QUASI-ISOTROPIC ALIGNED DISCONTINUOUS FIBRE COMPOSITES WITH THE HIPERDIF (HIGH PERFORMANCE DISCONTINUOUS FIBRES) METHOD

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ABSTRACT

Highly aligned discontinuous fibre composites are truly beneficial for mass production applications, e.g. automotive and sporting goods, offering better formability and comparable mechanical properties with continuous fibre reinforced composites. The HiPerDiF (High Performance Discontinuous Fibre) method, invented at University of Bristol, is able to produce highly aligned discontinuous fibre prepregs and composites thanks to its unique fibre orientation mechanism. Unidirectional composite materials manufactured with the HiPerDiF method showed high mechanical properties previously reported in [1]. However, it is usually necessary to balance the load-carrying capability in multiple directions. In this study, the HiPerDiF was used to manufacture a tape-type unidirectional highly aligned discontinuous fibre prepreg from 3 mm fibres. A quasi-isotropic laminate composite was prepared by laying up the tape-type aligned discontinuous fibre prepregs and tested in tension to characterise the mechanical properties and compared with a randomly oriented short fibre composite.

1 INTRODUCTION

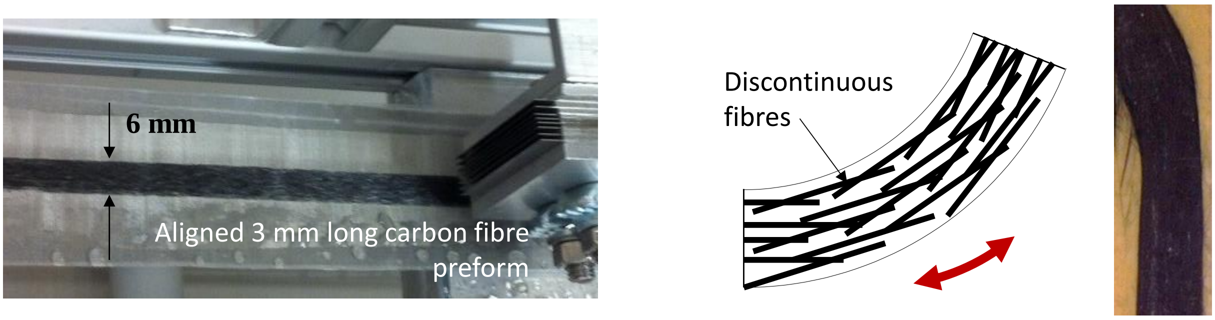
Continuous fibre reinforced composites achieve high structural performance with low weight, allowing replacing metal in many applications. However, the tendency to fail catastrophically and the long and continuous fibre nature sometimes limits design flexibility. In particular, continuous fibres prepregs cannot follow the geometry of complex shape moulds and deposition paths, generating manufacturing defects such as in-plane/out-of-plane wrinkles and resin rich pockets, which significantly reduce the mechanical properties of composite parts [2].

Highly aligned discontinuous fibre prepregs and composites draw attention as an alternative to overcome the manufacturing limitations of continuous fibre composites, offering better formability during moulding as well as a scope to provide ductility by slippage at discontinuity without compromised mechanical properties. To mitigate the manufacturing defects introduced by continues fibres, stretch-broken carbon fibre (SBCF) prepregs or yarns were developed and manufactured by industries such as Hexcel, Schappe Techniques, and SGL [3]. Unidirectional arrayed slit prepregs were also studied [4]. However, the discontinuity is generated in continuous virgin fibre prepregs: this requires an extra manufacturing step to produce aligned discontinuous fibre composite materials.

In this study, the HiPerDiF (High Performance Discontinuous Fibre) was used to manufacture aligned discontinuous fibre prepregs and composites directly from 3 mm fibres. The HiPerDiF method can align discontinuous fibres, with a length between 1 and 12 mm, thanks to its unique fibre orientation mechanism [1] (see Figure 1(a).) and manufacture tape-type prepregs with B-stage epoxy film. Unidirectional composite materials with highly aligned discontinuous fibres manufactured with the HiPerDiF showed comparable mechanical properties with continuous fibre reinforced composites

[1] and the potential to achieve better formability as shown in Figure 1(b). Moreover, the HiPerDiF allows hybridisation of fibre type and length to introduce pseudo-ductility to composites [5].

In this paper, as it is necessary to balance the load-carrying capability in different directions in composite products, a quasi-isotropic (QI) laminate $[0/+60/-60]_s$ was prepared by laying up the tape-type aligned discontinuous fibre prepregs and tested in tension. The mechanical properties of the QI HiPerDiF specimens were compared with randomly orientated short fibre composites with the same fibre volume fraction.



(a) (b)

Figure 1. (a) Aligned discontinuous carbon fibre preforms from the HiPerDiF orientation head, (b) advantage of aligned discontinuous fibre prepregs for formability.

2 EXPERIMENTAL

2.1 Materials

The 3 mm chopped carbon fibres, with a mean diameter of 7 μm, were sourced from TohoTenax.The fibre properties from the manufacturers are listed in Table 1. The fibres were coupled with a 43 gsm areal weight epoxy resin film (K51, SKchemicals).

C124, TohoTenax	Tensile modulus [GPa]	Tensile strength [MPa]	Density [kg/m^3]	Sizing
3 mm carbon fibre	225	4344	1820	Water soluble polymer

Table 1: Carbon fibre properties.

2.2 Sample preparation

In this study, quasi-isotropic (QI) composites with highly aligned discontinuous fibre preforms and randomly oriented short carbon fibre composites were manufactured. The randomly oriented short fibre mats were prepared as follows: 3 mm fibres were dispersed in a water bath with a stainless-steel mesh on the bottom and the mesh was slowly lifted to sieve the water and let all the fibres deposit on it. Eventually, the fibre mats on the mesh were dried in an oven and separated before use. The tape-type highly aligned discontinuous fibre preforms were manufactured with the HiPerDiF method [1, 5]. To manufacture the prepreg, the preform was placed between epoxy resin films and pressure and heat (60°C) were applied. Four plies of prepreg were used for the randomly oriented composites. For the QI HiPerDiF composite specimens the stacking sequence was [0/+60/-60]s. As the width of aligned discontinuous fibre prepreg is 5 mm, each tape was laid up side by side to form a 40 × 100 mm sheet, as shown in Figure 2. The stacked prepregs were cut into 5 mm wide stripes and placed in a semi-closed steel mould. The epoxy specimens were cured at 135°C for 135 minutes in an autoclave using vacuum bag moulding at a pressure of 6 bar. After manufacturing, burrs at all edges along the length direction were gently removed using sand paper. Table 2 shows the cured composite specimen dimensions.

2.2 Tensile tests

Tensile tests were performed on an electro-mechanical testing machine with a cross-head displacement speed of 1 mm/min. The load was measured with a 10 kN load cell (Shimadzu, Japan) and the strain was measured with a video extensometer (IMETRUM, UK). White speckles were spray-painted on the black background of the specimens to allow the strain measurement with the video extensometer. The gauge length for the strain measurement was around 40 mm. Glass fibre/epoxy end tabs were attached using epoxy adhesives (Aladite2014, Huntsman) to all the specimens.

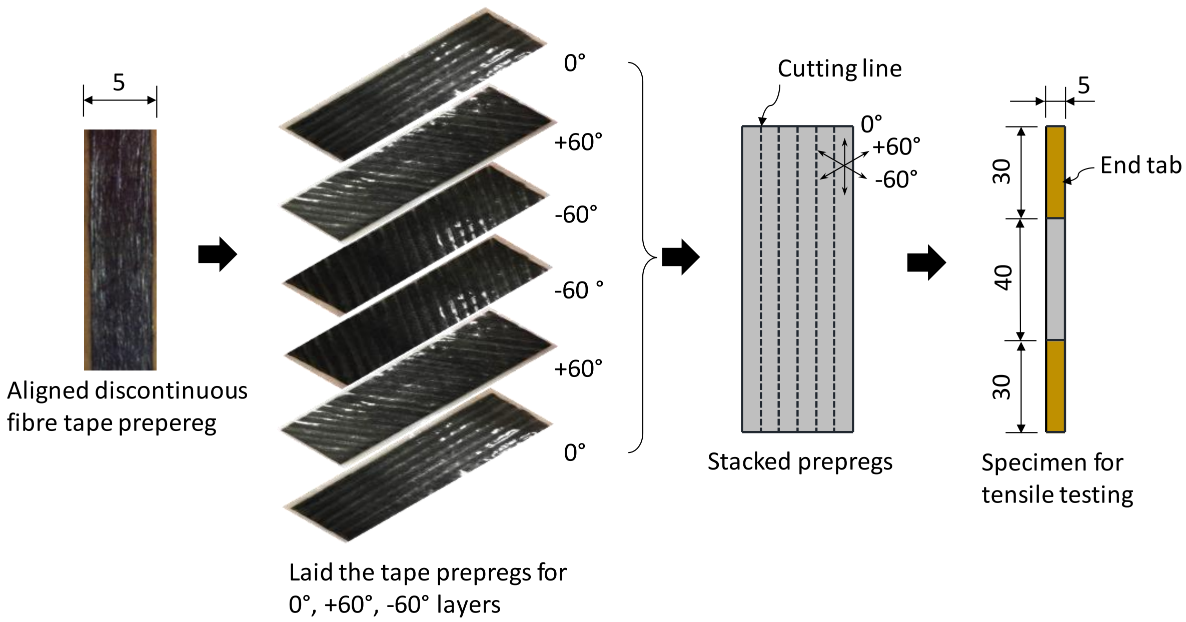


Figure 2. Manufacturing QI HiPerDiF specimens [mm].

	Randomly oriented	UD HiPerDiF [6]	QI HiPerDiF
Stacking sequence	$[R]_4$	$[0]_4$	[0/+60/-60]s
Number of specimens	5	3	6
Dimension ($l \times w \times t$) [mm]	150×5×0.39	150×5×0.26	100×5×0.5

Table 2: Sample preparation.

2.3 Fibre volume fraction

The ignition loss method [7] was applied to measure the fibre volume fraction of the QI HiPerDiF specimens and the randomly oriented short fibre composite specimens. To burn off the epoxy resin, the samples were placed in a furnace for 150 mins at a temperature of 500°C. The samples were weighed before and after resin burn off with a resolution of 0.1 mg. The fibre volume fraction was calculated based on the sample weights and the density of carbon fibres and epoxy (1210 kg/m^3).

3 RESULTS AND DISCUSSION

The representative tensile stress-strain curves for the UD HiPerDiF, QI HiPerDiF, and randomly oriented composites are shown in Figure 3.

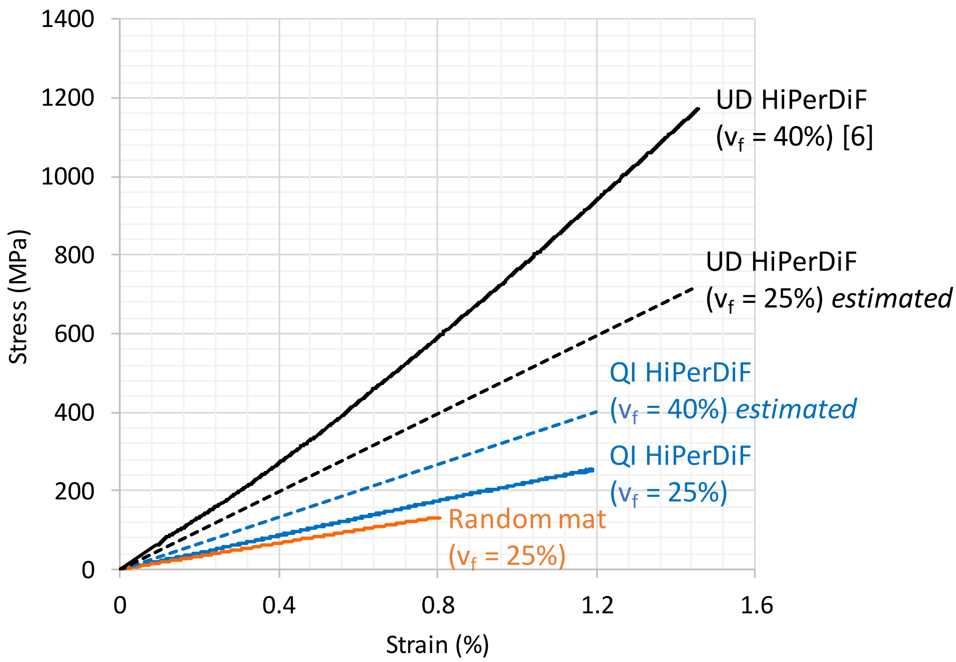


Figure 3. Tensile stress-stain curves for discontinuous fibre composites.

The tensile mechanical properties of the QI HiPerDiF composites are higher than the randomly oriented short fibre composites even though the fibre length and volume fraction are the same, as shown in Figure 4. The tensile modulus, strength, and strain to failure increased by 34%, 76%, and 30% respectively. Moreover, the QI HiPerDiF specimens showed more consistent results in comparison to the randomly oriented short fibre composites: a coefficient of variations in the range of ±5% versus 7-20%. This correlates to the fact that the randomly oriented short fibre composites inevitably contain entangled fibre clusters and irregular resin pockets or voids likely leading to a reduction of mechanical properties. In other words, the QI HiPerDiF composites have more organised microstructure. This can be also observed at the fracture section of the specimen. Figure 5 shows the failed specimens after the tensile testing. They failed along the ±60° similarly to QI continuous fibre reinforced composites. It seems that the matrix cracks between fibres in the ±60° layers appeared and propagated over the thickness direction of the specimen, and caused the whole specimen failure [8].

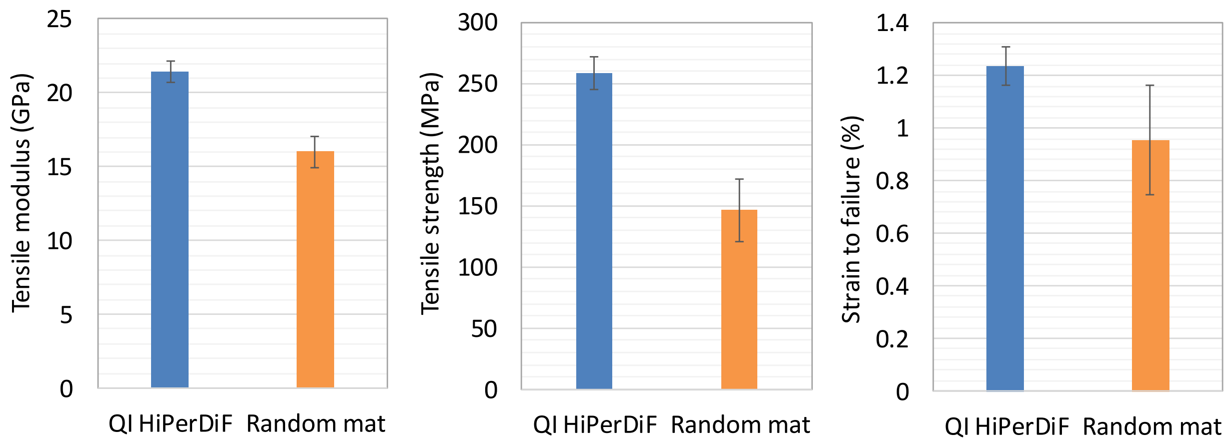


Figure 4. Tensile modulus, strength and strain to fail for the QI HiPerDiF and Randomly oriented composites at the same fibre volume fraction (v_f = 25%).

Higher QI HiPerDiF composites modulus and strength can be achieved with an increase of fibre volume fraction. A fibre volume fraction of 40% have been already achieved in UD HiPerDiF composites [6]. Based on the experimentally measured tensile modulus of the QI HiPerDiF composites at v_f 25%, the QI HiPerDiF materials modulus at v_f 40% can be calculated as 34 GPa, as shown in Figure 3. This is much higher than other short fibre composites. For instance, tensile modulus of short carbon fibre reinforced PA6 or ABS composites manufactured with an injection moulding process is in the range of 5-12 GPa [9, 10]. Also, this is comparable with a chopped-stand randomly oriented mat composites with 5 cm long strand showing 30 GPa of tensile modulus [11]. The HiPerDiF method can further increase the fibre volume fraction up to 55% [1]: still there is a room to improve the properties.

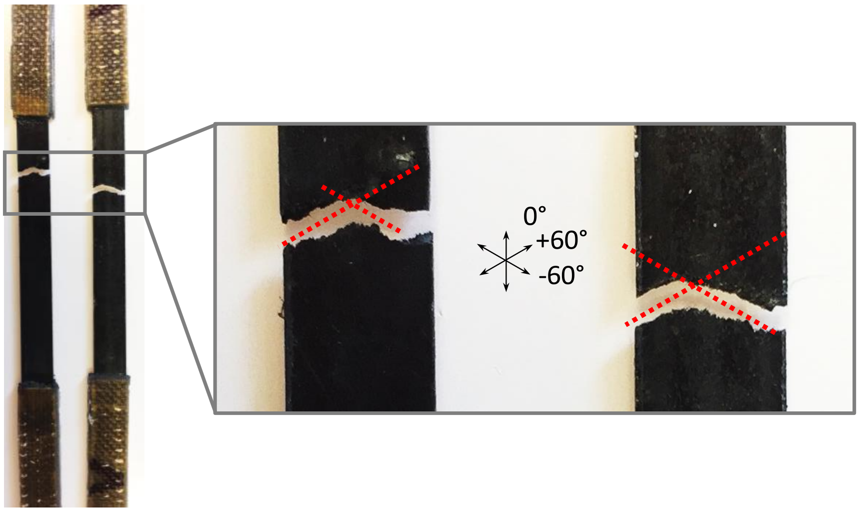


Figure 5. Failed QI HiPerDiF specimens.

4 CONCLUSIONS AND FUTURE WORKS

In this study, the HiPerDiF was used to manufacture a tape-type unidirectional highly aligned discontinuous fibre prepreg directly from 3 mm fibres and a quasi-isotropic laminate composite was prepared by laying up the tape-type aligned discontinuous fibre prepregs and tested in tension. The tensile mechanical properties of the QI aligned discontinuous fibre composites were directly compared with a randomly oriented short fibre composite with the same fibre length and volume fraction. The results showed significant increase of tensile modulus and strength, 34% and 76% respectively and a more consistent behaviour. Expectedly, this is because the QI aligned discontinuous fibre composites have more organised fibre microstructure.

There will be extensive future works, the first is to investigate the mechanical behaviour of the QI aligned discontinuous fibre composites at higher fibre volume fraction. The formability of QI aligned discontinuous fibre prepregs will be assessed with various method, e.g. a 90° corner mould, and compared with continuous fibre prepregs. Furthermore, angled-aligned discontinuous fibre composites ($[\pm\theta_n/0_m]_s$) and hybrid QI or angled-aligned discontinuous fibre composites will be investigated to achieve pseudo-ductility.

ACKNOWLEDGEMENTS

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