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Research Article

Physico-Mechanical Characterization of Plastic (Polyester) Reinforce With Palm Kernel Shell

Mbelle Samuel Bisong[1,2] **Andy Mbeng,**[3] **Bayock F. Njock**[2] **Valeriy V. Lepov,**[4] **and Kisito Pierre**[5]

[1]*College of Technology, University of Buea, P.O. Box: 63, Buea, Cameroon*
[2]*Department of Mechanical Engineering, ENSET Douala, University of Douala, P.O. Box: 1872, Douala, Cameroon*
[3]*Department of Mechanical Engineering, ENSET Kumba, University of Buea, P.O. Box: 249, Kumba, Cameroon*
[4]*Larionov Institute of Physical-Technical Problems of the North, FRC YSC SB RAS, 1, Oktyabrskaya, 677007 Yakutsk, Russia*
[5]*LMMSP, Faculty of Science, University of Dschang, P.O. Box: 96, Dschang, Cameroon*

Correspondence should be addressed to Mbelle Samuel Bisong; mbellesabi@yahoo.com

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The main objective of this research paper is to contribute to the characterization of a composite material with a polymer matrix reinforced with a palm kernel shell fiber for its application in the naval or aeronautic industry. To achieve this objective, it first opted for the fabrication of this composite by molding with different grain sizes (0.5 mm and 1.25 mm) and at different percentages of sand and PVC with the following proportions: (10%, 20%, 30%, and 40%), then subjected the sample pieces to physical and mechanical testing such as (three-point bendings, resilience and compression tests). The physical characterization allows us to obtain an experimental volumetric mass for the 0.5 mm sample varying between 1.72 and 1.59 kg/m^3 and for the sample 1.25 mm, varying between 1.66 and 1.61 kg/m^3 that is the more the percentage of palm kernel powder increases, the lighter our material becomes. The mechanical characterization shows a Young's modulus in bending varying between 3199.06 and 3236.16 MPa for the 0.5 mm and from 31,881.87 to 3244.03MPa for 1.25 mm that is the palm kernel powder and grain size make the material more rigid, normal stress due to compression varying between 32.05 and 56.41 MPa for 0.5 mm and from 44.8246 to 62.028 MPa for 1.25 mm. A resilience test varies between 0.61 and 2.00 J/cm^2 for 0.5 mm and from 0.94 to 2.39 J/cm^2 for 1.25 mm that is the more the percentage of palm kernel shell and particle size, the more the material becomes more resilient.

1. Introduction

Nowadays, there is a high need for the use of natural fiber which has so many applications in the industrial sector. By analysing their properties (physic mechanical, chemical and thermal), it has been discovered that natural fibers can be reinforced by some composites and are considered renewable and biodegradable, hence environmentally friendly, and lightweight compared to synthetic fiber [1–3]. The utilisation of natural plant fibers in industries and academic sectors is getting more attention [4]. One of the advantages of using reinforced natural plant fiber is the possibility to be recycled [5].

A lot of research is being conducted in the field of fibers, thereby bringing a discovery of new types of fibers that are environmentally friendly as compared to conventional composite materials [6], reason why most research is concentrated on the physicomechanical properties, chemical, and thermal behaviours of natural fibers. It is also very important to mention the measurement of environmental impact assessment and life-cycle assessment, which is also a current interest of researchers because of the increase in demand in terms of resource conservation [7].

Wood polymer composites (WPC) are a group of advanced materials with renewable energy [8]; therefore, their use can help to solve real problems, for example, some

(a) (b)

Figure 1: Processes to obtain the mold. (a) Powder state of palm kernel shell after grinding, and (b) plastic polyester after the mold from the powder state of palm kernel shell.

structures having a lot of waste materials and by-products. The issue of having natural and synthetic components together can affect the environment and can have an impact on WPC. Therefore, more research is needed to be developed in that area to help in resolving the conflict between plastics and natural products. However, one of the problems of natural fibers as a reinforced material to synthetic is having a complete homogenous mixture [9]. To evaluate the mechanical properties of Banana-Hemp-Glass fiber reinforced composites, Bhoopathia et al. [9] evaluated the mechanical properties and found out that the tensile strength of banana-glass fiber hybrid composites was 39.5 MPa, whose value was really acceptable. Garadimaniet et al. [10] in their research analysed the mechanical properties of Corn Cob particule and E-Glass fiber-reinforced hybrid polymer composites. From experimental results, it has been observed that there is an increase in the modulus of rigidity, impact strength, and the modulus of Elasticity. Sukhdeep et al. [11] studied the effect of tensile and flexural behaviour of hemp fiber-reinforced virgin recycled HDPE matrix composites. Their results showed that there was a decrease in tensile strength when they were reinforced with hemp fibers in the HDPE matrix. Cameroon and several other African countries have large biodiversity which can enhance the development of green materials to strengthen the continent's competitiveness so as to produce new technological materials for the future. Oil palm is therefore an important tree because of the value of the crude palm oil it produces. Its derivatives are the empty fruit bunch (EFB), palm fruit fiber (PFF), palm oil mill effluent (POME), and palm kernel shell (PKS) [2, 5, 12–15]. The palm kernel shell has been regarded as "waste" from palm oil proceeding. These wastes are either burned to supply thermal energy at palm oil mills or left in piles to be decomposed [16–20]. PKS has sometimes been laid on roads to improve vehicular traction along with plantations and farms where there are no tarred roads. In some communities, PKS had been commercialized as a source of heat for cooking [3, 9, 21]. However, the quest for suitable materials with lighter weight in the application of automobile industry, naval and aerospace to overcome aerodynamic forces, etc., has motivated the investigation that is done in this research to valorize its use for industrial application.

In this research, the characterisation of the composite material with polymer matrix reinforced with natural palm kernel shell fiber is set up. The physical and mechanical properties of the combination are applied.

2. Materials and Methods

2.1. Materials. This part consists of the raw material and the materials used for characterization. Figure 1(a) below represents the raw material, which is a palm kernel shell after grinding, while Figure 1(b) represents a plastic polyester after mold form of the powder state of the palm kernel shell. An electronic balance was used to take the weight of the specimen, while a universal testing machine was used to carry out a three-point bending test.

It is equipped with a camera that records every detail such as fracture appearance and breakage point, universal hydraulic grips with a set of wedge members are used to carry out bending tests, compression tests, high stiffness frame with a minimum deflection at maximum load (0.9 mm), upper/lower rollers: 160 mm, and ram travel: 110 mm.

The material characterization (compression and flexural strength) was performed using a universal testing machine (ZwickRoell Z600). A universal testing machine (Instron 8802) is intended for the measurement of force and linear dimensions of the measurement of samples of different materials on the static and dynamic tensile and compression flexural strength []. The maximum test load (FN) in tensile and compression directions are 600 kN in both directions. The measurement data transmission rate to PC was approximately 10 to 500 Hz. Low cycled fatigue (LCF) and other tests can be carried out at very high temperatures using furnace technology and specialized load strings. The maximum load of series 8800 is a block-modular design, consisting of a base on which is fixed to the frame cross member, an oil hydraulic, a movable piston as well as an electronic control unit, and a computer. This machine operates at a frequency of 5 Hz for low cycled frequency, 50 Hz, and 100 Hz for high cycled testing. It has a maximum working capacity of 4 hrs a day and the cooling of the machine was assured by a cooling system consisting of a 100-L container of liquid coolant incorporated into the machine and a pumping system to assure effective cooling.

Table 1: Nomenclature below shows the list of abbreviations.

PVC	*Polyvinyl chloride*
WPC	Wood polymer composites
HDPE	High-density polyethene *matrix*
PFF	Palm fruit fiber
EFB	Empty fruit bunch
POME	Palm oil mill effluent
PKS	Palm kernel shell
LCF	Low cycled fatigue
ASTM	American standard testing method
Epr	Sample

3. Methods

3.1. Method Used in Processing Palm Kernel Shells to Powder form. Step 1: Collection.

The hulls are collected from the mining site and, broken to remove the kernel fruit so that the shell can be gathered for further processing.

Step 2: Crushing.

The selection of palm kernel shell for crushing is done according to AFNOR standardisation [4] (see Table 2). An industrial crusher is used in crushing the shells and rendering them it into powder form.

Step 3: Screening.

The screening is done in the laboratory using a standard AFNOR grade sieve so as to get a common size of the powder grain.

Step 4: Molding.

The powder is put into a mold with light watering and mixed with a polyester hardener then put in an oven under a heat source of 50°C for 24 hrs to get it dehydrated which after is removed and ready for characterization.

Table 2 below shows the dimensions of some palm kernel shells that can be selected for crushing and its volume (V) of the shell has been calculated and presented in Table 2.

Table 2: Dimensions of a few palm kernel shells [4].

Landmark	Length L (mm)	Width I (mm)	Thickness E (mm)	Volume V (mm)
1	49.21	15.3	6.58	4954.16
2	17.88	14	2.41	603.27
3	9.13	8.57	8.7	680.72
4	53.98	31.76	5.23	8966.33
5	50.1	21.21	7.75	8235.31
6	44.45	37.19	4	6612.38
7	28.26	11.2	7.1	2247.23
8	35.67	34	9.1	11,036.29
9	57.18	27.80	7.83	2446.59
10	15.73	4.98	6.66	521.73

The values of 57.18 mm as length with 27.80 mm as width and 7.83 mm as thickness show that it encountered very large dimensions in raw palm kernel shells.

3.2. Physical characterization

3.2.1. Volumetric mass of the sample. The method used in determining the experimental volumetric mass of various samples was by immersing in an initial volume of water (V) containing a graduated cylinder which was weighed on a balance scale [28–30]. The test pieces of respective mass (m) and dimensions $150 \times 95 \times 7.5$, after taking the new mass m1, then finally a subtraction between two masses was done to obtain the volume of water displacement. Its determination was done as follows:

Fill water in a graduated cylinder and take its weight on a balance scale. Fill the graduated cylinder with a considerable volume of water [31, 32].

Fully immerse the test piece in this volume of water. The space occupied by the test piece in the cylinder increases the volume of water. Take measurement. Subtract the masses to obtain the water volume of the composite.

3.2.2. Water absorption rate. The water absorption rate protocol consists of measuring the initial mass M_o of the test piece chosen, immersing this test piece in distilled water, after a time t, removing the test piece from the 'water, and remeasure its mass allowing its absorption rate to be determined after time t, then return the test piece to distilled water until the mass no longer varies (this is saturation). The absorption rate is calculated by the formula:

$$T_A = \frac{M_t - M_O}{M_O} \quad (1)$$

3.3. Mechanical Characterisation

3.3.1. Compression test. One of the mechanical characterization is the compression test which consisted in subjecting a test piece to two conion terizatcentrated forces of equal intensity on two ends, in opposite directions. The dimensions for the compression test are 150 mm × 15 mm × 7 mm. The manufacturing dimensions of the ASTM D790 specimens are carried out according to the European standard NF EN 196-1. This standard details the methodology to be followed for the preparation and determination of the mechanical properties of palm nut shell fiber. The operation mode is as follows:

The test piece is first positioned on the two-end grip support. The length between supports is calibrated according to the standard of ASTM. The load is positioned above the specimen and on the section plane. Then, the slide assembly and the load are lowered so that the latter touches the upper surface of the test piece. The test ends after the test piece is broken and the values of the forces in (kN) and displacement in (mm) are given on the computer screen placed beside the equipment.

3.3.2. Flexural test. The flexural tests were carried out according to the following protocol [6, 33]:

1. Measure with the calliper, the dimensions of the test piece to be tested;

2. Using a marker and a metal ruler, draw two lines 110 mm apart on the test piece showing the length (L) normalized between supports [6, 23, 24]. That is to say a gap-to-thickness ratio of 11/1;

So we have; $\boldsymbol{L/h} = \mathbf{11/1} \longrightarrow L = 11\,\text{h} = 11 \times 10 = 110\,\text{mm}$, therefore $L = 110\,\text{mm}$.

Adjust the two supports of the device so that they are on the same horizontal and 110 mm apart from each other;

Introduce the test piece into the attachment system and place the assembly on the two supports. Position the comparator probe above the test piece in the center of the rectangular surface so that its axis is perpendicular to the latter the initialize (set to zero) the comparator and the dynamometers. Fix the mass door system then, take note of the force as well as the displacement (arrow) it generates then place the first mass and raise the second arrow it produces. Vary the masses by raising the boom each time, until the test piece breaks (the load must be applied gradually. Repeat the above steps for all the other test pieces to be tested. The operation mode of the impact test is as follows:

The specimen under test is held in a clamp on the Charpy test machine. A hammer in the form of a swinging pendulum fitted with a knife horizontally makes an angle θi is released from a fixed height and allows hitting the specimen at a point above the notch line. When the pendulum hits the specimen under test, it possesses kinetic energy that is equal to $mgh_{o,}$ which h_o is the height of the hammer concerning its equilibrium position. After the test piece is broken, the hammer rises at an angle θr concerning the vertical axis. During this test, the rising energy of the pendulum before and after impact using the formulas below. The rising energy before impact is given as:

$$W_{\text{o}} = mgh_{\text{o}}(1 - \text{COS}\beta), \tag{2}$$

where β represents the rising angle of the pendulum.

The rising energy after impact is:

$$W_{\text{R}} = \text{m}gh_{\text{R}} = mgh\text{I}\,(1 - \text{COS}\theta r). \tag{3}$$

where θr is the rising angle after impact.

The energy absorbed by the test piece is as:

$$W_{\text{a}} = W_{\text{o}} - W_{\text{R}} = mgl\,(\text{COS}\theta -), \tag{4}$$

$$W_{\text{a}} = W_{\text{o}} - W_{\text{R}} = mgl\,(\text{COS}\theta -). \tag{5}$$

The resilience K is given by the relation:

$$K = \frac{W_{\text{a}}}{S} = \frac{mg(COS\theta - COS\beta)}{S}, \tag{6}$$

where the length of pendulum $I = 340\,\text{mm}$. Mass of pendulum: $m = 100\,\text{g}$. Gravitational force $g = 10\,\text{N/kg}$.

3.3.3. Determination of Young's Modulus. To determine Young's modulus of the composite, it is first necessary to draw the regression line of point clouds of the different samples. To find their slopes, it used the formula below [7, 25, 34].

$$E = \frac{L3\alpha}{48l}. \tag{7}$$

Thus, the expression of Young's modulus is:

$$E = \frac{L^3 F}{48I\Delta I}\,\text{or}\,\alpha = \frac{F}{\Delta l}, \tag{8}$$

where $E = L^3\alpha/48I$ [7] with L is the length between the two supports (do not confuse that of the test specimen); I is the moment of inertia of the cross-section (function of the dimensions of the section); and α is the slope of the determined line (corresponding to the elastic domain).

To obtain Y, it used Excel to plot the regression line (gradient) exclusively for the points on the graph exhibiting linearity (to stay in the elastic zone) [7, 28, 35].

4. Results and Discussion

The test pieces obtained have been labelled to facilitate their handling during experiments.

4.1. Physical Characterization

4.1.1. Volumetric masses for shells. In Figure 2, one can see that the experimental volumetric mass decreases with the increased rate of particles. This is explained by the fact that the particles are less dense and have a low density compared to that of the matrix. Consequently, the volume occupied by the particles of palm kernel shells will decrease and hence this decrease in density varies from 1.66 to 1.61. Tables 3 and 4 show that the experimental volumetric mass decreases with the increase in the rate of particles. This is explained by the fact that the particles are less dense and have a low density compared to that of the matrix. Consequently, the volume occupied by the particles of palm kernel shells therefore decreases. Hence, this decrease in density varies from 1.72 to 1.59.

4.1.2. Water absorption test results. Table 5 and Figure 3 present a comparison of the different volumetric masses according to their water absorption rate for 0.5 mm samples. It is noticed that the different volumetric masses are low as compared to the diagram above (Figure 2), it can also be said that by observing the different volumetric masses, the more the increase of the rate of particles the more the decrease

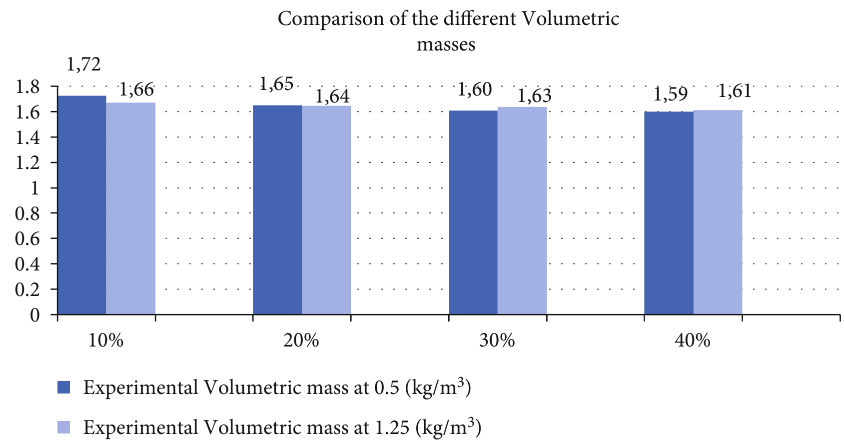

Figure 2: Comparison of the different volumetric masses.

Table 3: Summary of the experimental volumetric masses for shells of 0.5 mm.

Percentages	10%	20%	30%	40%
Grain size		**0.5**		
Experimental masses of 0.5 (kg/m^3)	**1.72**	**1.65**	**1.60**	**1.59**
Standard deviation	**0.05**	**0.02**	**0.07**	**0.08**

Table 4: Summary of the experimental volumetric masses for shells of 1.25 mm.

Percentages	10%	20%	30%	40%
Grain size		**1.25**		
Masses of 1.25 (kg/m^3)	**1.66**	**1.64**	**1.63**	**1.6**
Standard deviation	**0.03**	**0.03**	**0.02**	**0.04**

Table 5: Water absorption test results of 0.5 mm samples.

Samples of 0.5 mm	Percentages (%)	Duration					Standard deviation
		1 hr	3 hrs	24 hrs	48 hrs	72 hrs	
Epr1	10	48.02	49.93	51.8	53.3	55.66	2.95
Epr2	20	49.2	49.8	50	51.5	52.48	1.35
Epr3	30	47.02	47.5	48.3	48.8	50.7	1.35
Epr4	40	46.3	48.41	49.51	50.56	52.81	2.69

in the volumetric mass hence the material becomes lighter. Epr1, Epr2, Epr3, and Epr4 represent the different numbers of samples of the reinforced plastic with palm kernel shell, that is, sample 1, sample 2, sample 3, and sample 4.

Table 6 and Figure 4 show the statistical results regarding the classification of samples according to their water absorption rate for samples with 1.25 mm. The same remarks were observed in the experimental procedure. They were all sensitive to water.

Because of all that has been presented above, it can be said that all these samples are very sensitive to water, and also have a strong absorbent power. During the first 6 hrs, the samples absorbed a water mass greater than 60% of their starting mass. There is also a correlation between the sample thickness, the quantity of palm kernel shell powder, and the exposure time of the sample in water, that is, adding a higher percentage of palm kernel shell powder on the fiber and allowing it longer in water as seen in Figure 4 will have a higher tendency for a high water absorption rate, hence making the material susceptible to failure in industrial application.

4.2. Mechanical Characterization

4.2.1. Flexural Young's Modulus. Figure 5 shows the distribution of flexural Young's modulus, and Figure 6 shows the distribution of the compressive Young's modulus. These figures reveal a distribution of normal stress. It is noticed that

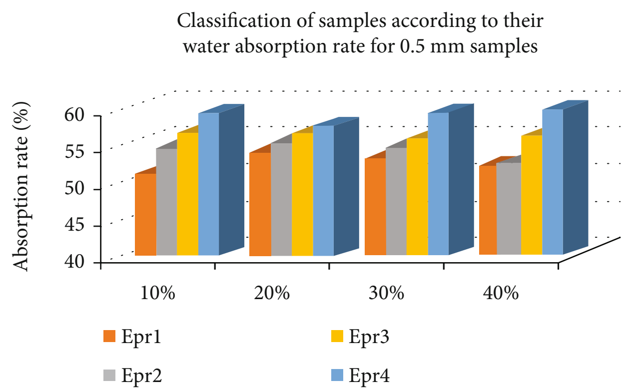

Figure 3: Classification of samples according to their water absorption rate.

Table 6: Water absorption test results of 1.25 mm samples.

Samples of 1.25 mm	Percentages (%)	Duration					Standard deviation
		1 hr	3 hrs	24 hrs	48 hrs	72 hrs	
Epr1	10	50.10	51.29	54.9	56.7	59.46	3.86
Epr2	20	51.67	54.58	55.65	56.77	57.81	2.36
Epr3	30	52.7	53.4	54.4	55.3	59.86	2.82
Epr4	40	51.78	52.87	53.46	56.37	61.28	3.82

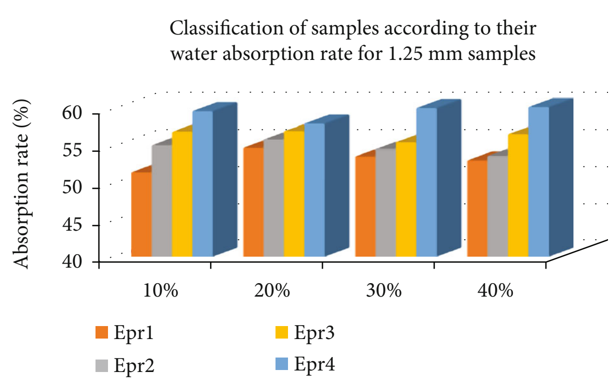

Figure 4: Classification of samples according to their water absorption rate.

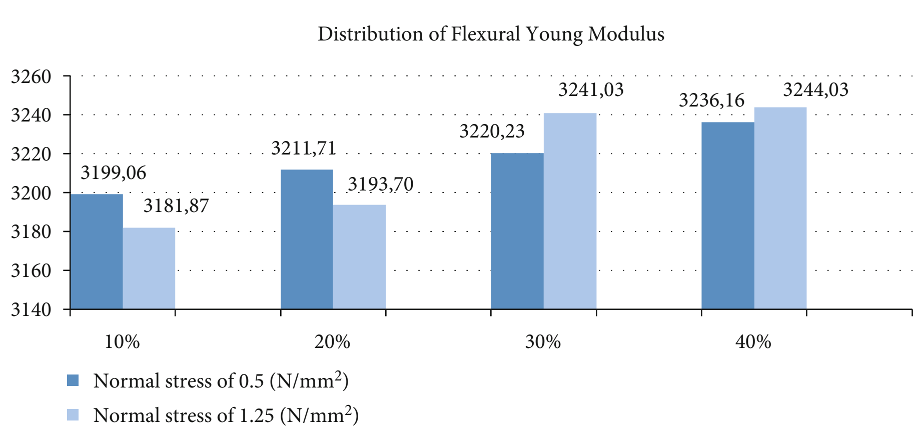

Figure 5: Distribution of flexural Young's modulus.

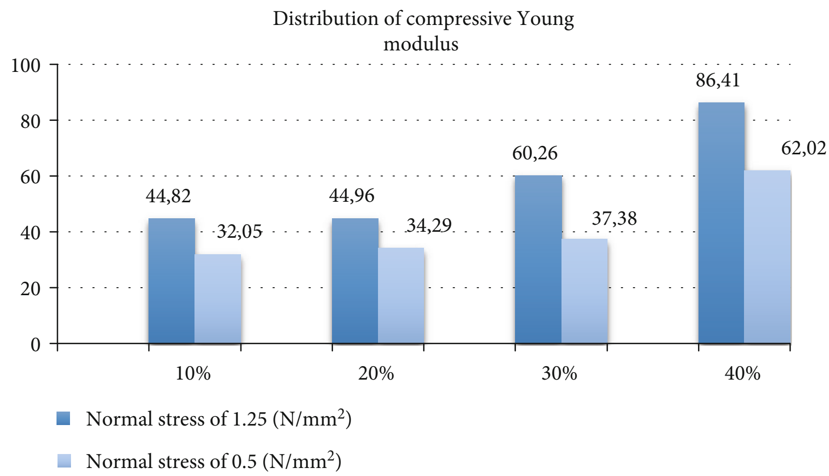

Figure 6: Distribution of compressive Young's modulus.

Table 7: Summary of the resilience test.

Grain size (mm)	Volume fraction (%)	Average resilience (J/cm^2)	General average
0.5	10	0.61	1.44
1.25		0.94	
0.5	20	0.96	
1.25		1.22	
0.5	30	1.20	
1.25		2.19	
0.5	40	2.00	
1.25		2.39	

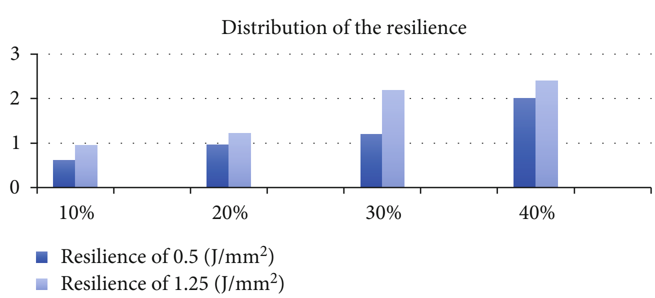

Figure 7: Distribution of the resilience.

Young's modulus in bending increases as the rate of particles increases; however, it was noticed that the level of 10% and 20% of 0.5 mm is greater than that of 1.25 mm which can be explained by handling errors during the dosage, weighing or during the molding of the samples. This shows that the increase in the rate of particles influences our material (an increase in the rigidity of our material).

4.2.2. Compressive Young's modulus

4.2.3. Resilience Test. Table 7 and Figure 7 show results of the resilience test carried out on 0.5 and 1.25 mm sample sizes and the rate of a particle of 10%, 20%, 30%, and 40%. It can be concluded that this material is very fragile and the sample size of 0.5 mm of 10% tends towards ductility. This is because it has the lowest average resilience. A close observation of the results of this test reveals that the increase in particle size will make the material more resilient (better resistant to shocks).

5. Conclusion

In the context of the general crisis, the growing population of Africa in general and Cameroon in particular, this work which is titled Elaboration and characterization of plastic reinforce with palm kernel shell falls among the category of work intended to find solutions to the problem of environmental pollution by the debris of certain materials. This work was so far carried out on composites which shows the complexity of this new material as well as the reinforcing fibers. The following observations are particularly noteworthy:

(i) The noticeable variation of mass volumetric of a sample of 0.5 mm in between 1.72 and 1.59 kg/m^3, and 1.66 and 1.61 kg/m^3 for a sample of 1.25 mm. The more the percentage of palm kernel powder increases, the lighter our material becomes

(ii) The mechanical characterization shows Young's modulus in bending varying between 3199.06 and 3236.16 MPa for 0.5 mm and from 31,881.87 to 3244.03 MPa for 1.25 mm is the palm kernel powder and grain size makes the material more rigid, normal stress due to compression varying between 32.05 and 56.41 MPa for 0.5 mm and from 44.8246 to 62.028 MPa for 1.25 mm

A resilience test varies between 0.61 and 2.00 J/cm^2 for 0.5 mm and from 0.94 to 2.39 J/cm^2 for 1.25 mm that is the more the percentage of palm kernel shell and particle size, the more the material becomes more resilient.

This study can provide methodological support for the application of this composite in the naval and aviation industry, especially in the building of the ship body and aircraft body. Therefore, a profound study of the material like its microstructure, etc., will be of great importance so as to combine these findings with the tensile test results for a better design modelling. Also, stochastic modelling will be of great interest to find out the behaviour of crack and their propagation.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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