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Development of Floor Tiles from Philippine Bamboos

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The study determined and evaluated some important physical and mechanical properties of floor tiles from kauayan tinik (*Bambusa blumeana* J. A. & J. H. Schultes) and giant bamboo [*Dendrocalamus asper* (Schultes f.) Backer ex Heyne] glued with urea formaldehyde (UF) and polyvinyl acetate (PVAc) without and with preservative treatments (deltamethrin, borax and boric acid, and chlorpyrifos) as well as their comparative costs. Standard procedures were used to test and evaluate the properties of the bamboo floor tiles such as relative density (RD), moisture content (MC), hardness (H), thickness swelling (TS), abrasive resistance (AR), and glue bond (GB). Kauayan tinik and giant bamboo are both acceptable for flooring although the former has generally better properties than the latter. UF-glued kauayan tinik treated with either deltamethrin or borax and boric acid is preferred over the others in term of physical and mechanical properties, as well as cost of glue and preservative combinations.

Key Words: Bamboo floor tiles, *Bambusa blumeana*, *Dendrocalamus asper,* polyvinyl acetate, physical and mechanical properties, urea formaldehyde

INTRODUCTION

Bamboo is an ideal substitute for wood because it is fast growing, easily propagated, and has a short rotation period. Numerous bamboo-based products have been developed. Most of the new products are in the form of composites and reconstituted panels such as floor tiles or parquet owing to bamboo's thin-walled, round, hollow, and small diameter.

The natural durability of bamboo is generally low. Once exposed to the natural agents of deterioration, it is prone to be attacked by wood-destroying organisms. Hence, proper preventive and control measures should be used to produce high quality bamboo products.

Non-chemical methods have been used for a long time in villages of many countries and quite often, not much is known about their effectiveness. The benefit of non-chemical method is still uncertain. They cost almost nothing and can be carried out by the villagers themselves without special equipment (Liese 1980). Although non-chemical method like soaking greatly improved the resistance of bamboo it did not totally render the samples immune to beetle damage (Reyes and Garcia 1998).

The chemical applications are generally the most effective methods (Reyes 1993). Information on the effectiveness of the chemical method has been established. This is attributed to the toxicity of chemicals and its residual effect on the materials in contrast with non-chemical method.

The effectiveness of chemical treatment depends on suitable preservatives in sufficient concentration. Over the years the effectiveness of chemical method based on numerous studies has been reported (Hunt & Garratt 1953; Garcia et al. 1997; Giron & San Pablo 1991; Giron et al. 1992). According to Giron & San Pablo (1991) and Giron et al. (1992), 2-thiocyanomethyl-benzothiozole (TCMTB) compared favorably well with sodium pentachlorophenate-based fungicides (NaPCP) in controlling two most common staining fungi associated with discoloration of bamboo. Garcia et al. (1997) reported

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that soaking the bamboo strips in deltamethrin, TCMTB, NaPCP and combinations of deltamethrin with either TCMTB or NaPCP prior to processing gave complete protection against powder post beetle and fungal attack both under laboratory and field conditions.

Bamboo board has been accepted as one of the world's finest flooring materials. There had been numerous technological developments on the bamboo boards (Jaranilla 1964; Ganapathy 1995; Lin 1983; Mohmod et al. 1990; Zafaralla & Malab 2009; Malab & Zafaralla 2006). The Forest Products Research and Industries Development Commission (FORPRIDECOM0M) now FPRDI, developed a bamboo parquet block which was granted Patent No. 386 (Utility Model) on August 24, 1964 by the Philippine Patent Office. The parquet is permanently assembled because the bamboo slats and veneers are securely bonded together with urea resin adhesive (Jaranilla 1964). Bamboo parquet flooring was developed by Import and Export Corporation in Hunan Province in 1986. This a good parquet for export (Zhu et al. 1994).

Preliminary study of Alipon et al. (2004) on glue laminated bamboo from kauayan tinik (*Bambusa blumeana* J. A. & J. H. Schultes) and botong (*Dendrocalamus latiflorus* Munro) showed that these bamboo species have moderately high strength as required for parquet flooring. These bamboo species have been considered excellent material for flooring.

Bamboo materials for floor tiles are commonly treated with various preservatives. Numerous studies have been done on preservative treatments of bamboo materials. Similarly, various types of glues have been used to produce engineered bamboo such as floor tiles. However, there is yet very limited information the effect of both adhesive and preservative on the properties of bamboo floor tiles as well the cost of producing the product without preservative treatment.

The study aimed to: 1. determine some important physical and mechanical properties of floor tiles made of kauayan tinik and giant bamboo glued with urea formaldehyde (UF) and polyvinyl acetate (PVAc) with and without preservative treatments; 2. evaluate the performance of various preservatives on UF and PVAc's glued floor tiles from kauayan tinik and giant bamboo and 3. evaluate the cost of producing bamboo floor tiles glued and treated with various preservatives.

MATERIALS AND METHODS

Bamboo culms were collected from the Ecosystem Research and Development Bureau's (ERDB) bamboo plantation in Mt. Makiling, Laguna. The poles were brought to the laboratory, scraped of their outer skin and then sliced into strips, planed (5 x 25 x 900 mm), treated with preservative (deltamethrin, borax and boric acid, and chlorpyrifos), dried, glued into three layers (urea formaldehyde and polyvinyl acetate) to produce 900 X 400 mm boards and cold pressed (overnight 1 MPa, 15 h).

Glue

Urea formaldehyde (UF) - designed for interior grade hardwood plywood.

The UF glue was prepared using the following formula:

Components	Parts by weight
UF	200
Catalyst R46 – 350	10
Industrial Wheat Flour	40
Water	50

The PVAc was applied as commercially prepared. It is a wood working adhesive (D3) with low water resistance and recommended for interior products. It has 65% resin solid content.

Preservatives

Deltamethrin- white to beige crystalline powder with clear odor.

Borax and Boric acid- white catalysts or granules.

Chlorpyrifos- termicide classified as an organo-phosphate.

Both the glue and preservatives were applied by brushing them into the bamboo strips at 140 g/m^2.

Testing Procedure

Properties of bamboo floor tile samples such as relative density, moisture content, hardness and thickness swelling were tested following the ASTM D805 – 47 (ASTM 1998). Bonding strength (shear strength along the glue line) was tested using ASTM Standards D1037 -72 (ASTM 1998) and abrasive resistance using the Rotary Abrasion Tester.

Abrasion Testing Method

Five samples 101.6 mm^2 were cut from each board. A 5.6 mm diameter hole was bored at the center of the sample and screwed it on the holder's center screw like a nut. Direct load was supplied by pressing the abrasive wheels against the specimen from specific abrasive wheel types. The Taber Wear Index (TWI) was determined by calculating the weight loss in mg per 1,000 cycles of abrasion under test conditions selected by means of a precision balance before and after the test. For example, if a specimen is tested 5000 cycles and looses 500mg of material, the wear index would be 100. Similarly, a material that underwent 5000 cycle of abrasion and lost only 100mg of material would have a wear index of 200. The smaller the TWI of a material, the larger is the resistance to wear (Figure 1).

Statistical analysis

Measured data were subjected to the Analysis of Variance (ANOVA) using Completely Randomized Design (CRD). The Least Square Mean (LSM) was used to determine the difference between and among significant variables.

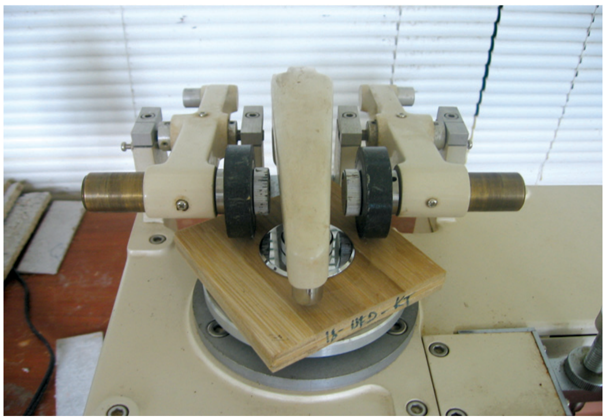

Figure 1. Abrasion test on glued bamboo samples.

Comparative Cost

The cost of glues (UF vs PVAC) and preservatives (deltamethrin and borax and boric acid, and chlorpyrifos) used to produce 900 x 400 mm laminated board was computed and compared.

RESULTS AND DISCUSSSION

Shear Strength

Tables 1 and 2 show the mean and ANOVA of physical and mechanical properties of glued bamboo for floor tiles.

The dry shear strength of giant bamboo and kauayan tinik glued with UF and PVAc each treated using the three types of preservatives as well as those without treatment are significantly different from each other. Between species, kauayan tinik had higher shear strength than giant bamboo both in the dry and wet samples, except in the UF- glued dry samples treated with chlorpyrifos.

Between glues, PVAc samples exhibited higher dry shear strength than UF samples. Conversely, the wet shear strength of PVAc-glued samples was lower than those

Table 1. Mean physical and mechanical properties of glued bamboo for floor tiles.

Species	Treatment	Shear (Kg/cm^2)		Hardness (kN)	TWR No Unit	RD (No Unit)	TS (%)	
		Dry	Wet				2 hrs	24 hrs.
GB	UF-No	26.38	9.51	3.13		0.566	1.627	5.256
	UF-Bo	26.9	8.09	4.74	340	0.626	2.388	8.486
	UF-De	25.51	10.07	4.8	332	0.561	3.358	8.772
	UF-Ch	28.25	9.13	3.96	310	0.584	2.314	6.748
	Average	**26.76**	**9.20**	**4.16**	**327.33**	**0.584**	**2.422**	**7.316**
GB	PVAc- No	30.17	0.383	2.34		0.538	2.54	4.52
	PVAc-Bo	38.94	1.38	4.27	280	0.625	1.692	6.978
	PVAc-De	35.18	1.89	4.81	588	0.636	2.16	6.686
	PVAc-Ch	26.89	0.593	3.53	232	0.619	2.72	4.2
	Average	**32.80**	**1.06**	**3.74**	**367**	**0.605**	**2.278**	**5.596**
KT	UF-No	34.11	5.44	3.57		0.508	1.119	3.234
	UF-Bo	29.18	19.43	4.78	396	0.644	5.88	8.726
	UF-De	28.64	21.5	4.73	292	0.643	6.058	9.292
	UF-Ch	24.7	8.78	4.37	252	0.631	3.754	5.39
	Average	**29.16**	**13.79**	**4.36**	**313**	**0.607**	**4.203**	**6.661**
KT	PVAc- No	44.8	4.93	4.05		0.582	1.179	4.223
	PVAc-Bo	44.78	1.42	4.78	384	0.644	2.682	7.782
	PVAc-De	42.75	4.09	5.68	488	0.65	2.978	7.932
	PVAc-Ch	38.16	2.79	4.32	292	0.65	5.124	9.786
	Average	**42.62**	**3.31**	**4.71**	**388**	**0.632**	**2.991**	**7.431**

GB - giant bamboo
KT - kauayan tinik
UF - urea formaldehyde
No - no treatment
TWR- Taber Wear Resistance
De – deltamethrin
Ch - chlorpyrifos
PVAc - polyvinyl acetate
Bo - borax and boric acid
TS- Thickness swelling
RD- Relative density

Table 2. ANOVA on the effect of adhesives and preservatives on the properties of *Bambusa blumeana* and *Dendrocalamus asper.*

Source of Variance	DF	F-VALUE/PROPERTIES					
		SHEAR		Hardness	TWR	RD	Thickness Swelling
		DRY	WET				
		(Kg/cm^2)	(Kg/cm^2)	(kN)	No Unit	No Unit	(%)
Species (A)	1	7.71*	22.91**	23.07**	0.10^{ns}	4.64*	1.36^{ns}
Adhesives (B)	1	18.24**	169.9**	0.00^{ns}	1.56^{ns}	3.81^{ns}	0.87^{ns}
A x B	1	2.52^{ns}	2.70^{ns}	13.75**	0.18^{ns}	0.041 ^{ns}	6.12*
Preservatives (C)	3	1.14^{ns}	8.16**	47.38**	0.75^{ns}	11.67**	12.65**
A x C	3	0.68^{ns}	5.40**	1.49^{ns}	1.39 ^{ns}	1.12 ^{ns}	1.85 ^{ns}
B x C	3	0.73^{ns}	7.49**	2.17^{ns}	3.30*	0.56 ^{ns}	1.49 ^{ns}
Error	64						
Corrected Total	79						
CV (%)		27.36	46.71	10.77	49.13	8.45	33.15
R^2 (%)		44	82	80	24	46.5	49.6

TWR- Taber Wear Resistance; RD- Relative density; DF- degrees of freedom; **Highly significant at 99% level of probability; *Significant at 95% level of probability; ^{ns} Not significant; CV- coefficient of variation; R^2 (%) – coefficient of determination

applied with UF. Among treatments, deltamethrin gave the highest wet shear strength in the UF and PVAc-glued samples of giant bamboo (0.105 MPa and 0.185 MPa) and kauayan tinik (2.11 MPa). This can be attributed to the thermoplastic characteristics of PVAc.

Since PVAc is thermoplastic, it repeatedly softens by heating and hardens by cooling. Hence, it has a very low resistance to changes in temperature such as when subjected to accelerated weathering. Furthermore, PVAc develops bond strength from loss of water, they do not cross link unlike UF which undergoes reaction between resins and catalysts (Olson & Bruce 1947).

Weathering is primarily the result of repeated dimensional changes in the surface layer of a piece of wood. Being hygroscopic substance, wood is readily influenced by the constantly changing moisture conditions of the atmosphere, with the result that the exposed surfaces of unprotected piece absorb moisture and swell in rainy and humid weather and give up moisture and shrink during period of dryness. Other factors, such the action of frost, the abrasive effect of rain, hail and wind-blown particles of dirt or sand, and the chemical changes of the wood substance induced by light, moisture, and oxygen, may contribute to the general process of weathering of wood (Hunt and Garratt 1953). For instance, when the relative humidity (RH) of air is very high then the wood absorbs water from the air. Water and glue diffuses into the wood. Resin like PVAc coagulates and coagulation is reversible depending on RH.

According to Lin (1983) dry shear along the glue line should exceed 1.4 – 2.0 MPa (14.27 kg/cm^2 – 20.39 kg/cm^2) for flooring used under light and medium traffic conditions, respectively. There is no standard or state regulation yet with properties requirements. The properties of bamboo floor board are usually compared with wood species traditionally used for floorings.

ANOVA showed significant difference in the dry shear strength between species and adhesives. The interactions of species x adhesives, species x preservatives, and species x adhesives x preservatives gave no significant results. In the wet shear strength, the effect of sources of variance was also not significant except preservative.

The significant difference between species may be attributed to the anatomical and chemical properties variations of giant bamboo and kauayan tinik. Espiloy et al. (2007) reported that the physical properties of bamboo significantly differ among species and within species. For instance, RD among species ranges from 0.461 to 0.644. Within species like kauayan tinik and giant bamboo, RD increased from the butt towards the top of the culm. The butt of the culm had higher shrinkage values in thickness and width than the middle and top portions both at 12% nominal MC and oven-dry conditions. There was a general increase in strength properties towards the top of the culm.

Across species, the vascular bundles vary in form, size number and shape. Fiber length influences physical and mechanical properties. For instance, it affects paper's strength properties since the length of the individual fiber is associated with the number of bonding sites between fibers (Wangaard & Woodson 1973). The fiber length of giant bamboo and kauayan tinik is 3.78 mm and 1.95 mm, respectively (Tamolang 1957). On the other hand, giant bamboo has higher lignin content and alcohol benzene extractives (23.5 % and 5.8 %) than kauayan tinik (20.4

% and 3.1 %). The silica content of the latter (3.4 %) was however lower than the former (2.1 %) (FPRDI 2000). These could have affected the properties through possible interactions of the number and bonding sites of the bamboo elements to the adhesives and preservatives.

Several studies on plywood and veneers glued using different adhesives with and without preservative treatments were reported to have either similar or different results (Shukla 1991; Dimri & Kumar 1998).

Hardness

The hardness of glued bamboo samples was improved with all of the treatments (Table 1). Kauayan tinik had significantly higher mean hardness (4.53 kN) than giant bamboo (3.95 kN).

The effect of adhesives was not significant indicating any difference between the hardness of UF and PVAc-glued samples. The insignificant difference can be attributed to the inherent hardness of bamboo which probably overshadowed the effect of adhesives.

The interaction between species x adhesives was significant. This indicates that the hardness of either kauayan tinik or giant bamboo samples differ depending on the adhesives. The difference in hardness of PVAc-glued kauayan tinik was significantly higher (4.71 kN) than those glued with UF (4.36 kN). Conversely, in giant bamboo sample, UF had significantly higher hardness (4.16 kN) than those glued with PVAc (3.74 kN). On the other hand, preservative treatments generally increased the hardness of bamboo as shown by the significantly lower values of samples without treatment than those treated with borax, deltamethrin, and chlorpyrifos.

Taber Wear Index

UF and PVAc glued giant bamboo treated with chlorpyrifos had the lowest TWI (310 and 232), respectively, indicating better abrasive resistance than those of other treatments. For kauayan tinik, both UF-and PVAc-glued samples treated with chlorpyrifos had the lowest TWI (252 and 292). Nevertheless, the TWI of UF-glued kauayan tinik treated with deltamethrin and PVAc-glued giant bamboo samples with borax and boric acid was 292 and 280, respectively.

The TWI of glued bamboo without treatment was not determined because standard strips for testing were not available during the experiment.

Relative Density

The relative density (RD) of glued kauayan tinik (0.607 & 0.632) was significantly higher than those of giant bamboo (0.584 & 0.605). On the other hand, the RD of glued samples treated with deltamethrin, borax and boric acid and chlorpyrifos did not significantly differ. All glued samples with any of the treatments had significantly higher relative density than those without treatments.

Density is a measure of the amount of cell wall substance in the material. It is closely related to the relative proportions of vascular bundle and ground tissue which greatly influence most of the plant's mechanical properties. (Janssen 1987; Espiloy et al.1992, 2007; Widjaja & Risyad 1985). This may explain the significantly higher strength properties of kauayan tinik than those of giant bamboo.

The relative density of glued bamboo regardless of the treatments obtained in this study exceeded 650 kg/m^3. The density (Dm) was calculated using the formula:

$$Dm = RD\,(1 + MC/100)1000.$$

Where:

Dm = density at any given MC
RD = relative density
MC = moisture content

Lin (1983) suggested that for light traffic conditions, an air-dry density greater than 650 kg/m^3 is required.

Thickness Swelling

The thickness swelling (TS) of glued giant bamboo and kauayan tinik increased with the preservative application. Samples treated with deltamethrin gave the highest TS after 2 h and 24 h soaking (3.358 % and 8.772%).

The effect of preservatives (C) and interactions between species (A) x adhesives (B) were significant. However, the effect of the interactions between A x B, and B x C were not significant. This indicates that preservative treatments affected the TS of glued bamboo depending on the species and adhesives.

Glued bamboo treated with deltamethrin, and borax and boric acid showed significantly higher TS after 24 h soaking than those with chlorpyrifos. The TS of UF glued giant bamboo was significantly higher (7.32 %) than those of the PVAc (5.60 %). On the other hand, PVAc-glued kauyan tinik had significantly higher TS (7.43 %) than giant bamboo (5.60%).

Espiloy & Espiloy (1992) reported that the average thickness shrinkage of giant bamboo (14.70%) was higher than that of kauayan tinik (12.02%). The difference was not however statistically significant. Conversely, the relative density of the latter (0.644) was significantly higher than the former (0.547). Results were based on samples without any glue and treatments. It is a common knowledge that shrinkage and swelling are positively correlated. She explained that the relatively higher frequency of fibrovascular bundles, low moisture content and high relative density in the thinner culm wall at the top of species with higher relative density may account for such reduction of shrinkage.

Table 3. Comparative material cost between floor tiles (900 x 400 mm) glued with UF and PVAc and treated with various preservatives.

Materials	Cost (Php)	
	UF-glued	PVAc -glued
Glue	6.53 (280 x 0.0233@ 23.32/kg)	11.40 (280 x0.0407@40.70/kg)
Catalyst	7.00 (14 x 0.5@ 500/kg)	7.00 (14 x 0.5@500/kg)
Wheat flour	1.68 (40 x 0.03@30/kg))	1.68 (40 x 0.03@30/kg)
Bamboo	160	160
Total Cost Without Preservative Treatment	175.20	180.50
Total Cost With Preservative Treatment		
Using deltamethrin[a]	185.20 [10 (2,000/L]	190.50 [10 (2,000/L)]
Using borax and boric acid[b]	177.06 [1.86 (930/500g)]	182.36 [1.86 (930/500g)]
Using chlorpyrifos[c]	193.20 [18 (1,800/L)]	198.50 [18 (1,800/L)]

[a] Php 10.00/panel; [b] Php 1.86/panel; [c] Php 18.00/panel

Comparative Cost

The total cost for gluing 900 x 400 mm floor tiles (three layers) using UF and PVAc was P15.21 and P 20.08, respectively. On the other hand, an additional P10.00, 1.86 and 18.00 was entailed when the glue laminated bamboo was treated with deltamethrin, borax and boric acid, and chlorpyrifos, respectively (Table 3).

CONCLUSIONS AND RECOMMENDATION

The properties of kauayan tinik and giant bamboo glued with either UF or PVAc, with or without preservative treatments are acceptable for floor tiles. The properties of glued kauayan tinik are generally better than those of the giant bamboo.

On the other hand, the properties of glued bamboo treated with any of the three preservatives generally improve, with those treated with deltamethrin, and borax and boric acid generally exhibiting better properties than those with chlorpyrifos. Hence, UF-glued kauayan tinik treated with either deltamethrin or borax and boric acid are preferred to the others in terms of better properties as well as cost of the glue and preservative combinations.

It is recommended that the durability of the glue-laminated bamboo treated with various preservatives be studied to validate their effectiveness on glued products such as floor tiles. A study on other adhesives and preservatives using locally available sources as well as the development of improvised equipment for bamboo processing is also highly recommended to magnify bamboos' contribution to the national economy.

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