3.5. Architecture, Engineering and Construction

Physical and Mechanical Properties & Fire Engineering (Poles & Engineered bamboo products)

EFFECT OF LAMINATE THICKNESS ON SELECTED STRENGTH PROPERTIES OF THERMAL-MODIFIED LAMINATED BAMBOO BOARD AS A STRUCTURAL MATERIAL

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Abstract

The use of bamboo as a structural material is growing as a topic of interest as focus is drawn towards more sustainable construction practices. Composite board made from bamboo, termed laminated bamboo board (LBB), has gained the particular interest of researchers and scientists of late, since it can be manufactured in well-defined dimensions similar to commercially available wood products. However, due to its use as a structural material, there is need to investigate its strength properties. This study therefore, investigates the effects of lamination and thermal treatment on selected strength properties of laminated bamboo as a structural material. Twenty Bamboo culms of 4yrs old were harvested from Gbedun, Akanran, Ona-Ara Local Government Area of Oyo State, Nigeria. The production of laminated bamboo board was carried out in the Department of Forest Resources Management using a circular saw. Laminate thickness of 4mm, 6mm, 8mm and 10mm were used to produce boards and were also thermal treated by steaming at 105 ± 2^0C temperature for 4hrs, 8hrs, 12hrs and un-treated (control). Selected strength properties test like; Modulus of Rupture, Modulus of Elasticity, Impact Bending and Maximum Compressive Strength Parallel to Grain were carried out on the laminated samples and data were analysed using descriptive statistic and ANOVA at $P<0.05$. From the results, Modulus of Rupture ranged from 35.16N/mm^2 to 92.82N/mm^2, Modulus of Elasticity ranged from 3986.29N/mm^2 to 19516.16N/mm^2, Impact Bending ranged from 0.33m to 1.21m and Maximum Compressive Strength parallel to grain ranged from 41.44N/mm^2 to 50.00N/mm^2 with strength properties of the boards produced increasing with increase in laminate thickness and decreasing with increase in thermal treatment periods. The study further showed that strength properties of untreated boards are usually higher than those of the treated ones.

Keyword: Bamboo**,** Strength properties, Laminate thickness, Thermal modification, glue laminate

Introduction

The depletion of forest resources and serious degradation of the environment are some of the problems the world is presently facing. The tropical forest, at an alarming rate today, is decreasing and the demand for wood and wood–product has continued to increase in proportion to human population. In an FAO report, the consumption sawn wood and wood based panels in 1993 was put at 2.688 and 0.121 million m^3 respectively while a projection for 2010 was put at 4.704 and 0.688 million m^3 (FAO 1995). These increases represent 57.1% and 17.6% for sawn wood and wood-based panels respectively. It is expected that there would continue to be high demand for wood due to its versatility and affordability over and above other construction materials. The high demand for wood and wood- based panels would result in over-exploitation of both the natural and plantation forest with its attendant environmental consequences (Geomatic 1998; Youngquist and Hamilton 1999; Falemara *et al.* 2012).

The over exploitation of existing forest resources and the disappearance of economic hard wood species are of great concern to the wood scientist, technologist and users as well. The supply of quality timber from the natural forest to wood based industries is no more available in the quantities that can sustain the usual large diameter class logs required by these industries.

Table 1: Production, Trade and Consumption of Wood-Based Panels, 2008.

County/Area	Production ($1000m^3$)	Imports ($1000m^3$)	Exports ($1000m^3$)	Consumption ($1000m^3$)
Nigeria	95	68	3	161
West Africa	986	126	336	775
Africa	2962	1019	574	3407
World	268788	73257	78342	263702

Source: FAO 2011.

With the high demand for wood, finding a substitute wood for structural purpose is an urgent necessity.

Bamboo can be used as an alternative source of raw materials for the wood industry due to its ability to grow in various soils, fast growth, short rotation and other desirable properties.

Bamboo is one of the oldest building materials used by mankind (Abd.Latif *et al.* 1990). It is a natural composite material with a high strength-to-weight ratio useful for structures (Lakkad 1981). The bamboo culm or stem has been made into an extended diversity of products ranging from domestic household products to industrial application. Examples of bamboo products are food containers, skewers, chopsticks, handicrafts, toys, furniture, flooring, pulp, and paper, boats, charcoal, musical instruments and weapons. In Asia, bamboo is quite common for bridges, scaffolding and housing, but it is usually a temporary exterior structural materials. Bamboo shoots are an important source of food (especially *Dendrocalamus asper* eaten as vegetable), and a delicacy in Asia.

Due to its (bamboo) circular and hollow shapes, for timber substitute materials, bamboo must first be converted into a flat and a relatively thick material. By using certain adhesives, it is possible to use bamboo strips to produce timber-like material, called Laminated Bamboo Board (LBB) to meet many service requirements especially for furniture.

Bamboo intended for use as a structural material should be treated to resist insect and fungi attack.

Thermal modification is an alternative way of protecting wood from decay and insects without the use of toxic preservatives and improving its dimensional stability (Rapp 2001; Homan and Jorissen 2004; Sundqvist 2004). It (thermal modification) is the process of subjecting solid wood to temperatures close to or above 200^0C for several hours in an atmosphere with low oxygen content (Rapp 2001). This process results to cell wall components modification. Portions of hemicelluloses are hydrolyzed into their monosaccharide components such as glucose, galactose, mannose, arabinose, and xylose, while the amorphous regions of cellulose are hydrolyzed, breaking cellulose into shorter chains. The two major components of the cell wall degradation lead to a reduction of free hydroxyl groups in their chemical structures. In contrast, lignin's cross-linking is believed to increase (Sundholm 2001; Sundqvist 2004; Nuopponen 2005).

These cell wall modification results in several changes in wood properties. Regardless of the process used, common results are color change from white or yellowish into brown or dark brown; improvement of biological durability; decreased mechanical strength by up to 30% etc. (Rapp 2001; Jamsa and Viitaniemi 2001; Homan and Jorissen 2004).

This paper therefore investigates the effect of laminate thickness on selected strength properties of heat treated laminated bamboo with a view to maximizing the utilization potential of bamboo as a substitute to other wood species for structural purpose.

Materials and Method

Raw-Material Source

Bamboo culms of *Bambusa vulgaris* were collected from Gbedun, Akanran, Ona-Ara Local Government Area of Oyo State, Nigeria located on latitude $7^0$13'60" N and longitude $4^0$1'60"E. Twenty culms of 4 years old with average diameter of 120 mm to 80mm and average thickness of the culm wall varying from 17 mm to 6.5 mm were harvested and taken to the Wood Workshop of the Department of Forest Resources Management, University of Ibadan, Ibadan, Nigeria for processing and conversion to laminated bamboo board.

Laminated Bamboo Board Formation

The harvested bamboo culms were cross-cut from the base into 3m long billet using a circular saw. The billets obtained were again cut into three sections of 1m long each to obtain straight pieces and then split in the radial direction into strips using a circular saw. The inner and outer surfaces of the strips obtained were later planed into laminate thickness of 4, 6, 8 and 10mm. The strips were thereafter edged on one end and cut on the other un-edged end to 25mm so as to obtain strips with straight and the same width for easy and proper clamping. The 25mm wide strips obtained were further cut into smaller length of 500mm long, thermal treated at different period intervals of 4hrs, 8hrs, 12hrs and un-treated, dried followed by application of adhesive bond (top bond, a starch-based adhesive) on the split faces of the strips. The strips were cold-pressed with a clamp for proper penetration of adhesive at the bond lines to form strong boards.

Thereafter, the boards formed were cured at room temperature for 14 days (2weeks) for proper bonding of the adhesive with the bamboo strips to enhance good machining.

Thermal Treatment of Bamboo Strips

Heat (thermal) treatment has been used for various wood products to improve their dimensional stability and durability against biodeterioration (Kamdem *et al*, 2002, Militz, 2002).

The produced strips of 500mm long by 25mm wide with 4, 6, 8 and 10mm thick were dried at indoor conditions until moisture content value range between 12 to 15%. Thermal treatment was conducted at Bio-Science Centre of International Institute of Tropical Agriculture (IITA), Ibadan, Oyo State, Nigeria in a Tomy SX-700 Autoclave. Strips were subjected to temperature of 140^0C at different treatment periods; 4hrs, 8hrs, 12hrs and untreated (serving as the control).

Testing of the Laminated Bamboo Boards Formed

At the end of the curing process, the bamboo boards produced were planed, edged and cut to 20mm x 20mm x 300mm for Modulus of Rupture (MOR), Modulus of Elasticity (MOE), Impact Bending (IMB) test and 20mm x 20mm x 60mm for Maximum Compressive Strength Parallel to Grain ($MCS_{//}$) test in accordance with British Standard specification BS 373 (BSI 1989). Each treatment combination was replicated four times and 64 samples were obtained for each of the variables tested. Analysis of variance in 4 x 4 factorial experiments in a completely randomized design (CRD) was carried out to determine if thermal treatment and laminate thickness had significant effects on the strength properties of the laminated bamboo boards produced.

Results and Discussion

Table 2: Summary of Mean Values of the Selected Strength Properties of the Laminated Bamboo Board Samples

		Laminate Thickness				
Strength Properties	Thermal Treatment	4mm	6mm	8mm	10mm	Mean
MOR (N/mm^2)	Untreated	57.66	64.69	74.53	92.82	72.42±15.63[a]
	4hrs	47.11	63.28	66.10	84.38	65.22±14.71[b]
	8hrs	42.19	50.63	52.03	73.13	54.49±13.11[c]
	12hrs	35.16	49.22	52.03	68.91	51.33±13.91[c]
Mean		45.53±10.58[c]	56.96±8.18[b]	61.17±1.12[b]	79.81±12.53[a]	60.87±16.40
MOE (N/mm^2)	Untreated	5674.91	7121.33	17232.37	19516.17	12386.19± 7909.51[a]

	4hrs	5273.52	6851.41	12041.92	14740.96	9726.95± 4913.35[ab]
	8hrs	4844.44	6048.65	7557.33	13287.61	7934.51± 4315.85[b]
	12hrs	3986.29	5190.47	7183.59	12249.47	7152.45± 4849.83[b]
Mean		4944.79± 1250.59[c]	6302.96± 3269.43[c]	11003.80± 6322.25[b]	14948.55± 5190.75[a]	9300.03± 5898.16
IMB (m)	Untreated	0.89	0.98	1.05	1.21	1.03±0.17[a]
	4hrs	0.47	0.97	1.01	1.13	0.90±0.33[b]
	8hrs	0.37	0.74	0.86	1.01	0.74±0.30[c]
	12hrs	0.33	0.54	0.81	0.85	0.63±0.25[c]
Mean		0.51±0.26[c]	0.81±0.30[b]	0.93±0.14[ab]	1.05±0.20[a]	0.83±0.30
$MCS_{//}$ (N/mm^2)	Untreated	48.56	49.69	50.00	50.00	49.56±0.99[a]
	4hrs	48.19	48.06	50.00	50.00	49.06±1.48[a]
	8hrs	43.63	46.94	49.13	49.88	47.39±2.69[b]
	12hrs	41.44	46.25	48.19	48.63	46.13±3.45[c]
Mean		45.45±3.67[c]	47.73±1.70[b]	49.33±1.15[a]	49.63±0.94[a]	48.04±2.68

* Means ± Standard Deviation of four replicate samples. Values with the same alphabet in each column and row are not significantly different at α= 0.05 using Duncan multiple range test.

Modulus of Rupture (MOR)

The mean value for MOR was 60.87 N/mm^2 ranging from 35.16N/mm^2 to 92.82N/mm^2 (Table 2). It was observed that MOR increases with increase in laminate thickness of the bamboo boards. The highest MOR values were obtained at the laminate thickness of 10mm from each of the 4, 8 and 12hrs thermal treated and untreated boards. The relatively high MOR of 10mm laminate board is an indication that it is strongest compared to other laminate thickness.

Meanwhile, it was observed that a strength property was affected by thermal treatment. The MOR of the bamboo boards decreased with increase in thermal treatment duration. The untreated LBBs had the highest MOR averaged, 72.42 N/mm^2 while the least, 51.33 N/mm^2 was obtained in 12hrs thermal treated LBBs. This deterioration in strength might be explained as due to hemicellulose degradation. Yildiz *et al.* (2006), reported that the heat treatment and control samples were tested for some mechanical properties; compression strength, bending strength, modulus of elasticity in bending, hardness, impact bending strength and tension strength perpendicular to grain. The result indicated that heat treatment samples had lower mechanical properties compared to the control samples (untreated).

The result of analysis of variance for MOR test presented in Table 3 shows that the differences in laminate thickness and thermal treatment had a significant effect on MOR while, their levels of interaction had no significant effect (P<0.05). The follow up test (Table 2) revealed that the untreated 10mm laminated boards were the strongest compared to 8, 6 and 4mm bamboo boards thermal treated for 12, 8 and 4hrs.

Table 3: Results of the Analysis Variance for Selected Strength Properties of Laminated Bamboo Board Samples

		F-cal							
Source of variation	df	MOR Sig.	MOR	MOE Sig.	MOE	IMB Sig.	IMB	$MCS_{//}$ Sig.	$MCS_{//}$
Laminate Thickness	3	0.000	64.502*	0.000	20.520*	0.000	26.896*	0.000	31.010*
Thermal Treatment	3	0.000	30.063*	0.003	5.291*	0.000	15.546*	0.000	21.092*
Laminate thickness * Thermal Treatment	9	0.876	0.487^{ns}	0.459	0.992^{ns}	0.376	1.107^{ns}	0.001	4.045*

Error	48
Total	63

* Significant at P= 0.05, ns= not significant at P=0.05

Modulus of Elasticity (MOE)

The mean MOE presented in Table 2 was 9300.03 N/mm^2 ranging from 3986.29 N/mm^2 to 19516.17 N/mm^2. It was observed that as laminate thickness increases, MOE increases. The laminate thickness of 10mm from each of the 4, 8 and 12hrs thermal treated and untreated boards had the highest MOE values followed by the laminate thickness of 8mm then, the laminate thickness of 6mm while, the laminate thickness of 4mm has the lowest MOE. This means that, the laminate thickness of 10mm from each of the thermal treatment periods produces the stiffest laminated bamboo board than the other laminate thickness of 8, 6 and 4mm.

It was also observed that, the MOE decreases with increase in thermal treatment. The stiffness of the boards decreased with increase in thermal treatment period. The untreated LBBs produced the stiffest boards while 12hrs thermal treated LBBs produces the less-stiff boards. The reason for the loss of strength might be as a result of the degradation of hemicellulose by heat. Anwar *et al.* (2005) and Zaidon *et al.* (2000) revealed that the strength properties of untreated laminates were relatively higher compared to treated laminates.
The result of analysis of variance for MOE (Table 3) revealed that the differences in laminate thickness and thermal treatment had a significant effect on MOE at $P<0.05$ while, their levels of interaction had no significant effect on MOE. The follow up test revealed that laminate thickness and thermal treatment were different from one another (Table 2).

Impact Bending (IMB)

From Table 2, the mean value for IMB of the laminated bamboo boards was 0.83m ranging from 0.33m to 1.21m. It was observed that IMB increases with increase in laminate thickness. The LBBs produced at the laminate thickness of 10mm from each of the thermal treatment periods of 4, 8 and

12hrs together with the untreated boards, had the highest IMB compared to the boards produced using laminate thickness of 8, 6 and 4mm from each of the thermal treatment period. It means LBBs produced from the 10mm laminate thickness from each of the thermal treatment periods have more ability to withstand shock loading compared to boards from the other laminate thickness used in this study.

It was also observed that IMB decreased with increasing thermal treatment. The untreated LBBs produced boards that can withstand loads, shock and have good strength compared to the 4, 8 and 12hrs thermal treated LBBs. Mechanical properties of untreated boards are usually higher than those of the treated boards (Anwar *et al.* 2005). The decrease in IMB as thermal treatment period increases may probably be due to the break-up of the hemicelluloses and cellulose polymers. Similar results for reductions in mechanical strength properties of heat-treated wood were reported by Santos (2000), Poncsak *et al.* (2006) and Shi *et al.* (2007).

The Analysis of variance result for IMB shows that the differences in laminate thickness and thermal treatment had a significant effect ($P<0.05$) on Impact bending while, their levels of interaction had no significant effect on IMB (Table 3). The follow up test further revealed that there are differences between the means of the laminate thickness and thermal treatment (Table 2).

Maximum compressive strength parallel to grain ($MCS_{//}$)

The mean $MCS_{//}$ was 48.04 N/mm^2 ranging from 41.44N/mm^2 to 50.00N/mm^2 as shown in Table 2. It was observed that $MCS_{//}$ increases with increase in laminate thickness. The highest $MCS_{//}$ were obtained at the laminate thickness of 10mm from each of the 4, 8 and 12hrs thermal treated and untreated boards. The implication of this is that, LBBs produced at this level have a very good maximum crushing strength than other laminate thickness.

Meanwhile, $MCS_{//}$ decreases as thermal treatment increases. The boards with good maximum crushing strength were obtained at the untreated LBBs compared to the treated LBBs. Meaning, $MCS_{//}$ was affected by thermal treatment. This reduction in strength might be as a result of the hemicelluloses degradation by heat treatment of the laminated boards. These findings are similar to that of Yildiz *et al.* (2006) that heat treatment samples had lower mechanical properties compared to the control (untreated) samples.

The result of analysis of variance for $MCS_{//}$ presented in Table 3 shows that the differences in laminate thickness, thermal treatment and their levels of interaction had a significant effect on $MCS_{//}$ at $P<0.05$ level of significance. Furthermore, the follow up test (Table 2) revealed that the untreated 10mm laminated boards have a very good maximum crushing strength compared to 8, 6 and 4mm bamboo boards thermal treated for 4, 8 and 12hrs.

Conclusion

The laminate thickness and thermal modification of bamboo laminated boards influenced its strength properties (such as; MOR, MOE, IMB and $MCS_{//}$). The degree of modification varied with temperature duration of treatment.

The study revealed that modulus of rupture, modulus of elasticity, impact bending and maximum compressive strength parallel to grain increased with increase in laminate thickness and decreased with increase in thermal (heat) treatment.

The study further revealed that the untreated LBBs had the highest strength properties compared to the thermal treated LBBs, which decreased the strength properties of the produced LBBs as thermal treatment period increases.

Bamboo glu-lam as alternative to choice timber species for structural purpose showed encouraging technical properties. Utilization potential of Bamboo glu-lam could be improved by thermal treatment manipulation of laminate dimensions.

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