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Circular manufacturing with the HiPerDiF technology using reclaimed carbon fibres from end-of-life sails

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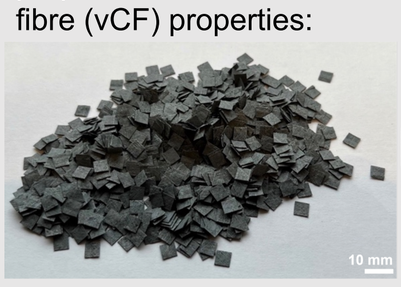
Many high-performance sails are flexible, carbon-fibre-reinforced polymer composites for which no end-of-life (EOL) waste-management plan is currently in place. A possible recycling pathway for an EOL North Sails' *3Di* sail is presented here. This involves the reclamation of the carbon fibre content, the remanufacture of the fibres into aligned discontinuous fibre reinforced prepreg-type tape, the build of a demonstrator, and the analysis of the environmental impacts of the recycling pathway compared to conventional waste disposal and manufacture using virgin materials.

1. Reclamation

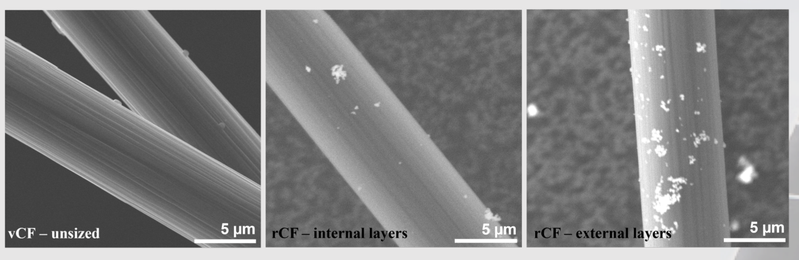
Carbon fibres were reclaimed from an EOL 3Di sail via Longworth's **DEECOM®** process in a controlled superheated steam (SHS) atmosphere at 450°C while undergoing pressure-swing cycles. The reclaimed carbon fibre (rCF) morphology and mechanical properties were tested and compared to virgin carbon fibre (vCF) properties:



3Di sail cut pre-reclamation to satisfy fibre length requirements for remanufacture.

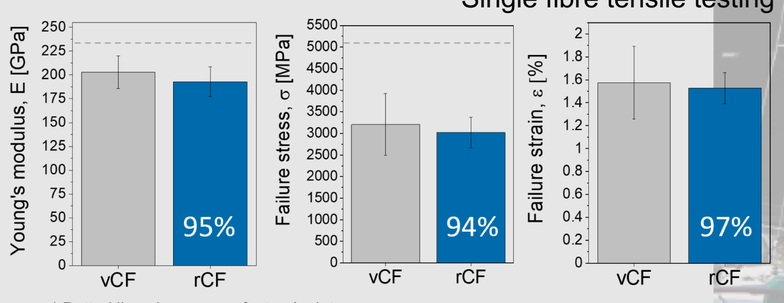
Reclaimed carbon fibres (rCFs) post-reclamation.

Fibre morphology

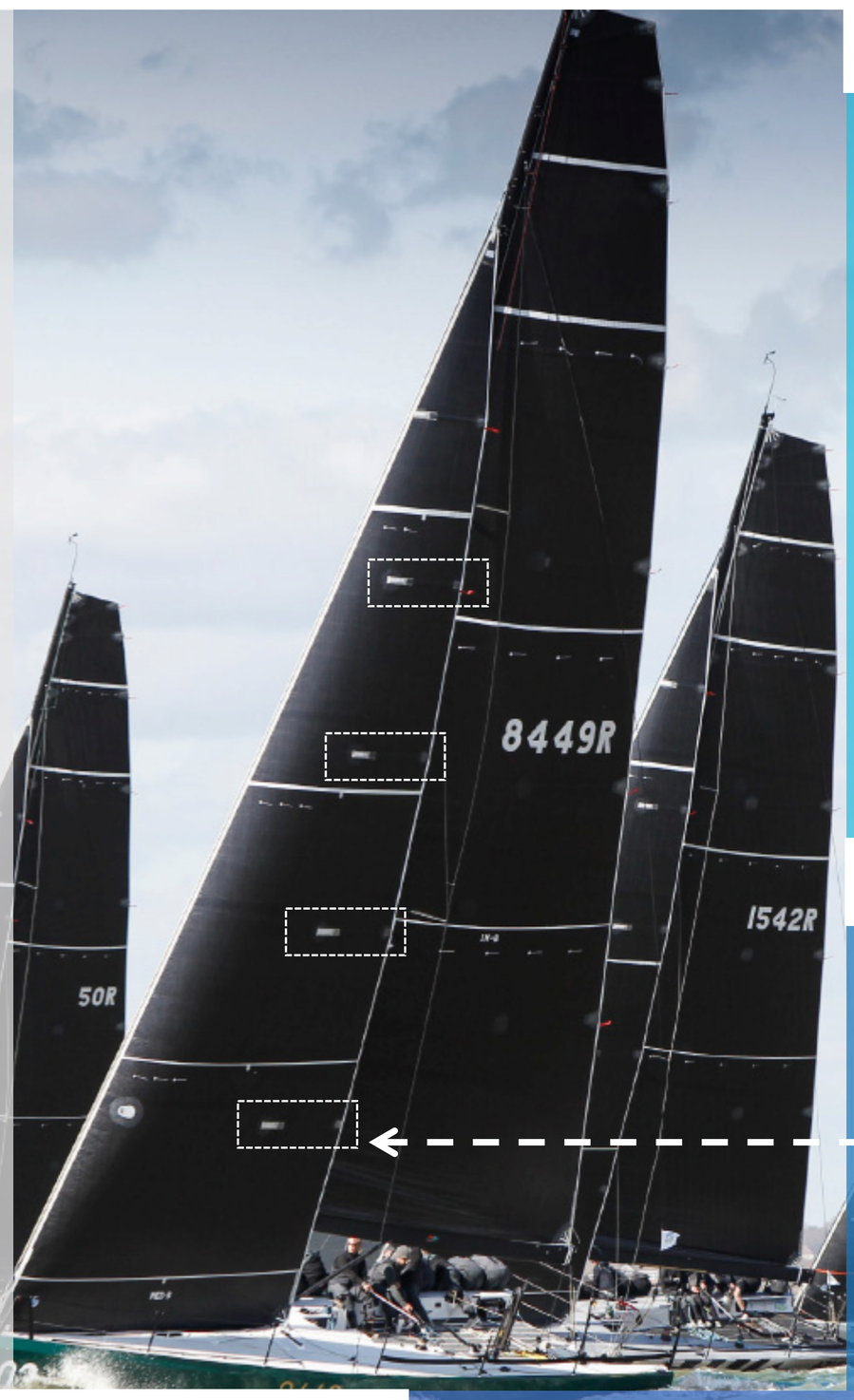


SEM images of virgin carbon fibres (vCFs) and reclaimed carbon fibres (rCFs). SEM-EDX analysis showed that the remaining particulates on rCFs are most likely residual TiO_2 pigment from resin used on the exterior of the 3Di sail.

Single fibre tensile testing

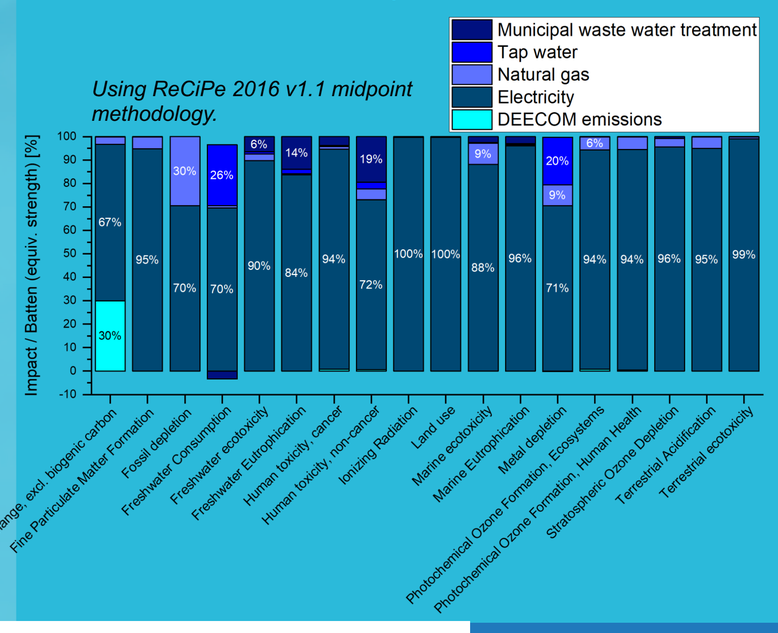


* Dotted line shows manufacture's data.



4. LCA

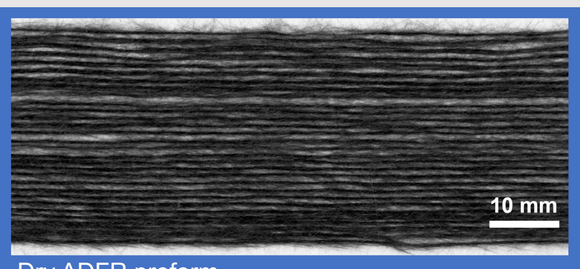
The environmental impacts of the recycling pathway was investigated following the life cycle assessment (LCA) methodology. An example of the sources of impact for the research-scale DEECOM® process is shown here.



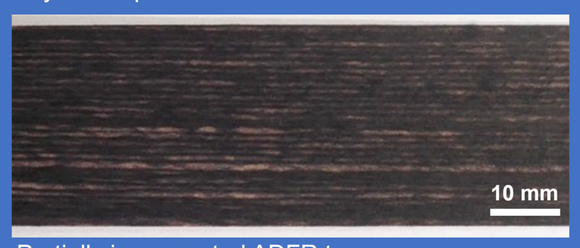
3. Demonstrator

A downscaled model of Hall Spars' *Ultraflex* batten (a stiffener in a sail) was manufactured to show how this ADFR tape could be incorporated into current manufacturing processes used in the sailing industry to build semi-structural components of yachts.

2. Remanufacture



Dry ADFR preform



Partially impregnated ADFR tape

Tensile test specimen

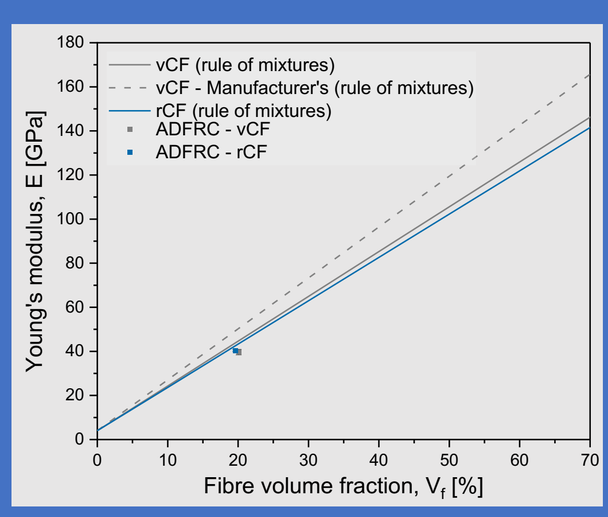
The rCFs were formed into partially impregnated aligned discontinuous fibre reinforced (ADFR) tape using the University of Bristol's water-based, High-Performance Discontinuous Fibre (**HiPerDiF 3G**) manufacturing technology [1].

Composite coupons were manufactured from vCF and rCF - ADFR tape for tensile testing (ASTM D3039) and flexural testing (ASTM D7264). Tensile properties are shown here.

[1] http://www.bristol.ac.uk/composites/research/hiperdif/

		ADFRC vCF	ADFRC rCF
Fibre volume fraction (V_f)	[%]	20.1	19.6
	SD	± 1.0	± 0.05
Tensile failure strain	[%]	1.53	0.975
	SD	± 0.07	± 0.05
Tensile failure stress*	[MPa]	658	425
	SD	± 26	± 19
Young's modulus*	[GPa]	39.7	41.4
	SD	± 1.3	± 0.47

* normalised to V_f of vCF.



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