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CHARACTERIZATION OF BAMBOO'S HONEYCOMB PANEL WITH CASTOR RESIN AND FIBERGLASS FACES

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Abstract. *Honeycomb sandwich panels are a class of structural composites, made of thin layers molded in hexagonal cells shape that fits the face planes with perpendicular oriented axes, normally the honeycomb material is an aluminum alloy or aramid polymer. Bamboo is considered a sustainable material because it is renewable, absorbs carbon dioxide and uses solar energy, being easily incorporated into nature at its life cycle end. The aim of this paper was to perform mechanical characterization of a honeycomb composite panel, made from sections of mature bamboo culms, using the species Phyllostachys Aurea, fiberglass, synthetic thermoset structural epoxy resin and polyurethane resin derived from castor oil, Ricinus Communis. Subsequently the sandwich panels production, samples were selected for the material mechanical characterization. Flexural and compression tests were performed following the ASTM D7249 and ASTM C365 standards. The flexural tests revealed that main mode of fracture was face buckling following by brittle rupture of the top face sheet and the compressive tests values indicate that honeycomb bamboo panels have good properties when comparing with similar composites.*
Keywords: *bamboo culms, honeycomb panels, Ricinus Communis resin, fiberglass, sandwich panels.*

1. INTRODUCTION

Honeycomb panels are formed from thin layers molded in hexagonal shape, and can be grouped into other forms, that fit together, with the axis perpendicular oriented to the face planes. Among the properties, the most relevant are compression and flexural properties. Projected for applications in products demanding high technology and performance, the honeycomb panels are a good choice to structural applications, because they provide an excellent specific strength, being also environmentally and economically attractive for commercialization. They can be used in the naval, automotive, aircraft industries, among others (Callister, 2002) and (Yap and Yeong, 2015)

Bamboo's culm are lignocellulosic plants tube, main aerial part of the plant, that can be used as raw material for manufacture of many industrialized products, among them glued laminated board composite panels, the bamboo is majority applied to manufacture woodframe, consequently, the use of this technique increases the demand for new structural materials. In Brazil, there are many bamboo's reserves, especially in Acre, it grow up easily in the Brazil's territory (Ghavami; Barbosa and Moreira, 2017).

The polyurethane resin obtained from castor oil has several advantages over other types of polymers derived from plants, especially because its raw material is not used as edible oil. It provides great versatility of applications, depending on the way the castor oil is processed (Azevedo, 1999).

According to the manufacturer, polyurethane resin (PU) presents as main properties: considerable durability and elasticity, weathering and ultraviolet rays resistance and great surface pore penetration, that ensure adhesion (IMPERVEG, 2019). When it comes to epoxy resin, has excellent mechanical properties when cured at room temperature. If cured by specific conditions, can provide extreme mechanical resistance and elastic modulus (E-COMPOSITES, 2019).

Either bamboo culms or honeycomb panels have high specific strength, joining the materials in the structural set, it behaves in high performance, ensuring structural stiffness when tested in the form of panels. Have as purpose to be less environmental impact for the sector of structural composites. As a differential, it offers great applicability and considerable mechanical strength (Darzi et al, 2018).

The paper's purpose is to present the mechanical behavior of a structural sandwich panel composite with bamboo culm core and fiberglass layers, or faces, impregnated with epoxy thermoset structural resin, according to the Fig. 2, in view of automotive application.

2. EXPERIMENTAL PROCEDURE

The manufacturing process sequence of bamboo for the accomplishment of 12 specimens for flexural test and 10 specimens for compression test, using the castor polyurethane impregnated GFRP (Glass Fiber Reinforced Polymer) honeycomb composite, followed by the mechanical characterization, is presented in Fig. 1. The schematic also shows the sequence of processes performed with the bamboo culms union with fiberglass faces, ranging your species selection, being one of the most important factors in production process, till the results obtained in mechanical tests.

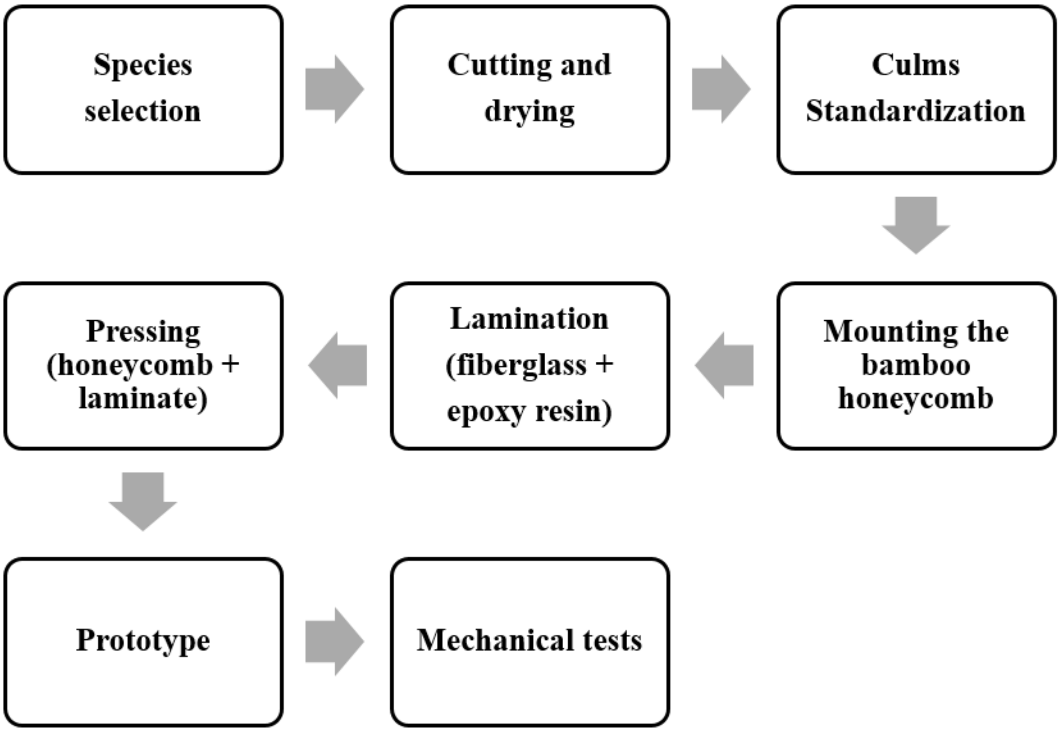

Figure 1. Flow chart of the adopted productive sequence. Source: Authors.

The core panels were produced from the Phyllostachys Aurea species. The culms were cut and stored in airy and without direct sunlight place. Thereby, were obtained cores with 18.11% moisture. The adhesive materials used: synthetic thermoset structural epoxy resin to faces lamination and polyurethane resin derived from castor oil RP 1315C for core union. Two layers of fiberglass were used, resulting in faces thickness of approximately 0.4 mm.

Starting with the screening, separating by the initial conditions of bamboo, green or mature, and later by the diameter variation, the next step was the cutting, done by a ribbon saw, following a culm standardized length in order to facilitate the panels assembly. For such, the adopted core thickness was 20 mm.

The moisture and temperature control at production sector is important for the plates assembly. The resin presents great variation of viscosity with temperature variation and high moisture levels, that can lead to problems in the resin adhesion with the rigid elements in the plate. To coincide with the resin curing time, the bamboo core was keep pressed with the laminated fiberglass faces during 24 hours. The resulting honeycomb design can be observed in the schematic drawing in Fig. 2.

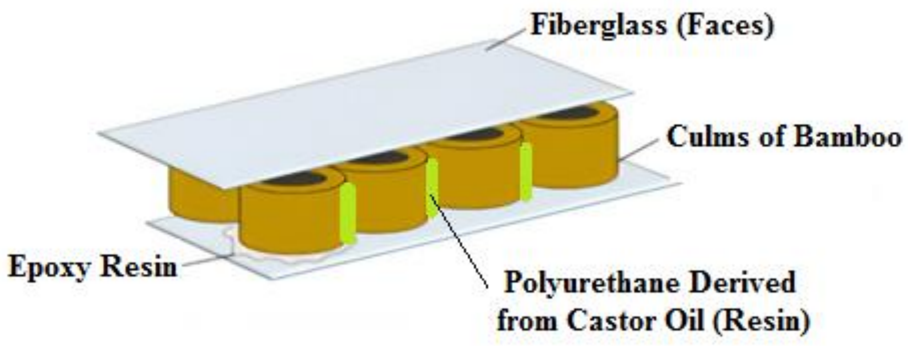

Figure 2. Honeycomb composite panel layers scheme.
Source: Authors.

The samples geometry follow the ASTM D7249 and ASTM C365 standards, and their dimensions are presented according to Tab. 1. The core has culms of 20 mm height, with an average external diameter of 30 mm, and a 4.55 mm wall thickness.

Table 1. Dimension of samples performed to flexural and compressive tests. Source: Authors.

Group	**Length (mm)**	**Width (mm)**	**Thickness (mm)**
Flexure (F)	600	75	20.08
Compression (C)	75	75	20.08

The four-point flexural test was performed to obtain flexural strength of 12 specimens manufactured as previously described, following ASTM D7249 standard. Samples position in the equipment is shown by Fig. 3.

Figure 3. Samples position during flexural tests.
Source: Authors

Geometry and culms disposition in the samples, for compression tests, are shown in Fig. 4.

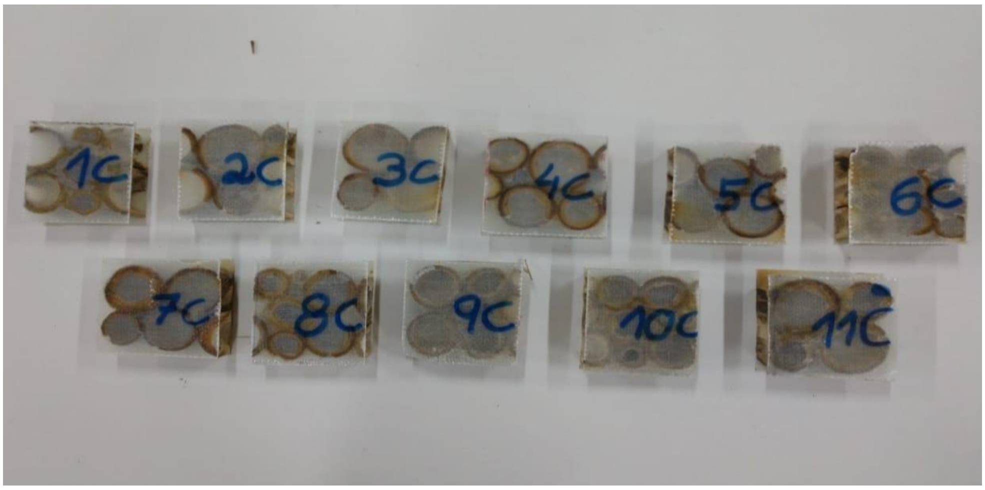

Figure 4. Compression test samples.
Source: Authors.

3. DISCUSSION AND RESULTS

After performing the tests, the values obtained are presented below. Values found were analysed as described by the respective ASTM standards mentioned previously. Initially, are shown the flexural test results for the 12 samples, according to Tab. 2.

Table 2. Maximum Deflection and Flexural Strength for the studied samples.

Sample	Maximum Deflection (mm)	Flexural Strength (MPa)
1	12.188	10.167
2	13.078	14.686
3	14.336	16.686
4	12.736	11.297
5	13.611	11.485
6	10.876	11.485
7	13.856	12.426
8	10.082	10.167
9	18.027	10.167
10	12.847	12.238
11	11.606	9.6022
12	13.881	15.062
Average	13.094	12.122
Standard Deviation (SD)	2.012	1.927

Flexural failure of the sandwich plates generally occurred beginning with a facing buckling of the top layer leading later to a suddenly crack to finally rupture in a fragile manner. The sandwich core was not affected.

Afterwards, are presented the compression test results, with 10 tested samples, shown by Tab. 3 and Fig. 5.

Table 3. Maximum Compress Strength for studied samples.

Sample	**Maximum Compressive Strength (MPa)**
1	12.7820
2	14.7835
3	13.9097
4	14.9893
5	12.3772
6	16.4828
7	13.1604
8	15.6979
9	15.3000
10	12.4606
Average	14.194
Standard Deviation (SD)	4.741

In the graph, corresponding to Fig. 5, it is possible to verify the bamboo core behavior under compression. It is interpreted that the first region occur a core adjustment driven by the face movement. Immediately after, there is the core elastic region, then occurs the yield and, finally, the failure. Regarding the characteristic curves variation, it can be caused by the culms inhomogeneity in core arrangement.

Similar materials are being studied, an example is a sandwich material, which the core is produced from cork, where its mechanical behavior has similar characteristics to those presented in this paper, presenting maximum face tension of 10.89 ±0.15 MPa (Rede, 2019).

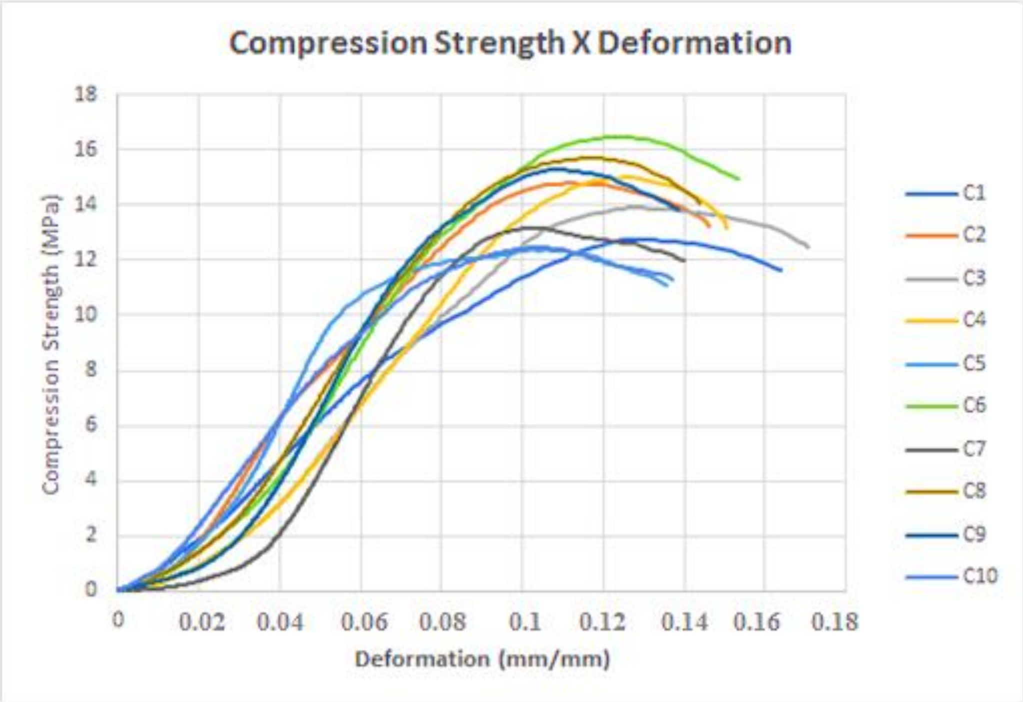

Figure 5. Second part of flexural test report containing the curve (Vertical Compression Strength x Horizontal Displacement) for each sample. Source: Authors.

4. CONCLUSIONS

In the manufacturing process of panels, some possible improvements have been verified, keeping the standard size of culm for making plates is crucial, so that they all have the same external specifications, which would be done through a hexagonal shape, because it allows better prototype homogeneity and, consequently, better efforts distribution. Another important aspect is the core surface finish, made with sanding processes in different granulations and, from the moment that the culms pass through this process, in their peripheral region, we perceive a significant improvement of the resin adhesion with the bamboo culm.

The prototypes produced were submitted to flexural and compression tests, showing good behavior compared to other similar works. For better understanding of mechanical properties, other tests are required, like core shearing.

A future work proposal is to use different materials in the faces, looking for composite efficiency improvement, For example, the use of carbon fiber, as well as kevlar, or even to obtain a better sustainability degree, using bamboo sheets. Another way would be to work with a hexagonal bamboo core, which could be sheets or the worker culm.

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6. RESPONSIBILITY NOTICE

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