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Performance of Polyvinyl Acetate and Phenol Resorcinol Formaldehyde as Binding Materials for Laminated Bamboo and Composite-ply from Tropical Bamboo Species*

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Abstract: Polyvinyl Acetate (PVAc) and Phenol Resorcinol Formaldehyde (PRF) were used to bind together three-layers laminated bamboo and composite-ply consisting of a single-layer bamboo strips and two layers of wood veneers. Tropical bamboo species *Gigantochloa scortechinii* were used in the study. Both panels were tested for their physical, mechanical and gluing properties. The results shows that both panels possess about the same values in density, MoE and MoR. These panels possess almost the same values in density about 780 (kg m^{-3}), Modulus of Elasticity (MoE) between 15, 000 to 16, 210 N mm^{-2}, Modulus of Rupture (MoR) in bending tests between 98 to 126 N mm^{-2} and means compression strength of 63 N mm^{-2} at 12% moisture content. Both panel were found to possess good gluing strength. The overall strength of these laminates passed the requirements of standard studies. These results are equivalent with some of the structural strength groups, which comparative with some high density commercial solid wood.

Key words: Polyvinyl Acetate (PVAc), Phenol Resorcinol Formaldehyde (PRF), laminated bamboo, composite-ply bamboo, bamboo strength

Introduction

Bamboos have a centuries-long documented history of human use. It has been used by communities throughout these countries to satisfy basic necessities-food, fuel, shelters, agriculture tools, cooking vessels, water jugs, arts, crafts, furniture, musical instruments, weapons and a host of other items. This plants has directly or indirectly contributed to the substance of over one billion people, mostly in the developing countries. Although bamboo has numerous uses, most of these are traditional, low-value and temporary products (Razak *et al*., 1997). The potential for high value added products has not been fully explored and in most cases production has not reached a commercial scale, despite the fact that timber is becoming increasingly scarce and the potential of bamboo as a viable substitute for wood is widely acknowledged.

In order for the bamboo industry to have the competitive edge in the international market, there need a shift-from the production of low end to high value added products. Bamboo is somewhat similar in properties to a certain timbers. Hence, such advantages should be exploited to make it into an ideal form of resource supplement for manufacturing and construction sectors.

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Efforts to promote its utilization into furniture and structural uses have not received favorable responses due to the low product quality and low market returns. Lack of research on product development also contributed to the lack of interest of public towards this material. Recent effort to rejuvenate interest on modified bamboo through lamination for furniture received overwhelming responses from the public.

This study present the properties of laminated bamboo and composite-ply that were bind together with PVAc and PRF.

Materials and Methods

The bamboo species used for making the three-layer laminated and composite bamboo ply for this study was *Gigantochloa scortechinii*. It is one of the most important and extensively used species in the bamboo industry and is the most widely distributed in Malaysia. All bamboo culms used in this study were taken from the Forest Research Institute of Malaysia's research trial plot in Nami, Kedah in Malaysia. Selected culms of young and matured age (2 and 4 year-old) were harvested, split into smaller sizes, treated with preservative and kiln dried. A very mild drying schedule were used as to avoid drying defects (Razak *et al*., 2000). After reaching about 10% moisture content, all strips were than manufactured into three-layer bamboo strips and a mixture of bamboo-wood consisting of one-layer of bamboo and two-layers of wood strip. The arrangement of layer are shown in Fig. 1. Types of adhesive used were phenol resorcinol formaldehyde and polyvinyl acetate (PVAc) with moisture resistance capability. These adhesives were chosen since it is commonly used by the furniture industry in Malaysia and easily obtained in the market. The manufacturing was carried out manually with hand-held roller and clamping. All boards were made from bamboo of internodes 6, 7, 8 and 9.

The strength tests for shear, compression parallel to grain and static bending were conducted using the Shimadzu Computer Controlled Universal Testing Machine on split and laminated bamboo-ply. The tests were conducted in the Structural and Mechanical Laboratory of Forest Research Institute Malaysia. The preparation of the test blocks and methods were made according to the ASTM D 143-52 (Anonymous, 1974) with some modifications. Ten replicates were used for each test.

(A): Three-layers laminated bamboo

(B): Composite-ply consisting of a single layer Bamboo and two layers of wood veneers

Fig. 1: Configuration of layer arrangement

Results and Discussion

The strength of bamboo boards from matured bamboo culm show slightly higher values than the younger culm (Table 1). These were expected as matured culms posses thicker cells wall materials and higher basic densities (Razak, 1998).

Whilst, strength properties of laminated bamboo boards applied with different type of adhesives indicate that the PRF treated board shows slightly higher values in the compression and bending strengths when compared to the PVAc (Table 2).

The 3-layer bamboo strip (TLS) exhibited highest basic density as compared to the single strip and bamboo composite board (CBP). The CBP however, showed a lower value of their basic density compared to single-layer. The basic density of single-layer strip, TLS and CBP were 670, 780 and 590 kg m^{-3}, respectively. A lower basic density of CBP was probably due to the usage of LRM, a low density species (Table 3).

In general, laminated bamboo boards, regardless of its matrix arrangement or mixture of species, were found to possess equivalent or higher strength properties than some of the commercial hardwood species (Table 4). This observation is in agreement with other findings such as Zoolagud and Rangaraju (1991) and Anonymous (1999).

In comparison to strength properties, a single bamboo strip possesses higher bending strength than TLS and CBP. However, data run under statistical analysis indicated that there were no significant

Table 1: Means comparative strength on single bamboo strip (with skin) of the 2 and 4-years old culms

		Compression strength (N mm^{-2})	Bending strength (N mm^{-2})
Culm age	Young (2-year old)	55	160
	Mature (4-year old)	60	171

Table 2: Means comparative strength of 3-layers bamboo board manufactured from 2 and 4-years old culms

			Compression strength (N mm^{-2})	Bending strength (N mm^{-2})
Type of glue used	PRF	2-year	59	113
		4-year	67	126
	PVAc	2-year	58	110
		4-year	63	118

Note: PRF is phenol resorcinol formaldehyde, PVAc is polyvinyl acetate (moisture resistance type)

Table 3: Means physical and mechanical properties of single strips, laminated 3-layers and composite bamboo boards of 4-years old bamboo

Properties	Bamboo strip (single)	3-layer bamboo strip (parallel laminate)	Composite bamboo ply (parallel laminate)
Moisture content	10 to 12%	10 to 12%	10 to 12%
Density (kg m^{-3})	670	780	590
Compression strength			
Longitudinal (N mm^{-2})	60	63	54
Transverse (N mm^{-2})	44	38	26
Bending strength			
MOR (N mm^{-2})	171	118	98
MOE (N mm^{-2})	15,520	16,210	15,830
Shear strength (N mm^{-2})	4.5	9.4	7.2
Tensile strength (N mm^{-2})	154	125	101
Swelling in 2 h			
Width	0.3%	0.4%	0.7%
Length	0.6%	0.8%	1.2%
Thickness	3.4%	4.9%	6.2%
Surface absorption in 2 h	4.1%	6.6%	7.8%

Table 4: Means comparative strength of laminated bamboo (4 years old) and some common tropical timber species

	MoR (N mm^{-2})	MoE (N mm^{-2})
Teak	98	12,839
Shorea species	101	12,545
Bamboo strip (single)	171	15,520
Laminated bamboo 3-layer	118	16,210
Laminated bamboo 4-layer	109	15,940
Composite bamboo ply 3-layer	98	15,070

different on MOE between all samples tested. This confirms earlier studies that MOE is not influence by the number of layers, as its is a function of stiffness.

Laminated bamboo possesses excellent mechanical properties especially with regards to tensile strength. Sekhar and Bhartari (1960) also made similar finding in his studies on the strength properties of bamboo. Tensile strength and compressive strength of laminated bamboo in the longitudinal direction were also found to be higher than those of wood. However, it has low parallel to grain shear strength and low resistance to splitting compared to wood (Janssen, 1980). Therefore, this property has been advantageously utilized in splitting the bamboo into strips for laminated boards.

Laminated bamboo-ply boards with higher ply layers have greater strength value compared to the boards of lesser ply layers (Table 3). This property can be of advantage when used in making construction and building materials when strength is the most crucial factor.

In dimensional stability aspects, the change of moisture content was significantly less than compare to most common tropical hardwoods (Anonymous, 1999). This makes bamboo laminated boards most suitable for used as flooring and paneling materials.

Studies on the strength properties of laminated bamboo boards applied with different types of glue indicated that the PRF treated samples possess slightly higher values in the compression and bending strength when compared to the PVAc (Table 2).

Conclusions

Laminated bamboo-ply boards provide higher strength properties and usage, as well as having better dimensional stability than bamboo composite boards and some solid wood. These boards are expected to be more important in the future furniture and construction industry. They have high strength properties in term of MOR and MOE values. However, composite bamboo that has strength of slightly lower can also be used as substitute to laminated bamboo in order to cut cost especially in panel products.

PRF adhesive proof to be slightly better than the moisture resistance PVAc. However, the differences in the bonding strength is very small and of no significant diffrences in the statistical analysis. The PVAc adhesive would be recommended for use by the bamboo-based industry as they are much cheaper than the PRF and are more readily available commercially in the local market.

With the sourcing of wood from natural forest is becoming increasingly scarce, the used of laminated bamboo and composite boards for future substitute to the wood industry is expected to receive good respond by the public. The potential of bamboo, particularly in laminated form, to replace wood is being increasingly acknowledged. Hence, it is important to address the issues mentioned earlier to fully exploit the versatility of bamboo not only in furniture but also in construction and other major applications.

Some technologies of the manufacturing laminated bamboo boards have been generated during the duration of these studies. However, despite these accomplishment, a lot of R and D effort still needs to improve processing techniques especially in turning bamboo to laminated boards and furniture. These include the development of a new products and designs.

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