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Physical Properties of the Stem of Dypsis Lutescens and Chrysalidocarpus Lutescens as a Vernacular Roofing Material

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Abstract The current trend in sustainable architecture is the use of natural and regional materials to reduce those that consume more energy in their production and those that are highly polluting due to the amounts of CO_2, damaging the environment. Concrete is one of the most materials used in construction. Still, it is possible to replace cement with other sustainable or vernacular materials. The objective of the present work is the mechanical characterization of the stem of the areca palm (*Dypsis lutescens* and *Chrysalidocarpus lutescens*); its obtention is very common in the area of Tampico-Madero-Altamira (Mexico); the easy planting and reproduction make possible to grow it elsewhere. Tests for compressive, flexural, and mechanical resistance, as well as durability, were carried out using Mexican standards. The maximum bending moment that a 2.5m long horizontal structure can support is estimated. The palm shows an acceptable resistance and a resistant moment of up to 6680 ± 0007kg.cm. We also found that durability may be possible for more than ten years. When a roof structure based on a shingle is made with this plant, including supports every 2.2m, it is possible to use it in vernacular house construction with minimal deformation. The use of this material can reduce the environmental impact by avoiding products derived from cement.

Keywords Palm Roof, Mechanical Characterization, Sustainable Architecture

1. Introduction

Palms with more than 3,000 species form an ornamental group par excellence in gardens, within these are *Dypsis*, with *Dypsis lutescens* being the most widely used species in terms of landscaping.

Chrysalidocarpus Lutescens, recently called *Dypsis lutescens*, is characterized by having multiple stems, each one with its roots, so it can be separated and planted in different sectors without dying, this characteristic facilitates its reproduction [1]. It can be used indoors as it is planted in pots and gardens, its growth is greater, in the coastal area it is a very common ornamental palm, called areca palm or bamboo palm, it is a tropical species native to Madagascar and with a high degree of adaptability. Its growth takes around 12 to 15 months for sale; however, for the stem to reach a resistant thickness, time is longer, and it can be accelerated by means of bioactive substances [2].

The botanical classification of *Dypsis lutescens* or areca palm is found within the kingdom of plants or *Plantae* is monocotyledonous, of the order Arecales and family: Arecáceas. This type of palm is generally propagated and reproduced by seed and there are conservation methods for it. [2, 3]

Given that the stem is very similar to that of bamboo [4], the objective of the present investigation is the mechanical characterization of the stem of the Areca palm, by means of resistance tests to both flexion and compression and to carry out durability tests on it and to propose a vernacular slab. In this regard, it is known that the insects that attack *Dypsis lutescens* are the *Coccotrypes carpophagus*, also known as the areca bit, which can be controlled with kairomone [5].

Although currently results have been presented for various vernacular or earth-based structural elements as well as other construction systems and proposals have been made for ecological slabs such as bamboocrete [6, 7], it is necessary to deepen the analysis and design of light vernacular slabs with a greater number of alternative materials. This work proposes one of easy acquisition that can promote the self-construction or the reduction of costs in the building. Vernacular architecture is understood to be one whose function and form are products of the reflection and need of the inhabitants, using the natural material of the region [8].

Some vernacular slabs where Areca Palm or Bamboo Palm can be used would be Roofing (i.e. these used in Northeast Mexico) supported by beams or logs [9] the aforementioned bamboocrete a technique that uses bamboo as concrete reinforcement arises.

In 2013 and with the financing of FOMIX-COTACYT within the grounds of the Faculty of Architecture, in Tampico, Tamaulipas, Mexico, the first prototype was made with a bamboo slab, using half bamboo canes of the Guadua-Angustifolia species, and with walls based on poured earth[10]. This prototype was monitored for more than 3 years, basically presenting problems in the slab due to low adhesion between bamboo and [11] lightened with volcanic stone, as well as cracking due to temperature. Although bamboo is an alternative, it is necessary to show other possibilities as *Dypsis lutescens* that is easy to grow in many places in the world [12,13].

2. Materials and Methods

To evaluate the mechanical resistance in a hydraulic press by Controls, a 60 cm long specimen was placed, and by means of 3 rollers (2 of support and 1 to apply force) with a separation of 15 cm and free clearance of 45 cm; the corresponding force was applied to perform the test. For the Compression test, the following was performed: From a 3.70-meter stem, three samples of 0.60 m were taken for flexing, from the first and third samples, 1 sample was obtained for compression, and from the second sample 2, on the upper and lower side. Also, for compression, the 4 according to their diameter, from the rest of the palm tree, 12 test specimens were taken for compression tests. For this test, a universal Controls brand press was used.

Both flexion and compression tests were carried out in 2 different months and with 10 test pieces per test, to avoid bias. The deformations caused by the load at the center of the gap were recorded to indirectly measure the modulus of elasticity, depending on the type of element that is subjected to load.

The durability test was carried out using 8 test pieces with a height equal to twice the diameter using the ends of the elements used for the flexural test. For the cutting, a Controls model 55-C0210 / BZ universal disc cutting machine was used.

A model QUV / spray accelerated aging test chamber was used, distributed in such a way that the panels where less UV rays are received would be free, according to the manufacturer's recommendations. A comparison was made with the test pieces by subjecting them to an accelerated artificial aging process (EAA), under the same laboratory conditions, evaluating their properties before and after exposure to humidity, temperature, and radiation, representing durability [14].

For the exposure of the tablets, the ASTM G 154 cycle was followed. The specimens were tested for a period of 180 hours in which a total of 15 cycles were completed

3. Results and Discussion

The samples' results were averaged to obtain a reliable value of the modulus of elasticity and the flexural stress, and the specimens were brought to rupture, although at this point the measurable deformation was in some cases outside the scope of the instrument. The modulus of elasticity was located at one third of the breaking load, and the results of the three samples were averaged to obtain a representative index.

For the specimens of 60.00 ± 0.01cm in length and average diameter of 5.35 ± 0.09cm and weight of 1,218 ± 0.010kg, it presented a volumetric weight of 902,595 kgm^{-3} and a moment of inertia of 40.27cm4 and an average section modulus of 15.05 cm3. In Table 1, the results for various loads can be observed, consisting of the deformations and supported moment as well as the elastic modulus and the stress for each of the loads with a free clearance of 45.00cm and 15.00cm of the distance between the loads as well as a linear load of 2,030kg for each linear meter.

A weighted average of the modulus of elasticity equal to 43,504.61 $kgcm^{-2}$ can be observed with the break at 443.89 $kgcm^{-2}$, these results have a maximum error of 2% for the tests carried out.

With the data generated from the previous experimentation, a proposal for a roof based on tile roof or palm was made, and various separation conditions between supports were examined, the data generated.

For the design of the roof shown in Figure 1, the corresponding loads were estimated from the volumetric weights of the materials and the spatial dimensions, finding that the *tejamanil* or palm has a weight of 16.00kgm^{-2} considering a set of overlaps that double the thickness in the section, adding 5.00 kgm^{-2} as well as a live load due to possible natural wildlife with a maximum of 15 kgm^{-2} adding a total of 36.00 kgm^{-2} and an elastic modulus of 43,504.61.

Table 1. Results of calculation Deformation and effort for Areca palm.

Applied load	P	Deformation	Flexing moment	Elastic module	Effort
(kg)	(kg)	(μm)	(kg.cm)	(kg.cm^2)	(kg.cm^{-2})
50.00	25.00	260.50	380.14	77,079.06	25.26
100.00	50.00	798.00	755.14	50,323.55	50.18
150.00	75.00	1181.33	1,130.14	50,990.93	75.10
200.00	100.00	2569.22	1,505.14	31,260.97	100.01
250.00	125.00	4254.11	1,880.14	23,599.64	124.93
300.00	150.00	4337.75	2,255.14	27,773.52	149.85
350.00	175.00	4377.86	2,630.14	32,105.59	174.77
400.00	200.00	5454.29	3,005.14	29,450.74	199.69
450.00	225.00	6588.57	3,380.14	27,428.08	224.61
500.00	250.00	6157.25	3,755.14	32,610.49	249.52
550.00	275.00	6578.00	4,130.14	33,577.08	274.44
600.00	300.00	8261.00	4,505.14	29,167.07	299.36
890.00	445.00	-	6,680.14	-	443.89

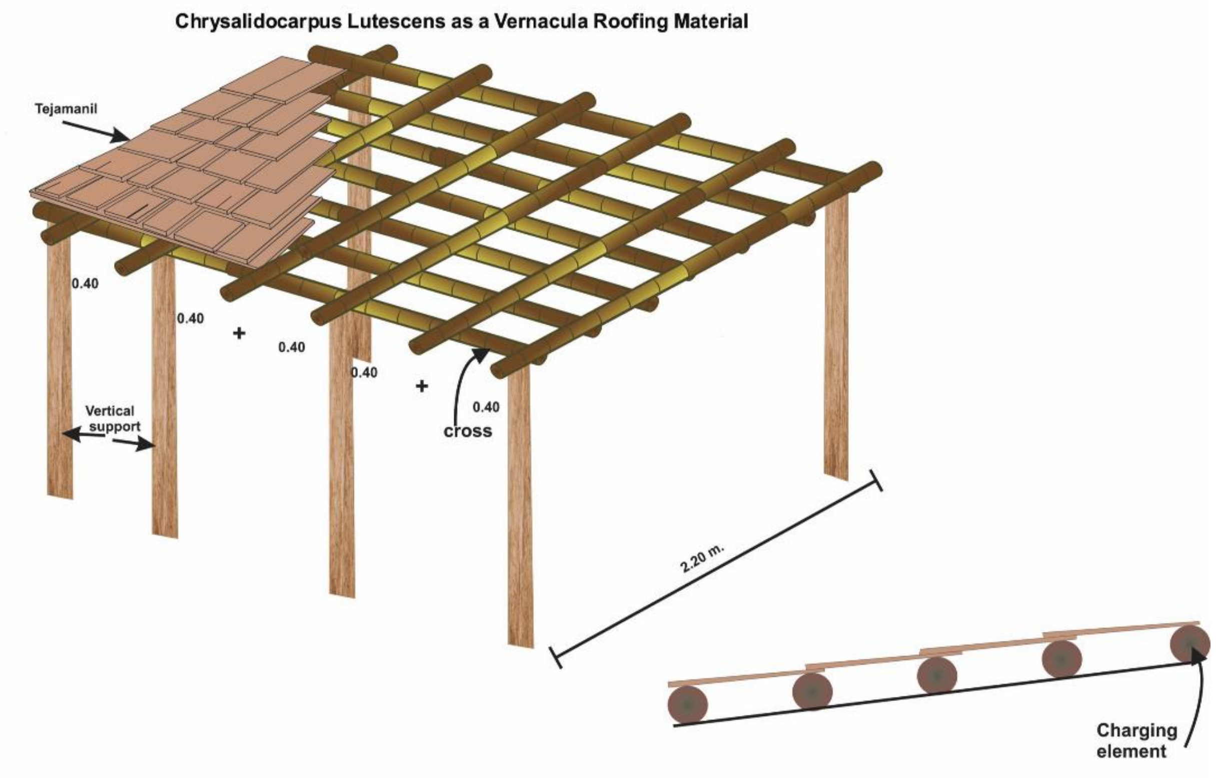

Figure 1. Representation of the system for *tejamanil*.

Table 2. Results of calculation of roofing from the experimental data.

Separation (m)	Length (cm)	W (kg)	Momentum (kgcm)	Deformation (cm)	Admissible deformation (cm)
0.250	240.00	11.02	793.59	0.544	0.960
0.375	220.00	15.52	939.09	0.540	0.880
0.500	200.00	20.02	1,001.11	0.476	0.800
0.750	180.00	29.02	1,175.40	0.453	0.720
1.000	160.00	38.02	1,216.71	0.370	0.640
1.250	152.50	47.02	1,366.95	0.378	0.610
1.500	142.50	56.02	1,422.00	0.343	0.570
1.750	135.00	65.02	1,481.29	0.321	0.540
2.000	130.00	74.02	1,563.72	0.314	0.520

With the previous data obtained from the experimental results, the possible values of load and possible deformation are presented in Table 2. In all cases for the designed structure, there is a deformation less than the admissible up to 40%.

Regarding the compression tests, an average result of 143.76 kgcm^{-2} was obtained but with values that can be between 73.86 and 225.24 kgcm^{-2}.

In general, setting a maximum admissible deformation in 1/250 of the gap supports at 2.20 m are suggested. Stems can be arranged with separations of approximately 40 cm.

The compression results are consistent with the results obtained for flexion considering an elastic range at 30% of the rupture stress.

Finally, we made the accelerated aging test finding that the durability of the palm is at less five years and up to 10 years after the first use. The comparison was made with a well know wood material degradation proving that period life. The average compressive strength was from 181.35 to 213.96 kgcm^{-2}. Once they have been subjected to degradation with the representativeness of 10 years, it decreases to values between 63.75 to 115.97 kgcm^{-2}.

In further work, we will make a pilot roof model using an 8m *x* 4m prototype existing at FADU from the Autonomous University of Tamaulipas to analyze the global deformation on time and degradation of the parts.

4. Conclusions

Derived from the study of the bending behavior of the areca palm on samples with a gap of 45 cm and a pair of concentrated loads separated by one-third of the gap, the modulus of elasticity corresponding to a stress of one-third of that of rupture was obtained. At the laboratory level, it was found that the palm presented a flexural resistance of 443.89 kgcm^{-2}, and compressive strength of up to 213.96 kgcm^{-2} and a minimum of 63.75 kgcm^{-2} with an estimated aging period of 10 years.

The load on the palm was estimated by varying the separation of the support and the tributary surface of the load. Maximum separation is determined in 2.20m.

It demonstrates the possibility to generate a roof system, using *tejamanil* or palm.

Regarding the accelerated aging tests, a loss in the diameter of 1 mm was found; this may be due to the loss of mass within the chamber; however, healthy fiber and a resistant system are observed. Compressive strength reduces up to 45% in a period of life of 10 years.

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