FIBRESHIP: Increasing the use of composite materials in large marine vessels

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FIBRESHIP INTEGRAL COMPOSITE SHIP

Bernal Institute

University of Limerick Ollscoil Luimnigh

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- Overview of the FIBRESHIP H2020 project
- Overview of the work being performed at UL
  - Manufacturing
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  - Dissemination Activities
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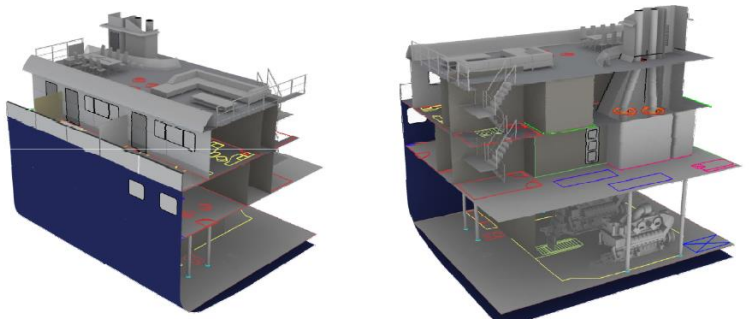
  - Acknowledgements



Ship Block Demonstrator

Background

- Composites dominate construction of small-to-medium length vessels (< 50 m) – single digit CAGR (8 %)
- Little uptake on ships longer than 50 m
- Main Reason: Lack of **design guidelines** from certification bodies
- Main issues: Safety particularly **Fire**
- The trend in aviation (e.g. B787, A350) demonstrates that extensive adoption of composite technology in primary and secondary structures is feasible

Courtesy of Tuco Marine (FIBRESHIP partner) – ProZero range of offshore/patrol/service FRP vessels (8-18 m)

PROMARINE, OUEST composites SEMI RIGID Boat (JEC 2019)

Challenge

- Enhance acceptance of composites in primary structures of ships > 50 m
- Recommend relevant changes in rules and regulations to the responsible bodies
- Create a niche market opportunity for the manufacture of large marine vessels in the EU

Light Commercial Vessels	Passengers transportation & Leisure	Special Services
		
Representative Container Vessel	Representative ROPAX	Representative Fishing Research Vessel

Response: FIBRESHIP

- **Engineering, production and life-cycle management for the complete construction of large-length FIBRE-based SHIPs**

- Innovation Action
- Total budget: 11.0M€; EU contribution: 8.7M€
- **UL budget: 0.72M€**
- Coordinator: TSI SL, Spain
- Duration: 36 months from June 2017

CATEGORY I
Light Commercial Vessels

Representative
Container Vessel

- RoRo vessel
- Car Carrier
- Multi-purpose
- Freezer Vessel
- LNG
- Wood Transportation
- .....

CATEGORY II
Passengers transportation & Leisure

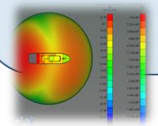
Representative
ROPAX

- Ferries
- Passenger vessel
- Megayacht
- .....

CATEGORY III
Special Services

Representative
Fishing Research Vessel

- Fishing vessel
- Seismic Vessel
- Supply vessel
- Rescue vessel
- .....



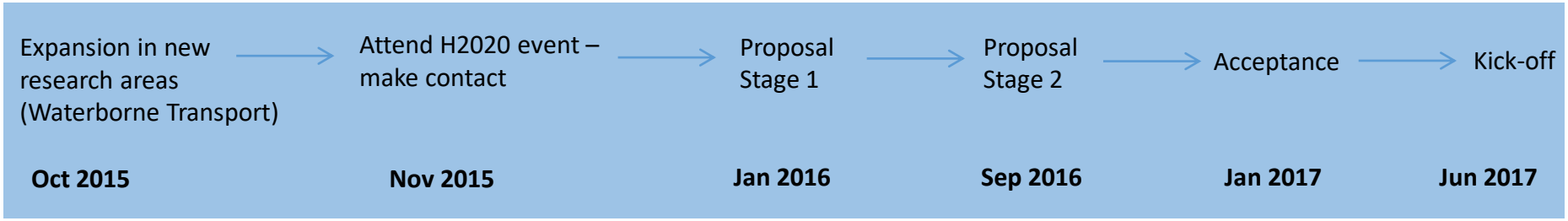
Partners

- 18 partners, 11 countries
- European shipyards: 3
- Naval architect/design/engineering companies: 4
- Ship owners & operators: 4
- R&D organisations: 4
- Classification/certification bodies: 3

Value Chain

Value Chain and Initial FIBRESHIP Community

Timeline


Expansion in new research areas (Waterborne Transport)
Oct 2015
Attend H2020 event – make contact
Nov 2015
Proposal Stage 1
Jan 2016
Proposal Stage 2
Sep 2016
Acceptance
Jan 2017
Kick-off
Jun 2017

Impact

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Technical:

- Feasibility of the concept of a composite large-length ship
- Reduce fuel consumption by 10-15%
- Lower greenhouse gas emissions
- Improve ship stability and safety
- Underwater noise reduction
- Reduce maintenance and life cycle costs by 30%
- Corrosion-free

Safehaven marine 11-18 m

Swedish Navy Visby > 70 m

Impact

FIBRESHIP 3
INTEGRAL COMPOSITE SHIP

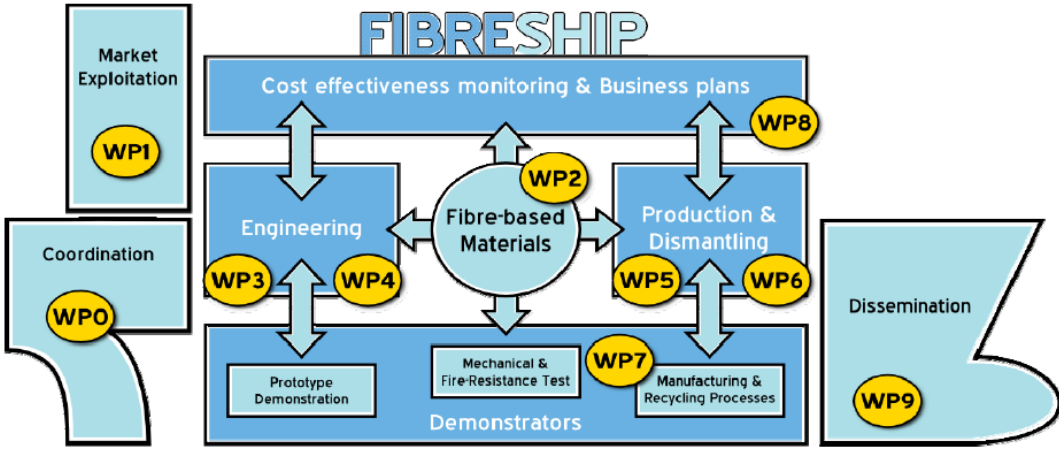
UL/Bernal/IComp:

- Links with new academic partners
- Links with new industrial partners
- Opportunities to join new consortia & funding bids
- Dissemination & visibility (e.g. *Marine Trade Show – Seafest 2017*, Galway; *Connecting Europe*, Tallinn, Estonia)
- Expanding in a new research area
- Technology transfer from aerospace

Our role in FIBRESHIP

Involved in 4 work packages:

- Materials (WP 2)
- Production (WP 5)
- Large-scale Validation (WP 7)
- Dissemination & Exploitation (WP 9)



Work Packages

Materials (WP 2)

FIBRESHIP
INTEGRAL COMPOSITE SHIP

Which resins and reinforcements are viable solutions for large marine vessels ?

considering….

- *TRL*
- *fire retardancy*
- *processability*
- *economics*
- *recycling*
- *mechanical properties*
- *environmental resistance..*

*Demonstrator currently under construction at iXblue showing **laminate** and **sandwich** construction*

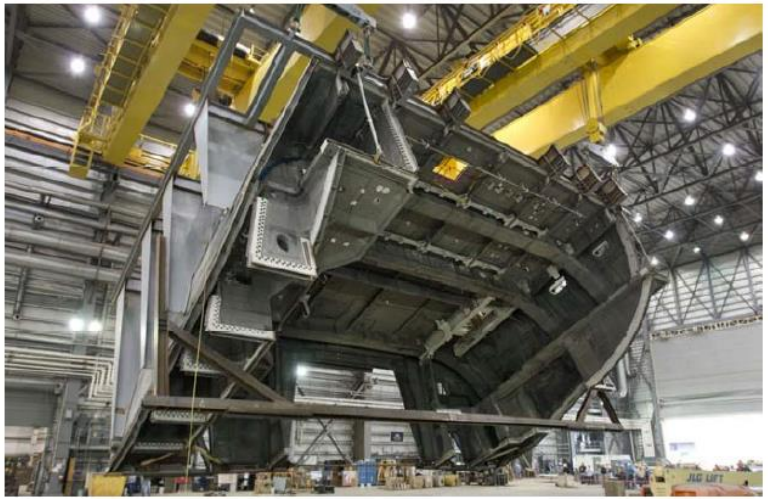
Materials (WP 2)

FIBRESHIP
INTEGRAL COMPOSITE SHIP

*Which **manufacturing processes** are most suitable for the manufacture of large marine vessels ?*

considering….

- *scale involved*
- *shipyard capabilities*
- *investment required*
- *future market*
- *skilled workforce available*
- *production rate*
- *need to automate..*



Composite ship block < 50 m long

Materials (WP 2)

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- **Liquid resin infusion identified as most suitable manufacturing technique….** familiar to ship yards, scalable, cost effective, flexible, closed mould infusion process

- **Matrix of infusible resin systems was drawn up**

- 7 TS resin systems – various chemistry
- 1 infusible thermoplastic resin
- 1 bio-epoxy
- All commercially available (High TRL project)
- All marketed as infusible
- **Fire retardant options**

#	Class	Resin	Curing agent (mass ratio)	Viscosity[a] (cP)	Tool	Infusion time / Temp (min/°C)	Curing Schedule	Post-cure schedule
1	Polyester	SYNOLITE	100 : 1.5	80-90 cP @ 25°C			24 hr @ RT	16 hrs @ 40°C
2	Vinylester	BUFA 8500	100 : 2.5	300-400 cP @ 20°C	Aluminum (heated)	20/17.3	24 hr @ RT	6 hrs @ 80°C
3	Urethane Acrylate	CRESTAPOL 1210	100 : 2 : 1 : 1[b]	175 cP @ 25°C (neat resin)	Glass	11/21.1	1h at RT	Not required
4	Epoxy	SR1125	100 : 14	680 cP at 20°C 305 cP at 30°C 160 cP at 40°C	GLASS (+ heated Mat)	40/19.9	16hrs @ 40°C	8 hrs @ 80°C
5		PRIME 27	100 : 28	190-200 cP @ 25°C			24 hr @ RT	7 hrs @ 60°C
6	Bio-epoxy	SUPER SAP CLR	100 : 33	300 cP @ 25°C	Aluminum (heated)	92/35	24 hr @ RT	2 hrs @ 120°C
7	Phenolic	CELLOBOND J2027X	100 : 4	270cP @ 25°C	Aluminum (heated)	36/60	15 mins @ 60°C	3hrs @ 80°C
8	Acrylic (TP)	ELIUM 150	100 : 2.5[c]	100 cP @ 25°C (neat resin)	Glass	23/21.9	24 hr @ RT	Not required

[A] values from TDS; [b] 2 parts by weight of accelerator D (10% solution of dimethyaniline in styrene): 1 part by weight of accelerator G (1% cobalt solution in styrene): 1 part by weight of peroxide catalyst (Trigonox 44B); [c] Benzoylperoxide Luperox A40FP-EZ9

Materials (WP 2)

FIBRESHIP 3
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Multi-stage down-selection (12 months)

Stage I:

- Candidate materials
- Scoring Table devised based on relevant criteria including:
  - Processability
  - Fire performance (VTT)
  - Mechanical properties
  - Environmental resistance
  - Cost
- Down selection agreed by partners

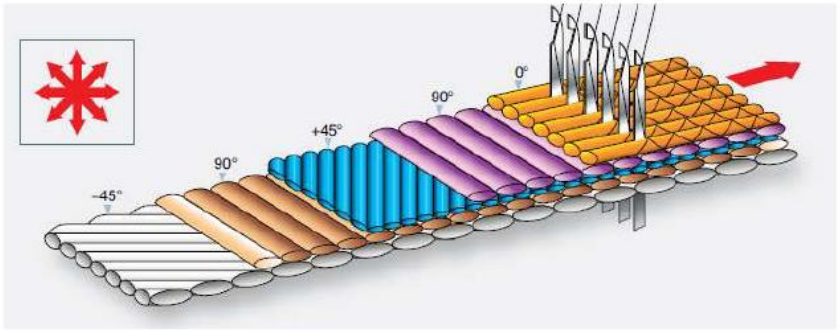
Stage II:

- More extensive mechanical testing
- Fatigue testing

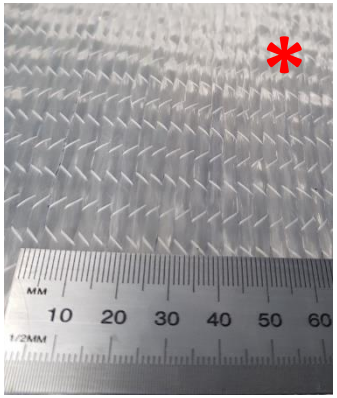
Reinforcement

Fibre Reinforcement suitable for infusion

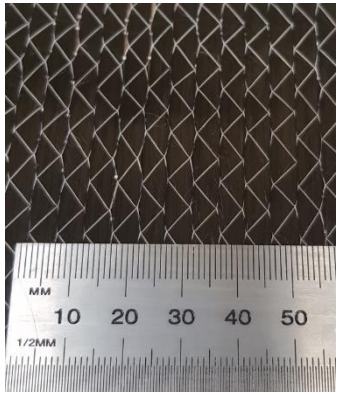
- Non-crimp-fabric from Saertex
- Glass | Carbon | Basalt fibres
- Unidirectional with some 90° tows and PE stitching (17 gsm)
- Fibre Sizing: Silane
- Fire retardant versions *



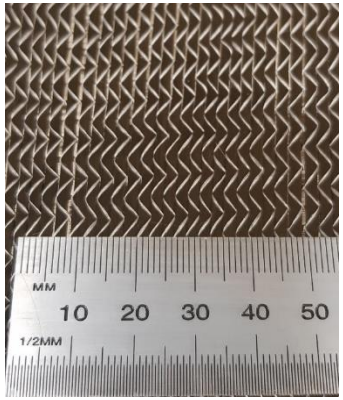
Glass
Saertex U-E-996g/m^2



Leo-Compatible Glass
Saertex U-E-900g/m^2



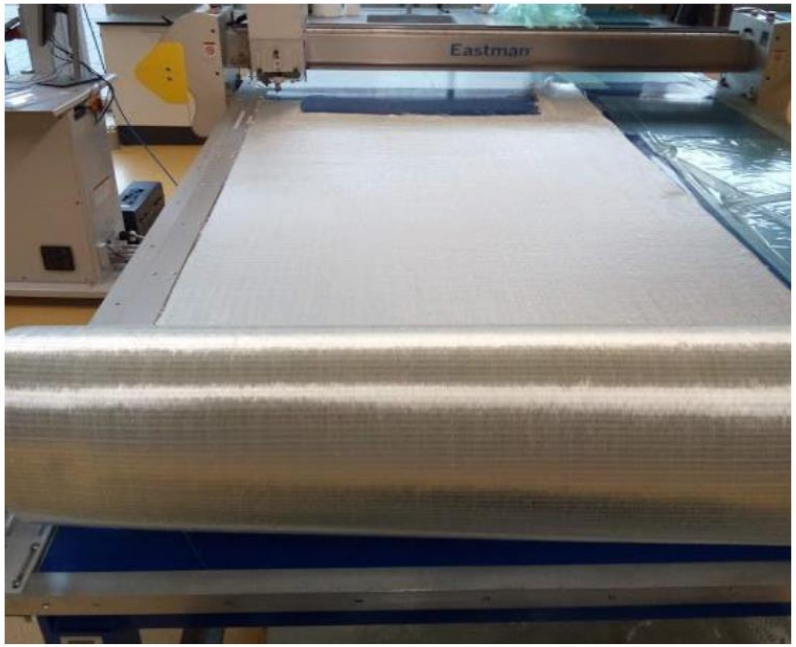
Carbon
Saertex U-C-314g/m^2

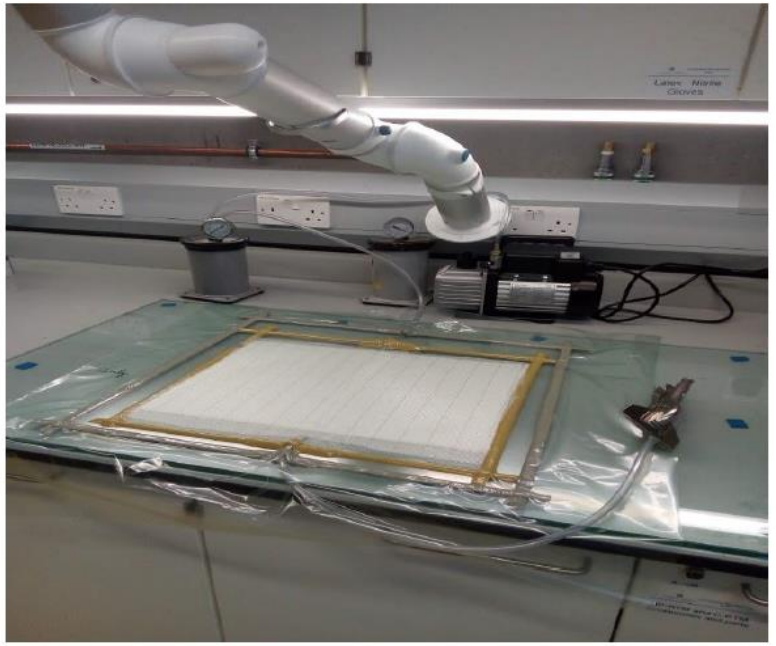


Basalt
Basaltex BAS-UNI-350 g/m^2

Manufacture

Preparation of Reinforcement for infusion

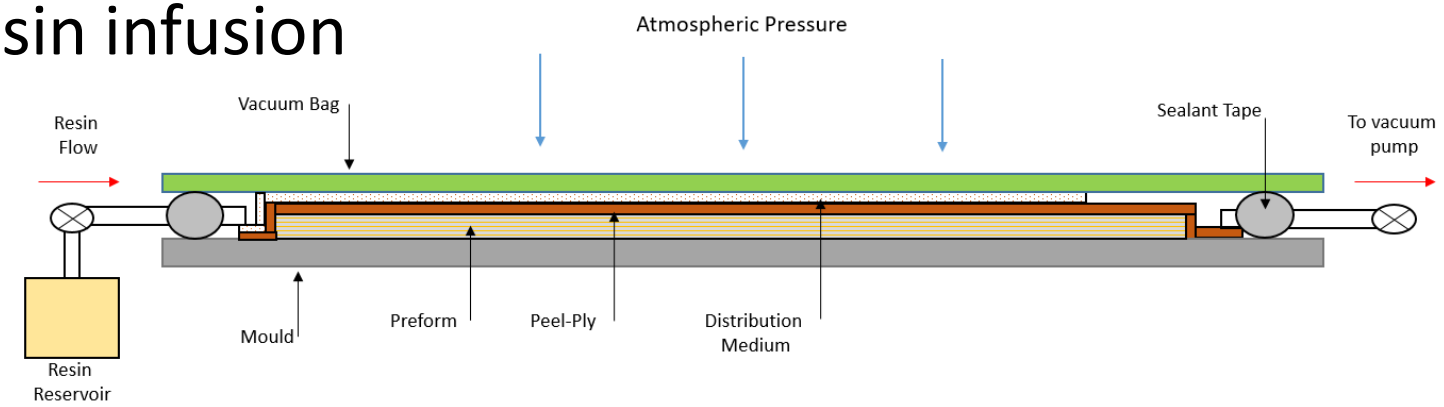


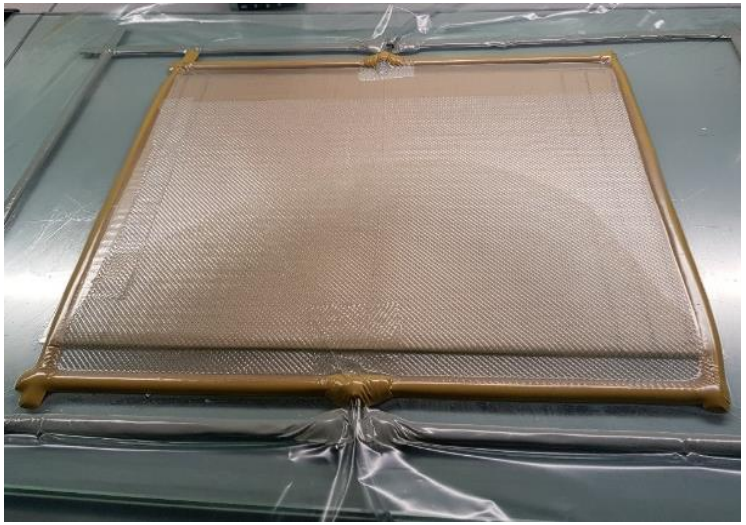


- NCF available on roles up to 4 m wide
- Cutting is automated (Not required by Shipyards !)
- All laminates nominally: 350 x 500 x 3 mm
- Lay-up: 0_{2S} (4 layers of NCF in a UD configuration)

Manufacture

Liquid resin infusion



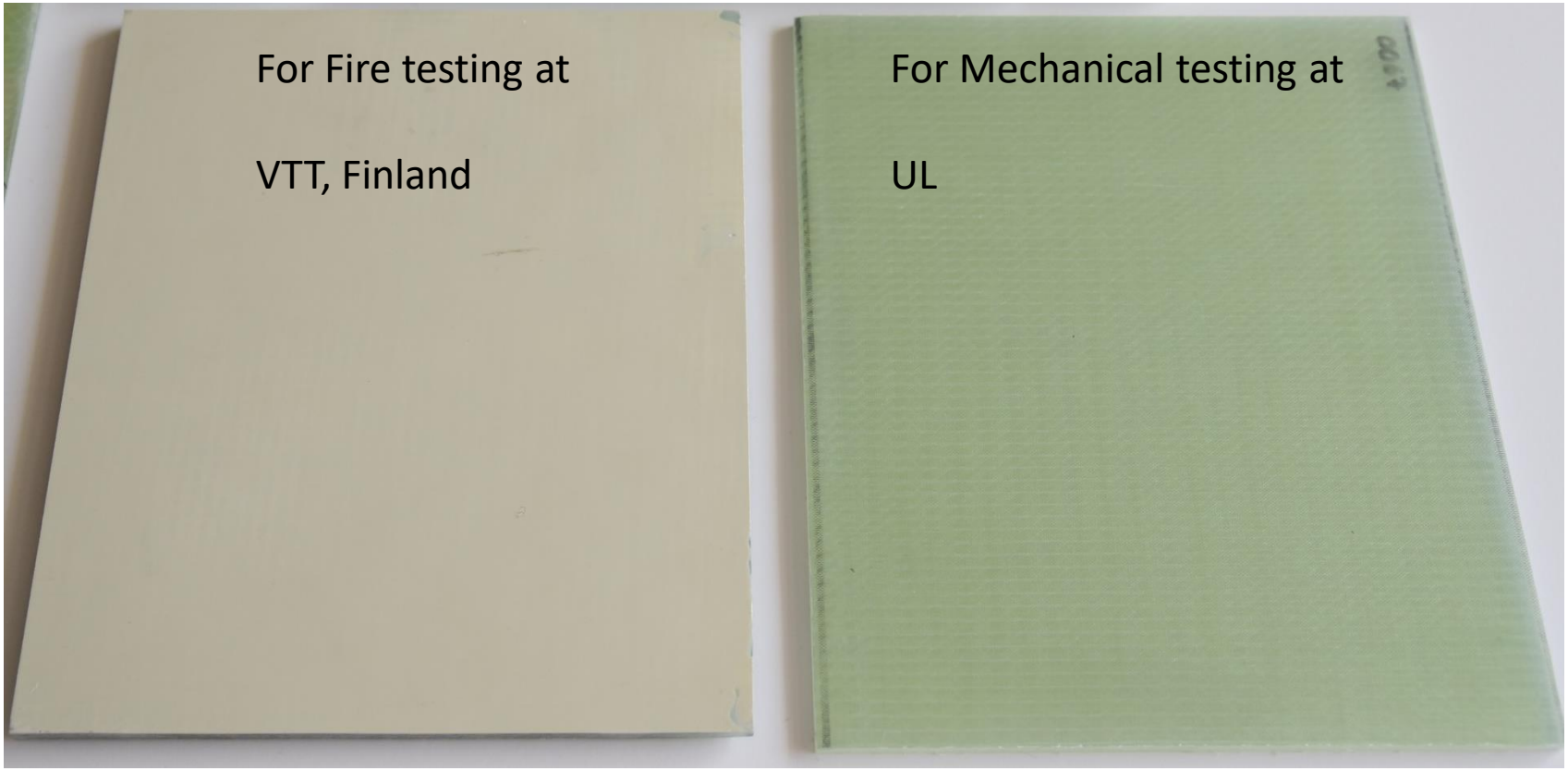


Infusion, cure and post cure schedule in line with manufacturers guidelines

Infusion issue with one of fire retardant resin systems

Manufacture

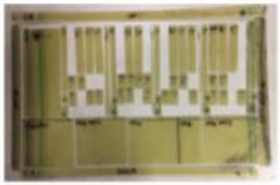
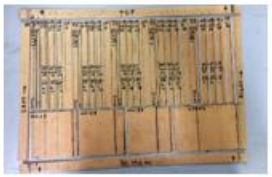
Laminate Production



Coated Laminate

Uncoated Laminate

Laminate Production

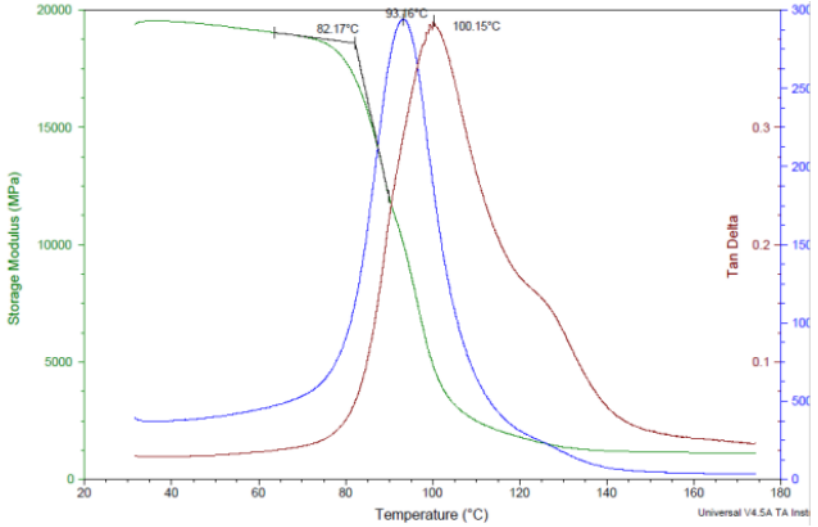
1	**Urethane Acrylate** $V_f = 57 \pm 0.3\%$		
2	**Epoxy** $V_f = 58 \pm 3.0\%$		
3	**Bio-epoxy** $V_f = 60 \pm 0.6\%$		
4	**Phenolic** $V_f = 58 \pm 0.4\%$		
5	**Acrylic (TP)** $V_f = 56 \pm 1.0\%$		

All laminates nominally: 350 x 500 x 3 mm

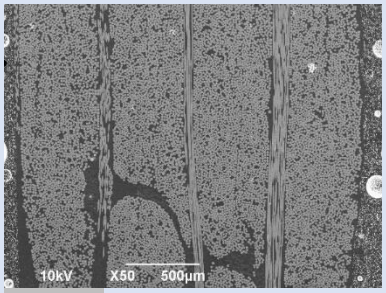
Quality Control

Material	Cured Ply Thickness	FVF
VE	0.71 mm	52%
PE	0.73 mm	54%
EP	0.74 mm	53%
TP	0.72 mm	55%

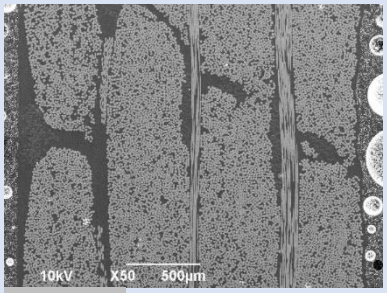
Tg and degree of cure



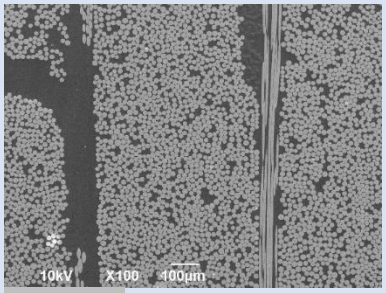
Void Analysis (MS 0051)



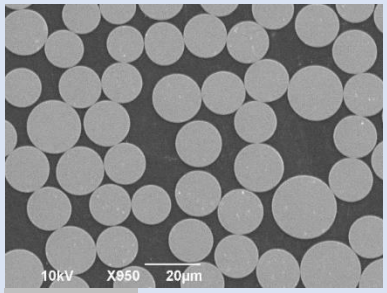
x50



x100



x100



x950

Conditioning

Immersion Bath (Deionised water @ 35 °C)

- Various Media: Dry, Water, diesel
- Partial saturation
- Fully saturated
- Fully Saturated followed by Drying
- Effect on Tg and mechanical properties

Data for Modelling

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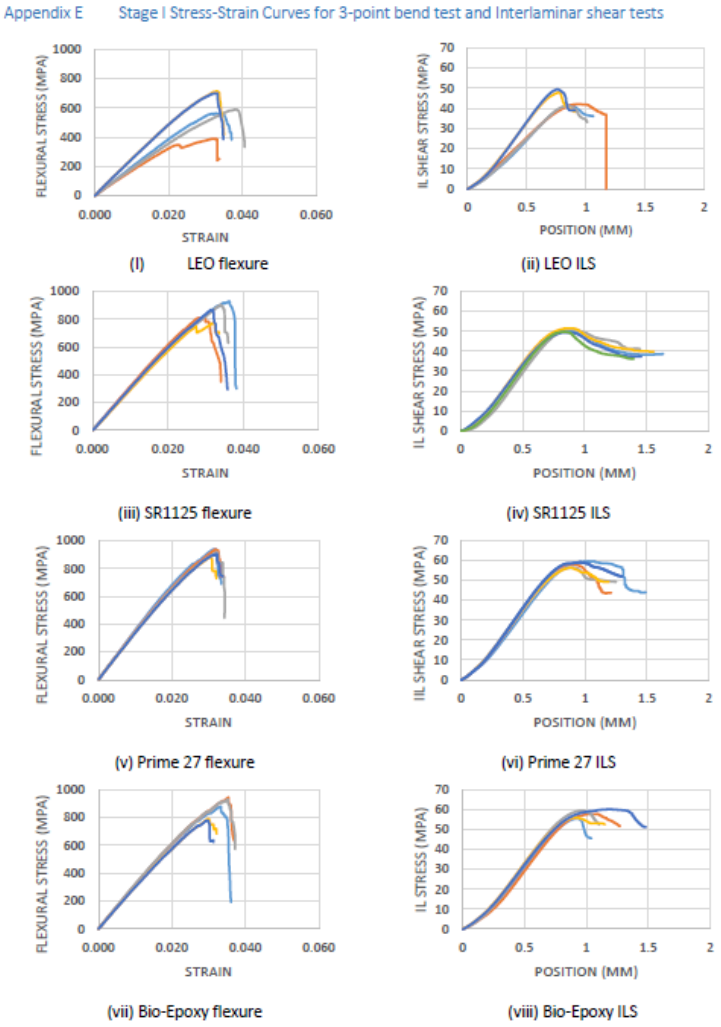
- CIMNE responsible for modelling data from WP 2
- Experimental data used for validation of models
- Models used in computational structural analysis/design software developed by Compass

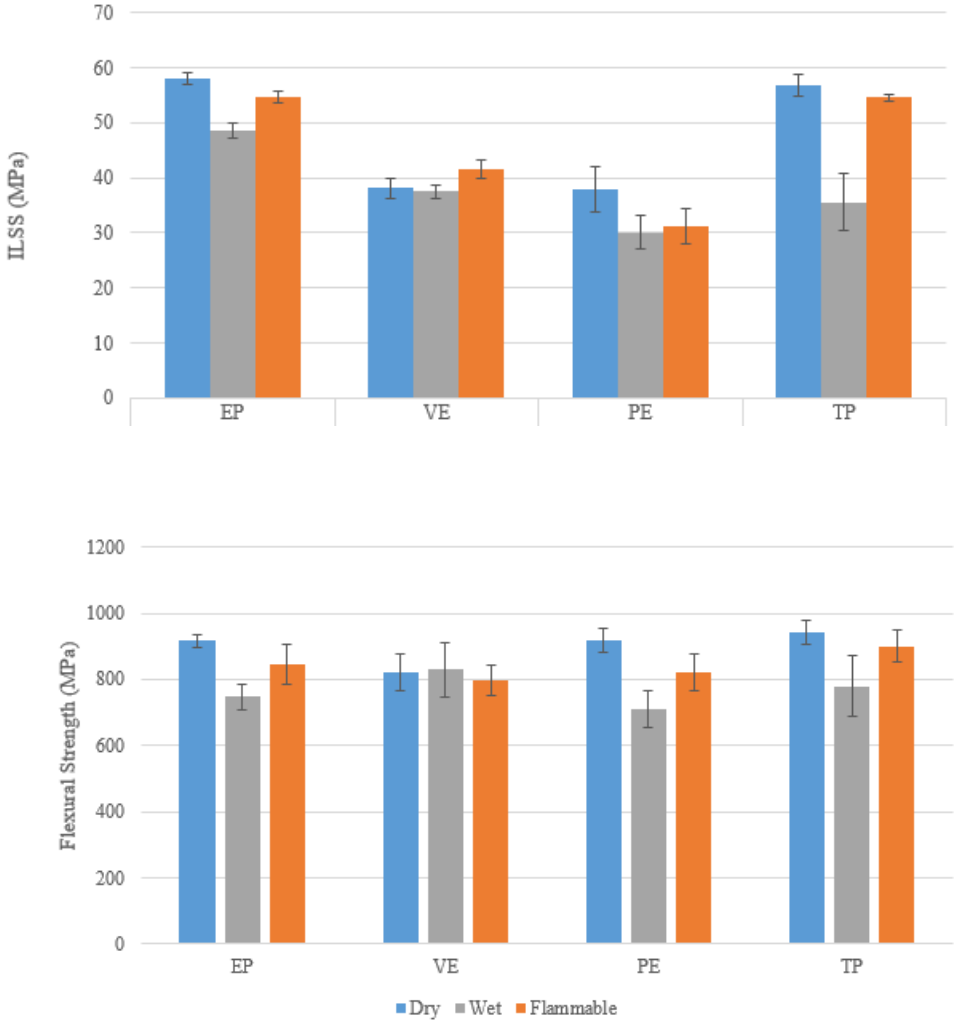


COMPASS
www.compassis.com

CIMNE

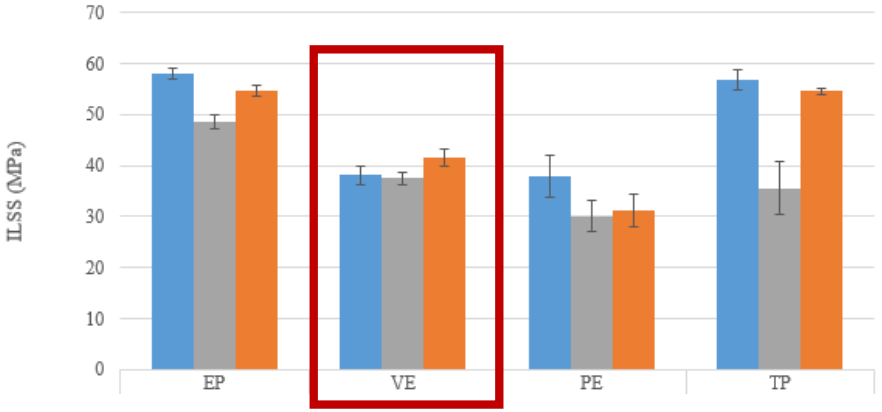
Failure Analysis

- Our first journal paper compares x4 different resins all with glass reinforcement
- Exposed to water and diesel for durations indicated by classification society
- Evaluated ILSS and Flexural properties
- Examine failure modes

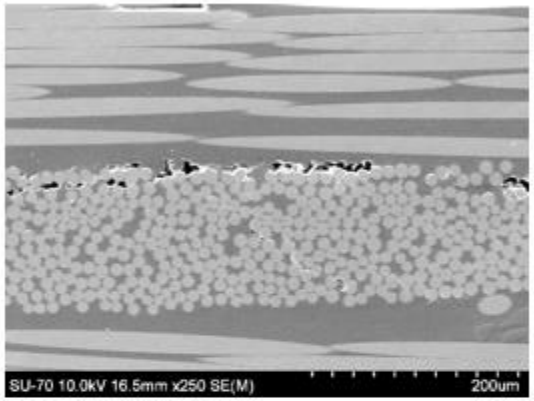


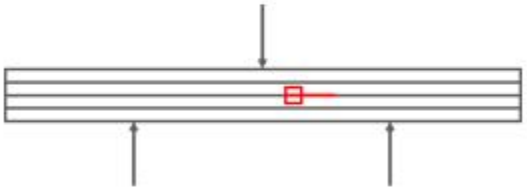
Failure Analysis

ILSS



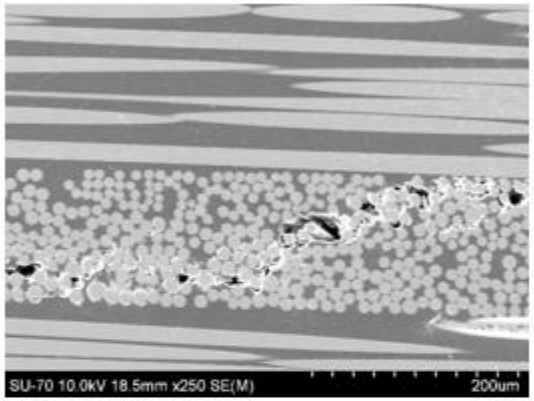
Vinylester Dry (100%)

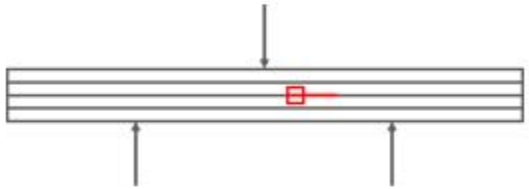




Midplane crack at 0° and 90° interface

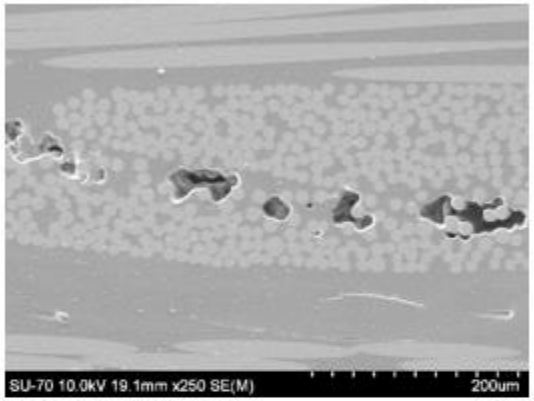
Vinylester Wet (98%)

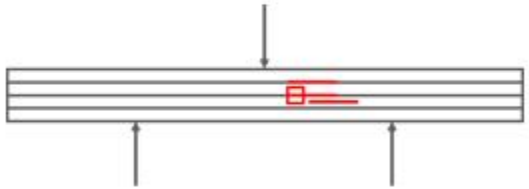




Midplane intratow crack at 0° and 90° interface

Vinylester Organic-Wet (108%)

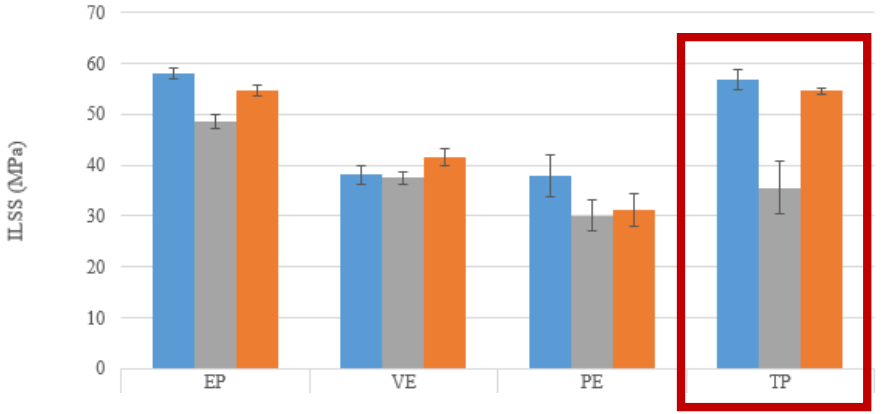




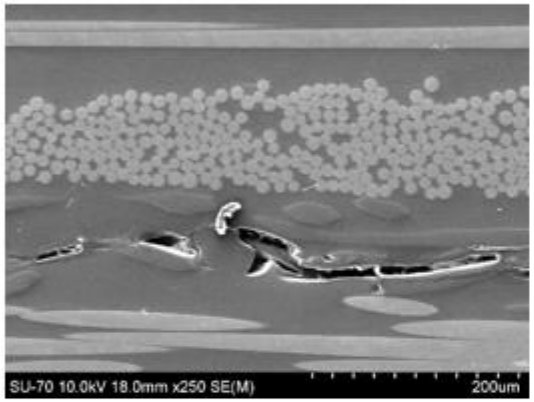
Midplane intratow crack at 0° and 90° interface, interply (ply 1 – top ply – and 2) and intraply cracks (ply 3)

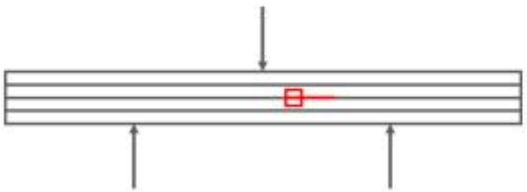
Failure Analysis

ILSS



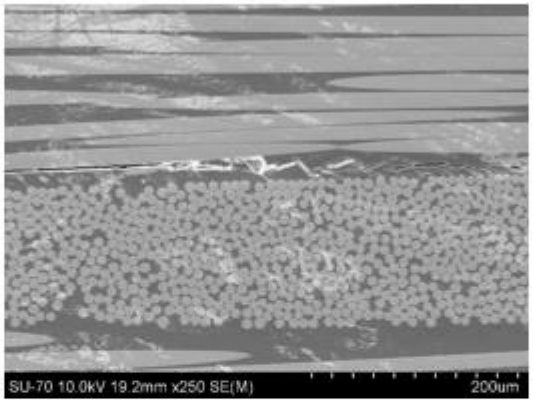
Thermoplastic Dry (100%)

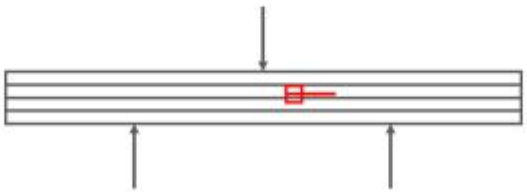




Matrix-dominated midplane crack

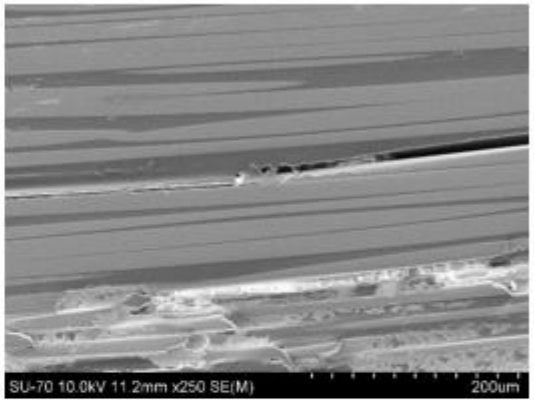
Thermoplastic Wet (63%)

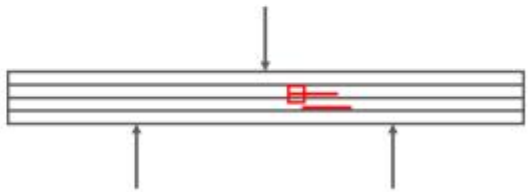




Intraply crack in second ply from top at fibre-matrix interface

Thermoplastic Organic-Wet (96%)

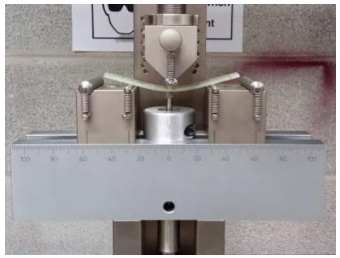


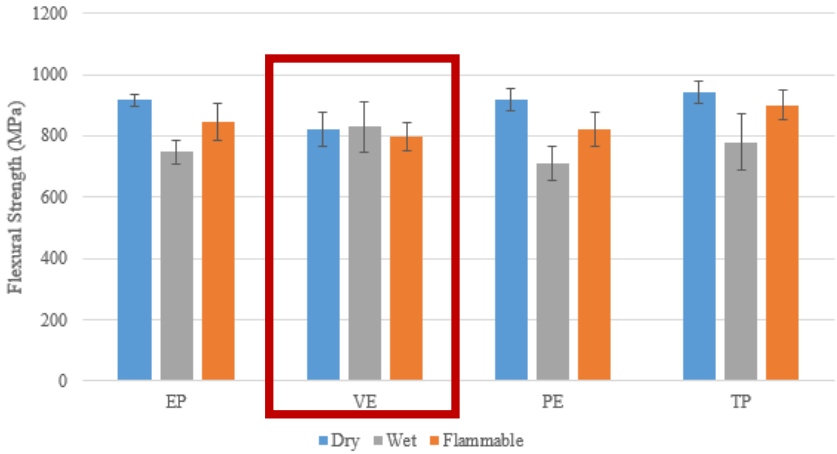


Intraply crack in second ply and interply crack between third and fourth plies from top at fibre-matrix interface

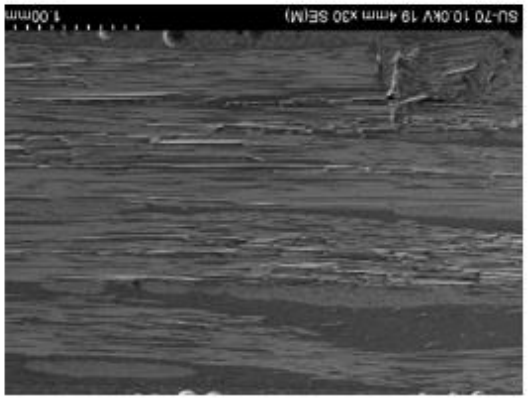
Failure Analysis

3 pt bend

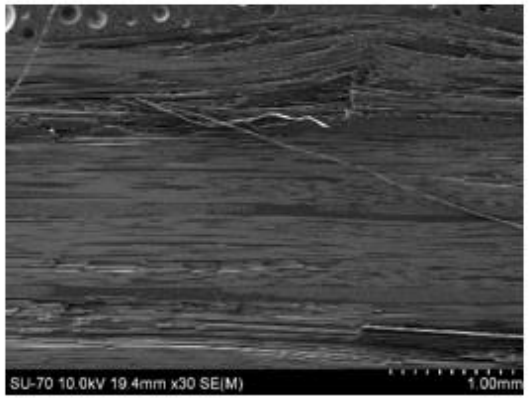




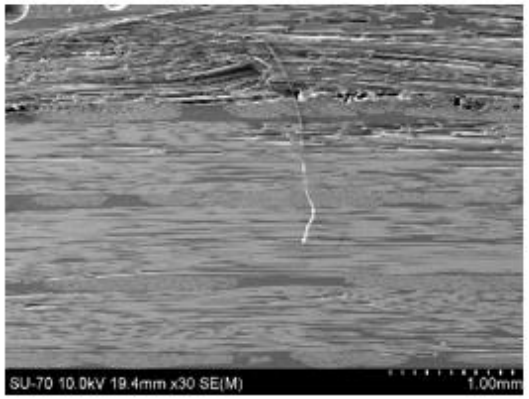
Vinylester Dry (100%)



Vinylester Wet (101%)



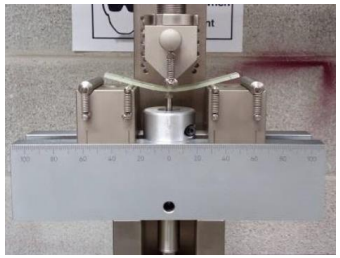
Vinylester Organic-Wet (97%)

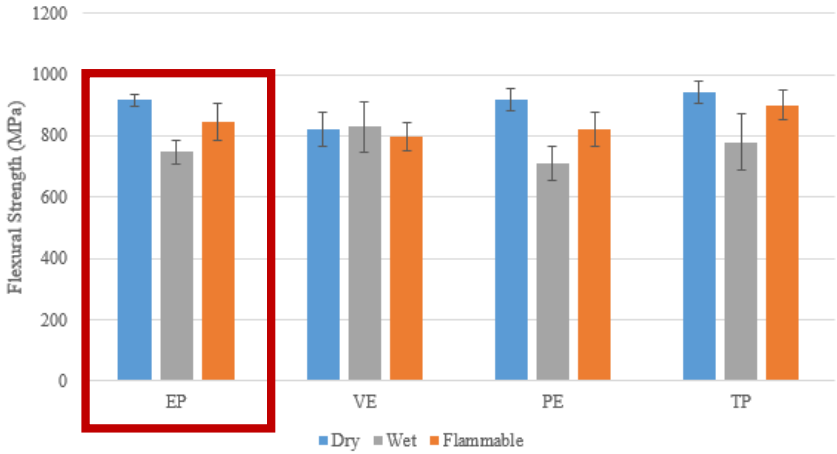


- Water: No change in strength or modulus
- Diesel: < 10% reduction in strength and modulus

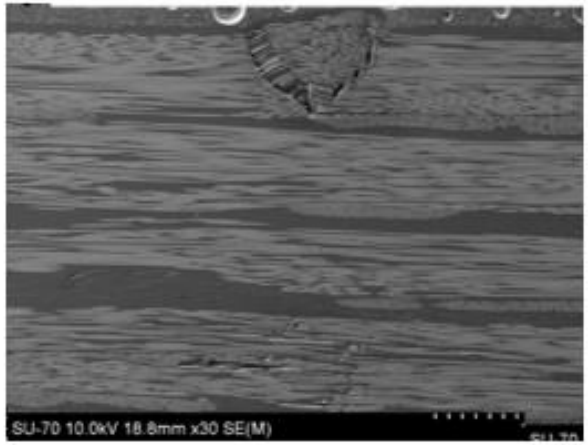
Failure Analysis

3 pt bend

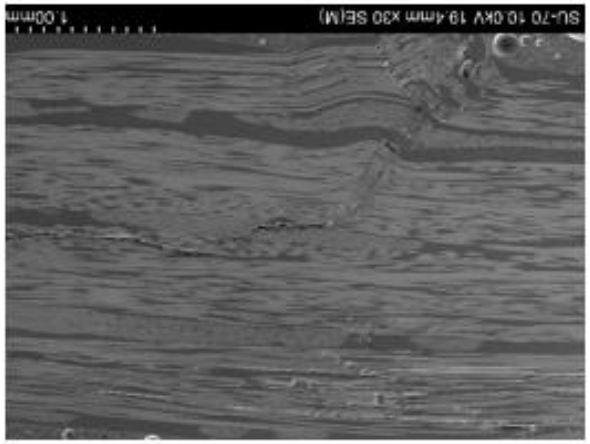




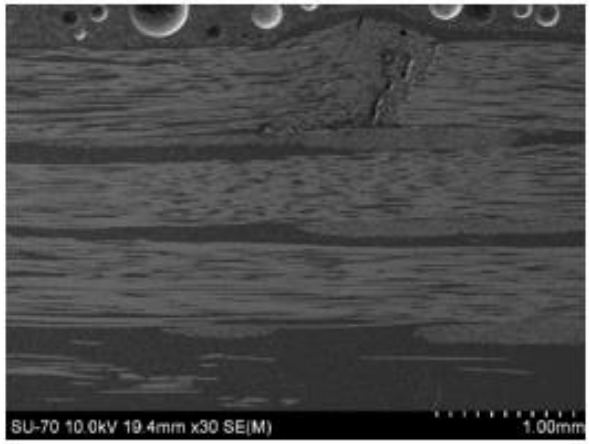
Epoxy Dry (100%)



Epoxy Wet (81%)

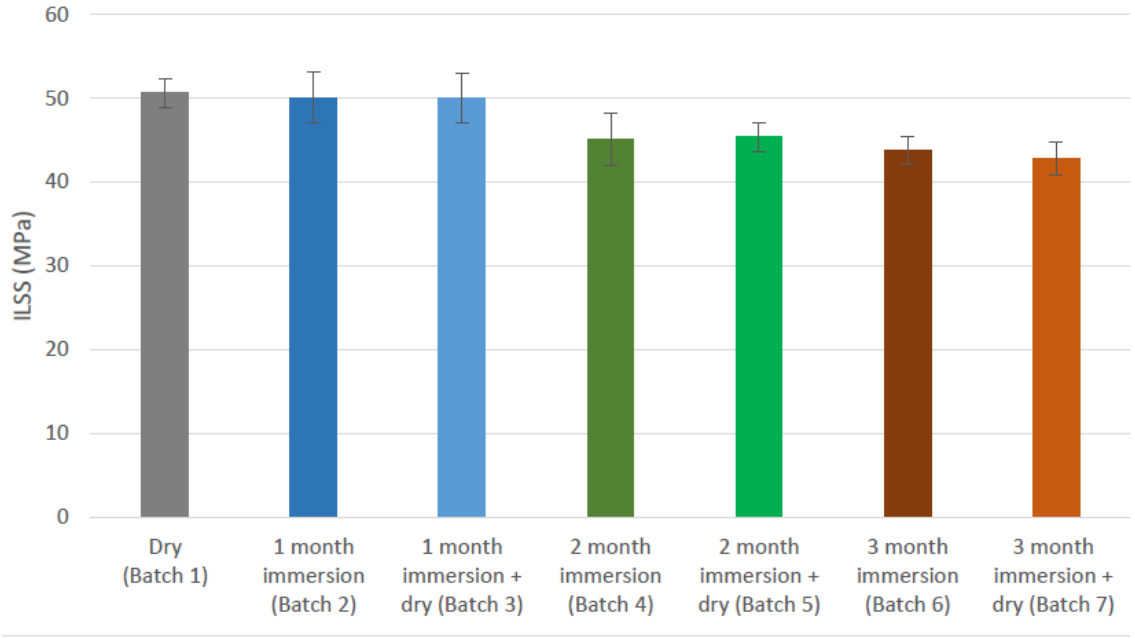


Epoxy Organic-Wet (92%)



- Water: 19% reduction in strength | < 5 % reduction in modulus
- Diesel: < 10% reduction in strength and modulus

Longer Term Immersion



FYP 2019: Aaron Reid, 14063379

New Tooling

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INTEGRAL COMPOSITE SHIP

- Laminate or Sandwich Panel
- Adjustable cavity
- Fixed cavity for better tolerance
- Vacuum or positive pressure

Sandwich Panels

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INTEGRAL COMPOSITE SHIP

- Single shot vacuum infusion
- 480 x 480 mm x 26 mm
- Glass skins
- 25 mm thick core
- No consumables/waste

VE with
Balsa Core

VE with
PET Core

MSc Project 2019

Sandwich Panel Manufacture

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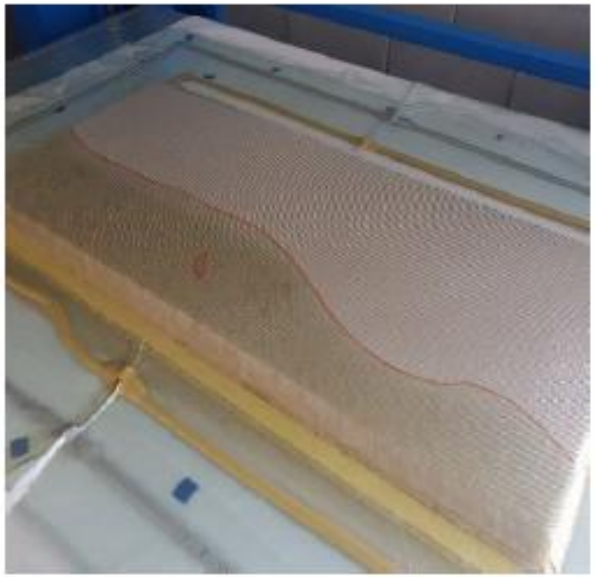
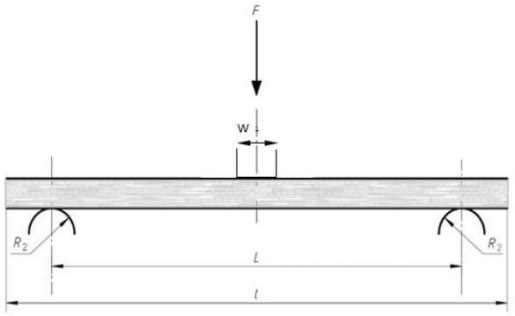
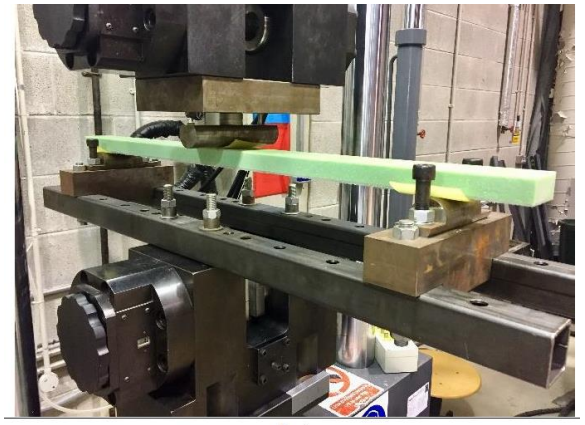
INTEGRAL COMPOSITE SHIP



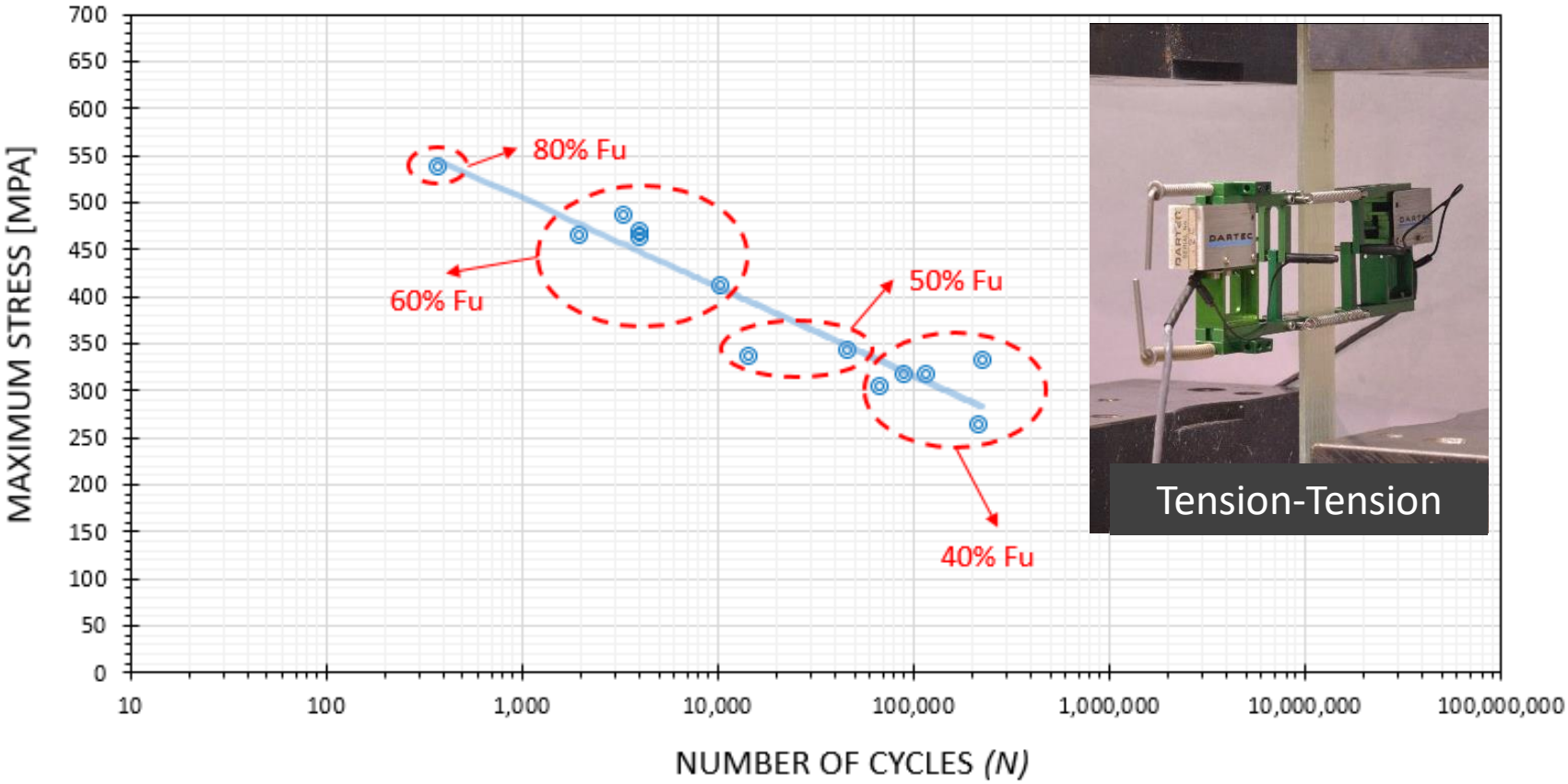




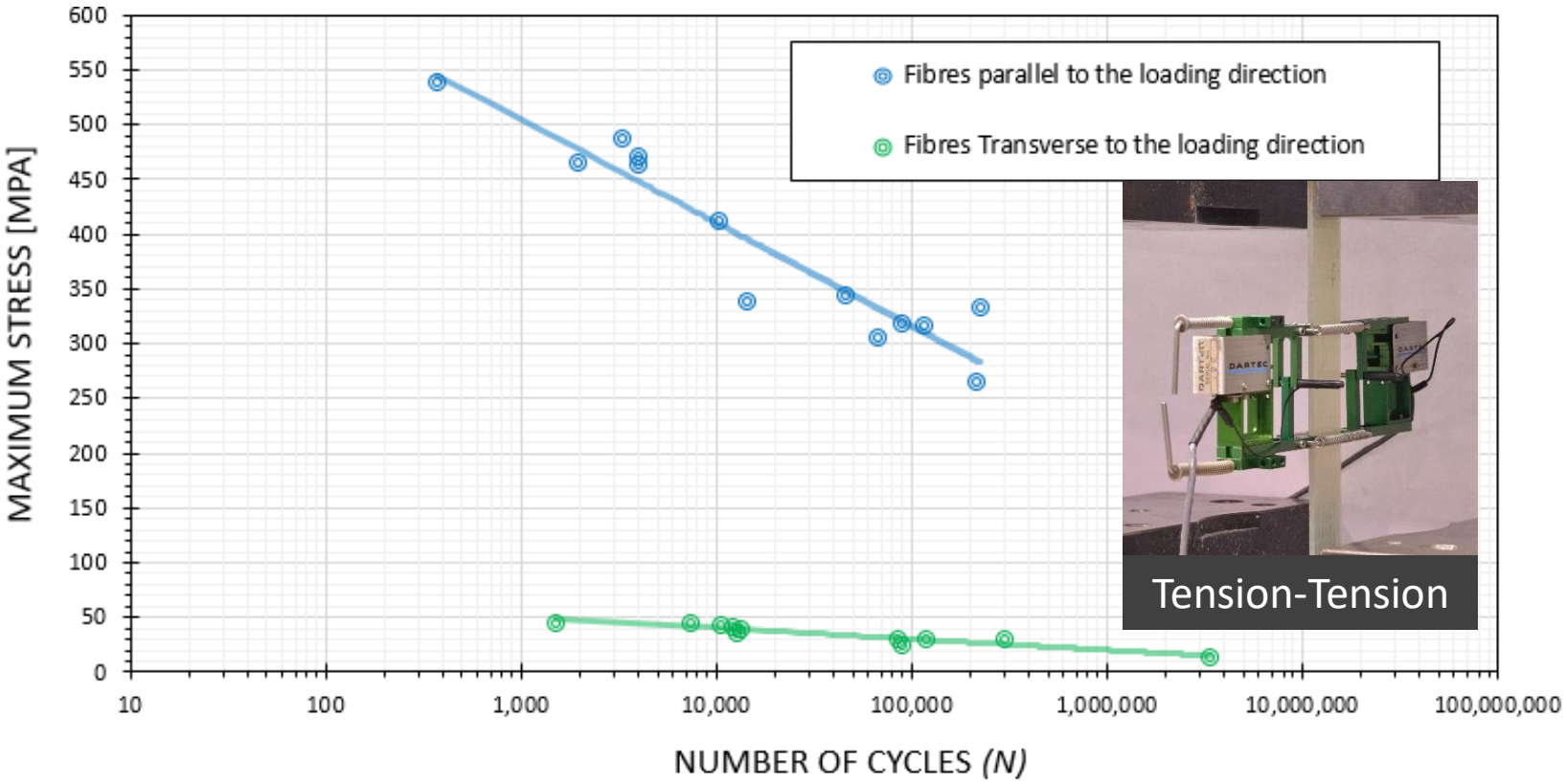
- Single shot infusion of sandwich panel

- Flexural Testing and Failure mode Analysis

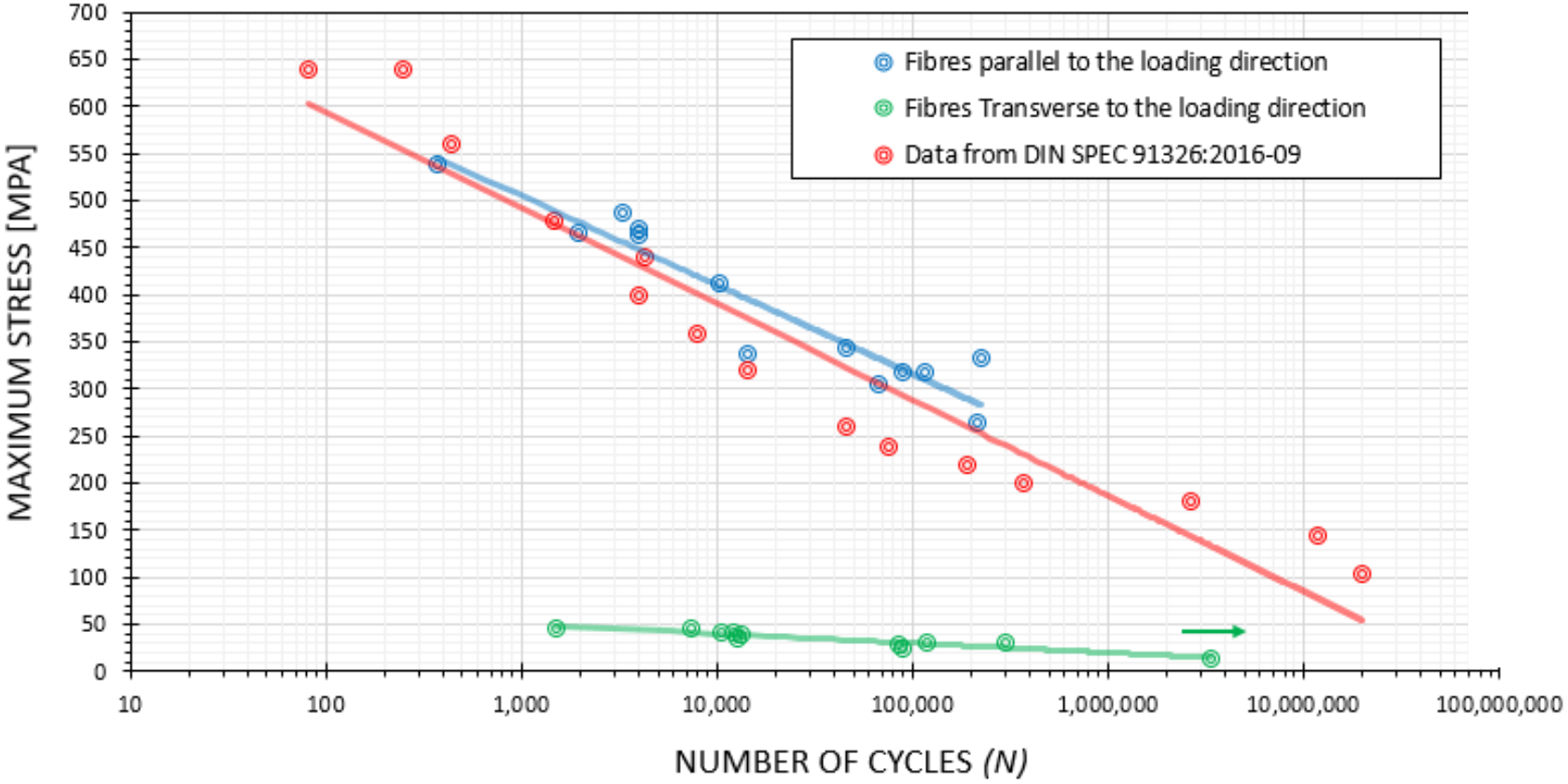
Fatigue


MAXIMUM STRESS [MPA]
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
10
100
1,000
10,000
100,000
1,000,000
10,000,000
100,000,000
NUMBER OF CYCLES (N)
80% Fu
60% Fu
50% Fu
40% Fu
Tension-Tension

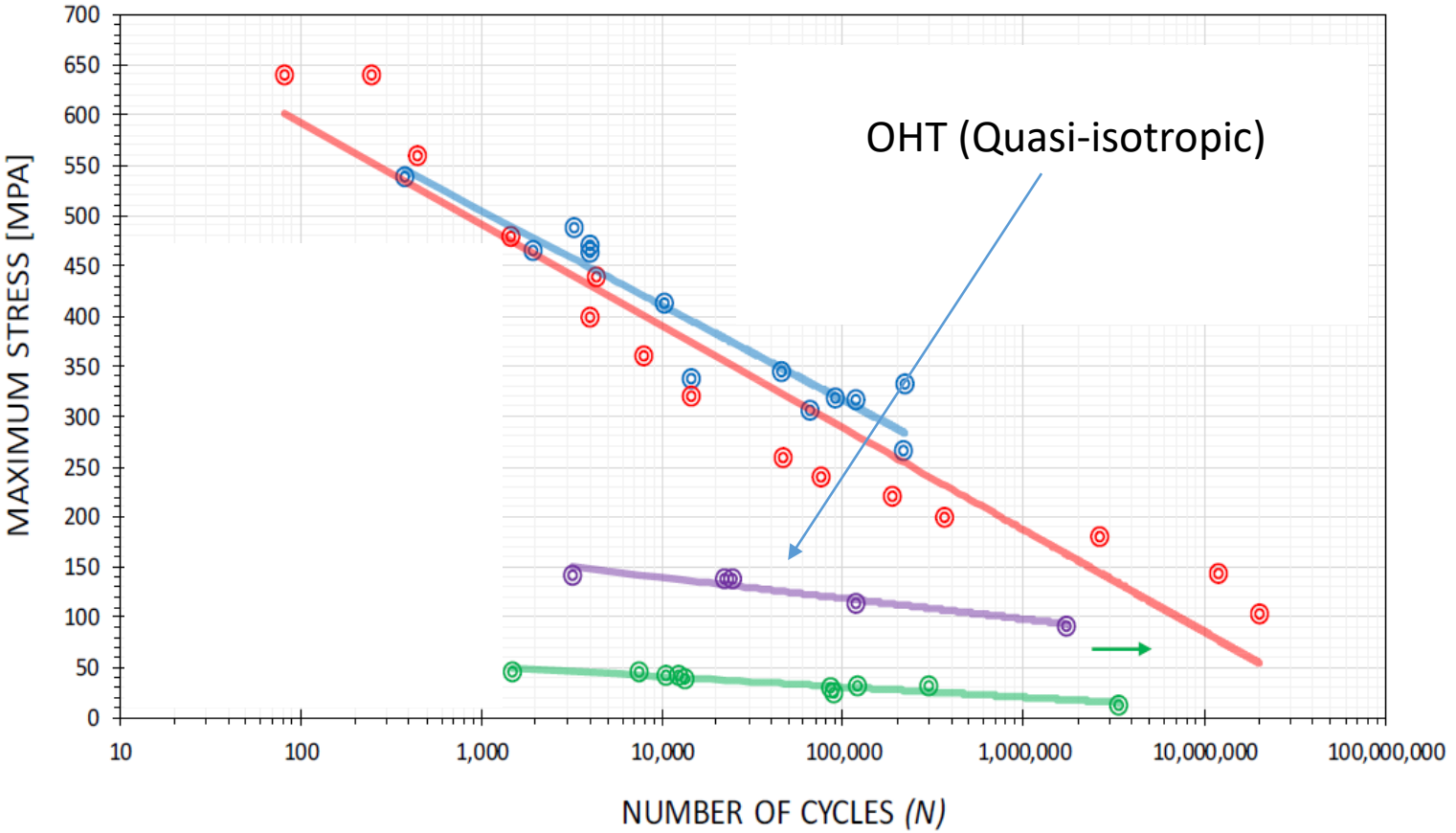
Fatigue

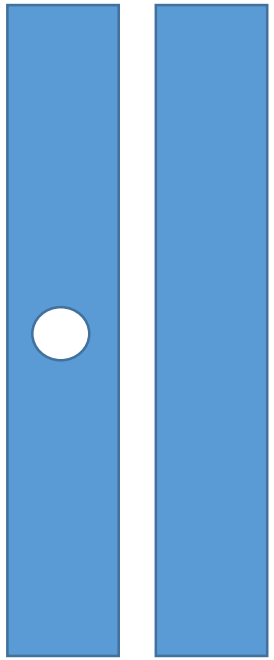

MAXIMUM STRESS [MPA]
600
550
500
450
400
350
300
250
200
150
100
50
0
10
100
1,000
10,000
100,000
1,000,000
10,000,000
100,000,000
NUMBER OF CYCLES (N)
Fibres parallel to the loading direction
Fibres Transverse to the loading direction
Tension-Tension

Fatigue


Fibres parallel to the loading direction
Fibres Transverse to the loading direction
Data from DIN SPEC 91326:2016-09
MAXIMUM STRESS [MPA]
NUMBER OF CYCLES (N)
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
10
100
1,000
10,000
100,000
1,000,000
10,000,000
100,000,000

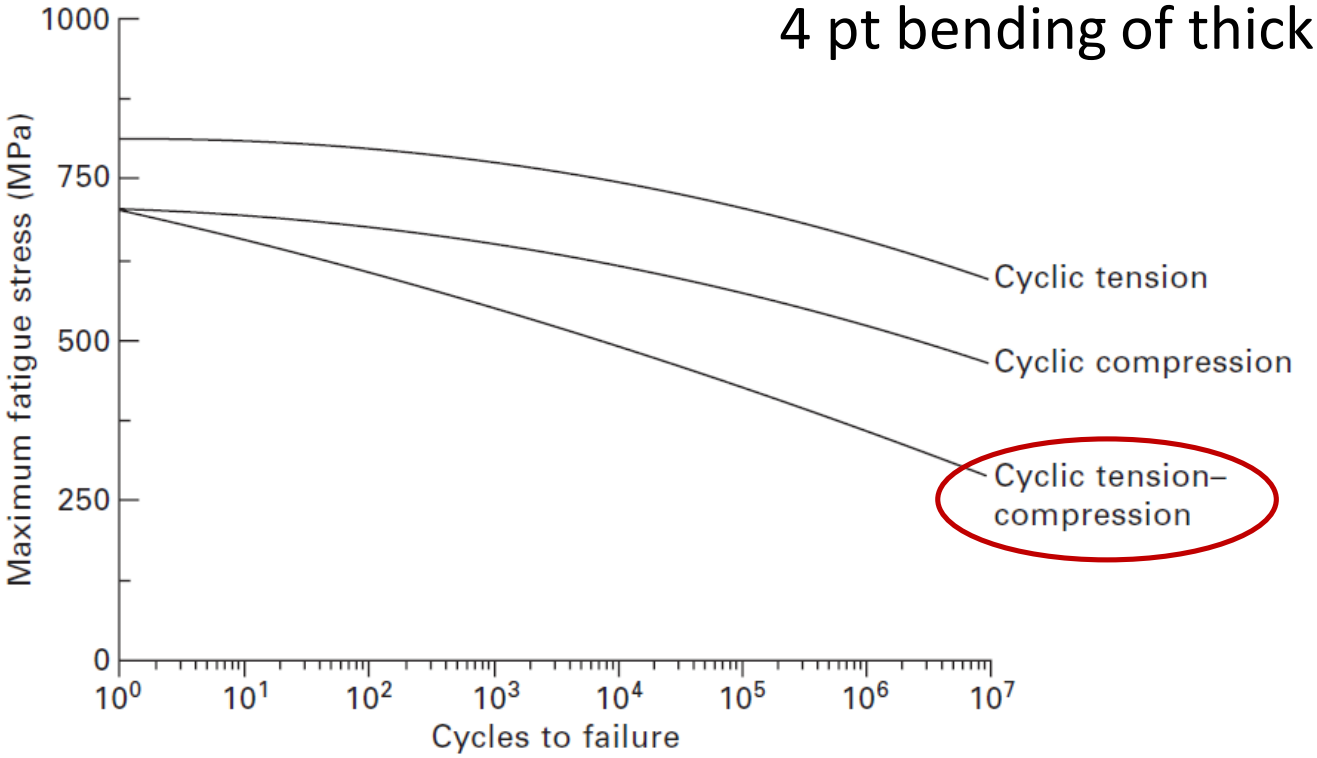
Fatigue


MAXIMUM STRESS [MPA]
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
10
100
1,000
10,000
100,000
1,000,000
10,000,000
100,000,000
NUMBER OF CYCLES (N)
OHT (Quasi-isotropic)
Fibres parallel to the loading direction
Fibres Transverse to the loading direction
Benchmark - DIN 91326:2006-09 - Railway vehicle applications
Fibres Quasi-Isotropic to the loading direction



Fatigue – future work

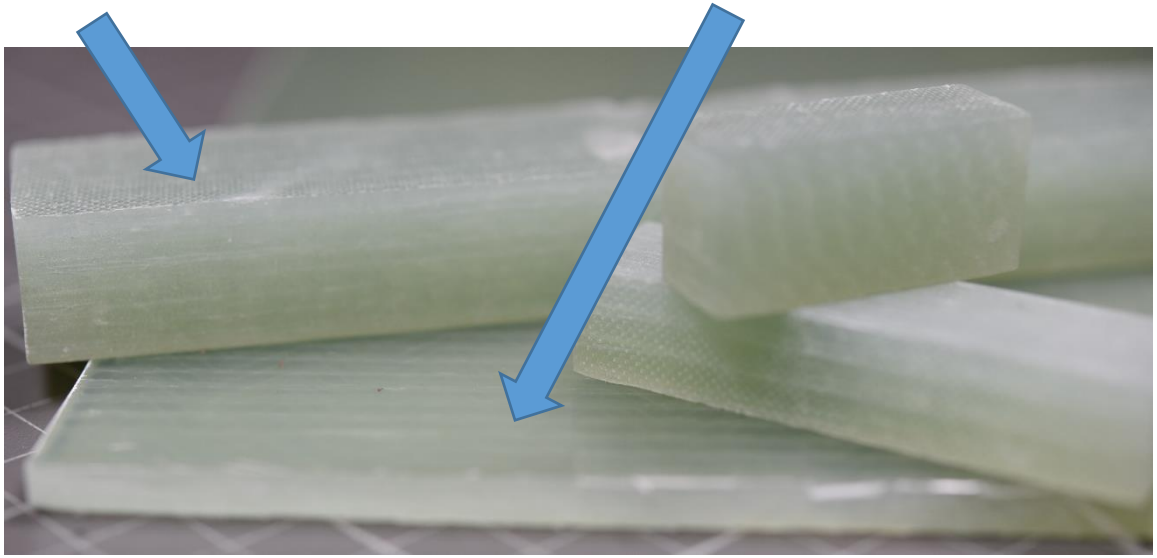
4 pt bending of thick laminates



Future work

Manufactured at Shipyards

Manufactured at UL



- **Thin** laminate (3.5 mm) manufactured at UL
- **Thick** Laminate (20 mm) manufactured at **ixBlue (France)**
- **Thick Laminate Testing to be performed at UL**

Demonstrator

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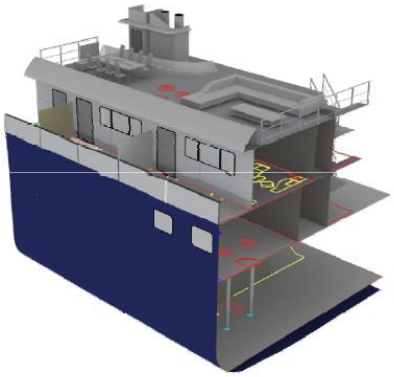
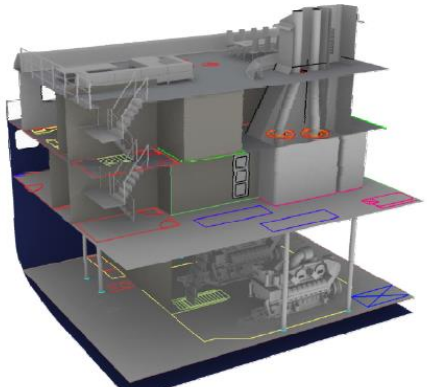
INTEGRAL COMPOSITE SHIP

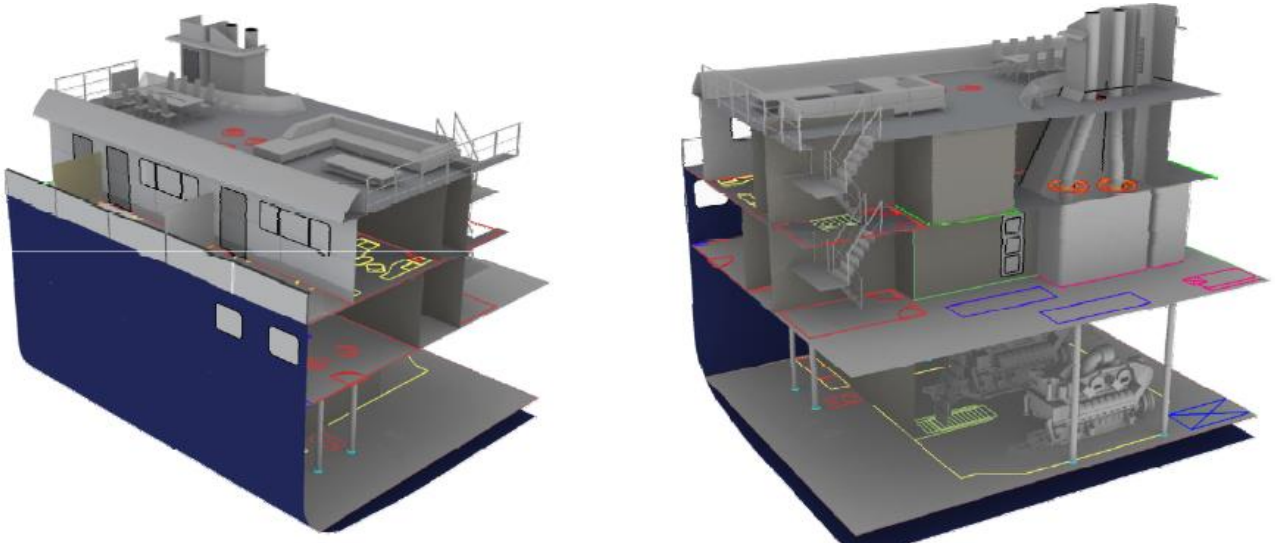




iXblue
DIVISION H2X

Main Outputs

- Rules and guidelines (Classification Societies)
- Catalogue of applicable materials (Classification Societies)
- Ship Block Demonstrator



Source: Fibreship Proposal

Progress so far..

FIBRESHIP
INTEGRAL COMPOSITE SHIP

- ✓ **Madrid**, June 2017 **(kick-off)**
- ✓ **Athens**, November 2017
- ✓ **Faaborg**, Denmark, October 2017 (Visit shipyard)
- ✓ **Barcelona**, March 2018
- ✓ **Cambridge/London**, June 2018 (Workshop)
- ✓ **Espoo**, March 2017
- ✓ Mid Term Review: **Brussels**, February 2019
- ixBlue, France June 2019

5TH PROGRESS MEETING AND 1ST REVIEW MEETING OF FIBRESHIP PROJECT

FEB 25- 2019

Progress so far..

FIBRESHIP
INTEGRAL COMPOSITE SHIP

- Responsible for two deliverables in WP2:
  - ✓ First (D2.1) delivered end of May 2018
  - ✓ Second (D2.3) delivered end of September 2018

- ✓ Mid term review completed – Brussels Feb 2019

- Focus now on supporting:
  - WP 5 (Production)
  - WP 7 (Demonstrator Construction)
  - WP 9 (Dissemination)

Dissemination

FIBRESHIP
INTEGRAL COMPOSITE SHIP

18th EUROPEAN CONFERENCE ON COMPOSITE MATERIALS
ECCM18

- ✓ ECCM 18, Athens, Jul 2018
- ✓ Thermosetting Resins 2018, Berlin, Sep 2018
- ✓ ICCS21, Bologna, Sep 2018

Thermosetting Resins 2018, 25. – 27. Sept. 2018, Berlin
International Conference

- MechComp, Lisbon, Jul 2019
- Sampe, Nantes, Sep 2019
- Marine Ageing, Brest, Aug 2019

Journal Papers

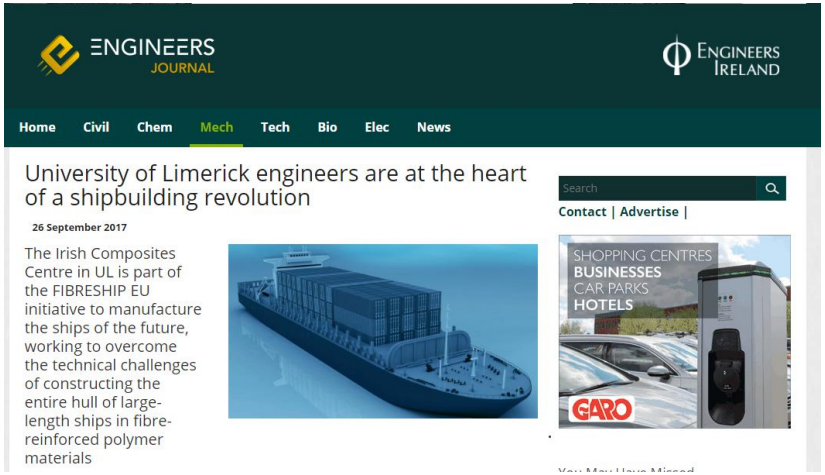
- Effect of Environmental Conditioning on the ILSS Properties of Thermosetting- and Thermoplastic-Matrix Composite Materials by Resin Infusion for Marine Applications – **Submitted** to Composites Part B: Engineering (Impact Factor 4.92)

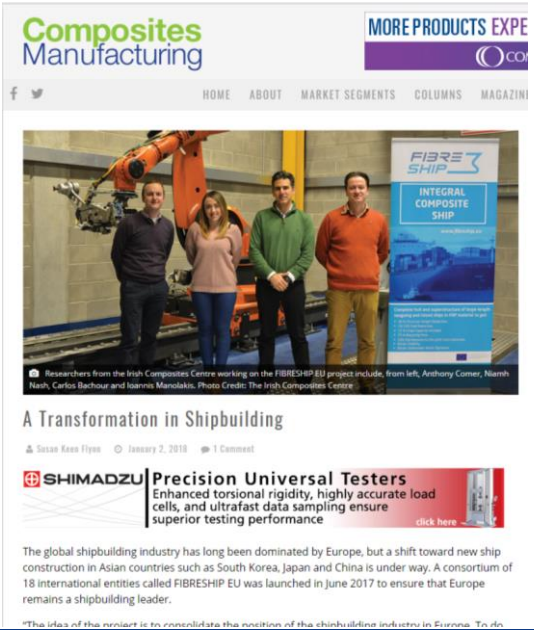
- Effect of Environmental Conditioning on the Flexural Properties of Thermosetting- and Thermoplastic-Matrix Composite Materials by Resin Infusion for Marine Applications – targeting submission to Composites Part B: Engineering (Impact Factor 4.92)

- Joint Publications also planned

Some Featured Articles

- Engineers Ireland Journal
- American Composites Manufacturing Association (ACMA)
- Irish Times
- BBC...http://www.bbc.com/future/story/20170918-the-ships-that-could-change-the-seas-forever
- Also had presence at *Marine Trade Show – Seafest 2017*, Galway; *Connecting Europe*, Tallinn, Estonia





Acknowledgements

This work has been funded by the H2020 project FIBRESHIP (www.fibreship.eu) under grant agreement 723360

Thank you for your attention

www.fibreship.eu

http://cordis.europa.eu/project/rcn/210787_en.html