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Research Article

Effects of Waste Fibers from Calamus Rotang on the Physical and Mechanical Characterizations of Compressed Earth Blocks Manufactured with the Elastic Soil of Western Region of Cameroon

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Abstract

Objective: In order to promote local materials in Cameroon, rattan waste is used to reinforce compressed earth blocks (CEB). The main objective of this work is to study the effect of rattan waste on the physical and mechanical properties of CEB.

Methods: The raw materials, namely the soil sample and rattan waste fibers, are collected in the western region of Cameroon, more precisely in Bangangté. In the laboratory, the soil samples were analyzed; the analyses include the granulometric analysis, the Atterberg limits, and the Proctor test. Different percentages of rattan waste contents were substituted in place of sand, that is, 0%, 2%, 4%, and 6%. These different samples were characterized in the laboratory through different tests, mechanical and physical.

Results: The better mechanical characteristics are obtained for blocks reinforced with 2% rattan waste, with 0.70MPa in three-point bending and 3.04MPa in compression, respectively. Thus, the presence of rattan wastes has a positive effect on the mechanical behavior of the composite by increasing its ductility compared to that of the control block.

Conclusion: The mechanical properties of the compressed soil block (CSB) improve with the incorporation of rattan wastes, which are optimal for a content of 2%. However, they increase the porosity of the material and thus its sensitivity to water, on the contrary to the control CSB.

Keywords: compressed earth block, rattan waste, mechanical characteristics, absorption and porosity, ductility

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1 INTRODUCTION

The current housing situation in Cameroon is not satisfactory, and it is important to to give some the qualitative and quantitative deficits in housing[1]. The constraints on these deficits being largely linked to high construction costs[2], these constraints have constrained Cameroon to direct research towards the valorization of local materials. This is why, a growing return to raw earth construction is necessary. Let us remember that, raw earth is one of the oldest building materials[3], which is still used today in many countries in the world[4] and more precisely in poor and developing countries[5]. Indeed, over the past century, several researchers such as Doat et al.[6], Houben et al.[7]; to name just a few, have carried out work aimed at improving the properties of soils under construction. The use of earth in construction has always been an obvious reality since it is available in abundance and widespread throughout the world. Earth comes from the degradation of the rocky substrate. Its proximity, its maneuverability and its relatively easy implementation require reduced tools, often of peasant origin[8]. It therefore, has both a positive economic impact and a positive ecological issue since it reduces CO_2 emissions and a social and cultural issue because it allows resources to be preserved and enhanced. Raw soils then appear to be serious candidates for construction. A glance at the heritage built in raw earth shows that, it enjoys both historical and cultural richness, which could inspire modern construction.

Worldwide, compressed earth block (CEB) is most widely used in mud construction, although it tends to have a relatively very limited lifespan. CEB suffers from a lack of resistance, systematic cracking due to shrinkage, and faces problems linked to their sensitivity to water[9]. As a result, several means of stabilization have been set up to improve the physical and mechanical properties of compressed soil blocks (CSBs), including the addition of hydraulic binders (cement, lime)[10-12]; the addition of natural fibers (raffia fiber, rattan, coconut) and artificial fibers (carbon fiber) [8,13,14]. Several studies on the physical and mechanical characterization of CSBs with fibers published in recent years justify this work. For example[8], who worked on the physico-mechanical behavior of the compressed earth block with fiber. It has become evident that the presence of fibers has a positive effect on the mechanical behavior of the composite by increasing its ductility compared to the fragile behavior of the matrix alone and the importance of the increase in compaction stress on the properties of CSBs. Similarly, from the work of[15], it emerges that the mechanical properties of CSBs with incorporation of coconut fibers are optimal for a content varying from 5% to 8%, but they increase the porosity of the material, which increases its sensitivity to water, unlike cement-stabilized CSBs. In the past decade, the popularity of eco-friendly plant fibers has been considerably enhanced because of their favorable properties, including cheap and abundant availability, flexibility in handling and usage, low density, comparable mechanical characteristics, high strength-to-weight ratios, etc. There are in the literature several works related the alternatives for the reinforcement of soils through the addition of natural fibers, since these are mainly residues of many agro-industrial processes that abound in developing countries[16]. The more recent works of Humphrey Danso et al. in 2015[17] working on the physical, mechanical, and durability properties of soil building blocks reinforced with natural fibers from agricultural waste proved that the physical, mechanical, and durability properties of the blocks are generally improved, and a recommendation of 0.5% fiber content and high clayey soil was made. More recently, in 2024, André Abanda et al. investigated the effects of oil palm mesocarp fibers on the physical and mechanical properties of expansive soils. They showed that the reinforcement of expansive soil for road subgrade is highly discouraged[18]. From these enumerated works, it is obvious that, little research has yet been done with rattan fiber as a reinforcing element for CSBs. It is in this concern for the preservation and valorization of rattan waste fibers that our work emerges. The main objective of this work is to improve the physico-mechanical properties of raw soil bricks following the addition of rattan plant fiber in order to popularize this process in the manufacture of CSBs in order to solve the problems related to construction costs and environmental preservation.

2 MATERIALS AND METHODS

2.1 Material Soil

The soil used was collected from a site near the town

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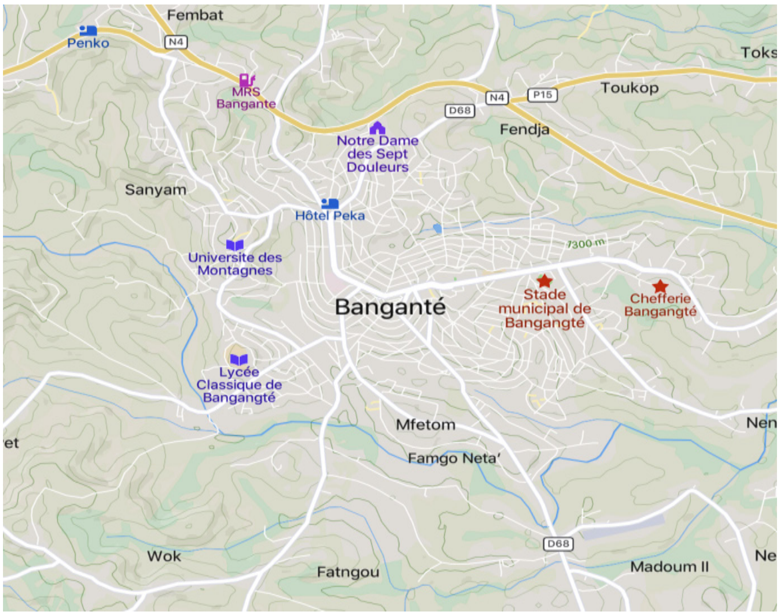

Figure 1. Geographical Location of the City of Bangangté[19].

Figure 2. Lateritic Soil Sample Used.

of Banganté in the West region of Cameroon, whose geographical coordinates are 5°08'29" N latitude and 10°31'18" E longitude, as shown in Figure 1.

On the site, the ground was dug to a depth of 120cm, and the operation was carried out manually using a pickaxe and shovel. The latter was collected and stored in a woven plastic bag for transport to the laboratory. In the laboratory, after drying, the samples were ground into powder using a ball mill for two hours at constant energy. The resulting powdered soil (Figure 2) served as the basic raw material in this study.

2.2 Calamus Rotang (Rottan) Waste Fibers

Rattans are species of thorny climbing palms that belong to the Calamoideae subfamily of the Arecaceae family (see Djomo C et al.[20] and references therein). It is available all over the world, with various species, including Asia-Pacific and Africa Djomo C et al.[20]. The plant waste fibers used are vine rattan, from its scientific name calamus, which is stripped of its leaf sheath as shown in Figure 3. They are pre-cut to a length of 30mm. The diameter of the fibers varies from 3 to 20mm. The fiber waste obtained is presented in Figure 4. They come from the accumulation of calamus rejects that were obtained from a technician at the calamus furniture factory in the city of Douala. The product obtained is cut into reasonable proportions (Figure 4); it has been dried before any use.

2.3 Physical and Mechanical Test Methods

2.3.1 Water Content

Water content involves determining the amount of water (w) in the soil material. It is determined by the standard NF EN ISO 17892-1[21]. The operation mode and the device used are defined in said standard. It is calculated according to the following formula:

$$W(\%) = \frac{(m_h - m_s)}{m_s} \times 100 \quad (1)$$

In which m_h and m_s respectively, represent the wet and dry masses of the samples.

2.3.2 Granulometric Analysis by Sieving

The granulometric analysis test is applied for aggregates with a diameter greater than 125 micrometers; the handling

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Figure 3. Liana-shaped Calamus Stem.

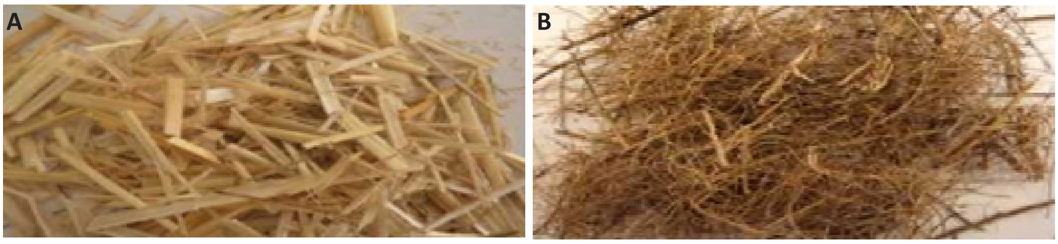

Figure 4. The Fiber Waste Obtained. (A) Calamus Cut into Pieces. (B) Waste Calamus Fibers.

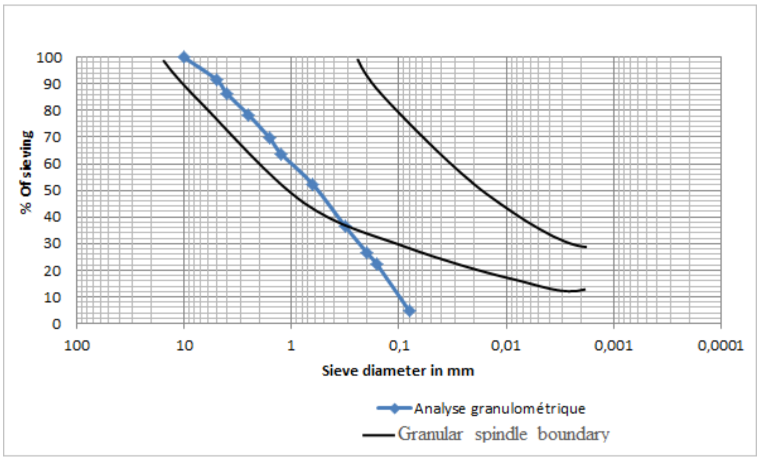

Figure 5. Particle Size Curve By Sieving.

conditions are described by the standard NF EN ISO 17892-4[22]. The soil was analyzed through said standard in the laboratory (Figure 5). The formula for calculating the refusal in percentage is as follows:

$$\text{Refusal}\ (\%) = \frac{M_i}{M} \times 100\ (2)$$

In which mi is the mass of the rejects from the ith sieve and M is the mass obtained after drying the washed sample, while the sieving percentage is given by.

$$\%\text{Sift} = 100 - \%\text{Refusal}\ (3)$$

2.3.3 The Atterberg Limits

Atterberg limits make it possible to determine the water contents corresponding to the transition of a soil from the plastic state to the solid state in accordance with standard NF EN ISO 17892-12[23]. This involves determining the liquidity limits (WL), the plasticity limits (WP), and the plasticity index IP.

2.3.3.1 Liquidity Limits

They allow the determination of the quantity of water required when a soil passes from the liquid state to the plastic state. It gives the minimum percentage of water at which the paste can flow under its own weight.

The soil soaked in water is kneaded with a spatula on a glass plate to obtain a homogenous paste. Place part of it in the cup of the Casagrande apparatus. Mix and then spread the material with a spatula to form a smooth paste 12mm thick from the lower half of the cup.

A groove is then drawn through the center of the mixture in the diametrical plane perpendicular to the axis; With the cup placed on the base, it is subjected to 15 shocks by operating the crank of the Casagrande apparatus. Take a small amount of the paste for the determination of the water content when the central groove is closed by about 1mm; If the intended closure is obtained before the 15 expected shocks, repeat the operation by kneading the paste quite vigorously. The objective is to make the dough lose a little water. If, on the contrary, the closure is obtained after the 15 shocks, the dough is slightly moistened, and the operation is resumed by mixing; With the flow line requiring at least

Table 1. Summary of Atterberg's Limit Standards According to CN 102-114 Standard[24]

Sample	Liquidity limit (%)	Plastic limit (%)	Plasticity index (%)
(NF P94-051)	25-50	20-35	2-30

four points, the water content corresponding to the closure of the central groove is determined for 10, 20, 25, and 30 shocks.

2.3.3.2 Plasticity Limits

WP is used to evaluate the quantity of water for which a soil passes from the plastic state to the solid state. The procedure is as follows.

Take a portion of the mixture and make small rolls on a marble slab until a diameter of 3mm is obtained. The roller is raised 1 or 2cm above the slab; it cracks and breaks, and the samples are taken from each piece to determine the water content, which will be the WP value. The plasticity index is calculated using the following formula.

$$\mathrm{Ip} = \mathrm{WL}{-}\mathrm{WP} \quad (4)$$

The soil results should conform to Table 1. The plasticity of the soil will preferably be recorded in the area of the plasticity diagram[24].

The boundaries of the recommended zones are approximate. In this regard, Cameroonian standard 102 to 114 specifies that it may happen that certain soils that do not fall within the recommended zones for the manufacture of earth blocks still give acceptable results in practice, but that compliant soils give satisfactory results in most cases.

2.3.4 Normal Proctor Test

The normal Proctor test allows, by compacting the material at different water contents, to determine the maximum density reached for a given compaction energy, as well as the corresponding optimal water content in accordance with the AFNOR standard NFP94-093[25].

2.4 Mechanical Characterization of the Material

2.4.1 Formulation and Preparation of Specimens

In the laboratory, the soil was first spread in a thin layer in the open air for 10 days, and then it underwent manual grinding and finally manually sieved using a 1.6mm sieve. The formulation of the material was carried out respecting the clause stipulating that the best mixing conditions are met when the soil is dry[26]. In this case, different mixtures were developed and recorded in the Table 2. For the stabilization of the bricks, we used 1,450g of soil which varied according to the proportions of waste fibers, which are 0%, 2, 4% and 6% of rattan waste fibers, all under the same amount of water.

In this study, we produced blocks measuring 4×4×4 for the compression specimens and 4×4×16 for the bending specimens. To do this, we used the hydraulic compression press under a compressive stress of 2MPa.

Table 2. Composition of Mixtures

Formulation	Soil	Rattan	Water (mL)
CSBR1 0%	100%	0%	450
CSBR2 2%	98%	2%	450
CSBR3 4%	96%	4%	450
CSBR4 6%	94%	6%	450

2.4.2 Three-Point Bending Test

Three-point bending test made it possible to determine the tensile breaking stress by bending the specimens. The bending resistance (σ_f in MPa) is given by the following relationship.

$$\sigma_f = \frac{3}{2} \times \frac{FL}{h^2} \quad (5)$$

In which *F* is the maximum load, *L* the total length of the specimen, and *h* its height.

2.4.3 Compression Test

This test made it possible to determine the nominal resistance to simple compression of the composite material. It was carried out on three test pieces from each formulation. The specimens were subjected to simple compression until crushing using a compression testing press. The compressive strength of the blocks σ_c is determined by the following relationship.

$$\sigma_c = \frac{F}{S} \quad (6)$$

where *F* is the maximum breaking load in kilo Newton and *S* is the average surface of the test faces in cm².

2.4.4 Capillary Absorption Test

After determining their dry mass, the blocks were submerged so that they were 5mm above the water level. After a while, the blocks were removed from the water and wiped with a damp cloth. We then weighed the masses of the wet blocks during the test in grams. Do the same by varying the immersion time of the test pieces. This test was carried out according to the ASTM C 20 standard[27]. The water absorption rate Cb of each block is conventionally expressed by the formula.

$$\mathrm{Cb} = \frac{100 \times (m_h - m_s)}{S\sqrt{t}} \quad (7)$$

where (m_h-m_s) is the mass of water in grams, absorbed by the block during the test. *S* is the surface area of the immersed face, in square centimeter; *t* is the duration of immersion of the block, in minutes.

2.4.5 Density Test

The density test consists of weighing each specimen of each sample and calculating the apparent density. The apparent density in the dry state of the specimen is

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Table 3. Particle Size Analysis by Sieving

Φ Sieve (mm)	Partial refusals (g)	Cumulative refusals (g)	Cumulative refusals (%)	Cumulative sieves (%)
10	0	0	0.00%	100.00%
5	208.42	208.42	8.33%	91.66%
4	130.43	338.85	13.55%	86.44%
2.5	204.24	543.09	21.72%	78.27%
1.6	213.61	756.7	30.26%	69.73%
1.25	149.13	905.83	36.23%	63.76%
0.63	289.82	1195.65	47.82%	52.17%
0.315	395.06	1590.71	63.62%	36.37%
0.2	240.61	1831.32	73.25%	26.74%
0.16	115.27	1946.59	77.86%	22.13%
0.08	437.5	2384.09	95.36%	4.63%
Bottom	86	2470.09	98.80%	1.19%

determined by the following formula (expressed in g/m^3).

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

where M is the mass expressed in kg and V is the volume in m^3.

3 RESULTS AND DISCUSSION

3.1 Characteristics of the Soil

3.1.1 The Water Content

Let us denote by W the natural water content of the material. A wet mass of 450g of earth is taken and placed in the oven; the dry mass of earth leaving the oven is equal to 397.52g. The water content is then W=13.20%.

3.1.2 Particle Size Analysis

The results of the particle size analysis by sieving are presented in Table 3. The results obtained make it possible to draw the particle size analysis curve Figure 5.

The fineness modulus is calculated as follows[28].

$$M_f = \frac{1}{100}\sum \text{cumulatives refusals } (0.16;\ 0.315;\ 1.25;\ 2.5;\ 5) \quad (9)$$

Which gives M_f=2.077. It is obvious that: 1.8<M_f<2.2, leading that the soils consists of fine grains.

The uniformity coefficient is calculated as

$$C_u = \frac{D_{60}}{D_{10}} \quad (10)$$

We obtain C_u=10, which is greater than 3, meaning that we have a varied or spread grain size.

Curvature coefficient:

$$C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}} \quad (11)$$

It is obvious that C_c=0.625<1. We therefore have a poorly classified soil.

By observing the particle size curve shown in Figure 5, we notice that part of the curve at its base leaves the granular zone of the CRA soils and also that the proportion of fine particles is very low. Thus, the soil considered is not one of those recommended for the manufacture of CSB. This result is similar to that of Cissé EM et al.[15], who worked on the characterization of blocks by adding coconut fibers and laterite-cement construction materials and who also used a soil sample taken from the western region of Cameroon. To correct this and improve these characteristics, we can add fibers to our soil to strengthen it for the manufacture of CSB. The fineness module of the soil shows that it is made up of fine sand. Likewise, the coefficient of uniformity and curvature shows us a poorly classified soil with a varied or spread grain size, explaining the absence of a wide variety of diameters.

3.1.3 Atterberg Limits

The results of the plasticity and liquidity tests carried out on the soil sample are summarized in Table 4. The following Figure 6 illustrates the water content versus the logarithm of the number of hits to determine the liquidity limit. The liquid limit is the water content that corresponds to 25 counts on the curve. We were able to obtain the following results as limits.

This plasticity index allows us to classify our soil in the moderately plastic soils according to the laboratoire central des ponts et chaussées (LCPC) classification. And the liquid limit allows us to say that our soil is highly cohesive. These values are higher than those of the author[8], who, working on the study of the physico-mechanical behavior of the compressed earth block with fibers, obtained the respective values of 36%, 23%, and 13%. This divergence of results is explained by the fact that the Atterberg limits make it possible to analyze the variations in consistency of fine soils according to the water content, but in this case the water content is high given the site of soil sampling as well as the

Table 4. Atterberg Limits

Liquidity limit				Plastic limit	
Nomber of stokers	15	20	30		
Tare nomber	01	02	03	01	02
Tare mass (g)	111.4	67.98	111.21	68.16	28.72
Total wet mass (g)	132.16	91.9	132.51	73.5	32.98
Total dry mass (g)	124.87	84.22	125.54	72.15	31.87
Water mass (g)	7.13	8.01	6.84	1.35	1.11
Dry soil mass	13.56	15.90	14.45	3.99	3.15
Water content W (%)	52.54	50.39	47.35	33.83	35.23
Average			50.09		
W_L			48.718		
W_P			34.54		
IP			14.178		

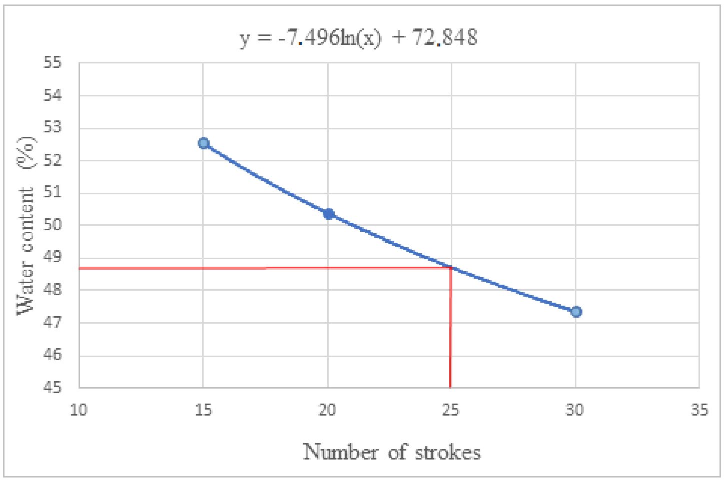

Figure 6. Liquidity Limit Curve.

sampling period (climatic conditions). In addition, these values are well within those of the lands usable for CSB according to the standard NFP94-051[29]. By putting these values in the plasticity diagram according to LCPC, this allows us to situate the soil in the silts and slightly plastic organic soils.

3.1.4 Normal Proctor Test

This test is borrowed from road geotechnics. Indeed, for the construction of rammed earth walls or CSBs, the consistencies of the soils are close to those required for road bodies[30]. The results of the normal Proctor test are recorded in Tables 5-9 and illustrated by the curve of Figure 7 of dry density as a function of water content.

We note that the water content is optimal at the abscissa of the tangent point to the curve, while the dry density is optimal at the ordinate of the tangent point to the curve, i.e., Wopn=31% and ρopn=1.31g/cm^3.

In addition, this optimal water content is higher than the optimal water content recommended for CSBs[5] because the higher this water content, the greater the risk of significant shrinkage during drying and therefore of cracking. Similarly, the optimal dry density obtained is lower than that required for CSBs. However, it is therefore necessary to reinforce our soil. This is what justifies our choice to reinforce the soil with waste fiber in order to obtain better characteristics from the CSBs.

3.2 Characterization of CSB

3.2.1 Point-Bending Test

The bending test was carried out on three specimens per percentage, and the result obtained is the average of the three specimens. Tables 10-12 in the appendix provide information on the results that allowed us to plot the bending stress histogram as a function of the percentage of CSB and the curing time (7, 14, and 28 days) as shown in Figure 8. From this graph, we see that at 0% fiber, the resistance of the CSB increases and reaches the maximum, which is 0.60MPa after 28 days of curing. The same observation is made at 2%, 4%, and 6% of waste rattan fiber, which reach the maximum values of 0.70MPa, 0.64MPa, and 0.62MPa, respectively, after 28 days of curing.

At 7 days, the resistance increases according to the rate

Table 5. Results of the Normal Proctor Test at 10% Water

Water content				Sample		
Tare n°	Dry soil mass (g)	Water content	Volume (cm^3)	Wet soil mass (g)	Wet density (g/cm^3)	Dry density (g/cm^3)
1	119.51	25.65	942.14	1270	1.348	1.0729
2	119.63	25.43	942.14	1270	1.348	1.0748
3	120.67	24.38	942.14	1270	1.348	1.0839

Notes: Average water content=25.15%; Average dry density=1.0772g/cm^3.

Table 6. Results of the Normal Proctor Test at 12% Water

Water Content					Sample	
Tare n°	Water mass (g)	Dry soil mass (g)	Water content	Wet soil mass (g)	Wet density (g/cm^3)	Dry density (g/cm^3)
1	31.44	118.79	26.46	1370	1.454	1.1499
2	31.51	118.63	26.56	1370	1.454	1.1491
3	32.15	117.93	27.26	1370	1.454	1.1428

Notes: Average water content=26.76%; Average dry density=1.1473g/cm^3.

Table 7. Results of the Normal Proctor Test at 14% Water

Water Content					Sample	
Tare n°	Water mass (g)	Dry soil mass (g)	Water content	Wet soil mass (g)	Wet density (g/cm^3)	Dry density (g/cm^3)
1	34.11	115.97	29.41	1570	1.666	1.2878
2	35.05	115.06	30.46	1570	1.666	1.2775
3	34.3	115.93	29.58	1570	1.666	1.2861

Notes: Average water content=29.82%; Average dry density=1.2838g/cm^3.

Table 8. Results of the Normal Proctor Test at 16% Water

Water Content					Sample	
Tare n°	Water mass (g)	Dry soil mass (g)	Water content	Wet soil mass (g)	Wet density (g/cm^3)	Dry density (g/cm^3)
1	35.81	114.41	31.29	1695	1.799	1.3704
2	36.27	113.97	31.82	1695	1.799	1.3649
3	37.05	113.12	32.75	1695	1.799	1.3554

Notes: Average water content=31.95%; Average dry density=1.3636/cm^3.

Table 9. Results of the Normal Proctor Test at 16% Water

Water Content					Sample	
Tare n°	Water mass (g)	Dry soil mass (g)	Water content	Wet soil mass (g)	Wet density (g/cm^3)	Dry density (g/cm^3)
1	37.38	112.64	36.19	1530	1.62	1.2224
2	36.48	113.54	36.13	1530	1.62	1.2351
3	37.19	112.84	36.30	1530	1.62	1.2236

Notes: Average water content=36.20%; Average dry density=1.2270/cm^3.

of waste fiber and reaches the maximum value (0.46Mpa) at 2% and then decreases. Beyond 7 days (14 and 28 days), the same observation is observed: the resistance increases and reaches the respective maximum values (0.66MPa and 0.70MPa) at 2% of waste fiber, then decreases.

In view of the above results, we can say that the CSB with addition of fiber which gives acceptable characteristics in bending is the CSBR2 2% with a maximum resistance in bending of 0.70Mpa and is more useful at maturity (28 days). The decrease in flexural strength after 2% fiber may mean the decrease in the fiber-CSB matrix bond, because the fibers are increasingly numerous and overlap each other[15]. These flexural strength values are significantly higher than those of the author[31] which are respectively 0.1; 0.14; 0.15; 0.16; 0.16; 0.08Mpa for respective fiber contents of 0%; 0.2%; 0.4%; 0.6%; 0.8% and 1%. This difference could be explained either by the difference in fiber used because they do not have the same characteristics, or by the difference in formulation, or by the particle size, or by the fact that this author treated his fibers with a potash solution at a concentration of 8% by mass of potash pellet because the treatment of fibers with basic solutions cleans their surface by degrading amorphous constituents such as:

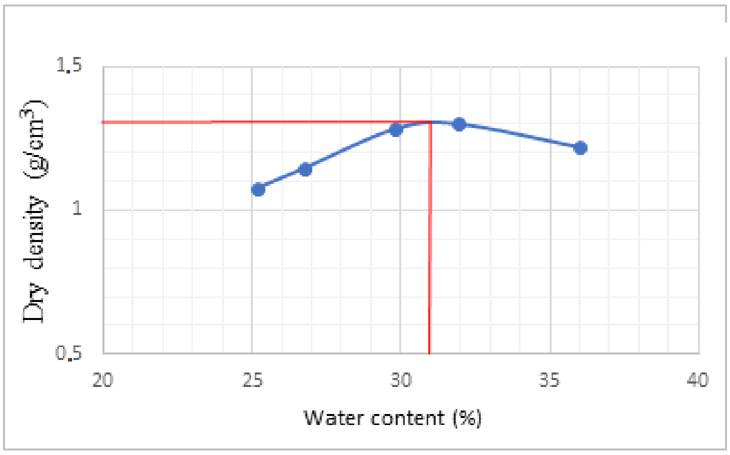

Figure 7. Dry Density Versus Water Content.

Table 10. Summaries of Bending Forces and Stresses at 7 Days

%	F1	F2	F3	Average	Stress
CSBR1 0%	115.236	86.887	110.218	104.1137	0.244016
CSBR2 2%	196.447	234.666	120.571	183.8947	0.461003
CSBR3 4%	354.654	73.644	114.342	180.88	0.423938
CSBR4 6%	100.425	186.639	113.456	133.5067	0.312906

Table 11. Summary of Bending Forces and Stresses at 14 Days

%	F1	F2	F3	Average	Stress
CSBR1 0%	116.603	213.503	226.100	185.402	0.434536
CSBR2 2%	155.363	305.235	393.414	284.6707	0.667197
CSBR3 4%	252.909	197.03	353.685	267.8747	0.627821
CSBR4 6%	208.981	233.852	322.354	255.0623	0.597802

Table 12. Summary of Bending Forces and Stresses at 28 Days

%	F1	F2	F3	Average	Stress
CSBR1 0%	253.878	276.488	241.604	257.3233	0.603102
CSBR2 2%	372.742	369.189	160.854	300.9283	0.705301
CSBR3 4%	215.118	214.149	370.481	266.5827	0.644803
CSBR4 6%	269.059	356.269	172.159	265.829	0.623037

lignins, hemicelluloses, waxes and fats (Malbila E et al.[32]). Thus the addition of 2% rattan fibers improves the bending strength of the CSBs.

3.2.2 Compression Test

The compression test was carried out on the test pieces per percentage, and the result obtained is the average of the three test pieces. Tables 13-15 in the appendix provide information on the results, which allowed us to plot the compressive stress histogram as a function of the rate of CSB and the maturation time (7, 14, and 28 days) as follows.

From the graph in Figure 9, we see that at 0% fiber, the resistance of CSB increases and reaches its maximum, which is 2.10MPa after 28 days of curing. The same observation is made at 2%, 4%, and 6%, which reach the respective maximum values of 3.04MPa, 2.75MPa, and 2.66MPa after 28 days of curing.

At 7 days, the resistance increases according to the fiber rate and reaches its maximum value (2.63Mpa) at 2% fiber and then decreases. The same observation is observed at 14 and 28 days with an increasing increase in resistance according to the fiber rate and reaches its maximum value (2.93Mpa and 3.04Mpa, respectively) at 2% fiber and then decreases.

In view of the above results, we can say that the CSB with added fiber, which gives acceptable characteristics in compression, is the CSBR2 2% with a maximum compressive strength of 3.04Mpa and is more useful at

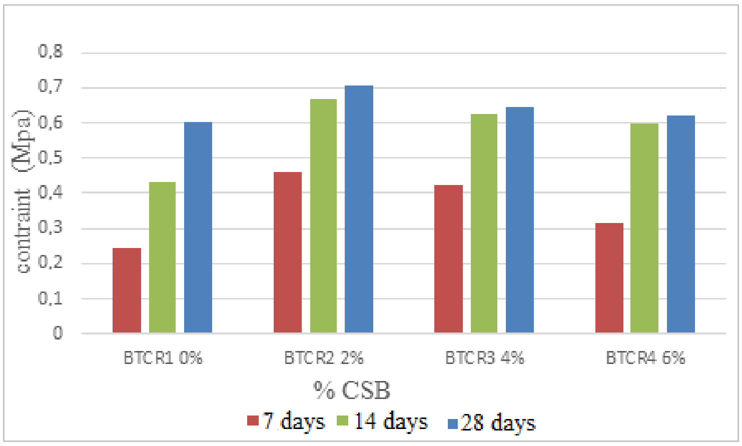

Figure 8. Bending Stress at 7, 14 and 28 Days.

Table 13. Summaries of Compressive Forces and Stresses at 7 Days

%	F1	F2	F3	Average	Stress
CSBR1 0%	3040.065	2859.913	1711.444	2537.141	1.5857129
CSBR2 2%	4143.496	3467.926	3467.926	4218.559	2.6365995
CSBR3 4%	4323.648	2949.989	4211.053	3828.23	2.3926437
CSBR4 6%	2251.9	1959.153	3558.002	2589.685	1.6185531

Table 14. Summaries of Compressive Forces and Stresses at 14 Days

%	F1	F2	F3	Average	Stress
CSBR1 0%	3985.863	2338.268	2210.570	2844.9	1.778063
CSBR2 2%	5697.307	4616.395	3783.192	4698.965	2.936853
CSBR3 4%	3332.812	3625.559	4683.952	3880.774	2.455484
CSBR4 6%	1598.849	3400.369	5156.851	3385.356	2.115848

Table 15. Summary of Compressive Forces and Stresses at 28 Days

%	F1	F2	F3	Average	Stress
CSBR1 0%	3152.66	4661.433	2274.419	3362.837	2.101773
CSBR2 2%	4323.648	5134.332	5179.37	4879.117	3.049448
CSBR3 4%	5382.041	3940.825	3895.787	4406.218	2.753886
CSBR4 6%	4120.977	3895.787	4774.028	4263.597	2.664748

maturity (28 days). In addition, the results shown in NC 102-114[24] on the resistance to compression of normal-facing CSBs are between 2MPa and 6MPa. So, the addition of 2% rattan fiber waste improves the compressive strength of our CSBs and meets the conditions for use in construction. At the end of our mechanical tests, either in bending or compression, we find that the addition of 2% rattan fiber improves the mechanical characteristics of the CSBs.

3.2.3 Density Test at 14 and 28 Days

In order to know the effects of calamus fiber on the physical properties of CSBs, the densities are determined for each test piece at 14 and 28 days, and we listed them in Tables 16 and 17. The following histogram shows us the evolution of the density according to the percentages of CSB and the maturation period.

According to the graph, we see that the density decreases with the increase in rattan fibers; therefore, the more fibers there are, the less dense the material is Abessolo D et al.[33]. We also note that the density decreases with the time of curing; this is explained by the fact that the longer the duration of curing of the CSB increases, the quantity of water it contains decreases, which thus decreases its density over time and in a decreasing way with the increase in rattan fibers. We have the highest density at 0%, which is $2.21 g/m^3$ at 7 days, and the lowest at 6%, which is $1.71 g/m^3$ at 28 days.

3.2.4 Water Absorption Test by Capillary Action

In order to know the water absorption speed of the CSBs, we determined the masses of water absorbed by each test piece at 28 days and listed them in Table 18. The following curve gives us the evolution of the masses of

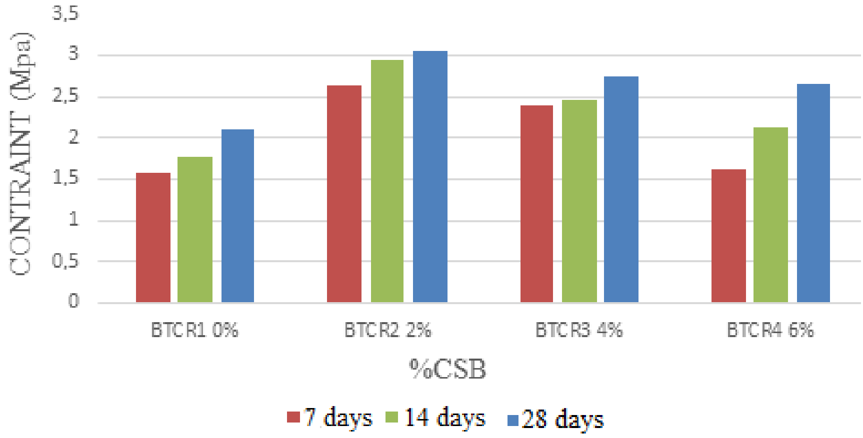

Figure 9. Compressive Stress at 7, 14 and 28 Days.

Table 16. 14-Day Density Summaries

CSB (%)	Mass (g)	Volume (cm^3)	Density (g/cm^3)
CSBR1 0%	567.17	256	2.215507813
CSBR2 2%	563.66	256	2.201796875
CSBR3 4%	536.98	256	2.097578125
CSBR4 6%	525.08	256	2.05109375

Table 17. 28-Day Density Summaries

CSB (%)	Mass (g)	Volume (cm^3)	Density (g/cm^3)
CSBR1 0%	548.26	256	2.141640625
CSBR2 2%	499.97	256	1.953007813
CSBR3 4%	485.28	256	1.895625
CSBR4 6%	440.06	256	1.718984375

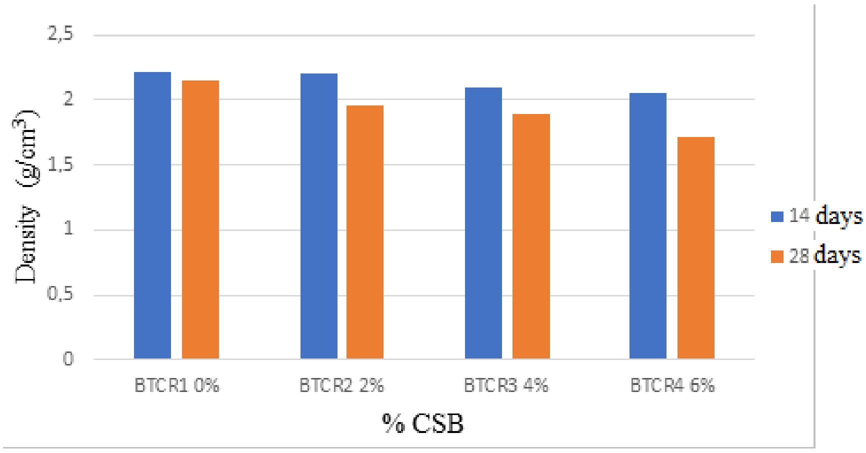

Figure 10. Density of CSB at 14 and 28 Days.

water absorbed by percentage as a function of time.

Regarding the curve of Figure 11, it is obvious that the CSBR1 0% begins with an increasing absorption up to 12s and then becomes constant up to 28s with a constant value of 4.43g and then increases to reach a maximum value of 9.58g after 58s. The same observation is made for CSBR2 2%, which reaches the constant value of 5.9g between 12 and 28s and then increases to reach a maximum value of 10.62g after 58s. As for CSBR3 4%, it begins with a constant absorption of water between 2s and 12s with a value of 2.47g, then increases to reach a maximum value of 12.4g after 60s. For the CSBR4 6%, we observe an increasing absorption up to 12s and then becomes constant up to 28s with a constant value of 5.9g and then increases to reach a maximum value of 13.11g after 58s.

We also note that CSBR1 0% is the CSB that has the minimum mass of water absorbed after 58s of immersion, and CSBR4 6% is the CSB that has the maximum mass of water absorbed after 58s of immersion. These results clearly show that the presence of rattan fibers in earth bricks increases the water absorption rate as the fiber percentage increases. This increase in the water absorption rate may be linked to the fact that the more fibers are added to the CSB, the more interstitial voids are created, promoting water infiltration[15,31]. According to Malbila E et al.[31], which classify CSBs according to their stress and their absorption rate, we observe that for our CSBs, the maximum absorption rate (10.76%) is lower than the absorption rate of 15% for water actions by vertical penetration. Therefore, it is suitable for construction. In general, the less water absorption of a block, the better its mechanical performance[20], which is why CSBR2 2% has the best mechanical characteristics of CSBs. It is also necessary to point out here the importance of the effect of compaction

Table 18. Summary of the Masses of Water Absorbed, at Different Rate of Waste Rattan Fibers, at 28 Days

	Dry mass (g)			
	0%	2%	4%	6%
	257.56	285.61	294.21	304.13
Time (s)	Mass of water absorbed (g)			
2	0.54	1.63	2.41	0.79
4	1.11	2.5	2.41	1.66
6	1.59	3.17	2.44	2.47
8	2.09	3.64	2.45	3.27
10	2.55	4.12	2.46	3.96
12	4.35	5.84	2.47	5.76
14	4.36	5.85	4.11	5.77
16	4.38	5.85	4.38	5.78
18	4.38	5.86	4.68	5.79
20	4.39	5.87	5.07	5.8
22	4.4	5.88	5.36	5.81
24	4.41	5.89	5.77	5.81
26	4.42	5.89	6.06	5.82
28	4.43	5.9	6.42	5.83
30	6.37	5.91	6.99	7.92
32	6.71	7.54	7.47	8.13
34	7.01	7.9	7.62	8.44
36	7.3	8.16	7.89	8.83
38	7.62	8.38	8.18	9.31
40	7.88	8.57	8.45	9.69
42	8.04	8.64	8.75	9.81
44	8.22	8.83	8.88	10.29
46	8.24	9.04	9.19	10.61
48	8.56	9.2	9.39	11.09
50	8.71	9.32	9.67	11.28
52	9.02	9.39	9.86	12.77
54	9.44	9.58	10.09	12.31
56	9.04	9.87	10.4	12.92
58	9.34	9.98	10.62	13.11

stress on water absorption because soil compaction modifies its density, mechanical strength, permeability, and porosity[20].

4 CONCLUSION

In the present work, the physical and mechanical properties of raw earth bricks reinforced with rattan fibers were characterized, with particular attention carried on the improving of the physical and mechanical performances of the CSB, by exploiting local materials: earth taken from the western region of Cameroon, more precisely in the city of Bangangté, and plant fiber, particularly rattan, which constitutes one of the plant riches all over the world. To achieve our objective, we first characterized the soil following some well-known tests in order to determine whether this soil is suitable for use in the manufacture of CSBs. Then, we made different test specimens with different proportions of rattan fiber (0%, 2%, 4%, and 6%). And finally, we carried out mechanical and physical tests. According to the results of the physical characterization of the soil used, one obtained a water content of 13.20%; the granulometric analysis showed that the soil of Bangangté is not rich in very fine elements and has mostly grains with a diameter between 1.6mm and 0.315mm; the Atterberg limits give us a liquidity limit WL=48.718%, a plasticity limit WP=34.54%, and a plasticity index IP=14.178%. These different results on the Atterberg limits show us that our soil was low-plastic organic silt according to the LCPC, and in accordance with the values of WL, WP, and IP, they fell within the standards for CSBs. As for

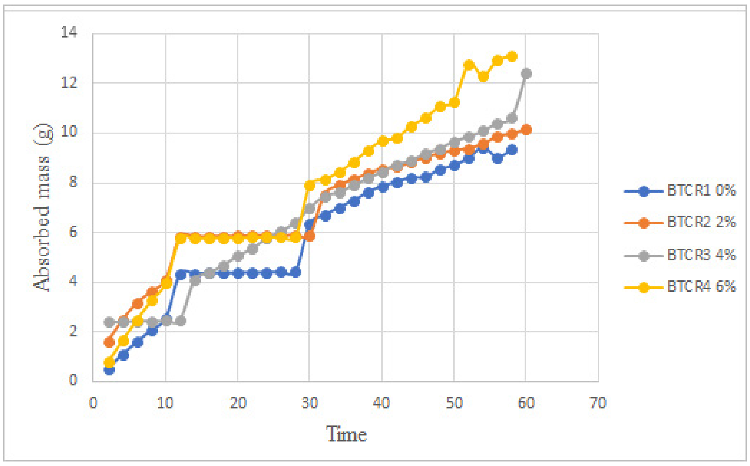

Figure 11. Mass of Water Absorbed as a Function of Time.

the mechanical characterization of CSBs, the mechanical tests showed that rattan fiber improves the flexural and compressive strengths. Both in bending and compression, the CSBs stabilized with 2% calamus fiber have maximum resistances that are 0.70Mpa and 3.04Mpa, respectively. For the water absorption rate, we also note that the more the percentage of fiber increases, the more the CSBs absorb water, with a maximum absorption coefficient of 10.76%, which complies with the standard. According to the density, it decreases with the percentage of fibers. From these obvious results, the addition of rattan fiber in CSBs improves both the mechanical properties of soil bricks and their sensitivity to water. Thus, the presence of rattan fibers in the manufacture of compressed soil bricks is an asset if the selection criterion is its resistance. According to the results obtained through this research and with a view to a future rational and efficient use of these materials. It would therefore be very useful to study further, in the sense of environmental safety, the hydrothermal behavior of CSB with the addition of rattan fibers; complete physical characteristics such as impact resistance, capillary potential, and durability.

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Conflicts of Interest
The authors declared no conflict of interest.

Data Availability
All data generated or analyzed during this study are included in this published article and its supplementary information files.

Author Contribution
Kenmogne F, Bayiha BN, and Ndoukouo AN participated in conducting experiments. Ndombou GB, Ndoukouo AN and Abanda A were involved in data analysis. Kenmogne F, Gouajio MJ and Bayiha BN contributed to the final writing. All authors contributed to the manuscript and approved the final version.

Abbreviation List
CEB, Compressed earth blocks
CSBs, Compressed soil blocks
LCPC, Laboratoire central des ponts et chaussées
WL, Liquidity limits
WP, Plasticity limits

References
[1] Raoul MK. Inequality in the Access to Social Housing in Cameroon: A Decomposition of the Poverty Effect. *J Ekon dan Studi Pembangunan*, 2018; 10: 1.[DOI]
[2] Fernández-de-Córdova G, Moschella P, Fernández-Maldonado AM. Chapter: Changes in Spatial Inequality and Residential Segregation in Metropolitan Lima. In: Urban Socio-Economic Segregation and Income Inequality. Springer Publishing: USA, 2021; 471-490.
[3] Banakinao S, Drovou S, Lolo K et al. Shear Resistance of Siltous Sands Improved with Bridelia Tannins. *Geomaterials*, 2024; 14: 1.[DOI]
[4] Menadi S, Hadidane Y, Benzerara M et al. Optimizing polymer-stabilized raw earth composites with plant fibers reinforcement for historic building rehabilitation. *Buildings*, 2023; 13: 2681.[DOI]
[5] Benzerara M, Guihéneuf S, Belouettar R et al. Combined and synergic effect of algerian natural fibres and biopolymers on the reinforcement of extruded raw earth. *Constr Build Mater*, 2021; 289: 123211.[DOI]
[6] Kouakou L, Kouamé A, Méité N et al. Characterization of Two Clay Raw Materials from Côte d'Ivoire with a View to Enhancing Them in Eco-Construction. *J Min Mater Charact Eng*, 2022; 10: 2.[DOI]

[7] Serlet M. Traité de construction en terre 3rd edition. Editions Parenthèses: Marseille, France, 2006.

[8] Abdelkader F, Mohamed R, Cheikh K et al. Improving The Mechanical and Thermal Behavior of a Compressed Earth Block Using Fibers. *J Eng Sustain Dev*, 2024; 28: 06.[DOI]

[9] Kplolanyo AD, Ouro-Djobo SE, Bollanigni AK et al. Experimental Study of the Physical and Mechanical Behaviour of Mortar Formulations with Fine Sands of Recycled Glass. *Open J Civ Eng*, 2023; 13: 2.[DOI]

[10] Korobko B, Vasyliev L. Test method for rheological behavior of mortar for building work. *Acta Mech Automatica*, 2017; 11: 3.[DOI]

[11] Yomanfo AJ, Jolissaint OSP, Emeruwa E et al. Mechanical Characterization of Rubber Latex-Based Carpets (Hevea bresiliensis): Influence of Rubber Latex Content and Fiber Fabrics (Cotton and Mosquito Nets) on Wear Resistance of Rubber Latex-Based Carpets. *Open J Compos Mater*, 2023; 13: 3.[DOI]

[12] Kouadio LM, Lebouachera SEI, Blanc S et al. Characterization of Clay Materials from Ivory Coast for Their Use as Adsorbents for Wastewater Treatment. *J Min Mater Charact Eng*, 2022; 10: 4.[DOI]

[13] Nouemssi GA, Amine B, Mbozo'O MN et al. Physico-Mechanical Characteristics of Earth Bricks Stabilized with Cement and Padouk Sawdust Residues. *Open J Appl Sci*, 2024; 14: 7.[DOI]

[14] Ahmad J, Arbili MM, Majdi A et al. Performance of concrete reinforced with jute fibers (natural fibers): A review. *J Eng Fiber Fabr*, 2022; 17: 1-17.[DOI]

[15] Fall M, Sarr D, Cissé EM et al. Physico-Mechanical Characterization of Clay and Laterite Bricks Stabilized or Not with Cement. *Open J Civil Eng*, 2021; 11: 1.[DOI]

[16] Medina-Martinez CJ, Sandoval-Herazo LC, Zamora-Castro SA et al. Natural Fibers: An Alternative for the Reinforcement of Expansive Soils. *Sustainability*, 2022; 14: 9275.[DOI]

[17] Danso H, Brett MD, Ali M et al. Physical, mechanical and durability properties of soil building blocks reinforced with natural fibres. *Constr Build Mater*, 2015; 101: 797-809.[DOI]

[18] Abanda A, Ngamie Ndoukouo A, Bahel B et al. Effects of oil palm mesocarp fibres on the physical and mechanical properties of expansive soils. *World J Adv Res Rev*, 2024, 22: 794-811.[DOI]

[19] Djuidje Chatue IA, Nyegue MA, Kamdem SD, Maloba F, Taliy Junaid I, Malhotra P, et al., Association between Epstein-Barr virus reactivation and severe malaria in pregnant women living in a malaria-endemic region of Cameroon. *PLOS Glob Public Health*, 2024; 4: e0003556. [DOI]

[20] Enongene K, Kaam R, Djomo C et al. Spatial distribution of rattan and indigenous perspectives vis-à-vis the growth rate of economically important rattan species in Cameroon: Sustainability and policy implications. *Curr Res Environ Sus*, 2022; 4: 100151.[DOI]

[21] NF (French Standard) EN ISO 17892-1. Geotechnical reconnaissance and testing-Laboratory tests on soils-Part 1: Determination of water content. December, 2014.

[22] NF EN ISO 17892-4. Geotechnical reconnaissance and testing-Laboratory tests on soils-Part 4: Determination of particle size distribution. January, 2018.

[23] NF EN ISO 17892-12. Geotechnical reconnaissance and testing-Part 12: Determination of liquidity and plasticity limits. July, 2018.

[24] CN 102-114. Terminology and Classification of CSB, 2006.

[25] AFNOR. NFP94-093. Soils: Recognition and testing-Determination of the compaction references of a material-Normal Protor test. Modified Protor test, 1999.

[26] Neme SDM, Zogo Tsala SA, Pierre Noah PMA et al. Study of the Phyco-Mechanical Behavior of Raw Clay Bricks from Cameroon Stabilized with Lime Reinforced with Tropical Vegetable Fibers. *Int J Eng Trends Tech*, 2024; 72: 101-120.[DOI]

[27] ASTM International. Standard Test Methods for Apparent Porosity, Water Absorption, Apparent Specific Gravity, and Bulk Density of Burned Refractory Brick and Shapes by Boiling Water. Accessed 8 December 2024. Available at:[Web]

[28] National Standards Authority of Ireland. NFP 18 560: 1990 XP Withdrawn. Aggregates-Granulometric analysis by sieving. Accessed 8 December 2024. Available at:[Web]

[29] Afnor Editions. NFP94-051. Atterberg limits. Accessed 8 December 2024. Available at:[Web]

[30] Abdel-Khadir MS, Mahamat AD, Oumar AA et al. Thermomechanical Characterization of Three Soils of Abeche in Chad. *Open J Civil Eng*, 2024; 14: 3.[DOI]

[31] Djohore CA, Djomo SA, Olivier BM et al. Effet de l'addition de fibres de coco traitées à la potasse sur les propriétés mécaniques des matériaux de construction à base d'argile-ciment. *Eur Sci J*, 2018; 14: 104.[DOI]

[32] Fati Zoma F, Yonli FH, Malbila E et al. Adding Hydrated Lime in a Material Made of Clayey Soil and Fibres: Formulation and Effects on Thermo-Mechanical Properties. *J Miner Mater Charact Eng*, 2020; 8: 3.[DOI]

[33] Abessolo D, Biwole AB, Fokwa D. Effects of the length and content of bamboo fibers on the physic mechanical and hygroscopic properties of compressed soil blocks used in construction Abstract. *Afriques Sci*, 2020; 16: 161-171.