ASSESSMENT OF PHYSICAL, MECHANICAL, AND BIOLOGICAL PROPERTIES OF BAMBOO PLASTIC COMPOSITE MADE WITH POLYLACTIC ACID

Moein Dehghan[1], Mehdi Faezipour[1], Majid Azizi[1], Hamid Zarea Hosseinabadi[1], Ehsan Bari[2,♣], Darrel D. Nicholas[3]

ABSTRACT

The effects of different mixing, bamboo mesh size and heat treatment on the physical and mechanical properties and biodegradability of a polylactic acid (PLA) composite were determined. The results indicated that this composite exhibited high strength in all mechanical properties examined, except hardness using the pure polymer (PLA). The mesh size of the bamboo flour and heat treatment had considerable effects on all tests expect the decay resistance. The water absorbance and thickness swelling of the PLA composite was reduced to nearly zero after 3000 hours immersion in water. Moreover, the fungal decay test results demonstrated that PLA was highly resistant to both Basidiomycetes and Ascomycetes fungi. The brown rot fungi, however, produced an extensive mass loss in the composite composed of different levels of bamboo flour.

Keywords: *Bambusa arundinacea*, biodegradable polymer, decay resistance, flexural strength, heat treatment, water absorption.

INTRODUCTION

Most composites are produced from natural resources (Eshaghi *et al.* 2013, Taghiyari *et al.* 2014, Tajvidi *et al.* 2016). In recent years, the development of bio-composites (BCs) have attracted considerable interest in composite science that use biodegradable polymers and natural fibers because they biodegrade in soil or a composting process and they do not emit any toxic or noxious components (Goda *et al.* 2013, Mohanty *et al.* 2005, Mohanty *et al.* 2000, Suganya *et al.* 2017). The natural resins under consideration are polylactic acid (PLA), polyhydroxybutyrate (PHB), cellulose acetate (CA), and polyhydroxyalkanoates (PHA) (Huber *et al.* 2010). Biofibers are one of the major components of BCs (Goda *et al.* 2013, Mohanty *et al.* 2005). The natural fibers are derived from straw bast, leaf, seed or fruit, and grass. These materials may be equally suitable for use in plastic composites. However, only limited data are available on the possibility of using bamboo in WPC's (Bahari and Krause 2016; Dehghan et al. 2019). The Giant thorny bamboo (*Bambusa arundinacea*) grows throughout the Indian sub-continent as well as south China (Verma and Chariar 2012). Only limited studies have been carried out on the durability of bio-fibers mixed with biopolymers (biocomposites) in natural and controlled situations (Gram 1983, Van den and Bos 2010). However, considerable research has been carried out on the modification of manufacturing possesses. In this regard, furfurylation, acetylation, and heat treatment methods were environment-friendly processes of interest (Bastani *et al*. 2016, Behr *et al*. 2017). Heat

[1]Dept. of Wood Science and Technology, Faculty of Natural Resources, University of Tehran, Karaj, Iran.

[2]Dept. of Wood Science and Engineering, Technical Faculty of No. 2, Mazandaran Branch, Technical and Vocational University (TVU), Sari, Iran.

[3]Dept. of Sustainable Bioproducts, Mississippi State University, Mississippi State, USA.

♣Corresponding author: bari_lenzites@yahoo.com

treatment is one of the processes used to modify the wood properties (Behr *et al.* 2017). This method improves the dimensional stability and resistance to biodeterioration and thus, improved the properties (Mazela *et al.* 2004, Hill 2006, Taghiyari 2011). Heat treatment reduces certain mechanical properties of wood, but improves some properties such as reduced shrinkage and swelling, low equilibrium moisture content, enhanced weather resistance, a decorative dark color, and better decay resistance (Yildiz 2002).

In this study a polylactic acid/bamboo composite was evaluated. The effects of heat treatment and mesh size of the bamboo on the mechanical properties, water absorption and decay resistance of the composite were evaluated.

MATERIALS AND METHODS

Material preparation

High-density polylactic acid (PLA) was purchased from Kia Chemie Paradise Company, Netherlands in granular form. Green stems of Bamboo (*Bambusa arundinacea* Willd.) with an average stem size between 0,8-10mm were obtained from a private garden (Sari, Mazandaran Province, Iran). Thereafter, the stems were air-dried under a sunshade for four weeks and then, cut into small pieces before fragmenting in a Pallmann rhinestone mill (USA). Then, the chips were treated in a warm water chamber for one hour to remove extractive material. The treated chips were air-dried under a sunshade for three days and then, kiln dried at 103±2°C for 24h. The dried chips were then ground in a hammer mill (RETSCH, Germany) and shacked (RETSCH, 3459LS2LV, Germany) to pass a 40-mesh screen. This mixture was then passed through a 60-mesh screen. The bamboo flour was heat treated under atmospheric conditions in a lab oven for 60 min at 190ºC. Afterward, the flour, polymer, and maleic anhydride grafted polypropylene (MAPP) were stored in an oven at 40°C for 24h to avoid moisture absorption. Details on each treatment are shown in Table 1.

Table 1: Compositions of bamboo/plastic polymer mixtures evaluated for thirteen treatments.

Treatment code	Bamboo flour (%)	Polymer (%)	MAPP[a] (%)	Mesh size	Treatment types
A	0	100	0	0	Control
B	55	44	1	80	-
C	45	54	1	80	-
D	35	64	1	80	-
E	55	44	1	60	-
F	45	54	1	60	-
G	35	64	1	60	-
H	55	44	1	80	HT[b]
I	45	54	1	80	HT
J	35	64	1	80	HT
K	55	44	1	60	HT
L	45	54	1	60	HT
M	35	64	1	60	HT

[a]Maleic anhydride grafted polypropylene.
[b]heat-treated.

Composite production

Extrusion

The dry blend was compounded in a counter-rotating twin-screw extruder (Collin, GMBH). Extrusion was carried out at screw speeds of 1.167 rad/s at a 2 kg/h feed rate with temperatures progressively increased from 150, 155, 160, 165, and 170°C between the hopper and the die. Pure polymer and a maleic anhydride grafted polyethylene (MAPP) additive were loaded into the feed hopper using a gravimetric metering device while bamboo fiber was introduced to the side feeder barrel. The bamboo/plastic composite strands leaving the

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circular extruder were cooled, pelletized by a semi-industrial mill (WIESER, WG-LS200/200) and then, oven-dried at 80°C for 24h before being stored under a desiccant prior to compression molding. The test samples were cut in accordance with the applicable standard using a Yueming laser device (CMA1325-RF) at a cutting speed of 10 m/min.

Compression molding

A compression molding method was applied in this research using 17×17cm molds covered with fireproof fabric. The dried and pelletized composites were put into molds and pressed (TOYO SEIKI, GAP1, Japan) at 180°C for 3min under 25 bar. Afterward, the molds were pressed again by another press that was equipped with two cooler plates (TOYO SEIKI, MP2F, Japan) for 5min under 25bar. The samples were stored for one week (25-30°C, 45-65% RH) and then conditioned for one week at 22°C and 65% relative humidity before testing.

Mechanical tests

The samples were evaluated for flexural, tensile, and impact bending properties. Flexural strength tests were conducted on 4 by 12 by 10mm long samples using an Instron 4489 universal testing machine equipped with Test Expert II software using a 10 KN load cell (ASTM D790-90 2016). Five samples were evaluated for each treatment. Span length was 50mm and the load was applied at 5mm/min until failure occurred. The load/deflection was continuously recorded and these data were used to calculate the flexural modulus of elasticity (MOE) and modulus of rupture (MOR) using Equation 1 and Equation 2, respectively:

$$MOR = 1,5 \frac{FL}{bd^2} \qquad (1)$$

$$MOE = \frac{FL^3}{4bd^3D} \qquad (2)$$

where: F= maximum force (N), L= span length (mm), b= sample width (mm), d= sample thickness (mm), D= deflection.

Tensile strength (TS) was determined on 4mm thickness by 10mm width by 130mm length specimens in accordance with ASTM D638-09 (2016). Five replicates were evaluated per treatment. Loading was applied at a rate of 5 mm/min until failure occurred. Tensile strength was calculated using the following Equation 3:

$$TS = \frac{F_{max}}{A} \qquad (3)$$

where: F= maximum force (N) and A= the cross section area (mm²).

Impact bending strength was assessed on five 4mm thickness by 13mm width by 80mm length samples per treatment according to ASTM D256-4 (2016) using an Izod impact machine with 5 Joule (J) energy pendulum apparatus and 60mm support span. Impact bending strength was calculated using the following Equation 4:

$$I = \frac{F}{A} \qquad (4)$$

where: F= maximum force (kJ), A= the cross section area (m²).

A hardness test was performed on five 4mm thickness by 12mm width by 30mm length samples per treatment according to ASTM D2240-03 (2016) using a SHORE-D apparatus (Santam Co.). The hardness

values were calculated according to Equation 5:

$$H = \frac{F}{\pi \times r^2} \times 1000 \qquad (5)$$

where: H is resistance to hardness (N/mm^2), F = force (J), r = radius of the sphere.

Physical tests

Water uptake and swelling test

The effects of BPC treatment on water uptake (WA) and thickness swelling (TS) were determined on 4mm thickness by 80mm width by 10mm length specimens that were initially oven-dried for 48hr at 103°C and weighed (nearest 0,01g) in accordance with ASTM D7031-04 (2005).

The samples were then submerged in distilled water for 18 weeks (3024 hours). Samples were periodically removed from the water so that they could be weighed and their dimensions measured. Water uptake and thickness swell were calculated based upon the initial oven dried values according to Equation 6 and Equation 7:

$$WA(\%) = \frac{W_2 - W_1}{W_1} \times 100 \qquad (6)$$

$$TS(\%) = \frac{T_2 - T_1}{T_1} \times 100 \qquad (7)$$

where: WA is water absorption; W_1 is dry mass before immersing (g); W_2: wet mass after each immersion (g); TS: thickness swelling (%); T_1 is thickness before immersing (mm); T_2: thickness after each immersion (mm).

Density evaluation

The density determination was carried out for each treatment that had different mixing ratios. The density evaluation was calculated in accordance with Kollmann and Cote (1975) by Equation 8:

$$D_0 = \frac{M_0}{V_0} \qquad (8)$$

where: D_o is the density of the oven dried samples (kg.m^{-3}); M_o is dry mass (kg) and V_o: is dry volume (m^3).

Differential scanning calorimetry (DSC)

To determine the heat capacity of the BPCs, DSC was performed with a TGA/DSC1 STAR System, Mettler Toledo thermal analyzer according to ASTM D3418 (2015). The thermal analyses were performed in a nitrogen gas atmosphere with a flow rate of 30mlmin^{-1} at a heating rate of 5°C.min^{-1} over the temperature range from 25°C to 200°C. The weight of the samples was maintained between 20-40mg.

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Biological tests

A modification of the European method EN-113 (2004) as described by Bravery (1978) was used to assess resistance to white and brown rot fungi. Samples were oven-dried (103°C) for 48 hours and weighed prior to being steam sterilized for 20 minutes at 121°C. The decay chambers were glass Petri-dishes containing 4,8% malt extract agar that were inoculated with an agar plug cut from an actively growing culture of *Gloeophyllum trabeum* and *Trametes versicolor* (isolate 18 and 12, Technical and Vocational University of Sari, No 2 (TVU), Sari, Iran) and *Chaetomium globosum* Kunze (isolate P10, University of Hamburg). The cultures were incubated at 25°C until the fungus covered the agar, and then, the sterile samples were placed on glass rods on the surface. The plates were incubated for 60 days at 25°C and 65% relative humidity. At the end of the test, the blocks were removed, scraped clean of mycelium and weighed to determine final moisture content. The blocks were then oven dried and weighed again to determine the final moisture content (MC) as well as the mass loss (ML) according to Equation 9 and Equation 10 (EN-113 2004):

$$MC(\%) = \frac{M_w - M_d}{M_d} \times 100 \qquad (9)$$

$$ML(\%) = \frac{M_i - M_d}{M_i} \times 100 \qquad (10)$$

where: MC is moisture content (%); ML is the mass loss (%); M_i is dry mass before decay (g); M_w is wet mass after decay (g) and M_d is dry mass after decay (g).

Statistical analysis

The data were subjected to a Two-way ANOVA test to discern significant differences between treatments using SPSS (2010) (α=0,05). The resulting treatment means were examined using Duncan's least significant difference test (α=0,05).

RESULTS AND DISCUSSION

Mechanical tests

Modulus of rupture (MOR)

MOR test results are shown in Table 2. According to the data, significant differences in MOR are apparent with varying levels of bamboo flour and heat treatment. This data generally shows that when the amount of bamboo flour increases, the MOR decreases. However, there was no significant difference in the composites made with 35, 45, and 55% bamboo flour. By adding bamboo flour to the polymer, the contribution of the polymer to the composite is reduced resulting in a reduction in MOR because of insufficient adhesion between the flour and polymer (Bledzki *et al.* 1998). The same results have been observed in other studies (Rozman *et al.* 2001, Gholizadeh *et al.* 2015, Liu *et al.* 2005, Poho and Taklau, 2015). Heat treatment of composites also results in a lower MOR compared to untreated samples. This strength reduction is probably due to thermal modification of the fiber surface wettability and fiber brittleness (Esteves *et al.* 2007, Tjeerdsma *et al.* 1998, Rapp and Sailer 2001, Manalo and Acda 2009).

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Table 2: Mechanical and physical properties of bamboo/plastic composites composed of different plastics.

Treatment	Bamboo/Plastic ratio	Properties					
		MOR (MPa)	MOE (MPa)	Tensile (MPa)	IB (J/m²)	HB (MPa)	Density (kg/m³)
A	0%B/100%P	175,13 ± 2,13	6387,67 ± 28,79	48,12 ± 2,41	1,33 ± 0,14	71,50 ± 1,20	1042 ± 10,22
B	55%B/44%P/80M	112,30 ± 2,48	8471,00 ± 89,06	22,14 ± 1,08	0,76 ± 0,09	75,75 ± 0,89	1035 ± 12,66
C	45%B/54%P/80M	115,37 ± 6,63	8743,33 ± 83,97	31,55 ± 14,83	0,65 ± 0,05	75,50 ± 3,89	1031 ± 10,54
D	35%B/64%P/80M	101,67 ± 4,67	8807,67 ± 62,32	37,31 ± 5,02	0,61 ± 0,10	74,50 ± 1,20	1033 ± 17,33
E	55%B/44%P/60M	93,43 ± 1,51	7840,00 ± 19,72	40,27 ± 1,71	0,65 ± 0,10	75,50 ± 1,60	1032 ± 18,96
F	45%B/54%P/80M	102,77 ± 1,79	8224,00 ± 24,01	34,32 ± 4,33	0,68 ± 0,08	75,00 ± 0,76	1032 ± 11,71
G	35%B/64%P/60M	103,63 ± 0,63	7765,33 ± 8,53	41,98 ± 0,45	0,80 ± 0,06	75,25 ± 0,89	1031 ± 12,58
H	55%B/44%P/HT/80M	99,00 ± 0,85	11250,00 ± 11,21	29,39 ± 2,92	0,56 ± 0,03	77,25 ± 1,39	1036 ± 16,87
I	45%B/54%P/HT/80M	96,90 ± 3,82	7860,00 ± 50,83	33,52 ± 2,50	0,63 ± 0,03	75,00 ± 0,76	1032 ± 19,73
J	35%B/64%P/HT/80M	95,07 ± 4,18	7714,33 ± 55,80	47,75 ± 3,86	0,63 ± 0,06	74,75 ± 1,39	1032 ± 14,55
K	55%B/44%P/HT/60M	85,47 ± 6,00	8046,67 ± 79,65	41,66 ± 0,59	0,69 ± 0,11	77,00 ± 1,07	1032 ± 10,11
L	45%B/54%P/HT/60M	88,73 ± 3,51	7777,67 ± 46,74	47,42 ± 1,57	0,70 ± 0,05	75,00 ± 1,31	1031 ± 16,34
M	35%B/64%P/HT/60M	117,87 ± 7,53	10127,67 ± 100,04	47,04 ± 5,12	0,57 ± 0,08	76,50 ± 1,77	1033 ± 10,97

B: bamboo; P: plastic; M: mesh size, HT: heat treatment
± Values represent standard deviations of the means

Modulus of elasticity (MOE)

The MOE test results show that the addition of 35 to 55% bamboo flour significantly increased the MOE values (Table 2). However, no significant difference was found between the samples made with 35, 45, and 55% bamboo flour. The MOE of a composite depends on the mechanical properties of its constituent parts. The reason for the increase of MOE is partially due to the higher MOE of lignocellulosic fibers compared to the pure polymer (Liu *et al.* 2005, Bataille *et al.* 1989, Chaharmahali 2005, Chotirat *et al.* 2007). The increase in MOE of the composite is probably also due to the higher contact surface area between the fibers provided by the smaller particles (Shakeri and Omidvar 2006, Stark and Rowlands 2007). The heat treatment of the composite made with 44%-55% and 35%-64% bamboo to polymer ratios also significantly increased the MOE of the composite, which is probably the result of improved contact between the bamboo and polymer.

Tensile strength

The amount of bamboo flour, particle size, and thermal treatment had a significant effect on the composite tensile strength (Table 2). The tensile strength of the composite was reduced by increasing the amount of bamboo flour from 35% to 55%. This reduction is likely due to the poor adhesion between the bamboo flour and the polymer, resulting in insufficient stress transfer. Polymers play the role of adhesive for bonding wood particles in wood plastic composites and have a significant effect on the bonding between components. Hence, the percentage of plastic is reduced by increasing the amount of wood flour and the degree of adhesion decreases. Moreover, the polymer cannot establish a good connection, resulting in reduced tensile strength with an increase of more than 35% of the flour in the composite structure (Poho and Taklau 2015, Chaharmahali 2005, Chotirat *et al.* 2007). In this regard, the mean tensile strength was greater for the 60-mesh compared to the 80-mesh (Table 2).

Impact bending strength (IB)

The addition of 35-55% bamboo flour to the plastic resulted in a significant decrease in the impact bending strength of the composite. Neither application of heat treatment or change in particle size had a significant effect on IB. Increasing the amount of bamboo flour from 0-55% resulted in a reduction in the IB. However, no significant difference was found between the samples. IB represents the resistance of the material to sudden failure. Therefore, a higher IB signifies the ability of the material to absorb energy (Tajvidi 2004). It is apparent from Table 2 that the addition of bamboo flour to the product reduces the IB. As a rule, the presence of lignocellulose materials increases the energy absorption in composites. Hence, the addition of material such as bamboo powder to composites creates high-stress regions in the polymer matrix, which results in breakpoints followed by the development of cracks from those regions. In other words, failure will develop easier in wood plastic composites (Oksman and Lindberg 1998). Previous investigations (Bataille *et al.* 1989, Chaharmahali 2005, Chotirat *et al.* 2007) also showed that an increased level of bamboo flour in composites results in a decrease in IB.

Brinell hardness (HB)

The data in Table 2 show that the addition of bamboo flour to the PLA resulted in a slight but significant increase in HB. No significant difference was found for heat treatment or the level of bamboo flour in the composite. Other studies have shown that the type of polymer has an influence on the HB of composites. For example, maleic anhydride (MAPP) has a bit more hardness than PLA and the addition of 1% MAPP to the composite results in an increase in HB in comparison with pure PLA (Shakeri and Omidvar 2006, Heidari-Gorji *et al.* 2011, Shahraki *et al.* 2016).

Physical evaluation

Density

The density results of composite treatments in Table 2 indicate that pure polymer (PLA) had a significantly higher density than the PLA/bamboo flour treatments. However, no significant difference was found between the treated and untreated samples. Previous studies demonstrated that different issues such as the low density of bamboo compared to the polymer, the impossibility of fully compressing bamboo flour in the hot press process, and an increase in the percentage of bamboo flour as well as improper mixing of flour and polymer. These factors resulted in improper dispersion of flour in the polymer phase (Madhoushi *et al.* 2009, Madhoushi *et al.* 2012).

Water absorption and thickness swelling

The results of water absorption (WA) and thickness swelling (TS) are shown in Figure 1 and Figure 2. All samples had low WA as well as TS after 3000 hours soaking in the cold water. The maximum range of WA and TS was near 4% for both tests. As would be anticipated, the pure polymer (PLA) did not show any appreciable water absorption or thickness swell. Furthermore, the size of bamboo flour particles had no significant effect on water absorption or swelling.
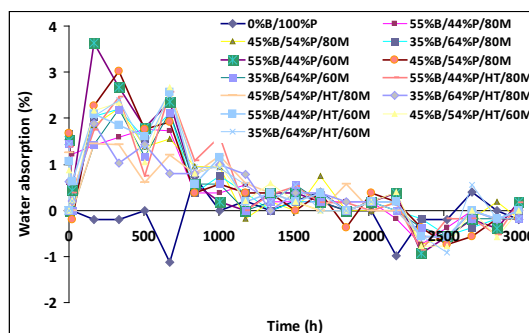
Figure 1: Effect of bamboo content on water absorption of bamboo (B)/plastic (P) composites composed of different plastics. M: mesh size, HT: heat treatment.

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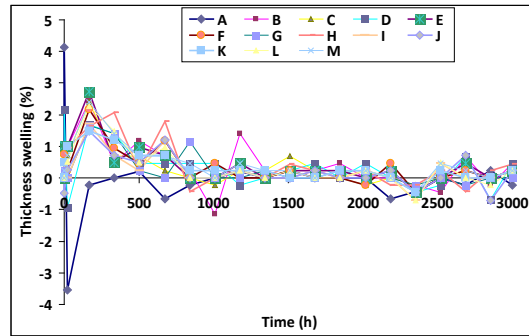
Figure 2: Effect of bamboo content on thickness swelling of bamboo (B)/plastic (P) composites composed of different plastics. M: mesh size, HT: heat treatment.

Differential scanning calorimetry (DSC)

The results shown in Table 3 indicate that the addition of bamboo flour to the composite resulted in a significant increase in the transition temperature. An increase in the glass transition temperature of composites compared to pure polymer represents a change in the softness and flexibility properties (Velasco *et al.* 1996). According to the results in this study, the degree of crystallinity of the composites increased in comparison with the pure polymer. This could be due to the presence of a coupling agent in the composite structure. The coupling agent results in an increase in the crystalline nuclei, which leads to increased development of crystals around the fibers, as well as an increase in the degree of polymer crystallinity. These factors improve the bonding of polymer chains and fibers.

Table 3: Thermal characteristics of bamboo/PLA.

Treatment code	Bamboo/Plastic ratio	Tc (°C)	ΔHc (J/g)	ΔHm (J/g)	Tm (°C)	Tg (°C)	Xc (%)
A	0%B/100%P	100,02	20,25	13,5	154,01	55	14,4
B	55%B/44%P/80M	99,40	27,2	20,4	156,40	68	48,38
C	45%B/54%P/80M	99,70	20,94	34	155,01	70	65,97
D	35%B/64%P/80M	102	23,68	32,92	155,36	59	54,50
E	55%B/44%P/60M	98,79	23,61	32,2	151,05	59	78,73
F	45%B/54%P/80M	98,50	23,79	22,32	150	61	43,31
G	35%B/64%P/60M	98,23	31,32	24,51	153,50	58	40,24
H	55%B/44%P/HT/80M	98,67	23,84	27,5	154	61	65,21
I	45%B/54%P/HT/80M	101	28,42	27,5	155,08	61	53,36
J	35%B/64%P/HT/80M	99	19,5	20,54	155,17	59	33,72
K	55%B/44%P/HT/60M	101,11	27,8	18,7	156,60	61	44,34
L	45%B/54%P/HT/60M	97,70	21,16	24,92	154,50	59	48,35
M	35%B/64%P/HT/60M	99,10	23,14	22,34	155	60	36,68

Crystallization temperature (Tc); Enthalpy of crystallization (ΔHc); Enthalpy of melting (ΔHm); Melting temperature (Tm); Glass transition temperature (Tg); Crystallinity index (Xc).

Biological assessment

Table 4 shows the biological resistance of composites prepared for this study. The decay test is an important indicator of the biodegradability of composite products. It was found that the amount of bamboo flour had a significant effect on composite degradation after 60 days incubation. In general, the lowest weight loss for all three fungi was for treatment A (pure polymer) among all treatments, In the other treatments, it was observed that adding bamboo flour resulted in an increase in mass loss (ML) of the composites. Exposure to the brown rot fungus resulted in the greatest amount of decay. There were no differences in degradation for the white and soft fungi. Overall, the heat treatment as well as the mixing ratios were not effective in preventing the fungal degradation of the composites. However, ML in F and K treatments exposed to the soft rot fungus was slightly higher than for the white rot fungus. Previous studies (Bari *et al.* 2017, Bari *et al.* 2015, Fabiyi *et al.*

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2011) demonstrated that brown, white, and soft rot fungi were able to degrade the composites composed of bamboo and wood flour with PP, HDPE, LDPE, and PVC. In contrast, this study shows that PLA is not water-soluble and is resistant to biodegradation by common wood decay fungi. The brown rot fungus *Gloeophyllum trabeum* caused a considerable mass loss in the mixed composites. Such high mass loss was reported by Cho *et al.* (2008). They were stated that G. *trabeum* attacks parenchyma cells and removes the mid-region of polylamellate structures, with degradation occurring uniformly leading to the presence of a clear zone in the mid-region of the secondary wall of the bamboo. Consequently, this study suggests that wood flour/PLA composites should be superior to those made with other polymers. One of the major issues concerning the lack of decomposition of PLA by the fungi as well as in the water may be the chemical structures of this polymer. Since, PLA is an aliphatic polymer and not a polyacid, therefore, its structure would be rather like a polyester (Martin and Avérous 2001). Hence, this material does not easily degrade in normal environmental conditions.

Table 4: Biological properties of bamboo/plastic composites composed of different plastics.

Treatment	Bamboo/Plastic ratio	Fungi		
		G. trabeum	*T. versicolor*	*C. globosum*
A	0%B/100%P	1,34±0,39	0,60±0,05	0,75±0,63
B	55%B/44%P/80M	24,62±0,80	3,65±0,96	3,29±0,65
C	45%B/54%P/80M	25,38±5,49	2,65±1,69	2,97±0,74
D	35%B/64%P/80M	22,80±3,98	2,27±0,58	10,81±6,49
E	55%B/44%P/60M	26,86±2,70	2,64±0,47	2,60±2,34
F	45%B/54%P/80M	18,28±2,26	2,28±0,11	4,12±3,79
G	35%B/64%P/60M	21,97±0,81	3,57±0,90	3,42±1,79
H	55%B/44%P/HT/80M	24,24±1,48	2,00±0,19	2,37±1,75
I	45%B/54%P/HT/80M	23,56±1,96	2,20±0,70	4,98±2,50
J	35%B/64%P/HT/80M	20,12±1,67	2,98±0,41	5,77±4,38
K	55%B/44%P/HT/60M	19,77±2,29	2,27±0,58	2,64±1,14
L	45%B/54%P/HT/60M	22,91±0,33	2,44±1,01	3,25±2,69
M	35%B/64%P/HT/60M	21,98±3,25	3,06±0,90	2,08±1,33

B: bamboo; P: plastic; M: mesh size, HT: heat treatment ± Values represent standard deviations of the means.

CONCLUSIONS

The fundamental properties of bamboo/plastic composites (BPC's) were evaluated by studying the effects of adding different levels of bamboo flour added to a composite product made with a PLA polymer. The mechanical and water sorption properties and biological decay resistance characteristics were investigated. It was found that the addition of bamboo flour to the PLA polymer resulted in a decrease in the impact bending strength, tensile strength, MOR, and an increase in the MOE as well as water absorption and swelling properties, whereas PLA exhibited resistant to water absorption and swelling. The mixed composite were biodegradable when exposed to wood decay fungi, whereas the pure PLA was totally resistant to biological decay. Based on these results, it is concluded that PLA polymer/bamboo flour based composite looks promising and should be the subject of future studies.

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