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Research Article

Elaboration and Characterization of Raw Clay Matrix Composites Reinforced by Vegetable Fibers with a View to Their Industrial Uses

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The increasing use of composites reinforced with vegetable fibers in the industrial field poses a serious problem of the reliability of the structures produced. For us, this credibility can be ensured when developing the composite, by a judicious choice of matrix and reinforcement, a choice leading to obtaining a material having acceptable mechanical and physicochemical characteristics. The main objective of this study is to characterize a composite material with a clay matrix reinforced with coconut and palm nut fibers. To achieve this objective, we first opted for the implementation of this composite by contact molding, at different fiber percentages (2.5%, 5%, 7.5%, and 10%), and we then subjected our specimens to mechanical tests (three-point bending and compression). The mechanical characterization allowed us to have a Young's modulus in compression varying between 63.82 and 68.82 MPa for palm nut fibers and from 68.28 to 74.43 MPa for coconut fibers (this allows us to note that our coconut fibers make the material rigid in compression), and a Young's modulus in bending varying between 5.71 and 6.51 MPa for palm nut fibers and from 6.50 to 6.525 MPa for coconut fibers (this allows us to see that our coconut fibers make the material rigid in bending). The results also show that the rate of water absorption of the composite increases with the increase in the fiber content, which is explained in particular by the fact that the fibers of plant origin are hydrophilic and have a porous character; therefore, they absorb water. This study also shows that there is a reduction in the density of the fiber composite with increasing fiber content.

1. Introduction

In Cameroon, as in other countries of the Central African subregion, the construction of individual residential houses rarely obeys technical and administrative regulations (when they exist) relating to the quality of the materials to be used for the foundation and height thereof, the quality of the materials constituting the load-bearing walls, etc. This is illustrated by the damage that rainwater causes to homes each year across the country and especially in rural areas [1].

In periurban areas, traditional materials turn out to be unsuitable for modern-format constructions, due to their poor performance. This leads to the massive use of cementitious materials, which also have significant drawbacks: energy cost for the production of cement, pollution-induced, thermal discomfort of concrete blockhouses in sub-Saharan areas, etc. The use of compressed Earth blocks is a credible and interesting solution being tested in some countries such as Gabon and Cameroon. To our knowledge, no structured approach exists to date for the production of building materials based on local raw materials [2].

However, in the city of Douala we encounter a very difficult climate such as the heat in the dry season, which leads to energy consumption in our homes and its overcharging. After multitudes of investigations made, we find that the building material suitable for the city of Douala, which can retain heat in the dry season, is less used such as BTC capable of providing the interior with a climate of freshness during the dry season [3]. Earth, as a raw material for construction, is mentioned again in view of the advantages it provides [3].

Among the advantages of raw clay, we can have the little energy required for its implementation, its esthetic qualities, and good thermal inertia, which makes it possible to have a cool habitat in the dry season and to conserve heat in the rainy season. But the problem with clay products is that they suffer from a deficit in resistance and run into problems related to their sensitivity to water [3].

Plant fibers are very diverse in their species. They are found in the roots, trunk, branches, fruits, and even in the leaves of some plants [4–10]. In recent years, the use of natural fibers in building materials has aroused a certain enthusiasm, especially in the industrial sector, and is perfectly in line with the sustainable development approach, with a view to enhancing renewable natural resources. We have in Cameroon a wide variety of plant fibers and in this case the fiber of Rhecktophyllum Camerunense (RC). This fiber was characterized in 2007 [11] and was used successfully as a plaster reinforcement in 2012 [12]. Its good characteristics argue in favor of its industrial use and many other tropical fibers.

Arguably, the use of coconut and palm fiber in brick is an essential ingredient in building material. Coconut and palm kernel fibers are commonly used in the production of materials due to their advantages such as resistance to mold and rot, provide excellent insulation against temperature and sound, are hard and durable, are not easy to fuel, and are resilient. In addition, coconut and palm fibers are also one of the substances that can be commercialized, recycled, and used in the manufacture of clay bricks in order to reduce the rate of solid waste and improve the quality of the material environment [13].

Recently, many researchers are interested in investigating the potential solid waste material that could be recycled into clay bricks. Much research has been carried out using different types of agricultural waste such as sawdust [14], rice husk [14], palm oil waste [15], vegetable matter [16], rice husk and bagasse [17], and pineapple leaves [18] in building materials. These materials have been shown to be a sustainable and environmentally friendly raw material in construction [19–32]. Therefore, due to their successful use, this study examined the potential of integrating coconut and palm fibers into a raw clay brick. This work aims to determine the mechanical characteristics of composite materials with raw clay matrices and to find one or more local industrial applications for this product. In order to complete our study and to facilitate the reading of this document, the work has been divided as follows: the first section is the present introduction, the second section is the methodology undertaken, the third is the discussion, and in the last section the conclusion.

2. Methodology

This session, therefore, details the test campaign carried out to characterize the base materials and the development of the various formulations and sample manufacturing conditions. In addition, this session also details the test methods that will be applied for the study of composites. Table 1 presents us with a schematic summary of these different materials and methods used during our study.

2.1. Materials Used and Method of Determining the Mechanical Characteristics. The materials used in this experimental study are clay soil now called "natural clay," coconut fibers, and palm nut fibers.

2.1.1. Origin of the Materials Used

a. Ground. Clay soil: this material is taken from the Centre Region, more precisely in the municipality of Dibang-Cameroon. Clay samples were taken at a depth of −50 cm from the natural ground level (Figure 1). This choice results from the difference in soil texture at this depth [20]. They were subjected to various identification tests (granularity, plasticity, and density) and compaction.

b. Fibers. The choice of coconut and palm nut fiber for the reinforcement of the mineral matrix is justified by their excellent specific mechanical properties and their availability at a very low cost [21].

Coconut Fiber. The coconut fiber shown in Figures 2 and 3 is used as a binder to clay by incorporating it at different percentages. The coconut fiber that was collected as part of the production of our composite material comes from the littoral region in the Sanaga-Maritime department. This fiber was obtained according to known extraction techniques [22–24] and was dried on a tarpaulin out of direct sunlight for at least 72 hours before being used in the brick (test tube).

Palm Nut Fiber. The palm fiber shown in Figures 4 and 5 is used as a binder to clay by incorporating it at different percentages. The palm fiber that was collected as part of the production of our composite material comes from the littoral region in the Moungo department. This fiber was obtained according to known extraction techniques [22–24] and was dried on a tarpaulin protected from the sun for at least 72 hours before being used in the brick (test tube).

2.2. Soil Identification Test Methods. In order to determine the physicomechanical characteristics of the Earth material

Table 1: Summary of characterization methods.

Used Materials	(i) Clay From the Centre Region in the commune of Dibang-Cameroun	They were subject to various identification tests (granularity, plasticity, and density) and compaction
	(ii) Palm nut fiber from the littoral region in the Moungo department	This fiber is obtained using known extraction techniques [22–24]
	(iii) Coconut fiber from the littoral region in the Sanaga-Maritime department	This fiber is obtained using known extraction techniques [22–24]
Soil identification test methods	(i) Particle size analysis by sieving with filtering (ii) Particle size analysis by sedimentometry (iii) Atterberg limits (iv) Methylene blue tests (v) Compaction tests (proctor test)	-
Method of making Earthen bricks	(i) Prevent cracking on drying by distributing the stresses due to shrinkage of the clay throughout the mass of the material [25] (ii) Accelerate drying by draining moisture to the outside through fiber channels [26] (iii) Lighten the material [25, 26] (iv) Increase tensile strength[25–27]	The compositions of the specimens for these various tests are as follows: (i) Clays (matrices) + fibers (2.5% reinforcements); (ii) Clays (matrices) + fibers (5% reinforcements); (iii) Clays (matrices) + fibers (7.5% reinforcements); (iv) Clays (matrices) + fibers (10% reinforcements);
Mechanical characterization method	(i) Mechanical resistance to compression	This involves submitting a $4 \times 4 \times 8\,cm^3$ test piece according to the XP P 13-901 standard
	(ii) Mechanical resistance to bending	This involves submitting a $4 \times 4 \times 16\,cm^3$ test piece according to the XP P 13-901 standard
Physical characterization method	(i) Water absorption	In general, this test consists of immersing the block in a water tank for different periods of time: 1, 2, 3, and 4 days, and measuring the increase in mass M_b compared to the mass of the block in the state dry M.
	(ii) Density of brick	It consists of weighing each specimen of each sample and calculating the apparent density
Determination of theoretical Yung's modulus	Determination of Young's modulus by the calculation model of Halpin-Tsai	-

Figure 1: Preparation of soil samples.

in order to better situate its behavior, the tests below were carried out.

(i) Particle size analysis by sieving with filtering
(ii) Particle size analysis by sedimentometry
(iii) Atterberg limits
(iv) Methylene blue tests
(v) Compaction tests (Proctor test)

Figure 2: Photograph of fibers after extraction.

2.3. Method of Making Earthen Bricks. In order to strengthen the matrix, we will use as reinforcement plant fibers (palm kernels and coconuts at different percentages), which

Figure 3: Photograph of fibers after treatment.

Figure 4: Photograph of fibers after oil extraction.

generally lead to the improvement of the mechanical characteristics of the treated soil. The role of fibers is to:

(i) Prevent cracking on drying by distributing the stresses due to shrinkage of the clay throughout the mass of the material [25]

(ii) Speed up drying by draining moisture to the outside through fiber channels. Conversely, the presence of fibers increases absorption in the presence of water [26]

Figure 5: Photograph of fibers after treatment.

(iii) Lighten the material. The volume of straw is often very large, reducing the density of the material and improving its insulation properties [25, 26]

(iv) Increase tensile strength, undoubtedly, the greatest interest of fibers [25–27]

The bricks were made by compacting with the mold used for the manufacture of the briquettes, and therefore, the dimensions are $16 \times 4 \times 4\ cm^3$ according to the NF EN-196-1 standard, manufactured in groups of three in the molds (Figures 6 and 7).

The compositions of the test pieces for these different tests are as follows:

(i) Clays (matrices) + fibers (2.5% reinforcements)

(ii) Clays (matrices) + fibers (5% reinforcements)

(iii) Clays (matrices) + fibers (7.5% reinforcements)

(iv) Clays (matrices) + fibers (10% reinforcements)

After standing in the oven at 105°C, the soil samples are cooled and weighed. However, the samples are very clayey and, therefore, sensitive to water, and the manufacture of the briquettes required the addition of a quantity of water in relation to that obtained during the Proctor test. This addition of water facilitates the mixing of the fiber in the water beforehand in order to make the soil plus fiber mixture much more homogeneous, in relation to its densification. Its density is of the order of $1390\ kg/m^3$ [28]. Also, this operation is facilitated by the fact that the fiber is soluble in water. In the context of our study, the binder dosage was by mass, and this is how a quantity of fiber is added to the Earth material according to the chosen percentage. The homogeneity of the mixture is decisive for the quality of the briquette, so we did a manual kneading for 5 to 10 minutes.

Blending the Fiber. The use of coconut and palm kernel fiber has been very tricky due to its very low mass. Thus, to prevent the fibers from intermingling and forming clumps,

Figure 6: Molds used for making bricks.

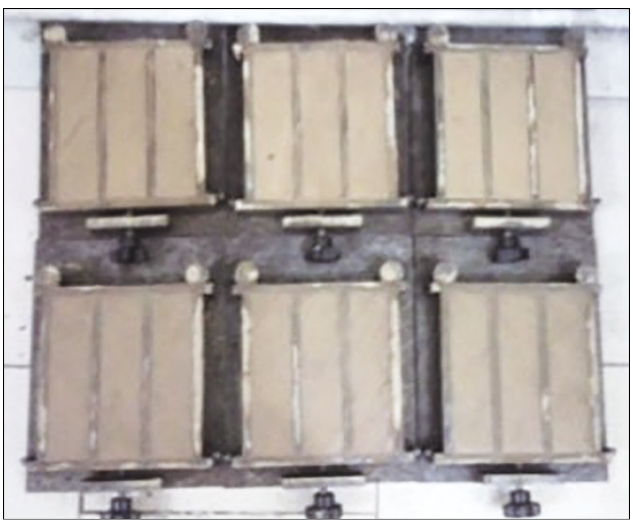

Figure 7: Briquettes on molds.

we mixed the soil plus the dry fiber; then, the water is gradually added (Figures 8 and 9).

For the feasibility of mixing on-site, we can first perform separately the grinding and sieving of the materials for a particle size of 0.01 mm (clay). Then, their association will be performed using an appropriate mixer while respecting the proportions described above.

Drying, Pressing, and Bending of the Briquettes. The samples were dried in an ambient air room at an average temperature of 25°C for 28 days before performing the bending test (Figure 10) and the compression test (Figure 11). Because in the building or civil engineering the beams and the columns (support element) work more in compression and in bending and the walls, cladding or partitions forming part of these support elements also work in these types of stresses.

2.4. Mechanical Compressive and Flexural Strengths. This test makes it possible to determine the nominal resistance in simple compression of the compressed raw Earth blocks.

Figure 8: Sample of the clay used with a particle size of 0.01 mm.

Figure 9: Photograph of some molded specimens.

This involves submitting a $4 \times 4 \times 8\,\text{cm}^3$ test piece in the case of $4 \times 4 \times 16\,\text{cm}^3$ test pieces and a sample consisting of two superimposed half-blocks and glued by a cement mortar joint in the case of blocks of masonry according to the XP P 13-901 standard with simple compression until fracture. Processing the data in Excel makes it possible to evaluate Young's modulus (E) and compressive strength (Rm).

The compressive strength is given by the formula:

$$\mathbf{R_C} = \frac{\mathbf{F}}{\mathbf{S}}. \quad (1)$$

With the following:

(i) $\mathbf{R_C}$: compressive strength of blocks in (MPa)

(ii) **F**: maximum force in (N)

(iii) **S**: compressed section in mm^2

Figure 10: Three-point bending test machine.

Figure 11: Compression testing machine.

The average compressive strength of the blocks is the arithmetic mean of the compressive strengths of 5 tests carried out on samples of the same formulation.

2.5. Mechanical Flexural Strengths. The three-point bending test is carried out on parallelepiped specimens of dimensions $40 \times 40 \times 160\,mm^3$ and masonry blocks in the dry state. The measurements are carried out on a mechanical press with a capacity of 50 kN. The traverse speed is $0.1\,mm\,min^{-1}$. The force and traverse displacement values are recorded simultaneously.

The test piece rests on two single supports spaced $l = 100$ mm apart, and the load F is applied to the center of the sample, symmetrically with respect to the supports. The composites of section $b \times h$ are assumed to be homogeneous, the data collected are processed in Excel, and the modulus of elasticity and the maximum stress at break are deduced for each specimen by the following relations, with the assumption that the material is homogeneous and isotropic.

The modulus of elasticity is as follows:

$$\mathbf{E} = \frac{\mathbf{F}\mathbf{L}_0^3}{48\mathbf{f}\mathbf{I}_{\mathbf{GZ}}}. \tag{2}$$

With the following:

(i) F: the elastic limit force in newton
(ii) L_0: the distance between the supports in mm, f: the deflection (recorded displacement) at the force F in mm
(iii) I_{GZ}: the moment of inertia of the section of the beam in mm^4

$$\sigma_{\mathbf{Rup}} = \frac{\mathbf{M}_{\mathbf{fmax}}}{\mathbf{I}_{\mathbf{GZ}}}\frac{\mathbf{h}}{2} = \frac{3}{2}\frac{\mathbf{F}_{\mathbf{Max}}\mathbf{L}_0}{\mathbf{b}\mathbf{h}^2}, \tag{3}$$

where F_{Max} is the maximum force recorded during the test in newton, b is the width of the test piece in mm, and h is the height of the test piece in mm.

2.6. Water Absorption

2.6.1. Equipment. To perform this test, we need our test specimens, in this case the bending test, but also water and a container.

2.6.2. Method. In general, this test consists of immersing the block in a water tank for different periods of time: 1, 2, 3, and 4 days, and measuring the increase in mass M_h compared to the mass of the block in the state dry M_s.

In our study, we first dried the test pieces in an oven at 105°C for 24 hours; then, the mass of the completely dry test piece is measured. The test piece is then immersed in water for 24 hours, and its quenched mass is measured again, M_t.

The absorption percentage is given by the following formula:

$$Abs = \frac{M_t - M_s}{M_s} * 100. \tag{4}$$

2.7. Brick Density

2.7.1. Equipment. Carrying out this test requires cubic test pieces (that of the compression test) and a balance (preferably digital) as equipment in order to have fairly reliable measurements.

2.7.2. Method. It consists in weighing each test piece of each sample and calculating the bulk density. The bulk density in the dry state of the brick is determined by the formula (expressed in kg/m^3) below:
Stress at break:

$$\boldsymbol{\rho} = \frac{\mathbf{M}}{\mathbf{V}}. \tag{5}$$

With the following:

(i) **M**: mass in kg

(ii) **V**: volume in m^3

2.8. Determination of the Theoretical Young's Modulus. After having examined the various models of calculations of the mechanical characteristics, we will determine these characteristics with the model of calculation of Halpin-Tsai.

2.8.1. Determination of Young's Modulus by the Halpin-Tsai Computational Model. The determination of the Young's modulus by the Halpin-Tsai computational model requires first to calculate the longitudinal E_L and transverse E_T modulus of elasticity of composite material, considering that the fibers are short and randomly arranged.

The general equation for Halpin-Tsai [27] is expressed as follows:

$$\mathbf{E_c} = \frac{3}{8}\mathbf{E_L} + \frac{5}{8}\mathbf{E_T}. \tag{6}$$

With

$$\begin{aligned} \mathbf{E_L} &= E_m\left(\frac{1 + (2l/d)\eta V f}{1 - \eta V f}\right), \\ \eta &= \frac{\left(E_f/E_m\right) - 1}{\left(E_f/E_m\right) + (2l/d)}, \\ \mathbf{E_T} &= E_m\left(\frac{1 + 2\eta V_f}{1 - \eta V_f}\right), \\ \eta &= \frac{\left(E_f/E_m\right) - 1}{\left(E_f/E_m\right) + 2}. \end{aligned} \tag{7}$$

(i) E_c: the Young's modulus of the composite

(ii) E_f: the Young's modulus of the fiber

(iii) E_m: the Young's modulus of the matrix

(iv) V_f: the volume fraction of the fiber

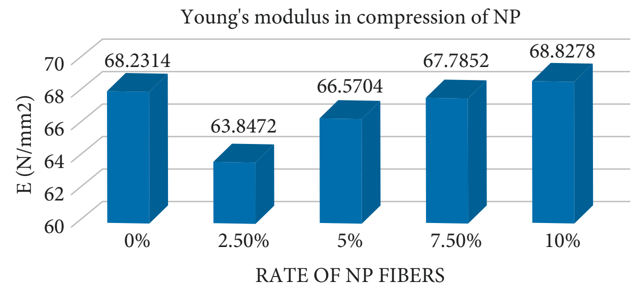

Figure 12: Distribution of the experimental Young's modulus of the different samples.

3. Results and Discussions

At the end of the implementation and the different characterizations, some results were found and analyzed. During the development of the composites, it was observed that some samples did not provide rigid and stable composites.

3.1. Results

3.1.1. Mechanical Resistance to Compression

a. Reinforcement with Palm Nut Fiber. The results in Figure 12 show that the sample of control bricks had a higher resistance compared to some samples with 68.23 MPa; for the nut fiber, the 10% palm nut fiber brick has a slightly greater strength compared to the control bricks (68.82 MPa). It is observed that the compressive strength increases as the amount of palm nut fiber have increased. Note that there is a threshold value at which the resistance decreases as the fiber rate increases.

b. Reinforcement with Coconut Fiber. The results in Figure 13 show that the control brick sample had lower strength compared to the other samples with 68.23 MPa. The coconut fiber brick considerably increased compared to the control bricks. Nevertheless, the 10% obtained the highest compression ratio (74.43 MPa) compared to 5% and 7.5%. The force difference values between 5% and 7.5% are 69.77 MPa and 68.63 MPa. It is observed that the compressive strength increases as the amount of coconut fiber have increased.

c. Comparative Study. We found that the relative error between these different Young's moduli is small in view of Figure 14 below, but the coco has good characteristics, from which we can use the Young's modulus of the coco in our calculations and have a reliable result. But the coconut fiber composite has better characteristics.

3.1.2. Mechanical Flexural Strength. a. Reinforcement with Palm Nut Fiber.

(i) Experimental Young's Modulus. The results in Figure 15 show that the control brick sample had a higher strength compared to other samples with 6.59 MPa. The palm fiber brick is slightly reduced

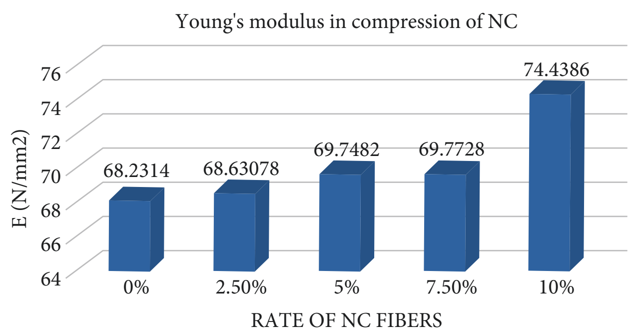

Figure 13: Distribution of the experimental Young's modulus of the different samples.

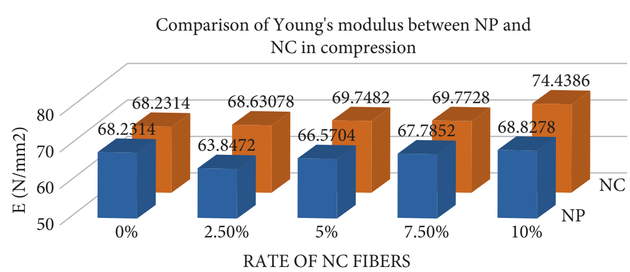

Figure 14: Comparisons of the different Young's moduli in compression.

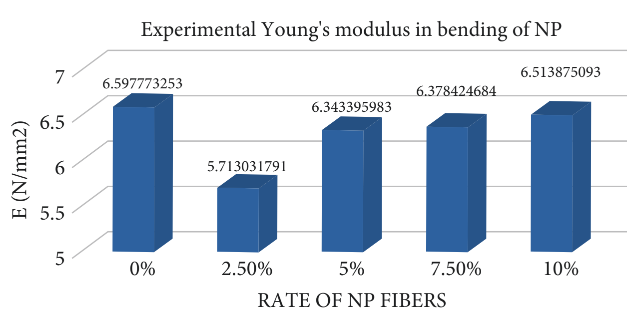

Figure 15: Distribution of the experimental Young's modulus of the different samples.

compared to the control bricks. Nevertheless, the 10% got the highest compression strength ratio compared to 5% and 7.5%. The force difference values between 10% and 7.5% are 6.51 MPa and 6.37 MPa. It is observed that the flexural strength decreases and varies depending on whether the amount of palm nut fiber has increased.

(ii) *Theoretical Young's Modulus*. The results of Figure 16 show that the theoretical behavior is similar compared to the experimental result of Figure 15 with a high bending rate at a force of 11.1402 MPa at 10% compared to the other samples.

b. Reinforcement with Coconut Fiber.

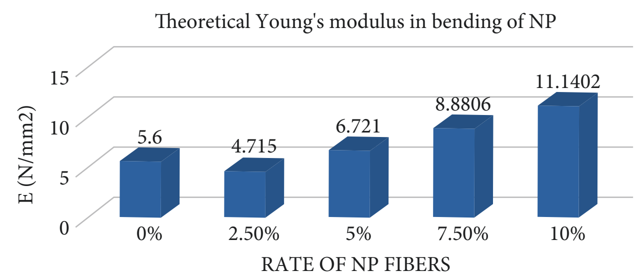

Figure 16: Distribution of the theoretical Young's modulus of the different samples.

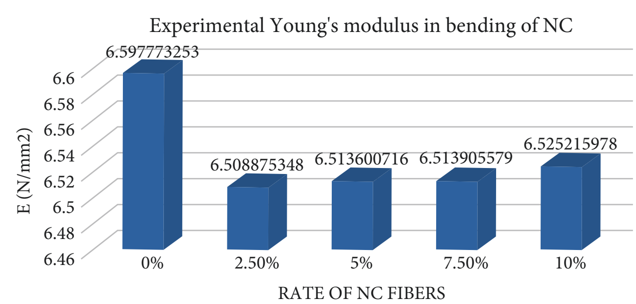

Figure 17: Distribution of the experimental Young's modulus of the different samples.

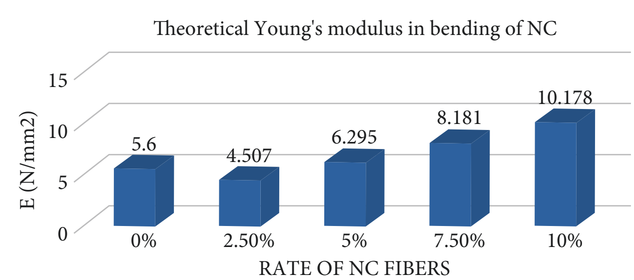

Figure 18: Distribution of the experimental Young's modulus of the different samples.

(i) Experimental Young's Modulus. The results in Figure 17 show that the control brick sample had a higher strength compared to the other samples with 6.59 MPa. The strength of the coconut fiber brick decreased compared to the control bricks. Nevertheless, the 10% got the highest compression strength ratio compared to the others. It is observed that the flexural strength decreases with the addition of fibers.

(ii) Theoretical Young's Modulus. The results of Figure 18 show that the theoretical behavior is similar compared to the experimental result of Figure 17 with a high bending rate of 10.178 MPa at 10% compared to the other samples.

c. Comparative Study. It can be seen that the relative error between these different experimental Young's moduli is low

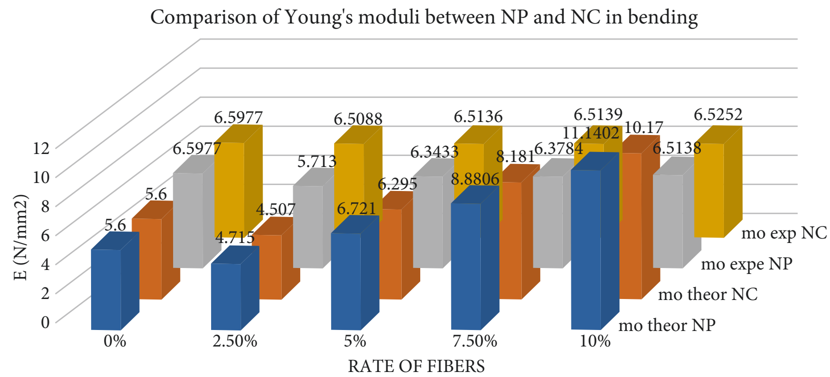

Figure 19: Comparisons of the different Young's moduli in bending.

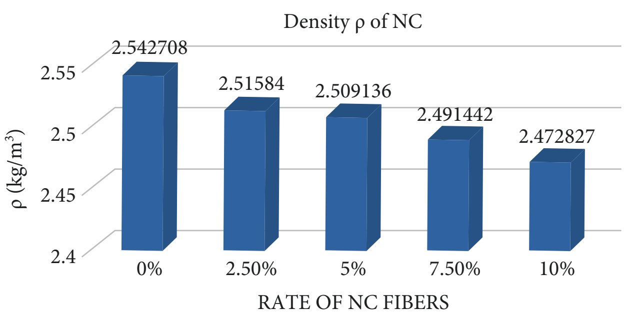

Figure 20: Density ρ of NC.

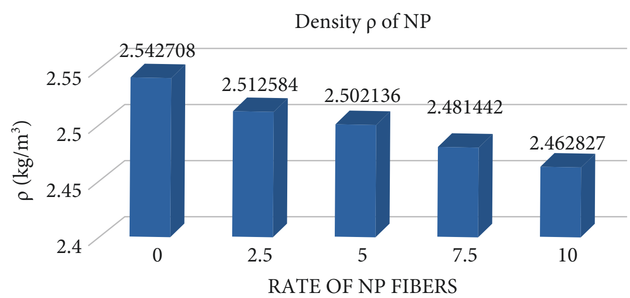

Figure 21: Density ρ of NP.

in view of Figure 19 below, but the theoretical calculation of these shows a behavior similar to those experimentally obtained with a high value at 10% for both fibers. Therefore, we can use any Young's modulus in our calculations and get a reliable result. But the coconut fiber composite has better characteristics in view of experimental studies with 6.5252 MPa at 10% fiber.

3.1.3. Density

a. Density ρ of NC. At first glance, it can be seen from Figure 20 that there is a reduction in density with increasing fiber content. We realize the highest density is that of unreinforced composites (0% fibers) and the lowest density is that of composites reinforced with 10% fibers, and the reduction rate between these two values is 2.75%.

b. Density ρ of NP. At first glance, it can be seen from Figure 21 that there is a reduction in density with increasing fiber content. We realize the highest density is that of unreinforced composites (0% fibers) and the lowest density is that of composites reinforced with 10% fibers, and the reduction rate between these two values is 3.13%.

c. Comparative Study. It can be seen that the relative error between these different densities is low in view of Figure 22 above, and we realize that the composite has coconut fiber at a higher density than that of the composites with coconut fiber and palm nuts at a maximum rate of 10%.

The density was observed to decrease as the amount of fiber increased and produced lightweight composites. The lightweight composite offers an advantage in terms of handling and transportation costs because it is lighter than a normal composite [24, 25].

3.1.4. Water Absorption Rate

a. Water Absorption of Palm Nut Fibers. Figure 23 shows the variation in the water absorption rate depending on the fiber content in our composites. There is a gradual increase in this rate. The results show that the addition of fibers in the mixtures slightly increases the total water absorption, which means that there is more water infiltration in the samples. This is attributed to the water absorption capacity of the fibers and the detrimental effect of the presence of foreign materials, such as fibers, on the binding capacity of the mixture.

This rate of change between the smallest value obtained at 0% fiber and the largest value obtained at 10% fiber is 26.66%. This increase is not only due to the fact that palm nut fiber is a vegetable but also to its porosity rate, which varies according to the size of the fiber.

b. Water Absorption of Coconut Fibers. Figure 24 shows the variation in the water absorption rate depending on the fiber

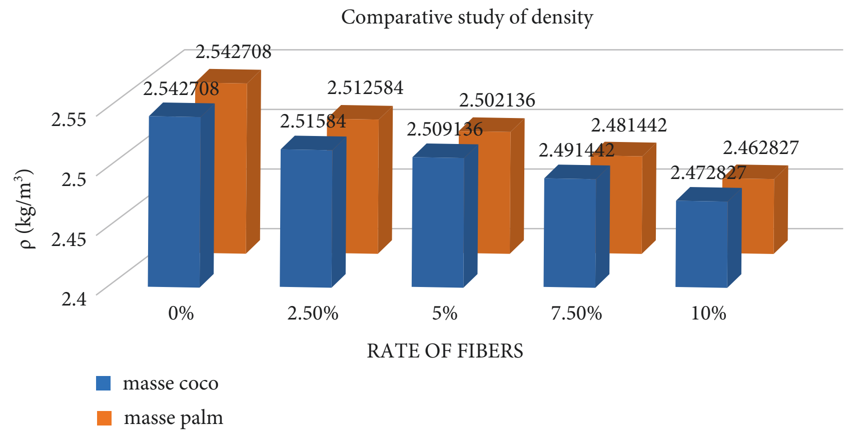

Figure 22: Density comparisons.

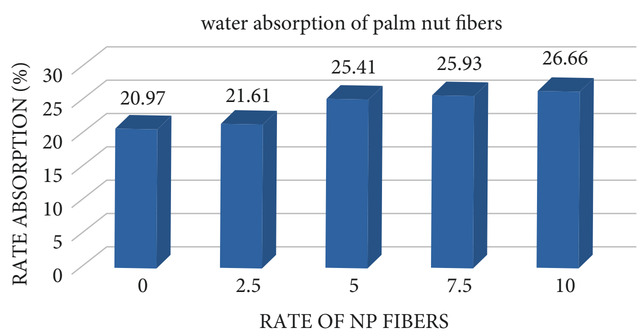

Figure 23: Water absorption of palm nut fibers.

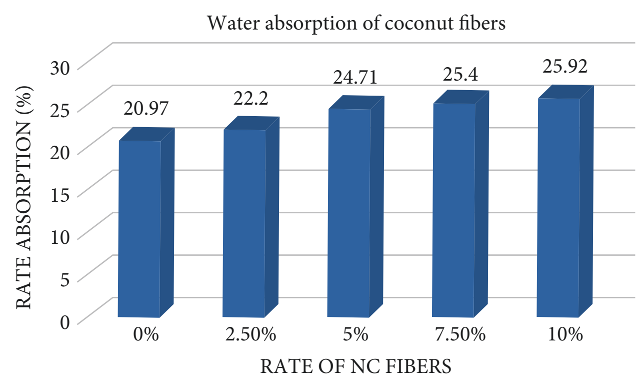

Figure 24: Water absorption of coconut fibers.

content in our composites. There is a gradual increase in this rate. The results show that the addition of fibers in the mixtures slightly increases the total water absorption, which means that there is more water infiltration in the samples. This is attributed to the water absorption capacity of the fibers and the detrimental effect of the presence of foreign materials, such as fibers, on the binding capacity of the mixture.

This rate of change between the smallest value obtained at 0% fiber and the largest value obtained at 10% fiber is 25.92%. This increase is not only due to the fact that coconut fiber is vegetable but also to its porosity rate, which varies according to the size of the fiber.

c. Comparative Study of Water Absorption Rate. Any material reinforced with these fibers in the raw state tends to be slightly more water absorbent as shown in Figure 25. The water absorbed by the fibers is either water held between the interstices of the bundles of microfibrils, or it is bound to the surface of the microfibrils.

But despite this increase, the values of the total water absorption remain moderate according to the British standard BS 5628 Part 1 (British Standards, 1985). According to this standard, the ATE values below 7% are considered low, while those above 12% are considered high. But the coconut fiber composite has a lower water absorption rate than that of palm nut fiber.

3.2. Discussion. The results obtained reveal interesting mechanical performances and those of whatever the formulation adopted. It appears that the values of compressive and flexural strengths obtained for the dosage of the fiber at 10% appear to be optimal. Thus, these dosages can be used for making quality bricks.

Taken together, these results suggest that the reinforcing fiber appears to be the essential element in the optimization of the formulations, and therefore, the fiber contributes to improving the mechanical performance of mud bricks.

However, in view of the work reported by:

(i) Ngouama (2008) who showed that the starch incorporated in the clay, for a percentage of fines between 30 and 100%, reaches compressive strengths of the order of 6.070 MPa and improves the mechanical properties of stabilized brick [29].

(ii) Talla et al. (2010) who highlight the stabilization of soils including the waterproofing of Earthen walls using extracts of "***Parkia biglobosa***," a construction technique used by the "Kassema" people in Burkina Faso by decoctions of hot drawn giving 1.83 MPa compressive strength at 2 days [30].

(iii) Malanda et al. (2017) who show that the sugar cane molasses associated in clay, for a percentage varying

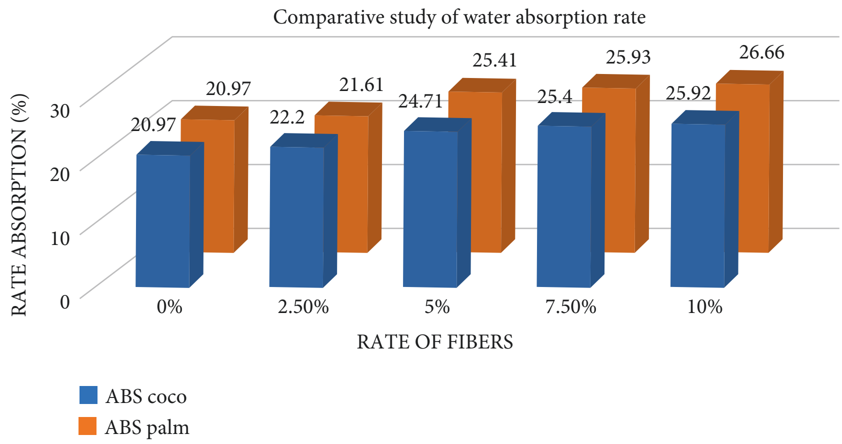

Figure 25: Comparisons of different water absorption rates.

by 12%, give the greatest value of resistance, i.e., 4.65 MPa at 28 days [31].

We can note that our various tests performed (compression and bending) were carried out in accordance with the standard enacted by CRATERRE-EAG (characteristic resistance of the BTC); the results obtained during these tests present higher values in view of the statistical results obtained in flexion and compression compared to Ngouama (2008), Talla et al. (2010), and Malanda et al. (2017) [32]. On the other hand, these results are better than those obtained in the literature.

Thus, except for the predominance given by stabilizing the Earth with cement or other binders, coconut and palm nut fibers with a dosage of 10% testify to the interest in the stabilization of Earthen bricks.

4. Conclusions

In this research work, it was a question of characterizing the mechanical and physical behaviors of a building material with a clay matrix taken with high porosity reinforced by fibers of plant origin. Through a vast experimentation campaign, we determined the mechanical characteristics of the constituents including coconut fibers, palm nut fibers, and clay taken unreinforced. We measured the mechanical characteristics of the materials resulting from the fiber/clay mixture. We tracked water uptake and density of fibers, unreinforced set clay, and clay/fiber composites.

There is a great limitation in the propagation of cracks in the clay with the presence of fibers and an increase in its rigidity. Coconut fiber provides more than palm nut fiber. However, coconut fiber imparts significant ductility to the clay matrix. In addition, these fibers guarantee better reinforcements in compression and a fairly homogeneous volume distribution provides some in bending.

The fibers are more absorbent in water than in the matrix, and the composite consequently absorbs more water than the unreinforced material. It is important to note a rather great difficulty, and mention is made by many other authors, in accurately predicting the behavior of a composite when it is reinforced with vegetable fibers. The selection of fibers with homogeneous characteristics is still problematic. The selection of fibers with homogeneous characteristics is still problematic due to morphological variation, the uniformity of properties throughout the fiber being difficult to control, so a large field of investigation is still available in this direction. A large field of investigation is still available in this direction. The conduct of water absorption and density tests presents a requirement in the identity of the geometry of the specimens. The information provided by our work already gives a workable idea: it is clear that coconut fiber is more hydrophilic than palm nut fiber, which in turn is more than clay. Further work is needed in further research on these materials.

Data Availability

The experimental data used to support the conclusions of this study are included in the article.

Additional Points

The authors declare that the various experimental tests were carried out in accordance with certain international standards.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this document.

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