Materials Research Express

PAPER

Effect of water absorption on the mechanical properties of cross-ply hybrid pseudo- stem banana/glass fibre reinforced polypropylene composite

RECEIVED
7 February 2019

REVISED
28 June 2019

ACCEPTED FOR PUBLICATION
12 July 2019

PUBLISHED
24 July 2019

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Keywords: banana fibre, glass fibre, hybrid composite, mechanical properties, water absorption

Abstract

The initiative to reduce the consumption of non-renewable resources increases the awareness of being green in composites. The synthetic fibres are currently substituted by natural fibres applicable in various industries such as automotive and building. In this study, the effects of water absorption on the tensile and flexural properties of cross-ply hybrid pseudo-stem banana/glass fibre reinforced polypropylene composites are investigated. The hybrid banana (B)/glass (G) polypropylene composites and the reference specimens of the non-hybrid composites of the plain banana and glass fibres termed the BBB and GGG specimens were fabricated using hot compression moulding method. Water absorption test was conducted according to ASTM D570 until the specimens reached saturation. Tensile (ASTM D3039) and flexural (ASTM D790) test were carried out on the dry specimens as well as the wetted specimens. It can be observed that non-hybrid GGG has the best water absorption properties and hybrid specimen with glass as outermost skin shows a comparable result. However, water absorption reduced the mechanical properties of the composites. The incorporation of glass fibre in the composites improved overall properties of the composites. The hybrid GBG dry specimen tensile strength and wet specimen flexural strength is 136.28 and 73.86 MPa respectively. The hybrid composite GBG shows comparable flexural properties to GGG composite.

1. Introduction

The upsurge of environmental concern has amplified the initiative to reduce the utilisation of non-environmental friendly materials such as thermoset polymers and man-made fibres [1]. Despite the increasing popularity of natural fibres due to its advantages such as biodegradability, low density and cost, availability in abundance, recyclability, and acceptable mechanical properties, these fibres tend to have high water absorption [2]. The hydroxyl groups (−OH) in natural fibre make them hydrophilic. This results in weak adhesion to hydrophobic polymer matrices, mainly hydrocarbon matrices [3]. Moisture and water absorption by natural fibres also leads to premature ageing due to degradation and loss of strength [4].

Banana pseudo-stem fibre is a secondary fibre accessible and could be gainfully utilised in assembling of fibre polymer reinforced composites since they have appealing mechanical and physical properties [5]. They offer better stiffness and quality for a reinforced composite, biodegradability, promptly accessible, practical underway and have minimal effort per unit volume basis [6]. Prasad *et al* [7] investigate the short banana fibre reinforced low-density polyethene composite on the effect of chemical treatment and compatibiliser addition. Results showed that the water absorption capacity increased by increasing fibre loading from 10 wt% to 30 wt%. Water absorption of modified composites reduced considerably compared to untreated banana fibre composite as the cellulose content is reduced. Mizera *et al* [8] investigate the effect of temperature and moisture content on the

(a) Polypropylene sheet (b) Banana fibre (c) Glass fibre

Figure 1. Shows (a) Polypropylene sheet (b) banana fibre and (c) glass fibre.

tensile behaviour of false banana fibre. The tensile strength of the banana fibre increases with increase in moisture content then decrease after 60% moisture content.

Previous studies argued that hybridisation of glass and Hibiscus cannabinus could improve the stiffness, strength as well as moisture resistance of the hybrid composites [9–11]. The hybridisation of natural and synthetic fibres improves the mechanical properties of the composite by securing the upsides of one fibre to overcome the detriment of another fibre, for example, hydrophilicity [12, 13]. Pothan and Thomas [14] studied the effect of hybridisation and chemical modification on water absorption behaviour of random banana fibre reinforced polyester composites. It was concluded that the water diffusion of banana/glass hybrid composites is dependent on the content of cellulose fibre. The chemical treatment removes the natural fibre impurities, hence improves the interfacial adhesion, which yields in a reduction of the water absorption. Nayak *et al* [15] investigated the influence of interfacial adhesion between fibre and matrix on the structural and mechanical behaviour of polypropylene short banana/glass hybrid composites. Based on the results, the water absorption increased with the increasing percentage of banana fibre due to the presence of hydroxyl group. However, water absorption can be reduced by replacing banana fibre with impermeable glass fibre which can act as a barrier preventing direct contact between banana fibre and water. Prasanna *et al* [16] investigated synthesis and characterisation of short banana/glass fibre reinforced epoxy based hybrid composite. The results showed that the rate of moisture absorption increases with the increase in fibre lengths. Composites with 10 wt% banana fibre loading have higher water absorption rate than 5 wt% due to abundant hydroxyl groups in banana fibre. The amount of water absorbed mainly depends on factors such as fibre type, hydrogen bonding sites in the natural filler, the volume fraction of the fibre, void spaces at the interfaces and the micro-cracks in the polymer matrix formed during the fabrication, and temperature [17, 18]. The water absorption capacity of all the composite samples is high in the early stages of the exposure; following which it decreases till reaching a saturation level. Cellulose and hemicellulose are mainly responsible for the high water absorption capacity since they contain maximum active hydrogen bonding sites [19].

Thus far, the investigation on the effect of water absorption on mechanical properties of cross-ply banana/glass fibre reinforced polypropylene composites is yet to be explored. Cross-ply banana and glass fibres were selected in order to reduce the overall cost, to fully utilise the banana plantation and to move towards greener future. Thus this paper presents the effects of water absorption on the mechanical properties of cross-ply hybrid banana-glass fibre reinforced polypropylene composite in terms of tensile and flexural.

2. Experimental procedure

2.1. Materials and equipment

J C Overseas Incorporation, India supply Cross-ply (0/90°) banana (B) fibre with the areal weight of 342.5 g m^{-2} used in this study. ZKK Sdn Bhd, Malaysia supplies Cross-ply (0/90°) glass (G) fibre with the areal weight of 600 g m^{-2}. Al Waha, Saudi Arabia supply polypropylene (PP) pellets with a density of 0.95 g cm^{-3}. Figure 1 shows materials for composite fabrication. Typical properties of banana fibre, glass fibre and polypropylene are tabulated in table 1.

Table 1. Typical properties of banana fiber [19], glass fiber [20] and polypropylene [21].

Properties	Banana fiber	Glass fiber	Polypropylene
Tensile Strength (MPa)	550	1700–3500	22–41.4
Young's Modulus (GPa)	22–32	65–72	1.5–2
Elongation at break (%)	3–4	3	3–700
Diameter (μm)	80–250	5–25	—
Density (g cm^{-3})	1.35	2.58	0.89–0.95
Cellulose (%)	60–65	—	—
Hemicellulose (%)	6–19	—	—
Lignin (%)	5–10	—	—
Melting point, T_m (°C)	163	1725	160–176

2.2. Composite fabrication

- PP granules were hot pressed to form a thin PP sheet with a thickness of 0.5 mm and dimensions of 250 × 250 mm.
- Both cross-ply banana and glass fibres were cut into dimensions of 250 × 250 mm.
- PP sheet and the cross-ply fibres were stacked alternately in picture frame mould of 250 × 250 × 3.5 mm.
- Three layers of cross-ply fibres were stacked in a single composite.
- The mould is then placed in the hot press machine and preheated at a temperature of 170°C for 5 min. Then the composite was compressed at 170°C at 3.5 MPa for 10 min before cooled for 15 min.
- The composite is cut into dimensions of 200 × 25 mm for tensile and flexural according to ASTM D3039 and ASTM D790 using a vertical band saw as shown in figure 2.
- Four types of stacking sequences which fall into two categories of hybrid and non-hybrid were prepared. Hybrid composites are BGB and GBG while non-hybrid composites are BBB and GGG. The stacking sequences of the composites are as shown in figure 3.

Table 2 shows the fibre and matrix volume fraction of the composites. Equation (1) is used to calculate the fibre volume fractions.

$$V_{fibre} = \frac{\frac{w_{banana}}{\rho_{banana}} + \frac{w_{glass}}{\rho_{glass}}}{\frac{w_{banana}}{\rho_{banana}} + \frac{w_{glass}}{\rho_{glass}} + \frac{w_{pp}}{\rho_{pp}}} \quad (1)$$

where w_{banana} and ρ_{banana} are the weight and density of banana fibre, w_{glass} and ρ_{glass} are the weight and density of glass fibre, w_{pp} and ρ_{pp} are the weight and density of polypropylene.

2.3. Water absorption test

The water absorption and thickness swelling test was carried out using distilled water according to ASTM D570. First, the specimens with a dimension of 200 × 25 × 3.5 mm were oven-dried at 80°C until the weight is constant. The specimens are then fully immersed in distilled water at room temperature (26 °C). The water absorption and thickness swelling were measured at 24 h' interval up to saturation. The specimens were removed from the water and wiped dry and then weighed using an analytical balance with an accuracy of 0.01 g. For each type of composite, three specimens were tested and the average result was recorded. The specimens were considered saturated when the difference in weight is less than 1%. The water content percentage, $\Delta M(t)$, was calculated using equation (2) [22].

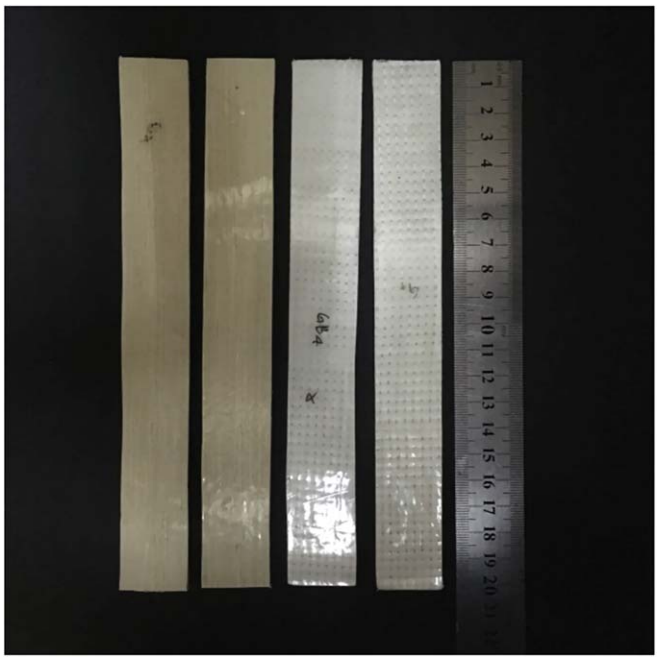

Figure 2. Tensile and flexural specimens.

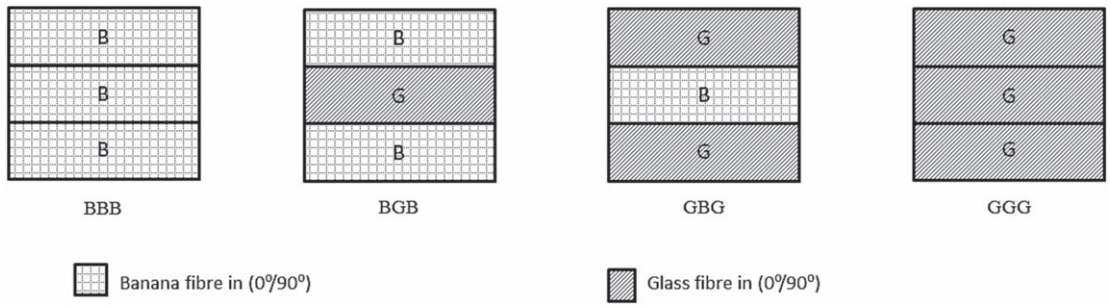

Figure 3. Stacking sequences of the composites.

Table 2. Fibre and matrix volume fraction in a composite.

Composite	Fibre volume fraction (%)	Matrix volume fraction (%)
BBB	24.36	75.64
BGB	22.99	77.01
GBG	19.35	80.65
GGG	18.92	81.08

$$\Delta M(t) = \frac{M_t - M_0}{M_0} \times 100 \quad (2)$$

where M_0 and M_t represent the mass of the dry and immersed sample, respectively, at a specific time. The percentage of water absorption was plotted against the square root of time in hours. Water absorption characteristics parameters such as diffusion coefficient, sorption coefficient and permeability coefficient are calculated using equations (3)–(5) [22].

The penetration of water molecules into the composite structure can be measured through the Fickian diffusion coefficient (D) [23]. It is computed from the slope of water content versus the square root of time [22].

$$D = \pi \left(\frac{h}{4M_\infty}\right)^2 \left(\frac{M_2 - M_1}{\sqrt{t_2} - \sqrt{t_1}}\right)^2 \quad (3)$$

where M_∞ is the percent water absorbed at saturation, h is the specimen thickness, $M_2 - M_1$ is the slope of the plot of water absorption rate during the initial ageing time and $\sqrt{t_2} - \sqrt{t_1}$ is the linear portion of the curve. Assuming the absorption process is linear at an early stage of immersion; time is taken at the beginning of the absorption process so that the weight change is expected to vary linearly with the square root of time. Sorption coefficient shows the resistance of diffusion of water molecules in the composites. Permeability coefficient is another important parameter, which shows the net effect of water absorption [2].

$$\textit{Sorption Coefficient},\ S = \frac{M_s}{M_t} \quad (4)$$

where M_s and M_t are the percentages of water uptake at saturation time and at a specific time t.

$$\textit{Permeability coefficient},\ P = D \times S \quad (5)$$

Thickness swelling behaviour is measured according to ASTM D570, the sample was measured using a Vernier calliper at three different locations and the average result is recorded. The percentage of thickness swelling is calculated using equation (6) [22].

$$\textit{Thickness Swelling}\,(\%) = \frac{T_i - T_o}{T_o} \times \% \quad (6)$$

where T_i is the thickness of a particular time and T_o is the initial thickness of the sample.

2.4. Mechanical testing

2.4.1. Tensile testing

The tensile test was performed using the Instron model 8872 servo-hydraulic universal Testing Machine with a load cell capacity of 25 kN and a crosshead speed of 2 mm min^{-1}. Tests were conducted according to ASTM D3039, using a tensile coupon with a dimension of 200 × 25 × 3.5 mm. The wetted saturated specimens are oven dried at 80°C until the difference in weight is less than 1%. Three specimens for dry and wet were tested and their average values and standard deviation are reported.

2.4.2. Flexural testing

The three-point flexural test was performed using the Instron model 8872 servo-hydraulic universal Testing Machine with a load cell capacity of 25 kN and a crosshead displacement rate of 2 mm min^{-1}. The specimens were prepared according to ASTM D790 with dimensions of 200 × 25 × 3.5 mm. Calculation of flexural strength and flexural modulus are made using equation (7) [2].

$$\textit{Flexural strength} = \frac{3FL}{2bd^2} \textit{ and Flexural modulus} = \frac{mL^3}{4bd^3} \quad (7)$$

where F is the maximum load (N), L is span length (mm), b and d are width and thickness of specimens (mm) and m is the slope of the load-displacement graph. The wetted saturated specimens are oven dried at 80°C until the difference in weight is less than 1%. Three specimens for dry and wet were tested and their average values and standard deviation are reported.

3. Results and discussion

3.1. Water absorption behaviour

Based on figure 4, there is a large linear increase of water absorption in the first two points and smaller uniform increase until the equilibrium. Specimen BBB exhibits the highest percentage of water absorption while specimen GGG has the lowest. The linear region occurred between the first two points for all four specimens, and this trend obeys Fick's law [24]. The specimens were immersed for $\sqrt{20}$ h and equilibrium occur from $\sqrt{17}$ h. The water absorption increased from specimen GGG to GBG to BGB and lastly BBB. At saturation, the water absorption is 13.36%, 8.73%, 4.41% and 3.00% for BBB, BGB, GBG and GGG respectively. Ghosh *et al* [25] found that an increase in the ratio of natural fibre increased the percentage of water absorption. This is due to the increase in the hydroxyl group in the composite. Figure 5 shows that the diffusion coefficient rate also increases from GGG to BBB. BBB has the highest diffusion coefficient of 1.49 $m^2\ s^{-1}$ followed by BGB at 1.19 $m^2\ s^{-1}$, GBG at 1.02 $m^2\ s^{-1}$ and GGG at 0.98 $m^2\ s^{-1}$. A similar trend was also observed for thickness swelling in the order of BBB, BGB, GBG and GGG with 18.13%, 13.66%, 12.87% and 9.43% respectively. Bujjibabu *et al* and Zabihzadeh [18, 26] reasoned that increasing soaking time would increase the water

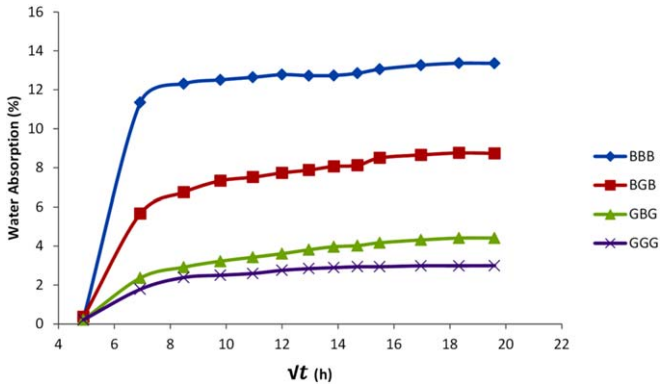

Figure 4. Water absorption versus square root of time for each stacking sequence.

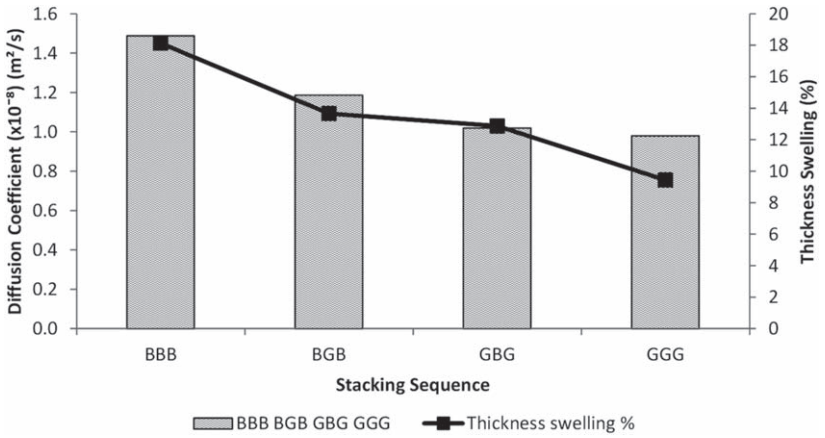

Figure 5. Diffusion coefficient and thickness swelling for each stacking sequence.

absorption until an equilibrium is reached. Greater diffusivity is expected for higher cellulose content in the composite [27].

Figures 4 and 5 show that water absorption depends on the diffusion coefficient of the specimens and hydrophilicity. It was argued that the higher the hydrophilicity, the higher the diffusion coefficient, thus increasing the percentage of water absorption. Pothan and Thomas [14] added that the absorption of water by polymer depends mainly on two factors which are the availability of free nano-sized holes in the polymer and the polar sites present in the polymer. Glass fibres are hydrophobic while banana fibres are hydrophilic. Water absorption decreases with the replacement of banana fibre by water-impermeable glass fibre, which acts as a barrier to the banana fibre, preventing its direct contact with water [16]. Natural fibres in contact with liquid water replace part of the hydrogen bonds between the macromolecules in the plant fibre cell wall, which contains hydroxyl groups (−OH) in cellulose, hemicellulose and lignin, triggering swelling phenomena [8, 28]. The water content of the fibres is dependent on the content of non-crystalline parts and void content of the fibres [29] and a greater interfacial area between fibres and matrix [2]. The chances that water molecules attack the interface, resulting in de-bonding of the fibre and the matric internally leads to composite structural failure [30]. Moisture and water absorption by natural fibres also leads to premature ageing due to degradation and loss of strength [4].

The diffusion coefficient is defined as the ability of the water molecules to diffuse into the composites, which mainly depends on the nature and orientations of fibres, which is found to reduce with the incorporation of hydrophobic glass. Sorption coefficient is the resistance of diffusion of water molecules in the composites with the highest is recorded by BGB and GBG, with a value of 1.11 followed by BBB and GGG, with the Sorption coefficient of 1.05 and 1.04 respectively. Permeability coefficient shows the net effect of water absorption. The permeability coefficient of BBB is the highest with 1.56 $m^2\ s^{-1}$ followed by BGB, GBG and GGG with 1.32 $m^2\ s^{-1}$, 1.13 $m^2\ s^{-1}$ and 1.02 $m^2\ s^{-1}$ respectively. As stated by Dhakal *et al* [27] and Venkateshwaran and Elayaperumal [31], higher sorption, diffusion and permeability coefficients result in high moisture absorption capability to the composite. The water absorption properties are summarised in table 3.

Table 3. Summary of water absorption properties.

Specimen	Water uptake at saturation stage (%)	Diffusion coefficient, D ($\times 10^{-8}$) ($m^2\ s^{-1}$)	Sorption coefficient, S	Permeability coefficient, P ($m^2\ s^{-1}$)
BBB	13.02	1.49	1.05	1.56
BGB	8.34	1.19	1.11	1.32
GBG	4.19	1.02	1.11	1.13
GGG	2.77	0.98	1.04	1.02

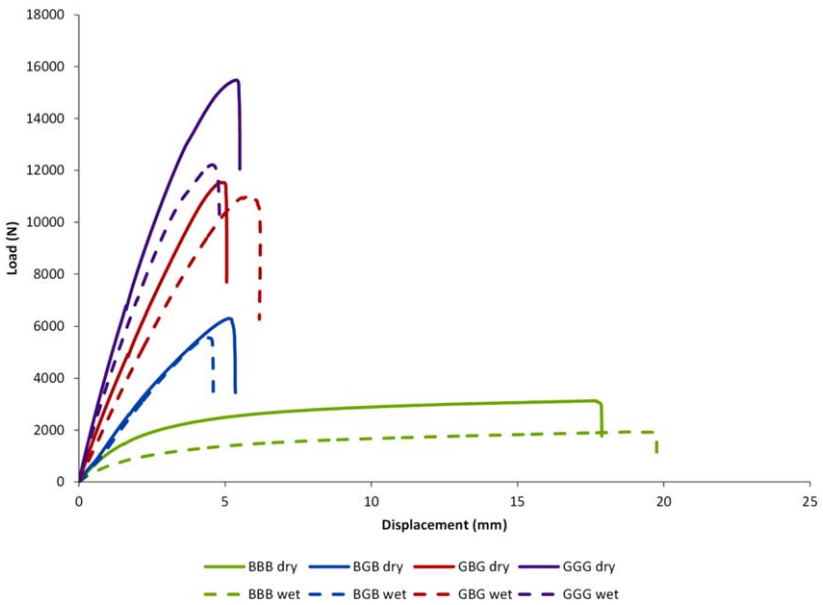

Figure 6. Typical tensile load-displacement curve for each stacking sequence in dry and wet conditions.

3.2. Tensile properties

Figure 6 shows the typical tensile load-displacement curve for each stacking sequence for dry and wet conditions. The incorporation of glass fibre increases the ultimate load of the composites. From figure 6, it is observed that dry specimens obtained higher load with increasing glass fibres. A similar trend was observed for wet specimens. However, in comparison, the wetted specimens have a lower load than dry specimens. A comparable trend also observed for tensile modulus.

Figure 7 shows the comparison of tensile strength on dry and wetted specimens. The figure shows that dry specimens require higher tensile strength compared to wetted specimens to fail. An increasing trend is observed when more glass fibre is incorporated. For dry specimen, BBB has a tensile strength of 38.55 MPa followed by BGB, GBG and GGG with 75.87 MPa, 136.28 MPa and 190.66 MPa respectively. A similar trend was found with wetted specimens where GGG has the highest strength at 161.05 MPa followed by GBG, BGB and BBB with 134.45 MPa, 61.78 MPa and 24.91 MPa respectively.

A comparable trend is found with tensile modulus as shown in figure 8. The incorporation of glass fibre in the composite increased the tensile properties because banana fibre has lower tensile properties compared to glass fibre. The tensile modulus decreased after moisture absorption because the stress transfer capability between fibre and matrix interface is reduced [27]. The specific tensile strength, which is defined as the strength to mass ratio, as given in figure 9 shows an increasing trend from BBB to GGG. Dry GBG and the wetted GBG is 28.15% and 16.09% lower than GGG respectively. The tensile properties of composites are summarised in table 4.

3.3. Flexural properties

Figure 10 shows the typical flexural load-displacement curve for each stacking sequence for dry and wet conditions. Increasing glass fibre in the composite has increased the composite stiffness. Based on the graph, the incorporation of glass fibre increases the load up to GBG then decreased for GGG in dry and wet condition.

Figure 11 shows that the flexural strength for wetted specimens is higher than dry specimens for GBG and GGG. Dry specimens BBB, BGB, GBG and GGG have a flexural strength of 55.59 MPa, 57.15 MPa, 65.32 MPa

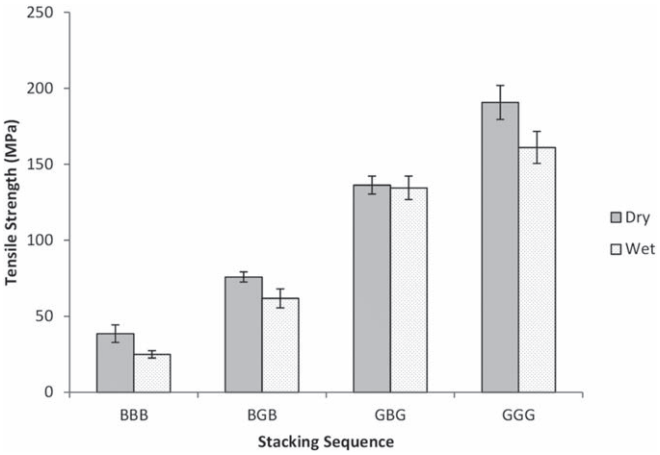

Figure 7. Dry and wetted tensile strength for each stacking sequence.

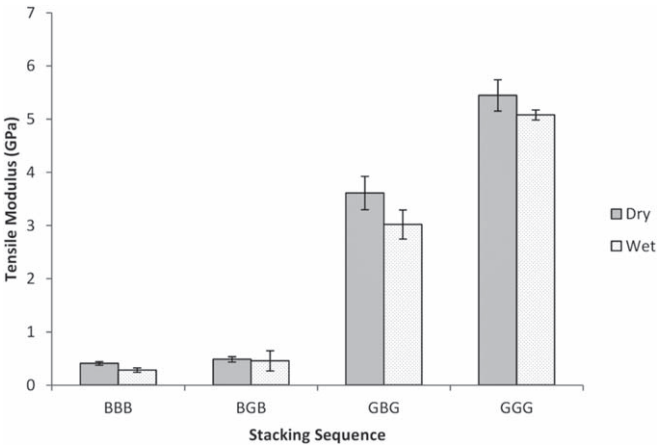

Figure 8. Dry and wetted tensile modulus for each stacking sequence.

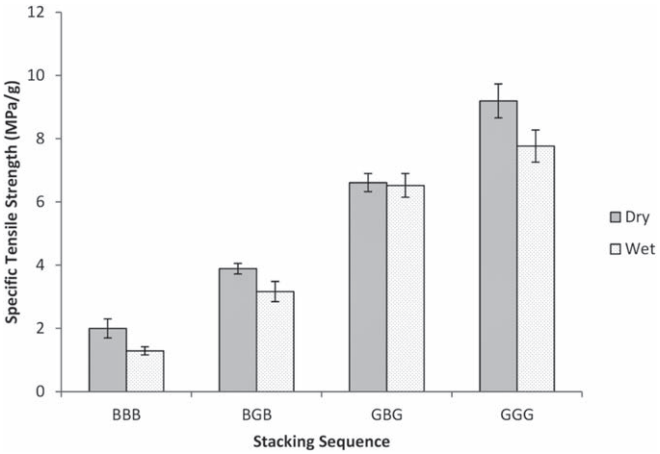

Figure 9. Specific tensile strength of the composites against the stacking sequence.

and 66.98 MPa respectively. For wetted specimens the highest flexural strength is found for specimen GBG with 73.86 MPa followed by GGG, BGB and BBB with 72.24 MPa, 54.17 MPa and 50.44 MPa respectively. Flexural strength of wet GBG is 2.24% higher than wet GGG while GGG dry is 2.54% higher than GBG dry specimen. Wet GBG has the highest flexural strength compared to other specimens; this phenomenon could be due to the

Table 4. Tensile properties of dry and wet composites.

	Tensile strength (MPa)		Tensile modulus (GPa)	
Composites	Dry	Wet	Dry	Wet
BBB	38.55 ± 5.77	24.91 ± 2.43	0.41 ± 0.03	0.28 ± 0.04
BGB	75.87 ± 3.32	61.78 ± 6.25	0.49 ± 0.05	0.46 ± 0.19
GBG	136.28 ± 5.96	134.45 ± 7.74	3.61 ± 0.31	3.02 ± 0.27
GGG	190.66 ± 11.11	161.05 ± 10.52	5.45 ± 0.29	5.08 ± 0.09

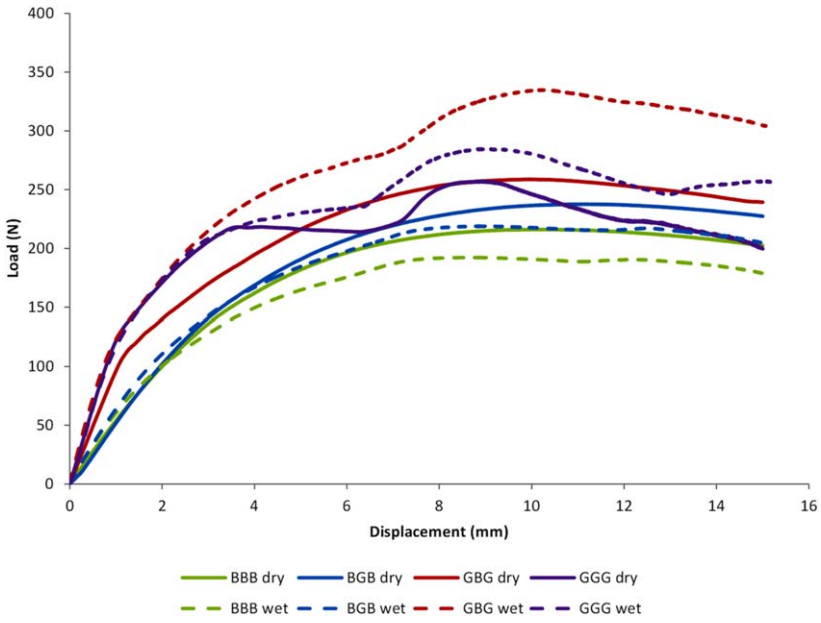

Figure 10. Typical flexural load-displacement curve with different stacking sequence in dry and wet condition.

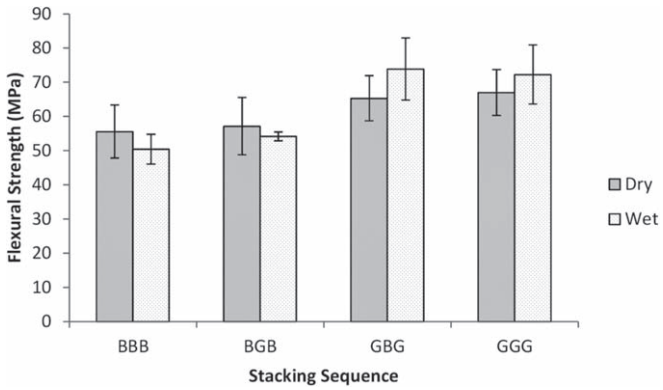

Figure 11. Dry and wetted flexural strength with different stacking sequence.

swelling of fibres which could fill the gaps between fibre and matrix and eventually increase the mechanical properties [27, 32].

Furthermore, Dhakal *et al* [27] stated that the water molecules destroy the rigidity of the cellulose structure in the cellulose network structure in which water act as a plasticiser and it permits cellulose molecules to move freely. Consequently, the mass of the cellulose is softened and can change the dimensions of the fibre easily with the application of forces. Ayensu [33] observed similar phenomena, where flexural strength of jute fibre reinforced composite increased after exposure to moisture.

Figure 12, shows flexural modulus of the dry specimen increases with the values of 1.67 GPa, 2.29 GPa, 3.12 GPa and 4.50 GPa for BBB, BGB, GBG and GGG specimen respectively. Wetted specimens possess lower

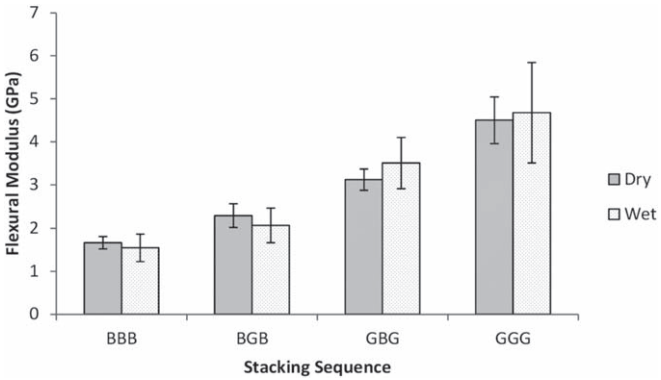

Figure 12. Dry and wetted flexural modulus with different stacking sequence.

Table 5. Flexural properties of dry and wet composites.

	Flexural strength (MPa)		Flexural modulus (GPa)	
Composites	Dry	Wet	Dry	Wet
BBB	55.59 ± 7.76	50.44 ± 4.35	1.67 ± 0.14	1.55 ± 0.32
BGB	57.15 ± 8.38	54.17 ± 1.30	2.29 ± 0.28	2.07 ± 0.40
GBG	65.32 ± 6.62	73.86 ± 9.07	3.12 ± 0.25	3.51 ± 0.60
GGG	66.98 ± 6.68	72.24 ± 8.65	4.50 ± 0.55	4.68 ± 1.17

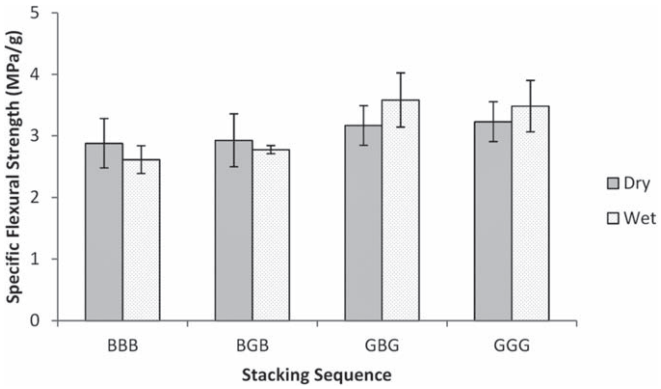

Figure 13. Specific flexural strength for each stacking sequence.

flexural modulus for both BBB and BGB, and then increased for GBG and GGG as compared to dry specimens, with the values of 1.55 GPa, 2.07 GPa, 3.51 GPa and 4.68 GPa for BBB, BGB, GBG and GGG respectively. This phenomenon can be observed in Dhakal *et al* [27] where the flexural modulus of hemp reinforced composite was not adversely affected by moisture content. The flexural properties of the composites are summarised in table 5.

The specific flexural strength in figure 13 is measured with the strength to mass ratio. Specimen GBG exhibit 2.87% higher specific flexural strength as compared to GGG in wet conditions.

Figure 14 shows the SEM micrographs of the banana fibre after a tensile fracture. Due to the hydrophilic nature, natural fibres tend to absorb moisture and swells and leaving high residual stress on the cell wall of the fibres [34].

Figures 14(a) and (c) reveal evidence of traces of matrix available on the banana fibre, which is an indication of a good wettability between the matrix and the banana fibre in the dry sample. Good wettability of fibre with polymer matrix enhanced the interfacial adhesion between fibre and polymer matrix, which reduce the fibre breakage, de-bonding between fibre and matrix, matrix breakage and fibre pull-out [33, 34]. Figure 14(b) shows the banana fibre in the wetted specimen. Even though the adhesion is good, the composite fails due to fibre breakage. Figure 14(d) shows a gap between fibre and matrix possibly due to swelling during water attack. Previous researchers argued that in water saturated composites, swelling of natural fibres is due to diffusion of

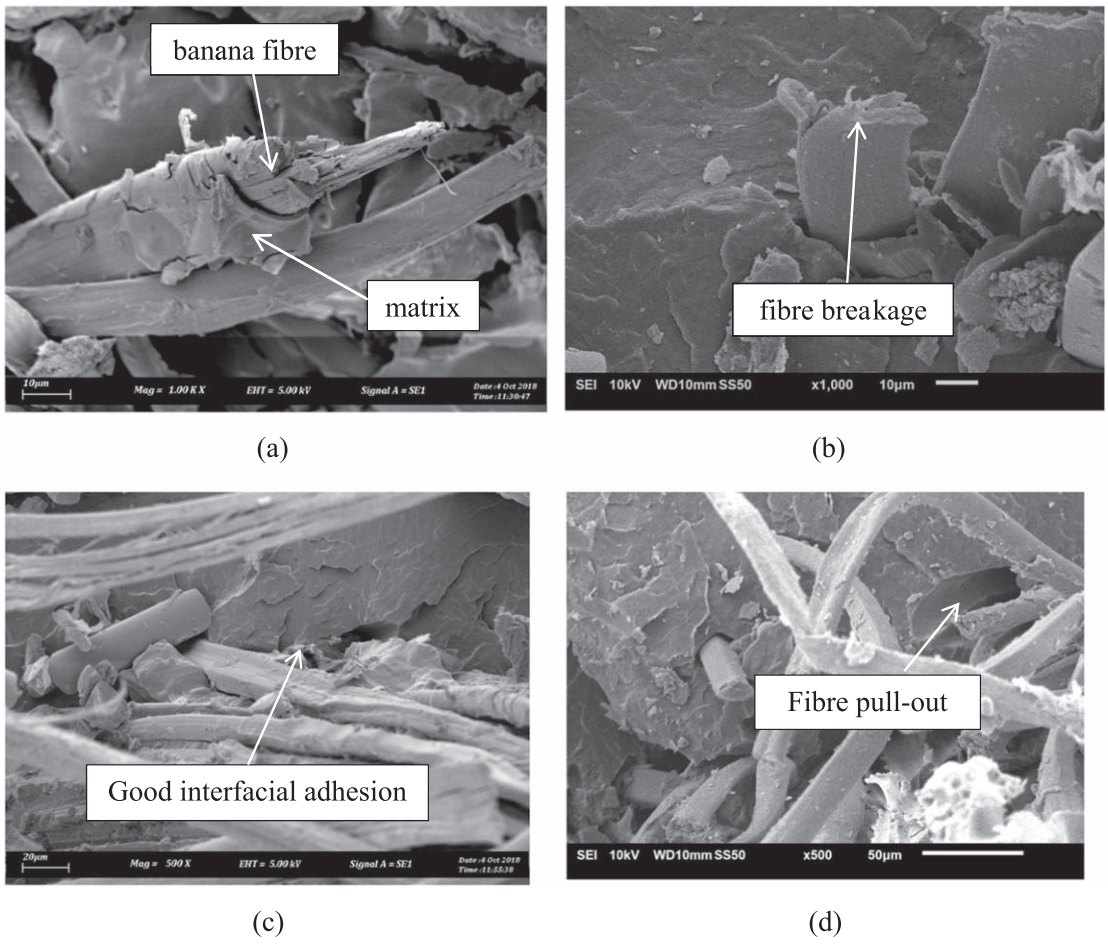

Figure 14. SEM images showing (a) and (c) banana fibre behaviour in the dry specimen (b) and (d) banana fibre behaviour in the wetted specimen.

water inside the composite inner structure, which results in fibre/matrix de-bonding, fibre fracture and fibre pull-out in tensile load [35, 36]. Based on figures 7 and 8, it is observed that dry specimens exhibit better tensile properties than those of the wetted specimens. Such observation could be due to swelling of fibres. With the increase in fibre loading, the weak interfacial area between the cellulose-based hydrophilic fibre and hydrophobic matrix increases [33, 36].

4. Conclusions

The effect of water absorption on mechanical properties of cross-ply pseudo-stem banana/glass fibre hybrid reinforced polypropylene composites were studied and the following conclusions were drawn:

- The positive hybrid effect is observed in which water absorption behaviour is improved when glass fibre is incorporated in the composite. Overall, non-hybrid GGG synthetic composite has the best water absorption properties. However, hybrid composites with glass fibre at the outermost layers show a comparable diffusion coefficient and thickness swelling to those of the non-hybrid GGG composite.
- Mechanical properties in terms of tensile and flexural increase with increasing glass fibre in the composite. The wetted specimens have lower tensile strength and modulus than dry specimens. However, hybrid GBG (wet specimen) has a higher flexural strength than non-hybrid GGG.
- The results obtained from the tensile test imply that non-hybrid GGG composites exhibit the highest tensile strength and modulus. Nonetheless, the specific tensile strength of GBG composite is only 28.15% and 16.09% lower than those of the dry and wetted GGG specimens.

- The results from the flexural test suggest that GBG composite has better flexural strength and specific flexural strength compared to those of the non-hybrid GGG. This implies the potential of using hybrid composite as a substitute for the synthetic non-hybrid glass fibre composites in bending load applications.

Acknowledgments

The authors would like to thank Universiti Teknikal Malaysia Melaka (UTeM) for the continuous support of this research project. The authors would also wish to express their gratitude to the Ministry of Education Malaysian for grant FRGS/1/2017/STG07/FKM-CARE/F00339.

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