

Research Article

Influence of the Addition of Palm (Borassus Aethiopum Mart.) Fibers on the Durability of Compressed Earth Blocks

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Abstract

This study aims to determine the influence of the content and length of the palm (*borassus aethiopum mart.*) fibers on the physical, mechanical and thermal properties of Compressed Earth Blocks (CEB). Three fiber contents (0.2%, 0.4% and 0.8%) of different lengths (10 mm, 20 mm, or 40 mm) were used to make CEB. CEB with 0% fiber content were manufactured to serve as control samples. CEB specimens stabilized with palm fibers or not were subjected to various tests according to standard XP P 13-901 for the determination of the following properties: dry density, water absorption, dry compressive strength, abrasion resistance and thermal conductivity. The results show that the dry density of CEB decreases from 4% to 7% when the content and length of the fibers increase respectively from 0.2% and 10 mm in length to 0.8% and 40 mm in length. The water absorption of fiber-containing CEBs ranges from 14% to 22% with increasing fiber content and length. The results also indicate that the mechanical and thermal properties are improved for well-chosen fiber contents. Thus, the dry compressive strength of the fibers increases by more than 13% for a fiber content of 0.2% and a length of 10 mm compared to CEB with 0% fibers. On the other hand, the optimal abrasion resistance values are obtained for a fiber content of 0.4% and a length of 40 mm. For all CEBs, the thermal conductivity values vary from 0.51 W/mK to 0.38 W/mK when the fiber content varies from 0.2% to 0.8%. Overall, palm fiber content has a greater influence on the measured physical, mechanical and thermal characteristics than fiber length.

Keywords

Compressed Earth Block (CEB), Content and Length of Palm Fibers, Dry Compressive Strength, Water Absorption, Abrasion Resistance, Thermal Conductivity

1. Introduction

Faced with the phenomenon of global warming, the development of innovative construction materials constitutes a major challenge for the building industry. Indeed, this sector

is one of the largest consumers of energy and is responsible for considerable emissions of carbon dioxide (CO₂) [1, 2]. However, due to the current energy and climate crises, efforts

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are being made to switch from conventional construction materials to sustainable, environmentally friendly and less energy-intensive materials [3]. Among the attempts to reduce energy consumption in the field of building construction, research work is devoted to the earth construction technique, in particular using compressed earth blocks (CEB) [4-7]. It is well-known that the stabilization of compressed earth blocks by cement improves their mechanical and physical properties [8-11], the incorporation of plant fibers in these blocks is now the subject of increasing attention from researchers in materials science [7, 12].

Numerous studies are being carried out on the use of natural fibers (date palm fibers, jute fibers, hemp fibers, bamboo fibers, sugarcane bagasse, etc.) in CEB [9, 13, 14]. The results indicate that the incorporation of plant fibers into these materials significantly improves their physical, mechanical and thermal properties compared to non-stabilized CEB. Namago showed that there is an increase in compressive and flexural strengths linked to the increase in sisal fibers [15]. Abessolo et al. showed that the addition of 0.05% of date palm fibers combined with 8% of cement leads to an improvement in the dry compressive strength of the blocks. But for higher fiber contents (> 0.1%), this addition has a negative effect on the properties of the CEB [13]. This study also indicated that the addition of bamboo fiber improved the properties of CEB and increases their sensitivity to water.

In West African countries, the palm tree (*Borassus aethiopicum* mart.) is a plant resistant to rot and abundant in savannah areas [16]. Like the date palm, it could be used in stabilizing blocks of compressed earth in an approach to sustainable development and the valorization of local materials.

This study aims to determine the influence of the addition of small proportions of palm tree (*Borassus aethiopicum* mart.) fibers on the physical, mechanical and thermal properties of compressed earth blocks.

2. Materials and Methods

2.1. Materials

2.1.1. Soil

The raw earth used is clay soil extracted in the Songon area (Town in the south of Côte d'Ivoire). This soil is chosen based on its availability and abundance in this country. The mineralogical composition of the soil determined by X-ray diffraction is indicated in Table 1. The granular composition is obtained through two tests: particle size analysis according to standard NF P18-560 [17] and sedimentometry according to standard NF P94-057 [18]. The results are presented in Figure 1. The curve obtained is located within the zone recommended by the compressed earth block standard XP P13-901 [19]. Table 2 shows the physical characteristics of the studied soil. The results indicate that it is a clayey soil with little

plasticity.

Table 1. Mineralogical composition of the soil (%).

Oxides measured	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	MgO
Content (%)	62.98	11.18	9.41	1.32	0.04

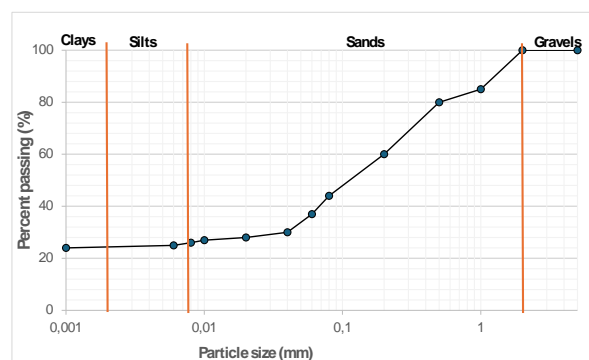


Figure 1. Particles size curve of tested soil.

Table 2. Physical characteristics of the soil.

Maximum dry density	Optimal water content	Liquid limit	Plasticity index
1.83	17.70%	48.6%	19.3%

2.1.2. Palm (*Borassus Aethiopicum* Mart.) Fibers

The fibers used come from the crushing of palm tree trunks. the fibers are immersed in water, resulting in fibers approximately 1 mm in diameter and cut to a length of 10 to 40 mm (Figure 2). The fibers are then rinsed with water and air dried for 48 hours. Table 3 presents the physical characteristics of palm fibers.



Figure 2. Defibrated palm tree trunk.

Table 3. Physical characteristics of palm fibers.

Diameter (mm)	Length (mm)	Apparent density	Absolute density	Initial water content (%)
0.8 – 1.0	10 - 40	0.260	0.687	12.76%

2.2. CEB Production

The mass of the dry mixture for each block is kept constant during the experimentation phase. It is approximately 500 g. The blocks are made using a mixture composed of stabilized earth with three fiber contents (0.2%, 0.4% and 0.8%) in relation to the total dry mass of the blocks. For each fiber content, three length variations were used: 10, 20 and 40 mm. During mixing, 12% water was added to the mixture. The mass composition of the blocks is shown in Table 4 below.

Table 4. Mass proportion of CEB constituents.

Designation	Soil (%)	Palm fibers (%)	Water (%)	Fiber length (mm)
M0	88	0	12	-
M1_10	87.8	0.2	12	10
M1_20	87.8	0.2	12	20
M1_40	87.8	0.2	12	40
M2_10	87.6	0.4	12	10
M2_20	87.6	0.4	12	20
M2_40	87.6	0.4	12	40
M3_10	87.2	0.8	12	10
M3_20	87.2	0.8	12	20
M3_40	87.2	0.8	12	40

Compaction is carried out using a hydraulic press. The compaction force is 10 MPa [13].

2.3. Tests Carried out

Most CEB characterization tests were carried out according to standard XP P 13-901. These are the following tests: dry density, water absorption, dry compressive strength, abrasion resistance and thermal conductivity. According to specifications, in each case three samples were tested.

2.3.1. Physical Characteristics

(i). Dry Density Test

The samples are dried in an oven at 105 °C until reaching a constant mass (M_s). The dimensions of the dried samples are measured at four points. This allows the volume (V) of the blocks to be calculated. Dry density is given by the relationship:

$$\rho(\text{g/cm}^3) = \frac{M_s}{V} \quad (1)$$

(ii). Water Absorption Test

The dried blocks (M_s) are immersed in a tank containing water until saturation (i.e. until their wet mass (M_h) is constant). The water absorption rate is obtained by:

$$w(\%) = 100 \cdot \frac{(M_h - M_s)}{M_s} \quad (2)$$

2.3.2. Mechanical Characteristics

(i). Dry Compressive Strength Test

Dry compressive strength is determined using the PER-RIER compression pressure with a capacity of 300 kN. The tests are carried out on samples measuring 40 x 40 x 80 mm³. The loading speed is approximately 0.2 mm/min.

(ii). Abrasion Resistance Test

This test consists of scratching the surface of the blocks using a wire brush in accordance with standard XP P 13-901. The abrasion coefficient (C_a) is given by the relationship:

$$C_a(\text{cm}^2/\text{g}) = \frac{S}{(M_0 - M_1)} \quad (3)$$

With: M_0 : initial block mass

M_1 : block mass after brushing

S : brushed surface

2.3.3. Thermal Conductivity Test

The measurements of the thermal properties of the CEB were carried out by the hot ribbon method. The scheme of the measuring device is shown in Figure 3 below:

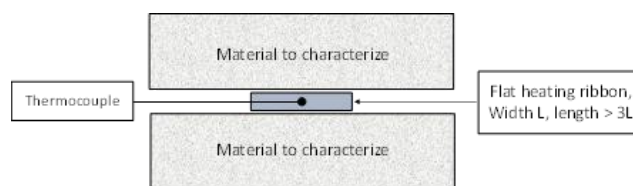


Figure 3. Scheme of the device for measuring the thermal conductivity of blocks.

3. Results and Discussion

Note: Each point in the figures below corresponds to the mean value obtained for the various tests carried out. Error bars correspond to the standard deviation calculated for each average value.

3.1. Physical Characteristics

3.1.1. Dry Density

The influence of the content and length of the palm fibers

on the dry density of the CEB is presented in Figure 4.

In general, CEB containing fibers have lower densities than those without fibers. The addition of fibers leads to a reduction in density from 4% (CEB with 0.2% of fibers of length 10 mm) to 7% (CEB containing 0.8% of fibers of length 40 mm) depending on the content (0.2% to 0.8 %) and fiber length (10 mm to 40 mm). Furthermore, for a given fiber content, CEB containing long fibers have lower densities. Thus, the longer the fibers, the greater the drop in dry density [12]. This is probably due to the presence of fibers which are less dense than clayey soil. The values obtained are lower than those of CEB stabilized with cement [15]. These results corroborate those of [20-22] and show that the use of plant fibers in CEB makes it possible to obtain lighter composites, and therefore lighter structures.

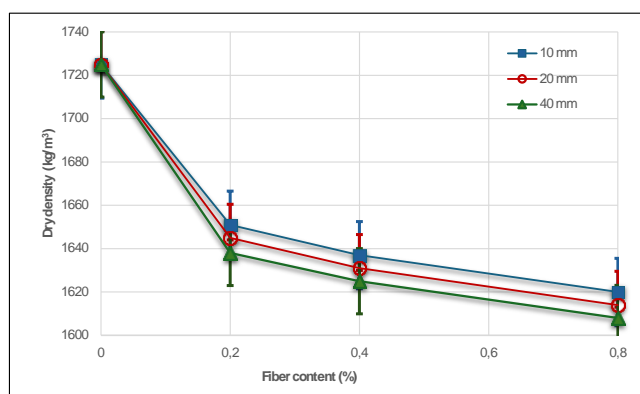


Figure 4. Dry density versus fiber content.

3.1.2. Water Absorption

Figure 5 presents the water absorption rate versus fiber content. The curves show that water absorption increases with increasing fiber content and length. For CEB containing 0.8% fiber of length 40 mm, the absorption rate is 22% and 14% for CEB containing 0.2% fibers of length 10 mm.

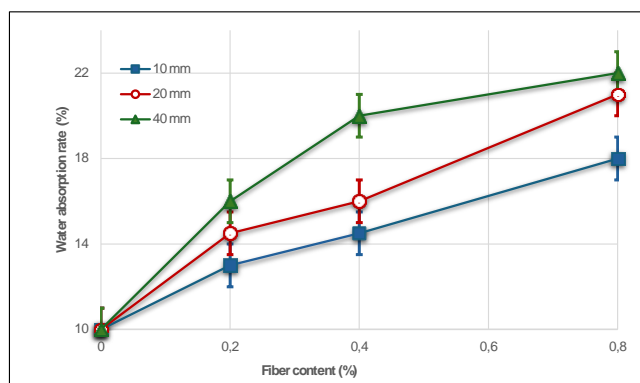


Figure 5. Water absorption rate versus fiber content.

CEB without palm fiber have a water absorption rate of

10%. Adding fiber appears to increase the water absorption rate of CEB. However, all the values obtained are within the acceptable range of water absorption for use in construction [14, 23, 24].

3.2. Mechanical Characteristics

3.2.1. Dry Compressive Strength

Figure 6 presents the dry compressive strength results of CEB. This figure indicates that the addition of fibers leads to an increase in resistance for the content and length of the fibers used. The increase in resistance varies from 6% to 12% from blocks without fibers to those containing fibers. The greatest value is obtained with the use of 0.2% of fibers of 10 mm length (increase of almost 12% compared to CEB without fibers). For higher fiber contents, there is a slight increase in the dry strength of the blocks (from 6% to 8%) compared to specimens without fibers. Furthermore, the shape of the curves obtained seems to indicate a drop in resistance with greater proportions of palm fibers. Fiber content and length greatly affect the dry compressive strength of CEB. The decrease in compressive strength for fiber addition could be explained by the low stiffness of palm fiber. This behavior has been obtained by previous works [25, 26]. It was reported that the incorporation of fibers increases the void network in the blocks, which is the main factor leading to decreased dry compressive strength. Moreover, the weak interfacial bond between fibers and the matrix decreases the mechanical performance. These results match with those of [14, 27] which indicate the existence of a fiber content that should not be exceeded in the case of CEB stabilized with hydraulic binders. This result can therefore apply to CEB stabilized with plant fibers only.

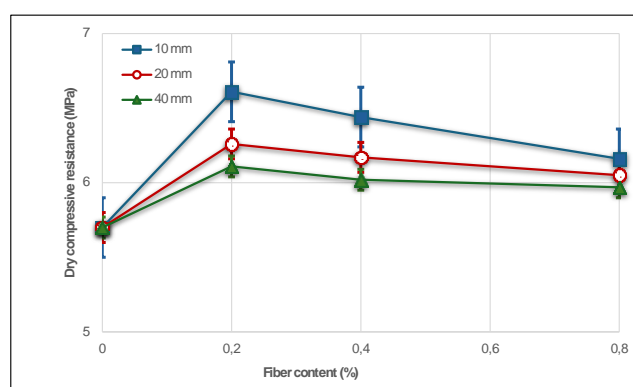


Figure 6. Dry compressive strength versus fiber content.

3.2.2. Abrasion Resistance

Figure 7 shows the variation of the abrasion resistance coefficient of CEB in relation to the fiber content and their length. This coefficient varies from 8.6 cm³g to 16.02 cm³g as the content and length of the fibers increase. The results

indicate that this coefficient increases with fiber content and length. The best results are obtained with blocks containing 0.4% fibers of 40 mm length. This can be due to the morphology of palm fibers, characterized by a rough (ridged) external surface, contributing to strengthen bonding between the fibers and the matrix. Beyond 0.8%, there seems to be a drop in the abrasion resistance value. Indeed, all the values obtained for samples containing 0.8% fibers remain lower than all the others regardless of the length of the fibers. However, for all the CEB studied, the values obtained are higher than the minimum values prescribed by the XP P 13-901 standard. These values make it possible to classify these CEB in the CEB 60 range with regard to their resistance to abrasion [28]. These results agree with previous works and make it possible to classify these specimens in the CEB 60 category with regard to their resistance to abrasion [29, 30].

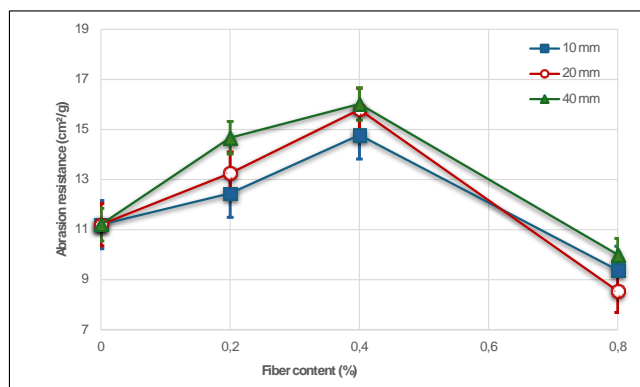


Figure 7. Abrasion resistance versus fiber content.

3.3. Thermal Conductivity

Figure 8 presents the thermal conductivity values of the CEB. For blocks without fiber, the thermal conductivity is 0.54 W/mK, for blocks containing fibers, the thermal conductivity drops from 0.51 W/mK to 0.45 W/mK, 0.46 W/mK to 0.41 W/mK and 0.40 W/mK to 0.38 W/mK, respectively for fiber contents of 0.2%, 0.4% and 0.8% and for fiber lengths varying from 10 mm to 40 mm. Which indicates that the thermal conductivity of CEB decreases with the content and length of the fibers. For a given fiber content, the drop in

thermal conductivity is of the order of 11% for a variation in fiber length from 10mm to 40mm. Whereas, the thermal conductivity decreases by more than 18% for a variation in fiber content from 0.2% to 0.8%. This shows that the impact of fiber content is greater on thermal conductivity than fiber length [31]. Thus, higher the fiber content, lower the thermal conductivity. The drop in thermal conductivity can therefore be attributed to the presence of fibers. These results confirm those reported by other authors on CEB stabilized with fibers with 7% reed fibers [32, 33].

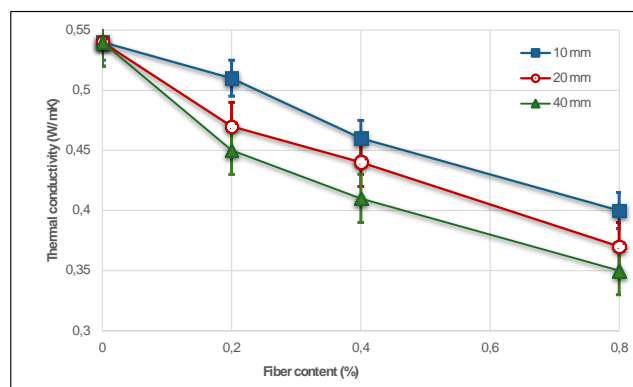


Figure 8. Thermal conductivity versus fiber content.

3.4. Comparative Analysis of Fibers Reinforced CEB Performances

The physical, mechanical and thermal characteristics of the CEB containing palm fibers are compared with those of previous work on CEB containing other fibers (Tables 5, 6 and 7). The fibers length varies from 10 mm to 50 mm, and dry weight varies from 0.2% to 1%. Overall, the addition of fibers makes it possible to obtain CEBs with acceptable physical, mechanical and thermal characteristics and in compliance with the specifications.

3.4.1. Comparison Based on Physical Characteristics

Table 5 below presents the physical characteristics of CEB with plant or synthetic fibers.

Table 5. Physical characteristic of studied CEB compared to other fibered CEB.

N°	Name of fiber	Dry density (kg/m ³)	Water absorption (%)	References
1	Palm fiber (0.2-0.8%)	1.61-1.65	13%-22%	-
2	Date palm fiber (0.2-0.5%)	1.55-1.68	11.4%-16.3%	[34]
3	Bamboo fiber (0.5-1%)	1.43-1.56	18%-24%	[13]
4	Sisal fiber (0.05-0.2%)	1.52-1.77	22%-28%	[34]

N °	Name of fiber	Dry density (kg/m ³)	Water absorption (%)	References
5	Coconut fiber (0.25-1%)	1.77-1.85	9.8%-15.3%	[35]
6	Kenaf (0.2%-0.8%)	1.8-2.3	-	[36]
7	Polypropylene fiber (1%)	1.64	21.8%	[37]
8	Plastic fiber (0.2%)	1.45	35%	[37]

The results indicate that the addition of palm fibers in the manufacture of CEB allows to obtain composites with physical characteristics (dry density, water absorption) approximately 11% higher than CEB containing other fibers, such as date palm fibers, bamboo fibers, or sisal fibers. However, the values obtained are within the range of values measured on most CEB stabilized only with plant fibers (1.45-2.2) [38].

3.4.2. Comparison Based on Compressive Strength

The results are given in Table 6 below. These results show that the addition of palm fibers in the making of CEB considerably improves the compressive strength of these composites. The results obtained on CEB stabilized with palm fibers are better than those obtained on CEB containing other types of fibers. Furthermore, the values are close to those obtained on CEBs stabilized with hydraulic binders [39].

Table 6. Compressive strength of studied CEB compared to other fibered CEB.

N °	Name of fiber	Compressive strength (MPa)	References
1	Palm fiber (0.2-0.8%)	5.97-6.61	-
2	Date palm fiber (0.2-0.5%)	3.50-6.02	[34]
3	Bamboo fiber (0.5-1%)	4.5-11.8	[13]
4	Sisal fiber (0.05-0.2%)	3.5-6.14	[34]
5	Coconut fiber (0.25-1%)	1.70-3.01	[35]
6	Kenaf (0.2%-0.8%)	2.20-3.55	[36]
7	Polypropylene fiber (1%)	5.20	[37]
8	Plastic fiber (0.2%)	5.80	[37]

3.4.3. Comparison Based on Thermal Conductivity

Table 7 gives the values of the thermal conductivity of the CEB stabilized with plant fibers. For the 3 types of fibers, the results are in the same order. The thermal conductivity of the CEB reinforced with fibers is then between 0.35 and 0.95. and remain lower than that obtained on CEB containing hydraulic binders [39].

Table 7. Thermal conductivity of studied CEB compared to other fibered CEB.

N °	Name of fiber	Thermal conductivity (W/mK)	References
1	Palm fiber (0.2-0.8%)	0.35-0.51	-
2	Date palm fiber (0.2-0.5%)	0.48-0.62	[34]
3	Kenaf (0.2%-0.8%)	0.35-0.95	[36]

4. Conclusions

This work focused on the study of the influence of the content and length of palm tree fibers (*borassus aethiopum* mart.) on the physical, mechanical and thermal properties of compressed earth blocks (CEB). The addition of palm fibers to CEB lowers their dry density, which decreases with the increase in the content and length of the fibers. In most cases studied, the addition of palm fiber increases the rate of water absorption. The greater the fiber content and length, the greater the water absorption rate. This phenomenon can be reduced by using short fiber lengths. The dry compressive strength of CEB is improved with the addition of palm fibers. However, the best results are obtained for fiber contents lower than 0.2%; beyond this value, there is a drop in the dry compressive strength of the CEB independently of their length.

Moreover, the addition of palm fibers regardless of their length improves the abrasion resistance of CEB. The values obtained make it possible to classify these materials in the CEB 60 class. The best results are obtained for CEB containing less than 0.4% fibers and for lengths not exceeding 40 mm.

Finally, thermal conductivity decreases with increasing content and length of palmate fibers. For most CEB containing fibers, thermal conductivity values are less than 0.50 W/mK.

The investigation on the properties of palm fiber reinforced CEB shows that the addition of this plant fiber improves the characteristics of the blocks compared to stabilization by other plant fibers.

Future research will focus on studying the effect of impermeabilizing fibers, with a polymer resin, on the characteristics of CEB.

Abbreviations

CEB Compressed Earth Blocks

Author Contributions

Stephane Koffi: Conceptualization, Data curation, Investigation, Writing – original draft

Athanas Konin: Data curation, Formal Analysis, Methodology, Supervision, Validation, Writing – review & editing

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Data Availability Statement

The data supporting the outcome of this research work has been reported in this manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography



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