulding of first the first specimen

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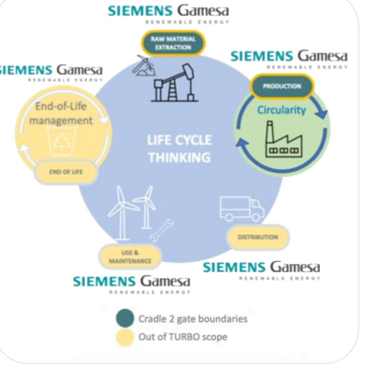
Life Cycle Assessment concept in TURBO

The manufacturing of composite blades, essential in various industries, relies on sophisticated resin infusion and coating processes. Despite modern techniques, defects remain a challenge, leading to re-work, waste, and repairs. The TURBO project aims to revolutionise this domain by minimising defect formation through advanced process simulation, monitoring, and control. Additionally, TURBO aims to enhance defect identification with innovative non-destructive testing (NDT) methods and to pioneer novel repair strategies for composites and coatings.

In its first phase (M1-M18), TURBO focused on creating a baseline scenario to benchmark the environmental, economic, and social benefits of its innovative technologies. Deliverable D11.1 (public report) is the reference for Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (S-LCA) methodologies. This comprehensive approach defined the system goals, boundaries, and functional units while assessing the environmental and socio-economic impacts of SGRE’s current manufacturing processes. By identifying key performance indicators (KPIs) and hotspots, the project sets the stage for achieving a zero-defect WTB manufacturing chain.



TURBO life cycle concept

Interim findings highlighted environmental hotspots and potential socio-economic impacts, using primary and secondary data sources. Sensitivity analyses have helped identify key parameters and evaluate green chemistry alternatives to improve outcomes. As the project progresses, these insights will guide large-scale implementation in industrial environments and integration into SGRE’s production line in the final demonstration, aiming to achieve sustainable and efficient manufacturing practices.

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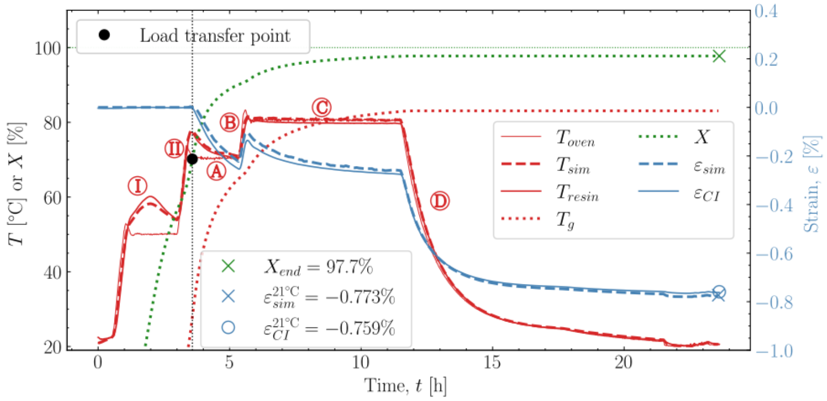
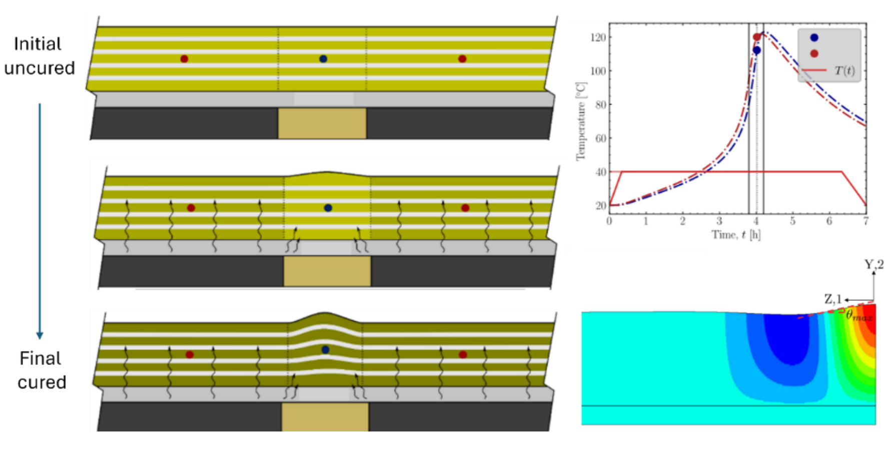
Predictions of the cure shrinkage

Following the cure-kinetic resin characterisation described in Newsletter #1, *in situ* cure-shrinkage characterisation of the selected resin system used in TURBO has been performed at DTU Wind using glass optical fibre with fibre Bragg gratings. The temperature and degree-of-cure-dependent thermal expansion and contraction have also been determined using the same test set-up. Parallel with these material characterisations, a user-defined material model has been implemented in the commercial finite element code *Abaqus*. Based on this model, including the experimentally determined material parameters, it is possible to make precise predictions of the cure shrinkage as a function of the applied temperature, T_{oven}, outside a 4 mm thick resin sample. Using this temperature as input in the numerical model, a precise prediction of the *in situ* development of the strain experienced by the embedded fibre gratings is achieved where the solid blue curve shows the measured values, while the dashed blue curve shows the predictions. The final load-transferred cure-induced strain is for the specific case found to be around 0.8 % strain. In addition, the exotherm is also well predicted (thick solid and dashed red curves) during the two initial pre-curing temperature jumps up to 50°C and 70°C, respectively, marked with (I) and (II) on the curve.



Experimental measured and numerical predicted temperature and cure shrinkages of the investigated TURBO resin system.

Modelling cure-induced wrinkles



A numerical model has been developed at DTU Wind to predict the formation of cure-induced wrinkles. A manufacturing-developed wrinkle formed in the load-carrying laminates in WTBs is critical. It can significantly lower mechanical performance, such as fatigue resistance, compression strength, and stiffness, lowering the buckling resistance.

The numerical model is developed for the TURBO project based on a well-characterised resin system regarding the cure-kinetic properties, the complex dependency of the thermal expansion coefficient on the temperature and degree of cure and the stiffness build-up during the resin curing. Putting those properties together in a user-defined material model, again implemented in the commercial finite element code *Abaqus,* makes it possible to model the development of cure-induced wrinkles. The sketch to the left of the figure above demonstrates how a wrinkle can form in the event of uneven heating.

Such uneven heating can be caused at mould joint sections, as simulated here, isolating inserts such as the polymeric foam or balsa wood core materials used in sandwich panels present in the blade's aerodynamic shells, or due to thickness variations of the laminates. Even minor fluctuations can lead to large temperature differences inside the curing laminate due to the exothermic curing of the resin system. For the specific 50 mm thick curing laminate, a mould temperature of 40°C with a slightly lower temperature in the middle is seen to lead to a significant exothermic reaction, resulting in temperatures up to 120°C inside the laminate. Consequently, the outer higher temperature and thus faster curing regions will thermally expand and compress the (not yet cured) cooler central region, thus developing a central wrinkle, which for this specific case has a final wrinkle inclination angle of 10°. The shape of the final predicted wrinkle shape is shown in the lower right corner of the figure. In other studies, a wrinkle size with such a magnitude has been shown to influence substantially the mechanical performance, lowering the compression strength to by >60 % reducing fatigue lifetime by more than an order of magnitude. The results of the study have been presented at the European Conference on Composite Materials in Jul-2024 and at the Düsseldorf Wind Turbine Blade Conference in Dec-2024.

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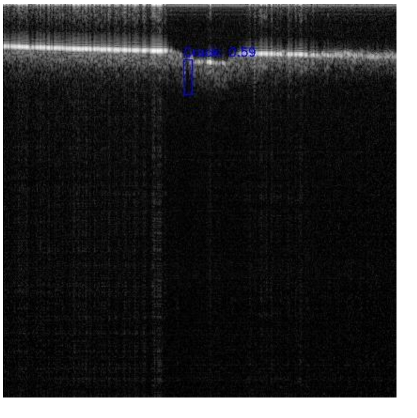
Advancing defect detection in wind turbine blade coatings

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

The TURBO project, in collaboration with the Universitat Politècnica de València (UPV), is breaking new ground in the development of automated defect detection algorithms adapted to Optical Coherence Tomography (OCT) and thermography images. These advances are aimed at improving the manufacturing and maintenance processes of WTBs, ensuring higher quality coatings and more efficient repair strategies.



Example of defect detection in an OCT image of a wind turbine blade sample.

OCT for sub-surface defect detection: One of the main focuses of this initiative is the development of an algorithm capable of identifying sub-surface defects using OCT technology. This approach is designed to locate significant defects in multiple layers of turbine blade materials. By leveraging the high-resolution imaging capabilities of OCT, the algorithm provides precise localisation of defects that could otherwise compromise the structural integrity and performance of the blades over time.

Thermography for surface defects during manufacturing: In addition to OCT-based solutions, the project also explores thermographic imaging for intermediate manufacturing processes. Thermography provides a non-invasive and fast evaluation method, ideal for real-time quality control during blade production. The development of a complementary detection algorithm for this modality aims to effectively identify surface defects.

From detection to improved repair strategies: By integrating these state-of-the-art imaging technologies and detection algorithms, the TURBO project aims to optimise repair strategies for defects that appear during the manufacturing of wind turbine blades. Understanding the implications of surface and sub-surface defects is crucial to developing robust solutions that improve durability and reliability.

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