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Original Article

Study of the Phyco-Mechanical Behavior of Raw Clay Bricks from Cameroon Stabilized with Lime Reinforced with Tropical Vegetable Fibers

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Abstract *- This work focuses on the geotechnical characterization of the raw earth material on the one hand and the other hand, mechanical and physical characterization of the raw clay bricks from Cameroon stabilized with lime reinforced with tropical plant fibers. This idea arises from the fact that housing in southern Cameroon is made of unstabilized mud bricks that crumble over time and are, therefore, unsustainable. They must be replaced by BTC. The objective of this work was to determine the physical and mechanical properties of raw clay bricks, which could be used for construction in this area. For this study, the experimental method was used. It was carried out through tests such as: geotechnical for the earth, mechanical and physical. It appears that the material used is plastic clay soil with an optimum density of 1.301g/cm3. The following formulations were made: Clays + fibers and Clays + Lime (12% stabilizer) + fibers at different percentages (1.5%, 2.5%, 3.5%, 4.5%) and tested after 28 days. It appears that these bricks in Raw clays have interesting properties. The lightest are clay bricks + 4.5% coconut fibers with 12% lime with an apparent density of 1.12 g/cm3. Water losses increase over time. The results indicate that there is an improvement in the compressive strength of the blocks, with the formulation having the best constraints being the 2.5% palm nut with a value of 7.36MPa. While the flexural strength of the different formulations with the best constraints is the 2.5% coconut fibers with a value of 5.99MPa. It appears that the addition of fibers to the clay increases the shear stress, whatever the content. Also, the highest shear stress is obtained with 2.5% palm nut fiber content at 12% lime. The results obtained by mechanical testing on these BTC, compared to those of the standard on BTC, show that all the formulations carried out can be used for the construction of homes in the southern Cameroon zone.*

Keywords *- Clay, Compression, Fibers, Influence, Shear.*

1. Introduction

Today, nationally and internationally, in the fields of industry, energy, transport and construction. Incentives and constraints are becoming more and more robust to incorporate projects into a sustainable development approach. Despite the technological development that mankind has experienced in recent centuries, which has allowed modern man to have a wide variety of building materials such as concrete and steel, there is now a growing return of earthen construction in Third World and industrialized countries. This raw earth material, often criticized for its sensitivity to water and lack of durability, has many advantages in its current form for the construction of sustainable, comfortable and economical housing, which can be explained first of all by the desire of these countries to carry out part of the programme dedicated to rural housing, secondly, by the concern to adapt legislation to the new international context in the field of sustainable development. With this in mind, a law on the promotion of renewable energies was promulgated in August 2004. [1]. Cameroon has several species of palm and coconut trees, including several varieties. The annual maintenance work on these plants generates significant quantities of waste composed mainly of palm leaves and surface fibers, which can be used as fibrous reinforcement in soil products.

Waste from different sources causes various environmental problems related to its storage and increasing quantities. Furthermore, traditional building materials of natural origin are facing exhaustion. It is, therefore, important to think about the development of composite materials with artificial or recycled aggregates from industrial and agricultural waste. This type of material meets economic and environmental requirements. In the building sector, the exploitation and recovery of industrial waste, as well as agricultural co-products, have given rise to a certain number of research projects on new composite materials [2-6].

The mechanical characterization of composites incorporating renewable materials such as co-products from agricultural exploitation (flax, hemp, coconut, jute, palm, etc.) as aggregates, in the form of particles or fibers, in a mortar or concrete ground matrix has been the subject of numerous publications [7-10]. This valorization of agro resources constitutes a solution of great interest compared to their elimination by stripping on site.

In addition, these composites are characterized by a relatively low density compared to traditional materials and present several potential applications, such as thermal insulation or acoustic insulation. On the other hand, they may exhibit some sensitivity to water and dimensional instability, such as shrinkage and swelling in service or the presence of a humid environment. This problem is usually treated by adding stabilizers to the soil.

The most commonly used stabilizers are cement, lime and sand [11-13]. Despite the addition of these stabilizers, the problem continues to exist, hence the addition of other additives, such as vegetable fibers. The presence of these fibers will oppose shrinkage and swelling responsible for cracks, thus improving mechanical resistance [14-16].

Several studies have shown the effectiveness of plant fibers in the production of composite materials. The incorporation of plant fibers, abundant and inexpensive raw materials, into a clay-based matrix can be an interesting way to improve the properties of earth mortars. [17], [18] were interested in studying the incorporation of sisal and coconut fibers into fine soil. They found that the mechanical performances are moderate, with an improvement in the ductility of the fiber-reinforced soil compared to the non-fiber-reinforced soil.

The studies of [14], [19-24] on the use of clays for the production of compressed clay bricks (BAC) on the one hand and on the use of non-biodegradable waste in the production of tiles and concrete on the other hand, which gave very satisfactory results. Additionally, compressed clay bricks are heavy, so transporting them from one locality to another is often difficult. One of the palliative solutions to these problems lies in the design of a composite material consisting of the clay matrix and another material having a density lower than that of the clay, with the aim of reducing the density of the BAC. The choice of this material was coconut fibers and palm nuts, which are industrial waste and potential sources of environmental pollution [25, 26].

The main objective of using coconut fibers and palm nuts in the production of raw clay bricks is to reduce weight and improve the mechanical and physical characteristics of raw clay bricks. In order to carry out this 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 the last section is the conclusion.

2. Methodologies

This session details the testing methods that will be applied to the study of composites.

2.1. Materials Used and Experimental Protocol

The materials used in this research are: clay soil, now called “natural clay”, quicklime, coconut fibers, and palm nut fibers. All these raw materials come from Cameroon, and the ultimate objective of this work is to demonstrate the viability of materials made from local raw materials for construction.

2.1.1. Soil

The land used in this research belongs to the Central Region (DIBANG) (Figure 1). The criterion for choosing sampling locations are availability and abundance in the region.

2.1.2. Physical Characteristics of the Soil

Determination of Physical Soil Tests

The Mission for the Promotion of Local Materials (MIPROMALO) in Cameroon served as a framework for carrying out physical and mechanical identification tests on the materials collected. The tests were carried out according to the French standard and concern, among other things:

- Granular composition according to standards NF P 94-056 and NF P94-057 [27] [28].
- Atterberg limits according to the procedure of standard NF P 94 051 [29].
- Methylene blue test called stain test (NF P 18-592) [30].

Fig. 1 Study Soil

Particle Size Analysis

a) Particle Size Analysis by Dry Sieving After Washing.

The particle size analysis is carried out according to the French standard NF P 94-056 [27]. It consists of separating agglomerated grains from a known mass of material by mixing under water. Once the material has dried, using a series of sieves fitted one inside the other and whose opening dimensions decrease from top to bottom, the cumulative residue is weighed successively on each sieve. The cumulative rejection mass on each sieve is related to the total dry mass of the sample.

Principle of Analysis

The material intended for this test is first steamed at 105°C for twenty-four hours, then five hundred grams (500g) of material are taken. This material, after a stay in the water, is washed using an 80 µm sieve. The refusal of the 0.08 mm sieve constitutes the coarse fraction, which, after being steamed at 105°C for 24 hours, is sieved dry using an Endecotts EFL 2000 brand electric sieve. The different meshes of the sieves used are 6.5 mm, 4 mm, 2 mm, 1 mm, 800 µm, 500 µm, 400 µm, 200 µm and 80 µm. Thus, the mass of cumulative rejects on each sieve is related to the total dry mass of the sample. The percentages of cumulative refusals thus obtained will be used to deduce the percentages of sieves necessary for drawing the particle size curve. Furthermore, the fine fraction, consisting of particles with dimensions less than 0.08 mm, will be used for particle size analysis by sedimentometry.

b) Particle Size Analysis by Sedimentometry

It is complementary to the particle size analysis by sieving of soils; it is applicable to soil particles with a diameter less than 0.08 mm and its operating mode is described by the standard [28]. The clay sample was subjected to sedimentometric analysis in order to perfect the grain size curve.

(a) Hardened material **(b) Washing the material**

(c) oven-dried material **(d) Appareillage de granulométrique**

Fig. 2 Some steps for performing particle size analysis.

Atterberg Limits

The aim of this test is to identify and classify fine soils whose particles are invisible to the naked eye.

Principle

The test is carried out in two distinct phases according to French standard NF P 94-051:

- Research of the water content for which a groove of standardized size, made in the soil placed in a Casagrande cup, closes under the action of 25 shocks applied in a standardized manner;
- Research of the water content for which a roll of soil with a diameter of 3 mm and a length of 10 to 15 cm, made manually, cracks when lifted.

The Liquidity Limit

It corresponds to the value of the useful water content for closing 1 centimeter of a groove after approximately twenty-five (25) shocks (Casagrande device).

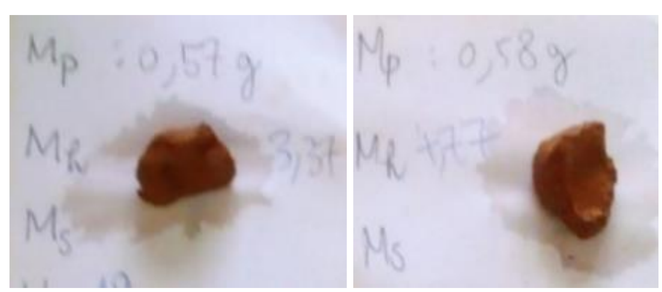
c) The Limit of Plasticity

For this test, the same paste used to determine the liquidity limit was used. The plasticity limit is the water content of a cylindrical roller that cracks when its diameter reaches 3 mm. The paste used for the liquidity test is first dried slightly on the plaster before being spread on the marble slab (clean and dry).

A ball of approximately 12 mm in diameter was formed, which was then used to make a cylindrical roller, 3 mm in diameter and 10 to 15 cm in length, on a smooth marble plate. The limit of plasticity is reached when, by slightly lifting the cylindrical roller from the middle, it cracks or breaks.

(a) Casagrande apparatus. **(b) Groove Dividing the dough in two**

Fig. 3 Operational mode of the liquidity limit



(a) Dumpling obtained from the paw

(b) Paw roll

Fig. 4 operating mode of the plasticity limit

d) The Plasticity Index (PI)

The plasticity index specifies the interval in which the clay material is easily deformable (shapeable). It is obtained by the numerical difference between the liquidity limit (ωL) and the plasticity limit (ωP).

$$I_P = \omega_L - \omega_P \quad (1)$$

Classification of Materials

The classification of the state of soil according to its plasticity index is summarized in Table 1 (French standard P 94-051, 1993).

Free Swelling Test

It makes it possible to define the swelling state of a clay material.The results from the calculation of the plasticity index will allow us to proceed to the classification of Snethen (1980) based on a single parameter: the plasticity index.

Table 2 presents the swelling potential as a function of the plasticity index (Chassagneux et al., 1995).

Methylene Blue Test Called the Stain Test (NF P 18-592)

The methylene blue test is a test used to determine the cleanliness of soil and the different types of clay it contains. Methylene blue is, in fact, preferentially absorbed by clays of the montmorillonite type (swelling clays) and organic materials. Other clays (Illites and Kaolinites) are not very sensitive to methylene blue.

The dosage was carried out by successively adding quantities of 'blue' solution and monitoring the absorption progressively. A drop of suspension was taken and placed on a filter (Figure 5). The operating mode and tools are described by standard NF P 18-592. This quantity of dye is called the blue value, noted VB and expressed in grams of blue per 100 g of soil.

The blue value of the test sample is thus calculated by the following formula:

$$V_{BS} = \frac{V_1}{M_1} \quad (2)$$

Fig. 5 Some steps for performing the methylene blue test.

Table 1. Classification of materials according to the plasticity index [29]

Plasticity index	Soil condition
0-5	Non-plastic
5-15	Little plastic
15-40	Plastic
> 40	Very plastic

Table 2. Swelling potential as a function of plasticity index

IP	Swelling potential
<12	Weak
12-25	Average
25-40	Strong
≥40	Very strong

Table 3. Soil classification [30]

(V_{BS})	Soil category
$V_{BS} < 0,1$	Soil is insensitive to water.
$0,2 \leq V_{BS} < 1,5$	Sandy loamy soil, sensitive to water.
$1,5 \leq V_{BS} < 2,5$	Sandy clay soil, little plastic.
$2,5 \leq V_{BS} < 6$	Loamy soil of medium plasticity.
$6 \leq V_{BS} < 8$	Clay soil.
$V_{BS} > 8$	Very clayey soil.

With V: total volume of the added blue solution (in ml), M: the dry mass of the intake in g.

Once the VBS has been obtained, the soil can be identified according to the Soil Classification Guide, which defines six categories of soil according to the VBS value. The following values are distinguished:

2.1.3. Lime

All types of lime are to be used in principle in the stabilization of earth material intended for construction; preference is nevertheless given to aerial limes rather than hydraulic limes. Lime is especially recommended for soils containing a clay fraction of less than 20% [31].

In this study, quicklime (Figure 6), produced by ROCA Figuil lime unit (Cameroon), was used. The chemical and physical composition of quicklime is presented in Tables 4 and 5.

Table 4. Chemical analysis

$Ca(OH)_2$	Al_2O_3	Fe_2O_3	SiO_2	MgO
95.4%	0.5%	1.2%	1.3%	1.3%

Table 5. Physical analysis

Absolute density (g/cm^3)	Apparent volumetric mass (g/cm^3)	Specific surface (Kg $/m^2$)
2230g/m 3	1490g/m 3	300/Kg/ m2

Fig. 6 Quicklime used.

Optimization of Lime

The optimum lime content for brick can be determined by a simple compression test. The percentages used to do this operation are: 8%, 10%, 12%, 14%. The optimization results allowed us to choose the optimal lime content of 12%.

2.1.4. Water

The water used in the mixture comes from the public network and at a temperature of (20 ± 1 C). The quality of this water meets the requirements of standard NFP 18–404.

2.1.5. Fibers

The choice of coconut and palm fibers for reinforcing the mineral matrix is justified by their excellent specific mechanical properties and their availability at a very low cost [32].

In this work fibers were obtained using known extraction techniques [33-35] and was dried on a tarpaulin away from direct sunlight for at least 72 hours before being used in the brick (test tube).

Coconut Fiber

The coconut fiber shown in Figures 7 and 8 is used as a binder for clay by incorporating it in different percentages. The coconut fiber that was collected as part of the manufacturing of this composite material comes from the Littoral region in the Wouri department.

Indeed, natural fibers for soil improvement have already been implemented by several previous researches, namely [36] [37]. This made it possible to know the physical and mechanical characteristics of coconut fibers.

The physical and mechanical characteristics are given in Table 6 below.

Table 6. Physical and mechanical characteristics [39]

Physical and mechanical characteristics				
Young's Modulu s E (Gpa)	Elongatio n A(%)	Ultimate stress σu (Mpa)	Water absorpt ion (%)	Density (g/cm3)
4-6	15-40	131-175	106	1,15

Table 7. Physical and mechanical characteristics [38]

physical and mechanical characteristics				
Young's Modulus E (Gpa)	Elongation A(%)	Ultimate stress σu (Mpa)	Water absorption (%)	Density (g/cm3)
1.4- 2.2	15-40	70-90	76	1,206

Fig. 7 Photo of the coconut fibers after extraction

Fig. 8 Photo of the coconut fibers after treatment

Fig. 9 Photo of palm fibers after oil extraction

Fig. 10 Photo of palm fibers after treatment

Palm Fiber

The palm fiber shown in Figures 9 and 10 is used as a binder for clay by incorporating it in different percentages. The palm fiber that was collected as part of the manufacturing of this composite material comes from the CENTER region in the Mfoundi department.

The physical and mechanical characteristics are given in Table 7 above.

2.1.6. Block Making (BTC) and Tests Carried Out

The weight of the overall dry mixture for each block is kept constant during all stages of this study; it is taken equal to 1.5 kg. A series of blocks are made using a mixture composed of clay, stabilized with lime and four fiber contents compared to the overall dry mixture. The mixtures are compacted using the single-effect static mode by applying a compaction constraint (10 MPa). To moisten the mixture during mixing, 10% water was used.

Fig. 11 Molds used for making bricks

Fig. 12 Briquettes in Molds

Fig. 13 Test specimens used

Process for Manufacturing Earth Bricks

In order to reinforce the matrix, plant fibers will be used as reinforcement (palm kernels and coconuts at different percentages), which generally leads to the improvement of the mechanical characteristics of the treated soil [39-41].

The bricks were manufactured by compaction with the tempered steel mold; it is composed of 5 elements forming after assembly a volume of 4x4x16 cm3 according to the NF EN-196-1 standard, manufactured in groups of three in the molds (Figure 11 and Figure 12).

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

- Clays (matrices) + fibers (1.5% reinforcements, 2.5% reinforcements, 3.5% reinforcements, 4.5% reinforcements) + Lime (12% stabilizer);
- Clays (matrices) + fibers (1.5% reinforcements, 2.5% reinforcements, 3.5% reinforcements, 4.5% reinforcements).

Preparation of Mixtures

The best mixing conditions are met when dry soil is available [42]. This requires prior drying of the soil. Thus, to prevent the fibers from intertwining and forming clumps, the materials (soil + lime + fibers) are first kneaded dry. The dry mixtures are homogenized for a few minutes. Then, these compositions are mixed with a percentage of water (Figure 13).

72 hours after casting, the samples are unmolded and then stored in a room at 24°C for 28 days of drying. After a 28-day cure, these samples were subjected to a number of tests such as the compression test (Figure 14), the bending test (Figure 16), and the shear test (Figure 17), Car in building or civil engineering, beams and posts (carrying element) work more in compression and bending and the walls, cladding or partitions forming part of these load-bearing elements also work under these types of stresses.

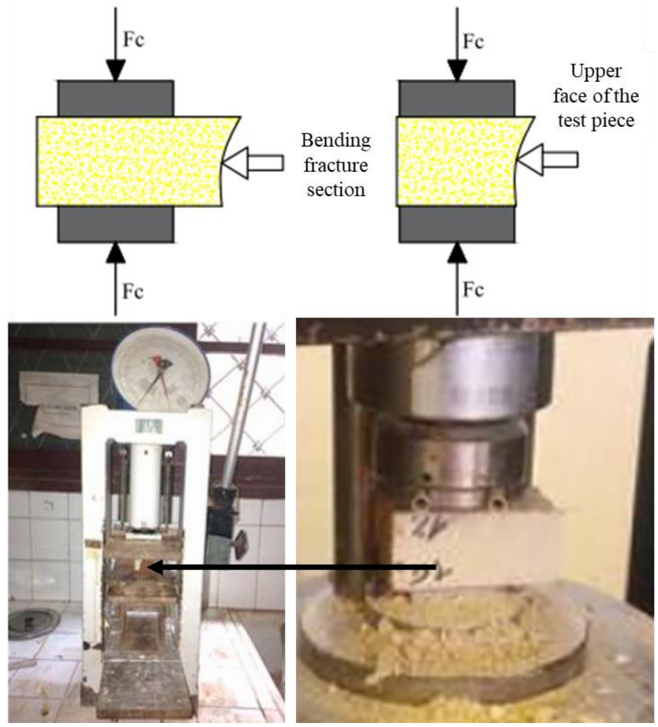


Fig. 14 Compression rupture device

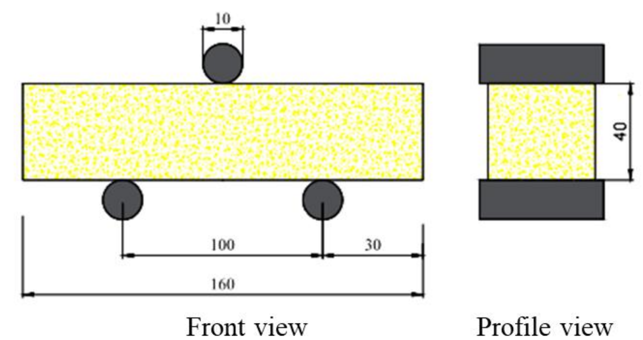


Fig. 15 Prince diagram of the bending test

Fig. 16 3-point bending test

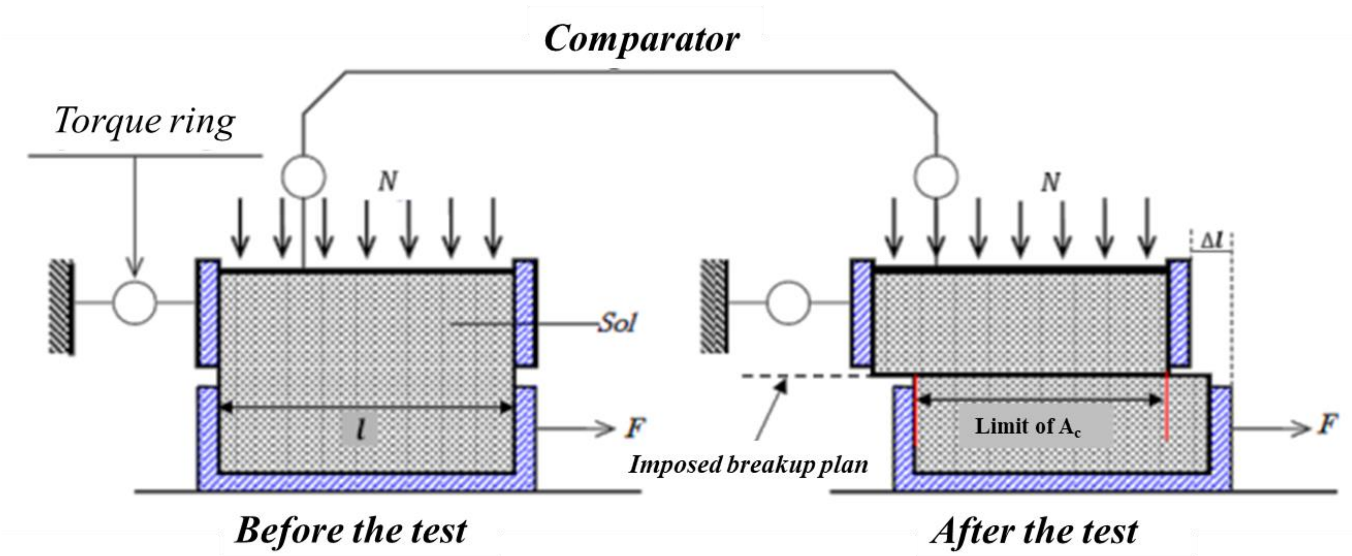


Fig. 17 Direct shearing device at the box

2.2. Mechanical Characterization

2.2.1. Compression Test

The simple compressive strength of blocks has been widely studied. It depends on the stabilization rate, according to [43]. This behavior of the blocks is also linked to the age of the blocks [43]. The compressed earth blocks also offer resistance to simple compression, which increases according to the duration of treatment, regardless of the stabilization rate and varies little from the 21st day [42], [44].

The compressive strength is determined according to standard NF P 18-406; the purpose of this test is to determine the compressive strength or the crushing strength of a part of the brick after the bending test. The following figure shows the experimental setup of the compression test.

The compressive strength is given by the formula:

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

Where,

• Rc compressive strength (MPa);
• F the maximum compressive load causing rupture (N);
• S the transverse surface of the specimen (mm^2).

2.2.2. Bending Tensile Test

The test was carried out according to standard NF P 18 – 407 [40] and standard EN 196-1[41]. The test pieces are tested after a 28-day cure in water. The specimen rests on two simple supports spaced l=100 mm apart, and the load F is applied to the center of the sample symmetrically in relation to the supports. For the composites with section (b x h) being assumed to be homogeneous, the normal tensile stress is applied to the section of the prismatic beam (Figure 15) (Figure 16).

The data collected is processed in EXCEL, and the modulus of elasticity and the maximum breaking stress is deduced for each specimen by the following relationships, with the hypothesis that the material is homogeneous and isotropic.

The Modulus of Elasticity:

$$E=\frac{FL_0^3}{48fI_{GZ}} \quad (2)$$

F: the elastic limit force in Newtons,
L0: the distance between the supports in mm,
f: the deflection (recorded displacement) at the force F in mm
IGZ: the moment of inertia of the section of the beam in mm4,

The Stress at Rupture:

$$\sigma_{Rup}=\frac{M_{fmax}}{I_{GZ}}\frac{h}{2}=\frac{3}{2}\frac{F_{Max}L_0}{bh^2} \quad (3)$$

Where,

F_{Max}: the maximum force recorded during the test in Newtons,
b, the width of the specimen in mm
h, the height of the test piece in mm

2.2.3. Resilience Test

The direct shear test made it possible to reveal the shear resistance parameters of the clay taken and of the different mixtures produced, namely cohesion C and friction angle φ. Cohesion is the force of attraction between the grains and the friction angle φ, which is the sum of the friction existing between the grains of the soil. The methodology followed in carrying out this test is recommended by the French standard (NFP 94-074-1) [47].

The test consists of:

- Apply to the upper face of the test piece a vertical force N maintained constant throughout the duration of the test;

$$\sigma_n=\frac{N}{S} \quad (4)$$

- Produce after a consolidation of the specimen under the force N, shear in the specimen according to the horizontal plane of sliding of the two boxes relative to each other by imposing on them a displacement relative to the constant speed,

- measure the Corresponding effort

$$\tau = \frac{F}{S} \quad (5)$$

The test is carried out on a series of at least 3 specimens by increasing the value of the force N for each specimen. The maximum vertical stress applied to the series of specimens must be greater than the effective vertical stress induced in the ground after work.

$$\sigma_{max} = \frac{N_{max}}{S} \quad (6)$$

By carrying out several tests on the same material with different vertical stress values, it is possible to determine the intrinsic curve of the material and define its cohesion and friction angle values.

2.3. Physical Characterization of the Composite Material

2.3.1. Water Absorption Rate

The water absorption test aims to determine the quantity of water absorbed by the material immersed for a period of 24 hours through Relation (5). In direct contact with water, the sample of composite material absorbs it by capillary action according to the formula below:

$$A = \frac{Ph - Ps}{Ps} * 100 \quad (7)$$

Where

A: water absorption coefficient (kg/m^2.s $^{1/2}$),

P_h: wet weight of the block (N)

P_s : dry weight of the block (N).

2.3.2. Measurement of Density (NF P94-054).

Carrying out this test requires cubic test pieces (that of the compression test) and a balance (preferably digital) to obtain fairly reliable measurements.

Method

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

$$\rho = \frac{M}{V} \quad (8)$$

With :

M the mass in kg

V the volume in m^3

2.3.3. Swelling

The measurement of the swelling of the BTC is done according to the following procedure (standard XP 13-901):

- Seal two measuring pads on each block using epoxy resin according to Figure 18a;
- Measure the distance between studs: l0.
- Place the blocks in a tray of water according to figure 18b;
- After 96 hours of immersion, let the blocks drain for 10 minutes, then measure the distance between blocks: l1.
- The amplitude of the swelling of each block is given by the following formula:

$$\Delta l_g = \frac{l_1 - l_0}{l_0} \quad (9)$$

With :

l_0 : the distance before immersion

l_1 : distance after immersion

3. Results and Discussions

3.1. Soil Characterization

3.1.1. Geotechnical Identification Tests

Particle Size Analysis

The particle size analysis data are grouped in Table 8. The clay sample is composed of 0.86% gravel, 28.63% sand, 58.72% silt and 11.80% clay. The corresponding particle size curve is illustrated in Figure 19. It appears from the exploitation of this curve that the sample analyzed has a spread grain size. According to the Belgian ternary classification system (Bah et al., 2005), the material is a slightly sandy silt.

(a) preparation of the plots **(b) immersion in water**

Fig. 18 Steps of the swelling test

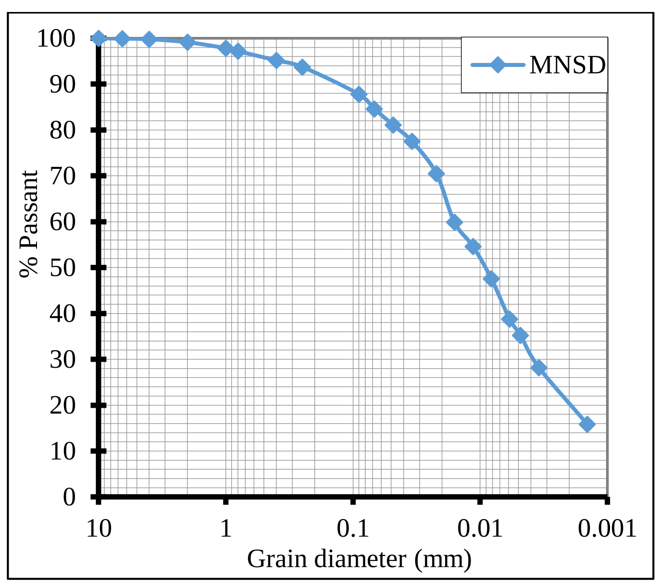


Fig. 19 Particle size curve of the materials analyzed

Table 8. Particle size analysis results of DIBANG clay materials

Samples	Proportion of materials				Total
	% of gravel (> 2000 µm)	% of sand (20<Φ<2000 µm)	% of silt (2<Φ<20 µm)	% clay (Φ≤ 2 µm)	
MNSD	0,86	28,63	58,72	11,80	100

Table 9. Atterberg soil limits.

Atterberg limits (%)			
Ground	Liquidity Limit (WL%)	Plasticity limit (WP %)	Plasticity index (PI%)
	70,39	39,54	30,85

The results of the particle size analysis revealed that the material studied is rich in sand. The particle size curve of said material is continuous. It has a better particle size distribution (Table 8 and Figure 19). The particle size of the material is therefore spread out, therefore suitable for the manufacture of BTC. In fact, the grain size of clay material for earth bricks must be spread out (Labour International, 1986). The projection of the material in the Winkler diagram shows that the material is suitable for the manufacture of dense bricks. The sand content of the material (28.63%) is different from that obtained by [49] on the alluvial clays of Ebebda (10.30%) and by [50] on the alluvial clays of the Ayos region (48%).

Atterberg Limits

The plasticity index of this earth is 30.85 (%), so it is in the range of 15<IP<40. According to the standard (NF P94-051:1993-03), the floor is said to be plastic. The plasticity of clay is mainly ensured by its large proportion of clay and silt particles [48],[50]. MNSD clay material can hold 70.39% water without sinking under its own weight. It can deform plastically when it has 39.54% water. Its plasticity index value is 30.85%. The plasticity of a material is inversely proportional to the size of the particles; the more coarse particles the material contains, the lower its plasticity and vice versa. The IP value of this MNSD material (30.85%) is different from that obtained by [54] on the alluvial clays of Sanaga in Ebebda (46.3%). On the other hand, these results are comparable to those obtained by [49] on alluvial clays from the Ayos region (26%).

Free Swelling

The results from the calculation of the plasticity index made it possible to conclude from Table 2 that the clay material has a strong swelling state because IP is equal to 30.85%.

Methylene Blue

The methylene blue test result obtained is VBS =2.25, which makes it possible to classify and identify the MNSD sandy-clay soil sample according to the GTR (Road Earthworks Guide).

Thus, in view of the clay fraction contained in this soil sample, it does not comply with the implementation of BTC according to the standard [51].

3.2. Effect of Fiber Content on the Physical Properties of BTC.

3.2.1. Effect of Fibers on Density

Effect of Coconut Fibers on Density

(a) 0% Lime

Through the graph in Figure 20 of the evolution of density as a function of the percentage of fibers, a decrease in density when adding fibers is observed. It appears that the least dense BACs are the specimens reinforced with 4.5%; this is due to the percentage of high fibers, and the higher densities are that of the control specimens (0% fibers) due to the absence of fibers; therefore, the reduction rate between these two values is 16.49%.

(b) 12% Lime

The figure below shows the results of the density tests of the fiber composite. Through the graph in Figure 21 of the evolution of density as a function of the percentage of fibers, a decrease in density when adding fibers is observed. It appears that the least dense BACs are the specimens reinforced with 4.5%. This is due to the percentage of high fibers, and the higher densities are that of the control specimens (0% fibers) due to the absence of fibers, so the reduction rate between these two values is 14.439%.

Effect of Palm Nut Fibers on Density

(a) 0% lime

At first glance, Figure 22 shows that there is a reduction in density with increasing fiber content. It is observed that the highest density is that of unreinforced composites (0% fibers), and the lowest density is that of composites reinforced with 4.5% fibers; the reduction rate between these two values is 9.985%.

(b) 12% Lime

The figure below shows the results of the density tests of the fiber composite. Through the graph in Figure 23 of the evolution of density as a function of the percentage of fibers, an increase in density when adding fibers is observed. It appears that the least dense BACs are the specimens reinforced with 4.5%. This is due to the percentage of high fibers, and the higher densities are that of the control specimens (0% fibers) due to the absence of fibers, so the reduction rate between these two values is 11.05%.

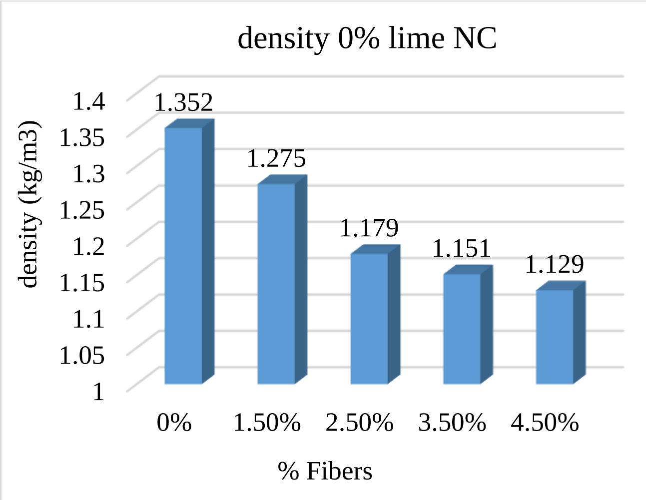


Fig. 20 the evolution of the density at 0% lime NC as a function of the percentage of fiber

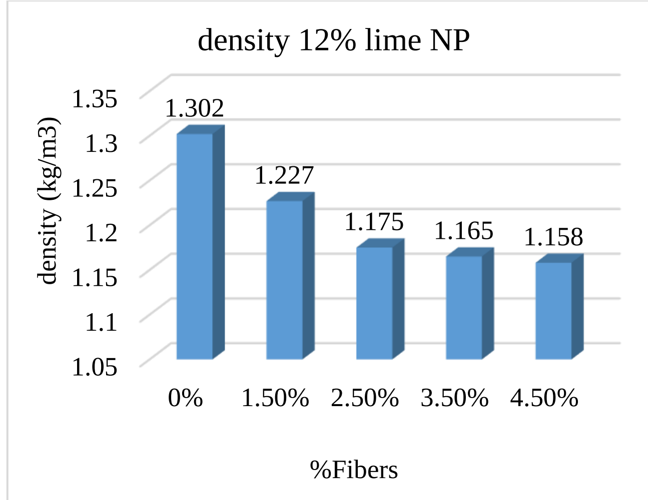


Fig. 23 The evolution of the density at 12% lime NP as a function of the percentage of fibers

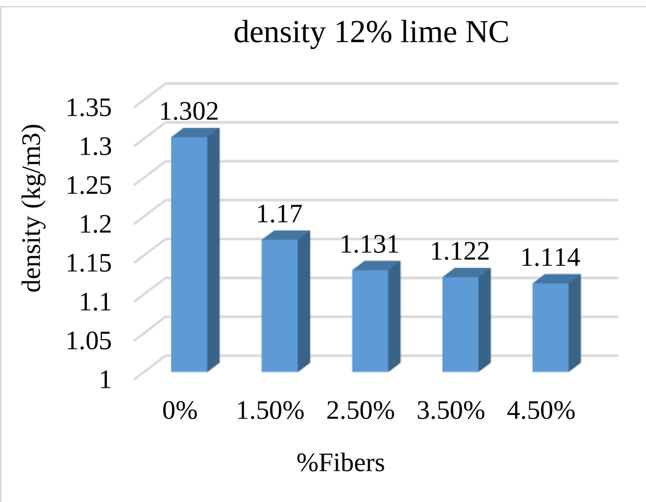


Fig. 21 The evolution of the density at 12% lime NC as a function of the percentage of fibers

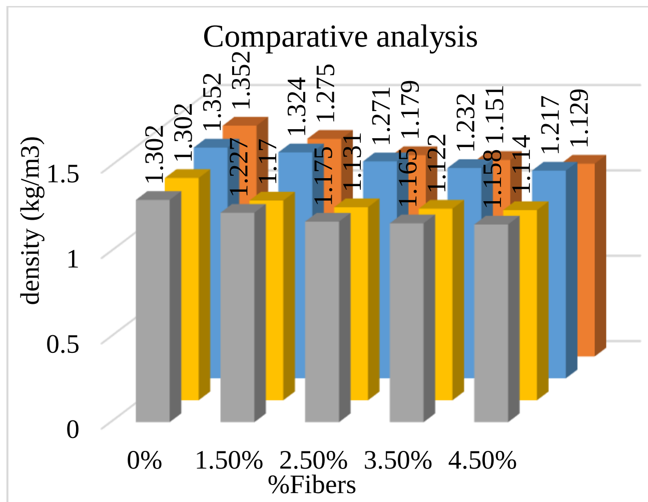


Fig. 24 Comparisons of different densities depending on the percentage of fibers

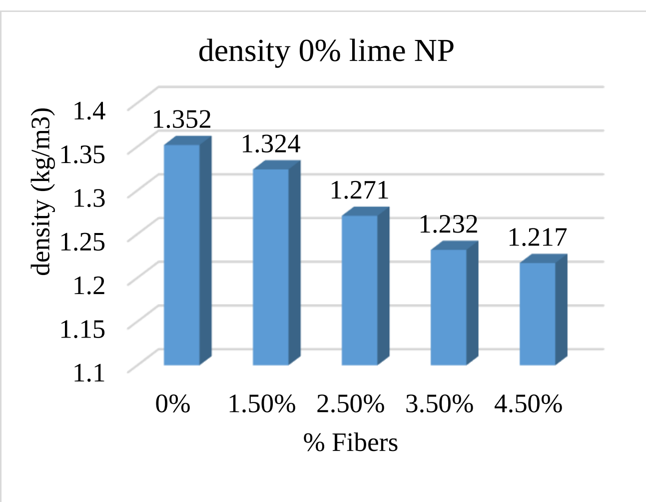


Fig. 22 The evolution of the density at 0% lime NP as a function of the percentage of fiber.

Table 10. Different densities depending on the percentage of fibers.

	0%	**1,5%**	**2,5%**	**3,5%**	**4,5%**
NP+12%CH	1,302	1,227	1,175	1,165	1,158
NC+12%CH	1,302	1,17	1,131	1,122	1,114
NP+0%CH	1,352	1,324	1,271	1,232	1,217
NC+0%CH	1,352	1,275	1,179	1,151	1,129

Comparative Study

It can be seen that the relative error between these different densities is small in view of Figure 24 above; moreover, the composite has coconut fiber at a higher density than composites with palm nut fiber at a maximum rate of 10%. The density was observed to decrease as the amount of fibers increased and produced lightweight composites. Lightweight composite offers an advantage in terms of handling and transportation costs because it is lighter than normal composite [51, 34].

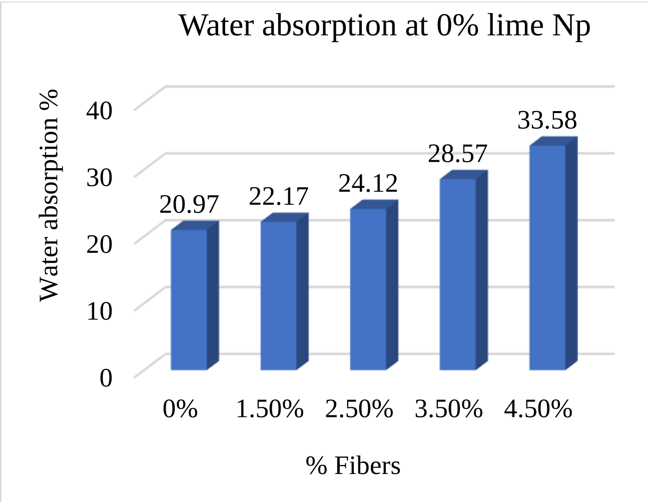


Fig. 25 The evolution of total absorption as a function of the incorporation of NP fibers

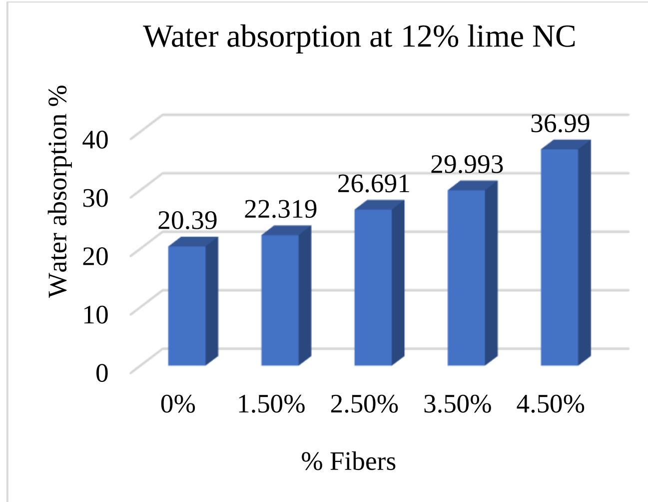


Fig. 28 Change in total absorption at 12% lime depending on the incorporation of coconut fibers

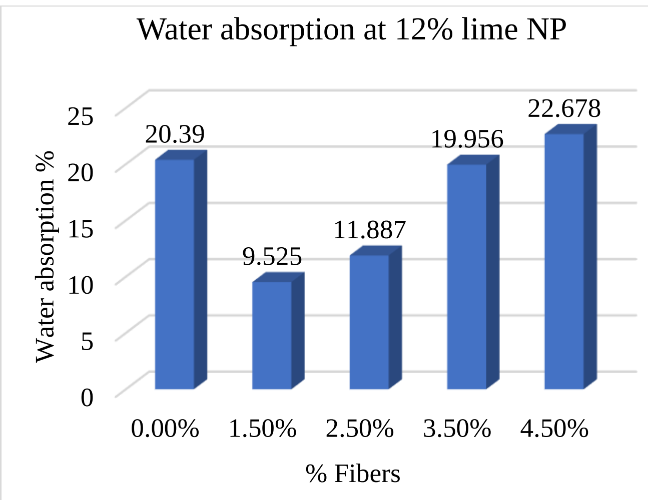


Fig. 26 change in total absorption at 12% lime depending on the incorporation of palm fibers.

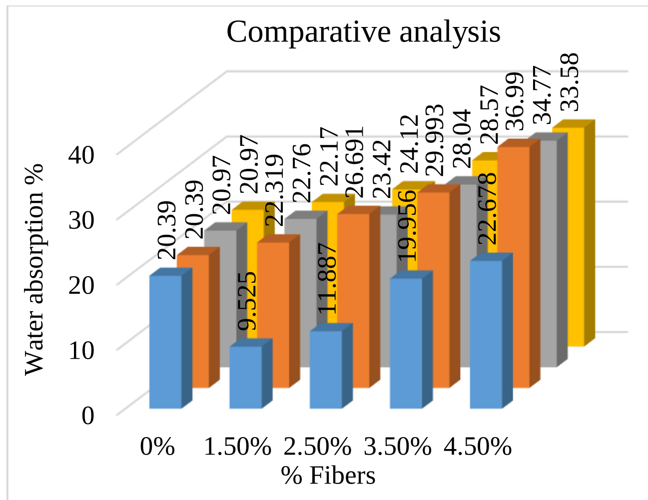


Fig. 29 Comparisons of different total absorption values as a function of fiber percentage

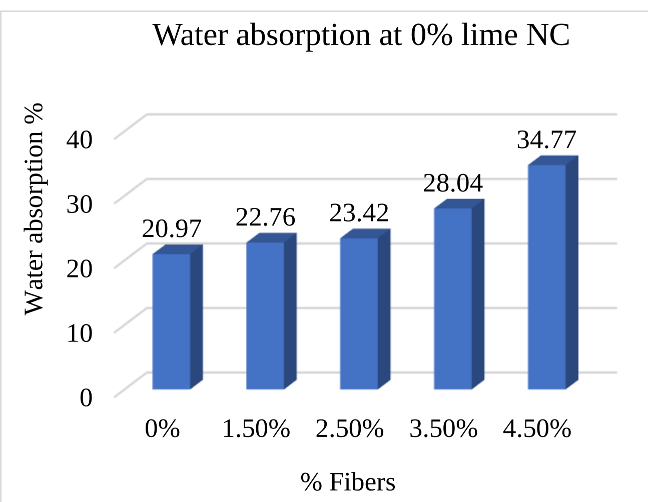


Fig. 27 Change in total absorption depending on the incorporation of coconut fibers

Table 11. Different total absorption values as a function of fiber percentage

	0%	**1,5%**	**2,5%**	**3,5%**	**4,5%**
NP+12%CH	20,39	9,525	11,887	19,956	22,678
NC+12%CH	20,39	22,319	26,691	29,993	36,99
NC+0%CH	20,97	22,76	23,42	28,04	34,77
NP+0%CH	20,97	22,17	24,12	28,57	33,58

3.2.2. Effect of Fiber on Water Absorption Rate

Effect of Palm Nut Fibers on Water Absorption Rate
(a) 0% Lime

Figure 25 shows the variation in the water absorption rate as a function of the fiber content of these composites. There is a gradual increase in this rate. The results show that adding fiber to the mixtures slightly increases the total water absorption, meaning there is more water infiltration into 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 variation between the smallest value obtained at 0% fiber and the largest value obtained at 4.5% fiber is 33.58%. This increase is due to the fact that palm nut fiber is vegetable, but also to its porosity rate, which varies depending on the size of the fiber.

(b) 12% Lime

Figure 26 shows the evolution of the total absorption value as a function of the fibre content of palm nuts. There is an increase in the value of total absorption and the percentage of fiber, where the higher the percentage of fiber, the greater the amount of absorption. It is also noted that the highest total absorption value is for specimens with 4.5% fibers that reach 22.678%, unlike fibers with a percentage of 1.5%, which gives the lowest value.

Effect of Coconut Fiber on Absorption Rate

(a) 0% Lime

Figure 27 shows the variation in the water absorption rate as a function of the fiber content of these composites. There is a gradual increase in this rate. The results show that adding fiber to the mixtures slightly increases the total water absorption, meaning there is more water infiltration into 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 variation between the smallest value obtained at 0% fiber and the largest value obtained at 4.5% fiber is 34.77%. This increase is due to the fact that coconut fiber is vegetable, but also to its porosity rate, which varies depending on the size of the fiber.

(b) 12% Lime

Through Figure 28 shows the evolution of the total absorption value depending on the content of coconut fibers. There is an increase in the value of total absorption and the percentage of fiber, where the higher the percentage of fiber, the greater the amount of absorption. The highest total absorption value is for specimens with 4.5% fibers that reach 36.99%, in contrast to fibers with a percentage of 1.5%, which gives the lowest value.

Comparative Study of Water Absorption Rate

Any material reinforced with plant fibers in its raw state tends to be slightly more absorbent to water, as shown in Figure 29. The water absorbed by the fibers is either in the form of water retained between the interstices of the bundles of microfibrils or it is linked to the surface of the microfibrils. It was found that, for all the fiber contents used, whatever the type of fiber mixed with 12% lime, there was a significant increase in the ATE. This result agrees with that obtained by Millogo et al. (Millogo, 2008) in a study on the properties of lime-stabilized adobe. It is also observed that ATE increases with increasing fiber content. This can be explained by the fact that the fibers have a hydrophilic character, in addition to the presence of more voids with the introduction of more fibers. But BAC reinforced with palm fibers and 12% lime has good properties compared to other formulations.

3.2.3. Swelling

Effect of Fiber on Swelling

The curves shown in Figure 30 illustrate the variation in swelling by immersion of earth mortar specimens as a function of the fiber content and the percentage of lime. Through this figure, the swelling of earthen mortar samples increases with increasing fiber content and different behavior when lime is added. All swelling values vary between 3.11mm/m and 4.694mm/m, representing the lowest and highest swelling values , respectively. While the highest values correspond to mixtures based on coconut fibers with 0% lime. The swelling values of the earth mortar are 10.42%, 22.60%, 40%, and 46.96% for a fiber content respectively of: 1.5%, 2.5%, 3.5% and 4.5%, respectively. For the case of mixtures based on palm nut fibers with 0% lime, the swelling values are 4.57%, 13.90%, 22.60% and 34.78% for a fiber content respectively of 1.5%, 2.5%, 3.5% and 4.5%, For the test pieces based on palm nut fibers with 12% lime the swelling values of the earth mortar are 0, 9%, 3.664%, 9.80% and 16.93% for the fiber content of: 1.5%, 2.5%, 3.5% and 4.5% respectively. For the test pieces based on coconut fibers with 12% lime, the swelling values of the adobe are 6.235%, 8.036%, 17.64% and 24.108% for a fiber content of: 1.5%, 2.5%, 3.5% and 4.5% respectively.

Table 12. The evolution of swelling depending on the incorporation of fibers

	0%	1,50%	2,50%	3,50%	4,50%
NP+12%CH	3,111	3,138	3,225	3,416	3,638
NC+12%CH	3,111	3,305	3,361	3,666	3,861
NP+0%CH	3,194	3,34	3,638	3,916	4,305
NC+0%CH	3,194	3,527	3,916	4,472	4,694

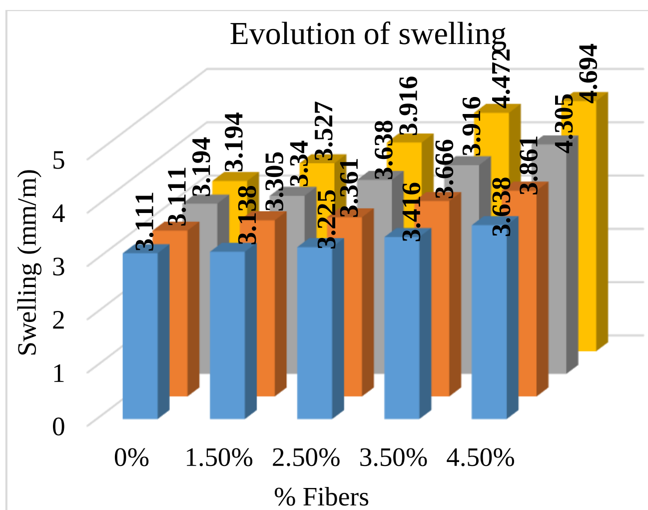


Fig. 30 The evolution of swelling depending on the incorporation of fibers

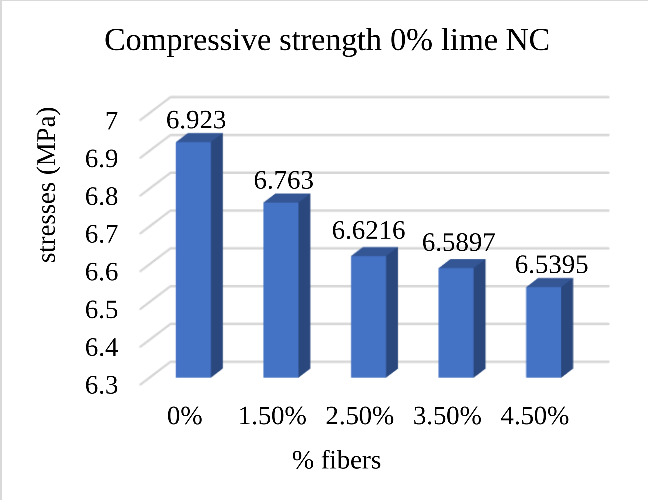


Fig. 31 Compressive strength of coconut fiber at different rates with 0% lime

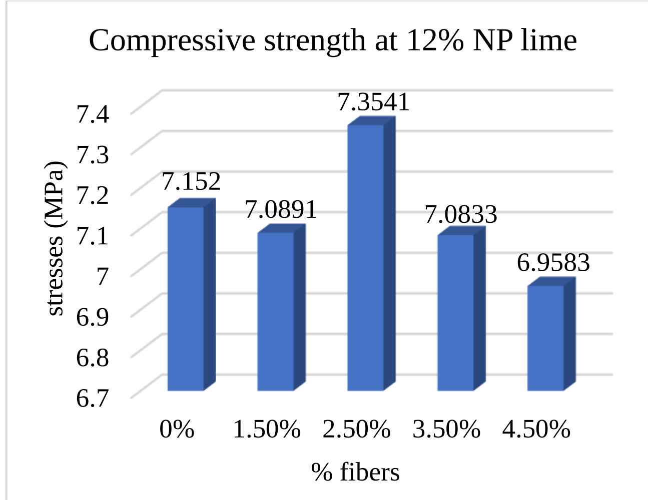


Fig. 34 Compressive strength of palm fiber at different rates with 12% lime

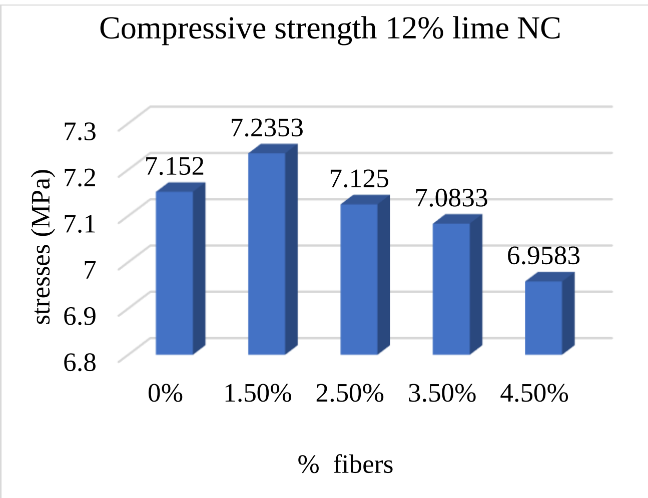


Fig. 32 Compressive strength of coconut fiber at different rates with 12% lime

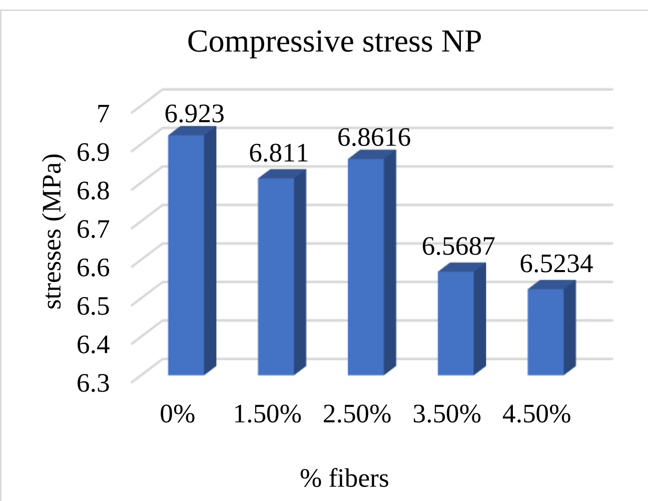


Fig. 33 Compressive strength of palm fiber at different rates with 0% lime

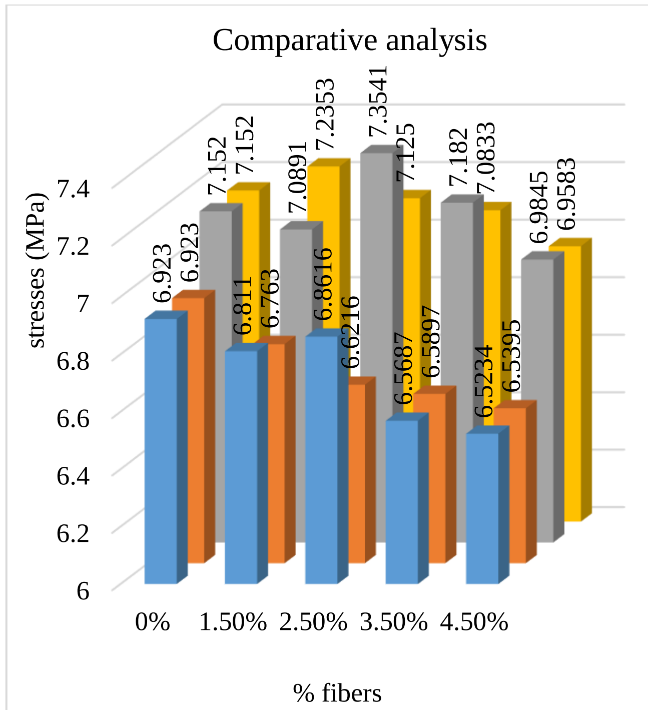


Fig. 35 Comparisons of different compressive strength

Table 13. Comparisons of different compressive strength

	0%	1,50%	2,50%	3,50%	4,50%
NC+0%CH	6,923	6,811	6,861	6,568	6,523
NP+0%CH	6,923	6,763	6,621	6,589	6,539
NP+12%CH	7,152	7,089	7,354	7,182	6,984
NC+12%CH	7,152	7,235	7,125	7,083	6,958

These results are in concordance with those of (Ferhat, 2020) in his study on the effect of fiber type on the properties of adobe. The author concluded that the swelling of bricks increases with the increasing content of fiber.

3.3. Effect of Fiber Content on Compressed Earth Block Properties

3.3.1. Dry Compressive Strength

Reinforcement with Coconut Fiber

(a) With 0% Lime

Figure 31 shows the influence of fibers on the compressive strength of the specimens. Indeed, the lowest resistance for any percentage of addition is obtained on raw clay specimens (without fibers) (6.923MPa) and the greatest value on clay specimens + 0% lime +1.5 % fibers (6.763 MPa). This increase is due to the addition of fibers to the clay and the density of the mixture. In conclusion, the addition of 1.5% coco fiber is the optimal content for better compressive strength of DIBANG clay. This increase in compressive strength has already been observed by other researchers for other plant fibers in the literature [52-54].

(b) 12% Lime

Figure 32 shows the influence of fibers on the compressive strength of the specimens. Indeed, the lowest resistance for any percentage of addition is obtained on the specimens of clay + 12% of lime + 4.5% of fibers) (6.9583 MPa) and the greatest value on the specimens of clay + 12% lime + 1.5% fibers (7.2353 MPa). This increase is due to the addition of fibers to the clay and the density of the mixture. In conclusion, the addition of 1.5% coco fiber is the optimal content for better compressive strength of DIBANG clay. This increase in compressive strength has already been observed by other researchers for other plant fibers in the literature [52-54].

Reinforced with Palm Nut Fiber

(a) 0% Lime

According to the results obtained in Figure 33, the compressive strength of BTC varies between 6.5234 Mpa and 6.923 MPa, which is acceptable for this type of material intended for separation in buildings. Resistance generally increases with the incorporation of plant fibers. It is thus noted that the strength of the BAC with 2.5% fibers obtained the highest compression ratio (6.8616) compared to the others.

This was observed by Danso et al., who used palm fibers and bagasse fibers to reinforce the earth blocks. They found that the compressive strength begins to increase and then it is followed by a decrease [56].

(b) 12% Lime

According to the results obtained in Figure 34, the compressive strength of BTC varies between 6.9583 MPa and 7.3541 MPa, which is acceptable for this type of material, which is intended for separation in buildings. Resistance generally increases with the incorporation of plant fibers.

It is thus noted that the resistance of BTC with 2.5% fibers obtained the highest compression ratio compared to the others. This was observed by Danso et al., who used palm fibers and bagasse fibers to reinforce the earth blocks. They found that the compressive strength begins to increase and then is followed by a decrease [54].

(c) Comparative Study

Figure 35 shows the influence of fibers on the compressive strength of the specimens. Indeed, the lowest resistance for all the mixtures is obtained on the clay specimens with 4.5% fibers and the greatest value on the clay specimens +1.5% fibers+12% lime for the coconut fibers (7.2353Mpa) and (7.3541Mpa) for the clay specimens + 2.5% fibers + 12% lime for the palm nut fibers.

This increase is due to the addition of fibers to the clay and the density of the mixture. In conclusion, the addition of 1.5% coconut fiber and 2.5% palm fiber to 12% lime is the optimal grade for better compressive strength of Dibang clay. This increase in compressive strength has already been observed by other researchers for other plant fibers in the literature [55-57].

The relative error between these different constraints is small according to the diagram above, and it is, therefore, possible to use any constraint in the calculations and have a reliable result. But palm fiber composite has better characteristics.

3.3.2. Resistance to Bending

Reinforced with Coconut Fiber

(a) 0% Lime

The strengths of samples without fibers and with fibers at different contents were determined. The results obtained are presented in the following figure 36. The lowest resistances are obtained with clay without fibers, and the highest is obtained with clay with +2.5% fiber content. In fact, at 2.5% fibers, the bending strength is 5.9842 MPa. The increase in resistance at this content is due to the presence of fibers which act as reinforcements taking up the forces transmitted to the clay. Beyond 2.5%, a reduction in resistance of up to 4.50% is observed.

In conclusion, the addition of 2.5% coco coir is the optimal content for better flexural strength. This improvement in flexural strength by the fibers has already been observed by other researchers for other plant fibers in the literature [53] [58].

(b) 12% Lime

The strengths of samples without fibers and with fibers at different contents were determined. The results obtained are presented in the following Figure 37.

The lowest resistances are obtained with clay without fibers, and the highest is obtained with clay with +4.5% fiber content. In fact, at 4.5% fibers, the bending strength is 3.3375 MPa. The increase in resistance at this content is due to the presence of fibers which act as reinforcements taking up the forces transmitted to the clay. Below 4.5%, a reduction in resistance down to 0% is observed.

In conclusion, the addition of 4.5% coconut fiber is the optimal content for better-bending resistance. This improvement in the bending resistance of the fibers has already been observed by other researchers for other plant fibers in the literature [53] [58].

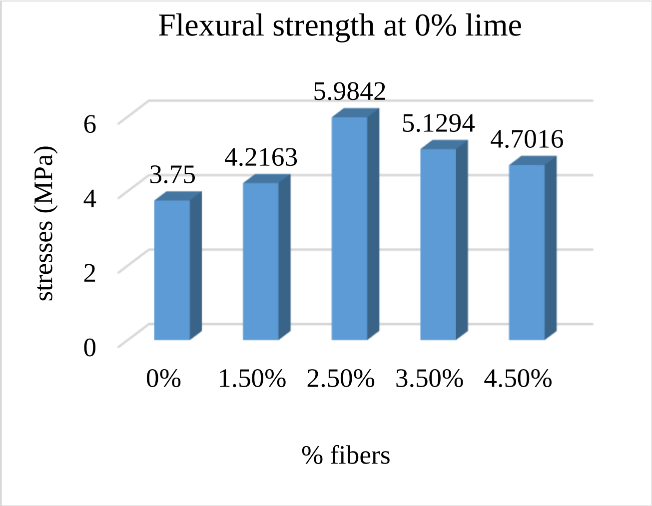


Fig. 36 Flexural strength of coconut fiber at different rates at 0% lime.

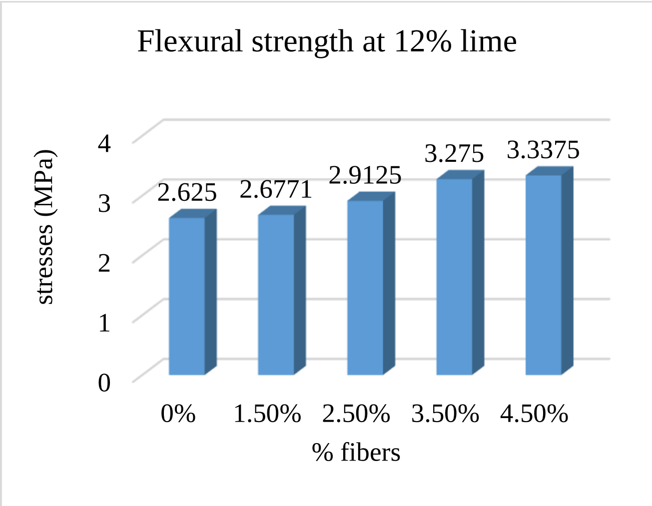


Fig. 37 Flexural strength of coconut fiber at different rates at 12% lime.

Reinforcement with Palm Nut Fiber

(a) 0% Lime

The tensile strength by bending at the three points, BAC, as a function of the different percentages of palm nut fibers is illustrated in the following Figure 38.

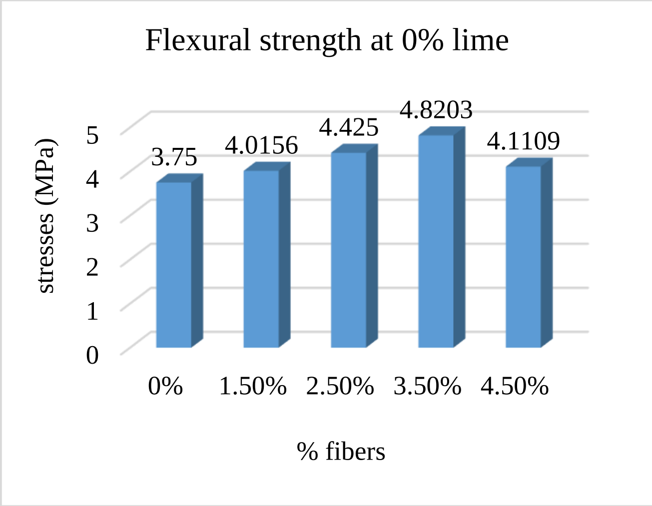


Fig. 38 Flexural strength of palm nut fiber at different rates at 0% lime

Depending on the results obtained, the tensile strength of BTC varies between 3.75 MPa and 4.8203 MPa. This is acceptable for this type of material intended for separation in buildings. The tensile strength increases with the presence of plant fibers compared to earth blocks without fibers. This is due to the good adhesion between the NP fibers and the BTC matrix consisting mainly of clay and lime. This adhesion which is probably due to the nature and morphology of the fibers.

(b) 12% Lime

The tensile strength, by bending at the three points of the BTC as a function of the different percentages of the palm nut fibers, is illustrated in the following Figure 39. According to the results, the tensile strength of BTC varies between 2.625 MPa and 5.8279 MPa. This is acceptable for this type of material intended for separation in buildings. The tensile strength increases with the presence of plant fibers compared to earth blocks without fibers. This is due to the good adhesion between the NP fibers and the BTC matrix consisting mainly of clay and lime. This adhesion is probably due to the nature and morphology of the fibers. In conclusion, the addition of 2.5% palm nut fiber is the optimal content for better flexural strength. This improvement in the bending resistance of the fibers has already been observed by other researchers for other plant fibers in the literature [53] [58].

(c) Comparative Study

Figure 40 shows the influence of fibers on the bending resistance of the specimens. Indeed, the lowest resistance for all mixtures is obtained on raw clay specimens (without fibers). Indeed, the lowest resistance for all the mixtures is obtained on the clay specimens with 1.5% fibers and the greatest value on the clay specimens +2.5% fibers+12% lime for the coconut fibers (5.9842Mpa) and (5.8279Mpa) for the clay specimens + 2.5% fibers + 12% lime for the palm nut fibers. This increase is due to the addition of fibers to the clay and the density of the mixture.

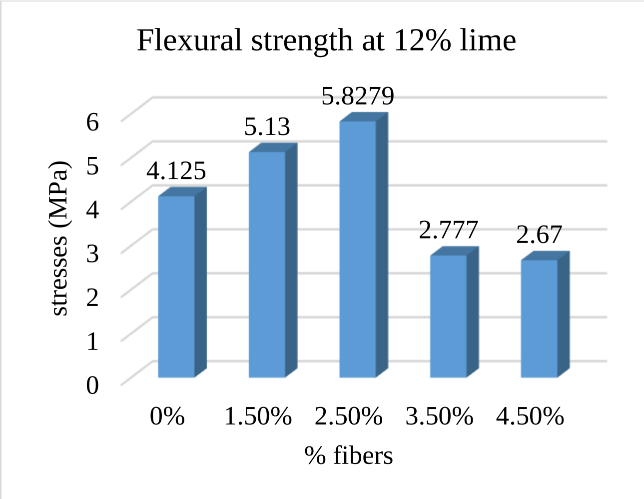


Fig. 39 Flexural strength of palm nut fiber at different rates at 12% lime

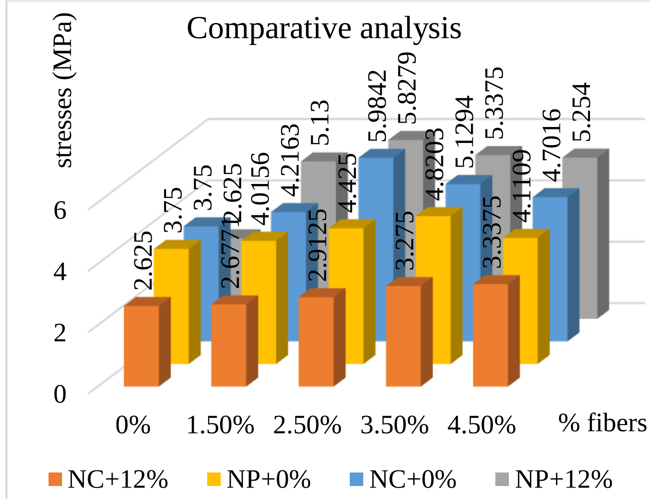


Fig. 40 Comparisons of different bending strength

In conclusion, the addition of 2.5% coconut fibers and palm fibers to 12% lime is the optimal content for better flexural strength of Dibang clay. This increase in bending strength has already been observed by other researchers for other plant fibers in the literature [55-57].

The relative error between these different Young's modules is small according to the diagram above, it is possible to use any Young's modulus in the calculations and have a reliable result. But coir composite has better characteristics.

3.3.3. Resistance to Direct Shear

From the results of the test obtained, it appears that the addition of fibers to the clay increases the shear stress, whatever the content.

Also, the highest shear stress is 224.02kpa, obtained with 2.5% coconut fiber contents at 12% lime.

From Table 15, it appears that the maximum value of cohesion, which is 118.78 KPa, is obtained with the fiber content of 2.5% of palm nut at 12% of lime, which corresponds to the friction angle weaker by a value of 3.784°

Table 14. Comparisons of different Bending Strength

	0%	**1,5%**	**2,5%**	**3,5%**	**4,5%**
NC+12%CH	2,625	2,667	2,912	3,275	3,337
NP+0%CH	3,75	4,015	4,425	4,820	4,11
NC+0%CH	3,75	4,216	5,984	5,129	4,701
NP+12%CH	2,625	5,13	5,827	5,337	5,254

Table 15. Value of cohesion and angle depending on binder content

Fibers	**Lime %**	**Formulation**	**C (KPa)**	***φ*** **(°)**	**Cmax (KPa)**
		Raw clay	26,554	3,827	
Coconut nuts	0% lime	Clay + 1,5 % fibre	26,828	21,62	74,448
		Clay + 2,5 % fibre	74,448	9,954	
		Clay + 3,5 % fibre	32,27	9,146	
		Clay + 4,5 % fibre	32,294	9,436	
Palm nuts		Clay + 1,5 % fibre	49,102	15,971	113,24
		Clay + 2,5 % fibre	113,24	6,096	
		Clay + 3,5 % fibre	47,883	6,164	
		Clay + 4,5 % fibre	33,607	8,553	
		Raw clay	27,864	4,226	
Coconut nuts	12% lime	Clay + 1,5 % fibre	105,84	9,146	105,84
		Clay + 2,5 % fibre	74,218	20,926	
		Clay + 3,5 % fibre	43,209	11,122	
		Clay + 4,5 % fibre	23,121	3,873	
Palm nuts		Clay + 1,5 % fibre	52,374	14,874	118,78
		Clay + 2,5 % fibre	118,78	3,784	
		Clay + 3,5 % fibre	45,313	6,701	
		Clay + 4,5 % fibre	29,578	9,887	

3.4. Discussion

By observing the results obtained, the raw clay bricks with lime based on coconut and palm fibers offer interesting physical and mechanical properties. For bricks without fibers, the cracks are very wide and deep; this shows the fragility of this category of bricks. Since the brick is stabilized with chemical stabilizers (lime), the clay particles are quite difficult to remove. When fibrous reinforcement is added, both types of behaviour are observed at the cracks left. This reflects an improvement in the bonds between the clay fibers and an improvement in the strength between the fibers.

In fact, at these rates, the plant fiber is rationally distributed throughout the brick; the interfaces are well reinforced and, therefore, quite solid. There is, therefore, an increase in inter-fibrous strength and stronger composites. These results suggest that reinforcement with fibers and lime as a stabilizer appear as essential elements in the optimization of formulations, and therefore, fiber and lime contribute to improving the physical and mechanical performance of raw earth bricks.

However, several experimental studies have been carried out in the study of BTC. Mechanical and physical tests were carried out to determine the physicomechanical parameters of the materials in view of the work reported by:

- E.R. Sujatha et al., 2017 showed that the addition of sisal fiber increases the resistance to a certain proportion of clay and modifies the compressibility and permeability of the soil.
- Djohore Ange Christine et al., 2018, studied the mechanical behavior of mortars based on coconut fiber and clay cement. To do this, coconut fibers 30 mm long with different contents (0, 0.2%, 0.4, 0.6%, 1%) were mixed with a quantity of clay; 8% cement was added to the clay-plus fiber mixture. Their study results show that from 0.2 to 0.8% fibers, the mechanical resistance of the material increases beyond 0.8% fibers, and the mechanical properties of the material drop. This decrease is certainly due to the fact that the fibers are no longer all linked to each other by the matrix.
- Abdelmoumen Alla Eddin Driss et al. (2018) studied the effect of lime on the stabilization of the geotechnical properties of clayey soil. This study showed that the maximum dry density of lime-stabilized soils decreases with increasing lime content. On the other hand, the optimal water content of lime-stabilized soils increased with increasing lime content. The increase in unconfined compressive strength is based on the percentage of lime addition and on the increase in the hardening period, which consists of short and long-term reactions.

It is concluded on the one hand that the addition of 2.5% coconut fibers or 1.5% palm nut fibers is the optimal content for better compressive strength of DIBANG clay, and respectively 2.5% is the optimal content for better flexural strength. This increase in mechanical properties has already been observed by other researchers for other plant fibers in the literature (E.R. Sujatha et al., 2017; Djohore Ange Christine et al., 2018; Ludovic Ivan NTOM NKOITO et al., 2020; M T. ADAGBE, 2021).

On the other hand, according to the results found, the water absorption of the samples was inversely proportional to the apparent density. Consequently, the lower the density, the more the quantity of pores increases, allowing a high water flow due to the capillary effect, which leads to a greater water absorption coefficient. Furthermore, it could be generalized that the addition of agricultural waste increases the water absorption rate due to the hydrophilic nature of lignocellulosic fibers [1], [55], [56]. During the research work of G. Djafri and N. Chelouah, the same phenomenon was observed when adding plant fibers to make terracotta bricks; however, the combustion of these generated more pores, which led to a more substantial absorption coefficient. From the values thus obtained from the tests carried out, it appears that the stabilization at 12% of lime of raw clay composites reinforced with coconut fibers and palm nut fibers at a certain optimal rate presents minimal physicomechanical performances in terms of their uses in partitions and increasing the lightness of buildings, and this, therefore, demonstrates the interest in stabilizing earth bricks.

4. Conclusion

This research work focused on the study of the physical and mechanical properties of clay blocks stabilized with 12% lime on the influence of the content of coconut fibers by comparing the characteristics of said materials to those of stabilized clay blocks at 12% lime on the influence of the content of palm nut fibers. The experimental results indicate that the incorporation of coconut fibers improves the mechanical strengths and deformability of clay + lime mortars compared to those of palm nut fibers in terms of three-point bending strength and compressive strength. The latter becomes more and more ductile with the increase in the proportion of fibers. These characteristics are better than those of lime-stabilized BTC without fibers and are optimal for a fiber content varying from 1.5 to 2.5%. Lime-stabilized BTC has better physical characteristics than fiber stabilized ones, so for strong and durable BTC, a study was done on the combination of the two stabilizers with the BTC matrix: coconut fiber - lime and palm nut fiber – lime. The physical characteristics show a reduction in the density of the bricks according to the increase in the percentages of the quantities of fibers and lime; in fact, the density of the clay is greater than that of lime. Ultimately, all the results show that the addition of coconut and palm nut fibers with an optimal rate of lime leads to an improvement in the various physical and mechanical properties of BTC. However, this reveals many perspectives, namely: the influence of the treatment of these fibers before incorporation into the clay soil and as well as the arrangement of the fibers in such mixtures.

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