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Mechanical Characteristics Of Tall-Palm (Borassus Aethiopum Mart., Arecaceae) Of Chad / Central Africa

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Abstract— **The study concerned the carried out the mechanical characteristics of the wood's palmyra (Borassus aethiopum Mart., Arecaceae) of Chad, a wood very much used as component of framework, lintel and post.**

The results of the tests in compression and bending on the samples of this wood Point out That:

- The breaking strength of it heartwood is 103.20 ± 1.13 MPa in longitudinal compression, 13.39 ± 0.35 MPa in radial compression and 180.01 MPa in tree points bending.

- The elastic modulus of it heartwood is 6 400 ± 92.77 MPa in longitudinal compression, 199.83 ± 25.80 MPa in radial compression and 15 044.87 MPa in bending tree points.

- The breaking strength of it sapwood is 69.89 ± 3.64 MPa in longitudinal compression, 14.78 ± 0.01 MPa in radial compression and 71.56 MPa in tree points bending.

- The elastic modulus of it sapwood is 5 603.22 ± 129.80 MPa in longitudinal compression, 285.83 ± 13.39 MPa in radial compression and 6 333.89 MPa in tree points bending.

This survey is a remarkable contribution in the research of the scientific and technological knowledge of the tall palm of Chad for it rational utilization.

Index Terms— **Palmyra, wood, mechanical characteristic, elastic modulus, rupture strength, sapwood, heartwood.**

I. INTRODUCTION

The palmyra wood is fairly abundant in Chad and widely used as prime material frames, slats in the construction of habitats and field fence posts because of its durability over time and its resistance to moisture and to termites. Unfortunately, the mechanical characteristics of this wood of Chad are not known. Previous work carried out on samples from the same log of this study allowed us to know the anatomical, chemical and physical characteristics of palmyra wood.

This work deals with the experimental determination of its mechanical properties in compression and three-point bending of the wood palmyra to validate the theoretical study carried out in 2010 [1]. This is to study the characteristics of radial and longitudinal cohesion under these stresses to predict the mechanical behavior under various external loads.

The knowledge of this mechanical behavior will not only proportion the structures made of this material, but to undertake its mechanical and thermal study as a natural composite material.

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II. STUDY MATERIALS

Palmyra wood used as case study is taken from a male aged around 40 years in Houndouma, a village at the southern of N'Djamena, located at 11°51.33' north latitude and 15°04.47' east longitude (Image.1). It is a biopolymer material comparable to a natural composite material [1], [2], [3].

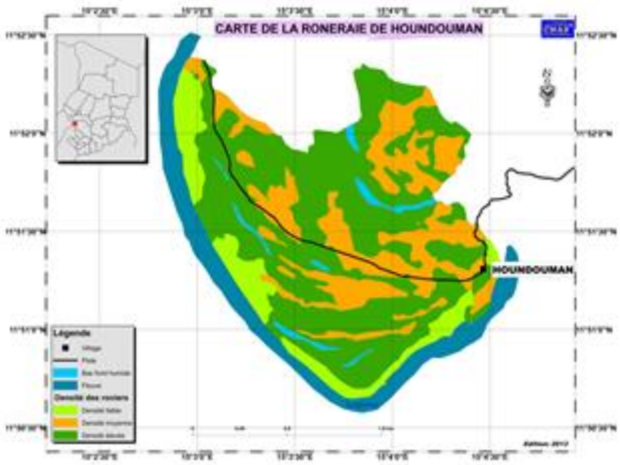

Image.1: Cartography of palmyra field in Houndouma.

Anatomically, this particular wood structure contains about 124 fibers per square centimeter in the heartwood and 77 fibers per square centimeter in the sapwood [4].

The chemical composition of its useful parts as a construction material in Chad [4] is:

- For sapwood: 61.89 (%) of cellulose, 19.68 (%) of lignin, 11.32 (%) of hemicellulose and 7.11 (%) of extractives;
- For the heartwood: 63.21 (%) of cellulose, 19.36 (%) of lignin, 9.60 (%) of hemicellulose and 7.83 (%) of extractives;
- Its physical characteristics are [4]:
- Average density at 12% of moisture content: 894.4 kg/m^3;
- Volumetric shrinkage: 6.05% linear shrinkage: 2.62% and tangential shrinkage: 0.57%.

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III. METHODOLOGY

The objective is to determine the tensile strength and the modulus of longitudinal elasticity (Young's modulus) in compression and in bending.

In compression, the tests are carried out in the longitudinal direction and in the radial direction of the fiber's sample. For this reason two specimens of sapwood and two specimens of heartwood, 20x20x60 mm in size, are taken in the radial direction and in the longitudinal direction of fibers. The compression load is applied gradually until the specimen breaks.

For bending, two specimens of heartwood and two specimens of sapwood of the same size (20 × 30 × 340 mm) are requested with a three-point bending with a displacement rate of 10 mm/min.

It involves applying to the test piece, resting on two distant rolls of 330 mm, a halfway load supports as shown in Image.1. This load is applied perpendicular to the fiber direction until the rupture of the specimens.

The choice of the moisture content of 12% is to be able to compare our results with other results that are generally given to this humidity [5].

Image.2: Specimen in bending 3 points: (a) unloaded specimen; (b) specimen ruptured.

The stress at the tensile breaking strength is calculated with the formula $R_r = \frac{F}{a^2}$ and the longitudinal modulus of elasticity using the formula $E = \frac{F \cdot L}{\Delta L \cdot a^2}$, where F, L and a are respectively the maximum applied load, the length L and the side of the square cross section of the tested specimen.

The bending strength is measured out using the formula $R_r = \frac{3F \cdot L}{2b \cdot h^2}$ and the longitudinal elastic modulus is obtained by applying the formula $E = \frac{F \cdot L^3}{4b \cdot h^3 \cdot f_{max}}$, in which:

- F, L and f_{max} are respectively the maximum applied load, the distance between the two support points, and the maximum arrow-bending.
- b and h are the width and the thickness of the tested specimen.

The forces and displacements are automatically recorded using a computer system for data acquisition. These data are subsequently processed in Excel to get the stress-strain curves for compression and force-displacement curves for bending. In both cases of stress, we used linear trend lines for the desired mechanical quantities.

IV. EQUIPMENT

The machine used for compression and bending test is a press Zwick brand, type 1484, having an electromechanical system. Its maximum capacity is 200 kN in force and 200 mm/min in speed. It is equipped with a speed control system for applying to the specimens a progressive force to obtain the values of displacement and load of suitable breaks. A steering computer with software Testx.pert.2 connected to the machine allows recording the data and tracing their evolution curves directly.

V. RESULTS AND DISCUSSIONS

The stress - strain curves (figures.1 and figure.2), provided by the Testx.pert.2 software, present the results of various tests carried out in compression along the radial and longitudinal directions

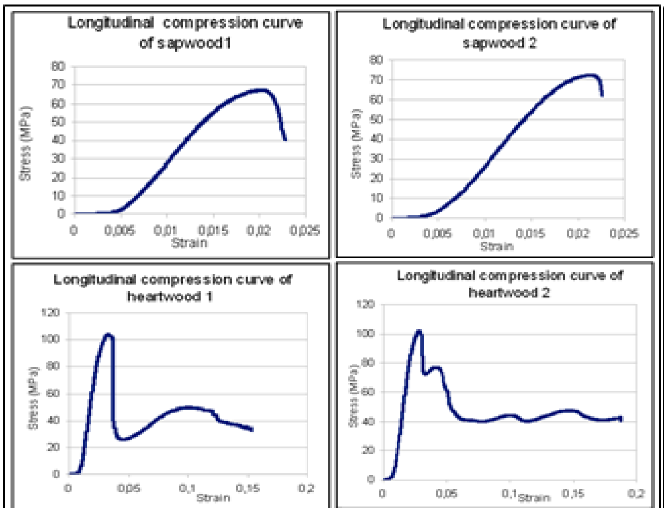

Figure.1: stress-strain curves in longitudinal compression of two specimens of sapwood and heartwood.

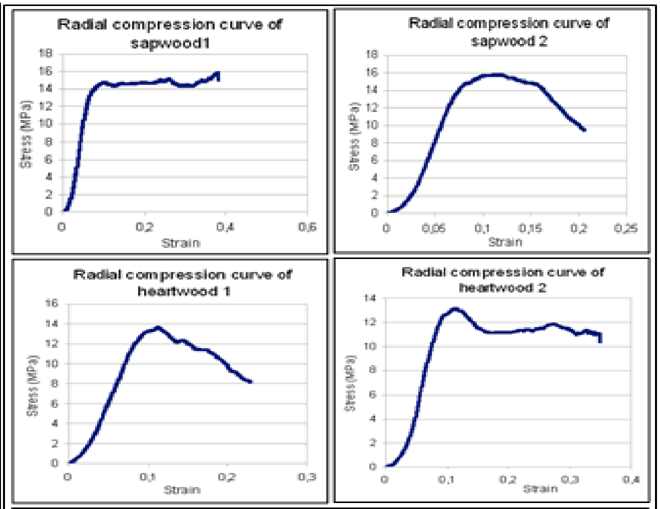

Figure.2: stress-strain curves in radial compression of two specimens of sapwood and heartwood.

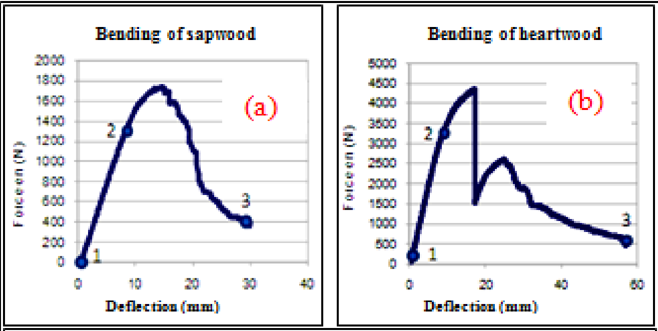

Figure.3: Force – deflection curves in bending: (a): Heartwood, (b): sapwood.

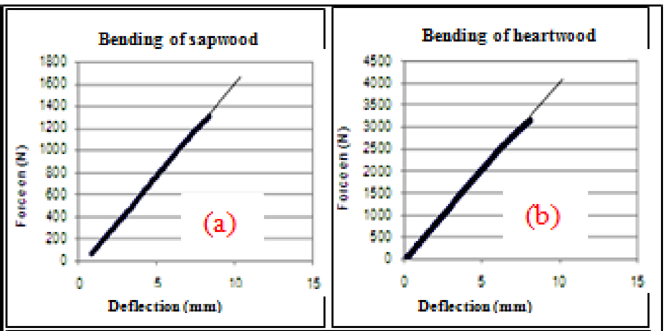

Figure.4: Linear force – deflection curves in bending obtained between points 1 and 2 of the Figure.4.

These compression curves generally include an elastic portion showing that the material of the specimen behaves linearly until a level of stress which depends on the direction of the solicitation with respect to the fiber direction. The behavior of the sapwood in compression load in the grain can be considered as brittle elastic. Its behavior in the radial direction seems to be elastic-plastic.

The heartwood has an elastic - plastic behavior in both direction of the load compression and in the radial direction of the bending load. These behaviors in tension were observed by a research team of Polytechnic School of Abomey Calavy - University of Abomey Calavy of Benin [11], [12] and [13].

Table.1: Values of Young's modulus E and the rupture strength R_r of the tall-palm timber obtained in compression loading.

Solicitation	Specimen	Young's Modulus E (MPa)	Rupture strength R_r (MPa)
Radial compression	sapwood	285.83 ±13.39	14.78 ±0.01
	Heartwood	199.83 ±25.80	13.39 ±0.35
Longitudinal compression	sapwood	5603.22 ±129.80	69.89 ±3.64
	Heartwood	6400 ±92.77	103.20 ±1.13

Table.1 gives the modulus of elasticity E and resistance to breakage R_r of both parties timber relative to the longitudinal and radial directions of the fibers.

According to this table, the sapwood is more resistant to compression in the radial direction than the heartwood, but the heartwood is better resistant than the sapwood in longitudinal compression.

Figure.3 presents respectively strength-deflection curves in bending for the heartwood and sapwood. These curves show two phases of evolution of the curvature according to the force:

- A phase of linear growth between the points marked 1 and 2,
- A phase of plastic deformation where the forces fall between the marked points 2 and 3, then breaking up (beyond the point 3).

Figure.4 shows the linear curves corresponding to the portion between 1 and 2 of the Figure.3. The maximum bending strengths are 4 366N for heartwood and 1 735N for sapwood. One obtained for these load values a tensile strength of 180 MPa for heartwood and 71 MPa for sapwood.

The Young's modulus values obtained are 15 044 MPa for heartwood and 6 333.89 MPa for sapwood in tree points bending.

Given these results, the heartwood has a double value of Young's modulus of sapwood in bending. It is the same for their resistance to rupture in bending (6333 MPa).

Table.2 and table.3 respectively give the classification of timber based on their elastic modulus and the mechanical characteristics of tall-palm of some countries of West Africa and those of other species of wood on the basis of which we will chair our discussions.

Table.2: Classification of timber based on their elastic modulus.

Young's Modulus E	Class
E < 10000 MPa	Low modulus
10000 MPa ≤ E ≤ 15000 MPa	Middle modulus
E > 15000 MPa	High modulus

Table.3 : Mechanical sizes of tall-palm of some countries of West Africa and those of other species of wood [4], [5], [6], [8], [9], [10].

Wood Species	Origin	Rupture strength (MPa)		Young's Modulus (MPa)	
		longitudinal compression	Bending	longitudinal compression	Bending
Palmyra	Chad	86.54	180	6001	15 044
	Niger	79	135		15 800
	Ivory Coast	70	125		
	Benin	81.17	186.34		17196, 86
	Togo	9.25	9.14		-
Ayous		31	55		6 000
Sipo		57	130	-	11 000
Azobé		98	235	-	17 600
Pui		2.45	4.2	-	-
Oak (Chêne)		2.45	6	-	-

According to the value of the Young's modulus of the table1 and the classification of table.2, the tall-palm is a low modulus of longitudinal compression wood (E < 10 000 MPa). It is even lower in radial compression, both for the sapwood than heartwood.

In bending, Chadian tall-palm wood is the high modulus type (E > 15 000 MPa).

Note that these results are dependent on its anatomic structure and humidity. Indeed, the grain plays a vital role in the resistance of wood. The wood of tall-palm comes in the longitudinal direction of the fibers as a rigid, tough and hard. In the transverse direction (radial), it is a little resistant material. In this direction, the micro-febrile networks (fibrous tissue) perpendicular to the axis of compressive stress constitute weak points. The walls being stressed, a slip at the middle lamella of the matrix might appear and improves deformable material. The behavior of tall-palm wood in the radial direction is almost that of the medullar rays that allow the adhesion of the fibers. When acted on by radial compression, cracks take births between the nearest fibers and wend through other regions. This mechanism develops simultaneously in different parts of the section and provides a brittle behavior to the whole tall-palm wood specimen. The medullar rays are crushed; afterwards, it appears some slips of different tissues. According TIAGO Edson [7], the wood of low lignin content has low cohesion of tissue elements. That's what could explain the low cohesion of the elements palmyra wood tissues of Chad which lignin content is 19.52%.

For comparison, we chose the heartwood part of palmyra of Chad considered harder and more resistant.

Given the results of table.3, the heartwood of the palmyra Chad has superior compressive breaking stress than the tall-palm Niger, the Ivory Coast and Togo, but close to that of Benin. It is less resistant to compression than Azobé wood. Its Young's modulus is in the same order of magnitude as that of Niger, but small compared to that of Benin and that of Azobé wood. Its mechanical characteristics are well above those of Ayous, Sipo, Pug and Oak wood.

Note that the Young's modulus in longitudinal compression of the Chadian tall-palm heartwood is very small compared to the Young's modulus in bending (Table.3). This results from the anisotropy of the wood. For wood, the bending strength reaches and often exceeds the compressive strength if the wood is very good. The woods offer mechanical strength depending on the direction of the force against the direction of fiber. Features vary with the species (fabric, humidity, etc.) in the same species with age, exposure conditions and in the same individual with the conditions of sample collection. Local conditions (soil, climate, etc.) from where the tall-palm developed have a preponderant effect on its quality [11], [12], [13], [14].

VI. CONCLUSION

Knowledge of mechanical characteristics is an indispensable way for implementing strategies in the rational use of tall-palm wood of Chad.

The various mechanical tests have shown that this tall-palm wood globally has mechanical properties above the average of the known mechanical properties of certain species, for the heartwood part. This part of tall-palm wood has an appreciable resistance, which can be explained in part by the value of its average density and thus the density of the fibers that constitute it.

Indeed, the behavior of tall-palm wood under mechanical stress differs according the direction of the load against of the direction fiber. The specimens have larger stiffness properties in the longitudinal direction.

It is therefore essential to clarify the rheology of tall-palm wood from metal materials and artificial composites.

THANKS

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