

MECHANICAL PROPERTIES OF BIODEGRADABLE POLYMER BLENDS AND HYBRID COMPOSITE FILLED WITH NANOCCLAY AND BAMBOO POWDER

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Abstract

Biodegradable polymers, poly(lactic acid) (PLA) and poly(butylene succinate) (PBS), were blended and compounded with nanoclay and bamboo powder. The content of the PBS in the PLA/PBS blends was 0-40 wt%. The contents of the nanoclay and bamboo powder in the composites were 1-5 wt% and 10-40 wt%, respectively. The blends and the composites were mixed in a twin screw extruder and fabricated into specimens by hot press molding. Mechanical testing was carried out by tensile testing. From the results, the tensile properties of the PLA blends and the composites were significantly influenced by the PBS dispersed phase. Elongation and toughness of the PLA/PBS blends increased with the increasing PBS content. The maximum value was found at 70/30 of the PLA/PBS blends. The incorporation of the nanoclay and bamboo powder improved the tensile strength and Young's modulus of the hybrid composites. The optimum contents of the nanoclay and bamboo powder in the composites were 1% and 10wt%, respectively.

Keywords: Bamboo, biodegradable, composite, hybrid, nanoclay, tensile

Introduction

Biodegradable polymer has been increasingly used due to its biodegradability and environmentally friendly materials. Poly(lactic acid) (PLA) and poly(butylene succinate) (PBS) are blended to form a bio- based polyester which is synthesized from renewable

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resources. PLA is a bio-based polymer derived from renewable resources and has been popular due to its good recyclability and superior strength and clarity. However, PLA is known to exhibit brittleness and have a tendency to deform significantly above its glass transition temperature. This behavior has exhibited the limitation of the utility of PLA (Ljungberg *et al.*, 2003; Li and Huneault, 2007; Chuayjuljit *et al.*, 2017). Various methods have been presented for improving the toughness of PLA such as incorporation of fiber reinforcement, blending with other micro- and nano-fillers. PBS has good processability and flexibility (Ljungberg *et al.*, 2003; Li and Huneault, 2007; García *et al.*, 2008; Yokohara and Yamaguchi, 2008; Meng *et al.*, 2011; Liu *et al.*, 2012; Zeng *et al.*, 2015). PBS can be applied to the extrusion and injection molding process. Blending between the PLA and PBS provided better properties for use in various applications.

Nanoclay is used as a filler to improve the stiffness of the PLA and the blends (Meng *et al.*, 2011). The effectiveness of the filler, however, would largely depend on the filler size and contents. Therefore, a nano-sized filler was used since it is known to provide good tensile and thermal properties.

Natural fiber is widely applied as a reinforcing fiber in polymer composites (Okubo *et al.*, 2004; García *et al.*, 2008; Yokohara and Yamaguchi, 2008; Meng *et al.*, 2011; Liu *et al.*, 2012). Bamboo fiber is one of the best fibers and is excellent in specific strength and biodegradability. Natural fibers such as bamboo fiber can overcome the drawback of biodegradable polymers (Okubo *et al.*, 2004; Liu *et al.*, 2012). In addition, the hybrid system of 2 or more additives would enhance performance of the polymer's properties (Meng *et al.*, 2011; Ziaei Tabari and Khademieslam, 2012). Nanoclay and bamboo fiber would yield higher mechanical properties in PLA/PBS mono and hybrid composites.

In this study, the PLA and PBS blends were prepared. Nanoclay was used to enhance the mechanical properties of the PLA/PBS composites. The hybrid composites of the blend with nanoclay and bamboo fiber were

additionally studied. The mechanical properties of the PLA/PBS blends and the composites were reported.

Materials and Methods

Materials and Sample Preparation

The poly(lactic acid) (PLA, Grade 2003D) was supplied by NatureWorks LLC, (Minnetonka, MN, USA) and the poly(butylene succinate) (PBS, GS Pla-FZ71PD) was supplied by Mitsubishi Chemical Corporation, (Tokyo, Japan). The nanoclay (Cloisite® 30B, d001 = 85°A), a natural montmorillonite modified with quaternary ammonium salt, was provided by Southern Clay Products Inc., (Gonzales, TX, USA). The bamboo fiber was cut, ground, and sieved through a standard 400 mesh sieve. The bamboo fiber content varied from 10-40 wt% in the hybrid composites.

The PLA and PBS were blended in a twin screw extruder (Chareon Tut Co., Ltd., Samutprakarn, Thailand). The barrel temperature was set at 160-200°C with a screw speed of 80 rpm. The content of the PBS in the PLA/PBS blend was 0-40 wt%. The PLA/PBS ratio for example at (70/30) is referred as PLA 70 wt% and PBS 30 wt%. The PLA/PBS (70/30) was a compound with 1, 3, and 5 wt% of nanoclay. The optimum content of the PLA/PBS/nanoclay composite was a hybrid mixed with 10-40 wt% of bamboo. The PLA, the blends, and the composites were fabricated into dumbbell-shaped specimens by compression molding (Chareon Tut Co., Ltd., Thailand) at 200°C.

Characterization

Tensile testing was carried out according to ASTM Standard D638-14 (ASTM International, 2014) using a universal tensile testing machine (CY-6102, Chun Yen Testing Machine Co., Ltd., Taichung, Taiwan). The testing speed was 50 mm/min. At least 5 specimens of each sample were tested.

The morphology of the blends and the composites was observed with a scanning electron microscope (JSM6400, JEOL Ltd., Tokyo, Japan).

Results and Discussion

Mechanical Properties of PLA/PBS Blends

Figure 1 presents the tensile properties of the PLA/PBS blends. The tensile strength of the blends was unchanged when adding 10-20 wt% and then slightly decreased with the increasing PBS content, as shown in Figure 1(a). The tensile modulus of the blends diminished while the elongation at break was promoted with the higher PBS content, as presented in Figure 1(b) and Figure 1(c), respectively. This was attributed to the softness and flexibility of the PBS that reduced the modulus while enhancing the ductility of

the PLA/PBS blends. The highest elongation at break was found at 30 wt% of PBS in the blends.

Mechanical Properties of PLA/PBS/Nanoclay Composites

The addition of PBS improved elongation but decreased the stiffness of the blends. Nanoclay was incorporated into the blends at 1-5 wt% to promote the stiffness. It was found that the tensile strength, Young's modulus, and elongation at break of the PLA/PBS/nanoclay composites decreased when increasing the nanoclay content, as depicted in Figure 2. This might be due to poor

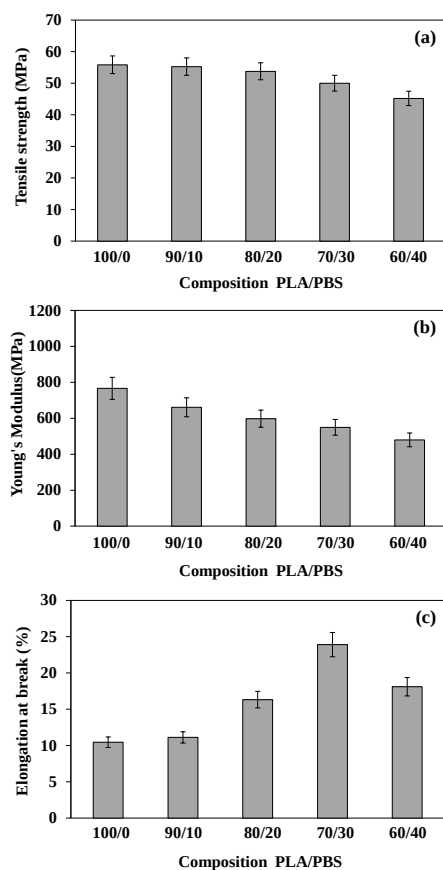


Figure 1. Tensile properties of PLA/PBS blends: (a) Tensile strength, (b) Young's modulus, and (c) Elongation at break

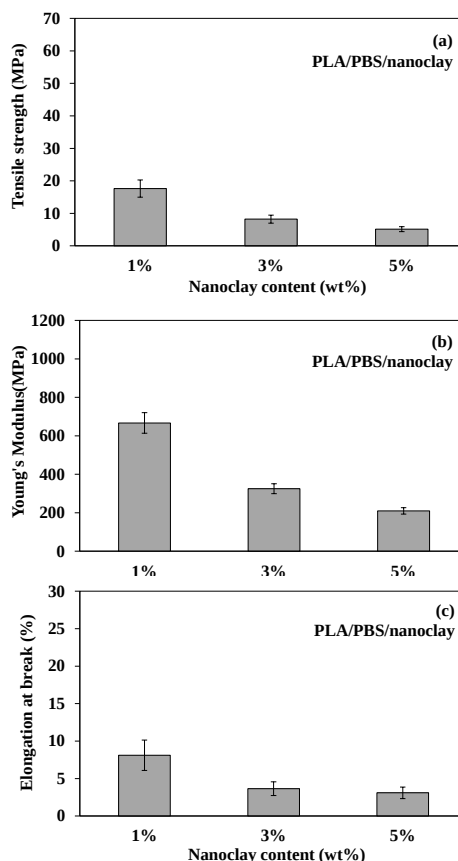


Figure 2. Tensile properties of PLA/PBS/nanoclay composites: (a) Tensile strength, (b) Young's modulus, and (c) Elongation at break

distribution and agglomeration of the nanoclay in the blends matrix even the nanoclay modified by ammonium salt and blended in the twin screw extruder. Hence, this system needs good distribution and prevention of the agglomeration of the nanoclay through the use of a dispersing agent (Immonen et al., 2017).

Mechanical Properties of PLA/PBS/Nanoclay/Bamboo Powder Hybrid Composites

The incorporation of nanoclay did not improve the tensile properties of the PLA/PBS/nanoclay composites. Bamboo powder was mixed into the composites for the hybrid

system. Figure 3 shows the tensile properties of the PLA/PBS (70/30) hybrid composites with nanoclay and bamboo. The content of the nanoclay was 3 wt% incorporated with 10-40 wt% of bamboo powder. The tensile strength and elongation at break of the hybrid composites decreased when increasing the bamboo content. Nevertheless, the hybrid filler system of the nanoclay and bamboo powder promoted the Young's modulus of the hybrid composites as compared to the blends and mono composite with nanoclay, which was considered to be due to the stiffness of the reinforcing bamboo fiber. The maximum of

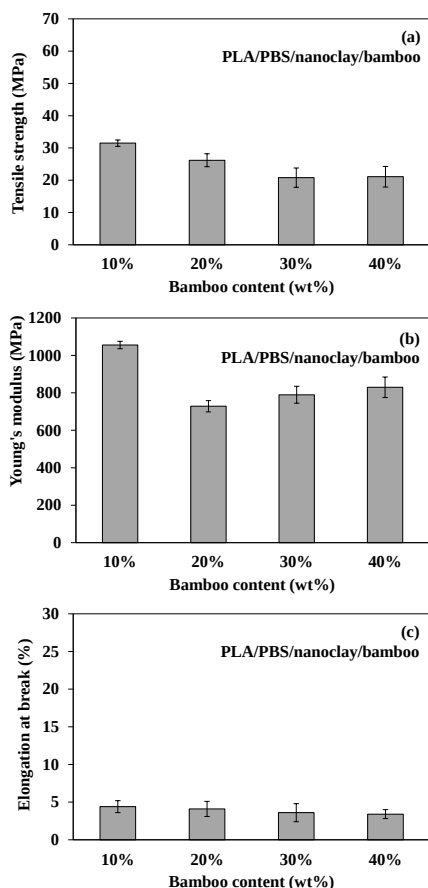


Figure 3. Tensile properties of PLA/PBS/nanoclay/bamboo hybrid composites: (a) Tensile strength, (b) Young's modulus, and (c) Elongation at break

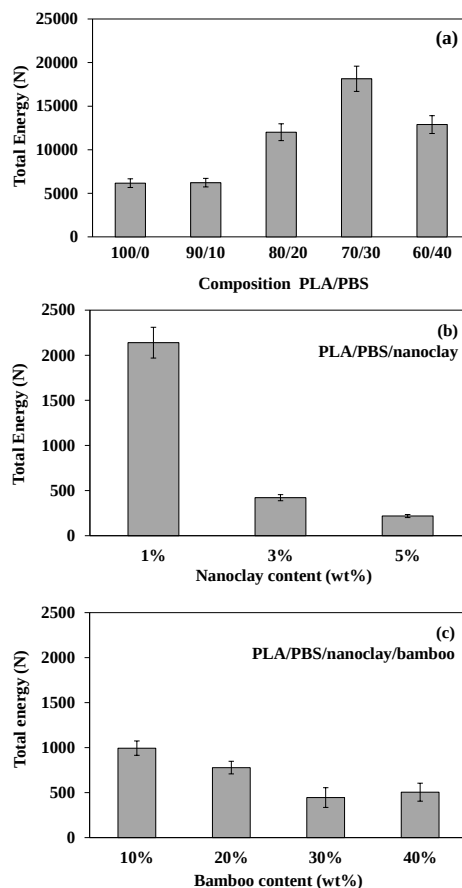


Figure 4. Total energy of PLA/PBS/nanoclay/bamboo hybrid composites: (a) PLA/PBS blends, (b) PLA/PBS/nanoclay composites, and (c) PLA/PBS/nanoclay/bamboo composites

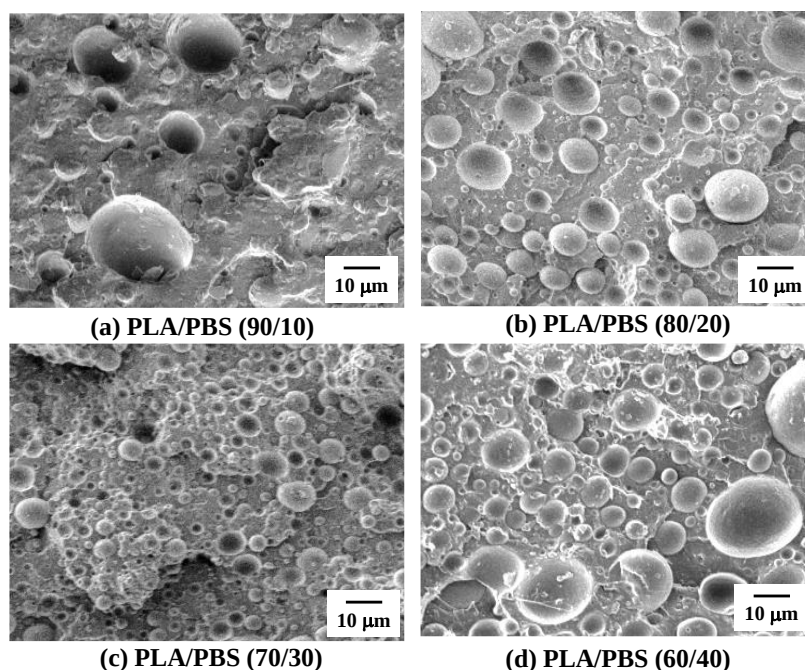


Figure 5. Morphology of PLA/PBS blends

the modulus was observed at 10 wt% of the bamboo content.

Total Energy of PLA/PBS Blends and Composites

Figure 4 illustrates the total energy from the area under tensile testing of the blends and the composites. The maximum of the total energy was in the 70/30 PLA/PBS blends, as shown in Figure 4(a). The total energy significantly decreased with the incorporation of the nanoclay in the composites, as presented in Figure 4(b). However, the total energy was improved in the hybrid composites with the nanoclay and bamboo powder at 10 wt%, as depicted in Figure 4(c).

Morphology of PLA/PBS Blends and Composites

The morphology of the PLA/PBS blends is shown in Figure 5. The PBS dispersed phase can be seen distributed in the PLA matrix. The amount of the PBS dispersed phase increased while the size of the PBS phase decreased with

increasing the PBS content. The morphology indicated the improvement of the ductility and toughness of the PLA/PBS blends. However, the aggregation of the PBS dispersed phase was found in the ratio of 60/40 that affected the reduction of the elongation at break of this blend.

Figure 6 depicts the morphology of the PLA/PBS (70/30) blend and composites with nanoclay and the hybrid composite with bamboo powder. It is difficult to observe the nanoclay in the SEM photographs. However, the large size of the PBS dispersed phase in Figure 3(b) had an influence on the reduction of the tensile properties of the mono-composite with the nanoclay. On the other hand, the small size of the PBS dispersed phase would control the tensile properties of the hybrid composites with the nanoclay and bamboo powder (Fenouillot *et al.*, 2009; Zeng *et al.*, 2015; Boonprasertpoh *et al.*, 2017; Chuayjuljit *et al.*, 2017). In addition, nanoclay might be a natural coupling agent for the bamboo and the blend matrix resulting in improving the tensile

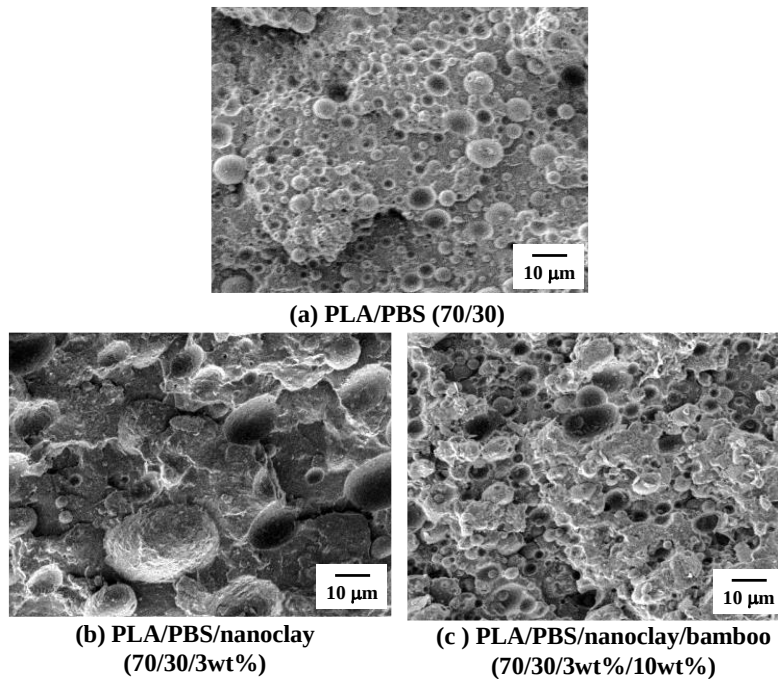


Figure 6. Morphology of: (a) PLA/PBS blend, (b) nanoclay composite, and (c) hybrid composite

strength and Young's modulus of the hybrid composites.

Conclusions

Blending of biodegradable PLA and PBS improved the ductility of the blends at the optimum content of 30 wt% PBS. The stiffness of the blends could not be promoted by the mono-filler of nanoclay. The hybrid filler with nanoclay and bamboo powder enhanced the stiffness of the PLA/PBS blends. The morphology of the blends and the composites indicated that the PBS dispersed phase significantly affected the tensile properties. It can be noted that the optimum content of the biodegradable polymer blends and the hybrid composites could be selected for suitable application as fully environmentally friendly composites.

References

- ASTM International. (2014). D638-14 Standard Test Method for Tensile Properties of Plastics. ASTM International, West Conshohocken, PA, USA.
- Boonprasertpoh, A., Pentrakoon, D., and Junkasem, J. (2017). Investigating rheological, morphological and mechanical properties of PBS/PBAT blends. *J. Metals, Materials and Minerals*, 27(1):1-11.
- Chuayjuljit, S., Wongwaiwattanakul, C., Chaiwutthanan, P., and Prasassarakich, P. (2017). Biodegradable poly(lactic acid)/poly(butylene succinate)/wood flour composites: Physical and morphological properties. *Polym. Composite.*, 38(12):2,841-2,851.
- Fenouillot, F., Cassagnau, P., and Majesté, J.-C. (2009). Uneven distribution of nanoparticles in immiscible fluids: Morphology development in polymer blends. *Polymer*, 50(6):1,333-1,350.
- García, M., Garmendia, I., and García, J. (2008). Influence of natural fiber type in eco-composites. *J. Appl. Polym. Sci.*, 107(5):2,994-3,004.
- Immonen, K., Lahtinen, P., and Pere, J. (2017). Effects of surfactants on the preparation of nanocellulose-PLA composites. *Bioengineering*, 4: 1- 13, doi: 10.3390/bioengineering4040091.

- Li, H. and Huneault, M.A. (2007). Effect of nucleation and plasticization on the crystallization of poly(lactic acid). *Polymer*, 48(23):6,855-6,866.
- Liu, D., Song, J., Anderson, D.P., Chang, P.R., and Hua, Y. (2012). Bamboo fiber and its reinforced composites: structure and properties. *Cellulose*, 19(5):1,449-1,480.
- Ljungberg, N., Andersson, T., and Wesslén, B. (2003). Film extrusion and film weldability of poly(lactic acid) plasticized with triacetine and tributyl citrate. *J. Appl. Polym. Sci.*, 88(14):3,239-3,247.
- Meng, Q. K., Hetzer, M., and De Kee, D. (2011). PLA/clay/ wood nanocomposites: nanoclay effects on mechanical and thermal properties. *J. Compos. Mater.*, 45(10):1,145-1,158.
- Okubo, K., Fujii, T., and Yamamoto, Y. (2004). Development of bamboo- based polymer composites and their mechanical properties. *Compos. Part A-Appl. S.*, 35(3):377-383.
- Yokohara, T. and Yamaguchi, M. (2008). Structure and properties for biomass-based polyester blends of PLA and PBS. *Eur. Polym. J.*, 44(3):677-685.
- Zeng, J. - B., Lia, K. - A., and Du, A. - K. (2015). Compatibilization strategies in poly(lactic acid)-based blends. *RSC Adv.*, 5(41):32,546-32,565.
- Ziaei Tabari, H. and Khademieslam, H. (2012). A study on nanocomposite properties made of polypropylene/ nanoclay and wood flour. *World App. Sci. J.*, 16(2):275-279.