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Tensile, Shear and Bending Properties of Raffia *vinifera. l. arecacea*

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Abstract: Historically, finding decent and affordable housing has been a major concern for people. The advantages of bamboo such as a renewable, ecological material, its fast growing and its low cost, allow it to be considered as a substitute for common nonrenewable materials. Using of raffia bamboo in construction as support, scaffold and carrying girder it's not subject to any norm recommend. It's very important to know his mechanical properties before use it in this field. The objective of this paper is to investigate the mechanical properties in tension, shear and bending. The method used is experimental. All test protocols were conducted in accordance with French standard EN NF 408. The results obtained show that the stiffness in the direction of the fibers of raffia shell (16905 MPa) is close to that of heavy woods. The marrow exhibits behavior similar to ductile materials. The experimental results have shown that it has a high capacity for deformation before breaking and a very weak elastic phase. Simple shear tests conducted on the shell in the direction of bamboo fibers have shown that the shear stress changes as the section becomes large. The convincing explanation attributed to this observation is the sensitivity of the dimension effect on the mechanical properties. All the data from the test campaigns allows us to catalog the raffia species among the promising renewable materials in construction.

Keywords: Bamboo, Raffia, Mechanical Properties

1. Introduction

The decent housing problems that some people face in developing countries have been acute for several years. The use of secondary materials (bamboos, coconut fibers, bamboo fibers) and resources is therefore an alternative to this dilemma. According to Gonda et al. [1], it is established that there are already 2000 species of which only a hundred would be the subject of scientific study. Among these materials worthy of interest, bamboo appears as one of the materials likely to take the leading position based on eco-friendly materials.

Bamboo is a plant found in several countries of the equatorial zone of Africa (Cameroon, Gabon, Democratic Republic of Congo...). In Cameroon, for centuries the raffia plant has been used in various ways (to make alcoholic beverages, art objects and buildings). Residential houses, hedges, beds, stools, are basically made from bamboo. The physico-chemical analysis and characterization of bamboo fibers have been the subject of numerous researches. Thus ovat et al. [2] used bamboo fibers to produce a composite by bonding the resins to obtain a product with added value.

Beckley Victorine et al. [3] extracted ligninin by Klaxon method and observed that this method yielded the greatest lignin content other species.

From the point of view of microstructure, the observation of the straight section of raffia bamboo reveals there are some similarities with that of other bamboo species. According to Foadieng et al. [4], the microscopic observation of the cross section of the fibers shows that all bamboo species have a hexagonal shape.

The species of raffia bamboo scientifically called vinifera is a material consisting of a shell and a marrow formed from fibers whose density decreases from the shell to the center of the stem [5]. The same author declare that the variation of the tensile rigidity of bamboo fibers is not only dependent on the area of sampling along the stem, but also on the mode of nutrition of the plant which is root to foliage. Studies [6-7-8] have been conducted to analyze the bamboo rupture. Yan Wei et al [9] studied the damage of bamboo under cyclic compression and observed three modes of failure: shearing, buckling and splitting. Following compression tests in the direction of the fibers carried out on pieces of bamboo, two statistical models are proposed to model its break [6]. Analyzes made on bamboo pieces indicate that this plant displays a delayed behavior. Indeed, the work [4, 6] carried out on compressive creep and flexural creeps, respectively, made it possible to deduce the parameters of Schapery's model on the one hand, and on the other hand to highlight the viscoelastic nature of bamboo.

The purpose of this work is to carry out a mechanical characterization of raffia bamboo. The desired properties such as tensile stiffness, stress, transverse shear modulus are determined in order to better integrate it into the modern construction process based on eco-friendly materials. As such, tensile, flexural and shear tests on shell and marrow are performed.

2. Materials and Methods

2.1. Materials

2.1.1. Sampling Area of the Stems

The stems planned for the experiment are carefully selected and are about five years old each. This age correspond at the maturity of stems for the construction. They have no physical degradation due to insect attacks. All the tested stems originate from the Gwegwa district of Baham in the Western region of Cameroon. The samples selected for the various tests show no macroscopically observable defects. The bamboo stems have lengths that vary between 4.5m and 6m. The average diameter was about 35mm (33-37) for six dry rods selected for the test campaign.

2.1.2. Sampling

The stem is divided into four parts coded in the area from 1/4 linked to the base to 4/4 linked to the vertex [11]. The samples to be tested are taken from the different parts using a sharp cutting tool. The electronic caliper is used for measurements.

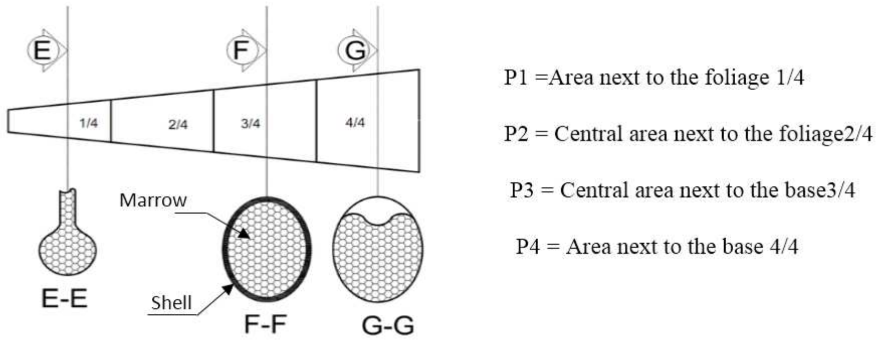

Figure 1. *Illustration of different areas.*

2.2. Characterization Methods

2.2.1. Water Content

Humidity is an important physical parameter to consider prior to any feasible biomaterial test. Our samples were conditioned according to a well-defined protocol [10]. According to standard EN-NF 408, a constant mass is considered when the results of two successive weighing carried out at a time of 6 hours do not vary by 0.1% of the mass of the test specimen. The selected samples are conditioned at a temperature of 60 ° C. The moisture content is defined as the ratio between the difference of the initial mass and the anhydrous mass by the anhydrous mass. The relative humidity of the weighed samples is 12.6.

$$H = \frac{(M_H - M_0)}{M_0} \times 100 \tag{1}$$

Where H is the water content; M_H the mass sample with water content and M_0 is the anhydrous mass and $(M_H\text{-}M_0)$ the mass water contained in the specimen.

2.2.2. Tensile Test

The tensile test consists of applying a constant load in the direction parallel to that of the specimen fibers for a period of 300s (± 120s) [10]. The test device used is a single hydraulic tensile machine of capacity 25 KN. In order to minimize slippage of the specimen at its ends, we used an adhesive to bond rectangular beads made of marrow as recommended by the standard. This technique has already been used [8-12]. The length of the test sample shall be sufficient to provide an unobstructed test length of the jaws equal to at least nineteen times the largest dimension of the cross section [10]. This allows us to take for dimensions: a length of 140 mm and transverse dimensions 4x2 mm2. Figure 2 below illustrates the principle of the test.

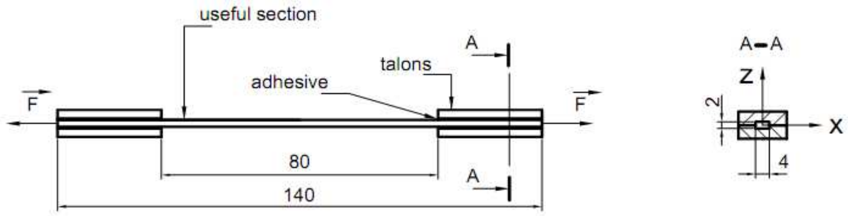

Figure 2. *Tensile sample.*

The modulus of elasticity in tension is given by the relation (2):

$$E_t = \frac{L\,\Delta F}{S\,\Delta L} = \frac{\Delta\sigma}{\Delta\varepsilon} \tag{2}$$

E_t: modulus of elasticity in axial traction; ΔF and ΔL are respectively the increase of the forces (N) in the linear zone of the force displacement curve and the increase of the arrows in (mm). Δσ and Δε are respectively the increase of the stress (MPa) and increase of the deformation. L and S represent the length of the specimen and the section of the specimen.

2.2.3. Shear Test

This test is performed on the same device as that of the simple tensile and conducted according to the same standard [10]. The principle of the test consists of imposing a state of uniform axial stress parallel to the direction of the fibers. The resulting axial deformations are then recorded, and the transverse modulus of elasticity is deduced. The geometrical characteristics of the specimen are shown in figure 3.

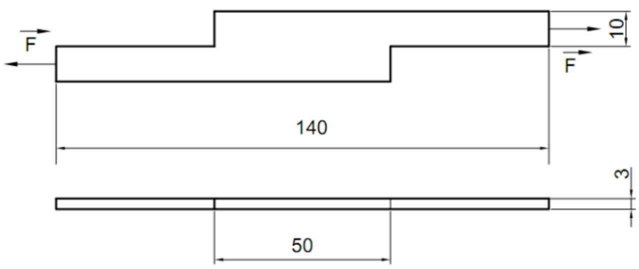

Figure 3. *Shear test.*

The transversal modulus of elasticity is given by the relation (3):

$$G = \frac{\Delta\tau}{\Delta\gamma} \tag{3}$$

G: Axial transverse elastic modulus; Δτ and Δγ are respectively the increase of the stress (MPa) and increase of the relative slip.

2.2.4. Bending Test

Standard [10], which governs the dimensions and shapes of the test specimen, recommends that: the latter must have a minimum length equal to nineteen times the height of the section. The minimum permissible range on the machine is 140 mm; This imposes to take as length of the test sample 200 mm with a rectangular section of 10 x 10 (mm^2). Figure 4 below shows a simple bending test piece.

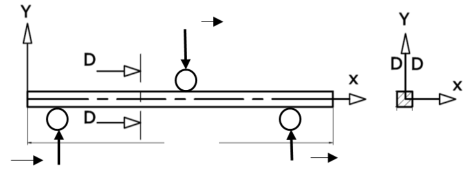

Figure 4. *Bending test specimen.*

Flexural elasticity modulus is given by the relation:

$$E_m = \frac{(F_2 - F_1)L^3}{48\,I\,(W_2 - W_1)} \tag{4}$$

Where: E_m, app: Flexural modulus of elasticity; (F2-F1) and (W2-W1) respectively represent the increase of the forces (N) in the linear zone and the increase of the arrows in mm of the displacement force curve; I the quadratic moment in mm^4.

3. Results and Discuss

In this section we present the results of tensile, shear and flexural tests. All samples were tested at their breaking point. The different mechanical properties were determined in the elastic domain by the linear regression method.

3.1. Tensile Test

Figure 5 shows the typical stress-strain curves of the specimens from the different respective sampling zones along the stem.

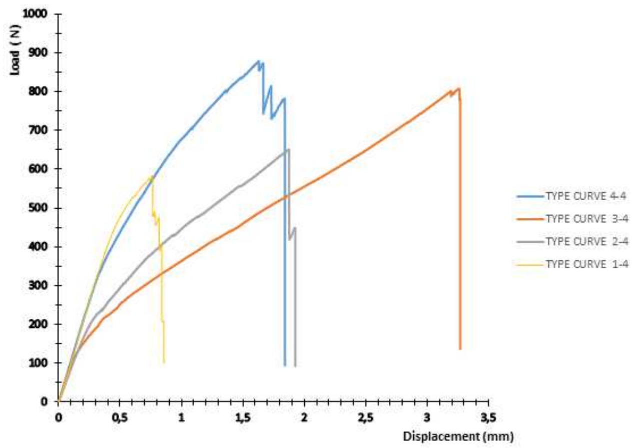

Figure 5. *Typical stress-strain curves.*

During the test campaign, four to five samples are tested per area sampling. The data curves obtains are very reproducible.

The variation of the elastic modulus of elasticity in traction of the shell along a rod is presented on the graph of figure 6.

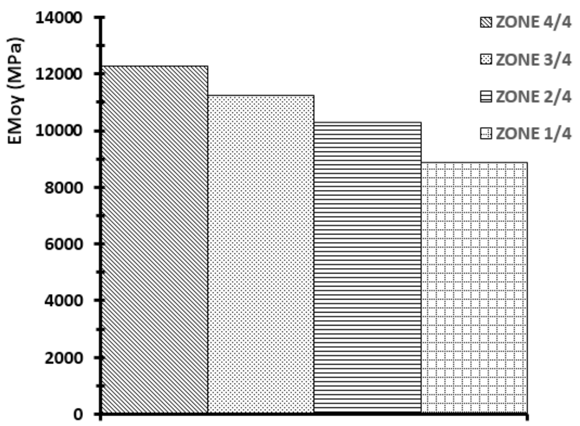

Figure 6. *Variation of the Young's modulus by sampling zone.*

The observation of the typical curves of Figure 5 reveals that they all present a quasi-bilinear behavior. There are three distinct phases of behavior on the stress-strain curve. The first presents an evolution linked to the reversible elastic behavior of bamboo. At this stage, no significant damage is noticeable. It is in this phase that the elastic modulus is measured. The second stage corresponds to the beginning of the nonlinear behavior which translates the beginning of mechanism of damage. The curve has a slight slope in this portion. The third phase makes it possible to appreciate a relatively linear behavior and extending over a large range of deformation. This is indicative of the rapid propagation of damage before macroscopic rupture. This phase is directly followed by a sudden drop in stress, a sign of complete debonding between the bamboo fibers.

This makes it possible to classify the behavior of bamboo shell in the category of brittle type materials. In addition, the analysis of the stiffness of the material in the elastic domain by the linear regression method reveals that the bamboo shell has a YOUNG modulus estimated at 10666.5 MPa [13] which is a heavy wood. The fiber decohesion observed during the tensile test resulted in a brush-type failure. This mode of breaking had already been observed among several types of rupture (by bursting, explosion) [12]. Figure 6 indicates that the rigidity of the stem decreases from the base to the top. This finding was established on the scale of raffia vinifera fibers [5]. This observation is also dependent on the fact that the plant is fed from the base to the top. Table 1 presents the different results of the mechanical characteristics obtained for raffia vinifera and some softwood species.

Table 1. *Mechanical properties in tensile test of bamboo and some wood species.*

Species studied		E_{moy} (MPa)	SD E_{moy}	σ_r (MPa)	H (%)
Tsuga heterophylla	[13]	10600		-	12.8
Acer peudoplatanus	[13]	10200		-	12
Pseudotsuga menzeii	[13]	16800		-	12
Pinus sp pine	[13]	16600		-	9.7
Dendrocalamus	[13]	8000		-	-
Raphia vinifera.L.arecacea	1/4	8874	667	58.52	12.6
	2/4	10273	526	58.45	
	3/4	11239	496	109.18	
	4/4	12280	1117	88.09	

A succinct analysis of Table 1 reveals that the tensile rigidity of bamboo shell is similar to that of many other species listed as heavy woods. Moreover, this is confirmed by the standard classification of the elasticity moduli of the two large classes of wood: hardwoods with an elastic modulus of 14400 MPa and softwoods with a stiffness of 13100 MPa [13].

3.2. Shear Test

The shear tests have made it possible to plot the transverse relative slip curves representing the behavior for different shear lengths. The standard used for the shear test is the same as in tensile test. All samples shear are tested at their breaking point. Figures 7 represent graphs of typical curves for different slip lengths.

With regard to Figure 7, we can see that the curves have a large elastic domain and a quasi-non-existent plastic phase. It appears that the shell of bamboo has a mechanical behavior comparable to that of brittle materials. Table 2 shows the different mechanical properties obtained in simple shear.

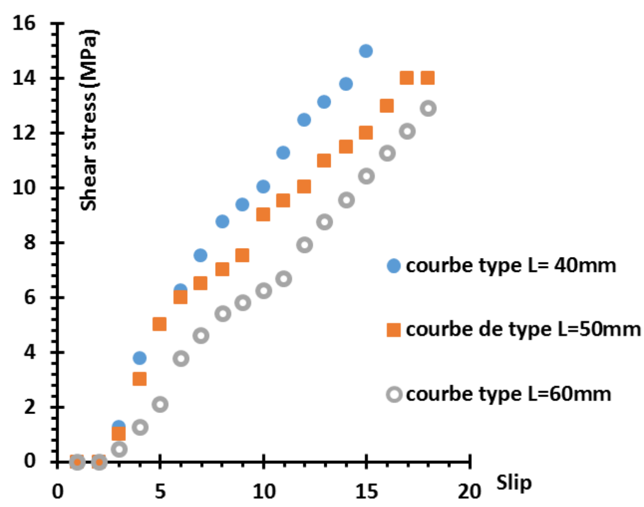

Figure 7. *Relative stress-slip curves: L= 40mm, L= 50mm and L= 60mm.*

Table 2. *Mechanical properties in simple shear of some species of resinous species and bamboo.*

Species studied	τ_{Moy} (MPa)	Standard deviation	Request areas (mm^2)	H (%)
Fraxinus sp frêne	1330		-	12.8
Eperua salcata wapa	1400		-	12
Distemonanthus movingui	1410		-	12
Pinus sp pine	1780		-	9.7
	1631	484	60 x 2	
Raphia vinifera L.arecacea	1643	556	50 x 2	12.6
	1718	498	40 x 2	

It can be seen from Table 2 that the average shear stress decreases as the slip area increases. This phenomenon can be explained by the sensitivity of the dimensional effect relative to the sliding zone. Moreover, this variation of the transverse shear modulus can be explained by another phenomenon. In fact, bamboo being a heterogeneous and anisotropic material, the larger the dimensions become, the greater the probability of presence of defects, the less it will be able to withstand the shear forces. The tangential stress values for bamboo in Table 2 are close to those of other softwoods (Distemonanthus movingui, Pinus sp pine and Fraxinus spash) considered heavy wood. This suggests that bamboo can be incorporated into the construction given its high shear strength.

3.3. Bending Test

The circular bending tests are carried out on marrow specimens according to the NF-EN 408 standard. The curves below represent the arrow force graphs of the marrow for different sampling zones along the stem.

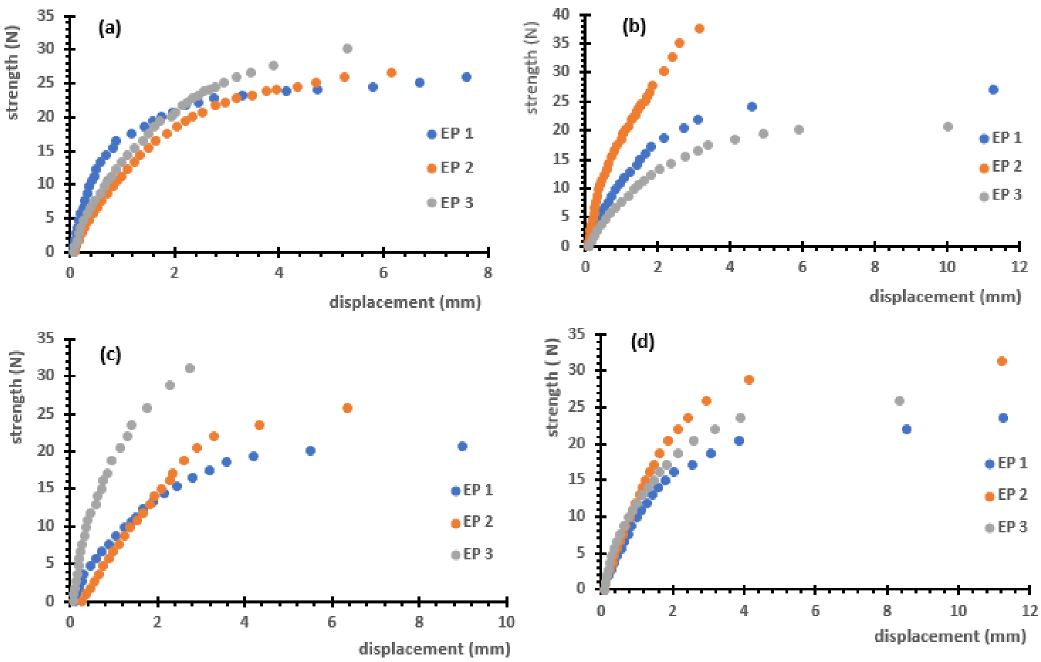

Figure 8. *Curves type force/arrow of the cork (a) zone 1/4, (b) zone 2/4, (c) zone 3/4, (d) zone 4/4.*

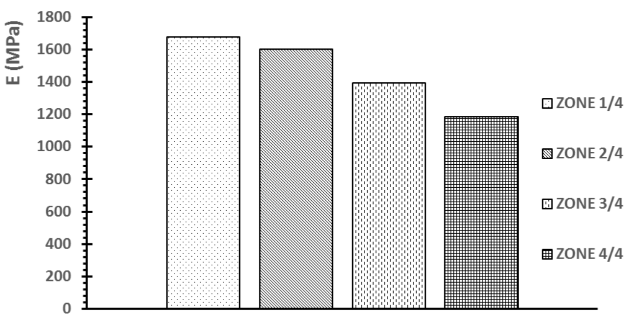

Figure 9. *Variation of flexural modulus.*

The curves of Figures 8 (a-d) show a weakly marked elastic domain; a large plastic deformation before rupture and distant breaking points signifying a sudden breaking at the end of the test. Such an observation allows us to classify bamboo marrow in the category of softness materials. Figure 9 shows the variation of Young's modulus in bending along the stem. We observe that this magnitude increases from the area near the foliage, to that near the base. Such an observation finds its explanation once more in the mode of nutrition of the plant which is from the base to the summit on the one hand. On the other hand, this variation of rigidity comes from the variation of the straight sections of fibers constituting our samples. Indeed, the fiber section increases from the area near the foliage to that near the base [5]. Table 3 summarizes the values of the flexural modulus of bamboo according to the different parts and that of some bamboo species.

Table 3. *Mechanical properties in circular bending of some bamboo species.*

Species studied		Sampling area	$E_{Average}$ (MPa)	Standard deviation	Dimensions (mm x mm)	H (%)
Dendrocalamus asper	[14]		595.33		ϕext 92.5 x ep 11.13	12
Bambusa blumeana	[14]		577.67		ϕext 75.13 x ep 7.93	10.67
Gigantohloa albociliata	[14]		188.33		ϕext 28.07 x ep 8.87	11.33
Raphia vinifera L.arecacea		1/4	1676	403	10 x 10	12.6
		2/4	1601	679		
		3/4	1393	672		
		4/4	1184	364		

Table 3 allows us to observe that the bending rigidity of the raffia bamboo marrow is substantially similar to that of some species mentioned in the table. However, these values remain very low in front of the resistance of the shell; which would make the marrow responsible for the flexibility of the raffia bamboo.

4. Conclusion

The approach used in this paper has been purely experimental. Several test campaigns were carried out respectively on the shell and bamboo marrow to evaluate their mechanical properties. These tests revealed the softness nature of the shell in tensile and the softness behavior of the bamboo marrow in flexion. Compared to the standard elastic modulus values presented in the literature, raffia bamboo seems to be the one that has excellent tensile characteristics in fiber direction, as well as in shear. Indeed, the average Young's tensile modulus for specimens from the same rod is evaluated at 10666 MPa. While for the two large families of hardwoods and softwoods, 10600 MPa and 13100 MPa elastic modulus are respectively registered [13]. Anything that allows us to put bamboo in the heavy wood category. This justifies explicitly its use in the construction field.

In addition, the shear strength of bamboo shell was evaluated and the average value obtained was 1690.54 MPa. This value is quite close to the resistance to shear that of conifers such as pinus. We note that the shear strength of raffia bamboo is similar to that of heavy woods (hardwood and softwood), it can be easily incorporated into the building construction process easily since the assemblies with bamboo stems are made by tying with creepers or with dowels. In the latter case, the assembly works in shear.

However, the low stiffness of the bamboo marrow in flexion implies that it is light and therefore the latter is the weakest element of the bamboo structure of raffia vinifera. In addition, its high deformation capacity before breaking allows to put it in the category of softness materials. Given the above, it would be interesting to consider an experimental and numerical study on the damage mode of raffia bamboo and lead to a constitutive law proposal specific to this material.

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