Hindawi
International Journal of Polymer Science
Volume 2019, Article ID 1230592, 12 pages
https://doi.org/10.1155/2019/1230592

Research Article

Hybrid and Nonhybrid Laminate Composites of Sugar Palm and Glass Fibre-Reinforced Polypropylene: Effect of Alkali and Sodium Bicarbonate Treatments

Isma'ila Mukhtar,[1,2] Zulkiflle Leman ,[1,3] Edi Syams Zainudin,[1,3] and Mohamad Ridzwan Ishak[4]

[1]*Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia*
[2]*Department of Mechanical Engineering, Faculty of Engineering, Kano University of Science and Technology, Wudil, P.M.B 3244 Kano, Nigeria*
[3]*Laboratory of Biocomposites Technology, Institute of Tropical Forestry and Forest Product (INTROP), Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia*
[4]*Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia*

Correspondence should be addressed to Zulkiflle Leman; zleman@upm.edu.my

Received 20 October 2018; Revised 25 January 2019; Accepted 20 February 2019; Published 4 April 2019

Academic Editor: Anjanapura V. Raghu

In recent years, the hybrid composites of cellulosic and synthetic fibres are tailored to yield materials with reduced cost and weight. Prior to the fabrication of the hybrid composite, in most case, the cellulosic fibre needs surface modification for proper bonding. Therefore, this study investigates the effect of sodium bicarbonate treatment on the physical and mechanical properties of the hybrid and nonhybrid laminate composites of sugar palm and glass fibre-reinforced polypropylene. The findings will be compared with the conventional alkali treatment. The laminate composites were fabricated using the film stacking technique and hot compression process. Prior to the fabrication process, the sugar palm fibre in it which is naturally woven mat was treated with 4 wt% and 10 wt% alkali and sodium bicarbonate, respectively. All the laminate composites were investigated by tensile, flexural, and impact test, water absorption, and morphological examination. The tensile strength increased with both alkaline and sodium bicarbonate treatments for the hybrid and nonhybrid composites. The increase was more pronounced with the alkaline-treated SPF composite (L03) which displayed the highest value of 61.75 MPa, while that of the sodium bicarbonate-treated SPF composite (L04) recorded 58.76 MPa against 53.01 MPa for the untreated SPF composite (L02). The same trend was observed for the flexural strength. In overall, the alkaline treatment yielded better performance in comparison with sodium bicarbonate treatment.

1. Introduction

Nowadays, the synthetic fibre-reinforced polymer (FRP) composite becomes the key material that is fast replacing the conventional material in the field of aerospace and automotive industry. Superior properties and lightweight are the key attributes for the adoption of the FRP. Notwithstanding, these synthetic fibre-reinforced polymer composites are not environmentally friendly, nondegradable, associated health risk, and nonrecyclable, amongst others [1–5]. To reduce the advance effect of FRP to the environment, the hybrid composites of synthetic and natural fibre are becoming an option where strength requirement is not critical. The hybrid is achieved through the incorporation of the natural fibre into the synthetic fibre, thus, leading to the paradigm shift from the FRP to hybrid-reinforced polymer composite system.

The incorporation of the natural fibre comes with a lot of benefits which include but not limited to low density, low cost, availability, renewability, biodegradability, and non-abrasive [6–11]. Therefore, combining these two different reinforcing materials, a hybrid composite with balance performance especially cost performance and lightweight can be synthesized.

Previous researches on the natural/synthetic fibre-reinforced polymer hybrid composites have shown desirable properties in terms of high specific mechanical properties at reduced cost. In addition, the hybrid composite scores were high in terms of environmental impact when compared to the synthetic fibre-reinforced polymer composite. This was verified by Mansor et al. [12] in the life cycle analysis of the parking brake lever fabricated with the glass/kenaf-reinforced polypropylene (PP) composite for the automobile car. There are many studies toward hybridizations which are numerous to mention. But few amongst them include oil palm and glass fibre-reinforced epoxy composite [13], jute-glass- and kenaf-glass-reinforced polyester [14], sisal- and glass-reinforced epoxy [15], and flax/glass-reinforced polyurethane polyester [16]. In all the research highlighted, the researchers manipulate the constituents of these composites and allow materials with balanced static and dynamic strength to be synthesized and used in structural or semistructural applications. In addition to improved strength, the incorporation of the glass into the natural fibre will increase both thermal properties and water resistance of the composite as compared to the natural fibre-reinforced polymer composite. These improvements were observed in a hybrid composite system found in the literature [17, 18].

Many factors are responsible for the properties of the hybrid composite; these include layer configuration, fibre loading, and matrix/fibre interface bonding. The study on the effect of the outlined factors will lead to so many types of the hybrid composites for various applications. Amongst the research is a study conducted by Atiqah et al. [19] in which a hybrid composite of kenaf/glass-reinforced unsaturated polyester was proposed for structural application. Also, Davoodi et al. [20] proposed a car bumper with the use of kenaf- and glass fibre-reinforced epoxy, though the material has a low impact property when compared to the glass mat thermoplastic (GMT) composite. Similarly, Cicala et al. [21] fabricated and tested the performance of various synthetic/natural fibre hybrid composites for use in the piping industry. The hybrid composites were hemp/glass-, kenaf/-glass-, and flax/glass-reinforced epoxy. Specifically, an elbow pipe was fabricated using hand layup, and it yielded 20% and 23% cost and weight reduction, respectively, when compared to existing commercial components. In another development, Mansor et al. [12] fabricated a glass/kenaf-reinforced PP hybrid for the parking brake lever as an alternative material to reduce an environmental factor. Also, the hybridized glass fibre- and sugar palm fibre-reinforced unsaturated polyester composite was used for the fabrication of small boat using hand layup technique [22]. The hybrid composite has a tensile modulus and impact properties of 1840.6 MPa and 2.41 kJ/m^2, respectively.

Looking at these various hybrid composites, more improvement can be obtained by treating the lignocellulose fibre for better adhesiveness and effective load transfer from the matrix to the stiff fibre. It is known that composite quality can be marred by the poor fibre-matrix bonding, because, naturally, hydrophilic fibre does not strongly bond with hydrophobic polymer. To improve the adhesiveness between the fibre and the matrix, treatment of the fibre becomes inevitable. The treatment can be translated into reduced moisture absorption, better bonding, and most importantly improved mechanical properties. This approach has been the conventional method of addressing these problems. Amongst the chemical treatment, alkaline treatment is one of the most common fibres' surface modification. This method has been proving to be an effective treatment by removing both natural and artificial waxy substances and impurities, thereby making the surface of the fibre to be rough for better adhesion with the polymer. But the alkaline treatments come with an additional problem of fibre degradation at a high concentration in which a mild chemical treatment using sodium bicarbonate could be an option. The improvement recorded by treating sugar palm fibre with sodium bicarbonate can be seen in our previous research [23]. Therefore, in this research, the sugar palm fibre was treated with sodium bicarbonate prior to the fabrication of the hybrid and nonhybrid composites. The aim was to examine the effect of sodium bicarbonate treatment on the properties of the hybrid and nonhybrid laminate composites and compared it with that of the alkaline-treated fibre laminate composite. The hybrid composite was fabricated by sandwiching two layers of sugar palm fibre between layers of glass fibre. The laminate composites were characterized based on physical properties as well as tensile, flexural, and impact properties. Furthermore, the morphological examination was carried out to study the adhesiveness between the matrix and the reinforcing fibres.

2. Materials and Methods

2.1. Materials

2.1.1. Sugar Palm Fibre. The sugar palm fibre which is locally known as ijuk was sourced from Kampung Kuala Jempol, Negeri Sembilan, Malaysia. It comes as a naturally woven mat which is wrapped around the sugar palm trunk. It does not require any extraction methods; it only involves disintegration from the sugar palm tree bark. Figure 1 shows a naturally woven mat being cut to 200 by 287 mm, with an approximate weight of 540 g/m^2. The properties of the sugar palm fibre (SPF) were determined in our earlier study [23], and they are listed beside the mat.

2.1.2. Glass Fibre. The synthetic fibre used is a plain woven E-glass fibre (GF) with an approximate weight and thickness of 400 g/m^2 and 0.4 mm, respectively. It was supplied by ZKK Sdn. Bhd, Malaysia, and the glass fibre has a density of 2.6 g/cm^3, tensile strength of 2400 MPa, modulus of 72 GPa, and elongation of 3%. This woven E-glass fibre was cut to the required size of the mould, i.e., 200 by 287 mm.

Density	1.33 g/cm^3
Diameter	314.33 μmm
Tensile strength	216.8 MPa
Tensile modulus	3.86 GPa
Elongation	23.34 %
Cellulose	43.95 %
Hemicellulose	8.24 %
Lignin	43.81 %
Moisture content	8.19 %

Figure 1: Sugar palm fibre mat and properties of a single fibre [23].

2.1.3. Polypropylene. The polypropylene (PP) used was the Titanpro 6331 PP homopolymer produced by Lotte Chemical Titan (M) Sdn Bhd, Malaysia. The PP was supplied in form of pellets, and it has a melting point of >160°C and relative density of 0.9 g/cm^3. Melt flow index at 230°C was given as 14 g/10 min, while the tensile strength, flexural strength, and elongation at yield are 35.3 MPa, 1.7 GPa, and 10%, respectively.

2.1.4. Treatment Chemicals. Two treatment chemicals were used to treat the sugar palm fibre in this research. These chemicals are alkali (NaOH) obtained from R&M Chemicals, Malaysia, and sodium bicarbonate ($NaHCO_3$) is obtained from Sigma-Aldrich. Both chemicals were used as received without any additional processing.

2.2. Treatment of Sugar Palm Fibre. The sugar palm fibre was treated with sodium hydroxide and sodium bicarbonate. Throughout the work, the notation SU is used for untreated, SA for alkaline treated, and SN for sodium bicarbonate treated-sugar palm fibre. In the case of alkaline treatment, 4 wt% concentration of NaOH was used with a soaking period of 1 hour as optimized by Bachtiar et al. [24], while 10% *w*/*w* was used for the sodium bicarbonate treatment with a soaking period of 5 days [25]. In all the cases, at the end of the soaking period, the sugar palm fibre was removed and washed thoroughly until the neutral value of pH is achieved. Thereafter, the fibre was dried in an oven at 60°C for 24 h and sealed in a plastic zipper storage bag while awaiting further processing. The chemistry governing the pretreatment of natural fibre with sodium bicarbonate is quite similar to that of sodium hydroxide. Both chemical treatments have similar products of dissociation, and, therefore, treatment of natural fibre with sodium bicarbonate falls under alkaline-based pretreatments.

2.3. Fabrication of the Hybrid and Nonhybrid Laminate Composites. A hybrid and nonhybrid laminate composites of sugar palm and glass fibre were fabricated using film stacking technique and hot compression processes. The arrangements of the layers are shown in Figure 2. In all the types of the composites, i.e., hybrid and nonhybrid composites, the thickness was controlled using a stainless steel mould with a targeted fibre loading of 40%. The configurations of the nonhybrid composites are arranged with 6 layers of GF/PP prepreg as shown in Figure 2(a) and four (4) layers of SPF/PP prepreg as shown in Figure 2(b). While for the hybrid composites, sandwich configuration was adopted with four (4) layers of GF/PP and two (2) layers of SPF/PP prepreg as depicted in Figure 2(c). The hybrid composite was designed at a ratio of 70 : 30 by weight of the glass and sugar palm, respectively, which is the optimum ratio as seen in some researches [19, 26, 27].

To fabricate the laminate composite, firstly, the polypropylene pellet was converted into PP film with a thickness of 0.7 mm. This was done by dispersing 36 g of the PP pellet into a stainless steel mould of $200 \times 287 \times 0.7$ mm with a Teflon sheet at both sides. The mould assembly was preheat in a hot press at 170°C for 6 min, followed by full compression/dwell for 4 min at the same temperature with a pressure of 25 bar and subsequently cooled at 25 bar for 2 min. Secondly, a prepreg of naturally woven sugar palm fibre-reinforced PP and glass fibre-reinforced PP was produced by placing one layer of PP film on both sides of the fibre layer. The arranged layers were inserted into the hot press with Teflon films at both ends. The assembly was preheated, compressed/dwell, and cooled using the same parameters for the fabrication of the PP films. In this process, the PP film will melt and impregnate the fibre thereby making a thermoplastic prepreg. The prepreg of the SPF shows a good fibre distribution due to its natural woven form, unlike kenaf long fibre mat-reinforced PP prepreg which was produced using the same method by Zampaloni et al. [28]. Comparison of the fibre distribution of the sugar palm fibre and kenaf fibre prepreg with PP is shown in Figure 3.

The fabricated layers of the prepreg were arranged according to the stacking sequence outlined in Table 1. Laminate with code L00 represents the unreinforced plate of PP, while the laminate composite with code L01 is a nonhybrid composite of GF/PP with six layers of glass fibre prepreg. L02, L03, and L04 are nonhybrid laminate composites produced with four layers each of untreated and alkaline- and sodium bicarbonate-treated sugar palm fibres. Furthermore, L05, L06, and L07 are hybrid laminate composites with

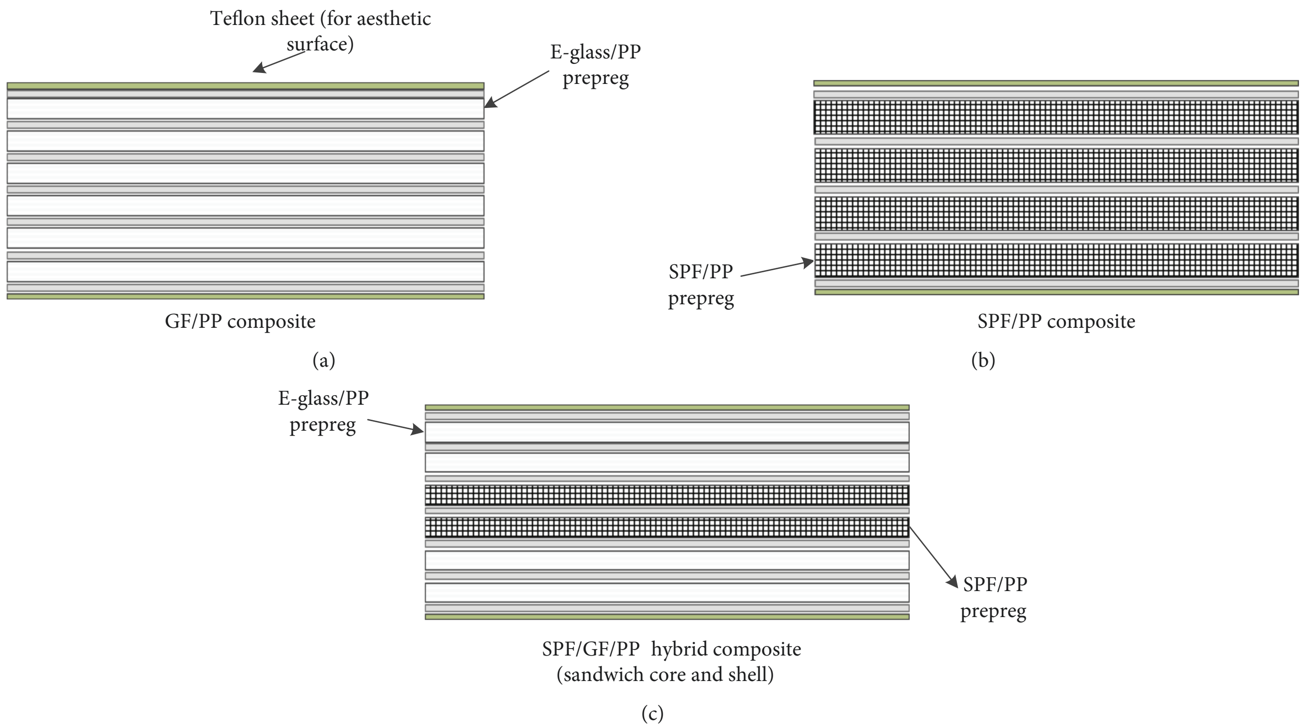

Figure 2: Layers configuration of the nonhybrid and hybrid composites.

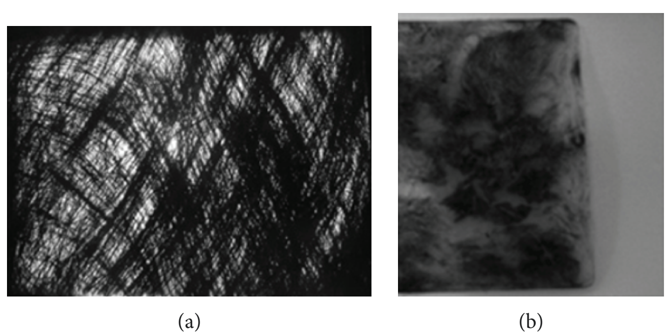

Figure 3: Prepreg of (a) SPF/PP with uniform fibre distribution and (b) kenaf/PP prepreg [28].

Table 1: Stacking sequence of the nonhybrid and hybrid composites.

Laminates code	Composite type	Stacking sequence
L00	Neat PP	Nil
L01	Nonhybrid	GF_6
L02		SU_4
L03	Nonhybrid	SA_4
L04		SN_4
L05		$GF_2/SU_2/GF_2$
L06	Hybrid	$GF_2/SA_2/GF_2$
L07		$GF_2/SN_2/GF_2$

untreated and alkaline- and sodium bicarbonate-treated SPF in the form of sandwich configurations. All the laminate composites were fabricated by setting the hot press at 170°C for 6 min of preheat. Compression/dwell was done at two stages at a pressure of 25 bar and 50 bar for 6 and 4 min, respectively. This was done to avoid fibre slipping during the compression process due to sudden high pressure. Finally, the composite was transferred to the cold press for cooling at 25 bar for 15 min. At the end of the fabrication processes, the laminate composite was removed from the mould and cut in accordance with the specified ASTM standard for the various test.

2.4. Characterizations of the Composites (Physical Properties). The densities of the composites were measured by following ASTM D792-13 [29] standard using the Mettler Toledo electronic densimeter, while the densities of both treated and untreated SPF were measured using the gas (helium) pycnometer. The void content was computed by firstly calculating the theoretical density of the composites using the following equation [30].

$$\text{Composite density theoritical } \rho_{\text{comp.theo.}} = \frac{1}{\left(w_f/\rho_f\right) + \left(w_m/\rho_m\right)}, \quad (1)$$

where w_f and w_m represent the weight fraction of the fibre and matrix, respectively, while ρ_f and ρ_m denote the density of the fibre and matrix, respectively. Subsequently, the volume fraction of void in the composites is computed as follows [30]:

$$\text{Volume fraction of void } V_{\text{Void}} = \frac{\rho_{\text{comp.theo.}} - \rho_{\text{comp.exp.}}}{\rho_{\text{comp.theo.}}}. \quad (2)$$

Furthermore, the fibre volume fraction (V_f) of the hybrid and the nonhybrid composites were determined as follows:

$$\text{Fibre volume fraction } V_f = 1 - V_m - V_{\text{void}}, \quad (3)$$

where V_m represent the matrix volume fraction of the composite system.

The water absorption test of the composites was conducted based on the ASTM D570-10 [31] standard. In this test, a rectangular test piece was cut from the composite plate. The dimension of the bar is 76.2 by 25.4 mm, and its edges were smooth with fine emery cloth. The samples were first dried in an oven, cooled in a desiccator, and subsequently weighed as W_1. The samples were then immersed in a distilled water in a controlled environment at room temperature (23 ± 2°C), and its changes in weight, i.e., W_2, were observed until there is no discernible increase in weight. The recorded values of the weight at interval time were used to compute the water absorption as follows:

$$\text{Water absorption } W_t = \frac{W_2 - W_1}{W_1} \times 100\%. \quad (4)$$

The wetting behaviour of the laminate composites were investigated using sessile drop contact angle measurement. At room temperature, a distilled water droplet with an average drop volume of 2 μL was deposited on the surface of the composite. The drops were captured and analysed using a microscope coupled with a microcharged coupled device camera [32–34]. An average value of the contact angle was reported from four (4) measurements.

2.5. Characterization of the Composites (Mechanical Properties). The tensile properties of all the composites were determined in accordance with ASTM-D3039/D3039M [35], while ASTM D638-14 [36] standard was used for the neat polypropylene sample. The tensile test was conducted for all the samples on the universal tensile testing machine, Instron 3382 with Bluehill software, USA, equipped with a 100 kN load cell. To avoid slipping at the machine clamp and rupture outside the gauge length, a prepreg layer of glass/PP was used as a material for the tab. The crosshead speed was set at 2 mm/min, and the test was replicated 5 times. The average values of the tensile properties were computed and reported therein. The flexural properties of all the samples, i.e., three-point bending, were determined in accordance with ASTM D790-15 [37]. The samples were cut according to the dimensions provided by the standard. The support span was set at 48, 88, and 90 mm for the glass/PP, SPF/PP, and hybrid composite, respectively. The support span was computed based on the general rule of support span to a specimen depth ratio of 16 : 1 as specified by the standard. Also, the crosshead speed was set at 1.8, 2.3, and 2.4 mm/min for the three different types of the composites. In this test, five (5) specimens were tested under deflection until ruptures occur in the outer surface of the test piece. Izod impact test was conducted according to the standard test method ASTM D256-10 [38] using the GT-7045-MD Izod digital impact tester. Five notched specimens were tested, and the mean value of the absorbed energy of the composite was computed. The impact strength in kJ/m^2 was calculated by dividing the recorded absorbed energy with the cross-sectional area of the specimen.

2.6. Morphological Analysis. The fractured surfaces of the tensile specimens were visualized under a scanning electron microscope (S-3400N SEM Hitachi). This technique will facilitate the qualitative analysis of the surfaces for a better understanding of the adhesion between the reinforcing fibres and polypropylene matrix due to the alkaline and sodium bicarbonate treatments. Also, the technique will ascertain whether the reinforcement surfaces have the best condition to be an efficient reinforcement.

3. Results and Discussion

3.1. Effect of SPF Treatments on the Physical Properties of the Laminate Composite

3.1.1. Density, Fibre Volume Fraction, and Void Content. The thickness of the fabricated composite plates, density, fibre volume fraction, and void contents of the various laminate composites are shown in Table 2. The measured densities of the treated and untreated SPF-reinforced PP composites, i.e., L02, L03, and L04 laminate composites, are 1.02, 1.03, and 1.02 g/cm^3, respectively, while for the hybrid composites, the densities are 1.15, 1.16, and 1.14 g/cm^3, respectively. This shows that amongst the nonhybrid and hybrid laminate composites, there is no significant difference in the densities.

Furthermore, the analysis of the void content of the laminate composites shows that a similar percentage of void was obtained for all the hybrid composites and the same trend was noticed for the of nonhybrid composites. In general, the percentage of the void content is low and this is one of the good characteristics of the composite. It should be noted that a good composite should have a less than 1% void content, while up to 5% void content can be seen in a poorly fabricated composite [39]. The fibre volume fraction of the SPF-reinforced PP (28.1%) is on the high side when compared to GF-reinforced PP (19.9%). This is due to the low packing ability of the plant fibre composite than synthetic fibre composites [40]. Also, the fibre volume fraction of the hybrid composites varies slightly; the reason is that same

Table 2: Density and volumetric compositions of fibre and void of the composites.

	Number of layers	Thickness (mm)	Density (g/cm^3)	Fibre volume fraction (%) V_{SPF}	V_{GF}	$V_{SPF} + V_{GF}$	Void content (%)
L01	6 (GF_6)	4.1	1.25	0	19.9	19.9	1.34
L02	4 (SU_4)	5.5	1.02	28.1	0	28.1	2.02
L03	4 (SA_4)	5.5	1.03	30.9	0	30.9	1.89
L04	4 (SN_4)	5.5	1.02	31.0	0	31.0	1.88
L05	($GF_2/SU_2/GF_2$)	5.6	1.15	16.9	12.4	29.3	1.64
L06	($GF_2/SA_2/GF_2$)	5.6	1.16	17.2	12.8	30.0	1.55
L07	($GF_2/SN_2/GF_2$)	5.6	1.14	15.9	11.7	27.6	1.58

configuration and a constant number of sugar palm fibre and glass fibre layers were used. The slight variation indicates that with an increase in fibre volume fraction, the void content decreases. This trend was also reported in another research [41].

3.1.2. Water Absorption and Contact Angle Measurement. Water absorption curves of sugar palm and glass fibre-reinforced PP hybrid and nonhybrid composites are shown in Figure 4. The characteristic curves of the water absorption are in accordance with most water absorption studies found in the literatures [42, 43]. Initially, the curves show a linear relationship and slowly approaches the saturation point. This depicts Fick's curve characteristic which is similar to the moisture absorption curve of the sugar palm fibre-reinforced epoxy composite reported by Leman et al. [44]. Differences in weight gain amongst hybrid and nonhybrid composites due to the chemical treatments and incorporation of glass fibre were noticed. It was observed that the untreated SPF-reinforced PP composite (L02) recorded 9.32% of water absorption when immersed in distilled water for 43 days. But due to the alkali and sodium bicarbonate treatments, a decrease in water absorption by 18.7% and 11.9% for L03 and L04, respectively, was recorded. This is due to the removal of waxy substances and hemicellulose which subsequently leads to fewer voids in the composite as reported by Mir et al. [45]. Similarly, the incorporation of glass fibre with sugar palm fibre in PP to form a hybrid composite also decreases the water absorption. This shows that the sugar palm fibre is hydrophilic in nature which causes significant weight gain. At the same time, the weight gain causes swelling that leads to micro cracks which will further give an opening for the water to penetrate into the composite [46]. This finding has similar trends in water absorption with sugar palm fibre-reinforced thermoplastic polyurethane conducted by Atiqah et al. [47].

The measured contact angles of the samples were presented in Table 3. These quantitative contact angle data were varied due to both chemical treatments and hybridization which depict the hydrophilic and hydrophobic behaviour of the composites. Generally, the hydrophilicity of the composite is inversely proportional to the contact angle. This means that the higher the contact angle the more hydrophobic the composite is and vice and versa. This is also applicable to nanocomposite membranes as seen in the literatures [32, 48].

Amongst the contact angle data, the glass fibre-reinforced PP (L01) shows the highest contact angle of 98.3°. This indicates the hydrophobic nature of the glass fibre and the thermoplastic PP which was used as matrix. Furthermore, the alkaline- and sodium bicarbonate-treated SPF composites, i.e. L03 and L04, have an increased contact angle when compared to the untreated SPF composite (L02). This is due to increase in roughness of the treated SPF composites which was also seen in other findings [33, 49]. In the case of the hybrid composites, an intermediate value of the contact angle in the range of 83.4° to 89.1° was observed. This shows that SPF is hydrophilic in nature due to its structure, and, subsequently, its plays a major role on water absorption sensitivity [50].

3.2. Effect of the Fibre Treatments on the Mechanical Properties of the Composites

3.2.1. Tensile Properties. The results of the tensile test on the hybrid and nonhybrid composites of sugar palm- and glass fibre-reinforced PP with and without chemical treatments manufactured as laminate composites are presented in Table 4. As shown in the table, the tensile strength increases with both alkali and sodium bicarbonate treatments for the hybrid and nonhybrid composites. The increase is more pronounced with the alkaline-treated SPF composite (L03) which displayed the highest value of 61.75 MPa, while that of the sodium bicarbonate-treated SPF composite (L04) recorded 58.76 MPa against 53.01 MPa for the untreated SPF composite (L02). As well known, the increase in strength was due to structural changes as a result of chemical treatments as observed in other studies [51, 52]. This structural change leads to strong adhesion between the fibre and the PP matrix. Hence, there is an effective stress transfer from the matrix to the fibre. Another reason for the improved mechanical properties could be due to proper wetting of the fibre with polypropylene matrix as a result of the presence of PP film between the fibre mats. This was evidently proven in another research conducted by Attia et al. [39] who investigated the effect inter- and intra-PP film on the mechanical strength of the glass fibre-reinforced polypropylene composite. Also, rougher topography due to the removal of waxy and impurity substances could be the reasons for the qualitative interface that was achieved between the fibre and the matrix. For the tensile modulus, similar trends of the increase were

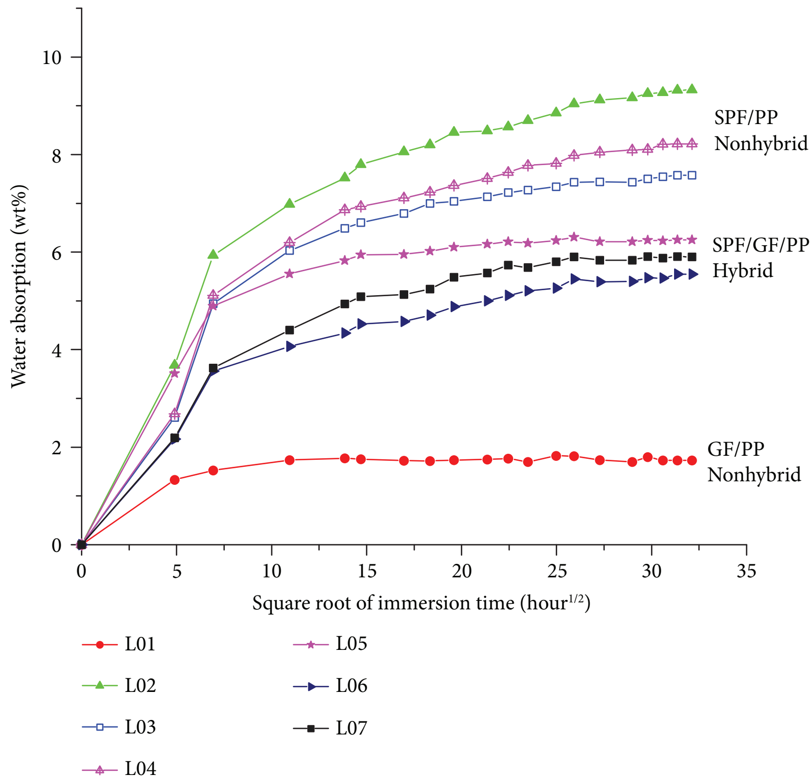

Figure 4: Water absorption of the hybrid and nonhybrid composites.

Table 3: Contact angle measurement of the nonhybrid and hybrid composites.

Laminates code	Stacking sequence	Contact angle (°)
L01	GF_6	98.3 ± 0.2
L02	SU_4	69.1 ± 0.9
L03	SA_4	76.2 ± 0.5
L04	SN_4	78.9 ± 0.6
L05	$GF_2/SU_2/GF_2$	83.4 ± 0.2
L06	$GF_2/SA_2/GF_2$	89.1 ± 0.3
L07	$GF_2/SN_2/GF_2$	87.7 ± 0.4

observed due to the chemical treatments and hybridizations. The tensile modulus for the untreated SPF/PP composite (L02) was low (1.80 GPa) in comparison with alkaline-treated SPF/PP (L03) and sodium bicarbonate-treated SPF/PP (L04) composites which registered 2.28 GPa and 2.06 GPa, respectively, whereas the incorporation of SPF and glass fibre causes brittleness in the PP matrix and hence the elongation percentage reduced by 52.8%. It is clear based on the tensile test results that alkaline treatment affects the properties of the composite in a more positive way when compared with sodium bicarbonate treatment. Though the problem of fibre degradation due to the high concentration of alkali can be minimized with sodium bicarbonate and at the same time the desired properties can be achieved. It is also noticed that the hybridization of sugar palm fibre with glass fibre significantly improves the overall mechanical performances of the composite. Furthermore, the benefits of the chemical treatments on the hybrid composites are readily apparent from the tensile results.

3.2.2. Flexural Properties. The chemical treatments of the sugar palm fibre with the alkali and sodium bicarbonate enhanced the flexural property of both the hybrid and non-hybrid composites. The analysis of the flexural properties of the composites is shown in Figure 5. The result of the bending test on the GF/PP composite shows a flexural strength of 127.58 MPa; this was presented for comparison purpose, and it is in agreement with the findings of Russo et al. [53] for the woven glass fibre-reinforced PP composite who reported a tensile strength of 129.6 MPa. The hybridization pays in terms of improved strength when compared with the SPF/PP composites, and it portrays considerable balanced in flexural properties amongst the GF/PP and SPF/PP composites. From the results of the hybrid composites with and without fibre chemical treatments, reasonable improvement was noticed for the flexural strength value by 25.2% from 86.54 MPa to 108.34 MPa for alkaline treatment and by 13.9% from 86.54 MPa to 98.55 MPa for sodium bicarbonate treatment. This result is comparable with the sisal/glass-reinforced polypropylene hybrid composite which was investigated by Birat et al. [54].

Also, due to alkali and sodium bicarbonate treatments on the SPF/PP single system composites, similar remarkable increase in flexural strength and its modulus were observed. Alkaline treatment increases the flexural strength of SPF/PP by 33.6% and flexural modulus by 51.2%, while sodium

Table 4: Tensile properties of the hybrid and nonhybrid composites.

Tensile properties	Neat PP	GF/PP	Nonhybrid SPF/PP			Hybrid (sandwich) $GF_2/SPF_2/GF_2$		
	L00	L01	L02	L03	L04	L05	L06	L07
Tensile strength (MPa)	37.28	172.80	53.01	61.75	58.76	95.66	96.71	96.64
Tensile modulus (GPa)	1.33	10.08	1.80	2.28	2.06	6.35	7.20	6.78
Elongation (%)	10.81	5.85	8.07	7.98	8.21	5.89	5.10	5.68

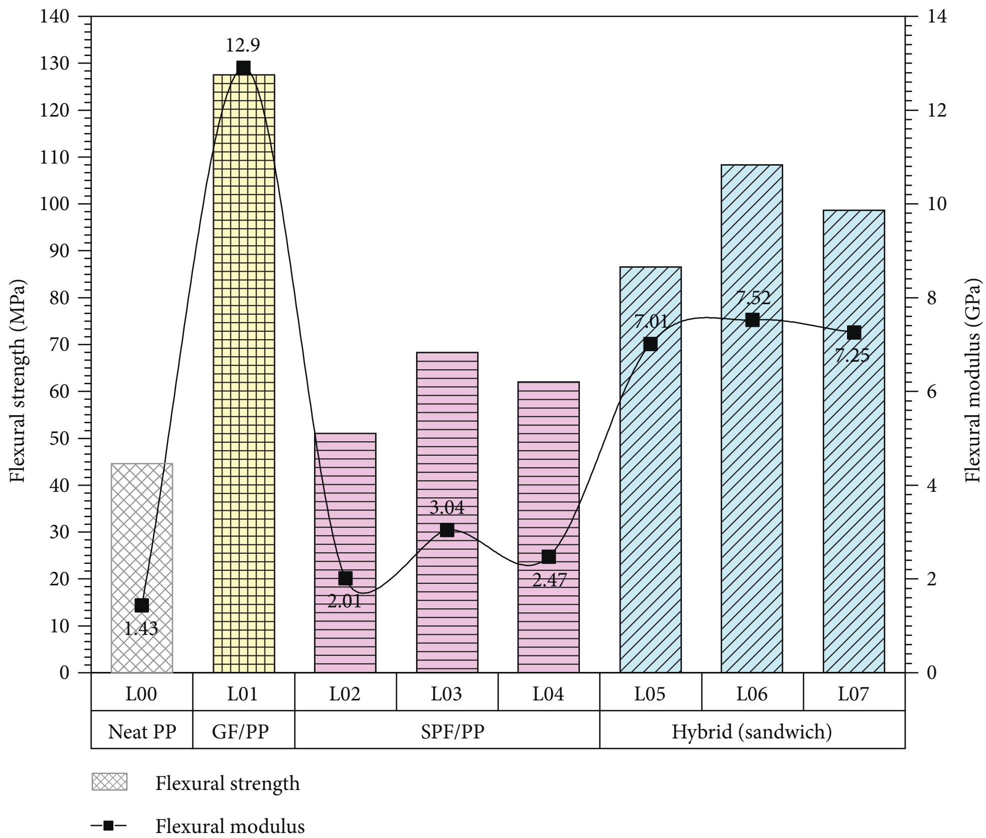

Figure 5: Flexural properties of the hybrid and nonhybrid composites.

bicarbonate treatment increases the flexural strength of SPF/PP by 21.2% and modulus by 22.9%. In both cases, the increase can be attributed to the partial removal of hemicellulose, wax, and disruption -OH bonding on the fibre thereby providing good adhesive bonding between the matrix and the fibre, while the low flexural strength recorded for the untreated fibre composite is due to weak interfacial bonding between the matrix and the fibre. This was equally seen in the fractured surface of the tensile specimen in the form of fibre pullout rather than fibre breakage which dissipates less energy compared to the latter.

3.2.3. Impact Strength. Impact strength test is another method for evaluating the interfacial adhesion between the treated and untreated fibre and the PP matrix. Figure 6 shows the impact test data measured from the nonhybrid and hybrid composites for the purpose of studying the effect of alkali and sodium bicarbonate as well as hybridizations with glass fibre. The incorporation of the glass fibre into the composite coupled with sugar palm fibre treatment tremendously increases the impact strength of the composite. The greatest improvement can be seen in a composite of alkaline-treated SPF with the incorporation of glass fibre, i.e., L06, which record an impact energy of 103.65 kJ/m^2. The hybridization remarkably improved the impact energy when compared with the nonhybrid composite (L03) with an impact energy of 20.36 kJ/m^2. For the nonhybrid composites, L03 and L04 composites show a high value of impact energy, which are 20.36 kJ/m^2 and 17.61 kJ/m^2, respectively, compared with L02 (16.37 kJ/m^2). As usual, the alkaline treatment yields better impact performance in comparison with sodium bicarbonate. The result of the alkaline-treated

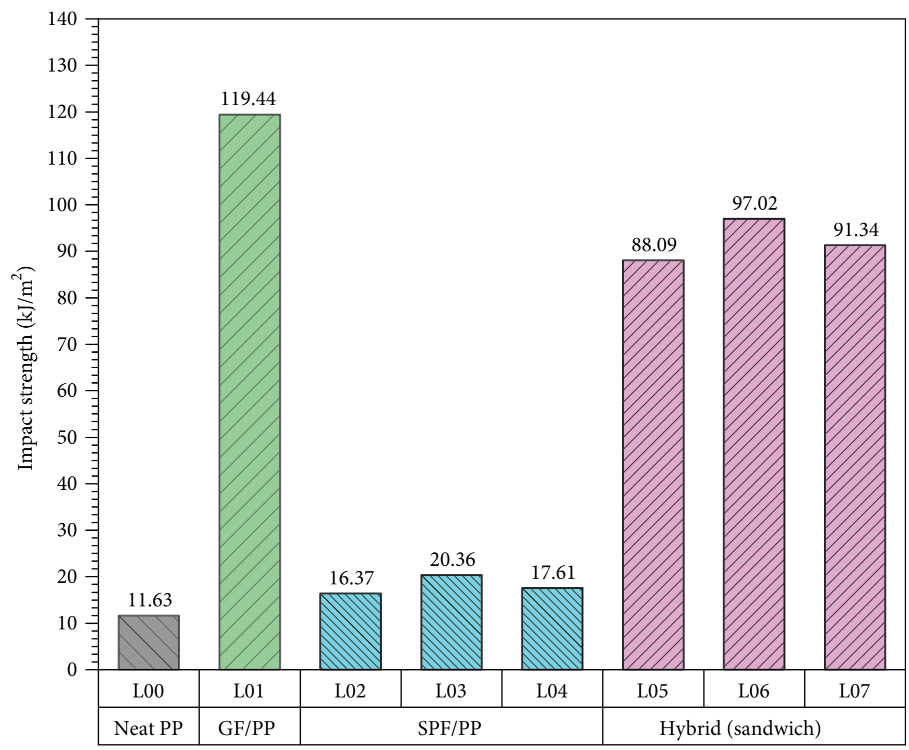

Figure 6: Impact energy of the hybrid and nonhybrid composites.

SPF-reinforced PP is much higher than the SPF-reinforced phenolic (7.28 kJ/m^2) investigated by Rashid et al. [55]. The increase can be attributed to the forms of the fibre (short/long/woven), type matrix, and/or manufacturing process used for the fabrication of the composites. The trend of the impact energy as observed in the nonhybrid composite of the SPF/PP system is in agreement with the literature such as the findings of Mutjé et al. [56] for the hemp-reinforced PP composite with impact strength of 12.0 kJ/m^2, sisal/PP 12.78 kJ/m^2 [18], and flax/PP 14.2 kJ/m^2 [57]. Due to the synergetic effect of both sugar palm fibre and glass fibre, approximately 90 kJ/m^2 impact strength was recorded for the hybrid composites. This shows positive hybrid effects of the composites.

It is important to note that interfacial bond strength is responsible for the kind of impact response that will be recorded. Usually, in a polymer composite, the impact energy is dissipated by fibre pullout, fibre or matrix fracture, and fibre debonding from the matrix. It is not surprising that treated fibre yields a high impact energy because fibre fracture was noticed due to strong adhesion, and it dissipates less energy when compared to other phenomena.

3.3. Fractured Surface Analysis of the Mechanical Test Specimens. On the morphological investigation, the focus will be on damage mechanisms such as the type of fibre failure, matrix cracking, and matrix-fibre debonding. Amongst these failure mechanisms, fibre failure is more common when compared to matrix cracking and fibre debonding. The surface roughness of the fibre reveals much information related to the interfacial bonding between fibre and matrix. Roughness can severely reduce molecular contact between the adjacent surfaces of the microfibrils depending on the matrix and the fibre used [58]. In this analysis, the researchers focused on single fibre surrounded with matrix, i.e., polypropylene. As detailed earlier, the fibres were treated with alkali and sodium bicarbonate. Closer looks at Figure 7(a), a composite of untreated SPF-reinforced PP (L02) had a poor interfacial adhesion as revealed by the presence of holes which arises due to fibre pullout. On the other hand, Figures 7(b) and 7(c), i.e., composites L03 and L04, are characterized with mostly fibre breakage which indicated good adhesion between the fibre and the matrix (polypropylene). It is clear from the SEM analysis that, just like alkali, sodium bicarbonate was able to modify the surface of the sugar palm fibre for better adhesion as evidently seen in another research [59].

4. Conclusions

A laminate composite based on sugar palm fibre, glass fibre, and polypropylene was manufactured by film stacking technique and hot compression moulding technique. The effect of the alkali and sodium bicarbonate on the physical and mechanical properties of the composite was assessed. It was observed that improvements in strength and stiffness combined with the high toughness of the hybrid and nonhybrid composites can be achieved by both alkali and sodium bicarbonate treatments. It is clear that the treatment has gone a long way in addressing the issue of matrix-fibre debonding as seen in the morphological examination. It is clear based on the tensile test that alkaline treatment affects the

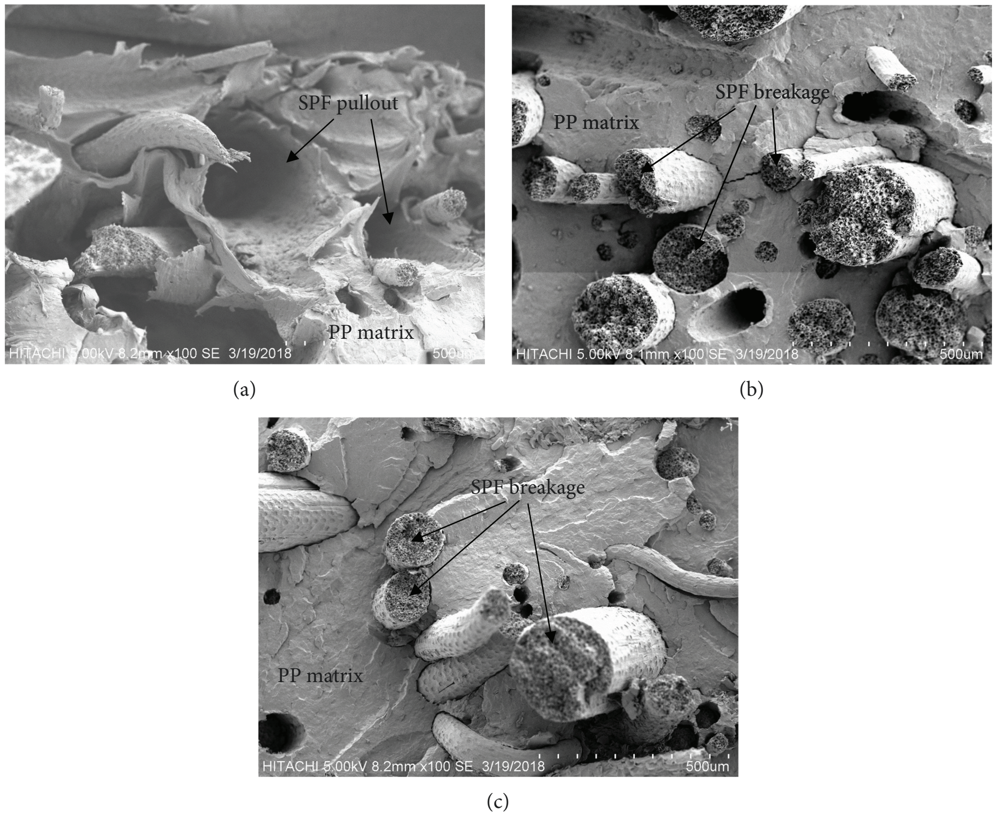

Figure 7: SEM micrographs of the nonhybrid composites of (a) untreated (L02), (b) alkaline-treated (L03), and (c) sodium bicarbonate-treated (L04) SPF-reinforced PP.

composite properties in a more positive way when compared with sodium bicarbonate treatment. Though the problem of fibre degradation due to a high concentration can be minimized with sodium bicarbonate. The improvement recorded in mechanical properties of the sodium bicarbonate-treated SPF is clearly comparable with that of the alkaline-treated SPF composite. In addition to the balanced flexural properties recorded for the hybrid composite, the system of the composite has recorded weight reduction and will equally enhance degradability and recyclability.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Acknowledgments

This research was supported and funded by the Universiti Putra Malaysia (UPM) through the Research University Grant Scheme (RUGS) with grant number (RUGS 9513500).

References

[1] M. L. Sanyang, S. M. Sapuan, M. Jawaid, M. R. Ishak, and J. Sahari, “Recent developments in sugar palm (*Arenga pinnata*) based biocomposites and their potential industrial applications: a review,” *Renewable and Sustainable Energy Reviews*, vol. 54, pp. 533–549, 2016.

[2] S. K. Garkhail, R. W. H. Heijenrath, and T. Peijs, “Mechanical properties of natural-fibre-mat-reinforced thermoplastics based on flax fibres and polypropylene,” *Applied Composite Materials*, vol. 7, no. 5-6, pp. 351–372, 2000.

[3] I. Mukhtar, Z. Leman, M. R. Ishak, and E. S. Zainudin, “Thermal and physicochemical properties of sugar palm fibre treated with borax,” *IOP Conference Series: Materials Science and Engineering*, vol. 368, no. 1, article 012038, 2018.

[4] M. Li, X. Yin, X. Zhou, and Q. Lin, “Surface treatment of single sisal fibers with bacterial cellulose and its enhancement in fiber-polymer adhesion properties,” *Composite Interfaces*, vol. 25, no. 9, pp. 839–853, 2018.

[5] H. Mohit and V. Arul Mozhi Selvan, “A comprehensive review on surface modification, structure interface and bonding mechanism of plant cellulose fiber reinforced polymer based composites,” *Composite Interfaces*, vol. 25, no. 5-7, pp. 629–667, 2017.

[6] D. U. Shah, P. J. Schubel, and M. J. Clifford, “Can flax replace e-glass in structural composites? A small wind turbine blade case study,” *Composites Part B: Engineering*, vol. 52, pp. 172–181, 2013.

[7] S. V. Joshi, L. T. Drzal, A. K. Mohanty, and S. Arora, “Are natural fiber composites environmentally superior to glass fiber

reinforced composites?," *Composites Part A: Applied Science and Manufacturing*, vol. 35, no. 3, pp. 371–376, 2004.

[8] K. L. Pickering, M. G. A. Efendy, and T. M. Le, "A review of recent developments in natural fibre composites and their mechanical performance," *Composites Part A: Applied Science and Manufacturing*, vol. 83, pp. 98–112, 2016.

[9] I. Mukhtar, Z. Leman, M. R. Ishak, and E. S. Zainudin, "Sugar palm fibre and its composites: a review of recent developments," *BioResources*, vol. 11, no. 4, pp. 10756–10782, 2016.

[10] M. E. González-López, J. R. Robledo-Ortíz, R. Manríquez-González, J. A. Silva-Guzmán, and A. A. Pérez-Fonseca, "Polylactic acid functionalization with maleic anhydride and its use as coupling agent in natural fiber biocomposites: a review," *Composite Interfaces*, vol. 25, no. 5-7, pp. 515–538, 2018.

[11] I. Mukhtar, Z. Leman, M. R. Ishak, and E. S. Zainudin, "Sugar palm fiber–reinforced polymer hybrid composites: an overview," in *Sugar Palm Biofibers, Biopolymers, and Biocomposites*, S. M. Sapuan, J. Sahari, M. R. Ishak, and M. L. Sanyang, Eds., pp. 145–164, CRC Press, 2018.

[12] M. R. Mansor, M. S. Salit, E. S. Zainudin, N. A. Aziz, H. Arep, and M. F. Alias, "A simplified life cycle analysis of an automotive parking brake lever using polymer composites," *Applied Mechanics and Materials*, vol. 699, pp. 395–400, 2014.

[13] A. B. A. Hariharan and H. P. S. A. Khalil, "Lignocellulose-based hybrid bilayer laminate composite: part I-studies on tensile and impact behavior of oil palm fiber-glass fiber-reinforced epoxy resin," *Journal of Composite Materials*, vol. 39, no. 8, pp. 663–684, 2005.

[14] H. M. Akil, I. M. De Rosa, C. Santulli, and F. Sarasini, "Flexural behaviour of pultruded jute/glass and kenaf/glass hybrid composites monitored using acoustic emission," *Materials Science and Engineering: A*, vol. 527, no. 12, pp. 2942–2950, 2010.

[15] K. Palanikumar, M. Ramesh, and K. Hemachandra Reddy, "Experimental investigation on the mechanical properties of green hybrid sisal and glass fiber reinforced polymer composites," *Journal of Natural Fibers*, vol. 13, no. 3, pp. 321–331, 2016.

[16] P. Pandey, D. Bajwa, C. Ulven, and S. Bajwa, "Influence of hybridizing flax and hemp-agave fibers with glass fiber as reinforcement in a polyurethane composite," *Materials*, vol. 9, no. 5, p. 390, 2016.

[17] S. Panthapulakkal and M. Sain, "Injection-molded short hemp fiber/glass fiber-reinforced polypropylene hybrid composites—mechanical, water absorption and thermal properties," *Journal of Applied Polymer Science*, vol. 103, no. 4, pp. 2432–2441, 2007.

[18] K. Jarukumjorn and N. Suppakarn, "Effect of glass fiber hybridization on properties of sisal fiber–polypropylene composites," *Composites Part B: Engineering*, vol. 40, no. 7, pp. 623–627, 2009.

[19] A. Atiqah, M. A. Maleque, M. Jawaid, and M. Iqbal, "Development of kenaf-glass reinforced unsaturated polyester hybrid composite for structural applications," *Composites Part B: Engineering*, vol. 56, pp. 68–73, 2014.

[20] M. M. Davoodi, S. M. Sapuan, D. Ahmad, A. Ali, A. Khalina, and M. Jonoobi, "Mechanical properties of hybrid kenaf/glass reinforced epoxy composite for passenger car bumper beam," *Materials & Design*, vol. 31, no. 10, pp. 4927–4932, 2010.

[21] G. Cicala, G. Cristaldi, G. Recca, G. Ziegmann, A. El-Sabbagh, and M. Dickert, "Properties and performances of various hybrid glass/natural fibre composites for curved pipes," *Materials & Design*, vol. 30, no. 7, pp. 2538–2542, 2009.

[22] S. Misri, Z. Leman, S. M. Sapuan, and M. R. Ishak, "Mechanical properties and fabrication of small boat using woven glass/-sugar palm fibres reinforced unsaturated polyester hybrid composite," *IOP Conference Series: Materials Science and Engineering*, vol. 11, no. 1, article 012015, 2010.

[23] I. Mukhtar, Z. Leman, E. S. Zainudin, and M. R. Ishak, "Effectiveness of alkali and sodium bicarbonate treatments on sugar palm fiber: mechanical, thermal, and chemical investigations," *Journal of Natural Fibers*, vol. 15, pp. 1–13, 2018.

[24] D. Bachtiar, M. S. Salit, E. Zainuddin, K. Abdan, and K. Z. H. M. Dahlan, "Effects of alkaline treatment and a compatibilizing agent on tensile properties of sugar palm fibre-reinforced high impact polystyrene composites," *BioResources*, vol. 6, no. 4, pp. 4815–4823, 2011.

[25] V. Fiore, T. Scalici, F. Nicoletti, G. Vitale, M. Prestipino, and A. Valenza, "A new eco-friendly chemical treatment of natural fibres: effect of sodium bicarbonate on properties of sisal fibre and its epoxy composites," *Composites Part B: Engineering*, vol. 85, pp. 150–160, 2016.

[26] M. J. Sharba, Z. Leman, M. T. Sultan, M. R. Ishak, and M. A. A. Hanim, "Effects of kenaf fiber orientation on mechanical properties and fatigue life of glass/kenaf hybrid composites," *BioResources*, vol. 11, no. 1, pp. 1448–1465, 2015.

[27] M. J. Sharba, Z. Leman, M. T. H. Sultan, M. R. Ishak, and M. A. A. Hanim, "Tensile and compressive properties of woven kenaf/glass sandwich hybrid composites," *International Journal of Polymer Science*, vol. 2016, Article ID 1235048, 6 pages, 2016.

[28] M. Zampaloni, F. Pourboghrat, S. A. Yankovich et al., "Kenaf natural fiber reinforced polypropylene composites: a discussion on manufacturing problems and solutions," *Composites Part A: Applied Science and Manufacturing*, vol. 38, no. 6, pp. 1569–1580, 2007.

[29] ASTM D792-13, *Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement*, ASTM International, West Conshohocken, PA, USA, 2013.

[30] S. B. R. Devireddy and S. Biswas, "Physical and mechanical behavior of unidirectional banana/jute fiber reinforced epoxy based hybrid composites," *Polymer Composites*, vol. 38, no. 7, pp. 1396–1403, 2017.

[31] D20 Committee, "Standard test method for water absorption of plastics," ASTM D570-98(2010)e1, ASTM International, 2010.

[32] D. P. Suhas, T. M. Aminabhavi, and A. V. Raghu, "Para-toluene sulfonic acid treated clay loaded sodium alginate membranes for enhanced pervaporative dehydration of isopropanol," *Applied Clay Science*, vol. 101, pp. 419–429, 2014.

[33] D. P. Suhas, T. M. Aminabhavi, H. M. Jeong, and A. V. Raghu, "Hydrogen peroxide treated graphene as an effective nanosheet filler for separation application," *RSC Advances*, vol. 5, no. 122, pp. 100984–100995, 2015.

[34] D. P. Suhas, T. M. Aminabhavi, and A. V. Raghu, "Mixed matrix membranes of H-ZSM5-loaded poly (vinyl alcohol) used in pervaporation dehydration of alcohols: influence of silica/alumina ratio," *Polymer Engineering & Science*, vol. 54, no. 8, pp. 1774–1782, 2014.

[35] D30 Committee, "Standard test method for tensile properties of polymer matrix composite materials," ASTM D3039 / D3039M-14, ASTM International, 2014.

[36] D20 Committee, "Standard test method for tensile properties of plastics," ASTM D638-14, ASTM International, 2014.

[37] D20 Committee, "Standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials," ASTM D790-15e2, ASTM International, 2015.

[38] D20 Committee, "Standard test methods for determining the Izod pendulum impact resistance of plastics," ASTM D256-10e1, ASTM International, 2010.

[39] M. Attia, M. Abd El-baky, and A. Alshorbagy, "Mechanical performance of intraply and inter-intraply hybrid composites based on e-glass and polypropylene unidirectional fibers," *Journal of Composite Materials*, vol. 51, no. 3, pp. 381–394, 2016.

[40] D. U. Shah, P. J. Schubel, P. Licence, and M. J. Clifford, "Determining the minimum, critical and maximum fibre content for twisted yarn reinforced plant fibre composites," *Composites Science and Technology*, vol. 72, no. 15, pp. 1909–1917, 2012.

[41] R. Meier, I. Kahraman, A. T. Seyhan, S. Zaremba, and K. Drechsler, "Evaluating vibration assisted vacuum infusion processing of hexagonal boron nitride sheet modified carbon fabric/epoxy composites in terms of interlaminar shear strength and void content," *Composites Science and Technology*, vol. 128, pp. 94–103, 2016.

[42] C.-M. Wu, W.-Y. Lai, and C.-Y. Wang, "Effects of surface modification on the mechanical properties of flax/β-polypropylene composites," *Materials*, vol. 9, no. 5, p. 314, 2016.

[43] D. Ariawan, M. S. Salim, R. M. Taib, M. Z. A. Thirmizir, and Z. A. M. Ishak, "Interfacial characterisation and mechanical properties of heat treated non-woven kenaf fibre and its reinforced composites," *Composite Interfaces*, vol. 25, no. 2, pp. 187–203, 2017.

[44] Z. Leman, S. M. Sapuan, A. M. Saifol, M. A. Maleque, and M. M. H. M. Ahmad, "Moisture absorption behavior of sugar palm fiber reinforced epoxy composites," *Materials & Design*, vol. 29, no. 8, pp. 1666–1670, 2008.

[45] S. S. Mir, N. Nafsin, M. Hasan, N. Hasan, and A. Hassan, "Improvement of physico-mechanical properties of coir-polypropylene biocomposites by fiber chemical treatment," *Materials & Design*, vol. 52, pp. 251–257, 2013.

[46] Y. Dan-mallam, T. W. Hong, and M. S. Abdul Majid, "Mechanical characterization and water absorption behaviour of interwoven kenaf/pet fibre reinforced epoxy hybrid composite," *International Journal of Polymer Science*, vol. 2015, Article ID 371958, 13 pages, 2015.

[47] A. Atiqah, M. Jawaid, M. R. Ishak, and S. M. Sapuan, "Moisture absorption and thickness swelling behaviour of sugar palm fibre reinforced thermoplastic polyurethane," *Procedia Engineering*, vol. 184, pp. 581–586, 2017.

[48] S. P. Dharupaneedi, R. V. Anjanapura, J. M. Han, and T. M. Aminabhavi, "Functionalized graphene sheets embedded in chitosan nanocomposite membranes for ethanol and isopropanol dehydration via pervaporation," *Industrial & Engineering Chemistry Research*, vol. 53, no. 37, pp. 14474–14484, 2014.

[49] K. J. Kubiak, M. C. T. Wilson, T. G. Mathia, and P. Carval, "Wettability versus roughness of engineering surfaces," *Wear*, vol. 271, no. 3-4, pp. 523–528, 2011.

[50] L. Calabrese, V. Fiore, T. Scalici, and A. Valenza, "Experimental assessment of the improved properties during aging of flax/-glass hybrid composite laminates for marine applications," *Journal of Applied Polymer Science*, vol. 136, article 47203, 2019.

[51] V. Fiore, T. Scalici, and A. Valenza, "Effect of sodium bicarbonate treatment on mechanical properties of flax-reinforced epoxy composite materials," *Journal of Composite Materials*, vol. 52, no. 8, pp. 1061–1072, 2018.

[52] O. M. L. Asumani, R. G. Reid, and R. Paskaramoorthy, "The effects of alkali–silane treatment on the tensile and flexural properties of short fibre non-woven kenaf reinforced polypropylene composites," *Composites Part A: Applied Science and Manufacturing*, vol. 43, no. 9, pp. 1431–1440, 2012.

[53] P. Russo, D. Acierno, G. Simeoli, S. Iannace, and L. Sorrentino, "Flexural and impact response of woven glass fiber fabric/-polypropylene composites," *Composites Part B: Engineering*, vol. 54, pp. 415–421, 2013.

[54] K. Birat, S. Panthapulakkal, A. Kronka, J. A. M. Agnelli, J. Tjong, and M. Sain, "Hybrid biocomposites with enhanced thermal and mechanical properties for structural applications," *Journal of Applied Polymer Science*, vol. 132, no. 34, 2015.

[55] B. Rashid, Z. Leman, M. Jawaid, M. J. Ghazali, and M. R. Ishak, "Influence of treatments on the mechanical and thermal properties of sugar palm fibre reinforced phenolic composites," *BioResources*, vol. 12, no. 1, pp. 1447–1462, 2017.

[56] P. Mutjé, M. E. Vallejos, J. Gironès et al., "Effect of maleated polypropylene as coupling agent for polypropylene composites reinforced with hemp strands," *Journal of Applied Polymer Science*, vol. 102, no. 1, pp. 833–840, 2006.

[57] T. J. Keener, R. K. Stuart, and T. K. Brown, "Maleated coupling agents for natural fibre composites," *Composites Part A: Applied Science and Manufacturing*, vol. 35, no. 3, pp. 357–362, 2004.

[58] M. A. Hubbe, "Bonding between cellulosic fibers in the absence and presence of dry-strength agents–a review," *BioResources*, vol. 1, no. 2, pp. 281–318, 2007.

[59] Z. Sun, L. Zhang, D. Liang, W. Xiao, and J. Lin, "Mechanical and thermal properties of PLA biocomposites reinforced by coir fibers," *International Journal of Polymer Science*, vol. 2017, Article ID 2178329, 8 pages, 2017.