Proceedings of the 7th World Congress on Mechanical, Chemical, and Material Engineering (MCM'21)
~~Prague, Czech Republic~~ Virtual Conference – August, 2021
Paper No. ICMIE 113
DOI: 10.11159/icmie21.113

Mechanical Characterization of Dendrocalamus Asper Bamboo Laminates from the Andean Region

Myrian Larco[1], Fredy Llulluna[2], Claudio Cordova[3]
[1,2] Deparament Sustainable Architecture / Universidad Regional Amazónica Ikiam
Parroquia Muyuna, kilómetro 7 vía a Alto Tena. Napo, Ecuador
myrian.larco@ikiam.edu.ec; fredy.llulluna@ikiam.edu.ec
[3] Department of Basic Sciences / Escuela Politécnica Nacional
Ladrón de Guevara E11-253, Quito, Ecuador
claudio.cordova@epn.edu.ec

***Abstract* –** The main objective of this research is to carry out the mechanical characterization of bamboo laminates manufactured with the dendrocalamus asper (LBDA) species, which are being produced in the Northwest of the Province of Pichincha in the Andean region of Ecuador. The results of this research identify the structural behavior of this material against compression forces, resistance to shear (shear), and bending, thus determining the possibility of its use in architectural projects that apply sustainable construction criteria. LBDA resistance is influenced by factors such as types of load, direction, and duration of load, temperature, and humidity. The tests are performed under the ASTM D143 standard to determine the mechanical properties. The average value of the compressive strength parallel to the fibers of LBDA is 53.17 MPa compared to the perpendicular to the fibers, which indicates a higher resistance compared to woods such as oak. The maximum shear stresses are present in the specimens whose stresses are parallel to the direction at the fiber with an average value of 8.71 MPa. For the bending test, the Fc11a series is obtained that is more resistant to breakage, resistance to bending, and greater ductility with a maximum value of 109.52 Mpa. These properties are very interesting to consider LBDA as a structural material and provide an alternative to wood as a sustainable construction material due to its reduced production time, mechanical properties, adaptability, natural beauty.

***Keywords*:** mechanical characterization, dendrocalamus asper, compression, tension, bending stresses

1. Introduction

Bamboo is a grass that grows in abundance around the world on all continents except Europe and the poles, it is estimated that there are more than 1439 species, and according to the International Network for Bamboo and Rattan organization INBAR in America 429 species grow that is they develop from Mexico to Argentina. Bamboo is a natural, ecological, renewable, and sustainable resource, developing more oxygen and absorbing 30% more carbon dioxide CO2 than a hardwood forest, which minimizes environmental impact and the greenhouse effect, it has the ability to auto multiply vegetatively, sprouting naturally in short periods, and its rapid growth favors its use as a constructive material. The whole process, from sowing until it reaches a suitable resistance level, takes four to five years. Unlike a tree that dies when it is cut down, bamboo can continue to be reborn from the same strain depending on the species for more than a hundred years. Acevedo J. maintains that during the search for sustainable and ecologically friendly materials, bamboo has been identified as a very promising option for the future of sustainable construction (3). For this reason, different cultures around the world have used bamboo in their daily lives for centuries. Currently, an estimated 2.5 billion people use it daily. China is the country with the greatest protagonist in the world economy of bamboo, generating income of more than 3.5 trillion dollars (4), and it is estimated that 2.5 billion people use it daily.

There are records of more than 1500 documented uses of the use of bamboo, among which are: raw construction material, houses, food, paper, floors, panels (plywood panels, laminates, parquet floors), ornaments, furniture, baskets, chairs, tables, bridge lamps, musical instruments, fans, utensils, toys, charcoal, industries, pharmaceuticals among many others (4).

Any other natural resource has more versatility, lightness, flexibility, strength, toughness, climatic adaptability, resistance, rapid growth, easy handling, and visual beauty. And above all these reasons it is the fact that bamboo is the building material with a more cost-effective, also easily meets environmental and the International Building Code (IBC) requirements. So, it can be said that bamboo is the plant species of the future.

Due to the, this research aims to carry out an experimental study of physical-mechanical characterization and show the results of the application of compression, tension and bending forces of the bamboo laminates of the dendrocalamus asper species produced in the Andean region of Ecuador. This study will establish a theoretical basis for the depth of study of the structural mechanics of bamboo to identify its mechanical characteristics, the basic performance and failure indexes.

2. Materials and Methods

Laminated bamboo LBDA must undergo a process of transformation from its natural morphology "beefy" to LBDA laminates from the raw material of the Andes Ecuador. To carry out the laboratory tests, the ASTM D143 standard is used, which establishes the dimensions of the specimens to determine the mechanical characteristics of the wood. The standard recommends using uniform pieces with a homogeneous section free of defects so that the results are representative; It also establishes that the number of specimens to be tested must be between 5 and 10 to validate the results obtained in each test (6). For the present investigation, the test tubes are made from bamboo laminates with the same characteristics as wood. In figure 1, the dimensions of the specimens for the test according to the ASTM D143.

The minimum dimensions of the specimens for compression tests are 50x50x100mm. Besides, samples must be free from defects because of the nodules. It is also necessary to consider that the specimens are made in layers with three different positions of the fibers concerning the direction of the load; C11- Compression parallel to the fiber; C22 Compression perpendicular to the fiber perpendicular to the plane of the boards; C33- Compression perpendicular to the fiber parallel to the plane of the boards. For the shear stress test, we have the series; V13 cutting parallel to the fiber; V23 and V32 for shear perpendicular to the fiber. Finally, for the bending test, specimens with dimensions 40x40x300mm Fc11a and Fc11b are used.

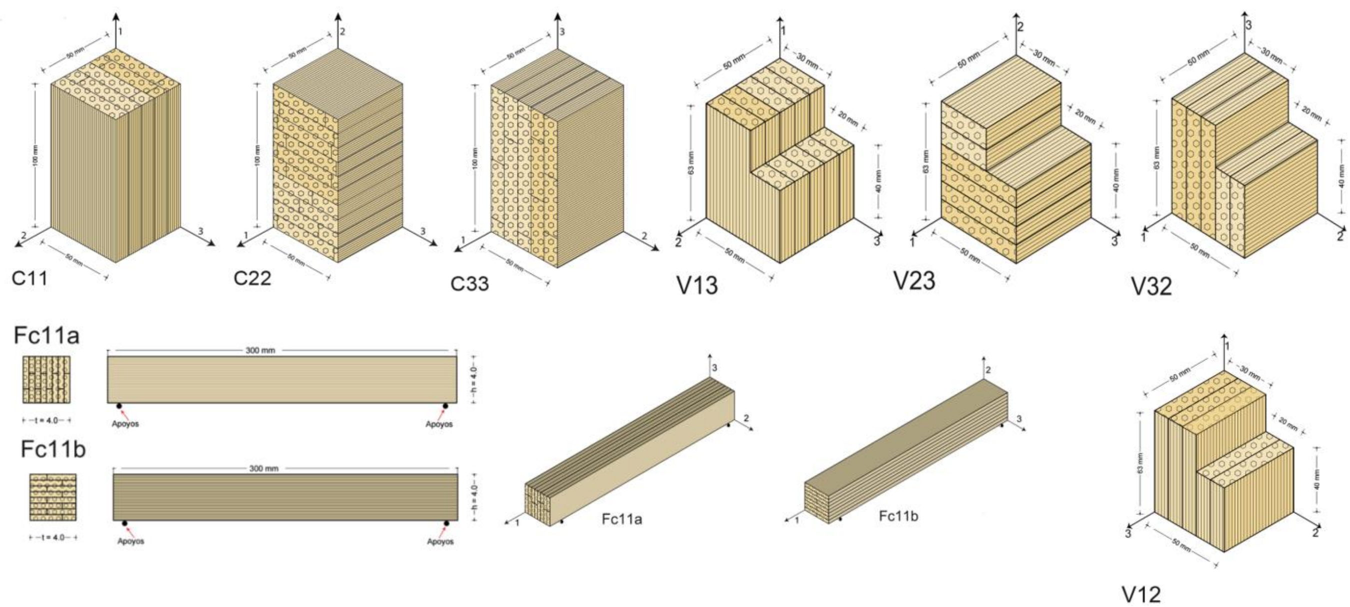

Fig. 1: C11 / C22 C33 specimens for compression test; V13 / V23 / V32 specimens for tensile test; Fc11a / Fc11b Bending Test Specimens, ASTM D143.

The process consists of introducing a specimen of the material to be tested in special presses. Once there is receiving increased pressure following the prescribed regimen until it breaks, being registered all necessary data on indicators of universal machine test. During the process, the stress curve is also obtained, from which we obtain the three main characteristic.

The process involves introducing a sample of the test material in special presses. Once there, it receives a greater pressure following the pre-established regime until it breaks, registering all the necessary data in the indicators of the universal testing machine. During the process, the stress curve is also obtained, from which we obtain the three main characteristic points:

a) The yield stress point from which the material enters flow state, unrecoverable deformation of the specimen.
b) The single resistance limit or breaking limit, which represents the maximum stress reached by a material before breaking.
c) The breaking point, which indicates the exact stress with which the material breaks.

3. Results

The mechanical tests were carried out following the guidelines established by the ASTM D 143-201 standard. In particular, the static bending tests were performed with a symmetrical arrangement, by applying a load at the midpoint of the test bodies arranged on two separate supports 360 mm. For the application of the loads, a universal testing machine brand SHIMADZU, model UH-1000, with a maximum capacity of 1000 kN and the possibility of moving the load head according to the requirements of the adopted standard was used. The loads were determined with an accuracy of 1%. The deformations, measured to determine the value of the modulus of elasticity in flexion, were obtained with instruments capable of registering 0.01 mm.

3.1. Residencia a compression

The tests with the samples to which loads are applied in a direction parallel to the fibers (C11) record the highest maximum load values (the C22 series represents 30% and the C33 almost 20% of the C11 value), of maximum stress (the C22 series represents 30% and the C33 19% of the C11 value), of breaking load (the C22 series represents almost 37% and the C33 24% of the C11 value), Breaking stress (the C22 series represents 37% and the C33 almost 24% of the value of the C11). However, the C11 series registers the lowest maximum deformations (8% of the deformation of the C22 series and 17% of the C33 series), figure 1. The C11 series is more resistant at breakage and its maximum value against compression, but having a much lower deformation at the break, the series behaves in a fragile way. The other series have lower resistance, but present greater ductility, as shown in Table 1.

Table 1: Compression test

Measured values	**Series – Compression test**		
	C11	**C22**	**C33**
Maximum load (N)	131647.7	39137,92	25485,84
Maximum stress (MPa)	53.17	16,13	10,12
Maximum displacement (mm)	2.13	27.41	12,27
Breaking load (N)	84414	30830.8	20560.1
Measured values	34.12	12.7	8.16

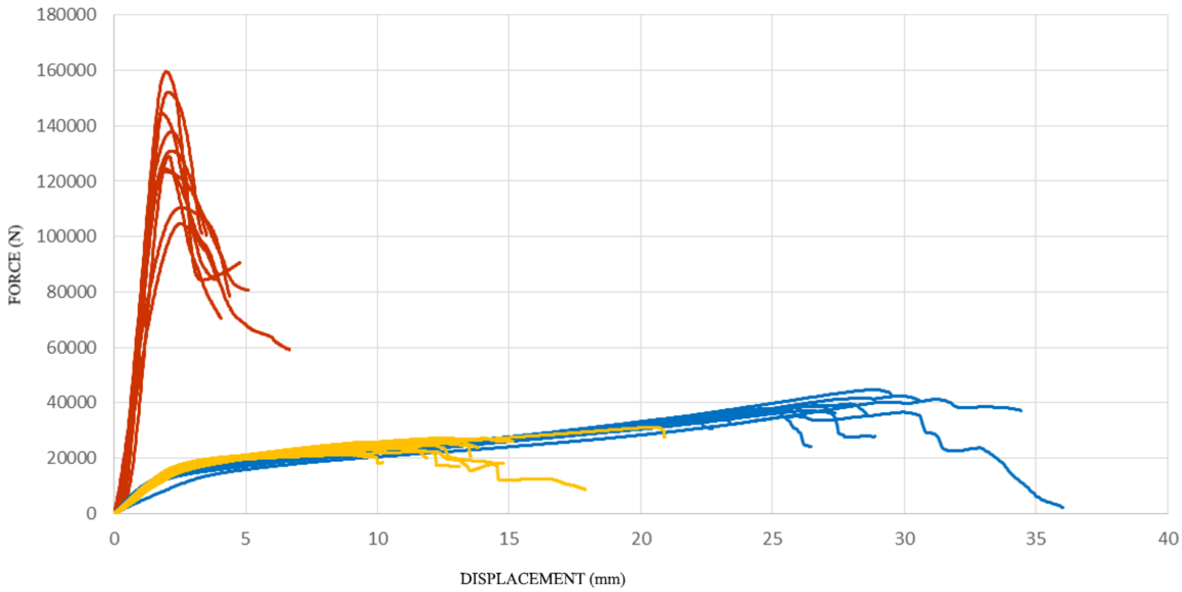

Fig. 2: Load-displacement, 10 specimens C11 (red), the 9 specimens of C22 (blue) and the 10 specimens C33 (yellow)

3.2. Shear stress

The results of the shear stresses of the V13, V12, V23, and V32 series are shown in table 1. To make the comparison of the four series, check figure 2. The samples in which the fibers are arranged parallel to the stress register higher strengths, and with lower breaking deformations, therefore, samples V12 and V13 have a more favorable behavior to resist shear stresses.

The V12 series registers a maximum load and tension 22% higher than the V13 series, it also registers a maximum deformation 60% lower. The load and breaking stress 20% higher than the V13 series. This indicates that the V12 series is more resistant at break and its maximum value against shear stresses, but having a lower deformation at the break, the material is more brittle. At the same time, the V13 is less resistant but more ductile.

Table 2: Shear stress

Measured values	Series - Shear test			
	V13	**V12**	**V23**	**V32**
Maximum load (N)	17833.6	22669.7	8521.7	6114.7
Maximum stress (MPa)	8.4	10.75	4.1	2.9
Maximum displacement (mm)	3.2	1.3	3.7	3.6
Breaking load (N)	17696.9	22013.1	7770.9	5317.7
Tensile strength (Mpa)	8.3	10.44	3.7	2.5

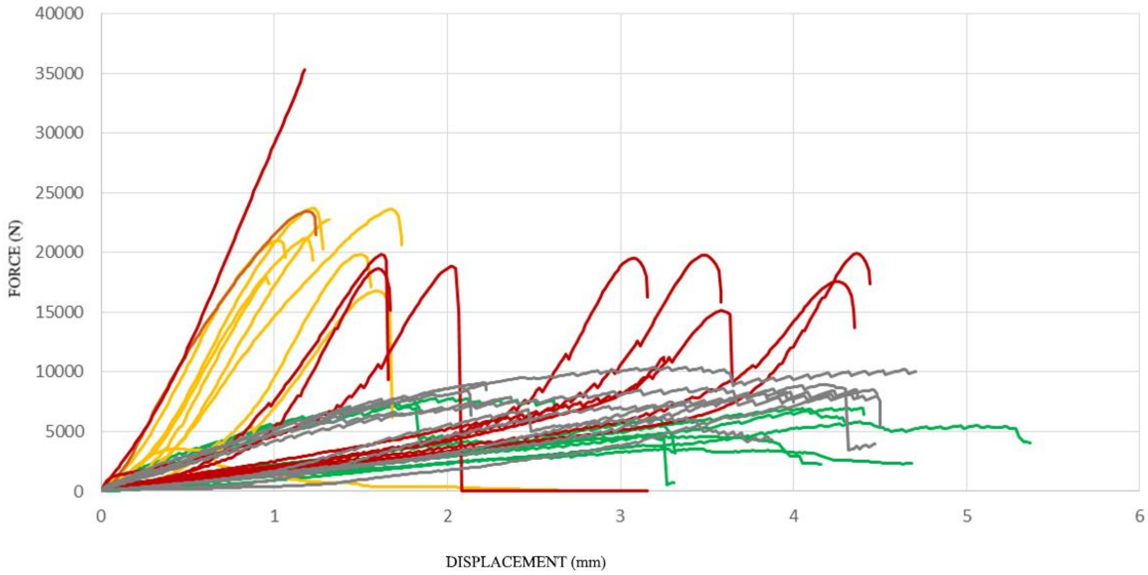

Fig. 2: Load-displacement relationship of the 10 specimens V13 (red), V12 (yellow), V23 (gray) and V32 (green)

3.3. Bending stresses

In this section, the bending behavior of LBDA samples will be analyzed. To carry out this analysis, two series of 10 specimens with a square section of 40mm x 40mm and a length of approximately 300 mm were tested. Said series have been named Fc11a and Fc11b, their names change as the placement arrangements of the ribs are different. In specimen Fc11a the arrangement of the sheets for the flexural test is arranged vertically, in this way the applied load is parallel to the joint plane between the boards. The Fc11b test pieces have the sheets placed in a horizontal position, therefore the applied load acts perpendicular to the joint plane between the boards.

Regarding the forms of breakage, there are two differentiated types, one that fails is the adhesive that joins the different strips, which produces a relative slip between them. The other type of rupture is characterized by the appearance of a longitudinal and perimeter fissure, caused by a traction failure of the parenchyma that occurs in the areas with the least presence of fibers. In both cases, localized crushing can be seen in the area of supports and the area of application of loads. Table 3 shows the results of the flexural tests. And in figure 3 the comparison between specimens.

Table 3: Bending test results

Measured values	**Series - Shear test**	
	Fc11a	**Fc11b**
Maximum load (N)	15504.17	12086.15
Maximum stress (MPa)	109.52	89.95
Maximum displacement (mm)	21.06	12.59
Breaking load (N)	1533.46	1236.46
Tensile strength (Mpa)	106.6	85.17

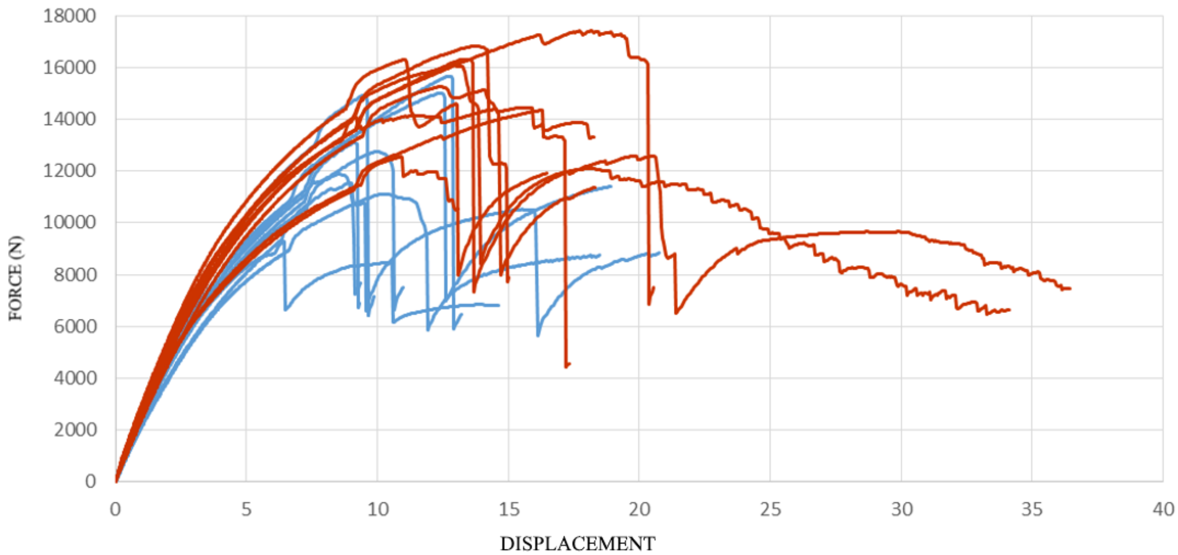

Fig. 3: Load-displacement relationship of the 9 specimens Fc11a (red) and the 9 specimens Fc11b (blue).

This information indicates that the specimens that have the cans with the intermediate dimension vertically (Fc11a series), register more favorable values than the Fc11b series, since the Fc11a series resists 17.4% more than maximum load, 17.9% more than maximum stress, it has 40.2% more deformation at break, resists a breaking load 19.4% higher and a breaking stress 20.1% higher. The Fc11a series is more resistant to breakage and presents a greater deformation at break. Very interesting characteristics for considering dendrocalamus asper bamboo laminates (LBDA) as a structural material for the manufacture of sustainable architectural projects.

4. Conclusion

When comparing the compression forces with various species of wood, it is obtained that oak and cedar have a greater resistance to compression with a value of 41.68 Mpa and 37.85 Mpa respectively. Indicating that these high load bearing timber species why are used to produce beams and columns in architectural projects. However, comparing efforts compression oak and cedar with we laminate bamboo LBDA series C11, it is determined that the laminated bamboo have a higher compressive strength with average value of 53.17 Mpa relative timber species. The comparison test results under the same conditions according to ASTM D143- 2007 standard.

The dispersion of the test results to mechanically characterize the material is like other studies with laminated bamboo other species, and lower than that obtained in the results of the same tests but made materials or constituent parts is that is, to isolated sheets of bamboo or bamboo logs. This indicates that the handling or processing carried out for bamboo laminate improves the structural behavior of the material because it homogenizes the physical characteristics and mechanical properties of materials, which allows us to understand and predict their behavior more reliably.

The mechanical behavior of the species investigated is consistent with that expected for other trials in laminated bamboo other species and even with several wood species such as oak, so you can set the LBDA are suitable for the construction industry sustainable and innovative architectural projects. It was observed that the configuration of samples is an important factor for analyzing the behavior of the LBDA, because in all types of tests (compression, shear and bending) were recorded values with large differences in some cases only the changing the arrangement of the latillas or change of direction of the fibers modify the properties of the building material.

It is important to further bend tests to gather more information, for example, evaluating samples with different lengths, so that one can determine the elasticity modulus and evaluate the interaction of the bending stress with shear.

As well as determining the behavior against tangential stresses, determining the shear modulus or transverse modulus of elasticity.

It is an important test that we implement for determining the adhesion between the parenchyma and fibers. In addition addition to characterizing the behavior of the material against tangential stresses. Additionally, perform fiber content tests tests that allow us a knowledge of the material, the behavior considering the appearance of knots in the formalization of the the latillas.

Acknowledgements

We would like to specially thank CENBA, Central de Bambú Andoas, for the support and cooperation in the development of this Research Project.

References

[1] Naciones Unidas, 2019. Perspectivas de la población mundial 2019. Departamento de Asuntos Económicos y Sociales, División de Población 2019.
[2] FAO. 2020. Evaluación de los recursos forestales mundiales 2020 – Principales resultados. Roma. https://doi.org/10.4060/ca8753es
[3] Acevedo, P. J. (2014). La Bio-construcción como una alternativa en la búsqueda de la sostenibilidad: el caso del bambú. *Revista Internacional de Desastres Naturales, Accidentes e Infraestructura Civil*, *14*.
[4] Bambú Ecuador, 2019. Punto de encuentro entre los sectores productivo, social, educativo y gubernamental, para optimizar el desarrollo y aprovechamiento del bambú en el ecuador
[5] ASTM, A. S. for T. M. (1994). ASTM D143 Standard Test Methods for Small Clear Specimens of Timber
[6] Y. Sánchez, A. Gallardo, R. Delgado (2018). Comparación de la resistencia de comprensión en maderas nativas. Universidad Tecnológica de Panamá, Revista RIC, Vol. 4, Mayo 2018.
[7] Alvarado, C., Moreno, J. I., & Takeuchi, C. (2010). Glued laminated guadua columns. In 12th InternationalConference on Non-conventional Materials and Technologies “Materials & Technologies forSustainable Infrastructure Systems” IC-NOCMAT 2010.
[8] Amada, S., Ichikawa, Y., Munekata, T., Nagase, Y., & Shimizu, H. (1997). Fiber texture and mechanicalgraded structure of bamboo. Composites Part B: Engineering, 28(1-2), 13–20.
[9] Cortes, J. C., Lozano, J., Rusinque, M., & Takeuchi, C. P. (2010). ASSESSMENT OF THE INFLUENCE OF GLUE TYPE IN THE MECHANICAL BEHAVIOR OF GLUED LAMINATED GUADUA (BAMBOO) Caori Takeuchi. In 12th International Conference on Non-Conventional Materials and Technologies (IC NOCMAT 2010).
[10] Correal, J. F., Echeverry, J. S., Ramírez, F., & Yamín, L. E. (2014). Experimental evaluation of physical and mechanical properties of Glued Laminated Guadua angustifolia Kunth. Construction and Building Materials, 73, 105–112. doi:10.1016/j.conbuildmat.2014.09.056.
[11] Jaramillo A., Librelotto L., Larco M. (2016). Inventario del ciclo de vida del proceso de producción de bambú rollizo tratado de la especie dendrocalamus asper en el Noroccidente de Pichincha. Revista Eídos 8ava. Edición. Recuperado de https://app.ute.edu.ec/Portal/Revista.aspx?idPortal=15&idCategoria=1144&idSeccion=1031&idArticulo=85
[12] Li, H., Zhang, Q., Huang, D., & Deeks, A. J. (2013). Compressive performance of laminated bamboo. *Composites Part B: Engineering*, *54*(May), 319–328. doi:10.1016/j.compositesb.2013.05.035
[13] Macías, J. (2017). Programa de gestión ambiental para la central del bambú Andoas (CENBA) del Gobierno Autónomo Descentralizado Provincia de Pichincha. Universidad Tecnológica de Pereira.
[14] Y. Sánchez, A. Gallardo, R. Delgado (2018). Comparación de la resistencia de comprensión en maderas nativas. Universidad Tecnológica de Panamá, Revista RIC, Vol. 4, Mayo 2018.
[15] Santos, A.; Teixeira, A.; Anjos, O.; Rogério Simões, R.; Nunes, L.; Machado, J.; Tavares, M. 2005. Wood potential use of Acacia melanoxylon growing in pure or mixed stands with Pinus pinaster by the portuguese forest industry. Série Técnica 15: 35. p.98.