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Article

Physico-mechanical characterization of compressed earth blocks reinforced with waste fibers from calamus rotang: Case of the elastic soil of western region of Cameroon

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Abstract: In order to enhance the value of local materials and contribute to reducing construction costs in Cameroon, rattan waste is used to reinforce compressed earth blocks (CEB). This main work's objective is the study of the effect of rattan waste on the physical and mechanical properties of CEB. For this, a soil sample taken in the western region of Cameroon, more precisely in Bangangté, was analyzed, the analysis includes the granulometric analysis, the Atterberg limits, and the Proctor test. Then the CEB samples with different rattan waste contents, that is 0%, 2%, 4% and 6%, were developed for a compaction stress of 7.5 MPa. These different samples were characterized through mechanical and physical tests carried out in the laboratory. It appears that the blocks reinforced with 2% of rattan waste have better mechanical characteristics, respectively 0.70 MPa in three-point bending and 3.04 MPa in compression. On the other hand, the presence of rattan wastes has a positive effect on the mechanical behavior of the composite, by increasing its ductility compared to the fragile behavior of the control block, which is observed during crushing. Thus the mechanical properties of CEB improve with the incorporation of rattan waste, which is optimal for a content of 2%. But they increase the material's porosity, and then its sensitivity to water unlike the control CEB.

Keywords: compressed soil block; rattan waste; mechanical characteristics; absorption and porosity; ductility; brittle behaviour

1. Introduction

The current housing situation in Cameroon as presented by civil society actors is unsatisfactory and the issue is also very worrying given the qualitative and quantitative deficits in housing [1]. One of the constraints linked to this deficit in terms of housing is largely due to high construction costs [2]. This situation has pushed Cameroon to direct research towards the valorization of local materials with the target of respect for the environment and low-cost construction. Hence a growing return to raw earth construction, raw soil being one of the oldest materials in construction [3]. It is still used today in many countries since it is estimated that 30% of housing is built with raw soil in the world [4] and more precisely 85% in poor and developing countries [5]. Indeed, since a century ago, several researchers like Doat et al in 1979 [6]; Houben et al. [7]; …etc, have carried out work aimed at improving the properties of soils in construction. The use of earth in construction has always been an obvious reality because it is available in abundance and widespread throughout the world because it comes from the degradation of rocky substrate. Its proximity, its maneuverability, and its relatively easy implementation require reduced tools, often of peasant origin [8]. It therefore has a positive economic impact because it reduces construction costs; a positive ecological issue because it reduces CO_2 emissions and a social and cultural issue because it allows us to preserve and enhance our resources. Raw soil then stands out as a serious candidate for construction. A glance at the built heritage in raw earth shows that it enjoys both a historical and cultural richness that could inspire modern construction.

All over the world, the compressed earth block (CEB) is the most used in raw earth construction. However, it tends to have a relatively limited lifespan, and it suffers from a lack of strength, from cracking systematically due to withdrawal, and comes faced with problems related to their sensitivity to water [8]. As a result, several means of stabilization have been set up to improve the physical and mechanical properties of CEBs, including the addition of hydraulic binders, namely cement, and lime [9–11]; the addition of natural fibers (raffia fiber, rattan, coconut) and artificial (the carbon fiber) [8, 12–14]. Several studies on the physical and mechanical characterization of CEBs with fibers published in recent years justify this work. For example, from the works of Taallah B in 2014, [8] 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 CEBs. Similarly, authors Ntom Nkotto et al. [14], showed that the mechanical properties of CEBs with the 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 CEBs. The works of Danso H et al in 2015 [15] 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 were generally improved and a recommendation of 0.5% fiber content and high clayey soil is made. More recently in 2024, Abanda A 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 [16]. From these enumerated works, it is obvious that little research has yet been done on rattan fiber as a reinforcing element for CEBs. 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 a rattan plant fiber in order to popularize this process in the manufacture of compressed soil blocks in order to solve the problems related to construction costs and environmental preservation.

2. Materials and methods

2.1. Presentation of the raw material

2.1.1. Raw material soil

The soil used was taken from a site near Bangangté city in the Western region of Cameroon, whose geographical coordinates are 5°08′29″ North and 10°31′18″ East, as shown in **Figure 1**.

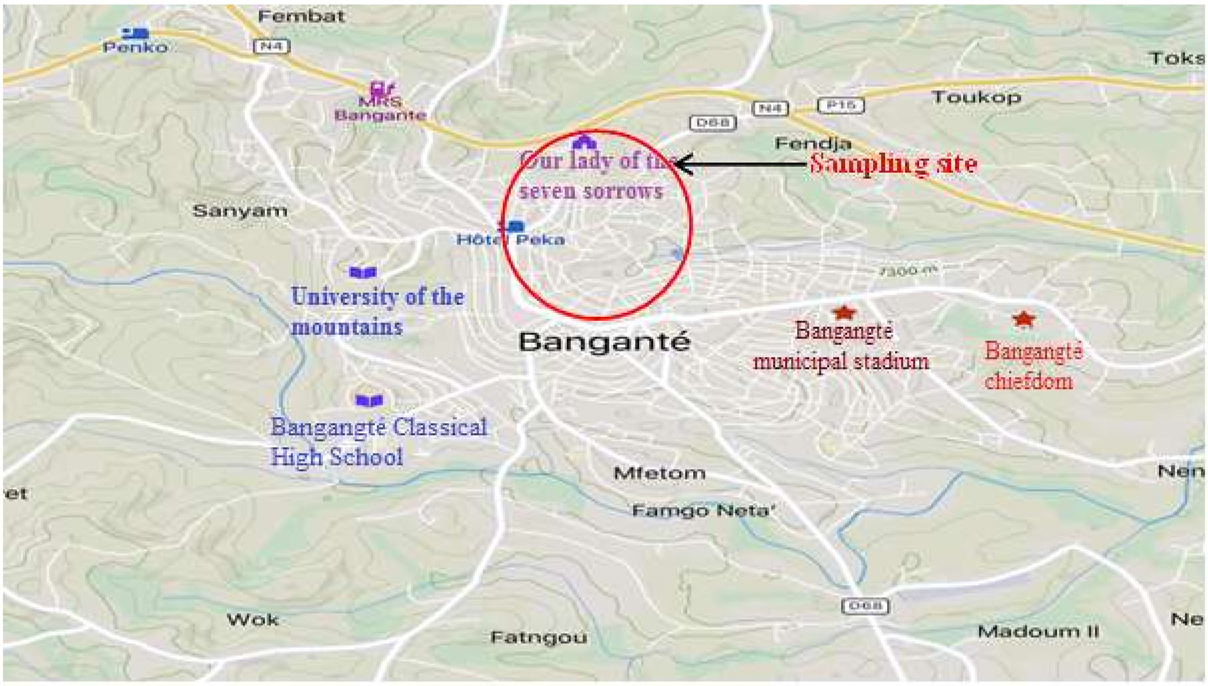

Figure 1. Geographical location of the city of Bangangté [17].

After a descent on the site, the ground was dug to a depth of 120 cm and the operation was carried out manually using a pickaxe and a shovel. The latter was collected and stored in a woven plastic bag to be transported to the laboratory. The first step in the laboratory is the drying process, in order to remove relatively small amounts of residual water thus rendering the soil samples suitable for packaging and storage, and this was done in an oven for 24 h at 105°C. After drying, the samples, as shown in **Figure 2**, were ground into powder using a ball mill for two hours with constant energy. The powdered soil obtained served as the basic raw material in this study.

2.1.2. Calamus rotang (rattan) waste fibers

Rattans are species of spiny climbing palms belonging to the subfamily Calamoideae of Arecaceae family [18]. It is available all over the world, with varying species, particularly in Asia-Pacific and Africa [18]. The plant waste fibers used are rattan vine of its scientific name calamus, which is stripped of its leaf sheath as shown in **Figure 3**. They are pre-cut into a length of 30 mm long. The diameter of the fibers varies from 3 to 20 mm. The waste fibers obtained are presented in **Figure 4**. They come from the cumulative calamus rejects that were obtained from a technician from 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.

Figure 2. Lateritic soil sample used.

Figure 3. Calamus stem in the form of a liana.

Figure 4. (a) Calamus cut into pieces; **(b)** waste calamus fibers.

2.2. Methods for physical and mechanical experiments

2.2.1. Water content by steaming

Water content is the determination of the amount (in percent by weight) of water in the soil material. Commonly used methods for determining soil water content are oven drying weighing, electromagnetic technique, and soil water sensor. The oven drying method is easy to implement and is used here, while 5 samples of the same soil were analyzed, taking into account the standard [19]. The operating mode and the apparatus are defined in the said standard. It is calculated according to the following equation:

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

m_h and m_s represent the wet and dry masses of the sample respectively.

2.2.2. Particle size analysis by sieving

This test is applied for aggregates with a diameter greater than 125 micrometers, the handling conditions being described by the standard [20]. The soil was analyzed through the said standard in the Laboratory (**Figure 5**). The equation for calculating the refusal in percentage is as follows:

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

where M_i is the mass of the sieve rejects of number (i) and M *is* the mass obtained after drying the washed sample, while the percentage of sift is given by.

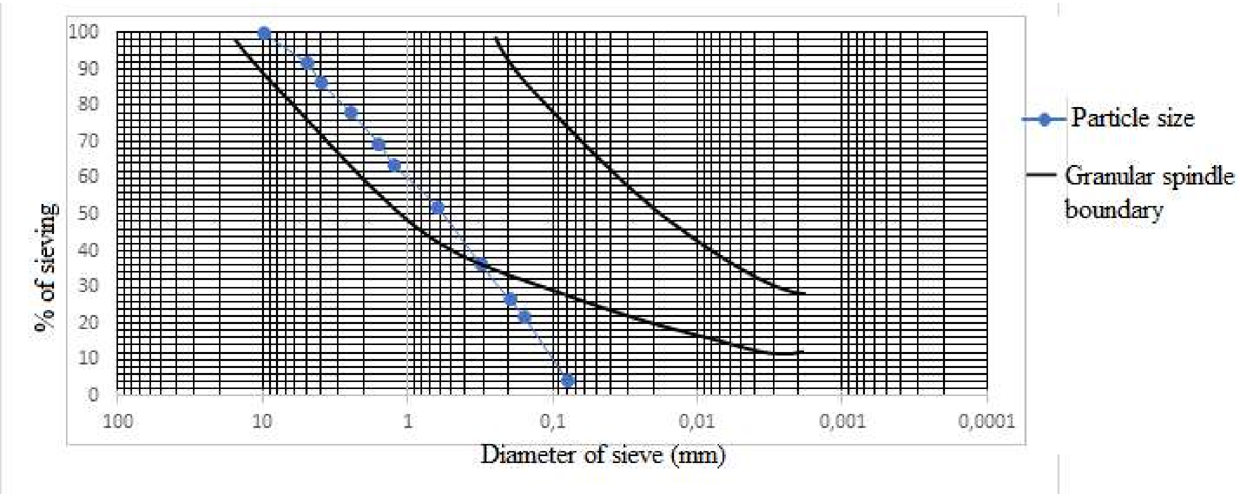

Figure 5. Results of the particle size analysis by sieving.

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

2.2.3. Atterberg limits

Atterberg limits allow the determination of the water contents corresponding to the passage of a soil from the plastic state to the solid state in accordance with the standard [21]. This involves determining the liquidity limits (WL), plasticity limits (WP), and the plasticity index IP.

Liquidity limits (WL)

Liquidity limits allow the determination of the quantity of water required when 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 homogeneous paste. Let's 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 12 mm 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 of the hinge,
- 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 1 mm.

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

Plasticity limits (WP)

The plasticity limit 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 3 mm 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 Ip

is calculated using the following equation

$$\mathrm{Ip} = \mathrm{WL} - \mathrm{WP}, \tag{4}$$

The soil results must be following **Table 1** [22]. The plasticity of the soil will preferably be entered in the zone of the plasticity diagram [22]. The limits of the recommended zones are approximate. In this regard, Cameroonian standard from 102 to 114 specifies that certain soils which do not fall within the recommended zones for the manufacture of earth blocs, still give acceptable results in practice, but that compliant soils give satisfactory results in most cases.

Table 1. Summary of Atterberg limit standards according to [20].

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

2.2.4. Standard proctor test

Standard 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 optimum water content in accordance with the standard [23].

The operating procedure is as follows:

- The material is dried in the open air or in an oven at a maximum of 60 °C,
- The material is then pulverized to destroy the clods,
- 6 samples of 2.5 kg each are prepared,
- A percentage of wetting water is added to each sample. The water is spread like rain so as to obtain uniform humidification of the mixture,
- The material is carefully mixed to homogenize it, this mixing is done by hand in a tank,
- Introduce the material into the Proctor mold in 3 successive layers and compact it equally slowly at 25 strokes per layer,

- Remove the rise from the mold and level,
- Then weigh the whole,
- Then take 3 samples, one on top, one in the middle, and the last at the base of the mold,
- Then weigh these samples and introduce them into the oven at 105 °C and determine the water content,
- Do the same for all the other samples by varying the water content.

2.3. Mechanical characterization of the material

2.3.1. Formulation and preparation of test specimens

Once in the laboratory, the soil was first spread in a thin layer in the open air for 10 days, then it underwent manual grinding and finally sieved manually using a 1.6mm sieve.

The formulation of the material was carried out while respecting the clause stipulating that the best mixing conditions are met when the soil is dry [24]. In this case, different mixtures were developed and recorded in **Table 2**. For the stabilization of the bricks, 1450 g of soil is used and is varied according to the volume proportions of waste fibers, which are 0%, 2, 4%, and 6% of rattan waste fiber, all under the same quantity of water.

Table 2. Composition of the mixtures.

Formulation	Soil	Volume proportions of Rattan	Water (Ml)
CEBR1 0%	100%	0%	450
CEBR2 2%	98%	2%	450
CEBR3 4%	96%	4%	450
CEBR4 6%	94%	6%	450

In this study, we made blocks of dimensions $4 \times 4 \times 4$ cm^3 for the compression test specimens and $4 \times 4 \times 16$ cm^3 for the bending test specimens. To do this, we used the hydraulic compression press under a compressive stress of 2 MPa.

2.3.2. Three-point bending test

Three-point bending test made it possible to determine the tensile breaking stress by bending of the $4 \times 4 \times 4$ cm^3 test specimens. The bending strength (σ_f in MPa) is given by the following relation:

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

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

2.3.3. Compression test

Compression test was used to determine the nominal resistance to simple compression of the composite material. It was carried out on the three $4 \times 4 \times 4$ cm^3 specimens resulting from each formulation. The specimens were subjected to simple compression until crushing using a compression test press. The compressive strength of the blocks σ_c is determined by the following relationship:

$$\sigma_c = \frac{F}{S} \tag{6}$$

where F is the maximum breaking load in kilo Newton, and S the average surface area of the block test faces in cm^2.

2.3.4. Capillary absorption test

After determining their dry mass, the blocks were immersed so that they were 5mm above the water level. After a certain amount of time, the blocks were removed from the water and wiped with a damp cloth. We then weighed the wet block masses during the test in grams. Do the same while varying the immersion time of the test pieces.), this test was carried out according to the standard [25]. The water absorption rate C_b of each block is conventionally expressed by the equation:

$$Cb = \frac{100\times(m_h - m_s)}{s\sqrt{t}}, \tag{7}$$

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 block, the immersed face, in square centimeter; t is the duration of immersion of the block, in minutes.

2.3.5. 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 determined by the following equation (expressed in g/m^3):

$$\rho = \frac{M}{V} \tag{8}$$

With M the mass in kg and V the volume in m^3.

3. Results and discussion

3.1. The soil

3.1.1. Water content

Let W be the natural water content of the material. A wet mass of 450 g of soil is taken and placed in the oven, the dry mass of the soil at the exit of the oven is equal to 397.52 g. The water content is then: $W = 13.20\%$.

3.1.2. The particle size analysis by sieving

The results of the particle size analysis by sieving are presented in **Table A1** (in the appendix).

The results obtained allow plotting the curve of the particle size analysis **Figure 6**:

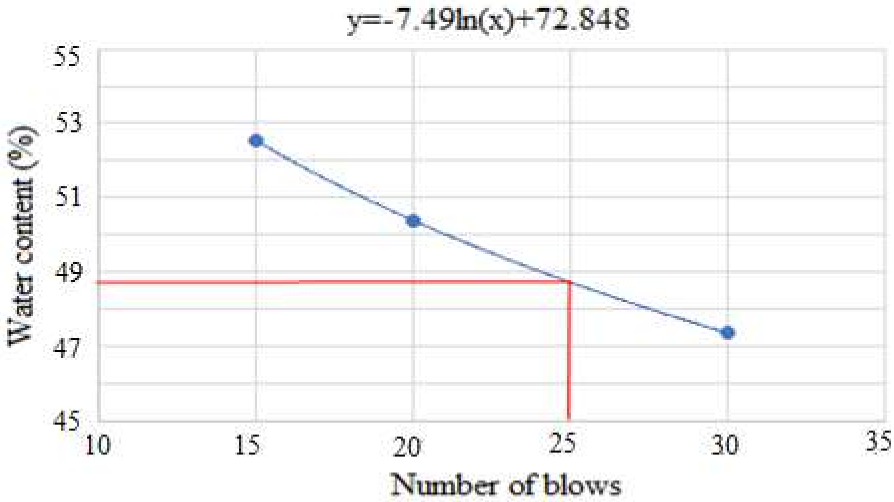

Figure 6. Water content (%) as a function of the logarithm of the number of blows, according to results of **Table A2** in the appendix, given the liquid limit.

Fineness module

It is calculated as follows:

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

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

Uniformity coefficient

$$C_u = \frac{D_{60}}{D_{10}} \tag{10}$$

Cu = 10 > 3 varied or spread grain size

Coefficient of curvature

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

$C_c = 0.625 < 1$ poorly graded soil

By observing the following granulometric curve one notices that a part of the curve at its base comes out of the granular zone of CRA earth and also that the proportion of fine particles is very low. So, the soil under consideration is not among those recommended for the manufacture of CEBs. This result is similar to that of Ntom Nkotto et al [14] who worked on the characterization of blocks by adding coconut fibers and laterite-cement building materials, who also used a soil sample taken in the western region of Cameroon. To correct this and improve these characteristics, we can add fibers to our soil in order to strengthen it for the manufacture of the CEB.

The fineness modulus of the soil shows that it is made up of fine sand. Similarly, the coefficient of uniformity and curvature shows us a poorly graded soil with varied or spread granulometry explaining the absence of a large 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 A2** (in the appendix). **Figure 6** illustrates the water content as a function of the logarithm of the number of blows for determining the liquidity limit.

The liquid limit is the water content that corresponds to 25 counts on the curve. We were able to obtain the results of **Table 3** as limits.

Table 3. Values of the Atterberg limits.

Sample	Liquidity limit (%)	Plasticity limit (%)	Plasticity index (%)
Lat B	48.718	34.54	14.178

This plasticity index allows us to classify our soil as moderately plastic soils according to the unified soil classification system (USCS). 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 sampling period (climatic conditions). In addition, these values are well within those of the lands usable for CEB according to the standard [26] (see **Table 1**). Putting these values in the plasticity diagram according to USCS, allows us to situate the soil in the silts and slightly plastic organic soils.

3.1.4 Standard proctor test

This test is borrowed from road geotechnics. Indeed, for the construction of rammed earth walls or CEBs, the consistencies of the soils are close to those required for road bodies [27]. The results of the standard proctor test are recorded in **Tables A3–A7** in the appendix and illustrated by the curve of **Figure 7** of dry density as a function of water content.

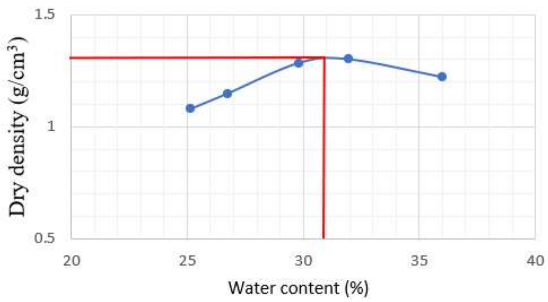

Figure 7. Dry density as a function of water content.

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.: W_{opn} = 31% and ρ_{opn} = 1.31 g/cm^3.

In addition, this optimal water content is higher than the optimal value recommended for CEBs (see ref [5]) because with higher water content, there is a risk of significant shrinkage during drying and therefore of cracking. Similarly, the optimal dry density obtained is lower than that required for CEBs. 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 CEBs.

3.2. Characterization of CEB

3.2.1. Mechanical Characterization

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 A8–A10** in the appendix provide information on the results that allowed us to plot the bending stress histogram as a function of the percentage of CEB 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 CEB increases and reaches the maximum which is 0.60 MPa after 28 days of curing. The same observation is made at 2%, 4%, and 6% of waste rattan fiber which reaches the maximum values of 0.70 MPa, 0.64 MPa and 0.62 MPa, respectively after 28 days of curing.

At 7 days, the resistance increases according to the rate of waste fiber and reaches the maximum value (0.46 MPa) 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 (0.66 MPa and 0.70 MPa) at 2% of waste fiber then decreases.

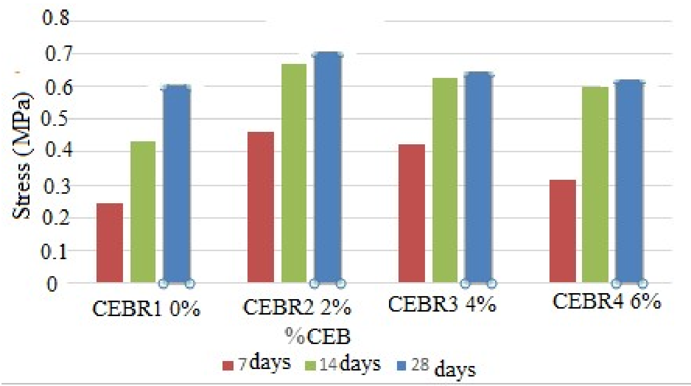

Figure 8. Bending stress at 7, 14, and 28 days.

Given the above results, we can say that the CEB with the addition of fiber which gives acceptable characteristics in bending is the CEBR2 2% with a maximum resistance in bending of 0.70 MPa and is more useful at maturity (28 days). The decrease in flexural strength after 2% fiber may mean the decrease in the fiber-CEB matrix bond because the fibers are increasingly numerous and overlap each other [14]. These flexural strength values are significantly higher than those of the author Djohore [28] which are respectively 0.1; 0.14; 0.15; 0.16; 0.16; and 0.08 MPa 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 lignins, hemicelluloses, waxes and fats [29,30]. Thus, the addition of 2% rattan fibers improves the bending strength of the CEBs.

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 A11–A13** in the appendix provide information on the results which allowed us to plot the compressive stress histogram as a function of the rate of CEB and the maturation time (7, 14 and 28 days) as given in **Figure 9**:

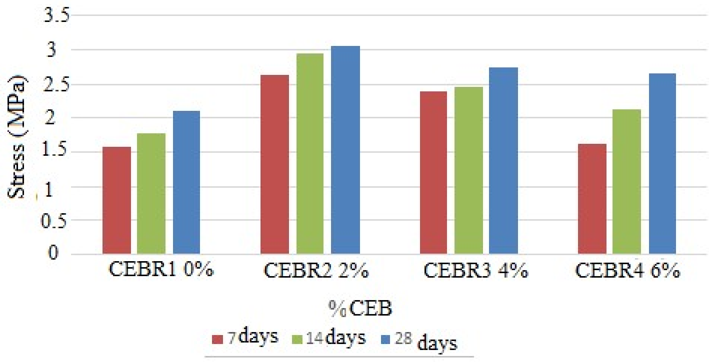

Figure 9. Compressive stress at 7, 14, and 28 days.

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

At 7 days, the resistance increases according to the fiber rate and reaches its maximum value (2.63 MPa) 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 (2.93 MPa and 3.04 MPa respectively) at 2% fiber and then decreases.

Discussion

Because of the above results, we can say that the CEB with added fiber which gives acceptable characteristics in compression is the CEBR2 at 2% of fiber addition, with a maximum compressive strength of 3.04 MPa and is more useful at maturity (28 days); this is the relevant age for exploitation for the manufacture of earth blocks for construction. In addition, the results shown in [31] on the resistance to compression of standard-facing CEBs are between 2–6 MPa. So, the addition of 2% rattan fiber waste improves the compressive strength of the CEBs and meets the conditions for use in construction. It should be noted that the slightest resistance during the initial maintenance period does not limit the use of this material in terms of the construction process or operation of the building. What can limit the use of this material, its availability and the decrease in stress observed in **Figures 9** and **10** after 2%.

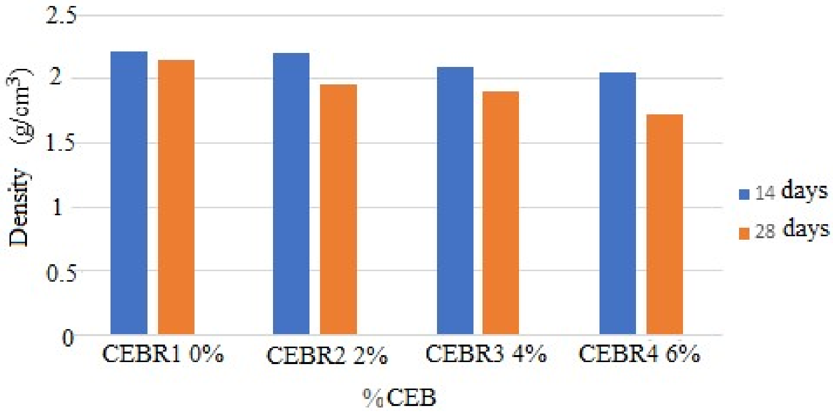

Figure 10. Density of CEB at 14 and 28 days.

Density test at 14 and 28 days

In order to know the effects of calamus fiber on the physical properties of CEBs, the densities are determined for each test piece at 14 and 28 days and we listed them in **Tables A14** and **A15**. The following histogram of **Figure 10** shows the evolution of the density according to the percentages of CEB and the maturation period.

According to this graph, we see that the density drops with the addition of fibers, this is a result of the difference in density between the fibers and the soil; therefore, the more fibers there are, the less dense the material is [32]. We also note that the density decreases with the time of curing this is explained by the fact that the more the duration of curing of the CEB 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/cm^3 at 14 days and the lowest at 6% which is 1.71 g/cm^3 at 28 days.

3.2.2. Water absorption test by capillary action

In order to know the water absorption speed of the CEBs, we determined the masses of water absorbed by each test piece at 28 days and we listed them in **Table A16**. The curve of **Figure 11** gives the evolution of the masses of water absorbed by percentage as a function of time:

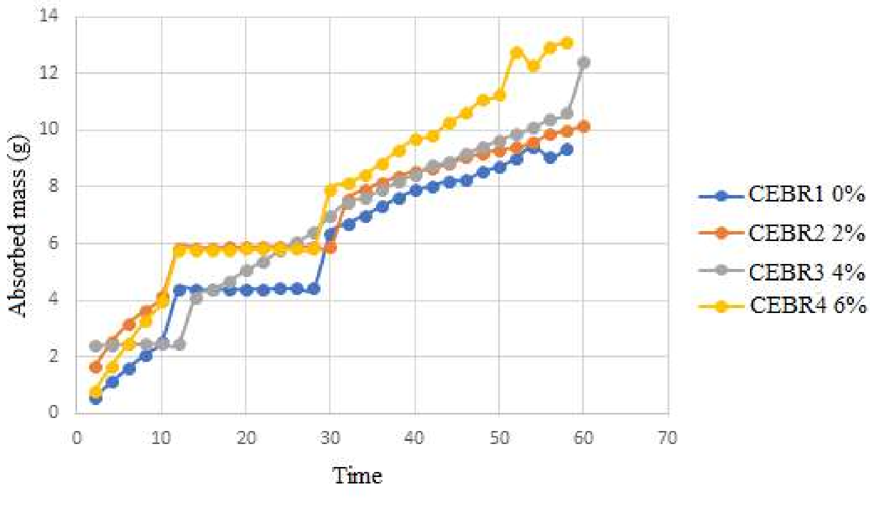

Figure 11. Mass of water absorbed as a function of time.

In view of the curve above, we note that the CEBR1 0% begins with an increasing absorption up to 12 s and then becomes constant up to 28 s with a constant value of 4.43 g and then increases to reach a maximum value of 9.58 g after 58 s. the same observation is made for CEBR2 2% which reaches the constant value of 5.9 g between 12 s and 28 s and then increases to reach a maximum value of 10.62 g after 58 s. as for CEBR3 4%, it begins with a constant absorption of water between 2 s and 12 s with a value of 2.47 g then increases to reach a maximum value of 12.4 g after 60 s. CEBR4 6%, we observe an increasing absorption up to 12 s and then becomes constant up to 28 s with a constant value of 5.9 g and then increases to reach a maximum value of 13.11 g after 58 s.

We also note that CEBR1 0% is the CEB that has the minimum mass of water absorbed after 58 s of immersion and CEBR4 6% is the CEB that has the maximum mass of water absorbed after 58 s 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 CEB, the more interstitial voids are created, promoting water infiltration [15,31]. According to the works of Sédan [28] which classifies CEBs according to their stress and their absorption rate, we observe that for our CEBs 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 [30], which is why CEBR2 2% has the best mechanical characteristics of CEBs. It is also necessary to point out here the importance of the effect of compaction stress on water absorption because soil compaction modifies its density, mechanical strength, permeability, and porosity [32].

4. Conclusion

The objective of this research was based on the characterization of the physical and mechanical properties of raw earth bricks reinforced with rattan fibers. In this research, we were interested in improving the performance (physical and mechanical) of the CEB, by exploiting local materials: earth taken from the western region of Cameroon, more precisely from the city of Bangangté, and plant fiber, particularly rattan, which constitutes one of the plant riches all over the world that is still neglected today. To achieve our objective, we first characterized the soil used (natural water content, granulometric analysis, Atterberg limits and the standard proctor test) in order to determine whether this soil is suitable for use in the manufacture of CEBs. Then, different test specimens are made with different proportions of rattan fibers. Finally, we carried out mechanical tests (flexural strength and compressive strength) and physical tests (density and water absorption rate). According to the results of the physical characterization of the soil used, the water content of the soil is determined, as well as the granulometric analysis, showing that the soil is not rich in very fine elements and has mostly grains with moderate diameters. Then the Atterberg limits, the liquidity limit, the plasticity limit and the plasticity index are found. The different results on the Atterberg limits show that the soil considered was low-plastic organic silt according to the USCS and following the values of WL, WP, and IP they fell within the standards for CEBs. As for the mechanical characterization of CEBs, the mechanical tests showed that rattan fiber improves the flexural and compressive strengths. Both in bending and compression, the CEBs stabilized calamus fiber reach maximum resistances at the same rate of fiber. For the water absorption rate, one also notices that the more the percentage of fiber increases the more the CEBs absorb water with a maximum absorption coefficient found, 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 compressed earth blocks improves both the mechanical properties of earth bricks and their sensitivity to water. Thus, the presence of rattan fibers in the manufacture of compressed earth bricks is an asset if the selection criterion is its resistance.

According to the results obtained from this research and with a view to a future rational and efficient use of these materials, it would be very useful to further study in the sense of environmental safety, the hydrothermal behavior of CEBs with the addition of rattan fibers; to complete physical characteristics such as: impact resistance, capillary potential, durability. It would also be interesting to study the hydrophilic properties of the fibers or their surfaces which can be irregular and would trap water molecules, which is possible by showing the microstructure of the fibers under an electron or optical microscope. These steps constitute a perspective for future investigations

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Appendix

Table A1. Granulometric 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%

Table A2. Atterberg limits.

Liquidity limit				**Plastic limit**	
Number of blows	15	20	30		
Tare number	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				

Table A3. Results of the standard proctor test at 10% water.

Water Content			**Sample**			
Tare n°	**Dry soil mass (g)**	**Water content**	**Volume (cm3)**	**Wet soil mass (g)**	**Wet density (g/cm3)**	**Dry density (g/cm3)**
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
Average water content = 25.15 %			Average dry density = 1.0772g/cm3			

Table A4. Results of the standard 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/cm3)**	**Dry density (g/cm3)**
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
Average water content = 26.76%				Average dry density = 1.1473g/cm3		

Table A5. Results of the standard proctor test at 14% water.

Water Content				Sample		
Taren°	**Water mass (g)**	**Dry soil mass (g)**	**Water content**	**Wet soil mass (g)**	**Wet density (g/cm3)**	**Dry density (g/cm3)**
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
Average water content = 29.82%				Average dry density = 1.2838g/cm3		

Table A6. Results of the standard 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/cm3)**	**Dry density (g/cm3)**
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
Average water content = 31.95%				Average dry density = 1.3636/cm3		

Table A7. Results of the standard proctor test at 18% water.

Water Content				Sample		
Tare n°	**Water mass (g)**	**Dry soil mass (g)**	**Water content**	**Wet soil mass (g)**	**Wet density (g/cm3)**	**Dry density (g/cm3)**
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
Average water content = 36.20%				Average dry density = 1.2270/cm3		

Table A8. Summaries of bending forces and stresses at 7 days.

%	**F1**	**F2**	**F3**	**Average**	**CONTRAINT**
CEBR1 0%	115.236	86.887	110.218	104.1137	0.244016
CEBR2 2%	196.447	234.666	120.571	183.8947	0.461003
CEBR3 4%	354.654	73.644	114.342	180.88	0.423938
CEBR4 6%	100.425	186.639	113.456	133.5067	0.312906

Table A9. Summary of bending forces and stresses at 14 days.

%	F1	F2	F3	Average	CONTRAINT
CEBR1 0%	116.603	213.503	226.100	185.402	0.434536
CEBR2 2%	155.363	305.235	393.414	284.6707	0.667197
CEBR3 4%	252.909	197.03	353.685	267.8747	0.627821
CEBR4 6%	208.981	233.852	322.354	255.0623	0.597802

Table A10. Summary of bending forces and stresses at 28 days.

%	F1	F2	F3	Average	CONTRAINT
CEBR1 0%	253.878	276.488	241.604	257.3233	0.603102
CEBR2 2%	372.742	369.189	160.854	300.9283	0.705301
CEBR3 4%	215.118	214.149	370.481	266.5827	0.644803
CEBR4 6%	269.059	356.269	172.159	265.829	0.623037

Table A11. Summaries of compressive forces and stresses at 7 days.

%	F1	F2	F3	Average	CONTRAINT
CEBR1 0%	3040.065	2859.913	1711.444	2537.141	1.5857129
CEBR2 2%	4143.496	3467.926	3467.926	4218.559	2.6365995
CEBR3 4%	4323.648	2949.989	4211.053	3828.23	2.3926437
CEBR4 6%	2251.9	1959.153	3558.002	2589.685	1.6185531

Table A12. Summaries of compressive forces and stresses at 14 days.

%	F1	F2	F3	Average	Stress
CEBR1 0%	3985.863	2338.268	2210.570	2844.9	1.778063
CEBR2 2%	5697.307	4616.395	3783.192	4698.965	2.936853
CEBR3 4%	3332.812	3625.559	4683.952	3880.774	2.455484
CEBR4 6%	1598.849	3400.369	5156.851	3385.356	2.115848

Table A13. Summary of compressive forces and stresses at 28 days.

%	F1	F2	F3	Average	Stress
CEBR1 0%	3152.66	4661.433	2274.419	3362.837	2.101773
CEBR2 2%	4323.648	5134.332	5179.37	4879.117	3.049448
CEBR3 4%	5382.041	3940.825	3895.787	4406.218	2.753886
CEBR4 6%	4120.977	3895.787	4774.028	4263.597	2.664748

Table A14. 14-day density summaries.

% CEB	Mass (g)	Volume (cm3)	Density (g/cm3)
CEBR1 0%	567.17	256	2.215507813
CEBR2 2%	563.66	256	2.201796875
CEBR3 4%	536.98	256	2.097578125
CEBR4 6%	525.08	256	2.05109375

Table A15. 28-day density summaries.

% CEB	Mass (g)	Volume (cm3)	Density (g/cm3)
CEBR1 0%	548.26	256	2.141640625
CEBR2 2%	499.97	256	1.953007813
CEBR3 4%	485.28	256	1.895625
CEBR4 6%	440.06	256	1.718984375

Table A16. Summary of the different masses of water absorbed at 28 days.

	Dry mass (g)			
	257.56	**285.61**	**254.21**	**304.13**
	Mass of water absorbed (g)			
Time (s)	**0%**	**2%**	**4%**	**6%**
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