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Effect of Chemical Treatment on Physical and Mechanical Properties of Coir Fibre-Polypropylene Composites

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ABSTRACT

Research on natural fibres as reinforcement in polymer composite has increased in the past few years. Due to environmental concerns, researchers are substituting synthetic fibres with natural fibres as the main component in composites. Natural fibres have acceptable mechanical properties, material renewability, cost-effective, biodegradable and eco-friendly. This study aimed to determine the effect of chemical treatment on physical and mechanical properties of composites made from coir fibre bonded with polypropylene. Coir fibres were used as reinforcements while polypropylene was used as the matrix. Coir fibre-polypropylene composites were produced with different mixing ratios of 0:100, 10:90 and 30:70. The coir fibres were screened at 30 mesh and treated separately with alkaline and alkaline-silane. The effect of chemical treatment on water absorption, thickness swelling, bending and tensile were determined in accordance with ASTM standards (ASTM D570, ASTM D790 and ASTM D3039). Results revealed that coir fibres treated with alkaline-silane resulted in superior performance in physical and mechanical properties compared to untreated coir fibres and those that were treated with alkaline. The alkaline-silane treatment resulted in a reduced number of hydroxyl groups, thus, increasing the physical properties of the composites. Additionally, the treatment also increased the mechanical properties by improving the level of adhesion between the

fibre and matrix. In conclusion, chemical treatment improves the strength and properties of coir fibre-polypropylene composites and can be used as a potential product for various industries.

Keywords: Natural fibre; thermoplastic; saline treatment; polymers; biocomposites

INTRODUCTION

The advancement in technology has led to the use of agricultural biomass in place of solid wood and other non-biodegradable materials. The demand of biocomposites materials is increasing in sectors such as transportation, building and construction, electronics and electrical, and consumer goods. This is due to the growing awareness of the harmful effects of plastic composites towards the environment. Apart from the environmental concern, the high cost of synthetic fibres encourages the use of natural fibres as reinforcement in polymer composites. Natural fibres have acceptable mechanical properties, material renewability, cost-effective, biodegradable and eco-friendly [1]. Coir fibre is one of the natural fibres that can be found in abundance. Although it is widely available, it has not been used extensively. It could be a potential alternative for solid wood as reinforcement in polymer composite while reducing biomass wastes in support of a green environment.

Coir fibre is a common name for coconut fibre, which can be extracted from the outer shell of the coconut. It is scientifically known as *Cocos nucifera* from the plant family Arecaceae (Palm) [2]. Coir fibres are derived from coconut husks and classified according to the peeled off time from the husks. The husks of fully ripened coconuts yield brown coir fibre, which is highly resistance to abrasion. Brown fibres are primarily used in brushes, floor mats and upholstery padding. On the other hand, white coir fibres come from the husks of coconuts shortly before they ripen. This fibre is softer and less strong than brown fibre. White coir fibre is usually woven into mats or twisted into twine or rope. About 55 billion of coconuts are harvested annually in the world and only 15 % of the husk fibres are actually recovered for use. Most husks are abandoned in the nature and contribute to environmental pollution [3]. In Malaysia, coconut is the fourth important industrial crop after oil palm, rubber and paddy in terms of total planted

area. It is also one of the oldest agro-based industries.

Apart from the advantages of natural fibres, many of the problems faced by coir fibres are related to the natural characteristics of the coir itself such as high moisture content sorption [4]. Coir fibres treatment is a crucial step that affects the interfacial adhesion between the natural fibre and matrix [5]. A previous study was conducted on the effect of chemical treatment on the properties of coir fibre reinforced with polypropylene (PP) and polyethylene (PE) composites [6]. The coir fibre was chemically treated with basic chromium sulfate and sodium bicarbonate. The results showed that the chemical treatment improved the physical, mechanical, and thermal properties of the composites [6]. Alkaline and silane treatments are examples of methods that can be used to improve coir fibre properties.

Numerous studies have been done on the use of natural fibres for polymer composites, however, there are still limited data on coir fibre performance. Thus, this study aimed to determine the effect of chemical treatment on physical and mechanical properties of composites made from coir fibre bonded with polypropylene.

MATERIALS AND METHOD

Materials

Coir fibres (CF), which were in brown (mature) condition with moisture content of 10 ± 2 % were provided by a local company located in Malaysia. The fibres were screened through a vibrating sieve at 30 mesh before proceeded to treatment process. Sodium hydroxide (NaOH) and silane A 174 were used as a precipitate removing and coupling agent, respectively. These chemicals were of analytical grade and were commercially available. Distilled water was used to achieve different concentration of 5 % alkaline and 6 % silane for both solvents.

Fibre Treatment Method

The coir fibres were treated with 5 % alkaline for 1 h. Half of the treated CF was used for subsequent 6 % silane treatment for 1 h. After that,

the CF were air dried for few hours before oven dried at 80 ± 2 °C for 24 h prior to testing.

Composite Fabrication

A mould was sprayed with a thin layer of silicone, which acted as a releasing agent. Composites of CF and PP were prepared at different weight ratios of 10:90, 30:70 with 0:100 being the control samples. The CF and PP were then mixed together in an extruder at 190 °C, which was the melting point for PP, and was cut into smaller pallets using a cutter machine. The pallets were filled into the mould. They were then transferred into a hot press with temperature of 190 °C for 3 minutes and then cooled for 3 minutes under a cold press before being demoulded.

Determination of Physical and Mechanical Properties

Water Absorption and Thickness Swelling

Water absorption (WA) and thickness swelling (TS) tests were carried out based on ASTM D570 [7] with a total of 45 rectangular specimens measuring 2.5 cm × 7.6 cm × 0.3 cm. The specimens were dried in an oven at 70 °C for 24 h followed by cooling in desiccators filled with silica gels. Samples' weights and thicknesses were measured immediately for accuracy of data. Both WA and TS tests were carried out by immersing the specimens in a container that contained distilled water at room temperature (25 °C) for 24 h. After immersion, the excess water on the surface of the specimens was wiped off using a piece of soft cloth for five times and the final weights and measurement of the specimens were taken. Based on the difference of weights of the specimens, the percentage of water absorption and difference of specimen dimension was calculated according to the following expressions:

$$\mathrm{WA}\ \% = \frac{(\mathrm{W2}-\mathrm{W1})}{\mathrm{W1}} \times 100 \quad (1)$$

$$\mathrm{TS}\ \% = \frac{(\mathrm{T2}-\mathrm{T1})}{\mathrm{T1}} \times 100 \quad (2)$$

Where;
W1 = Mass weight before immersion, g

W2 = Mass weight after immersion, g
T1 = Thickness before immersion, mm
T2 = Thickness after immersion, mm

Bending

Bending test measures the maximum fibre stress, which develops in a specimen just before it cracks or breaks in a flexure test. A three-point bending test was carried out and specimen deflection was measured from the crosshead position. Bending specimen were cut using a small band saw machine to a shape as specified in ASTM D790 [8]. There were 45 samples with dimensions of 0.32 cm × 1.27 cm × 12.5 cm. Test parameters were determined with support span of 50.8 mm and rate of crosshead motion of 0.05 in/min (1.27 mm/min). The test was ended when the specimen reaches 5 % deflection or the specimen breaks before 5 %.

Tensile

Tensile test measures the force that is needed to break a polymer composite specimen and the extent to which the specimen stretches or elongates to that breaking point. Tensile tests produce a stress-strain diagram to determine tensile strength and modulus. Specimens were placed in the grips of a universal testing machine and pulled until failure. Test speed can be determined by the material specification or time to failure (1 to 10 minutes) according to ASTM D3039 [9]. In this study, the test speed was 2 mm/min (0.05 in/min) and a strain gauge was used to determine elongation and tensile modulus. There were 45 samples with a constant rectangular cross section of 0.25 cm wide and 10 cm long.

Statistical Analysis

Statistical Analysis Software (SAS®) was used to analyse the data obtained in the study. An analysis of variance (ANOVA) and mean separation using the Duncan's test were conducted to evaluate the effect of weight ratio and treatment on the water absorption, thickness swelling, bending and tensile strengths of coir fibre-polypropylene (CF-PP) composites.

RESULTS AND DISCUSSION

Effect of Chemical Treatment on Physical Properties of CF-PP Composites

Table 1 presents the results of different types of treatments and ratios on water absorption and thickness swelling of CF-PP composites.

Table 1: Physical properties of CF-PP composites at different types of treatment and ratio

Type of Composite	Ratio	Water Absorption (%)	Thickness Swelling (%)
Control	0:100	0^{C}	0^{C}
Untreated	10:90	4.14^{B}	2.68^{BA}
	30:70	7.71^{A}	3.65^{A}
Alkaline treated	10:90	3.75^{B}	2.26^{BC}
	30:70	4.03^{B}	2.38^{BC}
Alkaline-Silane treated	10:90	1.22^{CB}	1.57^{C}
	30:70	2.51^{CB}	2.08^{BC}

Note: Mean followed by the same letters in the same column are not significantly different at $p \leq 0.05$

Water Absorption

The water absorption (WA) values of untreated and treated composite samples at different ratios are shown in Table 1. The soaking time and percentage of the CF were significant factors, which affected the WA of the composites. The WA mean values increased with an increase in fibre loading for all cases [7,10]. The WA of untreated composite at 10:90 ratio was 4.14 % whereas the WA of the alkaline treated composite was lower with 3.75 %. However, the alkaline-silane treated composite samples recorded the lowest water intake of 1.22 %. At 30:70 ratio, the WA of untreated composite had the highest water intake of 7.71 % followed by alkaline treated composite with 4.03 % and alkaline-silane treated composite with 2.51 %. The higher percentage of WA in composite was due to several factors such as void content, and the hydrophilicity of fibre and matrix. Previous studies show that water will be absorbed into available void and crack of composite

through capillary action. The presence of high hemicellulose content which is hydrophilic in nature is responsible for high water absorption [11, 12]. In the untreated state, the cellulosic –OH groups are reactive and they form strong hydrogen bonds that retain water. As the superficial treatment decreased the number of hydroxyl groups, the water uptake was reduced in the treated sample. In other words, the reduction in –OH groups of cellulose reduced the hydrophilic character of the fibre. Similar observation was reported in a study on the effects of silane coupling agent on coconut fibre filled PP composite [13]. The hydroxyl groups that are present on the surface of the fibres are responsible for WA.

Thickness Swelling

The thickness swelling (TS) results for all composites are shown in Table 1. Thickness swelling increased with fibre loading. As mentioned earlier, the hydroxyl group –OH of CF is responsible for the water absorbed and cause the swelling behaviour of the fibre. Water was absorbed by the fibre until the cell wall was saturated with water and at this point there were no more TS occurred. The highest TS was shown by untreated composite at 30:70 ratio with 3.65 %. When treated with alkaline and alkaline-silane, the percentage of swelling decreased with 2.38 % and 2.08 %, respectively. The same observation was shown by the samples at 10:90 ratio where untreated composites had the highest thickness swelling of 2.68 % followed by alkaline treated composite with 2.26 % and alkaline-saline treated composite with 1.57 %. It showed a decreasing result after the –OH group was removed through alkaline and silane treatment processes and supported the findings from previous studies [14, 15].

Effect of Chemical Treatment on Mechanical Properties of CF-PP Composites

Table 2 tabulates the mechanical properties of CF-PP composites at different types of treatments and ratios. Alkaline-silane composite performed better in bending and tensile for both MOE and MOR followed by alkaline composite and untreated composites.

Table 2: Mechanical properties of CF-PP composite at different types of treatment and ratio

Properties	Types	Ratio	MOE (MPa)	MOR (MPa)
Bending	Control	0:100	1035.14^{D}	37.48^{A}
	Untreated	10:90	1090.51^{DC}	28.07^{C}
		30:70	1101.34^{DC}	24.68^{D}
	Alkaline treated	10:90	1215.17^{BC}	30.67^{CB}
		30:70	1367.20^{BA}	32.67^{B}
	Alkaline-silane treated	10:90	1305.62^{BA}	31.49^{B}
		30:70	1460.38^{A}	37.10^{A}
Tensile	Control	0:100	1587.11^{C}	28.75^{A}
	Untreated	10:90	1583.80^{C}	16.51^{E}
		30:70	1854.38^{B}	13.51^{F}
	Alkaline treated	10:90	1877.63^{B}	19.23^{D}
		30:70	2011.94^{BA}	16.99^{E}
	Alkaline-silane treated	10:90	2100.35^{A}	22.00^{C}
		30:70	2206.93^{A}	24.63^{B}

Note: Mean followed by the same letters in the same column are not significantly different at $p \leq 0.05$

Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) in Bending Test

The bending modulus of elasticity (MOE) and modulus of rupture (MOR) or bending strength of the composites are tabulated in Table 2. The treated composite showed a marginal effect on the increasing strength in bending after treatment. The MOE for the control samples was 1035.14 MPa. The 30:70 ratio had the highest MOE recorded for all types of composites where the alkaline-silane treated composite recorded 1460.38 MPa, followed by alkaline treated composite with 1367.20 MPa, and untreated composite with 1101.34 MPa, respectively. The highest MOE was obtained at 10:90 ratio with 1305.62 MPa by alkaline-silane treated composite followed by alkaline treated composite with 1215.17 MPa, and the lowest MOE was

recorded by untreated composite with 1090.51 MPa.

The addition of fibre loading reduced the bending strength or MOR especially for untreated composite from 28.07 MPa for 10:90 ratio to 24.68 MPa for ratio 30:70, as compared to control sample with 37.48 MPa, respectively. The alkaline-silane treated composite showed a slightly lower MOR value compared to the control sample with 37.10 MPa at 30:70 ratio followed by alkaline treated composite with 32.67 MPa. Meanwhile, the 10:90 ratio for alkaline-silane treated composite recorded MOR of 31.49 MPa and alkaline treated composite with 30.67 MPa. This indicates that when these two surface treatments are combined, an additional increase is observed for the bending strength. This shows that a better contact and the increase in area of contact between the fibre and the matrix are improving the level of adhesion that could be due to the chemical treatments. When the fibre is treated with silane, an increase in bending strength is observed. When the chemical and the mechanical components of the adhesion are combined, an increase of strength is observed as shown in studies by other researchers [5,6].

The increase in mechanical strength is due to the reinforced effect provided by CF, which allows a uniform stress distribution from the polymer matrix to the dispersed fibre phase [7,10]. Higher percentage of fibre also leads to an increase in fibre-fibre interaction, which results in difficulties in the dispersion of the fibre within the polymer matrix.

Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) in Tensile Test

The values of modulus of elasticity (MOE) and modulus of rupture (MOR) in tensile for all types of composites are presented in Table 2. The tensile strength and Young's modulus of composites are some of the factors, which can influence the tensile properties of fibre reinforced polymer composites [16]. The MOE mean value of the control samples was 1587.11 MPa. The highest MOE was observed by composite at 30:70 ratio for all untreated and treated samples where alkaline-saline treated recorded 2206.93 MPa followed by alkaline treated composite with 2011.94 MPa, and untreated composite with 1854.38 MPa. As for 10:90 ratio, it followed

the same sequence, which were 2100.35 MPa, 1877.63 MPa and 1583.80 MPa, respectively.

It was found that an increase in the amount of fibres had caused a decline in tensile strength or MOR (Table 2). The results showed that the control samples recorded the highest MOR of 28.75 MPa. The fibre treatments tend to maximise the tensile strength for 30:70 ratio which was slightly lower than alkaline-silane treated composite with 24.63 MPa followed by alkaline treated composite with 16.99 Mpa, respectively. The samples for the 10:90 ratio recorded 22.00 MPa and 19.23 MPa for alkaline-silane treated composite and alkaline treated composite, respectively. However, untreated composite for 30:70 ratio of 13.51 MPa was lower than 10:90 ratio with 16.51 MPa.

Based on the tensile test results, MOE increased with fibre loading, which is consistent with other researchers [17]. During tensile loading, partially separated micro-spaces are created, which obstructs stress propagation between the fibre and matrix [10]. As the fibre load increases, the degree of obstruction increases, which consequently increases the stiffness. As a result, the treated fibre showed a higher MOE compared to untreated fibre. It is well known that the alkaline treatment increasing the fibre uniformity by reducing the impurities on the fibre surfaces and providing mechanical interlocking and may offer better interface adhesion [18]. Composites treated with silane coupling agent exhibit higher elastic modulus and stiffness than similar composites without silane coupling agent [13].

CONCLUSION

This study investigated the influence of chemical treatment as a way to enhance the physical and mechanical properties of CF-PP composite towards its uses as a good potential product for the market. Based on the findings, both alkaline and silane treatment were able to increase the physical and mechanical properties of CF-PP composite with the addition of fibre loading. It was also discovered that the combination of alkaline-silane treatment gave better improvement than just the alkaline treatment alone. Silane treatment decreases the hydrophilic characteristic of CF by forming a protective

chemical layer, which protects the bonds between CF filler and PP matrix from water attacks. This had reduced the water absorption and prevented deterioration of filler-matrix bonding, protecting the mechanical properties from degrading strength, which gave composites more stiffness and lower resistance to break. As a recommendation, varying the ratios of the CF and PP could be used for further investigation. Additionally, morphological evidence of the surfaces could be obtained through a scanning electron microscope (SEM) to evaluate the adhesion level of polymer matrix and filler towards producing better quality polymer composites.

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