TURBO newsletter Jun-2024 (#3)

TURBO

Towards turbine blade production with zero waste

Welcome to the third TURBO project newsletter!

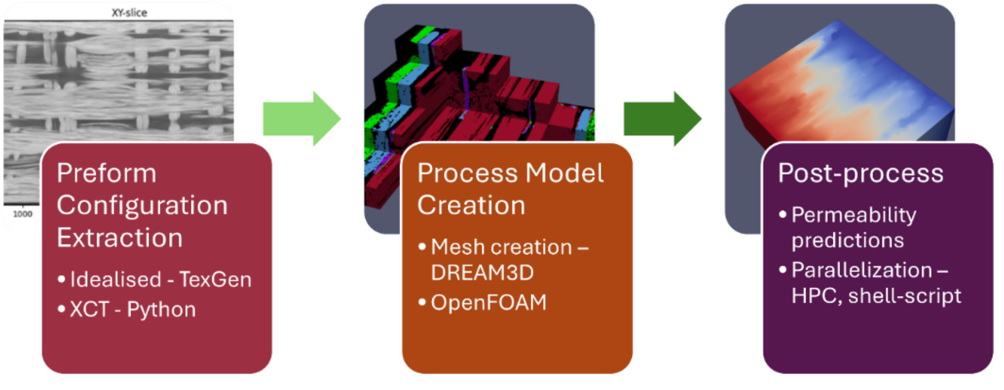
This edition contains technical updates on several TURBO research topics:

- Microscale model for prediction of local flow behaviour at DTU Construct
- DTU Electro development of a novel supercontinuum laser for MIR OCT
- NCC work on small-scale infusion trials for simulation validation
- Other NCC research on thermography inspection of thick GFRP laminates.

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

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

Microscale model for prediction of local flow behaviour



A schematic flow diagram showing the three main stages in the DTU-C simulation methodology and the software packages used in each phase.

The TURBO research team at DTU Construct focuses on the establishment of workflows for predicting the local flow behaviour during the resin transfer moulding (RTM) process in the manufacture of wind turbine blades. Three workflows have been established, utilising multiple software packages, for both idealised and real geometries of preforms used in TURBO. In fact, the workflow is demonstrated on idealised plain-weave geometries as well as on both idealised stitched non-crimp fabrics (NCF) and realistic voxel geometries of NCF.

Consortium

Coordinator	Ole Bang	Technical University of Denmark	oban@dtu.dk
Admin	Bruce Napier	Vivid Components Germany	bruce@vividcomponents.co.uk

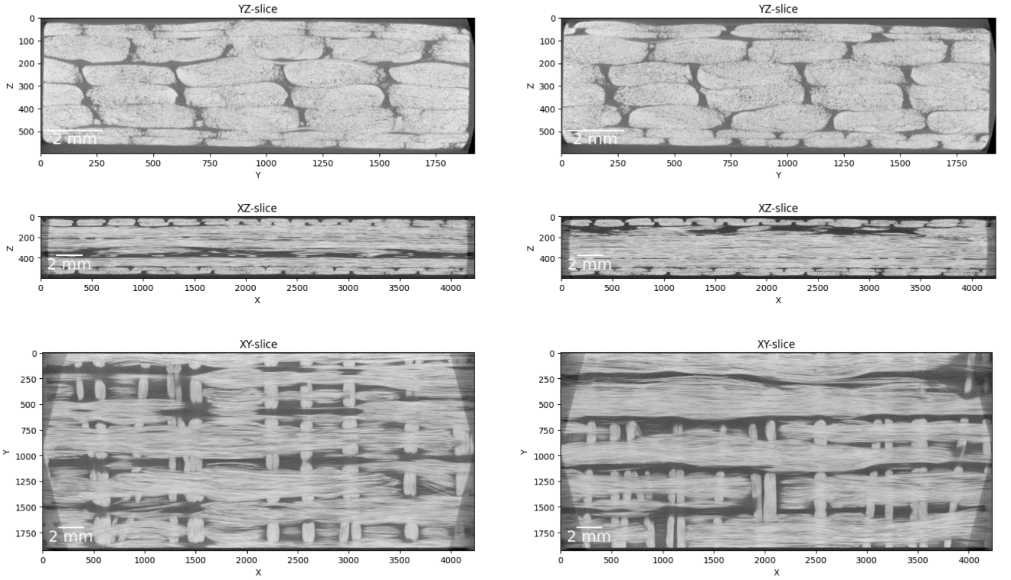
Funded by the European Union

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101058054 (TURBO).This includes funds from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee [grant numbers 10037822, 10042318 and 10044756] as part of the topic ID HORIZON-CL4-2021-TWIN-TRANSITION-01-02.

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.

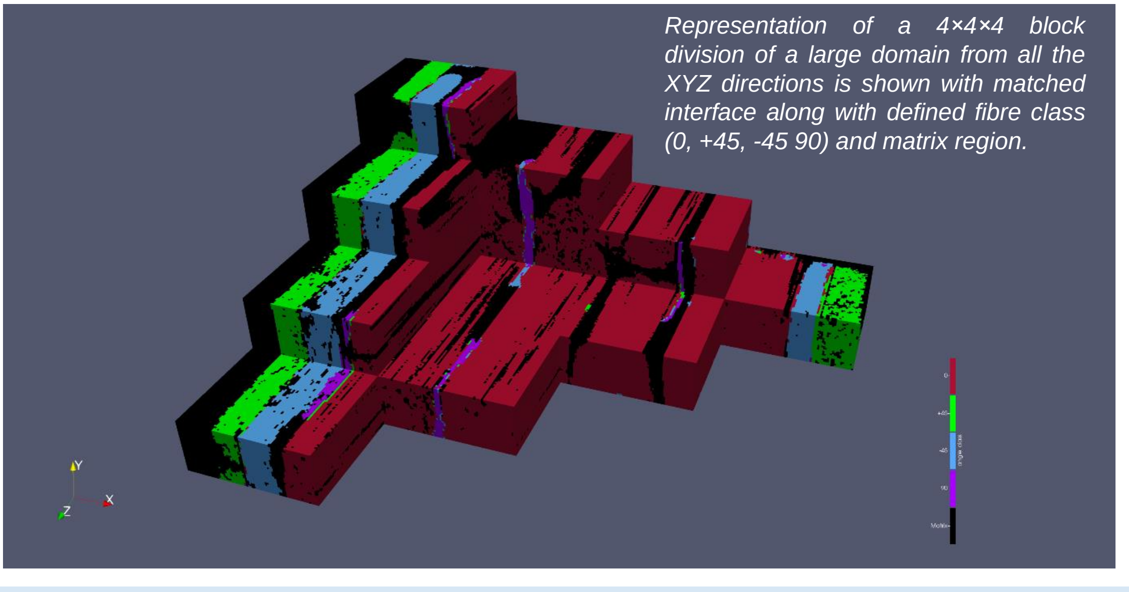
The underlying fluid flow model for the micro-meso-scale permeability prediction couples the Navier-Stokes models in the inter-yarn free regions with the volume-averaged Darcy Forchheimer flow models in the intra-yarn regions. Steady state simulations are then established with appropriate boundary conditions to predict the saturated micro-meso scale permeability of the modelled domain. Domain decomposition methods are utilised for solving the fluid flow problem, and inverse Darcy's law formulation is utilised for calculating the equivalent permeability tensor.

The simulation used the OpenFOAM open-source CFD solver, employing parallel processing to accurately predict the permeability of a large domain achieved by stitching together 64 inter-connected blocks. This approach incorporates intricate details such as local fibre orientations and volume fractions. A shell script was developed to automate the entire workflow, from TexGen and XCT-scan to DREAM3D, MATLAB, OpenFOAM, and Paraview.



Raw images of XCT Scan, stitching of multiple blocks and the pressure profile in CFD simulation. The YZ, XZ and XY slices of the original XCT scan before thresholding are shown.

In the upcoming phase of work, parametric mapping will be conducted to facilitate reduced-order modelling and analyse the micro-flow behaviour resulting from local fibre displacement during infusion. A selection of raw images of XCT Scan, stitching of multiple blocks and the pressure profile in CFD simulation are shown opposite.



Representation of a 4×4×4 block division of a large domain from all the XYZ directions is shown with matched interface along with defined fibre class (0, +45, -45 90) and matrix region.

For more info, please contact Debabrata Adhikari debaa@dtu.dk

DTU Electro supercontinuum laser for MIR OCT

Motivation

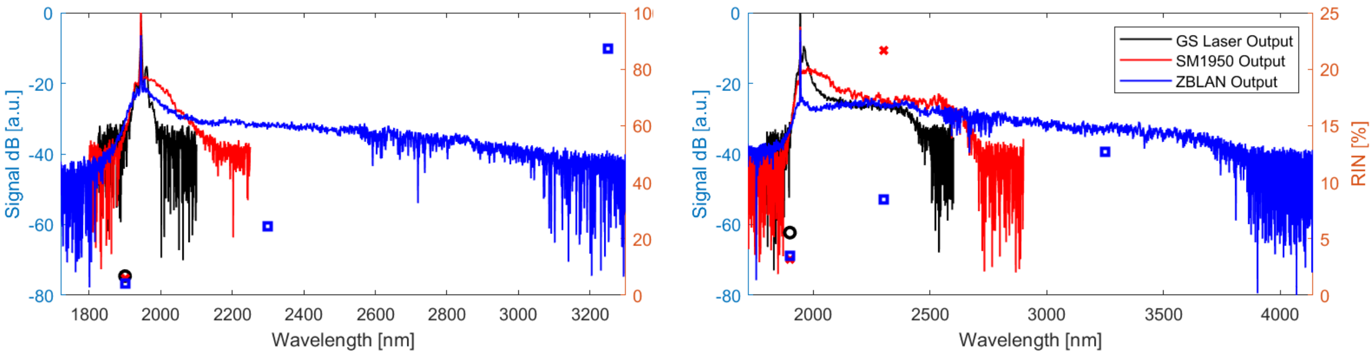
- Low-noise mid-infrared (MIR) supercontinuum laser sources are desirable for optical coherence tomography (OCT) applications where they can exhibit reduced scattering and thus deeper sample penetration compared with conventional near-IR (NIR) OCT.
- Axial resolution in OCT is inversely proportional to the source bandwidth, thus a wide bandwidth is desirable. TURBO targets a very broad spectrum covering 2-5 μm.

Implementation

- The MIR supercontinuum laser will be generated through soliton dynamics resulting from pumping ZBLAN fibre in the anomalous region with pulses from a 1946 nm source.

Initial Supercontinuum Results

- The figure below shows the observed supercontinuum using the 1946 nm source to pump 1 m of SM1950 fibre cascaded with 4 m of ZBLAN fibre at 1 MHz (left) and 10 MHz (right).



Measured supercontinua from the gain-switched 1946 nm source, 1 m SM1950 fibre followed by 4 m of ZBLAN fibre at 1 MHz and 10 MHz. Additionally, noise measurements are displayed at specific locations across the spectrum.

- -30 dB broadening to 2750 MHz may be observed when pumping the cascade at 10 MHz with an average power of 2.63 W, and further out to 3550 nm when pumping the same cascade at 1 MHz with an average power of 1.17 W.
- The increased broadening at 1 MHz is expected due to higher peak power at this lower repetition rate.
- Pulse-to-pulse noise measurements are also displayed at three points across the spectrum: 1.9 μm, 2,3 μm and 3.25 μm, with respective values of 3.4 %, 8.5 % and 12.7 % at 1 MHz, and 4.1 %, 24.3 % and 87.4 % at 10 MHz.

Outlook

- In order to increase the spectral broadening out to 5 μm the 1946 nm source will be optimised at 1 MHz with a target average power level of 3 W.
- Furthermore, the specific composition and length of supercontinuum generation fibers will be optimised.

For more info, please contact Callum Robertson Smith caros@fotonik.dtu.dk

Small-scale infusion trials for simulation validation

TURBO is aiming to reduce the occurrence of defects during production of wind turbine blades, specifically those arising during the infusion and cure of the complex, sandwich composites which form the blade structure. The core of these sandwich composites is made from kits of balsa wood panels. NCC have been conducting small-scale (~1.5 m × 1.5 m) physical trials to investigate the effect of balsa core placement and tool curvature on the flow behaviour of resin during the infusion process.

Laminates comprising a multi-layer glass fibre skin and balsa panels have been performed on curved (see Figure 1) and flat moulds with transparent mould surfaces to enable observation of resin flow from either side of the laminate. Initial results have confirmed that the racetrack effect created by gaps between balsa panels is significant, creating a localised advance in the resin flow front (see Figure 2) – this behaviour is expected to contribute to defect formation during wind turbine blade production.

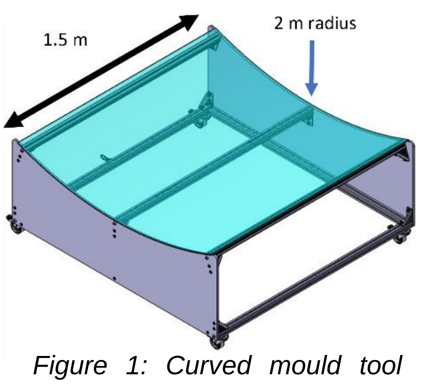


Figure 1: Curved mould tool with transparent mould surface.

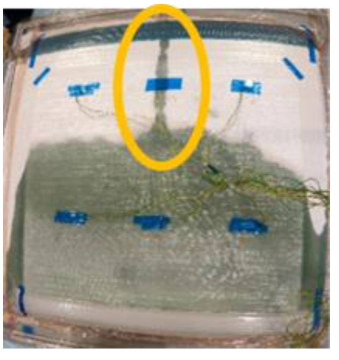


Figure 2: Flat infusion with a nominal gap between balsa panels, highlighting the advanced flow front.

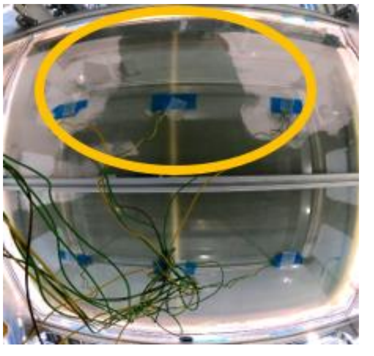


Figure 3: Curved infusion with an equivalent gap between balsa panels, highlighting the advanced flow front.

It has also been observed that the grooved balsa core acts to distribute resin throughout the laminate, adjacent to the glass fibre skin. This effect is evident in the comparison of flat (Fig. 2) and curved (Fig. 3) infusions. Curvature of the balsa panels opens up V-channels perpendicular to the direction of resin flow, which appears to result in a less localised advance in flow front as resin is distributed away from the inter-panel racetrack. These small-scale trials have also been used as a testbed for the novel, flexible resin arrival sensors developed by CPI for TURBO. These capacitive sensors can be seen taped to the bag and mould surfaces in Figs 2 and 3 respectively and have been shown to detect the presence of resin within the laminate without requiring direct contact with the resin itself. Planning is underway for the next scale of infusion trials, with a larger curved mould tool to enable investigation of resin behaviour over distances that are more representative of wind turbine blade infusions. The first handful of trials have already been conducted on an intermediate scale flat tool to better understand resin behaviour over greater distances to inform the design of the larger scale mould.

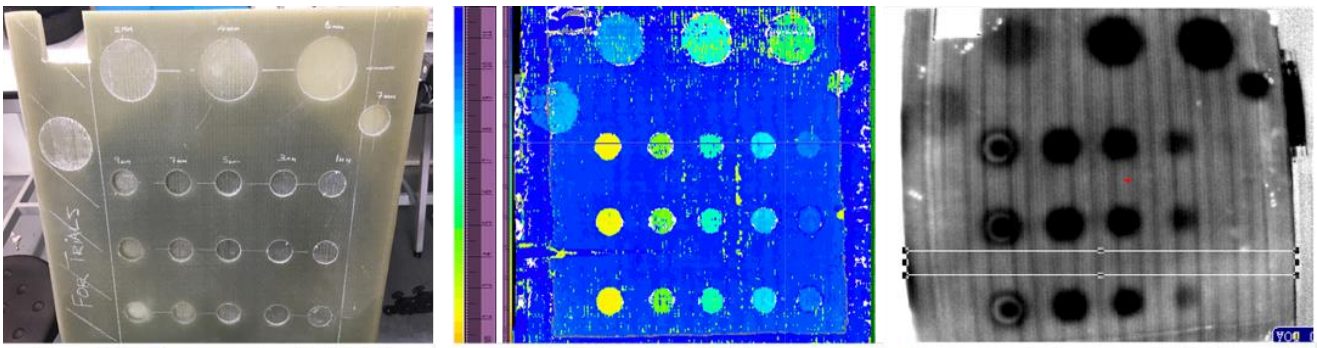
For more info, please contact Dan Griffin Dan.Griffin@nccuk.com

Funded by the European Union

NATIONAL COMPOSITES CENTRE

Thermography inspection of thick GFRP laminates

Inspection of a composite wind turbine blade structure once it has been removed from the mould tool is heavily reliant on manual, visual inspection, with ultrasonic testing (UT) performed only on a few critical regions. This visual inspection process is subjective, labour intensive, and results in low resolution data about manufacturing defects. TURBO is assessing the viability of active thermography (*aka* infrared NDT) as an automatable, high-resolution replacement for visual inspection. To date, trials conducted at NCC have focussed on the inspection depth penetration of transient thermography as a function of heat-up time in monolithic glass fibre composite panels. Initial results using a 12 mm thick reference panel have shown that artificial defects (*i.e.* drilled flat-bottomed holes) with a width of 30 mm can readily be detected at a depth of 8 mm below the inspection surface, as shown in Fig. 4.



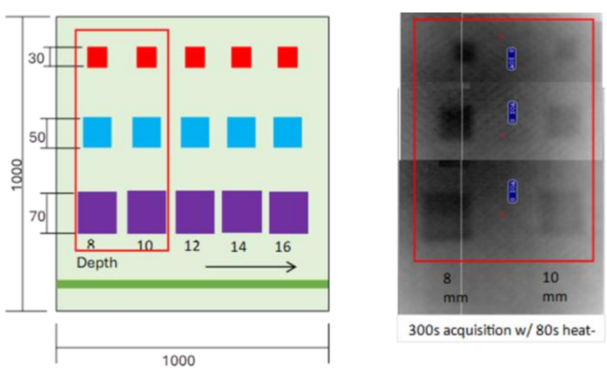
12 mm GFRP reference sample with drilled flat-bottomed holes

UT scan of reference sample (mirror image)

Thermogram of reference sample (final frame of 160s acquisition w/ 80s heat-up, mirrored)

Figure 4: Image of 12 mm reference panel, corresponding UT scan and thermogram.

Similar results have been generated for artificial delaminations (PTFE patches inserted into the glass fibre preform) in 30 mm thick monolithic reference panel provided by SGRE, with 30 mm wide defects easily detectable at a depth of 10 mm as shown in Fig. 5.



300s acquisition w/ 80s heat-

Figure 5: 30 mm thick reference sample illustration and corresponding thermogram showing 8 mm and 10 mm deep defects.

The set-up used for these trials has comprised a FLIR A6751sc infrared camera and 2×2 kW halogen lamps, positioned to cover ~ 500 mm × 500 mm inspection area (see Fig. 6)

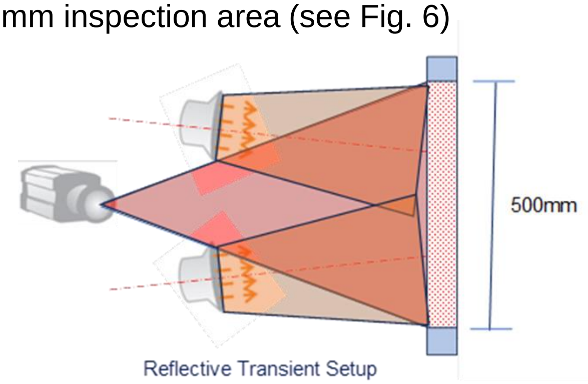


Figure 6: Reflective, transient thermography set-up used in initial trials at NCC.

In the next steps, the impact of increased-heat power on required inspection times will be assessed, through the introduction of another two 2 kW halogen lamps. The rate capability of this method will then be demonstrated through automation of the inspection process.