Resistance of Abaca Fiber-Reinforced Polypropylene Composites Against Drywood Termites

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Abstract

The study investigated the resistance of recycled polypropylene composites reinforced with abaca (*Musa textilis* Nee) fibers against the drywood termite, *Cryptotermes dudleyi* Banks. Composite boards were manufactured with varying fiber sizes (10 mm, +40 mesh, -40 mesh), with and without 3% maleated polypropylene (MAPP) coupling agent and different fiber loadings of (0, 30, 40 and 50% by weight). In addition, commercially- available wood, plywood and cement-bonded boards were used as reference materials. The resistance was measured by % mass loss and visual evaluation of the extent of damage. Results showed that the composites were more resistant to dry wood termites compared to wood and plywood but less resistant compared to cement-bonded boards. The resistance is inversely proportional to the amount of fiber loading. The addition of a coupling agent may reduce the damage caused by termites. Particle size had mixed effect on the properties evaluated. The study showed that a number of parameters should be considered in the determination of the optimum formulation for composites that would give the highest protection against drywood termites.

Keywords: *Cryptotermes dudleyi*, *Musa textilis*, biocomposites, termite resistance

Introduction

The use of natural fibers as reinforcement for polymer composites has gained much attention in the past years. These materials are preferred over synthetic fibers because of its lower density coupled with cheaper cost. Natural fibers are also renewable, sustainable and are carbon-neutral. Natural fiber reinforced polymer composites are currently receiving great attention as innovative materials for industrial applications in several sectors, such as automotive, appliance, building, packaging and biomaterials (Holbery and Houston 2006, Estrada 2008, Biswas *et al* 2010).

A number of natural fibers have been studied. These include sisal, kenaf, jute, ramie, flax, coir, pineapple, banana, bamboo, wood and abaca (Ichazo *et al* 2001, Jayaraman 2003, Arbelaiz *et al* 2005, Arib *et al* 2006, Mader *et al* 2006, Bledzki *et al* 2007,Klyosov 2007, Yan *et al* 2008,Gu 2009, Islam 2009, Villaseca *et al* 2010, Akil *et al* 2011,Girones *et al* 2011, Abgona et al 2012).

The biological performance of this hybrid material is continuously being studied either in the laboratory and/or in the field. A number of papers have been published on the susceptibility of the composite to or resistance against fungi, algae, bacteria, marine organisms and subterranean termites (Klyosov 2007, Schirp 2008, H' ng 2011, Manalo *et al* 2012,Ibach *et al* 2013, Kartal *et al* 2013, Tascioglu *et al* 2013). However, as of the writing of this manuscript, no studies have been reported on its durability against drywood termites.

This paper reports the resistance of abaca fiber reinforced polypropylene composites against the drywood termite, *Cryptotermes dudleyi* Banks. The effects of fiber loading, particle size and the addition of a coupling agent (MAPP) were investigated. In addition the resistance of the composite was compared with that of wood, plywood and cement-bonded board.

Materials and methods

Sample Preparation

Abaca fiber (AF) was obtained from Ching Bee Trading Corp. (Bulacan, Philippines). Recycled polypropylene (RPP) was supplied by Metalwealth Enterprises Co., Inc. with a density of 0.9 g/cm^3, melting point of 164°C and melt flow index of 21.3 g/10 min (230°C/2.160kg). Maleic anhydride polypropylene (MAPP) was provided by Connel Bros. Company Pilipinas Inc. The MAPP is Eastman™ G-3216 polymer with molecular weight of 60,000, acid number of 16 mg KOH/g, softening point of 142 °C DSC Tm and viscosity of 18,000 cP at 190°C.

The AF was cut using a fabricated fiber cutter to obtain 10 mm samples. Some of the AF were ground by passing through a # 16 wire mesh using a grinder (Thomas-Wiley Laboratory Mill model 4). The ground AF was further sieved with a # 40 wire mesh. The particles retained on the screen (+40) were collected and separated from the particles that were sieved (-40).

Formation of Abaca Fiber Reinforced Polypropylene Composites

The AF of varying particle sizes were oven dried at 60°C for 24 hours to adjust the moisture content to < 3%. These were stored in sealed polyethylene prior to compounding. The RPP and MAPP samples were used as received. The abaca fiber reinforced polymer composites (AFRPCs) were manufactured following a two-step process of compounding and compression moulding using the different formulations in Table 1. The RPP and AF were sequentially fed into two roll mill (Lab Tech LRM150, Thailand). For the formulation with MAPP (3%), it was fed after the RPP. The compounding process was done at a temperature of 180°C and a mixing time of approximately 10 minutes with a rotational speed of 60 rpm.

The compounded materials were formed into flat sheets with a conventional compression molding press (Shinto WFA-37, Japan). The mold was first hot pressed at 180°C for 7 minutes and then cold pressed at room temperature under pressure for another 7 minutes. The pressure for heating and cooling was maintained at 4.9 MPa.

Table 1. Formulation of the AFRPCs

Code	Particle Size	Amount By Weight [%]		
		RPP	Abaca Fiber	MAPP
R100	NA	100	0	0
R730-10	10 mm	70	30	0
R733-10	10 mm	70	30	3
R640-10	10 mm	60	40	0
R643-10	10 mm	60	40	3
R550-10	10 mm	50	50	0
R553-10	10 mm	50	50	3
R730+40	+40	70	30	0
R733+40	+40	70	30	3
R640+40	+40	60	40	0
R643+40	+40	60	40	3
R550+40	+40	50	50	0
R553+40	+40	50	50	3
R730-40	-40	70	30	0
R733-40	-40	70	30	3
R640-40	-40	60	40	0
R643-40	-40	60	40	3
R550-40	-40	50	50	0
R553-40	-40	50	50	3

Resistance of Abaca-Reinforced Composites to Drywood Termites

The drywood termite resistance experiment used a no-choice feeding test. *C. dudleyi* termites were collected from infested wood materials, placed in an enamel tray and left overnight in the dark. Only the vigorous and healthy termites were used in the test. Three pieces from each respective treatment of AFRPCs measuring 10 mm x 50 mm x actual thickness were prepared as board specimens. In addition, 3 samples each of *Anthocephalus chinensis* (Lamk.) Rich. ex Walp.(Kaatoan Bangkal) wood, plywood and cement bonded board were also used to serve as reference materials. These were dried to 14% MC, placed in a petri dish and introduced with 100 workers plus 2 soldiers. The introduction of test insects was conducted twice – at the beginning of exposure and 6 months after exposure. The experimental set-up was kept in a plastic tray, covered with a black cloth and maintained inside the termite exposure room in the laboratory.

The degree of termite damage to each board sample was monitored at quarterly intervals for 12 months. The resistance of each board to drywood termite attack was visually graded using the following rating system.

% Damage	Classification
0	*HR*-Highly resistant (No evidence of termite attack)
1-25	*R*-Resistant (Slightly attacked by termites; from initial nibbling to almost ¼ of volume is lost)
26-50	*MR*-Moderately resistant (Moderately attacked; more than ¼ to almost ½ of volume is lost)
51-75	*SR*-Slightly resistant (Severely attacked by termites; more than ½ to almost ¾ of volume is lost)
76- 100	*NR*-Non-resistant (Destroyed, more than ¾ of volume is lost)

The mass loss caused by *C. dudleyi* was determined from pre-exposure weight (W_1) and post-exposure weight (W_2) of each board sample. The percent weigh loss of a board was computed by the following formula:

$$\%WeightLoss = \left(\frac{W_1 - W_2}{W1}\right)100$$

Data on mass loss were subjected to an analysis of variance (ANOVA) fitted to a 3 x 3 x 2 factorial in a completely randomized design (CRD) and means were separated using Tukey's highly significant difference test (HSD, $\alpha = 0.05$)

Results and discussion

The results of the tests are summarized in Table 2. The AFRPCs were more resistant to drywood termites compared to wood and plywood but were less resistant compared to cement-bonded boards and neat polypropylene (R100). Nibbling was observed in all samples of AFRPCs as well as with cement bonded boards either on the sides or the surface. Nibbling is part of the behavior of drywood termites during host finding activity wherein they will taste or probe the substrate. It will continue to feed if the substrate is palatable or abandon the substrate, if otherwise.

Feeding by *C. dudleyi* on plywood and wood followed similar trends. After 3 months of exposure, less than a quarter of the volume for both samples was lost. Three months after, less than half of the samples remained. The feeding continued for the next quarter until the materials were completely consumed by the final observation at 12 months exposure.

Percent mass loss quantified the susceptibility of wood and plywood to drywood termite infestation. The percent mass loss for the plywood and wood samples were ~94 and ~91%, respectively. This was due to the nature of the two materials. These materials are rich in cellulose which is the main food source of termites. The cement-bonded board remained untouched with < 0.1% mass loss. The resistance of this material was due to the encapsulation of the fiber by cement. In addition, the amount of cellulose-rich fiber may be smaller compared to the amount used in fiber reinforced polymer composites. Drywood termites also do not feed on plastic which explains the negligible weight loss after the 12 month-exposure.

For the manufactured AFRPCs, higher mass losses were observed for boards with higher fiber loadings. Boards with 30% AF had the lowest average mass loss (~0.52%) while boards with 50% AF were more preferred with mass losses as high as 5.24%. This may be due to reduced encapsulation of the fiber by the RPP at higher fiber loading. This may have exposed the abaca fiber for termites to feed on. Statistical analyses revealed that indeed, fiber loading had a significant effect on the severity of termite attack ($p<0.001$).

Table 2. Summary of resistance after a 12 months exposure of the AFRPCs to *C.dudleyi*

Treatment Code	Damage by visual observation	Average Mass Loss [%]
R100	HR	0.10
R730-10	R	0.56
R733-10	R	0.41
R640-10	R	0.76
R643-10	R	1.88
R550-10	R	0.83
R553-10	R	1.72
R730+40	R	0.68
R733+40	R	0.36
R640+40	R	0.51
R643+40	R	0.30
R550+40	R	1.86
R553+40	R	0.37
R730-40	R	0.79
R733-40	R	0.32
R640-40	R	0.72
R643-40	R	1.40
R550-40	R	5.24
R553-40	R	1.73
Reference Materials		
Cement-Bonded	R	0.09
Wood	S	91.40
Plywood	S	94.40

Boards reinforced with the smallest AF (-40) obtained the highest percent mass loss followed by 10-mm and +40 with 1.70, 1.03 and 0.95%, respectively. *C. dudleyi* attack was dependent on the particle size ($p=0.006$). It was not clear why this trend was observed. The use of smaller particle sizes should ensure better encapsulation of the AF by the RPP. It is possible that the smaller AF have agglomerated during the compounding process that resulted to non-uniform distribution of the fibers.

The presence of the coupling agent generally minimized the damage caused by *C. dudleyi* although the difference was not significant ($p=0.260$). The average percent mass loss for boards with MAPP was 1.10% compared with the 1.32% for uncoupled ones. The improved compatibility and adhesion between the AF and RPP used brought about by the addition of MAPP may help explain the higher termite resistance. This may be due to one or more of the following reasons: better encapsulation which minimized void spaces where termites can start to feed or MAPP may be toxic to termites. The second reason necessitates further investigations.

The results of the statistical analysis are summarized in Table 3. The data revealed that fiber loading influenced the resistance of the composites to drywood termites more than the particle size. The interaction of any two and all three variables resulted to significant differences on percent mass loss.

Conclusions

Abaca fiber reinforced polypropylene composites had a wide range of resistance to drywood termites. However, if placed side by side with wood and plywood, it will last longer than the two other materials. On the other hand, for the resistance to be comparable to that of cement-bonded boards and neat polypropylene, the composite should be formed with lower fiber loading, smaller particle size and coupled with MAPP.

The resistance of abaca fiber reinforced polypropylene composites against drywood termites was dependent on a number of factors. The effects of these factors either working alone or in combination with other factors must be considered in the determination of the optimum formulation for the composites.

Table 3. Summary of ANOVA for the mass loss of AFRPCs

Sources of Variation	Mass Loss			
	df	F-value	p-value	Remarks
Particle Size (1)	2	6.00	0.006	**
Fiber Loading (2)	2	25.36	p<0.001	***
Coupling Agent (3)	1	1.31	0.260	ns
1x2	4	5.59	0.001	**
1x3	2	6.18	0.005	**
2x3	2	4.30	0.021	*
1x2x3	4	5.01	0.003	**
Error	36	104.55		

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