

MECHANICAL PROPERTIES OF GIGANTOCHLOA SCORTECHINII BAMBOO PARTICLE REINFORCED SEMIRIGID POLYVINYL CHLORIDE COMPOSITES

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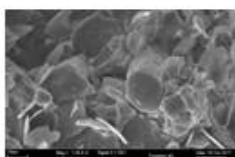
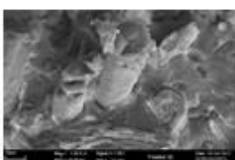
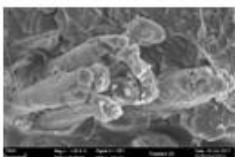
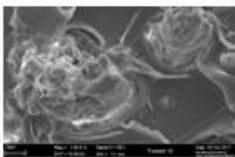
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Graphical abstract



Abstract

This investigation aims to study the mechanical properties of the bamboo particle (BP) (*Gigantochloa scortechinii*) reinforced with semirigid Polyvinyl Chloride (PVC) composites before and after the steam explosion (SE)-alkali treatment. Mechanical properties, namely, tensile, flexural and impact strengths, were determined using universal tensile and impact testing machines according to ASTM standard. The tensile and flexural strengths of the composites were improved after SE-alkali treatment. Results indicated that the tensile and flexural strengths of the composites increased and reached the optimum values of 17.42 and 11.86 MPa, respectively for SE-alkali treatment BP reinforced semirigid PVC with 40 wt% particle content. The impact strength of SE-alkali-treated composites was unimproved due to less dense and rigid particle.

Keywords: Alkali treatment, bamboo particle, polyvinyl chloride, steam explosion, mechanical properties

Abstrak

Tujuan kajian ini adalah untuk mengkaji sifat-sifat mekanikal komposit Polivinil klorida (PVC) separa tegar diperkuat partikel buluh *Gigantochloa scortechinii* sebelum dan selepas rawatan letupan stim (SE)-alkali. Sifat-sifat mekanikal iaitu kekuatan tegangan, lenturan dan hentaman ditentukan melalui mesin ujian tegangan universal dan mesin ujian hentaman mengikut piawaian ASTM. Didapati bahawa kekuatan tegangan dan kekuatan lenturan semakin meningkat selepas rawatan SE-alkali. Keputusan kajian menunjukkan setiap nilai kekuatan tegangan dan kekuatan lenturan telah mencapai nilai optimum iaitu sebanyak 17.42 dan 11.86 MPa bagi komposit PVC separa tegar diperkuat partikel buluh yang dirawat SE-alkali pada kandungan 40% berat partikel buluh. Tiada peningkatan berlaku pada kekuatan hentaman selepas rawatan SE-alkali kerana faktor partikel berkepadatan rendah serta tegar.

Kata kunci: Rawatan alkali, partikel buluh, polivinil klorida, letupan stim, sifat-sifat mekanikal

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1.0 INTRODUCTION

The use of natural fibres as reinforcement for composite has increased due to their excellent properties and environmental friendliness. Natural fibres are considered a potential replacement of glass fibres for use in composite materials because of their advantages, such as flexibility, stiffness, renewability, lightweight, low density, low abrasion, biodegradability, multifunctionality, unlimited availability, low cost and easy/no waste disposal [1], [2]. Natural fibre–polymer composites show better mechanical, physical and thermal properties than those of pure polymers [3]. However, many factors should be considered when using natural fibre; these factors include incompatibility between fibre and polymer due to polarity, high level of moisture absorption, poor wettability and inadequate level of adhesion between untreated fibre and nonpolar polymer which leads to a weak interface between fibre and matrix [4-5]. The poor adhesion between fibre and matrix indirectly hinder stress transfer in composites [6]. The previous study [7] observed many small voids and broken fibres, thereby indicating the weak adhesion between fibre and matrix in the case of sugarcane bagasse fibre-filled Polyamide 6. The weak adhesion between fibre and matrix caused the fibre pulled out during fracture instead of fibre breakage. Most of the natural fibres possess highly hydrophilic nature due to the presence of hydroxyl groups in lignocellulosic structure [8]. Previous research has used many techniques in modifying the surface properties of natural fibre to enhance the adhesion between matrix and natural fibre; these techniques include acetylation and stearation [1], alkali [9], chitosan [10], sulfuric acid [11], silane coupling agent [12] and SE [6].

A variety of natural fibres, such as kenaf, sugar palm, bamboo, sisal, flax, pineapple leaf and roselle, have been investigated. Bamboo presents excellent mechanical properties because of its weight and longitudinally aligned fibres in the body [13]. The specific mechanical properties of bamboo are also comparable to those of glass and has been proven by previous research [14] which shows that by using (25% bamboo and 75% glass fibre)/composites compared to 100% glass fibre/unsaturated polyester resin composites have the same mechanical properties while can reduce the density of the composites by 13%. The advantages of bamboo fibres, such as biodegradability, sustainability, recyclability, good mechanical properties and low cost, enable their use in composites. The Young's modulus of bamboo fibre is higher than those of jute and coir with values of 35.45, 28.43 and 3.97 Gpa respectively [15]. Several studies [16-18] have shown that bamboo displays considerably good potential for reinforcing thermoplastic composites; it is also a promising substitute for wood polymer composites. The bamboo fibre composites prepared via SE treatment exhibited higher tensile strength

compared with the same composites via mechanical extraction and alkali treatment [19].

PVC has begun to attract wood plastic composite manufacturers due to its low-cost thermoplastic, excellent physical properties, good dimensional stability, good processing ability and weathering resistance [20]. Additives, such as stabilisers, processing aids and lubricants, are typically needed to improve the processing ability and stability of PVC composites to avoid degradation caused by thermal history, residual solvents and irregularities in polymer structure [20]. A semirigid PVC is flexible PVC where plasticizer used as the main additives, thus resulting in increased freedom of molecular movement [21] in PVC. Plasticiser is used in plastics and elastomers to increase its flexibility, workability or extensibility [22]. PVC has been used in previous research because of its high flexural strength, flexural modulus and compressive strength [23].

The present work aimed to prepare bamboo particle (BP) reinforced semirigid PVC composites. The bamboo particles (BPs) were initially treated with SE and subsequently with alkali. The SE is a physical treatment method in producing fibres, because it involves hot steam with high temperature (180 -240 °C) and high pressure (1-3.5 MPa), followed by explosive decompression which results in cellulose bundles break and defibrillates [24]. The alkaline treatment is a chemical treatment in which the natural fibres are immersed in an aqueous sodium hydroxide (NaOH) to remove lignin and hemicellulose [25]. Afterwards, the untreated and SE–alkali-treated BP reinforced semirigid PVC composites were formed with 10 wt%, 20 wt%, 30 wt% and 40 wt% particle content. Hereafter, the two kinds of composites were referred to as untreated BP-reinforced semirigid PVC composites (untreated BP/semirigid PVC) and SE–alkali-treated BP-reinforced semirigid PVC composites (SE–alkali BP/semirigid PVC). In order to analyze the mechanical properties, the tensile test, flexural test and impact test were used respectively. The mechanical properties and fracture surfaces of the composites and the effects of the treatments and particle contents were investigated.

2.0 METHODOLOGY

2.1 Materials

The materials used in this study are BP, PVC, plasticiser, tin stabiliser and stearic acid. BPs from a three-year-old *Gigantochloa scortechinii* were obtained from the Forest Research Institute Malaysia (FRIM) in Kepong, Selangor, Malaysia. PVC, plasticiser, tin stabiliser and stearic acid were supplied by Innovative Pultrusion Sdn. Bhd., Seremban, Negeri Sembilan, Malaysia. Table 1 shows the semirigid PVC composition [26].

Table 1 Composition of Semirigid PVC

Ingredients	Concentration (phr)
PVC $M_n = 4000$	-
Plasticiser (diethylhexyl phthalate)	30
Tin stabiliser	4.5
Lubricant (stearic-acid-based compound)	1.5

2.2 Method

2.2.1 Processing of BPs

The branches and leaves of the bamboo were removed and the remaining parts were taken, and then cut it into pieces with approximately 5 cm length. The samples were dried at room temperature for 3 days prior to crushing by a string crusher machine, and grinding by a ball mill for 24 h. The sizes of the BPs after milled are 45-180 μm . Subsequently, the BPs were treated with SE at a pressure of 7 bar, a temperature of 160 °C and time of 30 min. Afterwards, SE BPs were soaked in 5% sodium hydroxide for 30 min [27]. The treated particles were thoroughly rinsed with distilled water until the pH of the particles became neutral (pH 7). The particles were oven dried at 103 °C for 24 h to eliminate moisture completely [28]. Figure 1 shows the untreated, SE and SE-alkali-treated BPs.



Figure 1 Conditions of (a) Untreated BP, (b) SE BP and (c) SE-alkali treated BP

2.2.2 Fabrication of Composites

The compression moulding technique was used for the fabrication of composites. The composites with 0 wt%, 10 wt%, 20 wt%, 30 wt% and 40 wt% of BP reinforced semirigid PVC were fabricated. Then, the PVC, plasticiser, tin stabiliser, stearic acid and BP were mixed by the hot-internal-mixer-type Brabender plastograph with a temperature of 170 °C, rotor speed of 50 rpm and time of 20 min (PVC compound mixing for 5 min and subsequent BP mixing for another 15 min). Afterwards, the samples were crushed by a crusher machine to decrease the composite sample size. The crushed composite samples were dried in a vacuum oven for 24 h at 70 °C before pressing to remove the moisture content. The crushed samples were hot pressed at a pressure of 20 tonnes, a temperature of 190 °C and time of 10

min (2 min, preheating; 3 min, contact temperature; 5 min, cooling).

2.2.3 Tensile Test

The tensile test was conducted according to ASTM D-638. The test was carried out on five specimens using a universal testing machine (Instron) with a 3 tonne load cell; the crosshead speed was maintained at 5 mm/min. The specimens for tensile testing semirigid PVC and composites were cut using a mill cutter to produce specimens following ASTM D638 which is in a dumbbell shape. The average tensile strength and tensile modulus values for five specimens were recorded.

2.2.4 Flexural Test

A three-point bending flexural test according to the ASTM D-790 standard was performed on five specimens using a universal testing machine (Instron). The crosshead speed was maintained at 5 mm/min. The hot pressed samples with 3 mm thickness were cut using the band saw machine to obtain rectangular shapes with specimens dimensions 127 mm \times 13 mm \times 3 mm. The average values for flexural strength and flexural modulus for five specimens were recorded.

2.2.5 Impact Test

The Izod impact test according to the ASTM D-256 standard was conducted on five specimens using the Zwick Roell impact testing machine. The hot pressed samples with 3 mm thickness were cut using the band saw machine to obtain rectangular shapes with specimens dimensions 127 mm \times 13 mm \times 3 mm. The average values impact strength and impact energy values for five specimens were recorded.

2.2.6 Morphology

The morphology of the fractured tensile samples was examined under a scanning electron microscope (Model VPSEM LEO 1450).

3.0 RESULT AND DISCUSSION

3.1 Tensile Properties

Figure 2 and 3 illustrate the tensile strength and tensile modulus of untreated and SE-alkali-treated BP/semirigid PVC composites with different particle contents (0 wt%, 10 wt%, 20 wt%, 30 wt% and 40 wt%), respectively. The highest tensile strength values of untreated BP/semirigid PVC in sequence are 17.11, 13.66, 11.84, 10.20 and 9.98 MPa for 0 wt%, 10 wt%, 20 wt%, 30 wt% and 40 wt% particle contents, respectively. The standard deviation of the tensile strength for untreated BP/semirigid PVC follow these

sequences are 1.07, 0.92, 0.24, 0.64 and 0.46. These results indicated a decrease in tensile strength with increased particle content. The highest strength values of SE-alkali-treated BP/semirigid PVC in sequence are 17.42, 17.11, 15.17, 12.01 and 10.97 MPa for 40 wt%, 0 wt%, 20 wt%, 10 wt% and 30 wt% particle contents, respectively. Meanwhile, the standard deviation for the tensile strength SE-alkali-treated BP/semirigid PVC in the sequence are 1.07, 1.09, 0.56, 0.64 and 0.75. These results showed that SE-alkali-treated BP/semirigid PVC with 30 wt% particle content possesses the lowest tensile strength. The tensile strength of SE-alkali-treated BP/semirigid PVC is higher than those of untreated BP/semirigid PVC and semirigid PVC (neat), with the values of 17.42, 13.661 and 17.11 MPa for 40 wt%, 10 wt% and 0 wt% fibre contents, respectively. This showed that the tensile strength of SE-alkali-treated BP/semirigid PVC at 40 wt% increased 2% compared to semirigid PVC (0 wt%). While at lower bamboo particle content (10 wt%) shows that tensile strength of untreated BP/semirigid PVC and SE-alkali-treated BP/semirigid PVC decreased with 20% and 30% compared to semirigid PVC (0 wt%) respectively. The previous study [29] shows that the decreased of tensile strength at lower fibre content are because the effect of crack initiation was more dominant as compared to the effect of crack inhibition and reduction in area that participates in the transfer of the loading stresses. The highest tensile modulus values of untreated BP/semirigid PVC in the sequence are 222.23, 218.79, 155.48, 147.66 and 4.4 MPa for 40 wt%, 20 wt%, 10 wt%, 30 wt% and 0 wt% particle contents, respectively. The standard deviations of the tensile modulus for untreated BP/semirigid PVC are 27.94, 10.22, 15.48, 18.98 and 0.53 sequentially. The highest tensile modulus values of SE-alkali-treated BP/semirigid PVC in the sequence are 564.562, 340.89, 147.72, 78 and 4.4 MPa for 40 wt%, 20 wt%, 30 wt%, 10 wt% and 0 wt% particle contents, respectively. The standard deviation of the tensile modulus for SE-alkali-treated BP/semirigid PVC follow these sequences are 38.49, 21.78, 23.99, 12.08 and 0.53. The tensile modulus of SE-alkali-treated BP/semirigid PVC with 40 wt% particle content (i.e. 564.56 MPa) is higher than that of untreated BP/semirigid PVC with 40 wt% particle content (i.e. 222.23 MPa). The effects of SE-alkali treatment on interfacial adhesion and sample properties were elucidated by investigating the morphology of fracture surfaces. Figure 4 shows the fracture surface morphologies of untreated BP/semirigid PVC and SE-alkali-treated BP/semirigid PVC with 10 wt%, 20 wt%, 30 wt% and 40 wt% particle contents.

The factors controlling the composite strengths are interface adhesion between fibre and matrix, hydrogen bonding, fibre size, stress-strain transfer between fibre and matrix and fibre dispersion [6,30]. The tensile strength and tensile modulus of SE-alkali-treated BP/semirigid PVC is higher than that of untreated BP/semirigid PVC; this result is consistent with that reported in [6] because of the small sizes

and large surface areas of the particles which can interact with the matrix. The increased tensile strength and tensile modulus may be due to the good adhesion between the particle and the matrix (Figure 4h). The surface roughness of SE-alkali-treated BPs is higher than that of untreated BPs; this result is also in agreement with that reported in a previous study [9], in which alkali treatment on sawdust increases the surface roughness of sawdust and indirectly enhances the compatibility between fibre and matrix.

Microscopic study on the fracture surfaces of poly(3-hydroxybutyrate-co-3-hydroxyvalerate)/bamboo pulp fibre without treatment demonstrated fibre pullout, thereby indicating insufficient interfacial adhesion between the fibre and the matrix [31]; this result can also be observed in Figure 4b. The improved interfacial adhesion enables high stress transfer between particle and matrix and reduces the possibility of particle bonding. A previous study [32-33] reported that tensile strength, tensile modulus and flexural strength are increased when the particle weight ratio initially increases until the optimal level and subsequently decreases.

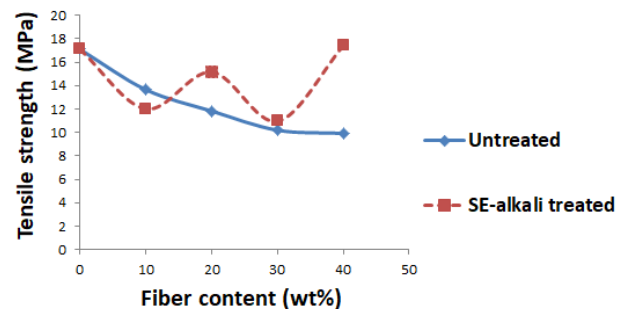


Figure 2 Tensile strength of untreated and SE-alkali-treated BP/semirigid PVC composites

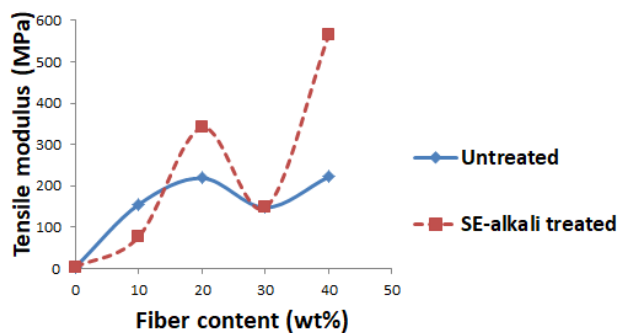


Figure 3 Tensile modulus of untreated and SE-alkali-treated BP/semirigid PVC composites

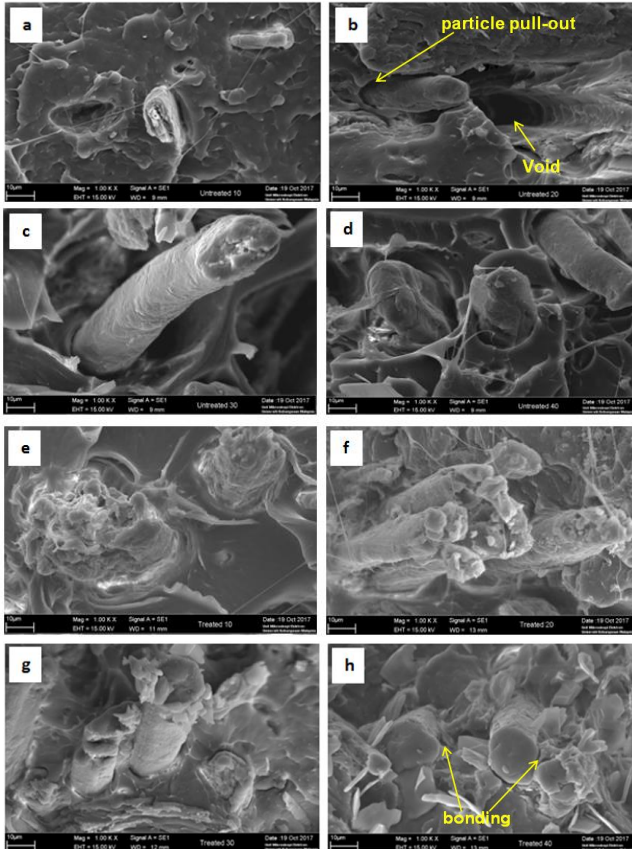


Figure 4 Fracture surfaces of (a) untreated BP with 10 wt%, (b) 20 wt%, (c) 30 wt% and (d) 40 wt% particle content/semirigid PVC composites; (e) SE-alkali-treated BP with 10 wt%, (f) 20 wt% and (g) 30 wt% and (h) SE-alkali-treated BP with 40 wt% particle content /semirigid PVC composites

3.2 Flexural Properties

Figure 5 and 6 display the flexural strength and flexural modulus of untreated BP/semirigid PVC and SE-alkali treated BP/semirigid PVC with different particle contents (0 wt%, 10 wt%, 20 wt%, 30 wt% and 40 wt%). The flexural strength values for untreated BP/semirigid PVC follow these sequences are 2.99, 7.14, 7.45, 9.18 and 10.25 MPa which the standard deviation are 0.2, 0.71, 0.62, 0.38 and 1.15. The flexural strength values for SE-alkali-treated BP/semirigid PVC that also follow these sequence are 2.99, 5.27, 5.32, 7.36 and 11.86 MPa which the standard deviation are 0.2, 0.26, 0.32, 0.43 and 0.74. The flexural modulus of the untreated BP/semirigid PVC are 113.72, 312.74, 333.52, 443.63 and 500.44 MPa with standard deviation 4.38, 37.75, 26.70, 25.18 and 35.65 for 0 wt%, 10 wt%, 20 wt%, 30 wt% and 40 wt% particle content, respectively. While the flexural modulus of the SE-alkali-treated BP/semirigid PVC are 113.72, 216.99, 222.70, 329.59 and 556.35 MPa with standard deviation 4.38, 18.28, 24.28, 28.55 and 34.67 for 0 wt%, 10 wt%, 20 wt%, 30 wt% and 40 wt% particle content, respectively. Results showed that flexural strength and flexural modulus increased with increased particle contents. The 40 wt% particle content presents

the highest flexural strengths of 10.25 and 11.86 MPa for untreated and SE-alkali-treated BP/semirigid PVC, respectively. Both of it increased by 242 % and 296 % compared to semirigid PVC (0 wt%), respectively. These results showed that the flexural strength of SE-alkali-treated composite is higher than that of untreated BP/semirigid PVC with 40 wt% particle content. The highest flexural modulus values of untreated and SE-alkali-treated BP/semirigid PVC composites with 40 wt% particle content are 500.44 and 556.35 MPa, respectively. These results also showed that the flexural modulus of SE-alkali-treated BP/semirigid PVC is higher than that of untreated BP/semirigid PVC with 40 wt% particle content. The flexural strength of untreated BP/semirigid PVC is higher than that of SE-alkali-treated BP/semirigid PVC with 10 wt%, 20 wt% and 30 wt% particle contents. The flexural modulus of untreated BP/semirigid PVC composite is also higher than that of SE-alkali-treated BP/semirigid PVC with 10 wt%, 20 wt% and 30 wt% particle contents.

The flexural modulus of SE-alkali-treated BP/semirigid PVC at 10 wt%, 20 wt% and 30 wt% is lower compared to untreated BP/semirigid PVC because the bamboo particle is likely to be less dense after SE-alkali treatment due to removal of hemicellulose and lignin [34]. The high flexural strength and flexural modulus at 40 wt% particle content can be attributed to that the particles and the matrix display good adhesion and good wettability [35]. These findings can be proven with observations on SE-alkali-treated BP/semirigid PVC after fracture in Figure 4h which shows that a matrix still exists on the particle surface. The low flexural strength and flexural modulus may be caused by poor bonding at low particle content [35]. High rigidity, large interface area, stiffness, uniform distribution and fibre dispersion improve the flexural strength and flexural modulus of the composites with efficient stress transfer via the interface [36–37]. Study results reported in [38] are consistent with those of SE-alkali treatment, in which the flexural strength and flexural modulus increase with the increased particle content because of the improved phase compatibility between the particle and the matrix after SE-alkali treatment on the particle; consequently, the hydroxyl group is reduced. The internal structure of the fibre cell walls also provides stability to the composites [39]. The previous study reported that the decreased flexural properties and impact energy of microfibril bamboo fibre-reinforced polylactic acid composites with approximately 40 wt% fibre content are due to the decreased specific gravity of the composites [40]. The composites exhibit good mechanical properties in terms of tensile and flexural strengths because of the good compatibility of particle/matrix loading [3].

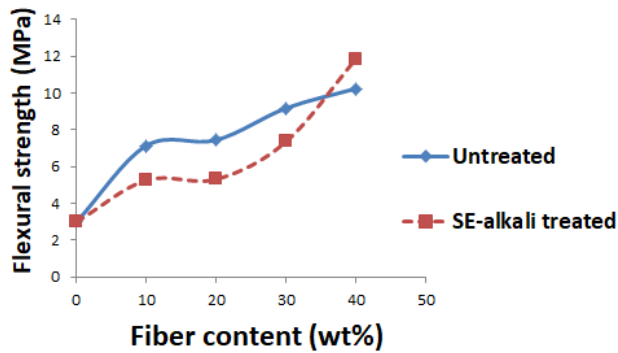


Figure 5 Flexural strength of untreated and SE-alkali-treated BP/semirigid PVC composites

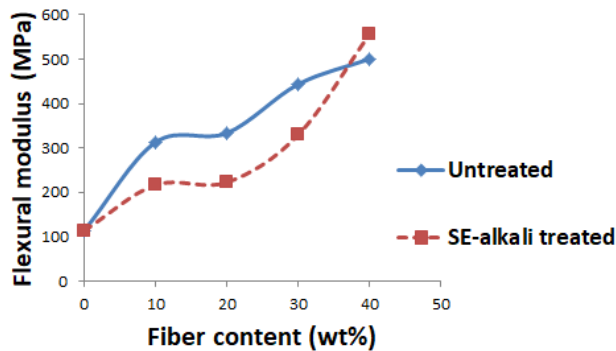


Figure 6 Flexural modulus of untreated and SE-alkali-treated BP/semirigid PVC composites

3.3 Impact Properties

Impact strength is the energy required to break specimens, and a v-notch is used to create an initial stress point. The impact strength and impact energy of untreated BP/semirigid PVC and SE-alkali-treated BP/semirigid PVC are shown in Figure 7 and 8, respectively. The impact strength of the untreated BP/semirigid PVC are 186.80, 137.05, 66.35, 60.65 and 49.66 kJ/m² with standard deviation 13.67, 71.58, 16.12, 18.02 and 8.49 for 0 wt%, 10 wt%, 20 wt%, 30 wt% and 40 wt% particle contents respectively. The impact strength of the SE-alkali-treated BP/semirigid PVC are 186.8, 12.67, 8.83, 31.37 and 13.12 kJ/m² with standard deviation 13.67, 2.96, 2.43, 10.56, and 8.77 for 0 wt%, 10 wt%, 20 wt%, 30 wt% and 40 wt% particle contents respectively. The energy of the untreated BP/semirigid PVC are 5.60, 4.11, 1.99, 1.82 and 1.62 J with standard deviation 0.41, 2.15, 0.48, 0.54 and 0.16 for 0, 10, 20, 30 and 40 wt% particle contents respectively. The energy for SE-alkali-treated BP/semirigid PVC are 5.60, 0.38, 0.27, 0.94 and 0.39 with standard deviation 0.41, 0.09, 0.07, 0.32 and 0.26 for 0 wt%, 10 wt%, 20 wt%, 30 wt% and 40 wt% particle contents respectively. The impact strength of untreated BP/semirigid PVC decreases with the increase in particle content; the values for 10 wt%, 20 wt%, 30 wt% and 40 wt% particle contents are 137.05, 66.35, 60.45 and 49.66 MPa, respectively. The impact strength of SE-alkali-treated BP/semirigid PVC

initially decreases with the increase in particle contents and subsequently increases; the values for 10 wt%, 20 wt% and 30 wt% particle contents are 12.67, 8.83 and 31.37 MPa, respectively. Afterwards, the impact strength of SE-alkali-treated BP/semirigid PVC with 40 wt% particle content decreases (i.e. 13.12 MPa). This result showed that the highest impact strengths of untreated and treated BP/semirigid PVC with 10 wt% and 30 wt% particle contents are 137.05 and 31.37 MPa, respectively. Overall, the impact strength of untreated BP/semirigid PVC composites is higher than that of SE-alkali-treated BP/semirigid PVC composites. However, the SE-alkali treatment improves the impact strength and impact modulus of treated BP/semirigid PVC with 30 wt% particle content.

The factors influencing impact properties are fibre debonding, fibre/matrix adhesion, fibre fracture and fibre pullout [35-41]. The impact strength of SE-alkali-treated BP/semirigid PVC is less than that of the untreated composite. The impact strength results of SE-alkali-treated BP/semirigid PVC with 30 wt% particle content are consistent with those reported in [41], in which treated sugar-palm-reinforced epoxy composites present lower impact strength than those of untreated composites due to the weak bond between fibre and matrix. The present results are also in accordance with those reported in [23], in which the increase in fibre content decreases the impact strength because of crack initiation upon stress application, and the PVC ductility cannot be involved in the stress-shifting mechanism at high wood concentration. A previous study also [41] showed that long soaking times during alkali treatment increase the impact strength of composites until the maximum value; this result contradicts the results in the present study. Alkali treatment removes lignin and hemicellulose, and the interfibrillar region of the fibre is probably less dense and less rigid [5]. Thus, the softening of the interfibrillar matrix adversely affects the stress transfer between the fibrils, thereby resulting in less dissipation of energy with impact loading on the composites. The previous study reported that fibre fracture dissipates less energy than that of fibre pullout [41]. The impact strength is reduced after treatment because the improved interfacial adhesion prevents fibre pullout, which is a major energy dissipation source, and indirectly increases the toughness of the composite [31]. By contrast, Sah and coworkers [38] found that the impact strength of the composites slightly increases with a corresponding increase in coconut shell powder in PVC, and the value is higher than that of pure PVC. Furthermore, good fibre dispersion contributes to the high strength to withstand crack propagation and acts as a load transfer medium, in which the applied stress is transferred effectively due to effective interfacial bonding [38].

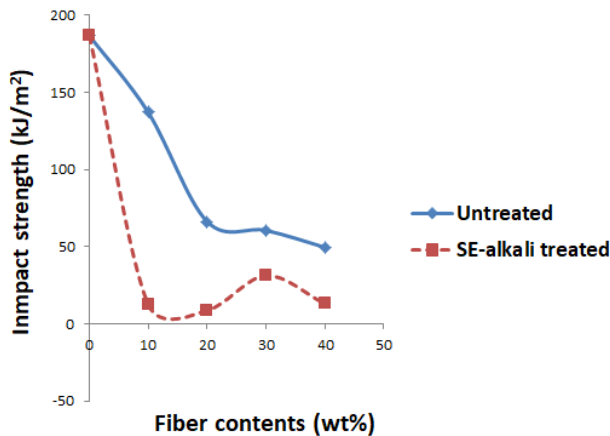


Figure 7 Impact strength of untreated and SE-alkali-treated BP/semirigid PVC composites

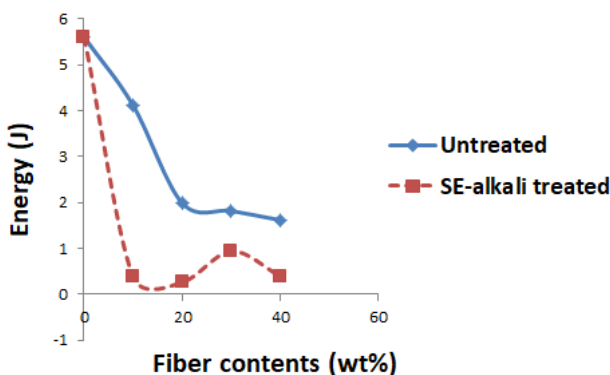


Figure 8 Energy for impact test of untreated and SE-alkali-treated BP/semirigid PVC composites

4.0 CONCLUSION

The tensile, flexural and impact properties of untreated and SE-alkali-treated BP/semirigid PVC composites with 10 wt%, 20 wt%, 30 wt% and 40 wt% particle contents were analysed. The SE-alkali-treated BP/semirigid PVC showed higher tensile strength and tensile modulus than those of the untreated BP/semirigid PVC. The tensile strength and tensile modulus of untreated BP/semirigid PVC decreased with increased particle content. The untreated and treated BP/semirigid PVC exhibited increasing flexural strength and flexural modulus with increased particle content. However, the SE-alkali-treated BP/semirigid PVC showed higher flexural strength and flexural modulus than those of the untreated BP/semirigid PVC. Although the impact strength of untreated BP/semirigid PVC was higher than that of SE-alkali-treated BP/semirigid PVC, the impact strength of untreated BP/semirigid PVC decreased with increased particle content. The SE-alkali-treated BP/semirigid PVC presented the highest impact strength at 30 wt% particle content. In conclusion, SE-alkali-treated BP/semirigid PVC composites with 40 wt% particle content showed the highest tensile and flexural values. Moreover, the impact strength of SE-alkali-treated BP/semirigid PVC composite with 40 wt% particle content was unimproved by treatment and

particle loading compared with that of untreated composite. High strength, low density and low cost may be considered in designing lightweight commercial material for indoor panel applications [40, 42].

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