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WEAMEC
Research, Education & Innovation in Pays de la Loire FOR MARINE ENERGY

OPIN Workshop

Advanced Materials and Manufacturing (Composite focus)

12/11/19, Nantes

Dr. Edward McCarthy

Lecturer in Composites Design and Testing/University of Edinburgh

Composites

Marine Composites Research at University of Edinburgh, UK.

- Context: Composites in Energy Blades.
- Past and Current Projects
- Case Study 1: Powder Epoxy Curing Study
- Case Study 2: Powder Epoxy Tape Production
- Case Study 3: Powder Tape in Water: Properties
- Case Study 4: FASTBLADE Fatigue Test Facility

Composites Group at Edinburgh

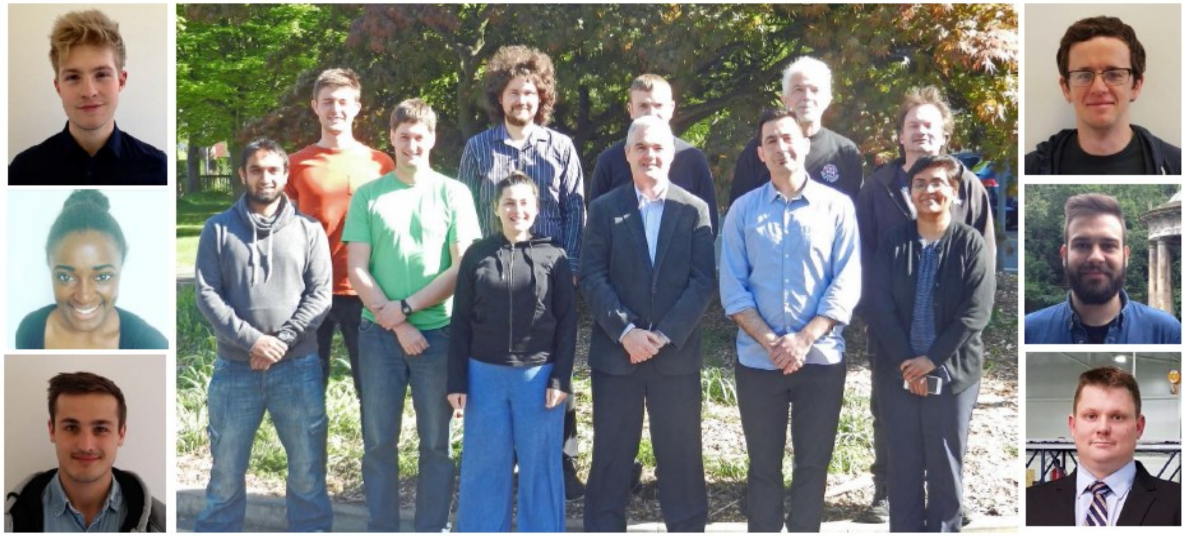
Prof. Conchúr Ó Brádaigh
Chair of Materials Engineering.

Dr. Dipa Roy
Senior Lecturer in Composite Materials and Processing.

Dr. Dongmin Yang
Senior Lecturer in Composite Materials.

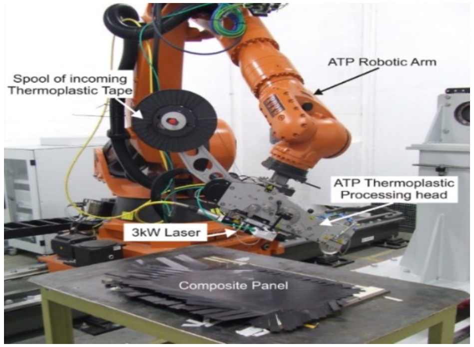
Dr. Parvez Alam
Senior Lecturer in Materials Modelling.

Dr. Edward McCarthy
Lecturer in Composites Design & Testing.

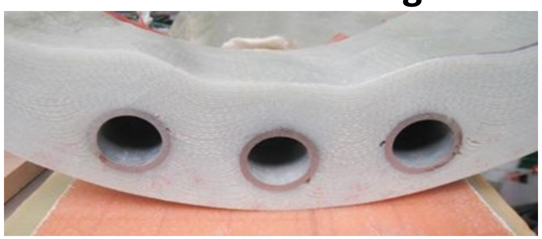


The Edinburgh Composites Group (Est. 2015)

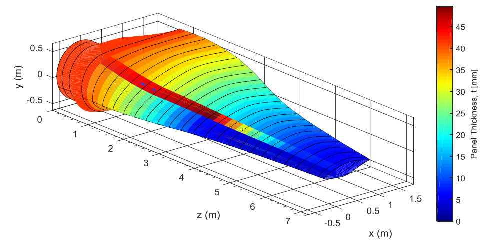
Composites Expertise at University of Edinburgh



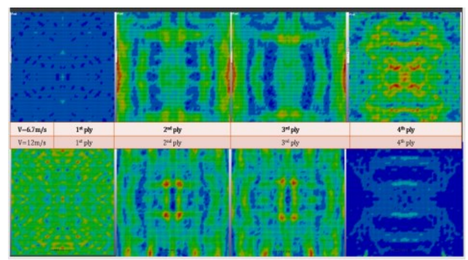
Laser Tape Placement for Faster Processing

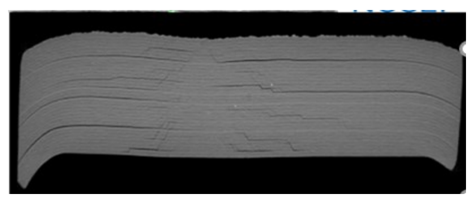


Wind/Tidal Blade manufacture using Advanced Powder Epoxy Composites

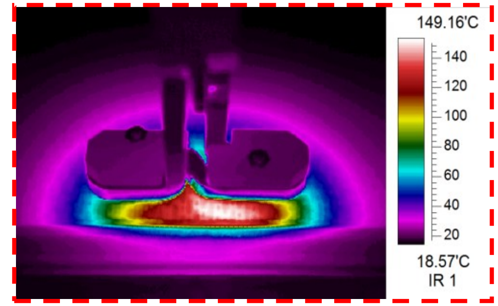


Stress Analysis/Design of Blades

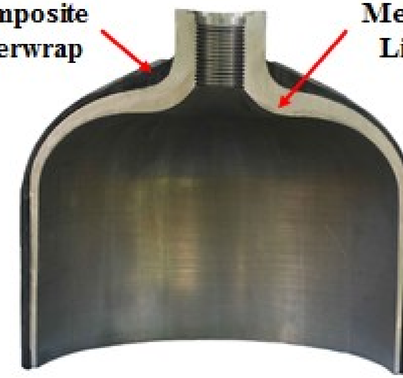




Modelling of Impact Damage



Induction Welding of Thermoplastic Composites.



Composite-Wrapped Pressure Vessels

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Blade Loads increasing with length

World's Largest Wind Turbine Blade - 88.4m long for 8MW Offshore Turbine, now outdone by their 107 m blade for a 12 MW. (Haliade-X, General Electric)

Fabricated in Glass Fibre/Epoxy.

Manufactured by Vacuum-Assisted Resin Infusion in 3-4 parts which are adhesively bonded.

LM Windpower 2016 – designed for 180 m rotor diameter turbine, Cherbourg

- Wind blades are about to get longer > 100 m for 12 MW !
- Increasing length drives increased power harvest **but higher loads**.
- Composites: reduce weight while maintaining stiffness.
- Tidal blades – shorter, higher root loadings.

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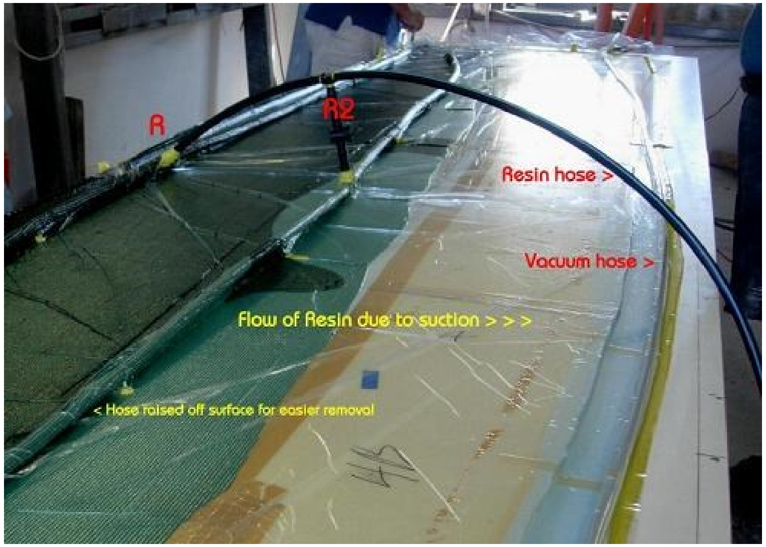
Issues with Liquid Epoxy Infusion of Blades

- **Current State of the Art is Liquid Epoxy Infusion** to a Fabric System followed by Oven Cure
- **This is manually intensive** and **lacks reproducibility** between fabrication teams
- Liquid travels into fabric in-plane > **long diffusion path, incomplete wetting, dry spots, inhomogeneous fibre volume**
- **Thick sections** characteristic of tidal blade roots create an **exotherm trap for current liquid epoxy systems**
- Blades have to be made in sections and **bonded together: lack of confidence/inspectability in bond lines**



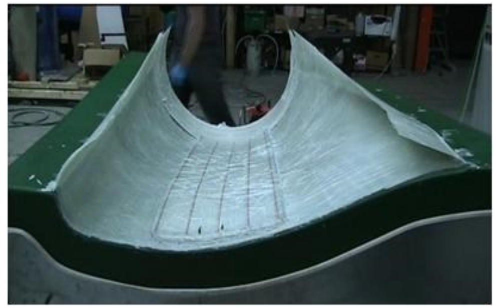
Resin Infusion of Liquid Epoxy

*This is actually a glass transition.

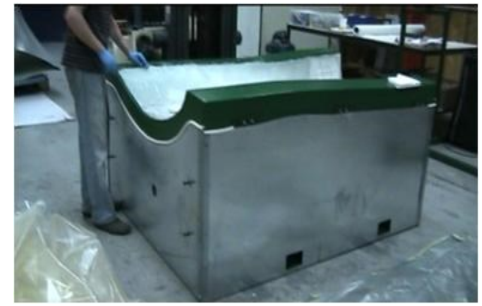
Tidal Blade Hub Manufacture

1. Initial Placement of Composite Sheets

Shear web



Bottom Skin



Top Skin

Surface coat being applied.

Shear web pre-form being placed in position

Top skin pre-form being placed on top of shear web

Flanagan, T. et al., "Smart Affordable Composite Blades for Tidal Energy", Proceedings of *EWTEC 2015 – 11th European Wave and Tidal Energy Conference*, Nantes, France, September 2015.

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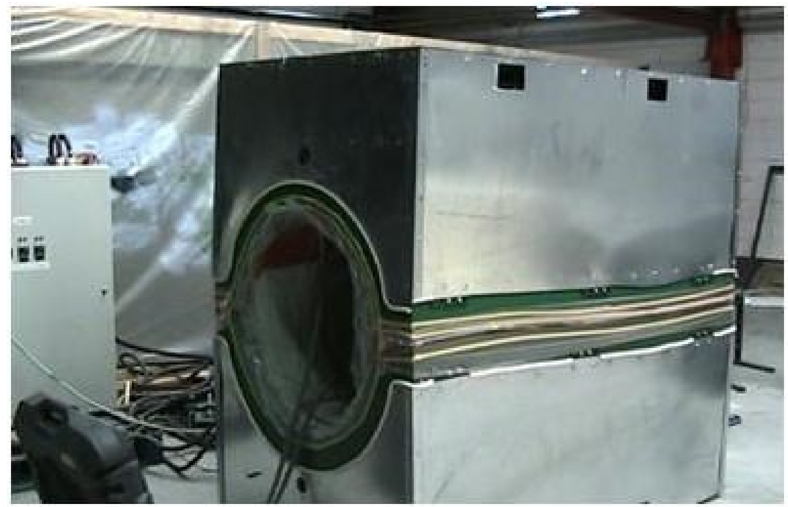
Tidal Blade Hub Manufacture

2. Final Assembly and Tool Cure

As all the sections are now net shape they fit together for final processing

All sections in position



Mould closed, vacuum bag placed inside the lay-up, vacuum applied and heated to 180ºC.

Flanagan, T. et al., "Smart Affordable Composite Blades for Tidal Energy", Proceedings of *EWTEC 2015 – 11th European Wave and Tidal Energy Conference*, Nantes, France, September 2015.

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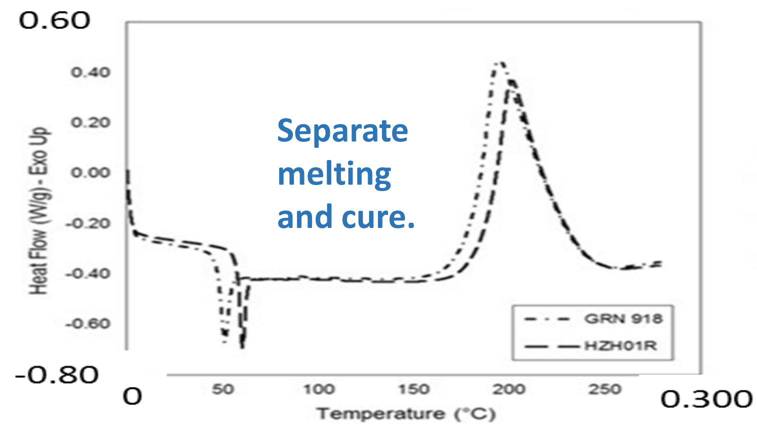
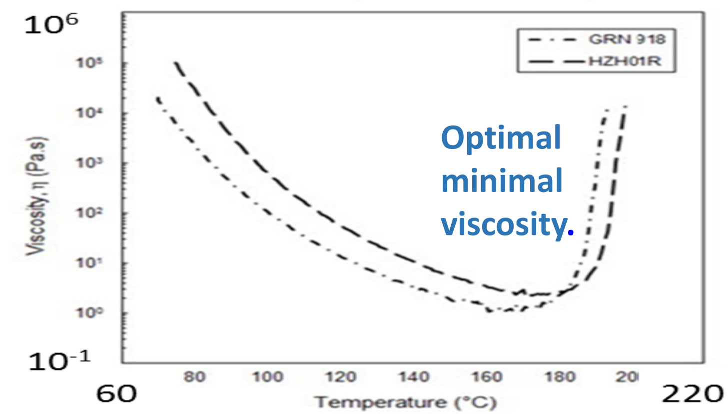
Powder Epoxy Advantages

- **Separate melting* and cure:** powder liquifies into dry tow, then cures at much higher temperature
- **Optimal minimal viscosity**[1]
- **Low curing exotherm:**
    - **reduction of thermal runaway risks in thick sections**[2] (tailored for wind and tidal blades)
    - **enables quicker manufacturing (cost reductio**
- **Powder and powdertape can be stored without refrigeration (cost reduction)**
- **No Volatile Organic Components emitted, very limited wastes (cost reduction)**
- **Part Joining by co-curing, no third material adhesive needed (cost reduction)**



Differential Scanning Calorimetry



Parallel-plate Rheometry

[1] J. Maguire, K. Nayak, C. M. O'Bradaigh, Characterisation of epoxy powders for processing thick-section composite structures, Materials & Design 2018.

[2] C. Robert, D. Mamalis, P. Alam, A.D. Lafferty, C. Ó Cadhain, G. Breathnach, E.D. McCarthy, C.M. Ó Brádaigh, Powder Epoxy Based UD-CFRP Manufacturing Routes For Turbine Blade Application, SAMPE 2018, Southampton.

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Powder Epoxy Research at Edinburgh

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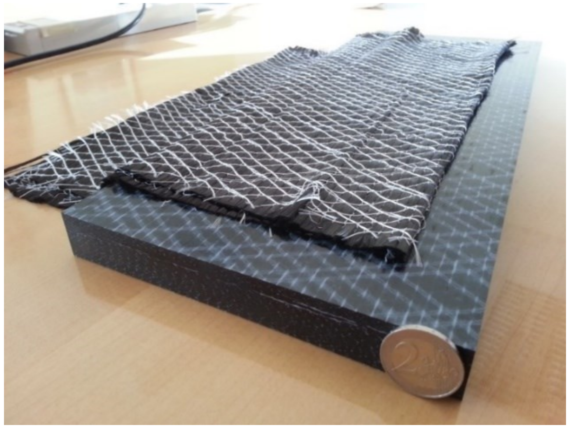
MARINCOMP

- EU FP7 Marie Curie Project led by UCC & the University of Edinburgh (2014-2018)
- Development of novel carbon-fibre reinforced powder-epoxy composite materials tailored for the marine environment.

SEVENTH FRAMEWORK PROGRAMME

MARIE CURIE ACTIONS



Carbon-fibre powder-epoxy laminate

POWDERBLADE

- EU H2020 Fast Track to Innovation Project led by ÉireComposites (2016-2019)
- To further develop and commercialise technology involving **carbon/glass fibres in powder epoxy** (+60 metres)

Scotrenewables Tidal Power Ltd

UCC Coláiste na hOllscoile Corcaigh, Éire University College Cork, Ireland

SUZLON POWERING A GREENER TOMORROW

ÉIRECOMPOSITES

University of ULSTER

TORAY

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Project 1: Powder Epoxy Heat Transfer

Manufacturing Process Modelling and Characterisation

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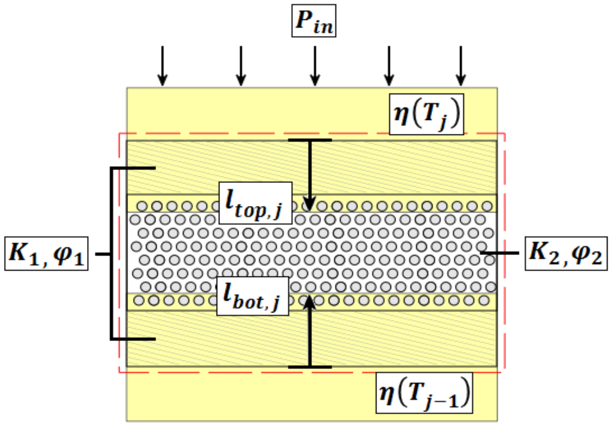
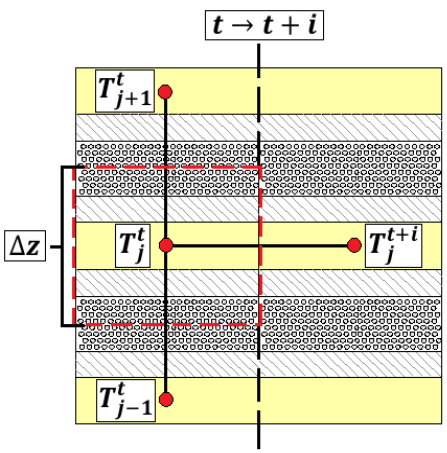
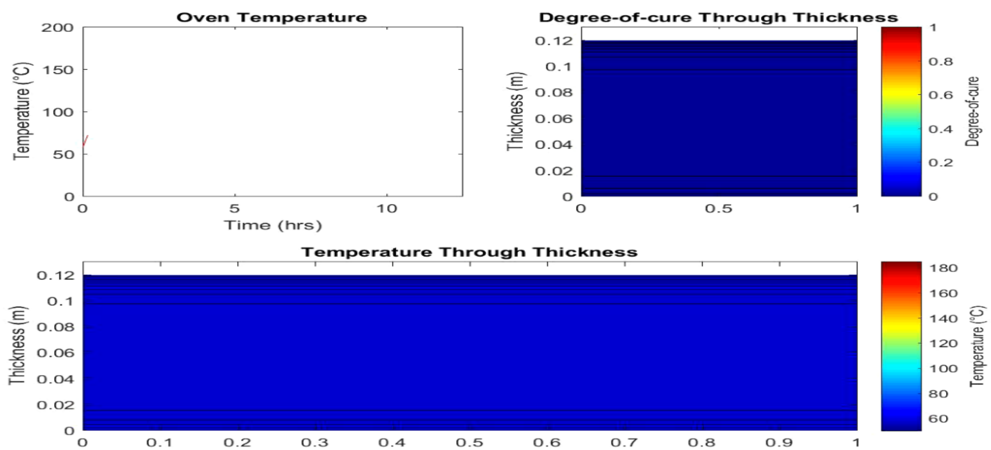


Novel powder epoxy composite process developed to reduce processing time, simplify manufacturing and reduce cost of large fibre reinforced composite structures

James Maguire
PhD Student



Coupled numerical modelling of consolidation flow and heat transfer through thick-section composites



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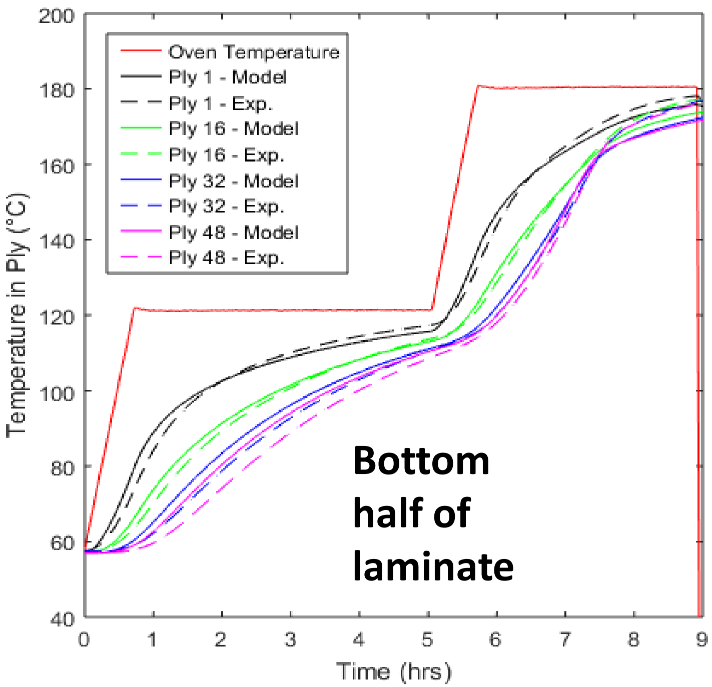
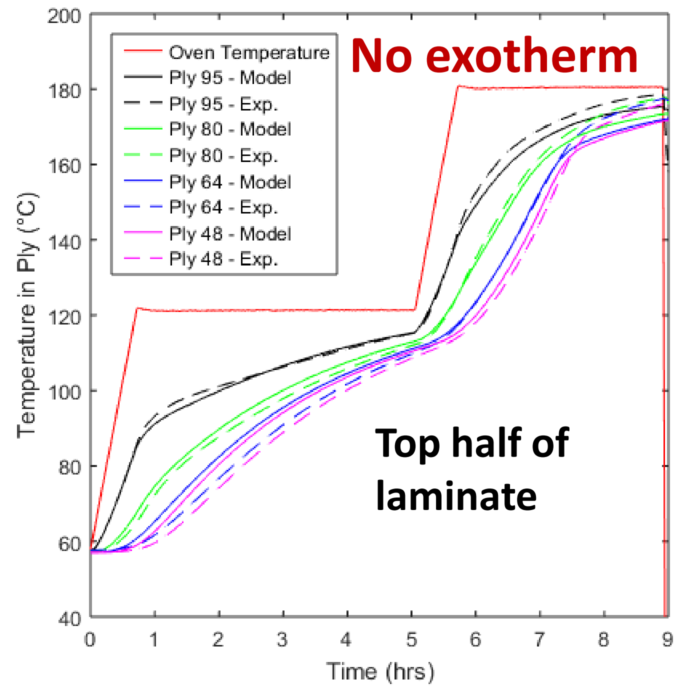
Model vs Experiment (Oven Cure) Powder

- **Model achieves good agreement with thermocouple data (100mm thick laminate after consolidation)**





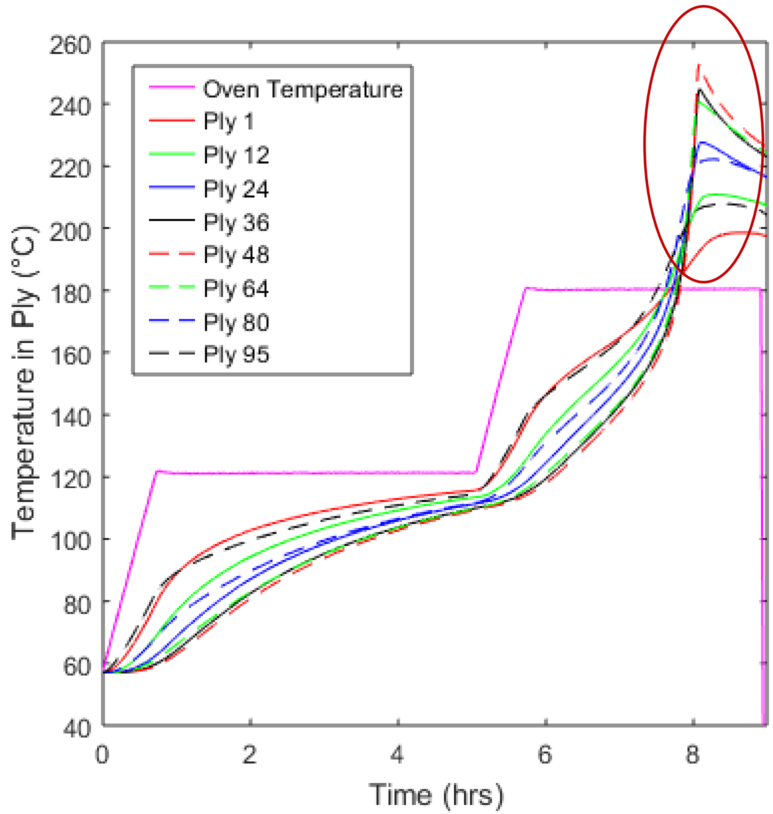
Maguire, J.M. et al. "Process Simulations for Manufacturing Thick-Section Parts with Low-Cost Fibre Reinforced Polymers", Proceedings of SAMPE Europe Conference, Stuttgart, Germany, Nov. 2017.

Thick Laminate Modelling with a Standard Resin

Simulation of processing the same 100mm laminate with a standard RTM resin.

- Based on a cure kinetics model and Cycom™ 890 resin data from Khoun et al*
- Much larger exothermic reaction (430 J/g)
- Significant temperature overshoot predicted

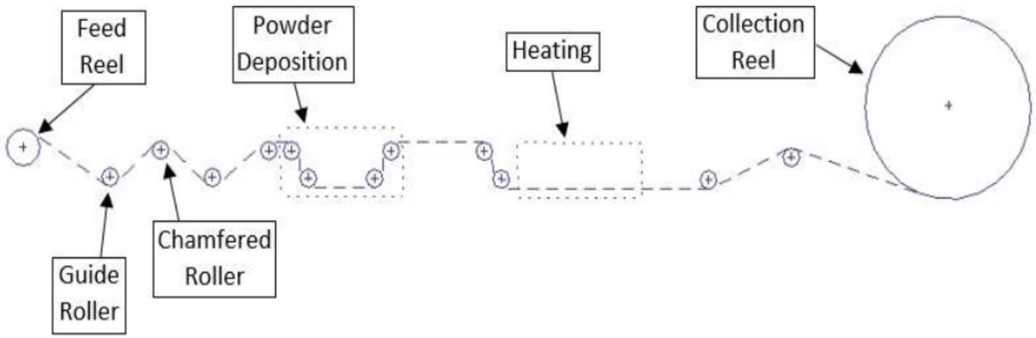
Clear exotherm in all plies



* L. Khoun et al, *J. Compos. Mater.*, 2009

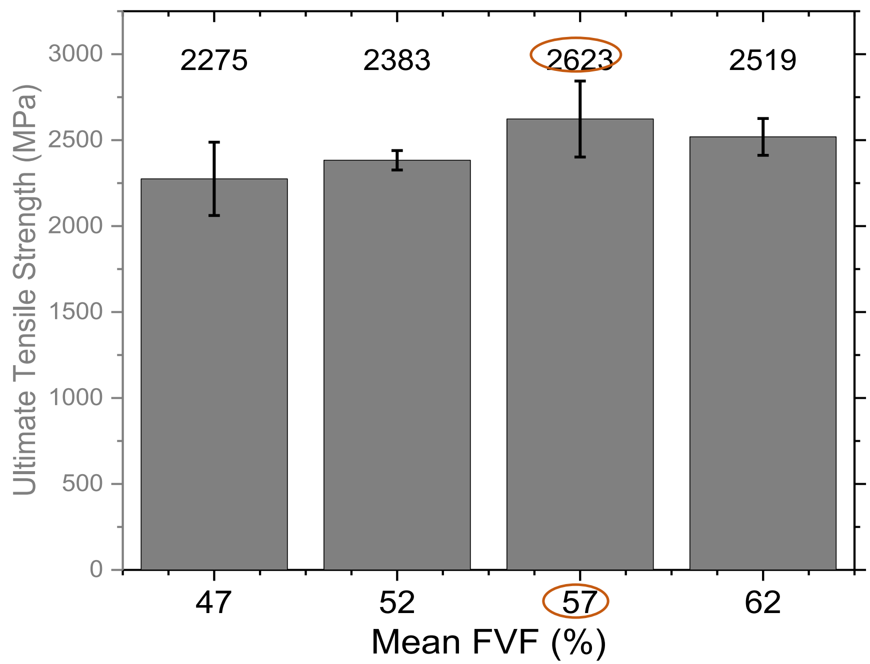
Project 2: Tapeline Manufacturing

- 2 step process: **towpreg** manufacturing then **composite** processing.
- Manufacturing upscale in scope of **Automated Tape Placement** (ATP) processing.
- Quick, reliable, reproducible, better mechanical properties than vacuum assisted resin infusion.



Towpreg manufacturing unit: electrostatic powder deposition gun, fibre heating zone and tow winding

Initial Results for Present Tapeline



TORAYCA T700s Data Sheet

COMPOSITE PROPERTIES*

Tensile Strength	370 ksi	2,550 MPa	ASTM D-3039
Tensile Modulus	20.0 Msi	135 GPa	ASTM D-3039
Tensile Strain	1.7 %	1.7 %	ASTM D-3039
Compressive Strength	215 ksi	1,470 MPa	ASTM D-695
Flexural Strength	245 ksi	1,670 MPa	ASTM D-790
Flexural Modulus	17.5 Msi	120 GPa	ASTM D-790
ILSS	13 ksi	9 kgf/mm^2	ASTM D-2344
90° Tensile Strength	10.0 ksi	69 MPa	ASTM D-3039

* Toray 250°F Epoxy Resin. Normalized to 60% fiber volume.

https://www.toraycma.com/file_viewer.php?id=4459

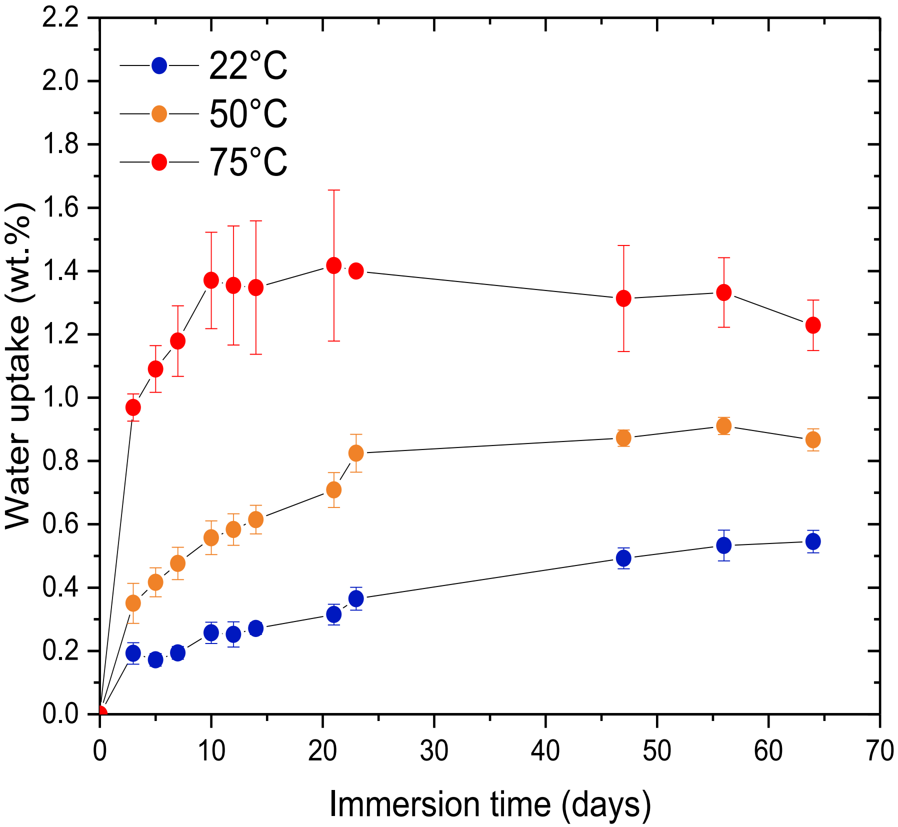
- Better strength for lower FVF compared to Toray TDS.
- How? Carbon fibres kept under tension throughout the whole process (towpregging and curing): preferential alignment, less waviness.
- Key argument compared with conventional liquid resin prepreg

C. Robert, C. Floreani, D. Mamalis, P. Alam, C. M. Ó Brádaigh, The Influence of Hygrothermal Ageing on Stress Distribution in Unidirectional Carbon Fibre Reinforced Epoxy Applications for Tidal Turbine Blades, Composites part B, soon to be published.

Project 3: PowderTape in Water

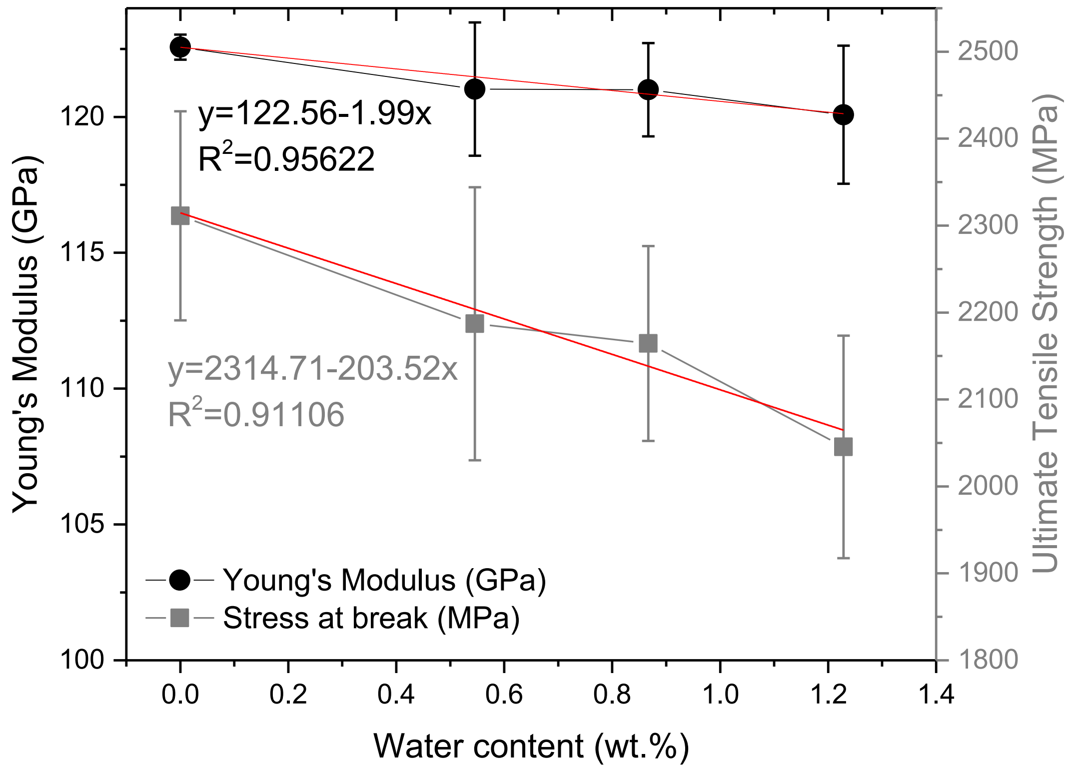
PowderTape: Water Uptake with Time

- **Water ingress** strongly influences composite **mechanical properties**.
- Seawater at **3 temperatures** well under T_g onset (~105°C): **22°, 50° and 75°C**.
- **2** months immersion.
- **Non-Fickian** absorption behaviour of samples at **50°** and **75°C**.
- Composite **matrix swelling** under water action, causing **damage** at the carbon fibres/ matrix interface.
- **Temperature exacerbates** this behaviour, allowing more water to come in and increases the saturation level.



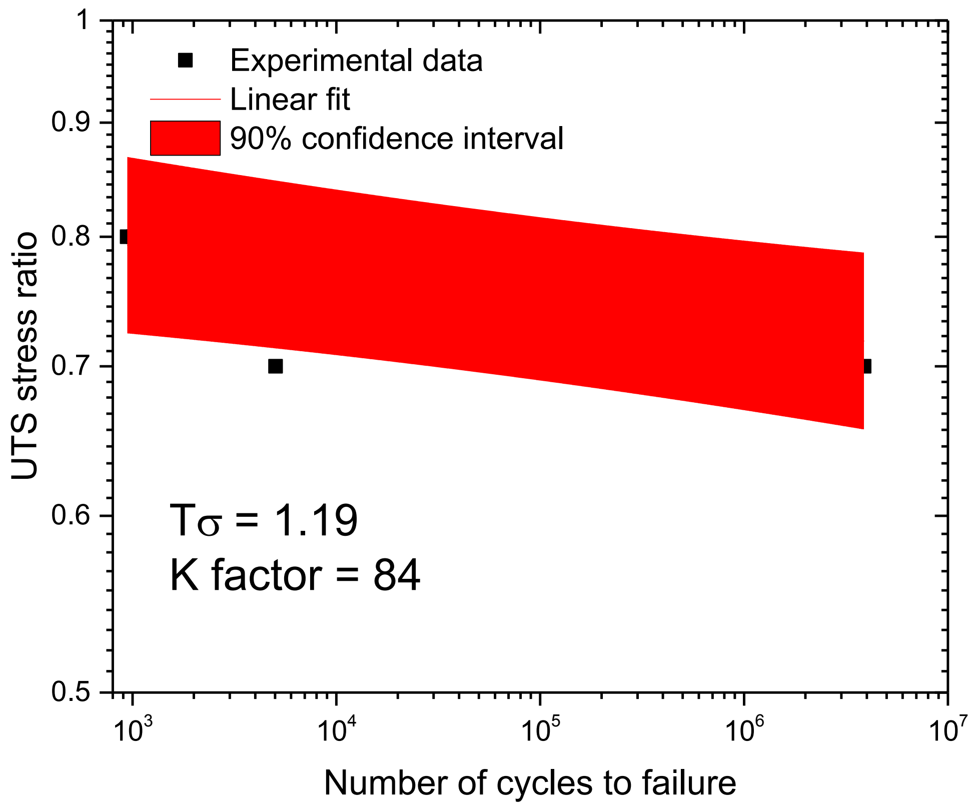
PowderTape: Water Influence on Static Properties

- **4 sets** of samples: **dry**, 2 months at **22°C**, **50°C** and **75°C**.
- Tested in **tension 0°**.
- Small loss of **Young's Modulus: -1.62%** per wt.% of water.
- Larger loss of **Strength: -8.79%** per wt.% of water.
- **Literature usually reports bigger loss for liquid epoxy based systems.**



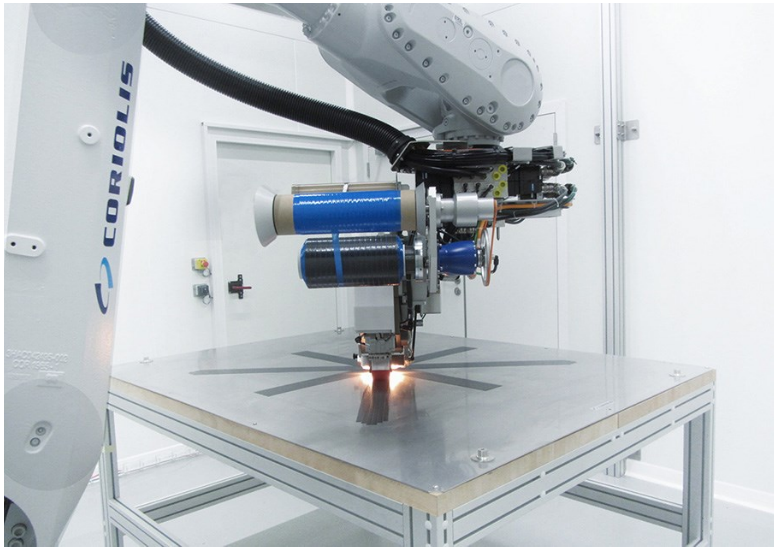
PowderTape: Fatigue Behaviour

- 75°C UD-CFRP samples tested in **0° tension**.
- Loading amplitude: **R=0.1**.
- Frequency = **5Hz**.
- 3 stress levels investigated: **70%, 75%** and **80% of UTS**.
- Scatter fair for composites (T_σ = 1.19)
- Life expectancy (**K factor**) important even for composite standards.



Potential of Powder Epoxy Tape for AFP

Csolo AFP System (Coriolis)



- **Single-fibre placement head with variable fibre width.**
- **Particularly suitable for local fibre reinforcement.**
- **Thermoset, thermoplastic and dry fibre manufacturing ability.**

- **Dr. Colin Robert at UoE** has won a Fellowship with NCC and Coriolis.
- To move the PowderTape technology and tapeline processing to higher TRL for adaptation to AFP tape.
- Objective of six month project, starting November 1 is to fully optimise and functionalise the tapeline to produce high quality tape at 25 mm width.

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FASTBLADE Fatigue Test Facility – Rosyth, Edinburgh

J. Steynor, University of Edinburgh

EPSRC Engineering and Physical Sciences Research Council

babcock

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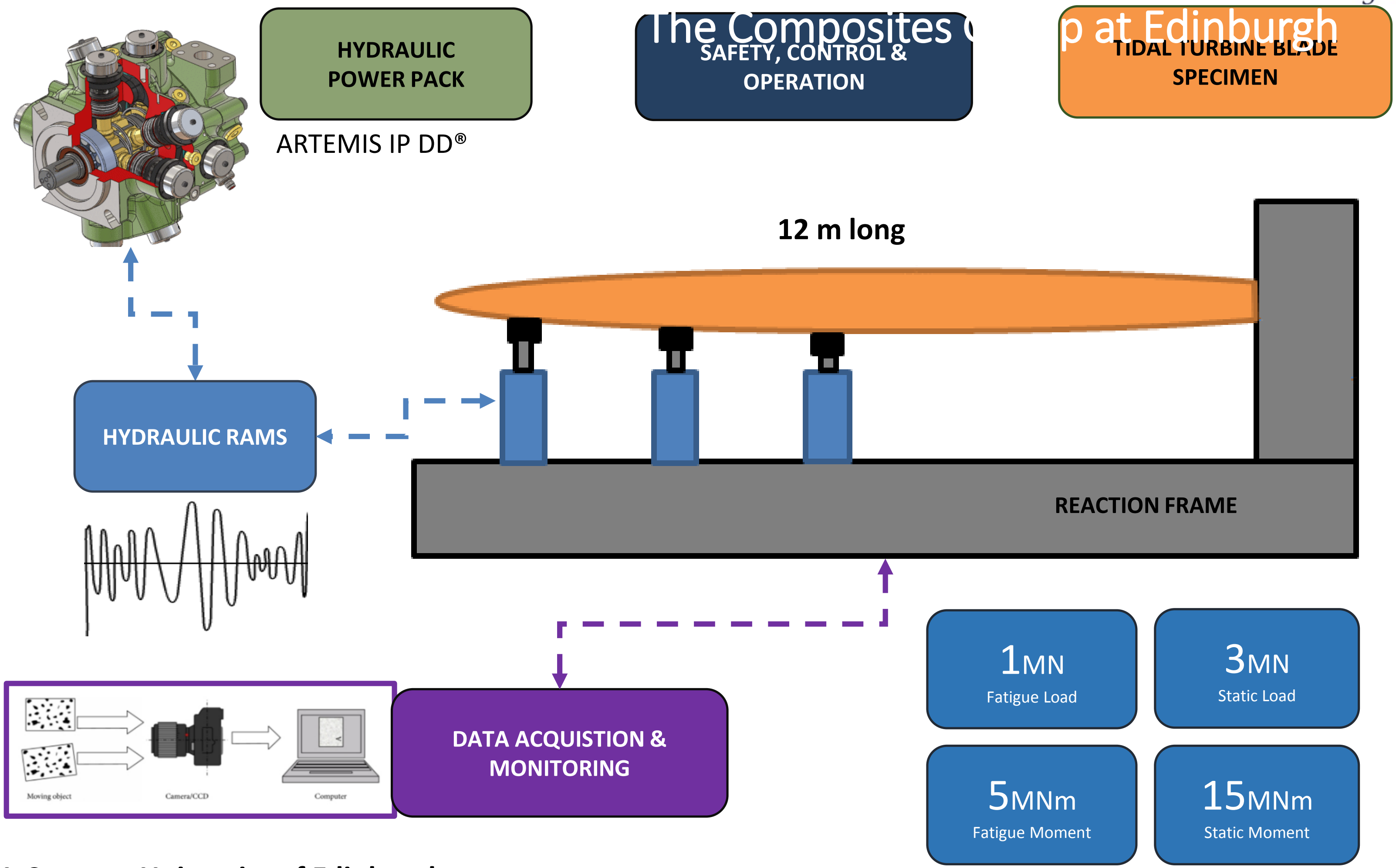
FASTBLADE Fatigue Test Facility



J. Steynor, University of Edinburgh

Questions?
Interested in working with us?

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Thank you!