TWENTY-SECOND INTERNATIONAL CONFERENCE ON COMPOSITE MATERIALS (ICCM22) TIDAL TURBINE BLADE COMPOSITES USING BASALT FIBRE REINFORCED POWDER EPOXY

Conference Paper · August 2019

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TIDAL TURBINE BLADE COMPOSITES USING BASALT FIBRE REINFORCED POWDER EPOXY

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Keywords: Basalt fibres, Epoxy based CFRP, Tidal turbine blades

ABSTRACT

Tidal turbine arrays have considerable potential in providing a reliable source of renewable energy. Technology limitations are obstructing the fast development of the sector, however, one of which is the lack of knowledge of mechanical properties of submerged composites used to build tidal turbine blades. Composites exposed to water are known to display lower mechanical properties than their dry counterparts. The extent of this reduction usually varies, depending on many parameters, such as the stress applied, the fibres, the matrix, the stacking sequence, the manufacturing route, the water temperature and degree of saturation. Improving the reliability of the composite tidal turbine blade by developing a better understanding of the material's immersed properties is therefore very important.

In this paper, basalt fibres were selected as reinforcements for the composites instead of the more usually employed glass fibres, as they typically exhibit better mechanical and corrosion properties and are less prone to water ingress. Unidirectional basalt fibre reinforced plastics (UD-BFRP) were manufactured using a novel towpregging tapeline and a powder based epoxy system. This pilot automated towpregging tapeline was tailored for a new epoxy powder based manufacturing route to build large structures, fitting the scope of tidal turbine blade manufacturing.

The objective of this study is twofold. First, it aims to show the superior manufacturing abilities of the towpregging tapeline developed. Secondly, it intends to compare the mechanical properties of two types of commercially-available basalt fibres, once incorporated into a powder-based epoxy composite, in dry and water-aged conditions.

1 INTRODUCTION

Ocean energy is a source of power that has remained largely unused, especially considering its incredible potential, estimated to 8000 TWh/year [1]. This is in part due to the demanding nature of the marine environment. Nonetheless, MW-scale prototypes are now producing electricity from tidal streams in Scotland, France and other European countries [2], although the industry is at an earlier stage in comparison to wind energy: in 2017, tidal had a 25MW capacity [3] in comparison compare to the staggering 546GW for wind power [4]. As composite materials are the predominant material for the moving blades of these marine energy harvesting devices, the development of the technology is retarded by a deficit of knowledge on composite material response in seawater. For instance, reduction in static and fatigue strength due to seawater ingress, as well as erosion and corrosion, are critical design criteria. In this context, new materials and processing techniques are needed. Basalt fibre composites usually exhibit better mechanical properties than E-glass composites in the dry state, better corrosion resistance and have a lower water saturation level [5-7], making them attractive for tidal turbine blade design. Secondly, a new epoxy powder-based composite processing technology has also been used in this study, which gives more control over out-of-autoclave manufacturing of large structures with thick sections.

2 EXPERIMENTAL METHODS

2.1 Materials

The powder-based epoxy resin (EC-CEP-0016) with a density of 1.22 g/cm3 was supplied by Swiss CMT AG, Freilacke. The main advantages of this epoxy are: a low melt viscosity [8,9], a low curing exotherm [8,9], the ability to co-cure one or more pre-consolidated parts without adhesive to produce complex one-shot-cure parts, room-temperature storage and an easy upscaling to out-of-autoclave industrial processes [10,11]. As basalt fibres are naturally sourced, mechanical properties usually vary depending on the basalt deposit quality [12]. Because of this, basalt fibres from two different companies were studied in this work. Recombined tows of 13-micrometer diameter basalt fibres with alkoxysilane sizing were supplied in 2400 Tex from both Mafic and Basaltex.

2.2 Towpregging process

Unidirectional basalt fibre reinforced towpreg plates were prepared using a custom-built tapeline (Figure 1). The basalt tows were mounted on two bobbins (A), then pulled through a closed chamber (F), wherein powder was deposited onto the fibres via an electrostatic spray gun (E). The powder-coated fibres were subsequently heated with an infrared source (H), melting the powder. The towpreg was then recovered with a winding drum (C). Prior to recovery, the melted epoxy had time to cool below the resin melting temperature and the towpreg was wound up in a glassy state (in monomer state). One of the main advantages of the tapeline is the ability to produce tows with very straight fibres and keep it that way throughout the towpregging process. Indeed, the fibres were under tension throughout the process, and kept in this configuration once the resin was in a vitrified state. The towpreg, with a width of 15 mm, was then cut in 30 cm long towpreg pieces, called "strips" in this study. Since the weight of a 30 cm length of fibre was known, all the strips' fibre volume fractions (FVF) were checked by weight, and all strips with FVF outside of a 44 – 55% range were discarded, as an average FVF of 50% was targeted for this study.

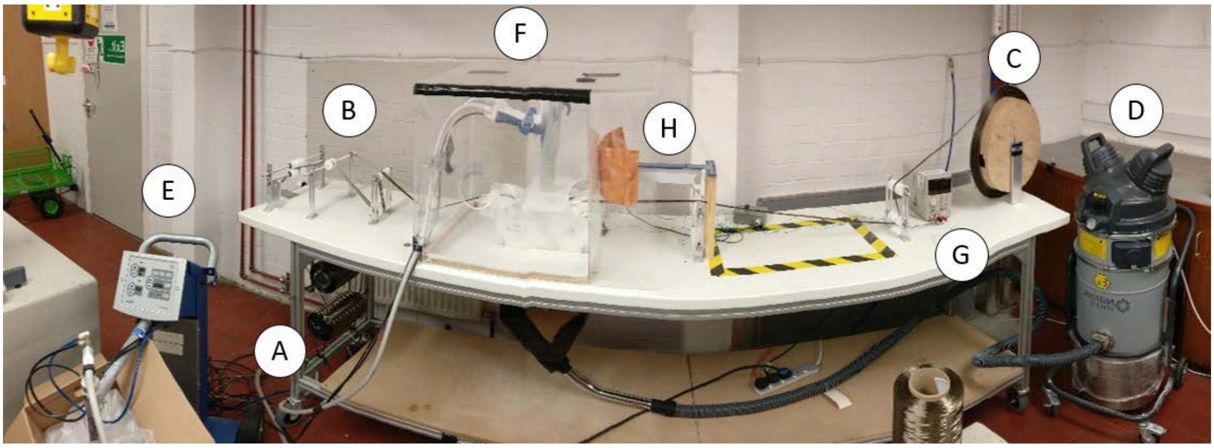

Figure 1: Basalt towpregging tapeline.

Component	Description
A	Basalt tow payout.
B	PTFE rollers tension rig.
C	Tape winding drum with 24V DC motor.
D	ATEX/HEPA extraction unit.
E	Electrostatic powder spray gun.
F	Powder-epoxy delivery chamber.
G	DC power supply (24V).
H	Infrared heating lamp.

2.3 Fibres alignment and curing procedure

The towpreg strips were aligned on a flat steel plate covered with PTFE, sitting on a custom-made tensioning rig developed by Mamalis et al. [13], as shown in Figure 2. A transparent plastic grid was used to ensure the correct alignment of the strips. The strips were pinched thanks to rubber parts attached to steel rectangular sections so to allow for load transfer between the rectangular section and the strips. Five layers of strips were required to obtain a 1 mm thick plate. The whole system was tensioned using two endless screws to a load of approximately 3000 N. The towpreg plates were then consolidated and cured under vacuum. The load kept the fibres aligned and under tension when the matrix changed from vitreous to liquid state, prior to curing. The plate was kept at 40°C for 12 hours to pre-dry the towpreg and thus minimise porosity in the final laminates. The plate was then heated to 130°C for 2 h, before curing the BFRP at 180°C for 2 h. Lastly, the plate was end-tabbed and cut to meet the mechanical testing standards used in this study (ISO527-5, ISO 14125, ASTM D3410).

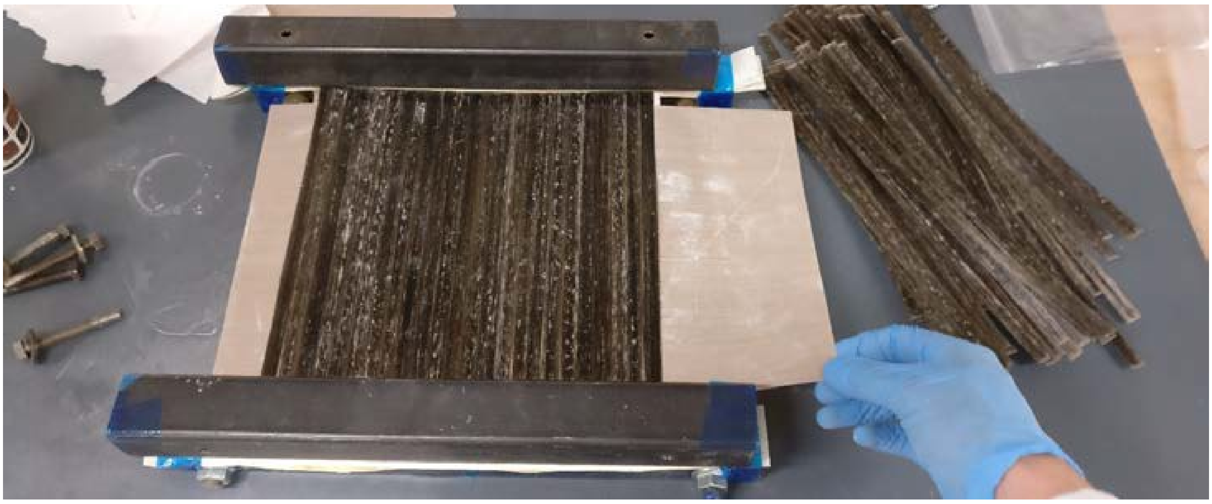

Figure 2: BFRP hand-layup consolidation process.

2.3 Hygrothermal ageing of Basaltex UD-BFRP

The sorption behavior of UD-BFRP with Basaltex fibres was investigated in this study. The samples were divided in two sets kept in seawater at ambient temperature or at 55°C for ca. 100 days (Figure 3). The temperature had an important influence on the sorption rate and the water saturation level. The water content obtained at saturation in this study is quite similar to contents obtained in other studies [14-16].

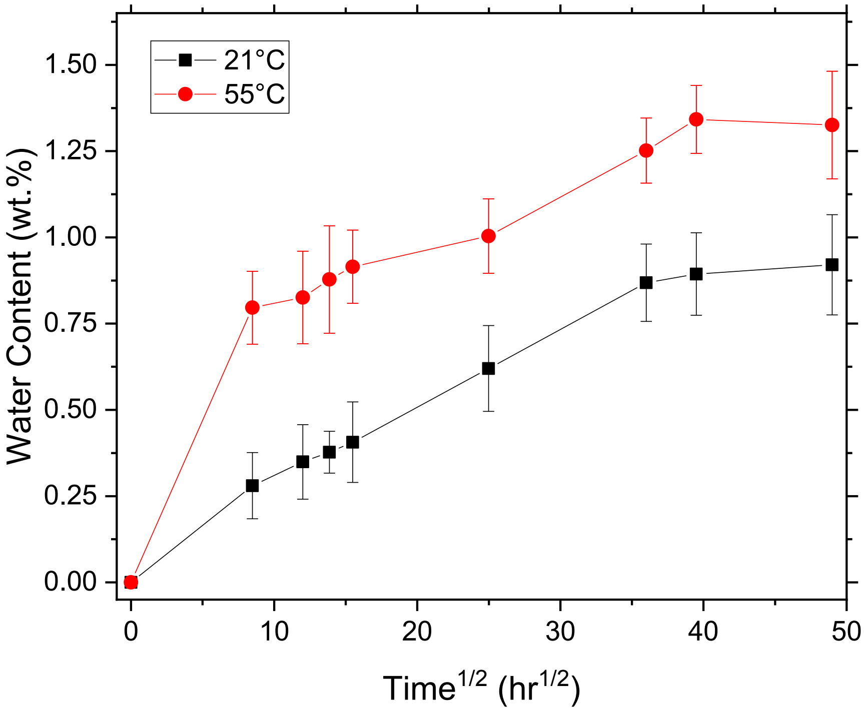

Figure 3: Water ingress in UD-GFRP vs. the square root of time at ambient temperature (black) and 55°C (red).

3 RESULTS AND DISCUSSION

3.1 UD-BFRP static mechanical properties comparison

	σ Basaltex (MPa)	Std dev σ Basaltex (MPa)	σ Mafic (MPa)	Std dev σ Mafic (MPa)	E Basaltex (GPa)	Std dev E Basaltex (GPa)	E Mafic (MPa)	Std dev E Mafic (GPa)
Tension 0°	1186.0	74.3	1020.0	124.0	42.9	0.9	39.0	2.4
Tension 90°	76.7	6.3	73.2	1.7	11.0	0.9	9.0	0.5
4 point Bending 0°	1209.0	54.3	915.0	61.3	46.2	2.7	40.2	5.2
4 point Bending 90°	132.0	4.0	128.0	13.3	10.4	0.1	8.1	1.0
Compression 0°	623.0	78.9	452.0	38.0	40.1	2.2	42.3	3.0

Table 1: Quasi-static mechanical properties and comparison of powder-based UD-BFRP with Balsatex and Mafic basalt fibres.

The powder-based UD-BFRP coupons were tested mechanically in tension, four-point bending and compression modes. Table 1 displays the mechanical properties in tension and four-point bending of UD-BFRP in the 0° and 90° directions, and compression in the 0° direction.

Both sets displayed excellent mechanical properties in comparison to the literature [14, 17-19]; (e.g. +43% strength compared to the Baslatex UD-BFRP samples of the reference [14]). The authors considered that since the powder-based towpregging manufacturing route keeps the fibres under tension throughout the process, it led to a superior fibre alignment, especially in comparison with UD-fabrics, which need stitching to keep the fibres together causing mediocre fibre alignment. Additionally, the very low pre-gel viscosity, allowed for superior consolidation.

The Basaltex UD-BFRP displayed superior composite properties to the Mafic fibres, both in terms of strength (+14.00%) and stiffness (+9.06%) when tested at 0°, with the mechanical properties dominated by those of the basalt fibres. The difference in mechanical properties is not surprising, as basalt fibres are naturally sourced and their chemical composition varies from one source to another [5].

In the 90° direction, the matrix and the interfacial properties dominate the strength of the composites. In our case, the tensile strength of Basaltex UD-BFRP is slightly better (+4.56%, with a scatter of 6.26%). A direct comparison of the sizing properties of both composites is possible, since the same powder epoxy was used and the same FVF was achieved. The better mechanical properties found in 0° tension for the Basaltex composites could suggest a superior sizing, and or superior mechanical properties of the fibres. The stiffness in 90° was vastly superior in the case of Basaltex samples (+18.3%), ca. double the difference obtained in the case of 0° tension. The authors assume that this important mismatch was driven by the better interface properties in the case of Basaltex. Also, the intrinsic properties of the fibres, which were stiffer in Basaltex case as highlighted by tension 0° results, helped obtaining better mechanical properties.

The results in tension were consistent with the four-point bending and compression results, as shown in Table 1. Baslatex samples in longitudinal four-point bending mode displayed a largely superior strength at break (+24.32%) and stiffness (+12.90%), in agreement with the tension results. The important stiffness difference at 90° is also a testimony of a better sizing and intrinsic transverse properties of Basaltex fibres.

Basaltex samples exhibited the largest strength increase (+27.45%) in comparison to Mafic's in compression, confirming better interfacial properties. However, the stiffness was found lower in this case (-5.47%). The authors hypothesized that the interfacial stress transfer ability in the case of Basaltex fibre was found to be superior, reducing the stiffness of the material and increasing the strength due to a more homogenized stress.

3.2 The influence of water ageing on Basaltex UD-BFRP mechanical properties

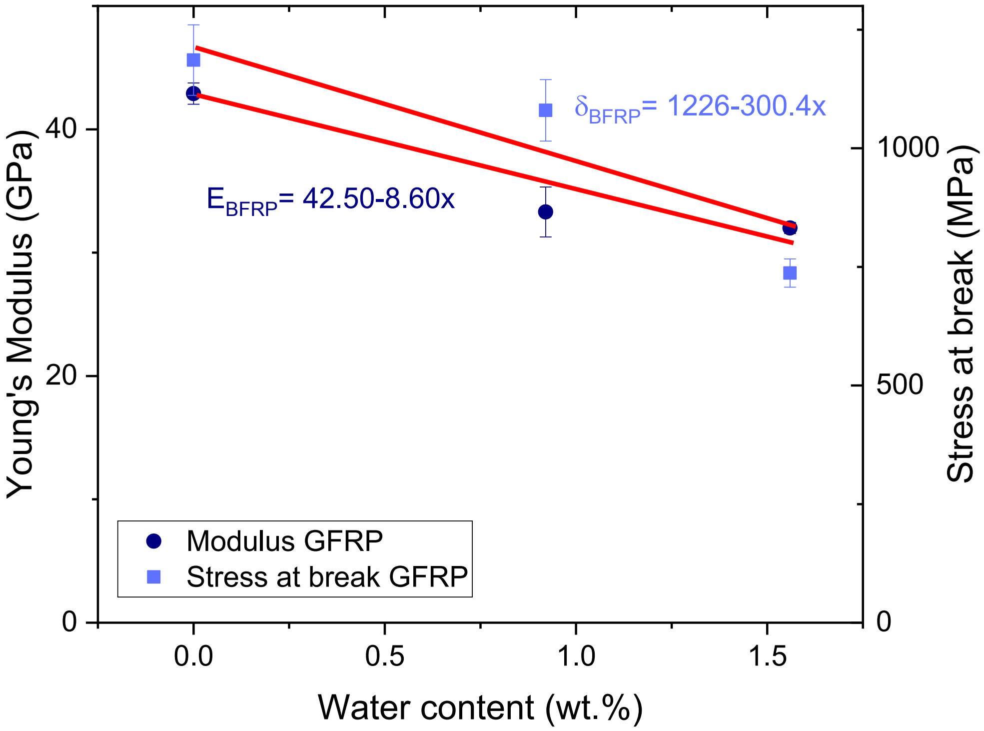

Figure 4: Static mechanical properties of powder based UD-GFRP depending on their water content.

It is well known that water presence in composites leads to plasticization and swelling, damaging the cohesion at the fibre/matrix interface [20]. Since the scope of this study is the selection of material for underwater use, a Basaltex-based composite, exhibiting superior mechanical properties, was selected for this study. The samples were aged at ambient temperature (21°C) or 55°C, tested in 0° tension following the ISO 527-5 standard and compared to the dry samples. Figure 4 displays the effect of the water content on the samples' stiffness and strength. As only three sets were investigated in this study, an indicative linear fit was plotted in both cases. For 1 wt.% of water, Basaltex UD-CFRP exhibited a deterioration of 11.22% in stiffness and 13.61% in strength. The deterioration in mechanical properties were found to be substantially less that other reported UD-BFRP ageing studies, such as the 55.76% strength deterioration per water percent weight in the case of Wei [15] and 21.80% reported by Davies [14], in comparison to their dry counterparts.

4 CONCLUSION

The paper describes an alternative processing route to resin infusion systems for large composite structures, such as tidal turbine blades. The ability to produce mechanically superior unidirectional composites with a pilot towpregging tapeline when coupled with a tensioning apparatus for curing have been presented. The mechanical properties of two types of basalt fibres from different providers, while incorporated in a UD-BFRP, were investigated and compared. Basaltex-fibres proved superior to those of Mafic. The influence of water ingress was focused on Basaltex composites , as they proved to be superior than Mafic's. Although the strength and stiffness reduction were apparent, they were found to be substantially less than those reported in the literature. The authors assume this was due to the superior manufacturing route, promoting a system always under tension and banishing any kind of stitching, both elements leading to preferential alignment of UD-BFRP.

ACKNOWLEDGEMENTS

The authors would like to thank FreiLacke, Mafic and Baslatex for giving us the material and details required for this study. The authors would also like to thank the European commission for their financial support to the POWDERBLADE and MARINCOMP projects (Horizon 2020 and IAPP respectively), which made this study possible.

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