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Contribution to the Characterization of Palm Kernel Shell from Littoral, Cameroon

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Abstract

The experimental study carried out in this work contributes to the physico-mechanical characterization of the palm kernel shells (PKS) *Elaeis guineensis* of the DURA and TENERA varieties. The knowledge of these properties gives an idea of their behaviour in the realization of composites and others. The absolute density was determined by the method of pycnometer, the porosity and compactness of PKS too; respectively 1428.81 kg/m^3 for Dura, 1395.81 kg/m^3 for Tenera; 0.041 for Dura, 0.158 for Tenera; 0.958 for Dura, 0.841 for Tenera. The impact energy of PKS by the pendulum sheep method has an average value of 2.066 J/cm^2 and 1.894 J/cm^2 for Dura and Tenera respectively at a temperature of 26˚C. The longitudinal Young's modulus of 19 GPa and 17.9 GPa for Dura and Tenera, respectively, was determined by applying the Castigliano theorem through a three-point bending test device.

Keywords

PKS, Density, Compactness, Impact Energy, Young's Modulus

1. Introduction

Oil palm, cultivated in more than twenty countries around the world, plays an important role in the peasant economy so far as this crop contributes firstly, to satisfy the domestic needs of farmers and secondly, to provide them with monetary income. Through our investigations, we have found that once the palm nut is separated from the shell, the latter is no longer used for anything or is sometimes used as a fuel for cooking, electricity production and decoration of art objects [1].

The annual world production of palm kernel shell amounts to about 21,359,000 tons, about 270,000 tons for Cameroon [2] [3]. In Cameroon, about 70% of these shells are dumped in the wild, causing pollution [1]. Because these plant by-products degrade very slowly.

Research work has been conducted on palm kernel shell, including the determination of physical-chemical properties [4] [5] [6]. The physical properties of PKS are essential parameters in the development of process methods and equipment design [7]. These properties include rheological, thermal, optical, electrical and some mechanical parameters. Palm kernel shells are also used in the production of activated carbon for water filtration and other applications [8]. Given their importance to the world economy in general and to Cameroon's economy in particular, palm kernel shell deserves more attention in order to optimize their potential. Further work has been or is being done on PKS. As a background application of palm kernel shell, we can mention their utilisation as fillers in the realization of brake pads, safety helmet. Also, in some localities in Cameroon, such as the Haut-Nkam, West region, palm kernel shells are dumped on muddy country roads in order to facilitate the adherence of car tyres [1], in addition, composite materials have been made from these shell and although their mechanical characteristics are poorly known, they have demonstrated many qualities, including their machinability and toughness [9].

In order to improve knowledge of the characteristics of PKS, this work aims to contribute to the physico-mechanical characterization of palm kernel shell.

2. Materials

Palm kernel shells used in this study come from a mature cob walnut from the production area of Nkongsamba for the DURA species and BOMONO for the TENERA species, all located in the Littoral Cameroon. The shells are extracted by drying the nuts. These shells are carefully cleaned before use to get rid of oil and fibres residues and are kept at a temperature of 105˚C in the oven for four hours before packaging.

3. Methods

3.1. Density

The determination of the density parameters of the materials indirectly provides an approximation of the quality of their constructive properties.

3.1.1. Absolute Density

The absolute density is determined experimentally by the pycnometer method according to NF P 94-054. The procedure used consisted in carrying out the following operations:

- Select a sample and place it in the oven at 105˚C for 24 hours.
- Weigh a pycnometer filled with distilled water to the mark and note its mass M_1.

- Weighing a sample of aggregate of mass M_2.
- Introduce the sample into a pycnometer after pouring in a quantity of water.
- Gradually fill the pycnometer up to the mark, eliminate air bubbles and note M_3 its mass.
- Note the temperature of the water in the pycnometer.

The values of the individual weights are used to determine the absolute density.

$$\rho_{abs} = \rho_e \cdot M_2 / \left[\left(M_1 + M_2 \right) - M_3 \right] \tag{1}$$

where ρ_e is water density taken conventionally

3.1.2. Apparent Density

The bulk density was determined by the hydrostatic balance method according to the recommendations of NF P 94-053. The principle of the method consists in determining the volume of a sample by means of the Archimede thrust. It is obtained from successive weighing of the sample. Samples are taken by the quartage method and weighed on a 10^{-3} g precision scale.

- Let methe mass of the sample, then the sample is immersed in previously melted paraffin.
- Let m_{e+p}, the mass of the sample plus paraffin (with a density of 0.87796 g/cm^3)

The wax sample is then carefully immersed in water.

- The displaced volume of water V_d is given by the expression $V_d = V_e + V_p$
- The volume of the paraffin is: $V_p = \dfrac{m_{e+p} - m_e}{\rho_p}$
- The volume of the sample is given by the relationship $V_e = V_d - V_P$

The bulk density is expressed as the ratio of the mass of the sample to the volume of the sample.

$$\rho_{ap} = \frac{m_e}{V_e} \tag{2}$$

3.2. Porosity (*p*), Void Index (*e*) and Compactness (*c*)

The dimensionless characteristics, given by Equations (3), (4) and (5), provide information on the voids in a body.

$$e = \frac{\rho_{abs} - \rho_a}{\rho_a} \tag{3}$$

$$p = \frac{e}{e+1} \tag{4}$$

$$c = 1 - P \tag{5}$$

3.3. Mechanical Characterization

The mechanical characterization of palm kernel shell consists here of determining the longitudinal Young's modulus, the fish coefficient and the impact energy. The species of interest are DURA and TENERA. All palm kernel shells are obtained from mature nuts from the same cob for each species.

3.3.1. Typology of Samples

The palm kernel shell has geometry similar to that of the globe, *i.e.* it has two poles and meridians. To test the isotropy hypothesis, we propose to take samples in the Meridional direction and the Equatorial direction as shown in **Figure 1**.

We took the PKS DURA and TENERA specimens in the southern and equatorial directions. The aim was to see whether its mechanical characteristics vary according to the orientation in which the specimen was cut, in order to ensure the isotropy of this material. **Table 1** represents the orientation M and E adopted; we have chosen a set of 20 specimens.

3.3.2. Resilience Energy

We determined it experimentally using the Charpy's Sheep method using a pendulum sheep adapted to plant shells, carried out at the LAMMA laboratory of ENSET, Douala as shown in **Figure 2**.

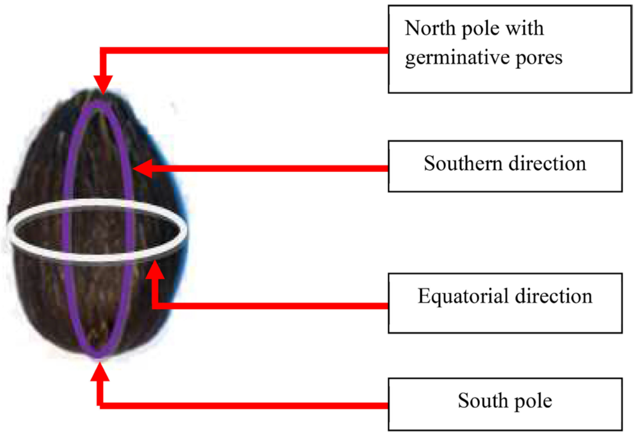


Figure 1. Image of palm nut.

Table 1. Adopted sample allocation terminology.

Designations	Symbols
Sample taken in the Southern direction	M
Sample taken in the equatorial direction	E

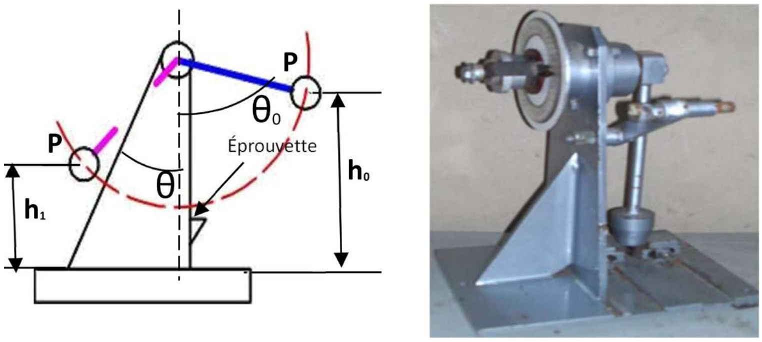


Figure 2. Schematic diagram of the pendulum sheep.

$$R = \frac{mgl\left(\cos\theta - \cos\theta_0\right)}{S} \tag{6}$$

with l: length of the pendulum arm (320 mm);

m: mass of the pendulum arm;

θ: angle of ascent after specimen breakage;

θ_0: angle of free upward movement;

g: acceleration of gravity at the test site;

S: cross-section of the test specimen.

Influence of temperature on impact energy

This influence has been assessed by impact tests on specimens subjected to temperatures ranging from 26˚C to 90˚C. For each temperature range, seven specimens were tested. The temperatures were measured using a type K thermocouple.

3.3.3. Young's Modulus

Due to the curved geometry, PKS does not offer the possibility to obtain straight specimens for the classical uniaxial tensile test; we will limit ourselves to three-point bending and elastic contact tests. The deformation energy will allow us to establish an equation whose parameters will be E and ν. We will take the fish coefficient value of 0.4 because palm kernel shells are similar to wood.

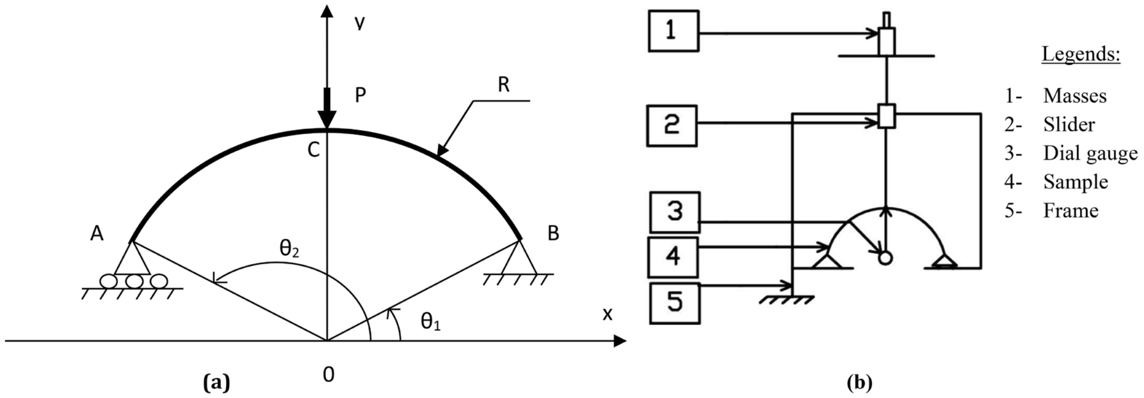
1) Principle of the three-point bending test

The bending test shall be carried out on a specimen in the form of a portion of a cylinder. This test piece is comparable to a curved beam whose mean line is in the form of an arc of a circle. We tested 20 specimens in the southern and equatorial directions. Figure 3 below shows the boundary conditions.

We place specimen (4) on the supporting surface integral with the frame (5), the end of the slide (2), bearing a steel ball is positioned at point C of the shell. The masses (1) are placed above a plate attached to the slide. The feeler of the dial gauge (3) is located under the shell and is used to directly measure the deflection corresponding to a given load in the extension of the slide rail. Several pairs of data (load, deflection) can be collected in the elastic range.

2) Mathematical expression of the deflection-load relationship

The application of Castigliano's theorem will allow us to establish a linear



(a) (b)

Figure 3. (a) Schematic diagram of the test (b) Three-point bending test apparatus.

relationship $P = \alpha \cdot Y_c$ with P the load applied at point C, Y_c the deflection at point C and α the slope of the straight line which is a function of the static Young's modulus, the fish coefficient and the geometric dimensions of the specimen.

3) Expression of the deformation energy of a specimen

The total deformation energy U is due to internal forces [10] [11] [12] [13] is described by Equation (7) and given by Equation (8).

$$U = 2\left(U_1 + U_2 + U_3\right) \tag{7}$$

with U_1 = Deformation energy due to normal effort N

U_2 = Deformation energy due to sharp effort T_R is negligible

U_3 = Deformation energy due to flexural moment M_{fz}

$$\begin{aligned} &U = 2\left(U_1 + U_2 + U_3\right) \text{ or } U_2 = 0 \Rightarrow \\ &U = 2\left\{\frac{RP^2}{16ES}\left[\frac{\pi}{2} - \theta_1 + \frac{1}{2}\sin\left(2\theta_1\right)\right] + \frac{P^2R^3}{8EI_{Gz}}\left[\left(\frac{\pi}{2} - \theta_1\right)\cos^2\theta_1\right.\right. \\ &\qquad \left.\left. - 2\cos\theta_1 + \frac{3}{4}\sin 2\theta_1 + \frac{1}{2}\left(\frac{\pi}{2} - \theta_1\right)\right]\right\} \end{aligned} \tag{8}$$

L and e are the dimensions of the cross-section S.

E is the static Young's modulus in longitudinal direction.

P is the applied load.

$I_{GZ} = \frac{1}{12} \times Le^3$ is the quadratic moment of the straight section.

The application of Castigliano's theorem to the midpoint of the specimen C allows us to write $Y_c = \frac{\partial U}{\partial P}$ we thus obtain the relation below:

$$\begin{aligned} &Y_c = \frac{\partial U}{\partial P} \\ &\Rightarrow Y_c = \left\{\frac{R}{4S}\left[\left(\frac{\pi}{2} - \theta_1\right) + \frac{1}{2}\sin 2\theta_1\right] + \frac{R^3}{2I_{Gz}}\left[\left(\frac{\pi}{2} - \theta_1\right)\cos^2\theta_1\right.\right. \\ &\qquad \left.\left. - 2\cos\theta_1 + \frac{3}{4}\sin 2\theta_1 + \frac{1}{2}\left(\frac{\pi}{2} - \theta_1\right)\right]\right\} \times \frac{P}{E} \end{aligned} \tag{9}$$

Let's pose

$$\begin{aligned} \beta = {} & \frac{R}{4S}\left[\left(\frac{\pi}{2} - \theta_1\right) + \frac{1}{2}\sin 2\theta_1\right] \\ & + \frac{R^3}{2I_{Gz}}\left[\left(\frac{\pi}{2} - \theta_1\right)\cos^2\theta_1 - 2\cos\theta_1 + \frac{3}{4}\sin 2\theta_1 + \frac{1}{2}\left(\frac{\pi}{2} - \theta_1\right)\right] \end{aligned} \tag{10}$$

Substituting Equation (10) into Equation (9), gives Equation (11)

$$Y_c = \beta \times \frac{P}{E} \tag{11}$$

The factor β depends on the geometrical characteristics of the specimens. From expression $\frac{P}{Y_c} = \frac{E}{\beta}$; E is determined. The slope P/Y_c has been obtained experimentally as the slope of the linear regression.

4. Results and Discussions

4.1. Density of PKS

The density of the palm kernel shell is given in **Table 2** below.

This result shows that palm kernel shells of the species TENERA are more porous than those of the species DURA. This is not due to their parameters of cultivation or area of production. But fundamentally, this is attributable to their microstructure with and important porous network.

4.2. Resilience Energy of PKS

The average impact energy of palm kernel shell is 2.066 J/cm^2 and 1.894 J/cm^2 for DURA and TENERA species respectively at a temperature of 26˚C. It is clear that DURA PKS are more resistant to breakage. This resistance is directly linked to the highest density, compactness and low void index of Dura variety. Moreover, their structure and thickness are considerable. We also note that the resilience energy of the palm kernel shell decreases linearly with a correlation coefficient R^2 of 0.914 with increasing temperature. It varies between 1.63J/cm^2 at 50˚C and 0.58 J/cm^2 at 90˚C as shown in **Figure 4** below.

4.3. Young Modulus of PKS

The Young's modulus of the palm kernel shell of the DURA variety is 19 GPa and that of the TENERA variety is 17.9 GPa at a temperature of 26˚C. **Figure 5** below shows the variation in deflection as a function of load with a correlation coefficient R^2 of 0.9956.

In **Table 3**, we find that palm nut shells have a density close to that of coconut

Table 2. Void index, porosity, compactness and density values.

SPECIES	DURA	TENERA
Apparent density (Kg/m^3)	1370	1174
Absolute density (Kg/m^3)	1428.81	1395.81
Void index (*e*)	0.043	0.188
Porosity (*p*)	0.041	0.158
Compactness (*c*)	0.958	0.841

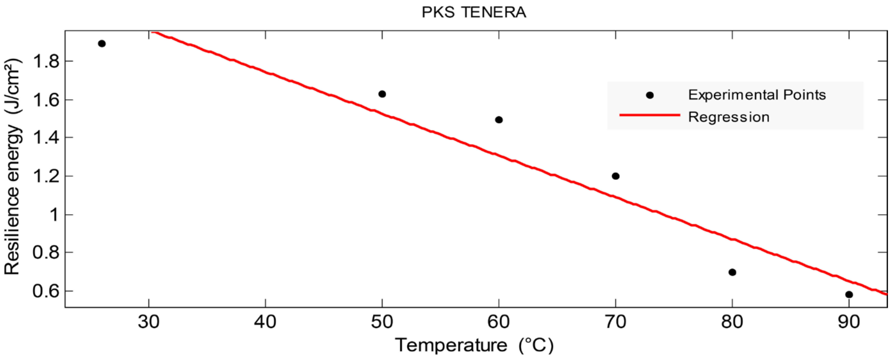


Figure 4. Impact enregy vs. temperature.

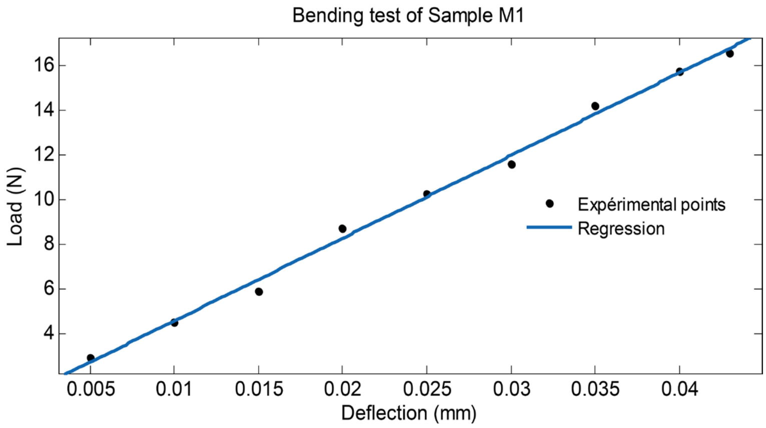


Figure 5. Variation of deflection with load.

Table 3. Comparison of absolute density and Young's modulus of some wood species.

Wood species	Absolute Density (Kg/m^3)	Young Modulus (Gpa)	References
ACAJOU	500 - 680	9.5	[2]
AFROMASIA	650 - 800	10.6	
AZOBE	1000 - 1100	17.3	
BILINGA	730 - 890	11.8	
BOSSE	600 - 700	10.8	
BIBINGA	750 - 950	16.3	
CELTIS	620 - 900	13.5	
DOUSSIE	700 - 880	13.7	
EBIARA	600 - 800	10.4	
EKABA(EKOP)	500 - 750	11.7	
GHEOMBI	650 - 800	15	
GOMBE	570 - 690	11.6	
IROKO	550 - 750	10.3	
KANDA	700 - 760	12.4	
KOSIPO	600 - 780	9	
LATI	700 - 880	13.2	
LIMBALI	730 - 880	14.5	
LONGHI	700 - 800	14.7	
MAKORE	600 - 750	11.2	
MANSONIA (BETE)	600 - 700	11	
MOABI	800 - 900	17	
SAPELLI	600 - 780	11.3	
Coconut shell	1293	11.9	[1]
Palm kernel shell TENERA	1395	17.9	Present work
Palm kernel shell DURA	1428	19.03	Present work

shells. The Young's modulus of the Tenera variety is close to that of AZOBE and MOABI that of the dura variety is higher than the majority of hardwood species available in Cameroon.

5. Conclusions

The physico-mechanical characteristics of the palm kernel shell of the DURA and TENERA varieties have been determined. The density of the palm kernel shells, by the Archimede thrust method, is 1428.81 kg/m^3 for Dura and 1395.81 kg/m^3 for Tenera respectively. Resilience energy was determined using a pendulum sheep at temperatures ranging from 26˚C to 90˚C. It was found that the resilience energy decreases with increasing temperature. The deformation energy through the bending test was used to determine the longitudinal Young's modulus of the palm kernel shell. This differs from the specimens taken in the southern and equatorial direction of the shells as shown in **Figure 1**. It can therefore be seen that PKS are anisotropic materials.

The physico-mechanical parameters of PKS are essential for optimal use in structural and non-structural industrial applications, the development of process methods and even in equipment design. According to the results obtained, direct application can be the use as aggregate in concrete, fillers in composite material and others.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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