Elaboration and Characterization of a Fiber Composite Material Made of Petioles of the *Elaeis guineensis* (Oil Palm)

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Abstract

The aim of this study is to characterize physically and mechanically a polyester/fiber palm petiole composite material. This work made it possible to provide the local database of composite materials but also to develop agricultural waste. According to BSI 2782 standard three formulations [A (10% fiber, 90% polyester); B (20% fiber, 80% polyester) and C (30% fiber, 70% polyester)]. Water Absorption rate, density, compressive and three points bending tests are carried out on the samples obtained by the contact molding method for each formulation. The material composite obtained by adding fibers from palm oil petiole has a density of 17.98% lower than the one made of pure polyester. Fiber reinforcement rate has no impact on the density of the composite. Formulation A most absorbs water while formulation C has good tensile/compression characteristics and the greatest breaking stress in bending among the three formulations.

Keywords

Elaboration, Characterization, Physico-Mechanical, Composite, Polyester, Petioles, Oil Palm

1. Introduction

We are less affected by materials in general, but their use mostly impacts our daily lives [1]. Globally, constant evolution of composite material makes them cheaper, high performing or both. Meanwhile, fiber reinforced composites in-

terest increases particularly in cars, aircraft, building manufacturers who seek to integrate ecological and biodegradable materials, due to their interesting mechanical properties, recycling and cost of production [2] [3]. Moreover, composites include/integrate ecological character which is environmental protection and public health interests [4]. The increasing use of plant fibers as reinforcements in composites with thermosetting or thermoplastic matrices provides environmental advantages very interesting [2] [3] [4] [5]. The outstanding characteristics of these fibers are their low cost, low mass, high specific modulus. The interest in these fibers lies in particular in their good specific properties: biodegradability, abundance, character, renewable, have relatively low densities and low cost. Because of their nature and their constitution, palm fibers have a distribution of force; moreover, the percentage of the amorphous and crystalline components of the fiber is determining in the mechanical behavior of the fiber [4] [6] [7].

Because of their mechanical characteristics and of the fact that Cameroon has about 83,600 ha of oil palm, palms (petioles and leaves) are the most important waste of these plantations; this waste is most often burned (for the most part) or used as fertilizer. Our work allows us to give another life to this waste, to recover it but also to allow the farmer to earn money. This study aims to determine the physico-mechanical properties of a composite material reinforced with palm oil petiole fibers and will also feed the local database with regards to composite materials.

2. Materials and Methods

2.1. Elaboration of the Composite Material

2.1.1. Process for Obtaining Oil Palm Petiole Fibers

The process for obtaining fibers from oil palm petioles (the *Elaeis guineensis*) is illustrated in the flowchart of Figure 1.

The petioles were collected in the: Nanga Eboko, a locality in the centre region of Cameroon from a young/five-year-old palm oil trees (the *Elaeis guineensis*) that produced for the first time. The risk of alteration of the physical and mechanical characteristics by the chemicals, the difficulty of obtaining enzymes and
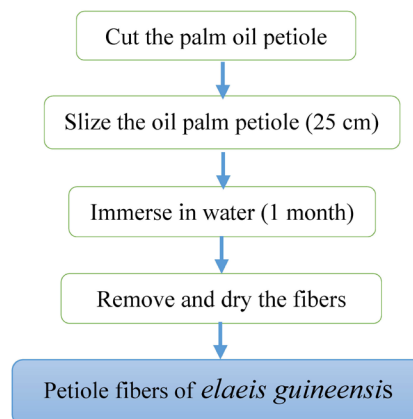

Figure 1. Process of obtaining fibers from *Elaeis guineensis* [Authors].

the monitoring of the reactions led us to choose the traditional extraction method (Retting with water) which presents as a main disadvantage the decomposition time of the cellulose. **Figure 2** and **Figure 3** briefly show the process to obtain fibers.

2.1.2. Formulation and Implementation of Test Pieces

Our samples are made by varying the rate of reinforcement. **Table 1** gives the proportions in the formulations adopted.

The proportions of reinforcement, polyester in composite are determined by Equation (1), Equation (2) and Equation (3) respectively:

$$P_r = \rho_r * v_r \text{ or } v_r = v_c * t \tag{1}$$

$$\Rightarrow P_r = \rho_r * v_c * t \tag{2}$$

Similarly

$$P_m = \rho_m * v_c * (1 - t) \tag{3}$$

With: ρ_r, ρ_m the respective densities of the reinforcements (1125 Kg/m^3) and of the matrix 1140 Kg/m^3) [8] [9]; v_r, v_c (m^3): respectively the reinforcement volume and composite volume; P_r (Kg): mass of reinforcement, P_m (Kg): mass of the matrix and t: reinforcement rate.

Table 2 presents the different formulations of the constituents of our material.

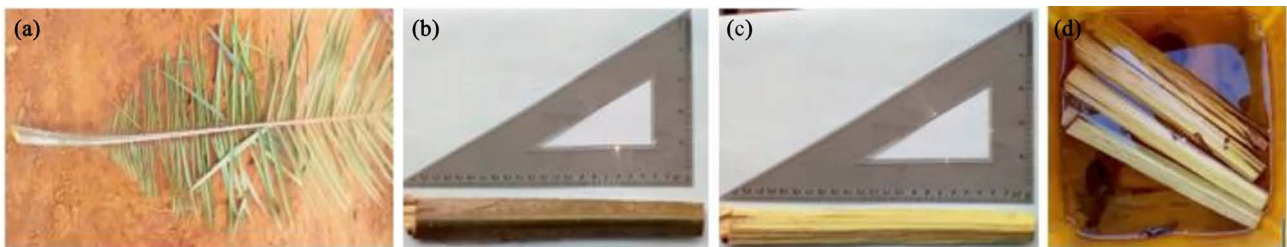Our composite was made with a hardener rate of 1% of the mass of the matrix

Figure 2. Steps of the traditional extraction method (retting with water): (a) Palm; (b) Palm section; (c) Section without bark; (d) Section immersion [Authors].
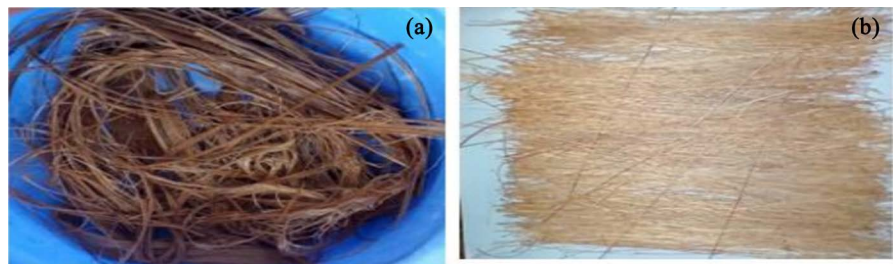

Figure 3. Fibers of oil palm petioles (*Elaeis guineensis*): (a) Hydrated petiole fibers; (b) Dehydrated petiole fibers [Authors].

Table 1. Proportions in the different formulations.

Formulations	O	A	B	C
Fiber:Polyester Proportion	0:100	10:90	20:80	30:70

[10] [11] [12] for each reinforcement rate.

2.1.3. Preparation of Samples

The test pieces produced according to the recommendations of standard BSI 2782 150 × 10 × 10 mm parallelepipedic block, of regular section [9]. The procedure is in the flowchart given in **Figure 4**. The samples obtained after demolding are presented in **Figure 5**.

Table 2. Different formulations of our composites.

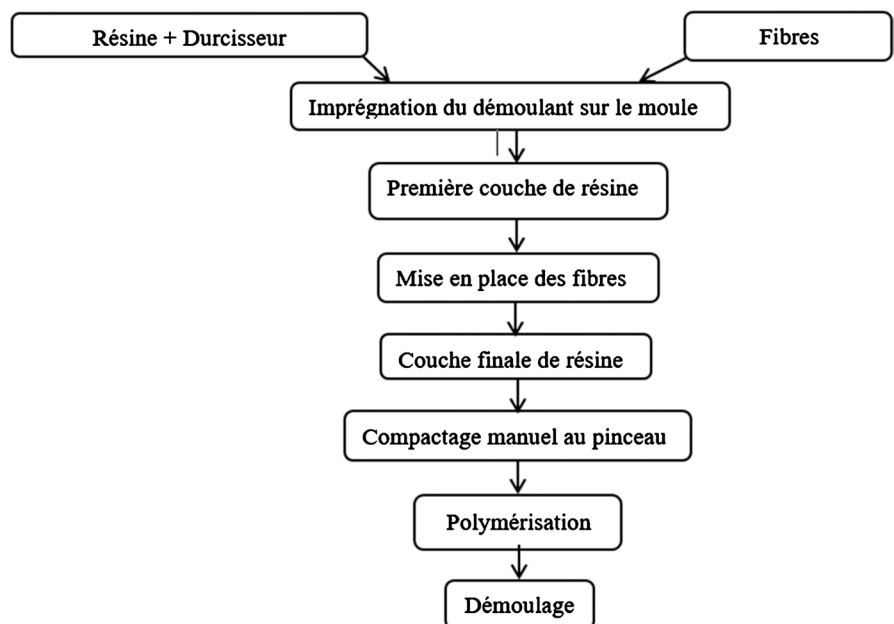| Formulations	Mass of reinforcements (g)	Reinforcement volume fraction	Mass of matrix (g)	Matrix volume fraction
O	0	0	13.68	1
A	1.35	0.0988	12.31	0.9011
B	2.7	0.1978	10.94	0.8021
C	3.05	0.2972	9.57	0.7027

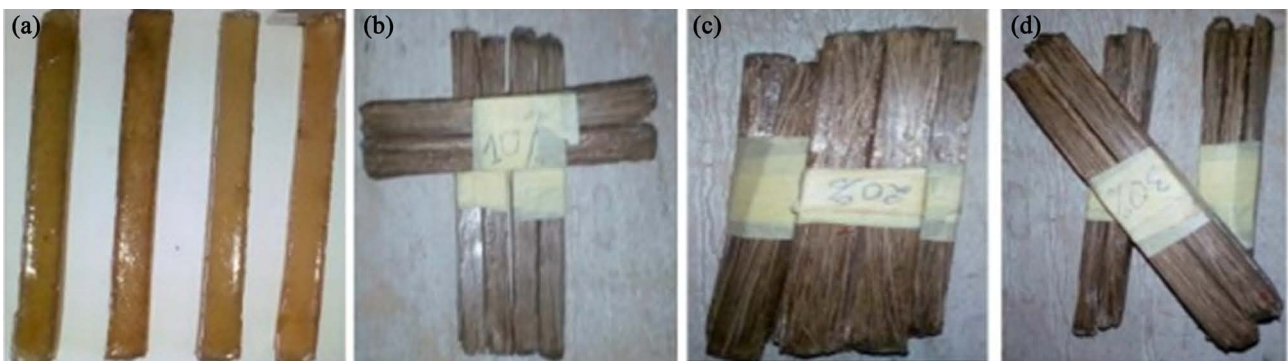**Figure 4.** Sample molding steps [Authors].

Figure 5. Test pieces after demolding (a) Formulation 0; (b) Formulation A; (c) Formulation B; (d) Formulation C [Authors].

3. Results and Discussion

3.1. Physical Characterization

3.1.1. Volumic Mass

The density of our composite material is given by Equation (4);

$$\rho_a = \frac{P_r}{v_r} \tag{4}$$

With: ρ_a (Kg/m³): apparent density; P_r (Kg): mass of reinforcement; v_r (m³): the reinforcement volume.

For each formulation, the experimental density of the composite is obtained by averaging Equation (5) for each test piece [13] [14] [15].

$$\rho_{\exp} = \frac{P_e}{\Delta v - \dfrac{m_p}{\rho_p}} \tag{5}$$

With: $\rho_{\exp}$ (Kg/m³): experimental density; P_e (Kg): mass of test piece; m_p (Kg): paraffin mass; ρ_p (Kg/m³): paraffin density; Δv (m³): variation of water volume.

The density of the composite material can also be obtained analytically by using Equation (6).

$$\rho_{an} = \rho_r V_r + \rho_m V_m \tag{6}$$

The densities of the reinforcements are $\rho_r = 1125$ Kg/m³, the density of the matrix is $\rho_m = 1140$ Kg/m³; V (m³): volume fraction of reinforcements; V_m (m³): volume fraction of matrix; ρ_{an} (Kg/m³): analytical density.

Table 3 presents the average values of the densities obtained after the experiments on the test pieces of each of the formulations.

Following **Table 3**, the average values of each of the densities obtained for each formulation. This comparative study allowed us to plot the histograms of **Figures 6-8**.

The density of the polyester/fiber composite material of oil palm petioles ranges from 928.66 Kg/m³ to 935 Kg/m³. Furthermore, increasing the volumic fraction of the reinforcement (fibers of oil palm petioles) has no influence on the density. The analytical density independently of the rate of reinforcement in oil palm petiole fibers is greater than the other densities. This may be linked to the fact that the analytical calculation does not take into account the shape of the

Table 3. Density by formulation.

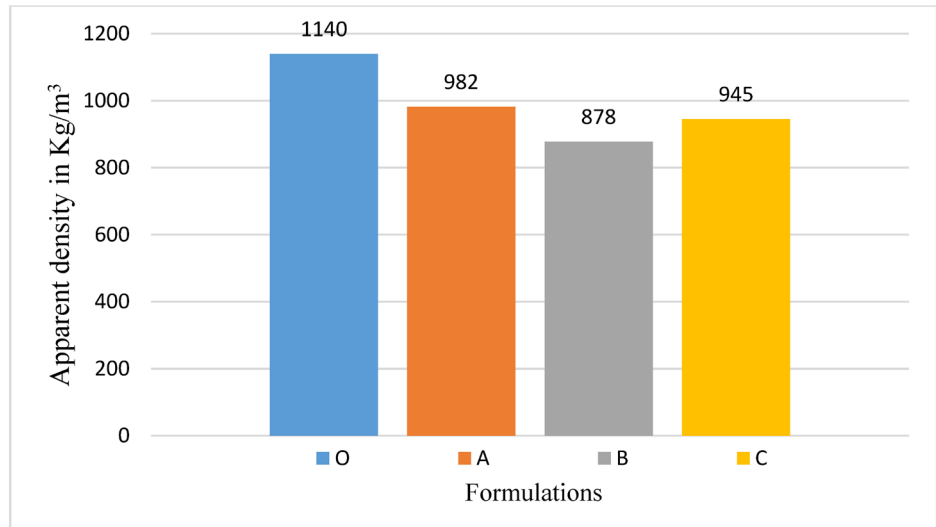| Formulations	$\rho_a \left(\text{Kg/m}^3 \right)$	Standard deviation	$\rho_{\exp} \left(\text{Kg/m}^3 \right)$	Standard deviation	$\rho_{an} \left(\text{Kg/m}^3 \right)$
O	1140	-	1140	-	1140
A	982	51.121	944	22.860	1138
B	878	20.234	911	73.049	1128
C	945	33.940	931	47.826	1135

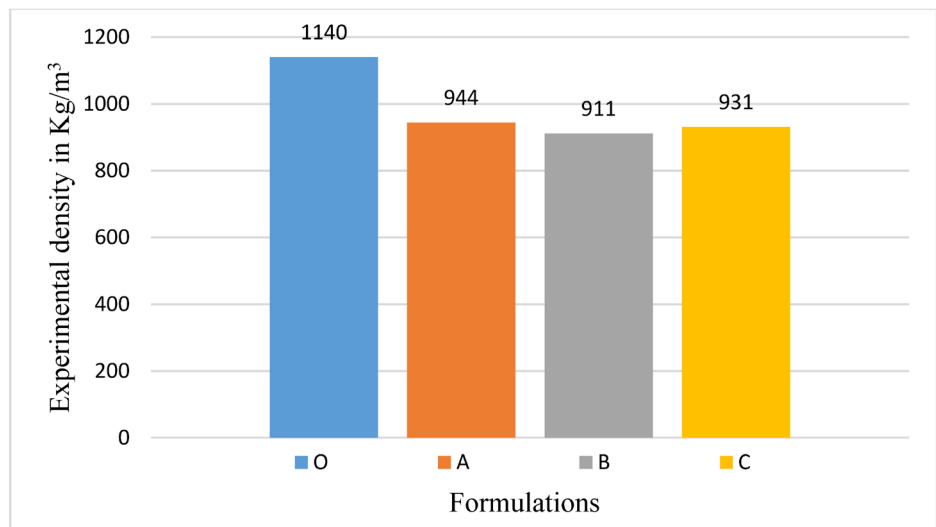**Figure 6.** Comparative study of apparent densities.

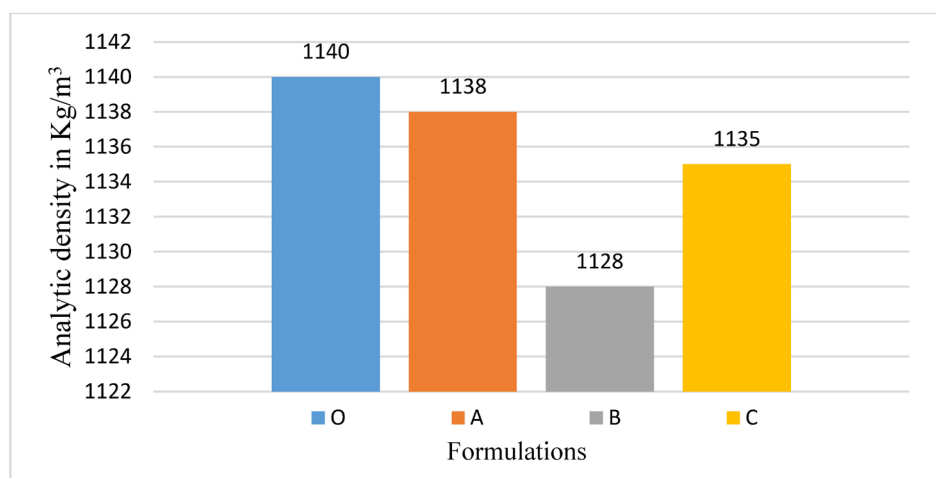**Figure 7.** Comparative study of experimental densities.

Figure 8. Comparative study of analytic densities.

test pieces or the distribution of the fibers.

3.1.2. Water Absorption Rate

The water absorption rate of this material is given by Equation (7) [16].

$$\%H = \frac{M_i - M_f}{M_i} \times 100 \tag{7}$$

With: $\%H$ absorption rate; M_i (Kg): initial mass; M_f (Kg): final mass.

The water absorption rate of each formulations values obtained with equation (7) are plotted in **Figure 9**.

We see that formulation A has the highest water absorption rate (6%) it is observed in Formulation B and Formulation C that increasing the fibers proportion reduces the water absorption rate.

In addition, the coordinates of the inflection points for each of the formulations are:

- Formulation A: A (45; 6%);
- Formulation B: B (90; 5%);
- Formulation C: C (120; 5%);
- Formulation O: O (120; 4%).

3.2. Mechanical Characterization

3.2.1. Compression Test

This test was carried out with a PERRIER 14570 200 KN press
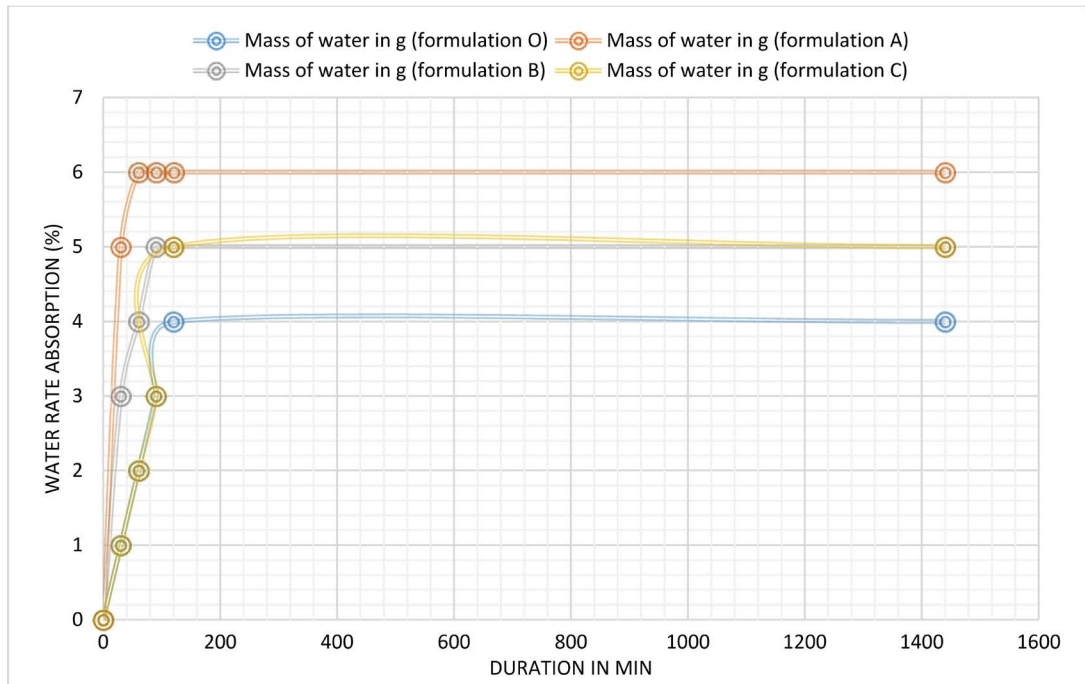
$$E = \frac{FL_0}{S_0 \Delta L} \tag{8}$$

Figure 9. Evolution curves of the water absorption rate.

where E (GPa): is the Young's modulus (E_O: Young modulus of formulation O; E_A: Young modulus of formulation A E_B: Young modulus of formulation B E_C: Young modulus of formulation C; F: load; L_0: initial length; S_0: initial section of sample; ΔL: length variation.

The comparative study of the average values of the Young's moduli obtained during the compression test allowed us to plot the histogram of **Figure 10**.

We notice that:

- $E_O < E_A < E_B < E_C$; where E_O, E_A, E_B and E_C stand for the Young's modulus for the formulations 0, A, B and C respectively.

- The ratio between E_A and E_O is of the order of 1.025 at a reinforcement rate of 10%, the Young's modulus is closed to the one without reinforcement.

- Between E_B and E_O we have 1.25 and the ratio between E_C and E_O is 2.475.

Consequently, the addition of oil palm petiole fibers almost doubles the tensile/compression characteristics of polyester.

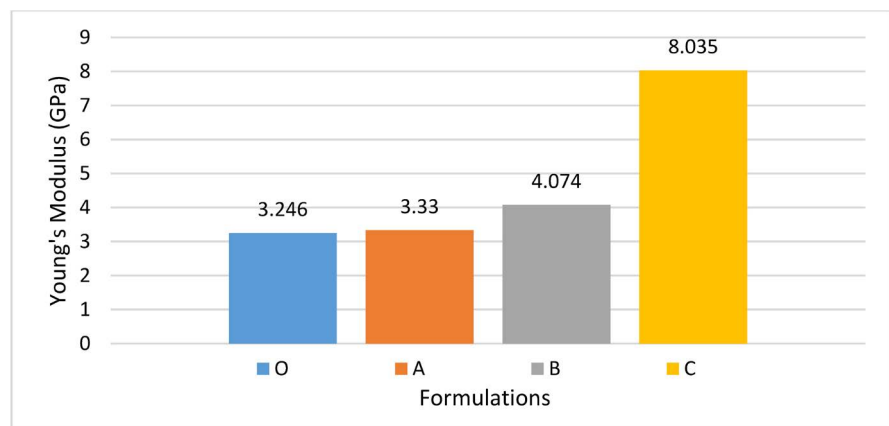**Figure 11** presents a comparative study of the Young's modules of composite

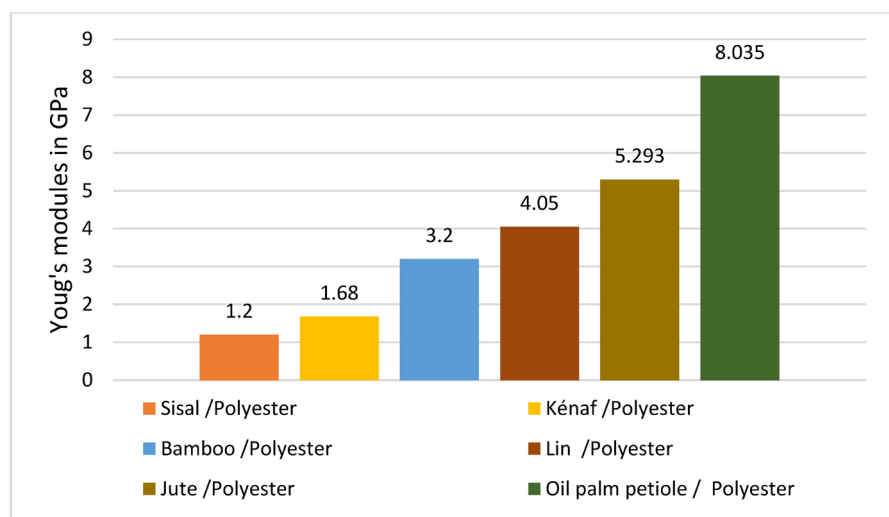**Figure 10.** Average values of Young's modulus.

Figure 11. Comparative study of Young's modules with those of the literature.

materials with vegetable fiber reinforcement and polyester matrix with our composite material (oil palm petiole/polyester).

It appears that:

The composite material (Oil palm petiole/Polyester) has a Young's modulus higher than that of the Sisal/Polyester, Kénaf/Polyester [13], Bamboo/Polyester [15] composite materials; while those of the Linen/Polyester and Jute/Polyester [14] composite materials belong to the interval [3.33; 8.035] (GPa).

3.2.2. Bending Test

The $150 \times 10 \times 8$ mm test pieces were subjected to bending three with a CBR press (CONTROL T1004). The stresses, strains, breaking stresses were deduced from Equation (9), Equation (10) and Equation (11) respectively [17] [18] [19].

$$\sigma = \frac{3Fb}{2le^2} \tag{9}$$

$$\varepsilon = \frac{6fe}{b^2} \tag{10}$$

$$\sigma_r = \frac{3bF_{Rup}}{2le^2} \tag{11}$$

With: σ (N/m$^{2)}$): stress; F: load (N); l: distance between supports (mm); b : width of test piece (mm); e: thickness of test piece (mm); f : deformed (mm); F_{Rup} (N): force measured at break; ε: distortion; σ_r : breaking stress (N/m^2).

The mean values of the transverse modules obtained during the three bending test for each formulation allowed us to make a comparative study on it. Which is presented in the histogram of **Figure 12**.

From the analysis of the histogram in **Figure 12**, the following observations emerge:

- $E_C < E_O < E_B < E_A$;
- The ratio between E_C and E_O is around 0.801; the Young's transverse modulus of the formulation C is lower than the one of the formulation O;
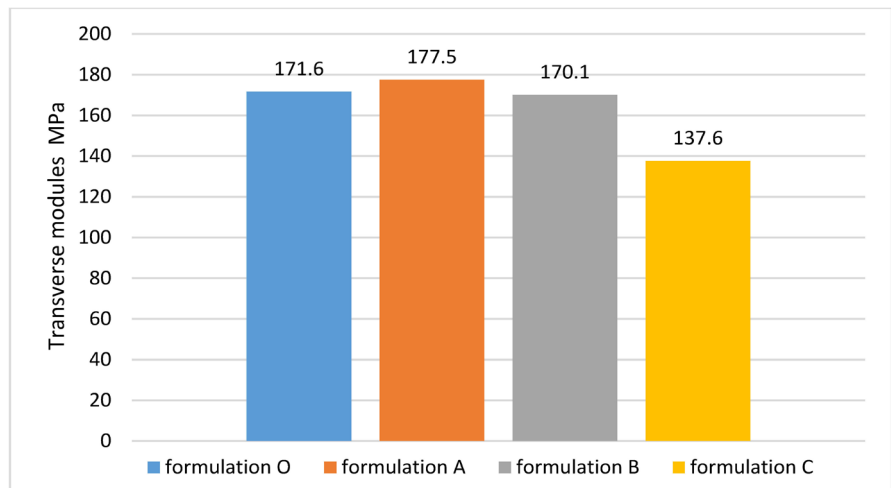

Figure 12. Comparative study of the average values of the transverse modules.
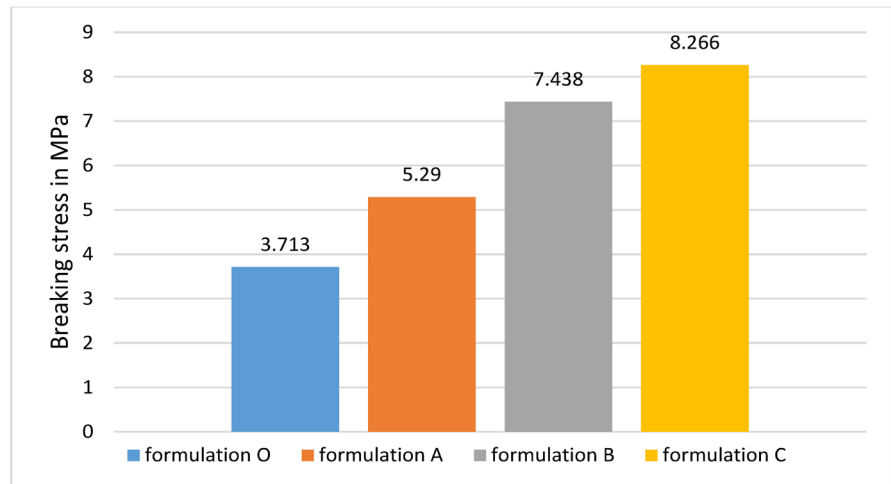
Figure 13. Comparative study of the mean values of the breaking stresses.

- Between E_B and E_O we have a ratio of 0.991; from this report, we note that for the formulation B, the material has a greater flexural strength than formulation O.
- In addition between E_A and E_O 1.034; it appears that the formulation A has a better resistance to bending than formulation O. At more than 10% reinforcement rate, a reduction of the transverse module in bending is observed.

The average values of the three-point bending rupture stresses of the test pieces of each of the formulations allowed us to plot the histogram of Figure 13.

It emerges that, the breaking stress increases proportionally with the rate of fibers reinforcement.

4. Conclusion

$150 \times 10 \times 8$ mm test pieces of our composite material with four formulations O, A, B and C were produced according to standard BSI 2782 and submitted to different tests. It emerges that with regard to compression, the characteristics of the composite material increase with the rate of reinforcement in oil palm petiole fibers. The Young's modulus of the composite at 30% of fiber reinforcement rate (formulation C) is greater than the Young's modulus of the reinforcement rates at 20% (formulation B), 10% (formulation A) and 0% (formulation O) respectively. In bending, we find that for the formulation A, the resistance the flexural strength is greater than the one of formulation B which is also greater than formulation C. In addition, the flexural strength of the composite material of the formulation C becomes lower than the one formulation O, therefore the addition of fiber beyond 20% reinforcement rate reduces the flexural strength. Furthermore, increasing the fibers of oil palm petioles reinforcement rate has no influence on the density.

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Conflicts of Interest

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

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