Offshore Renewable Energy

Evolving large blade materials, manufacturing and validation – What's going on in the UK?

Paul McKeever, September 2022

Agenda

- Introduction to OREC Catapult
- Blades Research within RTC
- Facilities Summary
- Specific Topics
  - Structural Characterisation
  - Leading Edge Erosion
  - Materials and Manufacturing
- Key Personnel
  - Mark Forrest
  - Kirsten Dyer
  - Peter Greaves

THE OFFSHORE RENEWABLE ENERGY CATAPULT

The UK's leading technology innovation and research centre for offshore renewable energy

Mission: to accelerate the creation & growth of UK companies in the offshore renewable energy sector.

- Unique facilities, research & engineering capabilities
- Bringing together innovators, industry and academia
- Accelerating creation and growth of UK companies
- Reducing cost and risk in renewable technologies
- Enabling the transition to a low carbon economy – multiple UK locations

UKRI Innovate UK

CATAPULT Offshore Renewable Energy

What we do

Research & Technical Capabilities (RTC)

- Leading the development and delivery of applied research and in-depth technical capabilities for OREC

Technology Development (TD)

- Next generation Turbines & Balance of Plant
- Design validation and component testing

Development & Operations (DO)

- Operations & Maintenance
- Developer/owner solutions
- Test & validate solutions

Strategy & Emerging Technology (SET)

- Evaluation and support for emerging technologies
- Floating wind, wave & tidal
- Gateway to UK academia

Blades Research within RTC – Topics

Structural Characterisation

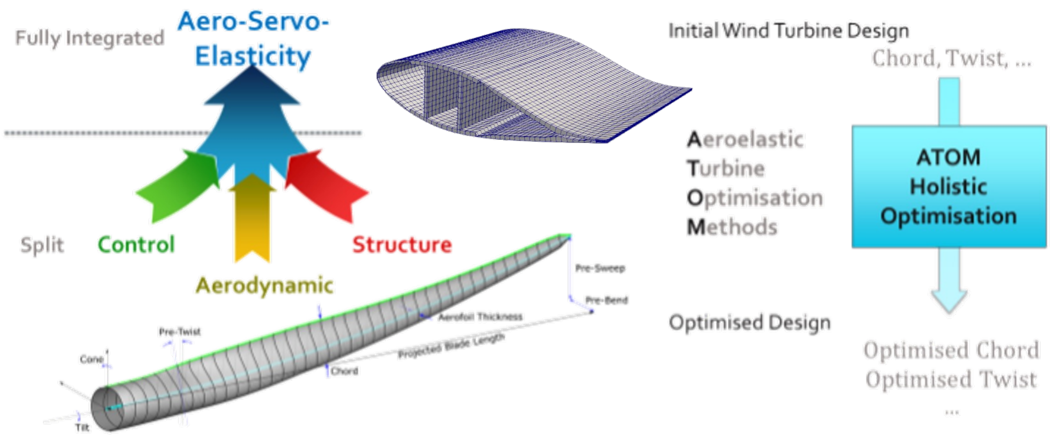
- Biaxial Fatigue Blade Testing via optimising loading to get damage equivalent to the service life
- Development of larger (20MW+) blade designs
- Development of Segmented Blade Testing Methodologies

Leading Edge Erosion

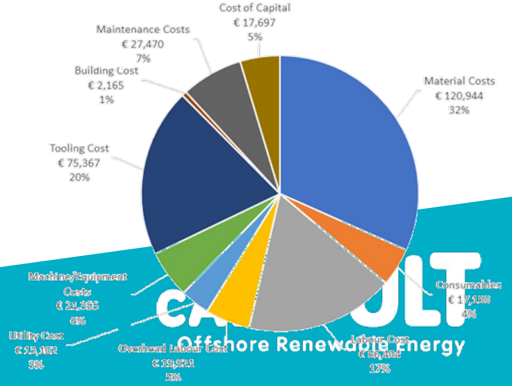
- Characterisation of erosion mechanisms
- Erosion lifetime modelling
- Test Procedure modified for more realistic WT sites and operation
- Development of Leading edge solutions (metallic/composite/TP)

Materials and Manufacturing

- Development of alternative blade materials and processing routes
- Composite manufacturing routes and cost modelling

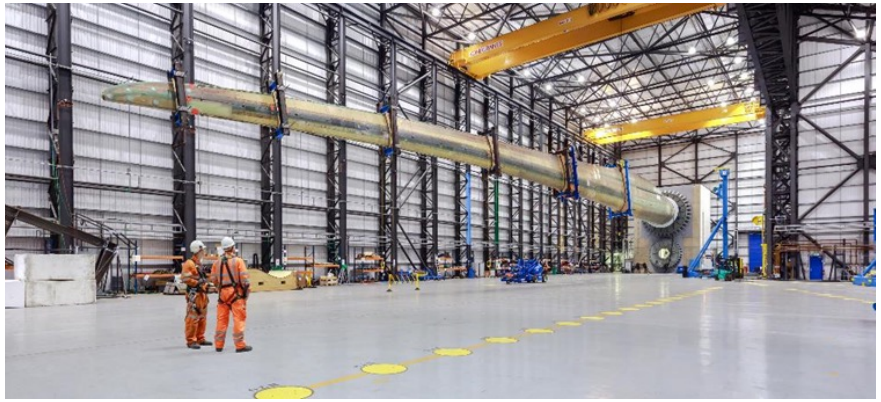


Courtesy: 3A Composites

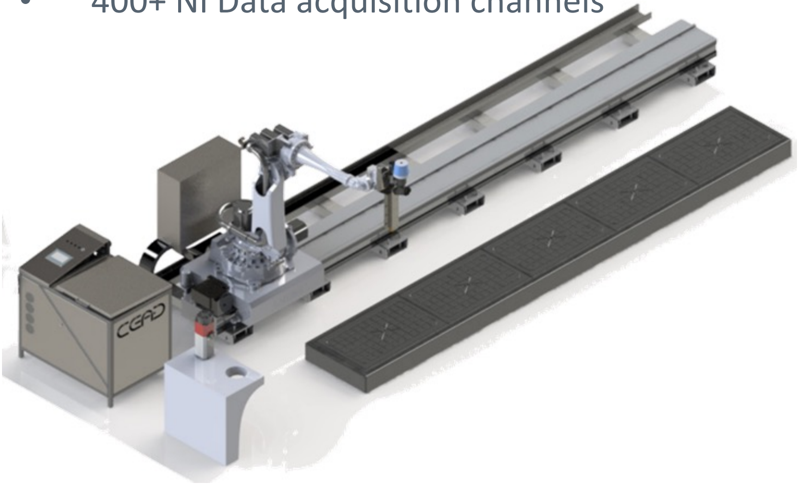


Blades Research within RTC - Facilities

Composite Laboratory
- Resin Infusion manufacture and test equipment
- Material characterisation Instruments (e.g. FTIR,DMTA)
- Coating preparation
- Hardness, adhesion, density and acoustic impedance measurement
- 3d printer
- Planetary Mixer

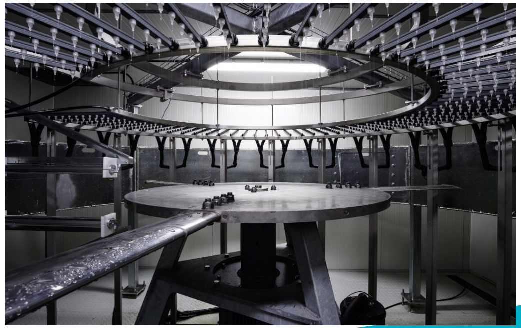


100m+ and 50m+ Blade Test Halls
- QUALISYS Optical blade displacement tracking
- Seven hydraulic motor winch for static testing
- Ground mounted hydraulic actuator and blade mounted exciters for fatigue testing
- Biaxial fatigue testing development
- 400+ NI Data acquisition channels



Rain Erosion Test Rig
- R&D AS RET rig
- Automated & adaptable test configurations and data capture
- Optical microscopy for surface characterisation
- Thin-film viscoelastic characterisation
- TTT – superposition and structural health durability

UV/Weathering Rig
- Q-LAB Q-Rack Natural weathering system
- Rain-gauge, radiometer, humidity and temperature tracking capability
- Environmental conditioning chamber
- Q-Fog and QUV future acquisition



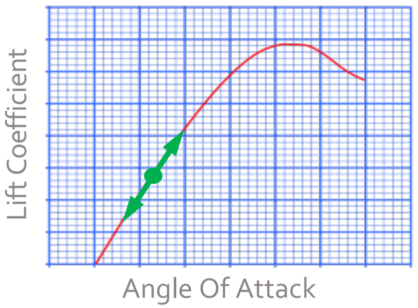
Additive Manufacturing Cell
- High output pellet based thermoplastic material deposition system
- Large 4 x 2 x 2.5 m build envelope
- 7-axis track based motion system
- High accuracy bead control & placement
- Continuous fibre systems possible

Structural Characterisation

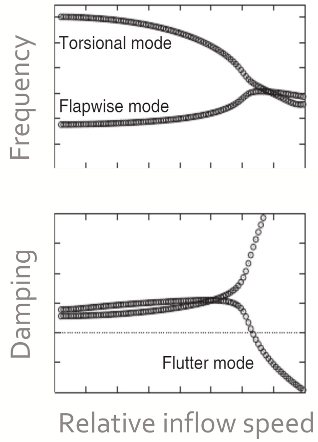
- Torsional Testing
- Segmented Testing
- Detailed FE Models

CATAPULT
Offshore Renewable Energy

Torsional Testing

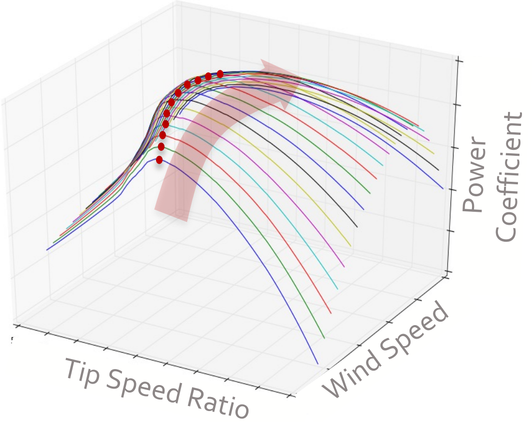


Aerodynamic Loading



(Hansen, 2007)

Rotor Stability



Power Production

Motivation

A true understanding of the torsional stiffness is important for properly characterising the aero-elastic model so that power production, loads and rotor stability can be accurately predicted.

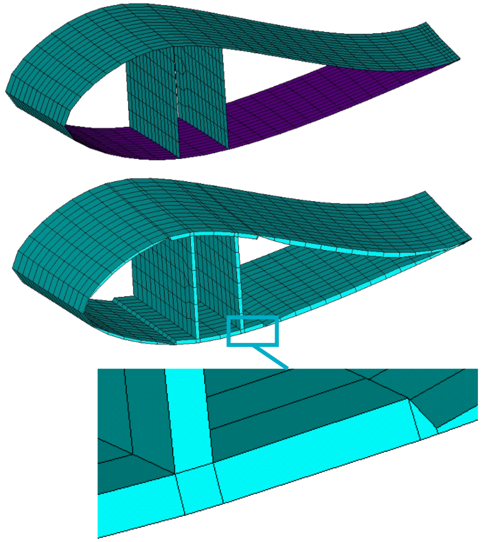
There is not currently a standardised method for performing torsional tests so this research will aim to develop a detailed understanding of best practice for test methodology and modelling techniques.

Modelling

The blade test will be simulated using beam, shell and solid elements. The beam model will be obtained using best practice techniques for extracting cross-section properties.

The shell and solid models will include a representation of the loading saddles accounting for clamping pressure of the saddles.

The models will be generated using ORE Catapult's in-house mesh generation tool.



Full Scale Test

A full scale test on a 40m blade for which detailed design information is available will be performed at ORE Catapult's test site in Blyth, Northumberland in Q4 2022.

The blade will be instrumented with DIC, inclinometers, strain gauges and pressure transducers between the saddles and blade to fully understand the influence of boundary conditions.

NATIONAL COMPOSITES CENTRE

CATAPULT Offshore Renewable Energy

Segmented Testing

Motivation

As blades grow in size, it becomes increasingly difficult to test them in one piece because the high deflections mean that creating a building which can house a test becomes very costly. The fatigue test also has a much longer duration and achieving the edgewise root loads without over-testing the rest of the blade becomes impossible.

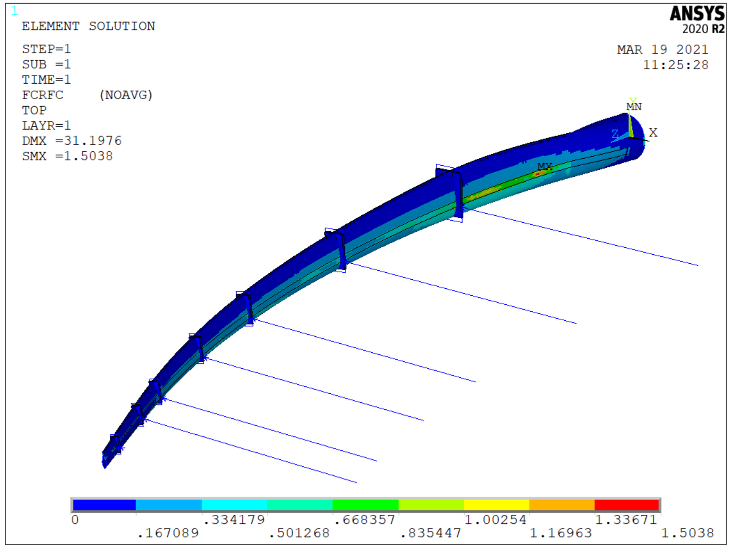
However, there are challenges related to segmented testing because if the blade is truncated then much higher forces must be applied in order to achieve the required bending moment at the root, which can lead to unrepresentative failure modes. Understanding how to hold the tip section is also a key consideration.

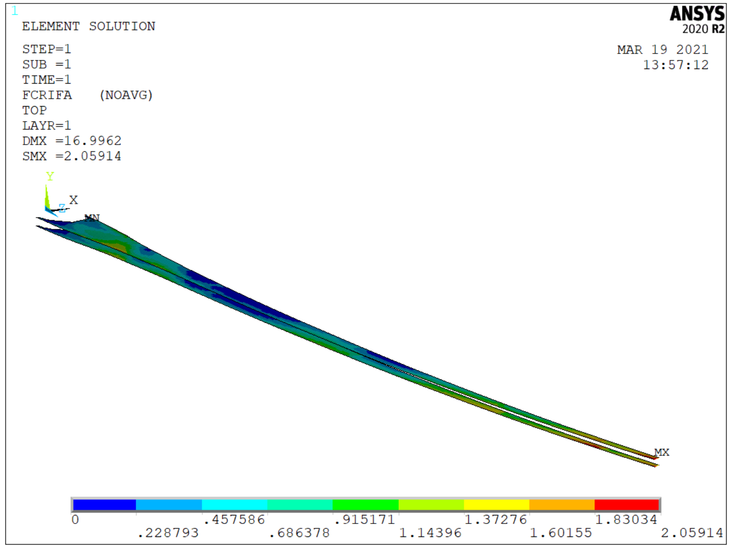
Modelling

A segmented test has been modelled using the IEA 15MW reference blade. We find that the critical failure mode and location can be replicated for the fibre failure criterion, but for matrix failure criteria the location and magnitude change considerably.

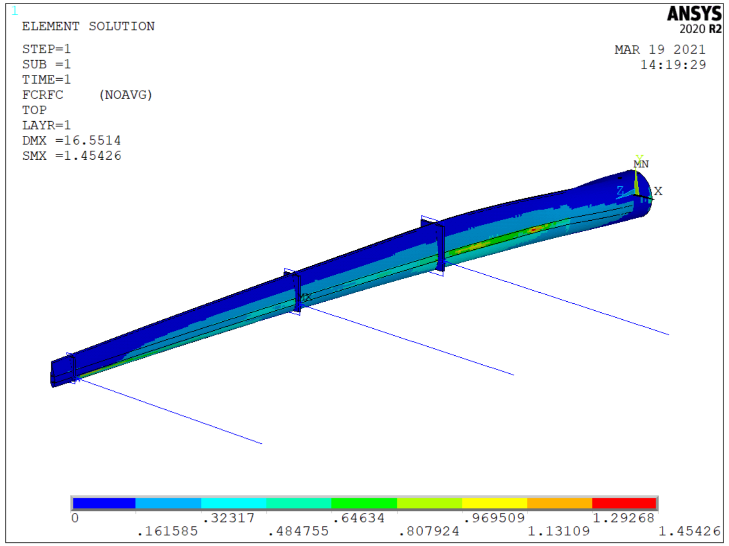
Further work will use a more refined reference blade model to understand how close to the tip the blade must be truncated in order to achieve comparable failure modes between the truncated and full length blade test.

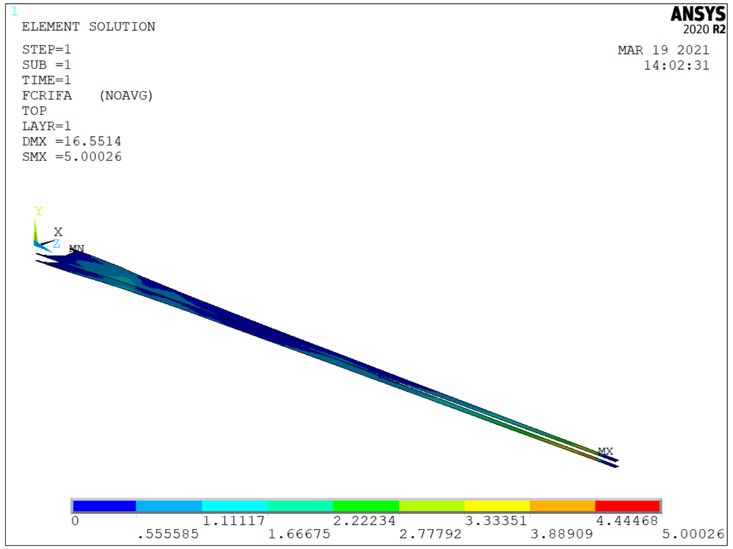
Full-length test





Root segment test





Fibre compression failure

Inter-fibre failure

NATIONAL COMPOSITES CENTRE

CATAPULT Offshore Renewable Energy

Detailed FE Models

Motivation

Wind turbine blades are modelled with finite elements at three different levels of complexity: beam, shell and solid.

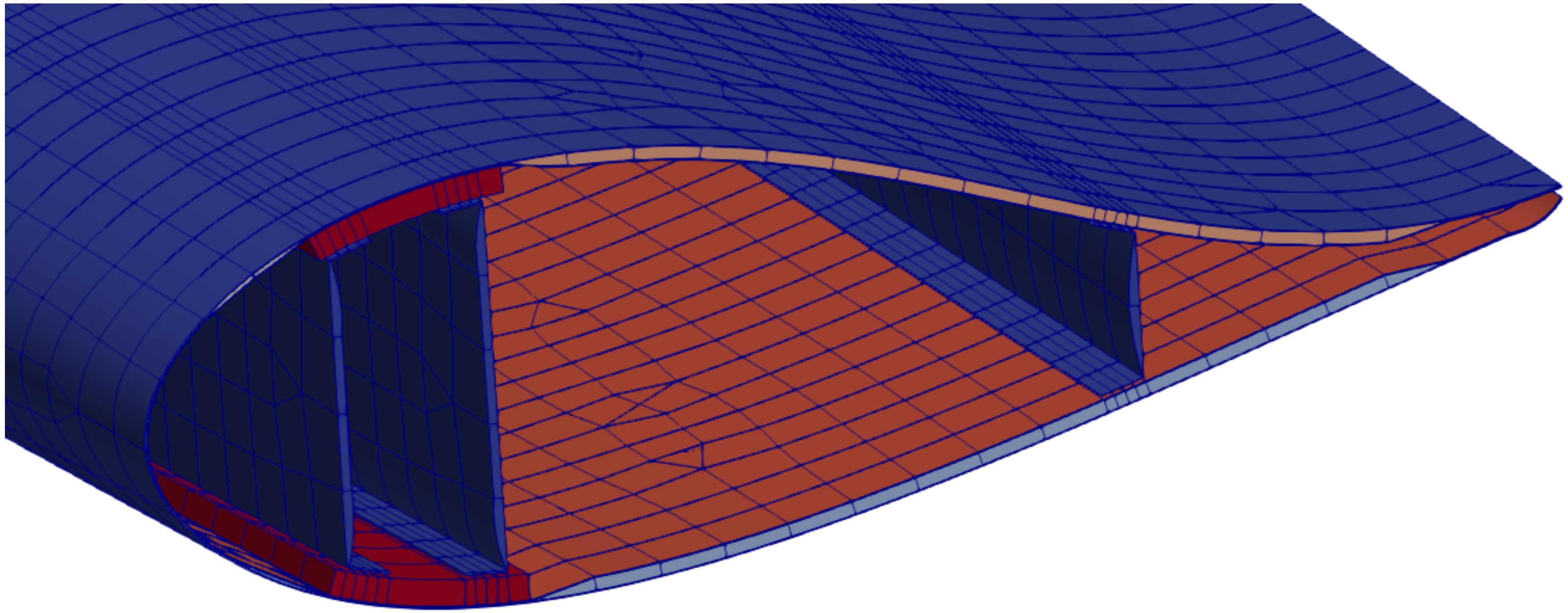
Beam elements are used in aero-elastic codes and for pre-design because they are highly computationally efficient. However, they cannot capture deformation of the cross section.

Shell element models are widely used for wind turbine blade models because they can provide reasonable results without challenging meshes and can capture cross-sectional deformation. However, they provide inaccurate estimations of the torsional stiffness and do not allow access to through-thickness stresses which in reality drive delamination – often the true cause of failure in the field.

Solid models are the most accurate and can capture all of the required failure modes, but they are extremely challenging to mesh and are computationally intensive. However, both of these shortcomings are addressable – the first by creating tools to mesh the blade at varying levels of fidelity and the second by throwing more processors at the problem!

Meshing

ORE Catapult is developing an in-house tool which creates a series of functions to generate arbitrary blade geometries.



Leading Edge Erosion

- Leading Edge Protection (LEP) Characterisation Methods and Testing
- Dynamic Mechanical Analysis (DMA)/Rain Erosion Testing (RET) Background
- DMA/RET Results and Analysis
- Conclusions

CATAPULT Offshore Renewable Energy

LEP Characterisation Methods and Testing

Development of in-house LEP characterisation methods:

- Combined Dynamic Mechanical Analysis (DMA) with short term rain exposure
  - Measures material properties relevant to erosion and their changes after exposure to rain
- Realistic Rain Erosion Testing (RET)
  - Last year we showed that the current RET to DNVGL-RP-0171 doesn't take into account viscoelastic properties as they occur on the WTG.
  - This year we have confirmed the effect exists across leading industry LEPs and are investigating how this changes the standard. LEPs with good results at low impact frequencies (speed + rainfall intensity) can have worse performance than lesser LEPs at high impact frequencies. This correlates to their viscoelastic properties using DMA.
  - Information can't yet be released but will need to update ASTM G73, ISO 19392-2
- Combined rain and environmental RET
  - Taking the realistic RET and adding in realistic UV, temperature and humidity. Work just initiated.

CATAPULT
Offshore Renewable Energy

DMA/RET background

- The novel DMA/RET combined procedure consists of the following experimental steps

1) Baseline characterisation of LEP material using DMA
   - Measure storage modulus – level of viscoelasticity and capability to store energy during impact
   - Measure loss modulus – capability to damp energy during impact. Maximising correlates to erosion performance in RET.
   - Measure tan δ (ratio of storage to loss modulus) at very high frequencies equivalent to rain droplet impact
   - Measure creep recovery: shows ability of the material to recover after load

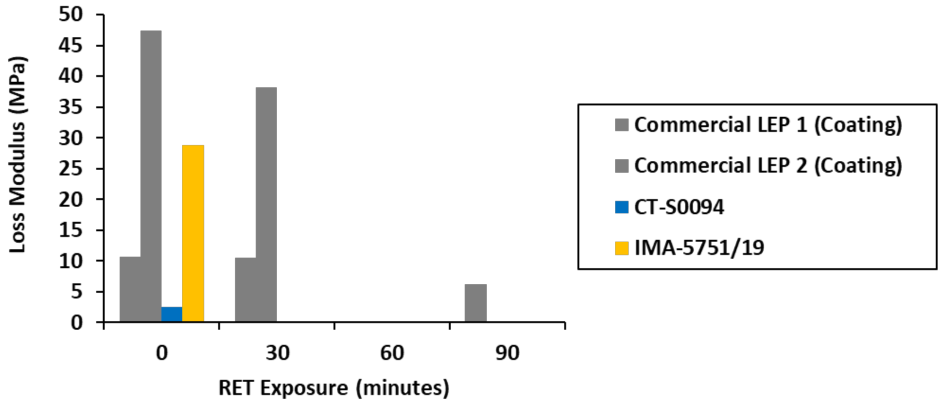
2) Expose DMA sample to short intervals of RET exposure

3) Repeat characterisation of LEP using DMA

DMA/RET Results and Analysis

- LEP1 performs best in all DMA tests. In RET it shows 0.2 MPa reduction after 30 mins and 4 MPa reduction after 90 mins.
- LEP2 has good properties but is pitched at slightly the wrong frequency. In RET it shows 10MPa reduction after 30 mins.
- CT-S generally had the worst properties due to the test method testing below Tg (20°C). It fell apart during RET.
- LEP3 has good properties but is pitched at slightly the wrong temperature losing performance.
- IMA has good properties but is pitched at slightly the wrong frequency losing performance.

Sample	RET	E’	E’’	Tan δ	Recovery	E“ @ 10^8 Hz
	Ranking	Ranking	Ranking	Ranking	Ranking	Ranking
LEP 1	1	1	1	1	1	1
LEP 2	4	2	2	2	4	3
CT-S*	5	4	5	3	5	4
LEP 3	2	3	4	4	3	2
IMA	3	5	3	5	2	5



Catapult Offshore Renewable Energy

Conclusions

- Novel combined DMA/RET allows:
  - Comparison of erosion performance without performing full scale RET
  - Analysis of LEP properties and elastic/viscoelastic behaviour
  - Connection of LEP properties with behaviour in RET
- These are being used with coatings formulators and OEMs to understand their LEP behaviour:
  - To reformulate
  - To understand how the LEP behaves between RET and WTG

Materials and Manufacturing

- Future Blade Design and Manufacturing Vision
- Scale-Related Blade Challenges
- Joule Programme

Offshore Renewable Energy

Future Blade Design and Manufacturing Vision

Blade design and manufacturing has seen only incremental change over the past three decades; the processes employed have essentially remained the same.

ORE Catapult has a thematic mission of:

Accelerating UK IP Growth for Next Generation Blade Manufacturing

Blade Development Objectives:

- Reduction of Levelised Cost of Energy (LCoE)
  - Manufacture blades faster and at lower cost
  - Enhance Turbine Performance (AEP)
- Develop technologies for larger floating wind turbines
- Reduce Environmental Impact

Scale-Related Blade Challenges

Larger swept areas – enhanced energy capture AEP & reduction in Levelised Cost of Energy LCoE

- Minimise Balance of System cost and number of Floating foundations
- Manufacture Blades faster and more efficiently

Larger Rotors entail higher system loads on drivetrain, tower, foundations

- Enhanced use of higher performance lightweight composite materials → “virtuous mass spiral” (cost??)
- Operate at higher tip speeds to reduce torque loading

Larger Rotors entail distinct manufacturing and installation challenges

- Manufacturing time and cost (esp. Lengthy and costly blade finishing)
- Larger Blade mass and length have distinct crane capacity installation concerns

Larger Rotors will produce a high volume of end-of-life waste

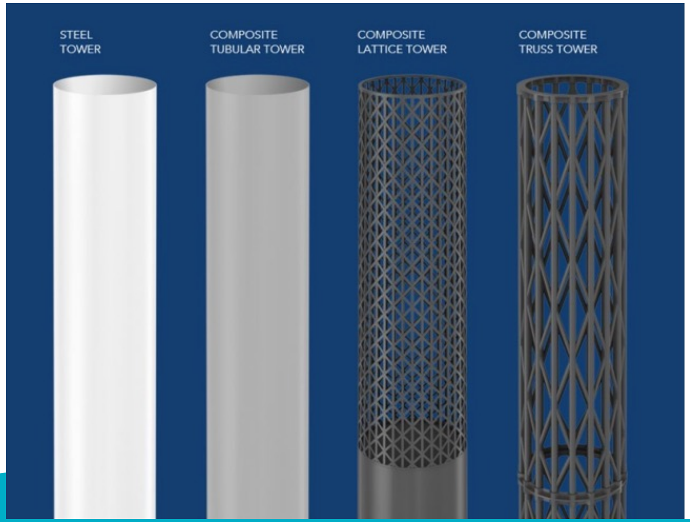
- Extensive use of next generation recyclable blade materials
- More robust materials to enhance life beyond 30+ years

Joule Programme

- £5m, 20-month programme, funded by UK Government (BEIS)
- Provides detailed roadmap for incorporating radically new composite-based components in the next generation of offshore wind turbines
- Phase 1 completed in 2020
  - Proved importance of composite materials in enabling next generation offshore wind turbines
  - Predicted impressive reductions in component masses of up to 60% and embedded carbon reduction of up to 55%.
  - Produced a Technology Development Plan for a 20MW demonstration turbine
- Phase 2 project will be delivered by Offshore Renewable Energy (ORE) Catapult and High Value Manufacturing (HVM) Catapult
  - Looking to prove composite materials can deliver significant performance and light-weighting opportunities
  - Essential to developing the next generation wind turbine platform beyond 20MW
  - Developing concept components utilising High Value Design & Manufacture (HVDM) expertise to capitalise on existing UK capabilities

Joule Programme

- https://www.nccuk.com/news/uk-manufacturing-technology-for-next-generation-turbines-joule-challenge-phase-1-report/



CATAPULT
Offshore Renewable Energy

Key Personnel

- Materials & Manufacturing
- Dr. Mark Forrest – Blade Research Leader
  mark.forrest@ore.catapult.org.uk

- Leading Edge Erosion
- Dr. Kirsten Dyer – Principal R&D Engineer
  kirsten.dyer@ore.catapult.org.uk

- Structural Characterisation
- Dr. Peter Greaves – Principal R&D Engineer
  peter.greaves@ore.catapult.org.uk

CATAPULT
Offshore Renewable Energy