Evaluation of selected mechanical properties of new Laminated Guadua Mats for structural use

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Abstract

This study presents the experimental evaluation of selected mechanical properties of a new laminated bamboo plywood-like panel made from *Guadua angustifolia* Kunth mats, in order to provide a proper characterization of this product for structural use. Bending and shear tests were performed following standard test methods, and maximum strength and stiffness values were determined for each property. Experimental results indicated clear differences according to the direction of loading with respect to the exterior plies of the panel for all properties. This experimental data is expected to be used as a basis for providing reference design values for the new laminated bamboo product.

Introduction

Guadua angustifolia Kunth is a giant species of bamboo that grows naturally in many Central and South American countries. Previous studies have shown that laminated products derived from *Guadua angustifolia* have physical and mechanical properties as good as wood or wood based products (López and Correal 2009; Correal and Varela 2012). Recently, the Civil Infrastructure and Materials Research Center (CIMOC) at Universidad de los Andes, in Bogotá, Colombia, conducted an extensive study in order to validate the structural behaviour of systems comprised of Glued Laminated Guadua (Correal and Ramírez 2010; Varela et al. 2013). As part of this research project, the possible application of laminated Guadua panels as sheathing in light-frame shear walls was studied, indicating that these panels may be considered as a substitute for wood based panels commonly used in this system. However, the manufacturing process of Glued Laminated Guadua panels was considered expensive in comparison to wood based panels, due to the reduced production scale and limited industrialization, and therefore, this product was not entirely competitive.

Given the latter, a new type of cost-effective laminated Guadua panel was developed, comprised of pressed-and-glued-together Guadua mats in a similar fashion as plywood, thus implying fewer stages in its manufacturing process, and therefore reducing its cost. This new Laminated Guadua Mats (LGM) may be used as structural sheathing in shear walls or diaphragms, in the same manner as wood based panels have been successfully used in light-frame construction in the United States, Canada and Europe.

The Civil Infrastructure and Materials Research Center (CIMOC) at Universidad de los Andes conducted an experimental evaluation of selected mechanical properties of the LGM panels, as part of a research project oriented to study the structural behaviour of a modular prefabricated light-framesystem using these panels. An initial validation of the suitability of LGM panels for structural use in exterior exposure was conducted in the early stages of the project (Correal and Echeverry 2014), proving an adequate behaviour of the panels. This paper presents the second phase of the research project, a more proper experimental programme for the determination of selected mechanical properties, such as bending strength and stiffness, rolling shear strength, and panel shear strength and stiffness, considering for all properties both the longitudinal and transverse directions of loading with respect to the direction of the exterior plies of the panel.

Materials and Methods

Laminated Guadua Mats

The laminated Guadua mats are produced by the company V&V Laminados de Guadua S.A.S. Four-year-old *Guadua angustifolia* Kunth bamboo culms harvested from the region of Risaralda, Colombia, are cut into 3 m long pieces on site and transported to the warehouse where culms with an average diameter of 10 to 18 cm are preselected. Guadua mats are obtained by performing radial cuts along the culm length, which allow splitting open the element. After this, the remaining inner node membranes are cut and discarded. The flattened Guadua mats are passed through a grinding process for removing the inner and outer layers, and then are cut in the transverse direction, obtaining 2.5 m long mats. Immunization is carried out by introducing the Guadua mats in an autoclave that supplies water vapour at 140°C and pressure of 0.5 MPa for 1.5 hours, and then dried in a mechanically ventilated chamber during 48 hours, until an average moisture content of 6% is reached.

The mats undergo a new grinding process to obtain an adequate finishing on both sides. Then, they are introduced in a sewing machine that glues ten 4-strand wool threads along the transverse direction in order to avoid further longitudinal splitting of the mat, and are cut in the longitudinal direction to obtain approximately 25 cm wide elements. The panel assembly is achieved by applying a phenol formaldehyde resin (Polymer 66 DO) on one side of the mat with a spread rate of 150 g/m², and placing together these 2.5-by-0.25 m elements in three orthogonal layers or plies (similar to plywood), comprising the entire 2.5 m x 1.25 m unit. The panel assembly is immediately introduced in the pressing machine, which applies a pressure of 1.2 MPa at 150°C during 25 minutes, resulting in an average panel thickness of 18 mm and an average specific gravity of 0.76, which was determined by experimental tests based on ASTM D2395 (ASTM 2007a). Finally, the Guadua panels are cut to obtain the standard size of 1.22 m by 2.44 m, and sanded until an average thickness of 16 mm is obtained. Figure 1 presents an overview of different stages of the manufacturing process.

(a) (b) (c)

Figure 1. Manufacturing process: (a) Guadua culms; (b) raw Guadua mats; (c) finished Laminated Guadua Mats.

Test Methods

Since no standard test methods for the determination of properties of laminated Guadua products have yet been established, all the tests in this study were conducted following international ASTM standards for wood and wood products, considering the latter to be the closest fit for these Laminated GuaduaMats. All tests for the determination of mechanical properties were conducted at the Structural Models Laboratory of the Universidad de los Andes.

Bending Tests

Bending tests were conducted in accordance with Method B (two-point bending test) of ASTM D3043 (ASTM 2011a), for both the longitudinal and transverse directions of loading with respect to the direction of the exterior plies of the panel. Since the three-ply panel has both exterior plies oriented in the same direction, and perpendicular to the inner ply, both longitudinal and transverse directions are considered to render different mechanical properties. Figure 2 illustrates the two directions considered for bending tests, and the same directions are extended for the shear tests.Ten tests were performed for each direction. Test specimens were 50 mm wide and 16 mm thick, and were simply supported over a span of 920 mm and 600 mm, for longitudinal and transverse specimens respectively.Load was registered by an external load cell, whereas midspan deflection was measured by a linear variable differential transformer (LVDT) mounted over the test specimen. Figure 3 presents the bending test setup.

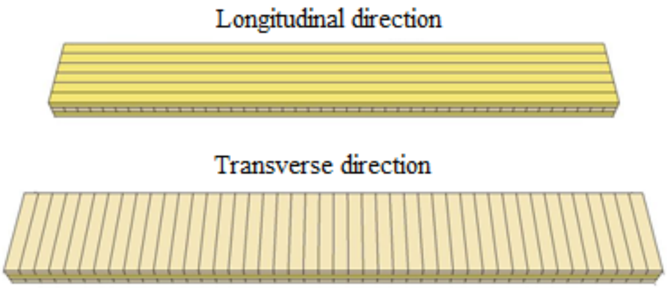


Figure 2. Orthogonal directions of panels.

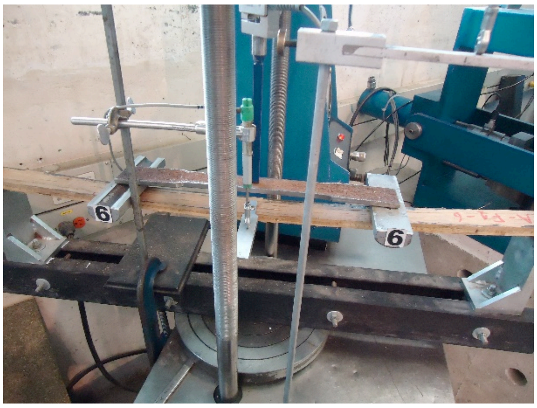


Figure 3. Bending test setup.

Rolling Shear Tests

Rolling shear (or planar shear) tests were conducted in accordance with Method A (planar shear loaded by plates) of ASTM D2718 (ASTM 2011b), for both the longitudinal and transverse directions of loading with respect to the direction of the exterior plies of the panel. Twenty tests were performed for each direction. Test specimens were 225 mm long,150 mm wide and 16 mm thick, and were glued to steel plates on both faces using a sufficiently rigid adhesive as indicated by the test standards. Load and displacement were recorded by an external load cell and LVDT mounted over the steel V-block used of load application, and directly connected to the movable crosshead of the testing machine. Figure 4 presents the rolling shear test setup.


Figure4. Rolling shear test setup.

Panel Shear Tests

Panel shear (or shear-through-the-thickness) tests were conducted in accordance with Method C (two rail shear test) of ASTM D2719 (ASTM 2007b), for both the longitudinal and transverse directions of loading with respect to the direction of the exterior plies of the panel. Ten tests were performed for each direction. Test specimens were 600 mm long, 400 mm wide and 16 mm thick, and were mounted using steel rails on both ends, where the load was applied. Load was recorded by the movable crosshead of the testing machine, while relative displacement between the two load rails for measuring distorsion was registered by an LVDT mounted on one side of the specimen. Figure 5 presents the panel shear test setup.

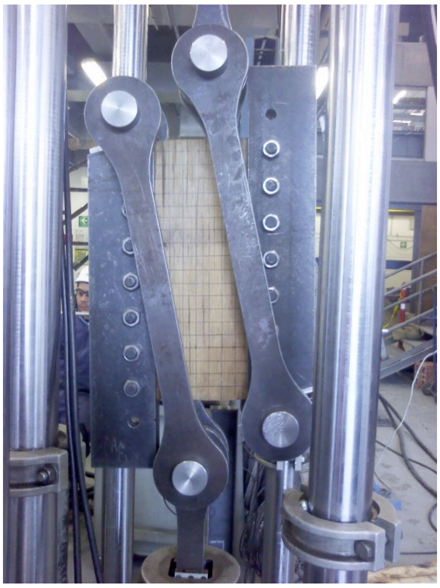


Figure 5. Panel shear test setup.

Test Results

Table 1 presents the results for all test of selected mechanical properties, indicating the average values, standard deviation, coefficient of variation (COV), maximum and minimum values, for both the longitudinal and transverse directions. A more detailed description of test results for each property is presented below.

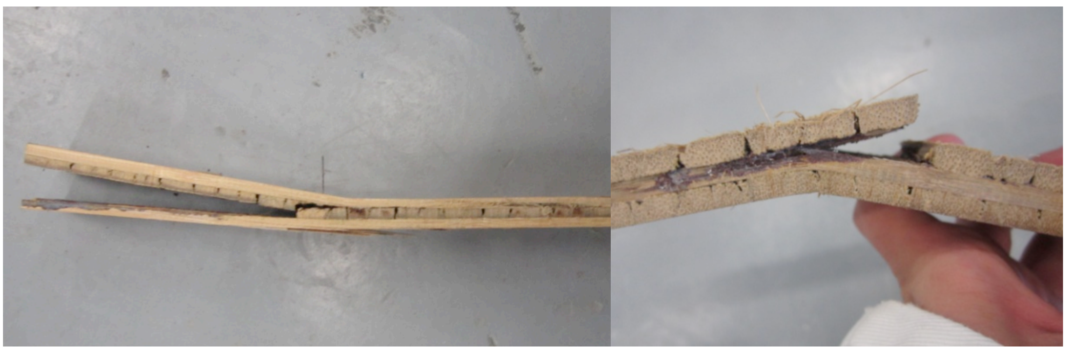
Table 1. Summary of test results.

Property	Average	Std. Dev.	COV	Maximum	Minimum
Longitudinal bending					
Maximum strength (MPa)	65.0	22.4	35%	119.0	31.0
Modulus of elasticity (MPa)	18067	1984	11%	21871	14847
Transverse bending					
Maximum strength (MPa)	41.7	16.2	39%	67.6	6.7
Modulus of elasticity (MPa)	1625	1093	67%	4619	920
Longitudinal rolling shear					
Maximum strength (MPa)	1.25	0.36	29%	1.90	0.73
Transverse rolling shear					
Maximum strength (MPa)	0.88	0.30	34%	1.49	0.41
Longitudinal panel shear					
Maximum strength (MPa)	1.79	0.29	16%	2.32	1.32
Shear modulus (MPa)	136.1	106.6	78%	371.5	68.1
Transverse panel shear					
Maximum strength (MPa)	1.85	0.45	25%	2.27	0.93
Shear modulus (MPa)	141.6	52.7	37%	232.9	71.1

Bending Tests

The differences in terms of maximum strength depending on the loading direction (longitudinal or transverse) may be explained by the failure mode of test specimens. Longitudinal test specimens failed due to cracking through the glue line, which extended from the support towards the midspan, and fiber rupture in the tension side ply at midspan. On the other hand, in transverse specimens the observed predominant failure mode was cracking through voids between the Guadua plies, followed by the failure of the adhesive. Therefore, the maximum strength achieved in longitudinal specimens is higher, since it considers the tension strength of fibers in the exterior ply, and shear strength in the glue line, whereas in transverse specimens the failure spreads through voids between the Guadua mats. These distinct failure modes are presented in Figure 6.

Results for modulus of elasticity follow the same pattern, since longitudinal specimens have a higher stiffness due to the contribution of fibers in tension and compression in the exterior plies, whereas transverse specimens only have the inner ply’s fibers oriented in such a way to contribute to bending stiffness. However, this reduced strength and stiffness of the transverse direction may be prevented for service conditions, taking into account that the panel may be oriented to work mainly in one direction.



(a) (b)

Figure 6. Bending test failure modes: (a) longitudinal specimens; (b) transverse specimens.

Rolling Shear Tests

Differences observed in terms of maximum rolling shear strength may be accounted for the presence of voids and lack of uniform adhesive surface in transverse specimens, where the exterior plies are oriented perpendicular to the direction of loading. Therefore, the glue line is not continuous through the length of the specimen, whereas in longitudinal specimens is. This in turn provides a higher shear strength. Figure 7 presents the typical failure mode for both directions of loading, which consisted in shear through the glue line. No specimens failed through the rigid adhesive between the Guadua panel and the steel plates.

Figure 7. Typical observed failure mode for rolling shear specimens.

Panel Shear Tests

Panel shear tests rendered a different pattern to previous tests, since transverse specimens sustained a higher load, and displayed higher shear moduli than longitudinal specimens. Similar to rolling shear tests, loading of transverse specimens was perpendicular to the direction of the exterior plies of the panel, but in this case, this orientation implied a higher strength due to transverse shear strength of Guadua fibers in these plies, whereas in longitudinal specimens, only the inner ply contributed to such resistance.

For these tests, a particular condition was observed, since the load on all specimens did not drop considerably below the maximum strength, but rather sustained this load for almost twice the displacement at maximum load. Hence, the failure point for all tests was considered after a significant amount of time had passed and the maximum load was reached and sustained.

Conclusions

Based on the experimental work conducted within this research, the following conclusions may be drawn:

1. Bending tests on Laminated Guadua Mats rendered an important difference in terms of strength and stiffness for longitudinal and transverse directions of the exterior plies, due to the predominant failure modes observed for each direction.

2. Differences for maximum strength in rolling shear tests were found to be influenced by the continuity of the adhesive surface, since in transverse specimens the presence of voids affected this uniformity, and thus a lower strength was achieved.

3. Maximum strength and shear modulus in panel shear tests was observed to be higher in transverse specimens, due to a more convenient disposition of the fibers in the exterior plies of the panel. However, the magnitude of the differences is not significant, and therefore this property may be considered to be relatively the same for both directions.

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