Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268
e-ISSN: 2395-3454

Vol. 18 | No. 1 | pp. 307-312 | 2019

Original Research Paper | **Open Access**

Analysis of Sea-water Treated Laminated Bamboo Composite for Structural Application

Teodoro A. Amatosa, Jr.*(**)†, Michael E. Loretero*(***), Romeo B. Santos and Marnie B. Giduquio***

*****Engineering Graduate Program, School of Engineering, University of San Carlos, Talamban Campus, Cebu City, 6000 Philippines

******College of Engineering and Technology, Northwest Samar State University, Calbayog City, Samar, 6710 Philippines

*******Department of Mechanical Engineering, University of San Carlos, Talamban Campus, Cebu City, 6000 Philippines

†Corresponding author: Teodoro A. Amatosa, Jr.

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 04-06-2018
Accepted: 02-08-2018

Key Words:
Green engineering
Laminated bamboo composite (LBC)
Epoxy resin
Structural application

ABSTRACT

Green engineering is increasingly investigated as a possibility to treat organic green material for structural applications. *Dendrocalamus asper* bamboo culms as green engineering materials were processed to produce composite materials using epoxy resin from a natural treatment by soaking with an average of pH 7.6 level of sea-water. Mechanical properties of proposed laminated bamboo composites (LBCs) have been assessed under loading conditions and standards. The study provides a comparison of the structural performance with different conventional timbers as avenue for application in engineering design and practices. Comparison of laminated bamboo with woods indicate that average value of 27.47 MPa and 52.59 MPa for compressive and bending strength respectively, obtained much higher allowable value and average strength, which are comparable to stiffness values of softwoods and hardwoods. However, even though the present study shows properties with higher and comparable to other composite materials, further research must be given better attention for characterization and standardization before acceptance in the marketplace as alternative green engineering material to timber and wood-based composites and other building materials for construction design, and structural elements as composite materials for engineering utilization.

INTRODUCTION

Evaluation of bamboo through life cycle assessment is presented in an effort to resolve the environmental implication of bamboo as a source for construction material. The results of this interpretation show that, in some applications, bamboo has marked a high "factor 20" environmental impact, which means a 20 times less load on the environment than compared to some alternatives (Van der Lugt et al. 2006). Wood and bamboo have recently been renowned in the green engineering technology industry because of their environmentally promising characteristics. They can be replaced by a natural processes, biodegradable, confine carbon from the atmosphere, low in combined energy, and create less pollution in development than concrete or steel (Falk 2009 and Mahdavi et al. 2011). Bamboo is a green material that can possibly substitute the wood for reasons that, bamboo can be cropped in 3-4 years from the time of plantation as compared to timber which takes decades (Lakkad & Patel 1980 and Amada et al. 1997). Compared with other similar composite building materials, strength-to-specific gravity ratio, bamboo is much stronger and has a greater value than that of common hardwood, softwood and even metals such as aluminium alloy, cast iron, and structural steel (Mahdavi et al. 2011).

Bamboo has high strength fibres, and as one of the existing flowering plants and available forest resources, it plays an important economic and cultural role in tropical areas worldwide. For instance, bamboo utilization in China's pulp industry is very significant, with the production of approximately one million tons (Zhou et al. 2010). These bamboos are characterized as a competitive material in relation to wood and other non-wood vegetal fibres to produce pulp (Correia et al. 2015) and nanofibrillated bamboo cellulose as reinforcements made without using any artificial chemicals and inorganic matrices, such as in polymeric composites (Lu et al. 2013, Guimaraes et al. 2015) and in construction building materials like cement and concrete reinforcement (Coutts & Ni 1995, Correia et al. 2014 and Xie et al. 2015).

Although bamboo is a potential wood replacement, structurally it can be used with a certain limit by the proportionate dimension of the bamboo culm and the low inflexibility of the bamboo. To address the limitation of member size and to increase the measurement consistency, capacity and

Table 1: Macroscopic characteristics of giant bamboo (*Dendrocalamus asper*).

Macroscopic characteristics	Unit	Literature 1	Literature 2	Literature 3	Native Bamboo*
Culm length	m	20-30	18-23	-	20-30
Internode length	cm	20-25	35	14-45	30-35
Internode Diameter	cm	8-20	9-13	1.2-9.3	8-18
Culm wall Thickness	mm	11-20	10-14	4-30	6-13

Literature: 1/ Dransfield & Widjaja (1995) 2/ Othman et al. (1995) 3/ Pakhkeree (1997) / *Present study

Table 2: Comparison of average mechanical properties of *Dendrocalamus asper* bamboo culm to other common building materials.

Building materials	Specific gravity	Compressive		Bending		
		MOR (MPa)	Standard Deviation, S.D.	MOE (GPa)	MOR (MPa)	MOR to specific gravity ratio (MPa)
*Dendrocalamus asper**	0.54					
Freshwater treatment		45.20	12.16 (±26.93%)	17.658	188.05	348.24
Sea-water treatment		53.60	15.59 (±29.08%)	23.578	218.35	404.35
Untreated		34.10	5.00 (±14.65%)	7.608	71.75	132.87
Giant timber bamboo[a]	0.52	-	-	10.7	102.70	197.50
Other bamboo[a]	-	-	-	9.0-20.7	97.9-137.9	-
Hardwoods						
Beech[b]	-	50.30	-	-	103.00	-
Oak (Pin)[b]	-	41.78	-	-	71.02	-
Poplar, Balsam[b]	-	27.70	-	-	47.00	-
Mahogany[b]	-	46.70	-	-	79.30	-
Rosewood, Indian[b]	-	63.60	-	-	116.50	-
Teak[c]	-	69.50	-	-	128.00	-
Softwoods						
Cedar[b]	-	24.80	-	-	42.00	-
Redwood, young[b]	-	35.99	-	-	54.46	-
Loblolly pine[b]	0.51	36.00	-	12.3	88	172.50
Douglas-fir[b]	0.45	50.00	-	13.6	88	195.60
Metal						
Cast iron[d]	6.97	-	-	190	200	28.70
Aluminum alloy[d]	2.72	-	-	69	200	73.40
Structural steel[d]	7.85	-	-	200	400	50.90
Carbon fiber[d]	1.76	-	-	150.3	5,650	3,205.10

*Present study; [a]Lee et al. 1998; [b]Forest Products Laboratory 1999; [c]Krestschmann 2010; [d]Rittironk & Elnieri 2007

uniformity, the bamboo culm can be dismantled into thin, slender laminae and then laminated into one group with adhesive to form genuine structural members. The composite material is called laminated bamboo (Correal 2008). Mechanical properties of the laminated bamboo composite will look closely with those of common hardwood and softwood, and so laminated bamboo structural members are better than others with commonly used building construction materials, whilst also able to be extended for another period of time (Lopez & Correal 2009, Mahdavi et al. 2012, De Flander & Rovers 2009 and Nugroho & Naoto 2001). Much research work has been carried out on wood (Verma & Chariar 2012, Verma & Chariar 2013, Verma et al. 2014 and Sulastiningsih & Nurwati 2009), but less on laminated bamboo lumber (Lee et al. 2012, Sulaiman et al. 2006, Paes et al. 2009, Correal & Ramirez 2010, Lee et al. 1998, Wei et al. 2011, Sinha et al. 2014, Yeh & Lin 2012, Li et al. 2013, Xiaohong 2011, Yu et al. 2003, Yu et al. 2005, Siddhaye & Sonar 2006, Richard & Harries 2012 and Li et al. 2015), so more work needs to be done on this kind of new building material.

MATERIALS AND METHODS

Materials

Three-year-old giant bamboo (*Dendrocalamus asper*) was harvested from Mandaue city, in the Philippines. Portion cut up to 3.0 m from the basal region was used for the assessment (Fig. 1). The bamboo was manually cut into a speci-

Table 3: Comparison of mechanical strength properties of LBCs *Dendrocalamus asper* with other similar composites.

Materials	Density	Compressive		Tension		Shear	Bending
	ρ_{mean} kg/m³	$f_{\|\|}$ (MPa)	f⊥ (MPa)	$f_{\|\|}$ (MPa)	f⊥ (MPa)	f_{mean} (MPa)	f_{mean} (MPa)
Laminated Bamboo*	1,022.24	27.47	1.97	-	1.49	-	52.59
C24 - EN 338[a]	420	21.00	-	32.00	-	4	24.00
GL 24h-EN 14080-06[b]	420	24.00	-	14.00	-	3.5	24.00
Norway spruce[c,d]	-	44.00[h]	-	19.50	-	6	48.00
Glue laminated spruce[e]	450	32.00	-	-	-	-	50.00
Thermally modified beech[f]	580	48.70[h]	-	14.00	-	-	31.00
Caramelized bamboo[i]	686	77.00	22.00	90.00	2.00	16	77 – 83
Sitka spruce[j,k]	383	36.00	-	59.00	-	9	67.00
Douglas-fir LVL[l,m]	520	57.00	-	49.00	-	11	68.00
Sheathing-grade Plywood[n]	-	20.7-34.5	-	10.3-27.6	-	-	20.7-48.3
Sheathing-grade OSB[n]	-	10.3-17.2	-	6.9-10.3	-	-	20.7-27.6
Normal laminated wood[n]	-	44.10	-	153.10	-	-	140.60
Low density cement-wood[n]	-	0.69-5.5	-	0.69-4.1	-	-	1.7-5.5
Wood-Popypropylene[n]	-	38.3-72.4	-	28.5-52.3	-	-	-

*Present study; [a]CEN (2009); [b]CEN (2013); [c]Steiger & Arnold (2009); [d]Jenkel et al. (2015); [e]De Lorenzis et al. (2005); [f]Widmann et al. (2012); [g]Test not conducted in accordance with EN 408 (CEN, 2012); [h]Experimental mean; [i]Sharma et al. (2015); [j]Lavers (2002); [k]Kretschmann (2010); [l]Kretschmann et al. (1993); [m]Clouston et al. (2002); [n]Forest Products Laboratory (1999)

fied length of 300 mm and was split longitudinally at the top, middle and bottom part. During the submersion of specimens, five for each bamboo parts were immersed in salt water to protect bamboo against insect attack for 7 days cycles as traditional preservation. A setup was performed using traditional treatment to show up the specimens to wetting and drying cycle; the bamboo specimens were removed from the water and stacked vertically for air-drying for one week (Amatosa & Loretero 2017).

Production

Manufacturing of the laminated bamboo composite (LBC) from *Dendrocalamus asper* was made in the Mechanical and Manufacturing Engineering Laboratory at the University of San Carlos, Cebu City, Philippines. The culm sections of 2 m to 3 m were cut again into 1 m to 1.5 m in order to have straight pieces. Each piece was split in the longitudinal direction for a proper number of slices and the node sections were removed. The slices were vertically placed for air-drying to an average of 6% to 8% moisture content. Each slice is manually cut off, the inner and outer faces containing wax and silica that weaken adhesive bonding are not included to form LBC with a thickness from 3 mm to 5 mm. . All laminas were impregnated with epoxy resin and staked to form laminated bamboo. Each LBC was cold pressed in a hydraulic press at a pressure of 1.5-2 MPa for 15 minutes.

RESULTS AND DISCUSSION

This paper analyses the treated giant bamboo species within one week and air-dried for another week, if it could influence the mechanical properties of the specimen, specifically compressive and bending strength together with the other properties of the laminated composite.

Mechanical Properties of Bamboo Culm/Laminated vs Woods

Table 2 gives the comparative analysis of mechanical strength properties of a full culm of *Dendrocalamus asper* bamboo to other woods and comparable materials, and Table 3 presents the variation in nature of mechanical properties of LBC as a possible substitute to woods and wood-based composites. These data provide that *Dendrocalamus asper* bamboo can be deployed for fabrication as LBCs.

Using the internode section from a full culm bamboo parallel to the grains, the mechanical properties of *Dendrocalamus asper* are given in Table 2. ASTM D 695 - 96 test procedure (ASTM 1999) has been used for the assessment of compressive strength, wherein specimens treated in sea-water got the highest average value which reached up to 53.60 MPa with S=15.6 MPa, followed by the specimens in freshwater and untreated with average strength of 45.20 MPa, S=12.5 MPa, and 34.10 MPa, S=5.00 MPa respectively. It shows that the *Dendrocalamus asper* specimens, which are treated in sea-water, have gained its strength by 62.98% and freshwater increased by 32.36% from untreated specimens. As the results prove, unlike the untreated specimens, the fresh water and sea-water treated specimen have a larger amount to withstand specified loads.

The present study went through different variations of treatment (soaking it from fresh and sea-water, and untreated as control), same with properties of some bamboo species

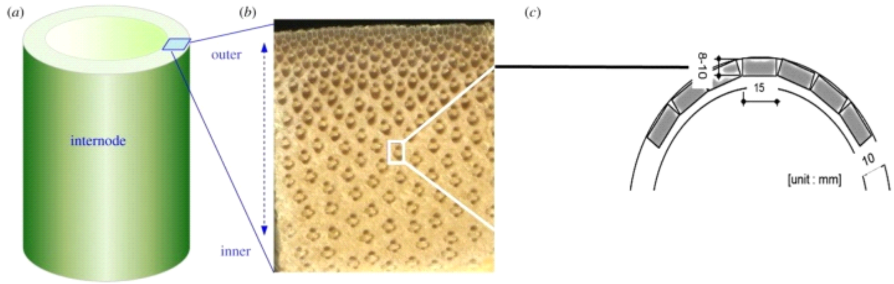

Fig. 1: Extraction of specimens (cross section of bamboo).

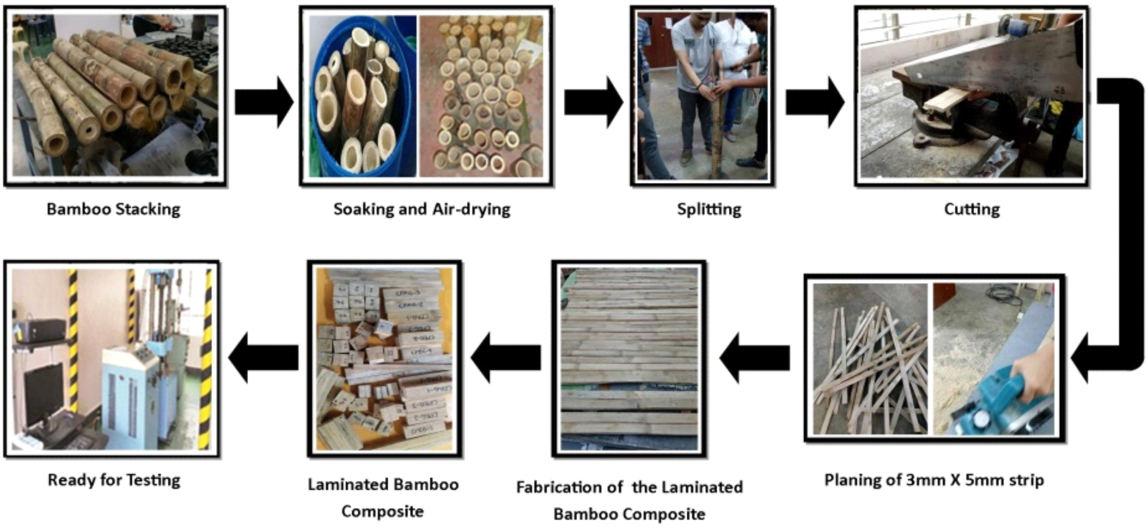

Fig. 2: Distribution flow of laminated bamboo composite.

for construction building materials; and, this wood species such as Teak or Beech for hardwood has most likely the same quality of *Dendrocalamus asper.* The information indicates that *Dendrocalamus asper* bamboo is stronger in strength for flexural rather than timber, and its strength-to-weight ratio is higher than that of all other materials indicated except for carbon fibre. Not just bamboo is fast-growing, but it is also highly effective substitute material in relation to other green construction materials for structural application.

Comparison of Strength of LBCs with Other Structural Composite Lumber Products

Different laboratory tests were conducted for mechanical properties of *Dendrocalamus asper* bamboo for laminated bamboo composite (LBC) specimens to provide a direct comparison with some commercial composite products. Specimens were produced with prescribed dimensions and tests were performed according to ASTM D143 (ASTM 2014). Due to the higher value of properties by sea-water treated bamboo, this was used to produce LBCs for evaluation. The size of the specimen and test procedure was selected to be consistent with other LBLs to establish similarities of strong values and to prevent contrast of configuration result between size and load. Flatten specimens were tested in the horizontal lamination (joist) orientation. All tests were performed using a 600 kN capacity universal testing machine. A continuous compression load with a load rate of 0.6 mm/min was applied and distributed up to deformation equal to 5% of the specimen thickness, until it reached and the stress at that point is calculated. The relative humidity of the specimen with an average moisture content of 8%-12%, was placed in the laboratory using ambient temperature for drying.

Presenting from this research work, the mean strength values of these tests are provided for the proposed LBCs

(Table 3). This table also presents the flexural properties of LBL with those published from the Forest Products Laboratory (1999) with the consistency of specimens of 10% moisture content made using Method 3 (Lee et al. 1998). The flexural strength is most comparable data to some CEN standards and other softwood and hardwood structural composites. LBC specimens may share partly to the observed differences of the samples; flexural properties exhibit an inclination to increment with a decrease in moisture content for clear wood (Bergman et al. 2010). Data analysis indicates that mechanical properties of LBCs of *Dendrocalamus asper* are better than other structural composite materials and even comparable to one of the hardest and strongest woods such as the teak wood.

CONCLUSIONS

Laminated bamboo composite from *Dendrocalamus asper* bamboo has properties showing better performance, that it can be compared to some other structural composite wood products. The study provided a natural treatment soaking in sea-water from a full culm bamboo to justify the strength of the materials for possible structural application. Anisotropy is the one that could add up for this research to develop more flexible and unique materials that are comparable to the results of other structural composites from hardwood and softwood in relation to structural design innovation. In general, it is concluded that the LBC does have a much higher allowable and mean strength values in tensile and flexural data, which are comparable to woods stiffness values. However, further research to give attention on the characterization and standardization is needed before acceptance in the marketplace of LBC as structural composite materials for design and engineering use.

ACKNOWLEDGMENTS

This study was conceptualized by the author/s and sponsored by Engineering Research and Development for Technology under the Department of Science and Technology, the Philippines, and all experiments were carried out in the Department of Mechanical and Manufacturing Engineering Laboratory, University of San Carlos, Cebu City, Philippines.

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