MECHANICAL PROPERTIES OF UNIDIRECTIONAL JUTE FIBER REINFORCED POLY(BUTYLENE SUCCINATE) BIODEGRADABLE COMPOSITES

Tran Huu Nam, Shinji Ogihara
Department of Mechanical Engineering, Tokyo University of Science, Chiba, Japan

1. Introduction

Biodegradable composite materials produced 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 composites such as, eco–friendliness, low cost, lightweight, high specific mechanical properties and biodegradability [2–4]. Among the biodegradable polymers, poly(butylene succinate) (PBS) is increasing commercial interest. PBS is thermoplastic aliphatic polyester and can be naturally degraded into the environment by bacteria and fungi [5]. PBS has excellent biodegradability in nature, such as in soil, lake, sea, and compost [6]. It can be completely combustible by fire without evolving toxic gases [7]. It has comparable mechanical properties with several thermoplastics like 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, flax, coir, etc. offer specific benefits such as low cost, low density, low pollutant emissions, acceptable specific properties, renewability and biodegradability [2]. Among the natural fibers, jute is the second most important vegetable bast fiber after cotton. It is produced from plants in the genus *Corchorus*. Traditionally jute is used for making hessian clothes, ropes, gunny and shopping bags, floor mats, etc. A major drawback of using jute fiber as reinforcing material is its hydrophilic nature and responsible for moisture absorption. As a result, several researchers have carried out chemical treatment of jute fiber to improve its hydrophilic character and the mechanical properties of jute fiber reinforced polymer composites [8-12]. In this study, the unidirectional jute/PBS biodegradable composites were developed. The effect of alkali treatment and fiber content on mechanical properties of jute/PBS composites was studied. The fiber surface morphologies and fractured surfaces of composite specimens 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 raw jutes were supplied by Hung Yen Jute and Garment JSC (Hung Yen, Viet Nam). Biodegradable PBS pellets (#1001) with a melting temperature of 115 ^{o}C was provided by Showa High Polymers Ltd. (Tokyo, Japan). The density of jute fiber and PBS are 1.4 g/cm^3 and 1.26 g/cm^3, respectively.

2.2 Alkali treatment of jute fibers

First of all, jute fibers were treated with 2% sodium hydroxide solution in a glass beaker for 3 h at room temperature (RT). Then jute fibers were taken out of the solution, washed several times with fresh water and subsequently with distilled water. Finally, jute fibers were air–dried for more than 2 days.

2.3 Composite fabrication

To begin with, jute fibers were dried at 60^{o}C in a vacuum oven for 24 hours. Next dried jutes were cut into the segments with the length of 150 mm. Then jute fibers were weighed, aligned in a parallel array and placed in the mold between the PBS sheets. Lastly, the composite plates made from PBS and different untreated and alkali–treated jute fiber content (10–60 wt%) were fabricated by hot press equipment (Imoto Corp., Kyoto, Japan).

2.4 Tensile and flexural test

Tensile properties of jute/PBS composites with different fiber weight content were measured according to JIS K7113 standard by universal testing machine RTF–1350 (JTT Inc., Tokyo, Japan). The specimen dimensions are 120 x 10 x 2 mm^3 and the gauge length is 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 universal testing machine Senstar SC–5H (JTT Inc., Tokyo, Japan). The flexural tests were carried out at RT with a crosshead speed of 2 mm/min. The ratio between span distance and depth of flexural specimens is 16. The mean values of tensile and flexural properties of each composite were obtained from seven test specimens.

2.5 Surface morphology

The jute surface morphology and fractured surface of the composite specimens were examined using SEM (VE−7800, Keyence Inc., Osaka, Japan).

3. Results and discussion

3.1 Alkali treatment of jute fibers

Fig. 1 shows SEM micrographs of jute fiber surface before and after alkali treatment. As seen in Fig. 1, the removal of natural and artificial impurities on jute fiber surface can make the fiber cleaner and rougher than before. It can be realized that alkali treatment increases the surface roughness leading to better mechanical interlocking between jute fiber and PBS resin. Moreover, alkali treatment exposes the cellulose on the fiber surface resulting in the compatibility of jute fibers with PBS resin.

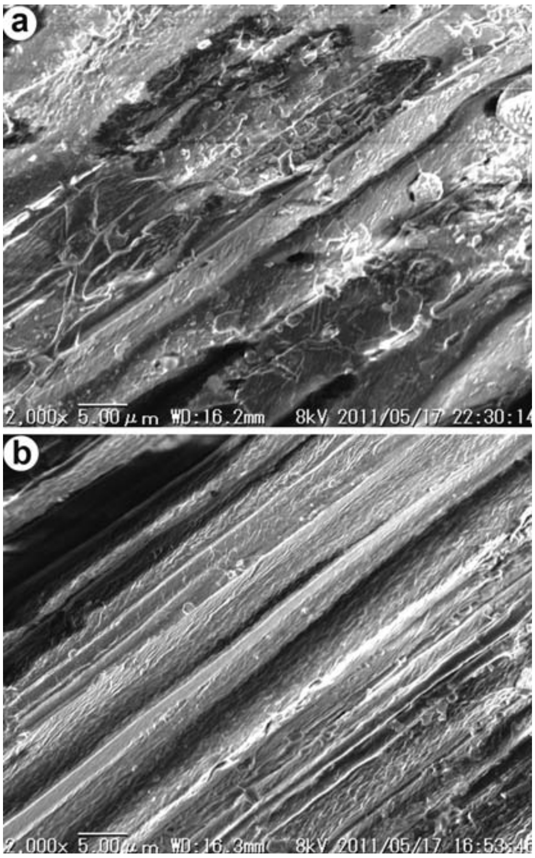

Fig. 1. SEM micrographs of jute fiber surface: (a) before alkali treatment; (b) after alkali treatment

3.2 Tensile properties

Tensile properties of PBS and untreated jute/PBS composites with different fiber weight content are summarized in Table 1. As seen in Table 1, the incorporation of jute fibers improved tensile strength and modulus of PBS. Tensile strength of the composites increased with increasing the fiber content up to 50 wt%, but decreased with upper fiber content. Tensile modulus of the composites gradually increased with increasing fiber content up to 60 wt%. The increase in tensile strength and modulus of the composites is due to the reinforcement of jute fibers in PBS matrix in the direction of external load. The decrease in tensile strength at 60 wt% fiber content probably resulted from incomplete fiber wetting, because PBS content is not sufficient to wet all fiber surfaces. The high tensile strength at 50 wt% fiber content might be due to adequate fiber content in composites, which leads to greater wetting. Compared with PBS, untreated jute/PBS composite at 50 wt% fiber content shows an increase in tensile strength by 320% and tensile modulus by 2594%.

Table 1. Tensile properties of PBS and untreated jute/PBS composites

Fiber content (wt%)	Tensile strength (MPa)	Tensile modulus (GPa)	Fracture strain (%)
0	37.5 ± 1.1	1.0 ± 0.06	9.0 ± 0.91
10	66.6 ± 5.3	10.2 ± 1.6	0.97 ± 0.07
20	98.0 ± 6.5	13.2 ± 2.0	0.86 ± 0.05
30	131.1 ± 10.5	20.5 ± 2.2	0.85 ± 0.06
40	143.3 ± 11.3	23.2 ± 2.3	0.79 ± 0.07
50	157.7 ± 10.5	27.0 ± 2.4	0.75 ± 0.08
60	147.5 ± 9.90	30.8 ± 2.8	0.63 ± 0.08

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 decrease in fracture strain, as seen in Table 1, is mainly due to the structural integrity of PBS being destroyed by the loading of jute fiber, and increasing fiber content imply poor interfacial fiber–matrix bonding leading to quicker fracture than pure PBS [9]. Compared with PBS, fracture strain of untreated jute/PBS composite with 10 wt% fiber content significantly reduces to 89%. This indicates that the ductile nature of PBS resin strongly decreases with the addition of jute fibers.

Alkali treatment of jute fibers improved tensile properties of jute/PBS composites, as seen in Figs. 2−3. Compared with untreated jute, alkali−treated jute/PBS composite at 50 wt% fiber content exhibited an increase in tensile strength by 43.8%, in tensile modulus by 21.4% and in fracture strain by 23.7%. The increase in tensile properties of alkali−treated fiber composite may be due to greater fiber–matrix interfacial and physical bonding. As described above, alkali treatment can improve the compatibility between jute fiber and PBS matrix leading to less interfacial fiber–matrix debonding. As shown in Fig. 4a, the pulled–out fibers can be found on the fracture surface of untreated jute/PBS, suggesting poor interfacial fiber–matrix adhesion. However, almost the pulled–out fibers disappeared in the case of alkali–treated jute (Fig. 4b), proving good compatibility being formed in PBS composites. Alkali–treated jute fiber having a good adhesion with PBS can effectively disperse and transfer stress, leading to the improvement in mechanical properties of the composites.

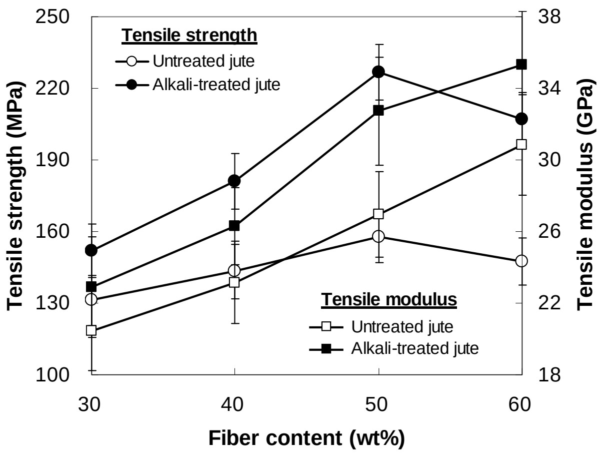

Fig. 2. Effect of fiber content and alkali treatment on tensile strength and modulus of jute/PBS composites

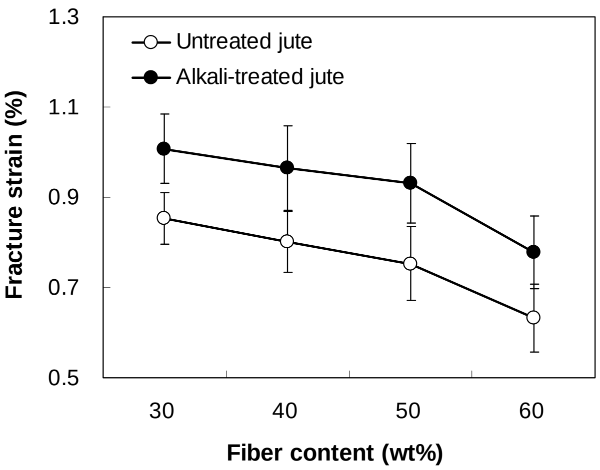

Fig. 3. Effect of fiber content and alkali treatment on fracture strain of jute/PBS composites

3.3 Flexural properties

Flexural properties of PBS and untreated jute/PBS composites with different fiber weight content are given in Table 2. As seen in Table 2, flexural strength and modulus increased with increasing fiber content up to 50 wt%, but they decreased at 60 wt% fiber content. The decrease in flexural strength and modulus beyond 50 wt% fiber content can be explained due to a shortage of PBS resin to fully wet out all jute fibers during composite processing. As shown in Fig. 5, alkali–treated jute/PBS composites yielded higher mean flexural properties compared with untreated ones. This reflects the contribution of NaOH in terms of changes of fiber properties and the enhancement of fiber–matrix adhesion.

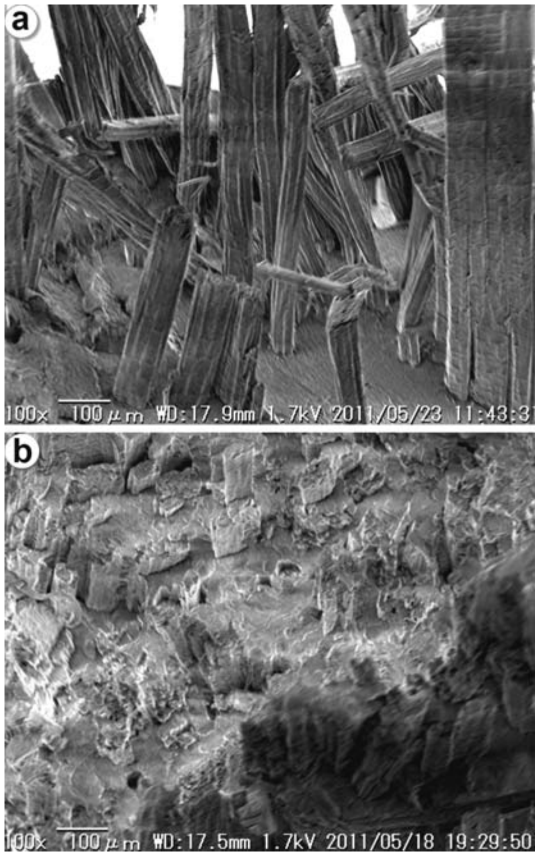

Fig. 4. Fracture surface of jute/PBS composite with 30 wt% fiber content: (a) untreated; (b) alkali-treated

Table 2. Flexural properties of PBS and untreated jute/PBS composites

Fiber content (wt%)	Flexural strength (MPa)	Flexural modulus (GPa)
0	49.4 ± 2.4	0.9 ± 0.2
10	70.3 ± 4.8	2.9 ± 0.5
20	115.9 ± 6.9	7.4 ± 0.6
30	137.2 ± 8.9	9.0 ± 0.7
40	161.1 ± 8.7	11.6 ± 0.9
50	185.1 ± 8.6	14.4 ± 0.8
60	150.1 ± 9.5	12.7 ± 0.8

Compared to untreated fiber, alkali–treated jute/PBS composite at 50 wt% fiber content shows an increase in mean flexural strength by 5.5% and mean flexural modulus by 17.5%. The results indicate that surface modification by alkali treatment has less influence on flexural properties compared to tensile properties. This can be explained that the flexural failure mode usually shows little fiber pull–out [9], because applied force is perpendicular to reinforced fibers of the composite specimens in flexural test. It is interesting to note that flexural strength has the same trend as tensile strength with increasing the fiber content. In this study, the addition of 50 wt% fiber content showed the best mechanical strength of jute/PBS composites. In short, the results of mechanical strength point out the importance by using the right amount of natural fiber as reinforcement in the composites.

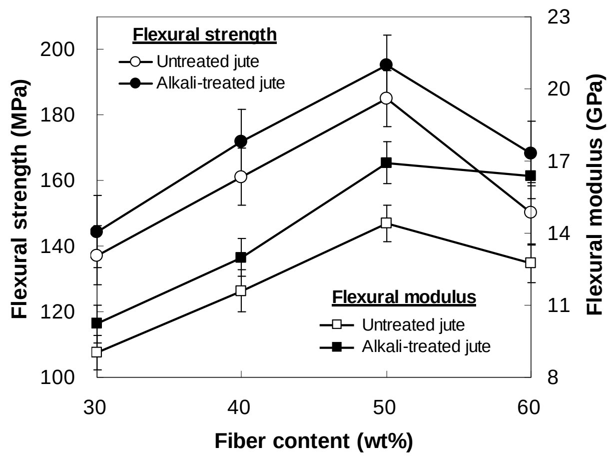

Fig. 5. Effect of fiber content and alkali treatment on flexural properties of jute/PBS composites

4. Conclusions

The poly(butylene succinate) (PBS) biodegradable composites reinforced with unidirectional jute fibers were developed and studied. The effect of alkali treatment and fiber content on mechanical properties of jute/PBS composites has been investigated. The mechanical strength and modulus of untreated jute/PBS composites are significantly higher than those of PBS. Alkali treatment of jute fibers increased the fiber surface roughness and the wettability of the fibers by PBS resin leading to the enhancement in the mechanical properties of jute/PBS biodegradable composites. Mechanical strength of the composites increased with increasing fiber content up to 50 wt%, but decreased over 50 wt%. The authors propose that PBS biodegradable composites reinforced with 50 wt% jute fiber content have the best mechanical strength in this study. The experimental results in the present work suggest that a useful composite with good strength could be successfully developed using jute fiber as a reinforcing agent for the PBS matrix.

References

[1] H.Y. Cheung, M.P. Ho, K.T. Lau, F. Cardona and D. Hui. Natural fibre–reinforced composites for bioengineerring and environmental engineering applications. *Composites Part B*, Vol. 40, pp. 655-663, 2009.

[2] A.K. Mohanty, M. Misra and G. Hinrichsen. Biofibres, biodegradable polymers and biocomposites: An overview. *Macromol Mater Eng*, Vol. 276, pp. 1-24, 2000.

[3] S.N. Monteiro, F.P.D. Lopes, A.S. Ferreira and D.C.O. Nascimento. Natural–fiber polymer–matrix composites: cheaper, tougher, and environmentally friendly. *JOM*, Vo. 61, No. 1, pp 17–22, 2009.

[4] K.G. Satyanarayana, G.G.C. Arizaga and F. Wypych. Biodegradable composites based on lignocellulosic fibers – an overview. *Progress in Polym Sci*, Vol. 34, No. 9, pp. 982–1021, 2009.

[5] D.Y. Kim and Y.H. Rhee. Biodegradation of microbial and synthetic polyesters by fungi. *Appl Microbiol Biotechnol*, Vol. 61, No. 4, pp. 300–308, 2003.

[6] T. Hirotsu, T. Tsujisaka, T. Masuda and K. Nakayama. Plasma surface treatments and biodegradation of poly (butylene succinate) sheets. *J Appl Polym Sci*, Vol. 78, pp. 1121–1129, 2000.

[7] S.M. Lee, D. Choa, W.H. Park, S.G. Lee, S.O. Han and L.T. Drzal. Novel silk/poly(butylene succinate) bio-composites: the effect of short fibre content on their mechanical and thermal properties. *Compos Sci Technol*, Vol. 65, pp. 647–657, 2005.

[8] A.K. Mohanty, M.A. Khan and G. Hinrichsen. Surface modification of jute and its influence on performance of biodegradable jute–fabric/Biopol composites. *Compos Sci Technol*, Vol. 60, pp. 1115–1124, 2000.

[9] L. Liu, J. Yu, L. Cheng and W. Yu. Mechanical properties of poly(butylene succinate) (PBS) biocomposite reinforced with surface modified jute fibre. *Composites Part A*, Vol. 40, pp. 669–674, 2009.

[10] K. Sever, M. Sarikanat, Y. Seki, G. Erkan and U.H. Erdogan. The mechanical properties of γ–Metha-cryloxypropyltrimethoxysilane–treated jute/polyester composites. *Journal of Composite Materials*, Vol. 44, pp. 1913–1924, 2010.

[11] X. Wang, Y. Cui, Q. Xu, B. Xie and W. Li. Effects of alkali and silane treatment on the mechanical properties of jute–fiber–reinforced recycled polypropylene Composites. *Journal of Vinyl & Add Technol*, pp. 183-188, 2010.

[12] M.J. Miaha, M.A. Khan and R.A. Khan. Fabrication and characterization of jute fiber reinforced low density polyethylene based composites: Effects of chemical treatment. *J Sci Res*, Vol. 3(2), pp. 249–259, 2011.