MECHANICAL PROPERTIES OF SHORT COIR/PBS BIODEGRADABLE COMPOSITES: EFFECT OF ALKALI TREATMENT AND FIBER CONTENT

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Abstract

The short coir fiber reinforced poly(butylene succinate) (PBS) biodegradable composites were developed. The effect of fiber content varying from 10 wt% to 50 wt% on the mechanical properties of short coir/PBS composites was investigated. The effect of alkali treatment on mechanical properties of the composites was also studied. The mechanical properties of alkali–treated coir/PBS composites are significantly higher than those of untreated coir fiber. The best mechanical strength of short coir/PBS composites was achieved at fiber content of 20 wt% in this study. Tensile and flexural modulus of the composites increased with increasing fiber content. Compared with untreated coir fiber, alkali–treated coir/PBS composite at 20 wt% fiber content showed an increase of tensile strength (TS) by 29.6%, tensile modulus (TM) by 32.6%, flexural strength (FS) by 19.1% and flexural modulus (FM) by 21.3%. The fractured surface of tensile specimens exhibited an improvement of interfacial fiber-matrix bond in the alkali–treated coir/PBS composites.

1. Introduction

Biodegradable composite materials producing by the combination of biodegradable polymers and natural fibers have attracted great interests in recent years due to their potential applications in biomedical, bioengineering and environmental fields [1]. Natural fiber biodegradable composites have some major advantages over conventional composite materials such as, eco–friendliness, low volumetric cost, light weight, high specific mechanical properties and biodegradable characteristic [2–4]. However, natural fiber composites have disadvantage for example, interfacial bond between natural fiber and polymer matrix is poor and thus fiber surface modification is necessary to improve interfacial adhesion [5–7].
Among the biodegradable polymers, poly(lactic acid) (PLA) and poly(butylene succinate) (PBS) are increasing commercial interest. However, PBS is commercially available at lower cost than PLA. PBS can be naturally degraded into the environment by bacteria and fungi [8]. PBS has excellent biodegradability in nature, such as in soil, lake, sea, and compost [9]. It can be completely combustible by fire without evolving toxic gases [10]. It has comparable mechanical properties with several thermoplastics such as, polyethylene, polypropylene and polystyrene. As a result, PBS can be a good candidate material for the matrix of biodegradable composites.
The natural fibers such as, hemp, jute, kenaf, sisal, flax, bamboo, coir, silk, and, etc. offer specific benefits such as low cost, low density, low pollutant emissions, acceptable specific properties, renewable characteristics and biodegradability [2]. Among the natural fibers, coir fibers extracted from the tissues surrounding the seed of coconut palm (Cocos nucifera) are nowadays extensively used in many applications. Due to hardwearing quality, durability and its other advantages, coir is usually used for marking a wide variety of floor–furnishing materials, yarn, rope, and, etc. However, the traditional coir products consume only a small percentage of the potential total world production of coconut husk. Hence the research and development efforts have been underway to find new use of coir as a reinforcement in polymer composites such as, coir-polypropylene or coir–polyester composites [6, 7].
The combination of coir fibers and PBS resin can produce the environment–friendly biodegradable composite. In present work, the PBS biodegradable

composites reinforced with untreated and alkali–treated coir fibers were fabricated by compression molding method. The effect of alkali treatment and fiber content on mechanical properties of coir/PBS composites was studied. The fractured surfaces of untreated and alkali–treated coir/PBS composites were investigated by scanning electron microscope (SEM) providing the information for the evaluation of interfacial fiber‑matrix adhesion.

2 Experimental procedures

2.1 Materials

The brown coir fibers were supplied by Betrimex JSC, Bentre, Vietnam. Biodegradable poly(butylene succinate) resin (PBS, #1001, Showa High Polymers Ltd., Tokyo, Japan) which was used as a composite matrix is thermoplastic aliphatic polyester. The melting temperature of the PBS is about 115^{o}C and the density is 1.26 g/cm^3.

2.2 Alkali treatment of coir fibers

First of all coir fibers were treated with 5% sodium hydroxide solution in a glass beaker for 72 h at room temperature (RT). Next the fibers were taken out of the solution then washed several times with fresh water and subsequently with distilled water. Finally, the coir fibers were air–dried for more than two days.

2.3 Composite fabrication

Coir fibers were initially dried at 60^{o}C in a vacuum oven for 8 hours. The dried untreated and alkali-treated coir fibers were cut into short fibers varying from 10 mm to 20 mm long and mixed thoroughly with melted PBS resin at 10/90, 20/80, 30/70, 40/60 and 50/50 wt% mixing ratios by Brabender Mixer (Germany) at a constant temperature of 140^{o}C. The mixtures were laminated and cut into about 5 mm long pieces. All the pieces were cut into the smaller pellets using a Strand Pelletizer (LZ 120, Sweden). Composite plates were compression molded from coir–PBS pellets at 140^{o}C by hydraulic molding test press (GT-7014-A, Gotech Inc, Taiwan).

2.4 Tensile and flexural test

Tensile properties of short coir/PBS composites with different fiber contents were measured according to JIS K7113 using universal testing machine Senstar SC-5H (JTT Inc., Tokyo, Japan). The specimen dimensions were 120 x 10 x 2 mm^3 and the gauge length was 50 mm. All tensile tests were carried out at RT with a crosshead speed of 0.5 mm/min.

The flexural properties were measured by a three-point bending method according to JIS K7171 using testing machine Autograph AGS-1000A (Shimadzu, Kyoto, Japan). The flexural tests were carried out at RT with a crosshead speed of 1 mm/min. The ratio between span distance and depth of composite specimens was 16. The average values of tensile and flexural properties of each composite were obtained from seven test specimens.

2.5 Surface morphology

The fractured surface morphology of the composite specimens was examined using scanning electron microscope (VE-7800, Keyence Inc., Osaka, Japan).

3 Results and discussion

3.1 Tensile properties

The tensile properties of PBS, untreated and alkali-treated coir/PBS composites with different fiber content are summarized in Table 1.

Table 1. Tensile properties of PBS, five different untreated and alkali-treated coir/PBS composites

Fiber content (wt%)	Alkali treatment	Tensile strength (MPa)	Tensile modulus (GPa)	Fracture strain (%)
0	-	37.5 ± 1.1	1.00 ± 0.06	9.00 ± 0.91
10	No	20.9 ± 1.2	1.18 ± 0.07	3.12 ± 0.25
	Yes	24.7 ± 1.1	1.43 ± 0.06	3.41 ± 0.20
20	No	21.5 ± 1.5	1.40 ± 0.10	3.05 ± 0.25
	Yes	27.9 ± 1.2	1.86 ± 0.10	3.29 ± 0.24
30	No	17.8 ± 0.9	1.62 ± 0.11	2.32 ± 0.24
	Yes	21.8 ± 1.4	2.00 ± 0.08	2.78 ± 0.29
40	No	15.4 ± 0.6	1.85 ± 0.11	1.04 ± 0.11
	Yes	18.1 ± 0.7	2.22 ± 0.09	1.27 ± 0.11
50	No	15.2 ± 1.0	2.07 ± 0.13	0.95 ± 0.12
	Yes	17.6 ± 0.8	2.43 ± 0.11	1.17 ± 0.10

As shown in Table 1, the incorporation of short coir fibers improved TM of PBS. Compared with pure PBS, TM of untreated coir/PBS composites with five different fiber contents enhanced to 17.9%, 40.3%, 61.9%, 84.4% and 106.6%, respectively. However, TS of short coir/PBS composites was lower than that of PBS. The increases in fiber content enhance the interfacial area and weaken the fiber–matrix interaction, resulting in a decreasing trend of TS [6]. The decrease of TS may be explained due to poor wettability leading to a weak interface. In principle, lack of proper wetting between the fiber and the matrix should lead to the formation of voids at the fiber–matrix interface. The debonding results in void formation, which lowers TS because cracks can easily propagate through regions containing voids as shown by Liang et al. [11]. In general, the polymer matrix composites reinforced with high fiber content of low fiber modulus like coir which are made by applying pressure would result in a highly porous structure, thus their strength will be much lower than that of the matrix. As seen in Table 1, TS of the composite increases up to 20 wt% fiber content, but decreases with upper fiber contents. The increase in TS is due to increased wetting of the fiber with the matrix. The high TS at fiber content of 20 wt% might be also due to adequate fiber content in composites, which leads to greater wetting.

The incorporation of high fiber content can reduce fracture strain of the composite, because increasing the amount of filler will lead to the decrease in the amount of polymeric matrix available for the elongation. The elongation in coir/PBS composite arises from the PBS matrix because coir fiber is relatively rigid comparing with PBS resin. As shown in Table 1, the fracture strain are evidently reduced compared with PBS resin. At a fiber loading of 10 wt% the fracture strain of untreated coir/PBS composite significantly reduced by 65% compared with that of PBS resin. Besides, the addition of higher fiber amount increases the possibility of fiber agglomeration and can lead to the formation of stress concentrated region where less energy is required for elongating the crack propagation. During tensile deformation, the inefficient stress-transfer nearby the stress concentrated region may result in the failure of specimens before the yield [11]. Furthermore, the decrease in fracture strain is mainly due to the structural integrity of PBS being destroyed by the loading of coir fiber, and increasing fiber content imply poor interfacial adhesion resulting in quicker fracture than PBS resin [12].

The tensile properties of alkali-treated coir/PBS composites are significantly greater than those of untreated ones, because alkali treatment increases the fiber surface roughness and the amount of cellulose exposed on the fiber surface resulting in better mechanical interlocking [5]. Alkali treatment can improve the compatibility between coir fiber and PBS resin, leading to less fiber–matrix debonding. As shown in Fig. 1a, visible gap can be found between the untreated fiber and PBS matrix, suggesting poor interfacial adhesion. However, the gap disappeared in the case of alkali-treated coir fiber (Fig. 1b), proving good compatibility being formed in PBS composites. Alkali-treated coir fiber having a good adhesion with PBS matrix can effectively disperse and transfer stress, leading to the improvement in mechanical properties of coir/PBS biodegradable composites.

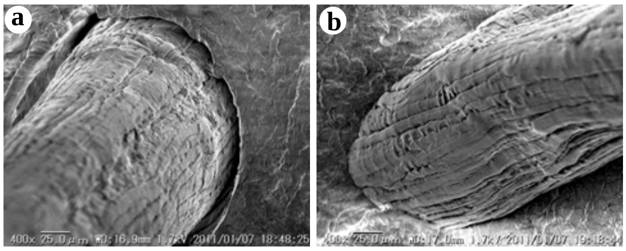

Fig.1. Fracture surface of coir/PBS composite with 20 wt% fiber content: (a) untreated; (b) alkali-treated

3.2 Flexural properties

Flexural properties of PBS, untreated and alkali-treated coir/PBS composites with five different fiber weight contents were presented in Fig. 2. As shown in Fig. 2, FS increased with increasing fiber content up to 20 wt%, but decreased with upper fiber contents. The decrease may be explained by insufficient filling of melted PBS resin into the coir fibers during composite processing. FM gradually increased with increasing fiber content up to 50 wt%. This result can be attributed to the addition of the filler resulting in an increase of the modulus due to the incorporation of rigid coir into the ductile PBS matrix.

Flexural properties of alkali-treated short coir/PBS composites are higher than those of untreated ones. This reflects the contribution of NaOH in terms of changes of fiber properties and enhancement of fiber–matrix adhesion. Compared with PBS resin, alkali-treated coir/PBS composites at 20 wt% fiber content exhibited 36.1% enhancement in FS and 89.5% in FM. It is interesting to note that flexural properties have the same trend as tensile properties with the increase of fiber content. In this study the incorporation of 20 wt% fiber content showed best mechanical strength of coir/PBS biodegradable composites. This might be explained due to adequate fiber content in the composites, which leads to greater wetting. In a word, the results of mechanical strength point out the importance by using the right amount of natural fiber as reinforcement in the composites.

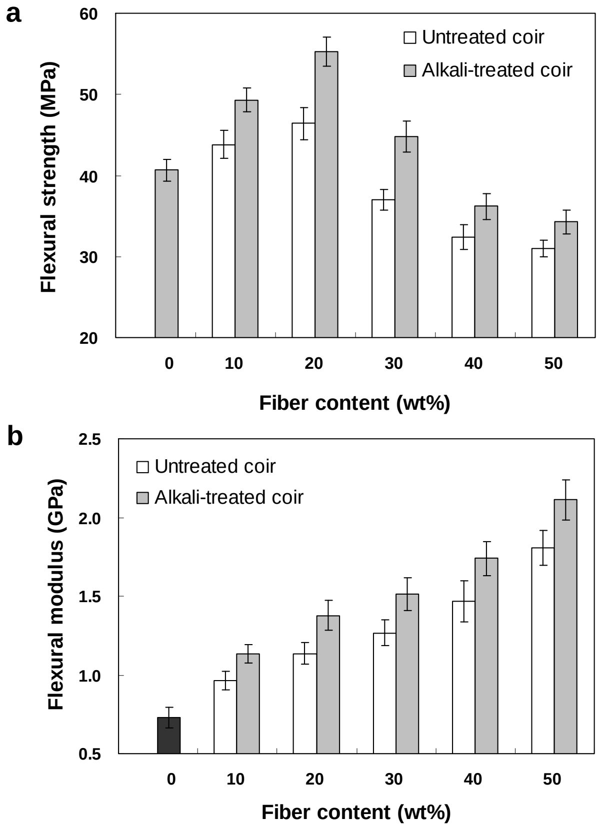

Fig.2. Effect of fiber content and alkali treatment on flexural properties of short coir/PBS composites

4 Conclusions

The short coir/PBS biodegradable composites have been developed. The effect of fiber weight content and alkali treatment on the mechanical properties of short coir/PBS biodegradable composites has been studied. Alkali treatment of coir fibers increased the interfacial fiber–matrix adhesion and the wettability of the fibers by PBS resin leading to the enhancement in the mechanical properties of short coir/PBS biodegradable composites. Mechanical strength of the composites increased with increasing fiber content up to 20 wt%, but decreased over 20 wt%. The authors propose that PBS biodegradable composites reinforced with 20 wt% short coir fiber content have a best mechanical strength in this study.

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