PERFORMANCE OF DISCONTINUOUS ALIGNED GLASS FIBRE MAT AND WET-LAID NON-WOVEN MATERIAL FROM RECYCLED WIND TURBINES

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ABSTRACT

There is an urgent need for high-value recycling routes for Glass Reinforced Polymer composites (GRP). GRP scrap will increase with End-of-Life (EoL) wind turbine blades likely to reach over 20,000 tonnes/yr. in the UK by the mid-2030s.WindEurope's call for a ban on the landfill of decommissioned wind turbine blades by 2025 adds greater pressure for new recycling options. Recyclability and recycled content are equally important in construction and automotive. While increased durability and lower weight make GRP products more sustainable in the long term, limited recycling options are already damaging the GRP industry. WindEurope, Cefic and EuCIA strongly endorse reprocessing composite waste to produce higher-value recyclates enabling the production of new composites as essential as we move to a more circular economy. The developed alignment process allows discontinuous random recycled glass fibre to be processed into mats with a highly aligned orientation distribution. This allows composites with high fibre content to be manufactured at lower moulding pressures with the added benefit of keeping fibre length degradation to a minimum. The Wetlaid process has also been used to convert the fluffy fibre to a nonwoven material which is a format close to the traditional short glass fibre materials. The research work has been focused on understanding the feasibility of processing recycled glass fibre with the alignment process and Wetlaid system. In addition, early-stage mechanical testing has been done which indicates 3 mm fibre wetlaid nonwoven gave a 60.9 MPa tensile strength and 4.8 GPa tensile modulus. Through the same vacuum infusion process, the laminate made with 70wt% of 3 mm fibre and 30wt% 6mm fibre nonwoven can achieve 12.1% fibre volume content and obtain 56.63 MPa tensile strength and 4.98 GPa tensile modulus.

1 INTRODUCTION

There is an urgent need for high-value recycling routes for Glass Reinforced Polymer composites (GRP). At present, almost all of around 80 kt/year of thermoset GRP scrap generated in the UK and around 530 kt/year in Europe goes to landfill or energy from waste [1]. The volume of GRP scrap will increase substantially, with End-of-Life (EoL) wind turbine blades likely to reach over 20 kt/yr. in the UK by the mid-2030s [1]. Recyclability and recycled content are increasingly important in construction and automotive, and limited recycling options are already damaging the GRP industry, though in many cases increased durability and lower weight would make GRP a far more sustainable solution in the long term.

Efforts to recycle GRP overseas have had limited success. GRP can be recycled into cement clinker at one plant in Germany. Mechanical regrinding is economically challenging, feedstock dependent and limited to small-scale applications. Both are down-cycling and viable closed-loop GRP recycling requires higher value recyclate. Pyrolysis processes (not fluidised bed) have been researched over 20

years in Denmark (ReFiber), Spain (Reciclalia), USA/Germany (ACMA/CHZ) and at several universities. They are limited by low throughput (batch not continuous), high energy input, high levels of char and low fibre properties. None, to our knowledge, is commercial. A higher value route, retaining the embodied energy in the fibres, is essential as we move to a more circular economy. The Fluidised Bed process at the University of Nottingham [2] has been developed as a carbon fibre recycling technology. The researchers at the University of Strathclyde (UoS) have explored glass fibre recycling with the Fluidized Bed process [3] and patented sizing [4] for thermal recovery and post-treatment of glass fibres from GRP scrap to achieve near-virgin quality short glass fibres.
Although composites can be recycled using a number of recycling technologies, these processes are still immature and not commercially viable. The cost of recycling operations and the lack of a market for the recyclates have been identified as the main barriers towards composites recycling. This study investigates the mechanical performance of different recycled glass fibre (rGF) material formats, namely (a) discontinuous aligned fibre mat - manufactured using hydrodynamic alignment developed at the University of Nottingham (UoN) [5] and (b) wet-laid recycled glass fibre nonwoven material – manufactured using Wet-laid process at the Lightweight Manufacturing Centre (LMC) (part of National Manufacturing Institute, University of Strathclyde).

2 MATERIALS AND METHODOLOGY

2.1 Intermediate Materials Manufacturing

The hydrodynamic fibre alignment process, as described in Fig.1 [5], was used in this work. The fully dispersed fibre suspension is gently transferred into an intermediate pressurized tank which ensures that the flow through the conical nozzle is steady. The nozzle is attached to a linear actuator that keeps moving transversely to reach the desired width of fibre tape. By gathering the fibre volume concentration in suspension, jet volume flow rate, nozzle moving speed, fibre density and the area of deposited tape, the areal density of a single layer of tape can be calculated. The nozzle travel cycle is controlled and monitored by the machine controller so the number of deposited layers can be counted and converted to the total areal density of tape.

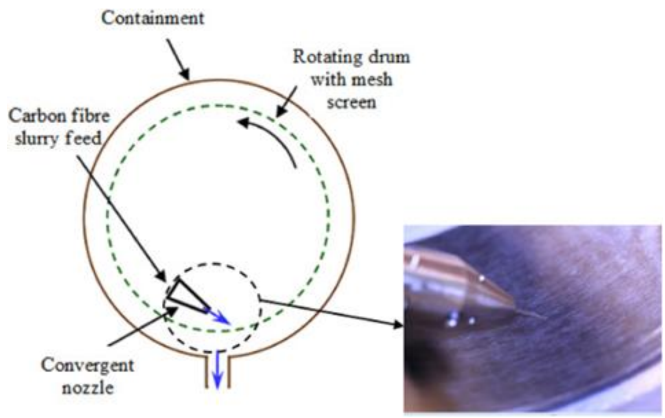

Figure 1. A schematic representation of the hydrodynamic alignment process [5].

The Wet-laid process, a modified papermaking process is shown in Figure 2 [6]. The fibres are suspended in water or an aqueous solution to form a slurry, pumped into a headbox, deposited onto a moving forming belt, and subsequently dried. Typical features include the random orientation of fibres, the ability to produce a wide range of areal density mats, and the ability to process short fibres, such as recycled glass fibres.

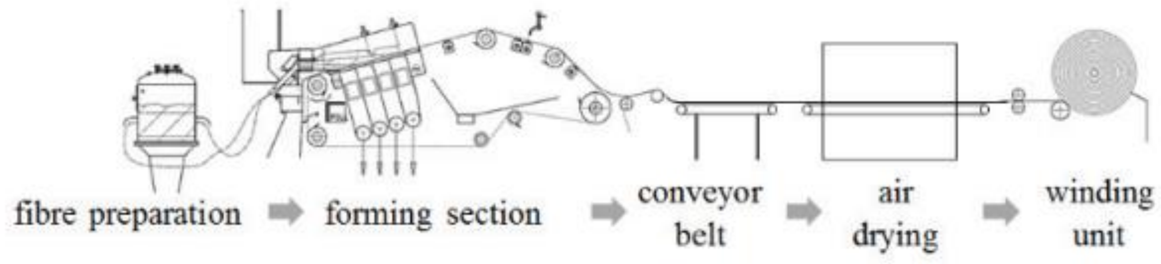

Figure 2. A schematic representation of the wet-laid process.[6]

The 562E E-Glass fibre chopped strands manufactured by JUSHI were supplied by GRP Solutions Ltd, the details of fibre properties have been listed in Table 1. Thermally reclaimed E-Glass fibre chopped strands with 3mm and 6mm fibre lengths have been investigated in this study and processed in a furnace for 25 min at 500°C. The areal density of the aligned fibre mat and wet-laid nonwoven is 100gsm, with category (a) 100wt% 3mm fibre and category (b) 70wt% 3mm fibre plus 30wt% 6mm fibre.

Product No.	Type of Glass	Chop Length	Filament Diameter	Density	Tensile Strength	Modulus of Elasticity
		mm	µm	g/cm^3	MPa	GPa
562E	E	3, 6	13	2.54	3400	72

Table 1 Details of fibre properties

2.2 Intermediate Material Characterization and Composites Samples' Mechanical Testing

Compaction testing is a better way of discerning small differences in alignment quality than tensile testing, although the latter clearly provides a definitive guide to performance the results are confounded by several additional factors (such as resin mechanical properties, moulding conditions, errors in the tensile testing process etc.). A compaction test rig was used to measure the thickness of carbon fibre tape (in order to determine the fibre volume content) with varied pressure. The testing rig consists of two flat platens; the bottom one is mounted on the base of the Instron 5969 universal testing machine; while the top one is connected to a 10 kN load cell attached to the machine crosshead. The machine's control software automatically logged the crosshead location. The thickness of dry fibre material (in order to determine the fibre volume content) with varied pressure has been recorded by linear variable differential transformers (LVDTs) attached to the compression platens. This is also a way of discerning small differences in alignment quality than tensile testing, although the latter clearly provides a definitive guide to performance the results are confounded by several additional factors (such as resin mechanical properties, moulding conditions, errors in the tensile testing process etc.).

Fibre Length	Material	No. of Layers	Compaction Testing Specimen Dimensions	Total Areal Density
mm	/	/	l × w (mm)	g/m^2
3	Aligned Fibre Mat	4	35 × 35	400
3	Wetlaid Nonwoven	4	35 × 35	460

Table 2. Specification of dry compaction test samples

Fibre Length	Nonwoven Areal Density/layer	No. of Layers Nonwoven	Tensile Testing Specimen Dimensions	No. of Specimens
mm	g/m^2	/	l × w × t (mm)	/
3	100	8	250 × 25.1 × 5.1	5
3 & 6	100	8	250 × 24.6 × 4.6	5

Table 3. Specification of Wetlaid nonwoven preforms and composite samples

The intermediate materials were moulded into composite panels through vacuum resin infusion (shown in Figure 3)with the IN2 Epoxy Infusion Resin with AT30 slow hardener both sourced from Easycomposites. The details of laminates which were manufactured from these intermediate materials are listed in Table 3. Tensile tests were carried out in accordance with BS EN 2747:1998 and ASTM D3039 using a Testometric X500-50 universal testing machine with a 50 kN load cell. The composite specimens with dimensions of 250 mm x 25 mm x thickness were tested at a crosshead speed of 2 mm/min until failure occurred. The strain in the gauge length was measured using a clip-on extensometer. The ultimate tensile strength and Young's modulus, E taken at the linear slope of the curve were calculated. At least five specimens for each panel were tested.

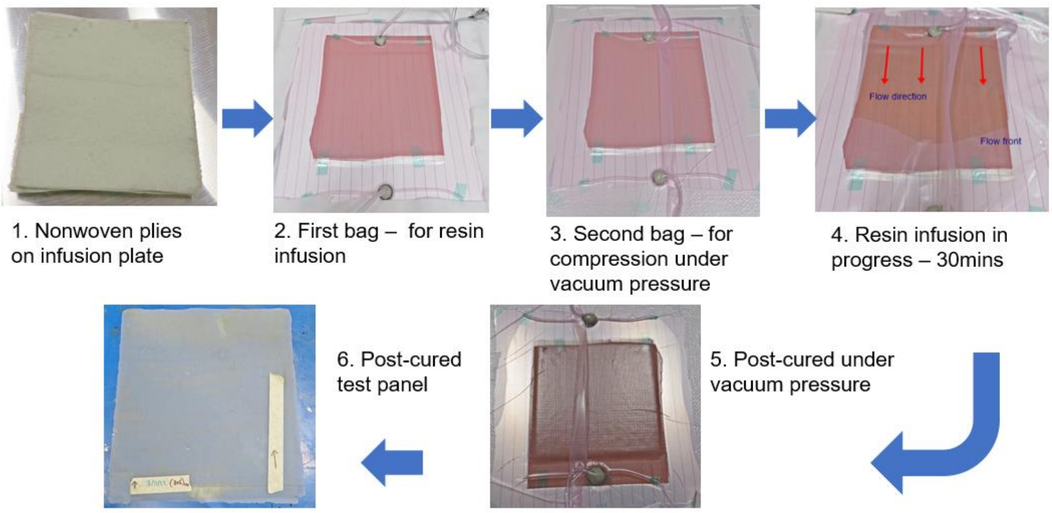

Figure 3. A flow chart of the vacuum infusion process

3 RESULTS AND DISCUSSION

3.1 Dry fibre tape compaction results

The compaction result curves are plotted in Figure 4. Under 7 bar compression pressure, the fibre volume content of the aligned fibre mat achieves 36% while the wetlaid nonwoven with a random fibre orientation can only obtain 16% fibre volume fraction which indicates that fibre packing efficiency can be significantly improved by the aligned fibre orientation.

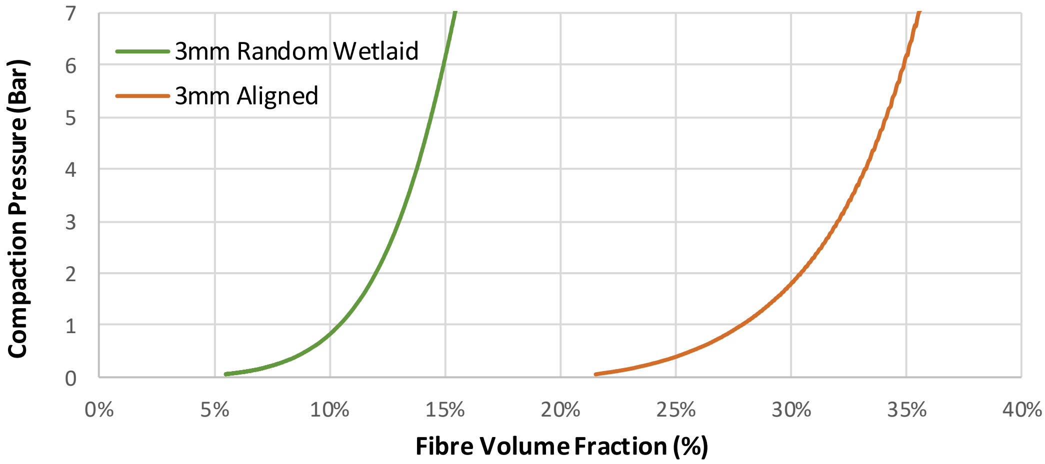

Figure 4 Dry fibre intermediate materials compaction test results.

3.2 Mechanical properties

In Table 4, the results from the tensile test are listed, which include the measured fibre volume fraction of each specimen, mean values and standard deviations of modulus and strength. The fibre lengths investigated in this paper are longer than the critical fibre length. Thus, fibre breakage results rather than matrix or interface failure. Thus, an extensive fibre pull-out situation was not witnessed at the fracture surface of both virgin fibre samples and recycled fibre ones. The fibre volume content is measured by the burn-off method, the matrix is physically removed entirely from the composite test sample by using a Muffle Furnace to increase the temperature of the sample to 550 °C for 4 hours. The sample is then cooled and measured again for its volume and weight, to know the volumetric percentage of the fibre. With an 11.7% fibre volume fraction, the composite made from 3 mm wetlaid nonwoven gave a 60.9 MPa tensile strength and 4.8 GPa tensile modulus. With the same curing pressure (1 bar), the laminate made with 70wt% of 3 mm fibre and 30wt% 6mm fibre nonwoven can achieve 12.1% fibre volume content and obtain 56.63 MPa tensile strength and 4.98 GPa tensile modulus. The mechanical performance of composites containing 6mm fibres hasn't become higher than 100wt% 3mm fibre one. The reason for this discrepancy is thought to be that the 3+6 mm fibre tape has a more uneven fibre distribution due to a complicated fibre-to-fibre interaction which also potentially causes a poor fibre dispersing quality.

Fibre Length	Width	Thickness	Strength	Strength SD	Modulus	Modulus SD	Fibre Volume Content
mm	mm	mm	MPa	MPa	GPa	GPa	%
3	25.1	5.1	60.9	6	4.8	0.1	11.7
3+6	24.6	4.6	53.63	2.7	4.98	0.2	12.1

Table 4. Tensile test results

4 CONCLUSION

The wetlaid process and the hydrodynamic alignment process have been developed and studied in this work. The discontinuous fibre intermediate materials have been shown to exhibit significant fibre volume content increase when the alignment level of the fibres is high. The composite laminates were made with 3 mm and 3&6mm recycled glass fibre under 1 bar curing pressure through a resin vacuum infusion process. With an 11.7% fibre volume fraction, the composite made from 3 mm wetlaid nonwoven gave a 60.9 MPa tensile strength and 4.8 GPa tensile modulus. With the same curing pressure (1 bar), the laminate made with 70wt% of 3 mm fibre and 30wt% 6mm fibre nonwoven can achieve 12.1% fibre volume content and obtain 56.63 MPa tensile strength and 4.98 GPa tensile modulus. The future work will include understanding the mechanical performance of composites made with aligned recycled glass fibre mate and the comparison with the nonwoven products. Detailed Life Cycle Assessment (LCA) and cost modelling will be developed to understand the potential of CO_2 saving and evaluate the routes to the market.

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