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Effect of Reinforcement Thickness and Content on the Properties of Compressed Earth Blocks

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RESEARCH ARTICLE

Effect of Reinforcement Thickness and Content on the Properties of Compressed Earth Blocks

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ABSTRACT

This study explores the mechanical, hygroscopic, and thermal behavior of stabilized and unstabilized compressed earth blocks (CEB) by incorporating date palm wood chips (DPWC) as a natural fiber additive. The investigation covers a range of DPWC thicknesses (1 mm, 2 mm, 3 mm) and content variations (0% to 1% by weight), focusing on the interaction between the bio-based reinforcement and the stabilized soil matrix, which is stabilized with 10% white Portland cement. The mixtures were compressed at a pressure of 5 MPa using a hydraulic press, providing a detailed examination of how these parameters impact the structural integrity and functional properties of CEB. The experimental analysis encompassed a comprehensive set of mechanical tests, including flexural and compressive strength assessments, to understand the role of DPWC in enhancing structural performance under both dry and wet conditions. Additionally, the study evaluated total water absorption and thermal conductivity to explore the multifaceted role of DPWC as a reinforcement. The findings indicate that achieving optimal compressive strength in stabilized blocks necessitated precise calibration of wood chip thickness according to the reinforcement ratio. The flexural strength was enhanced by incorporating wood chips of varying thicknesses in specific proportions. Higher reinforcement content correlated with increased water absorption and reduced thermal conductivity, suggesting potential applications in thermal insulation.

Keywords: Compressed earth block, Date palm wood chips, Fiber, Mechanical properties, Water absorption, Thermal conductivity

1. Introduction

Throughout history, ancient civilizations utilized the Earth as a basic building material, employing various techniques. Even in modern times, a large segment of the world's population resides in structures made from earthen materials [1]. Recognized for its eco-friendly attributes, Earth exhibits minimal carbon emissions, low thermal conductivity, beneficial hygroscopic properties, and favorable acoustic insulation [2–4]. However, earthen building materials are often characterized by low compressive and tensile strength, brittleness, and sensitivity to humidity [5, 6]. These drawbacks have led to a decline in their use

in modern construction for an extended period, where more durable materials such as fired brick and concrete have become predominant alternatives [7–9].

Achieving sustainable development leads us to search for locally available materials and construction techniques [10, 11]. Compacted earth construction, specifically compressed stabilized earth blocks (CEBs), presents a promising solution. CEBs are produced by mixing soil with chemical stabilizers to enhance their mechanical strength and durability [12]. The method has gained rapid development and acceptance [14].

Numerous studies have explored various ways to improve the mechanical properties of CEB, including

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using natural fibers as reinforcement to reduce shrinkage and enhance tensile strength and ductility [9]. Natural fibers, widely available locally, allow for reduced environmental impacts and thermal conductivity of composite materials [14, 15]. These fibers exhibit diverse shapes and sizes, making them versatile for construction [16, 17]. A variety of natural fibers have been successfully incorporated into CEB, such as sisal fiber [18], sugar cane bagasse fiber [19], and jute fiber [20].

Among these natural additives, date palm fibers have shown potential in enhancing the properties of compacted earth blocks. Ismail & Yaacob [21] found that a low proportion of date palm fibers improved the dry compressive strength of CEBs, while higher fiber proportions led to a decline in mechanical performance. The water absorption test results of CEB demonstrated a positive correlation between increased palm fiber content and higher water absorption rates [22]. Palm fibers have fibrous tissues characterized by their low cost, durability, and lightweight [23].

Investigations were conducted to examine how varying lengths of banana and kenaf fibers affect the mechanical and thermal properties of CEB. The study found that using specific lengths improved flexural and compressive strength [23, 24]. While several studies have investigated the impact of natural fiber content and length on the performance of compressed earth blocks (CEBs), the effect of reinforcement thickness, particularly in the form of wood chips, has received significantly less attention in the scientific literature. Most existing research has focused on optimizing fiber volume or aspect ratio to improve strength, shrinkage resistance, or thermal insulation. However, the thickness of the reinforcement plays a significant role in the interaction between the bio-based additive and the soil matrix, influencing compaction, adhesion, and porosity. This work thus introduces chip thickness as a new variable, exploring how differences in this dimension affect both the mechanical properties (compressive and flexural strength) and hygrothermal performance (water absorption and conductivity) of stabilized and unstabilized CEBs. By filling this gap, the research contributes to a complete understanding of how to alter reinforcement geometry for improved CEB performance.

Although commonly referred to as fibers, the reinforcing material in this study is wood chips obtained from date palm rachis after using a wood chipper machine. The term “chip” is used throughout to ensure consistency, while “fiber” is used in previous studies.

Furthermore, treating fibers with chemical solutions can degrade their natural strength and sustainability, reducing their inherent biocompatibility and ability to bond with materials naturally. This study

aims to investigate the effect of date palm wood chip (DPWC) as natural reinforcement without treatment on the mechanical and thermal properties of CEB. Due to the difficulty of sorting wood chips according to different thicknesses in the same context, an easy and simple technique has been developed to classify the thickness of wood chips. This technique can be applied to natural fibers and agricultural waste to determine the appropriate thickness of the fibers used in the reinforcement.

The traditional earthen structures are experiencing degradation, mainly mud brick buildings. These bricks are formed by manually shaping a blend of Earth, straw, and water inside a wooden frame, which is left to dry in the sunlight [14]. Next to these buildings, located in desert areas, disposing of palm frond residue, which is produced in abundance annually, is a significant challenge. As summer approaches, this waste becomes a potential source of fires, prompting the exploration of new and beneficial applications for this secondary agricultural material. In this context, there is a growing interest in utilizing palm frond fibers to enhance the mechanical properties of earthen materials [25–28]. Integrating natural fibers into earthen construction materials aligns with the development of advanced, multifunctional, and sustainable materials that meet the mechanical and structural performance requirements.

This research investigates the effects of incorporating date palm wood chips of different thicknesses and contents on the properties of stabilized and unstabilized CEB, utilizing locally available materials such as soil and date palm wood. The study will first assess the mechanical properties of these heterogeneous materials, focusing specifically on their compressive and flexural strength. Additionally, the hygroscopic and thermal properties of the CEB will be evaluated through tests measuring total water absorption and thermal conductivity.

2. Materials

2.1. Soil

The soil origin used in this investigation was from Moughel, which is situated 50 kilometers southwest of the state of Bechar, Algeria. The soil grain size distribution was conducted following the NF EN ISO 14688-1 standards; the results of the experiment are depicted in Fig. 1. The Atterberg limits determined following the NF EN ISO 17892-12 resulted in a liquid limit of 23.17 and a plasticity index of 5.80. The PH measurement was 7.80, and the methylene blue value was 0.83, per NF P 18-592 standards. Following the triangular textural classification of the soil [30], the results show that the soil was sandy loam, containing

Table 1. The chemical soil compounds (%).

Al ₂ O ₃	SiO ₂	CaO	MgO	Fe ₂ O ₃	SO ₃	TiO ₂	Cl	K ₂ O	LOI
6.55	51.83	15.03	7.01	5.07	2,49	2,50	1.51	0.93	7,08

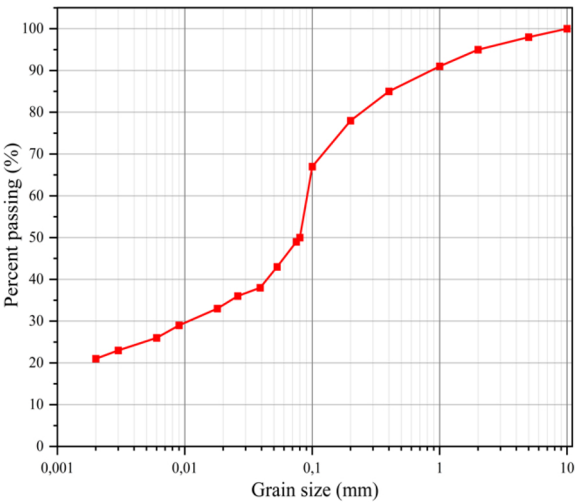


Fig. 1. Particle size distribution of the soil analyzed.

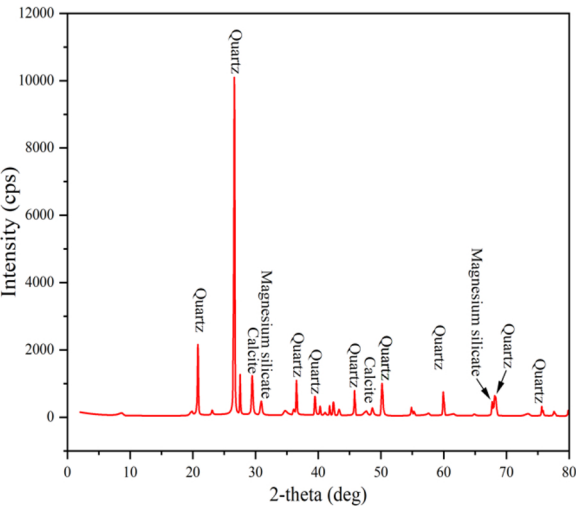


Fig. 2. X-ray diffractograph of the natural soil.

58.02% sand. The absolute and apparent densities are 2.5 g/cm³ and 1.3 g/cm³, respectively.

The elemental composition of the soil, as analyzed through Epsilon3 XL X-ray fluorescence, is provided in detail in Table 1. Fig. 2 shows the X-ray diffractogram of soil tested using the MiniFlex 600 X-ray Diffractometer; the mineralogical properties of the natural soil were assessed. The radiation was used in the XRD procedure at 15 mA and 40 kV. The range of the scan was 2°–80° 2θ, where θ stands for Bragg’s angle. With a step width of 0.026°. The mineralogical

Table 2. Clinker composition (%).

Chemical composition			
SO ₃	MgO	Cl	LOI
2.6 ± 0.6	2.5 ± 0.8	< 0.1	11.5 ± 1
Bogue composition			
C3S	C3A		
54 ± 3	10 ± 1		

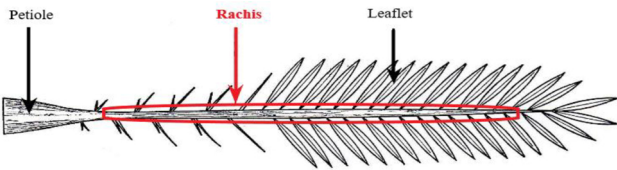


Fig. 3. The part used is from date palm leaves.

analysis reveals that the soil comprises 69.1% quartz, 25.4% magnesium silicate, and 5.5% calcite.

2.2. Cement

This study utilized Portland cement CEM II/B-L 42.5 N NA 442. Table 2 shows the chemical and mineralogical compositions of cement. 10% of white cement was used as a stabilizer. As highlighted in several studies, the optimal cement dosage for CEB is typically 5% to 10% [29–31].

2.3. Water

Potable water with low sulfate content was used and maintained at 20 ± 2°C.

2.4. Date palm wood chips

The wood chips used in this study as reinforcement were obtained from date palm leaves, specifically the part called Rachis, after removing the Leaflet and Petiole (Fig. 3). The literature provides information on the physical characteristics of different palm wood parts, as summarized in Table 3. The findings suggest that the Rachis has the highest bulk density value and less water absorption than the other parts [32]. The chosen thicknesses (1 mm, 2 mm, and 3 mm) represent an adequate variety of sieved wood chip dimensions usually achieved in field-scale sieving procedures. These parameters were determined based on prior research on fiber length and the notion that thickness, like length, might influence interfacial



Fig. 4. Sorting wood chips according to their thickness using bar sieves.

Table 3. Physical properties of different palm wood parts [32].

Type	Water absorption (%)	Absolute density (g/cm ³)	Bulk density (g/cm ³)
Petiole	146.32 ± 20.40	0.995 ± 0.32	0.160 ± 0.54
Rachis	36.88 ± 10.15	0.857 ± 0.37	0.635 ± 0.22
Bunch	63.25 ± 5.00	0.838 ± 0.32	0.555 ± 0.11
Fibrillium	115.11 ± 15.7	0.976 ± 0.33	0.209 ± 0.31

bonding and mechanical performance. Notably, a comparative study was conducted between the outer fibers of palm trees, whose thickness ranges between 0.7 and 4 mm, and wood sawdust [33]. The wood was chopped using a wood chipper machine. Fig. 4 shows how we obtain wooden chips with a thickness of 1, 2, and 3 mm using bar sieves; their lengths vary between 2 cm and 5 cm. The chips were added to the mixture in different proportions: 0.1, 0.3, 0.5, 0.7, and 1%.

2.5. Samples preparation

Forty-eight mixtures were prepared to study the influence of wood chip thickness on the properties of stabilized and unstabilized compressed earth samples. The following describes all the steps in sample preparation.

- Soaking and draining the wood chips: The date palm fibers were treated in several ways; the best results were by immersing them in water according to a study conducted by Abdelghani et al. [26]. The wood chips underwent a 24-hour soaking in water. At laboratory temperature, to remove excess water, place the wood chips on a sponge for 10 minutes before adding them to the mixture.
- Dry soil-cement mixing: The dry soil with 10% white cement is mixed in a blender according to weight, operating at low speed for 10 seconds. Table 4 provides details on the contents used in

each combination. According to several studies, the Proctor compaction test was unsuitable for defining the optimum moisture content of the stabilized and unstabilized earth blocks using static compaction [34, 35]. For this, the optimum amount of water was extracted by compressing soil samples using a hydraulic press with different proportions of water. The ideal water ratio that achieves maximum density has been chosen.

- Gradual addition of water and drained chips: After dry blending, the optimum water content was gradually added to the mixture, while we continued blending for 2 min. In the next step, wood chips of different thicknesses (1, 2, and 3 mm) and different ratios (0, 0.1, 0.3, 0.5, 0.7, and 1 mm) were added and mixed manually.
- Molding and compaction: After mixing, the material was placed in a mold of (40 × 40 × 160 mm) and compacted instantly by a hydraulic press; the compaction pressure was fixed at 5 MPa during the study. The compaction pressure of 5 MPa was chosen to imitate field compaction conditions and guarantee consistency between samples, as indicated in earlier CEB compaction experiments [21, 37–39]. Fitzmaurice [13] examined the molding pressure of earth blocks ranging from 1 to more than 40 MPa, classifying 4 to 6 MPa as medium pressure.

Table 4. Details of mixture proportions.

	Unstabilized compositions						Stabilized compositions					
Soil (%)	100						100					
Cement (%)	0						10					
Water (%)	12						14					
Wood chips content (%)	0	0.1	0.3	0.5	0.7	1	0	0.1	0.3	0.5	0.7	1
Wood chips thickness (mm)	0	1	1	1	1	1	0	1	1	1	1	1
	0	2	2	2	2	2	0	2	2	2	2	2
	0	3	3	3	3	3	0	3	3	3	3	3

**Fig. 5.** The CEBs dry after the plastic cover is removed.

- **Demolding and curing mode:** The blocks are immediately and cautiously removed after demolding. The stabilized earth blocks are covered by plastic film to avoid rapid drying of samples and maximize the hydration of cement, and are conserved at a temperature of 20 ± 2 °C for 24 h. According to a study conducted by Benamar et al. [40] on the effect of curing mode on the properties of compressed stabilized earth blocks, the covered blocks cured in the oven at 65 degrees for 7 days had the highest strength compared to those cured in a laboratory environment and with natural steam [41]. The plastic cover was removed, and the CEB was dried in the laboratory environment as shown in Fig. 5. Finally, the weight of the blocks was measured in an oven at 60 °C before being submitted to experiments.

3. Experimental methods

3.1. Scanning electron microscopy

A FEI Quanta 650 FEG scanning electron microscope was used to evaluate the morphology and structure of the samples, wood chips, and earth masses by scanning electron microscopy (SEM). The SEM was used in low vacuum mode with an accelerating voltage of 25 kV.

3.2. Dry compressive and flexural strength

This test is performed by continuously loading until specimens fail, as illustrated in Fig. 6. A double-chamber automatic press measured the ultimate charge sustained by the block through the experience with a capacity load of 300 KN. For the compressive test, $40 \times 40 \times 80$ mm cubic samples were used, while the three-point flexural tests were conducted on samples with dimensions of $40 \times 40 \times 160$ mm. Tests were conducted at an increased pressure rate of 0.01 MPa/s for compressive strength and 0.2 MPa/s for the three-point bending test until the specimen completely ruptured. The mechanical tests were performed after 28 days. Three specimens per condition were used for all testing. Error bars are displayed in figures where necessary.

3.3. Wet compressive strength

This test demonstrates how the bricks operate under harsh conditions. The earthen bricks are thoroughly soaked in water for two hours before being retrieved and superficially dried with a rag. The blocks are stored in laboratory conditions for 48 hours before the test. This process is based on the XP P 13-901 norm.

3.4. Total water absorption

The samples are submerged in water. Before soaking, their initial dry weights (W_d) are measured. Subsequently, wet weights (W_w) are recorded at various intervals (1, 2, 3, and 4 days) after removal from the water. The absorption rate can be determined using the following equation:

$$A(\%) = (W_w - W_d) \times 100/W_d \quad (1)$$

3.5. Thermal conductivity

The test results were acquired using Dual-Needle SH-1 sensors in the KD2-PRO thermal analyzer. Two small parallel holes at least 1.5 cm deep are made in the samples using a drill to insert the sensor. The SH-1

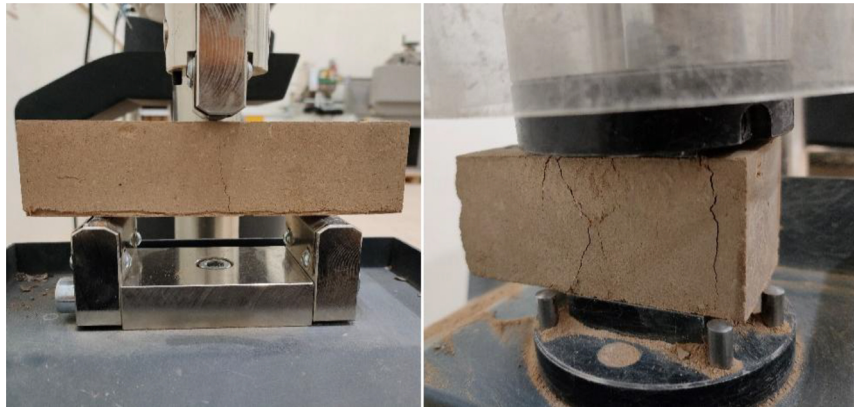


Fig. 6. Failure and crack pattern of samples under three-point flexure and compressive test.

sensors give off a heat pulse and accurately measure most solid and granular materials.

4. Results and discussion

4.1. Morphology composition

The SEM images provide a detailed insight into the microstructure morphology of DPWC, as depicted in Fig. 7. The SEM of the natural DPWC used in the reinforcement of the earthen blocks is displayed in Fig. 7a at a 100 μm scale, which exposes the typical roughness and holes on its surface. Fig. 7b displays scanning electron micrographs of wood with a cross-section at a scale of 100 μm . The cavities are microscopic channels of different diameters. This can explain the plastic behavior of the compressed earth blocks after hydraulic decompression when the mold is removed during the sample preparation stage. Fig. 7c and Fig. 7d show SEM images of fibers taken from stabilized and unstabilized earth blocks, respectively. The concave surface nature of the DPWC may assist an adhesive bond between the fiber used and the soil matrix, which explains the presence of residual in the soil matrix in diverse dimensions and forms on this surface. Fig. 7e and Fig. 7f show the matrix-fiber interface, which indicates that filling pores on the surface of wood chips with matrix particles can contribute to increasing matrix-fiber cohesion. μm scale, which exposes the typical roughness and holes on its surface. Fig. 7b displays scanning electron micrographs of wood with a cross-section at a scale of 100 μm . The cavities are microscopic channels of different diameters. This can explain the plastic behavior of the compressed earth blocks after hydraulic decompression when the mold is removed during the sample preparation stage. Fig. 7c and Fig. 7d show SEM images of fibers taken from stabilized and unstabilized earth blocks, respectively.

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4.2. Dry compressive strength (DCS)

Several factors can affect the compressive strength of the stabilized and unstabilized CEB, including the stabilizer proportion, the type and content of reinforcement, and the length and thickness of the reinforcement. Fig. 8 illustrates the dry compressive strength of the stabilized and unstabilized compressed earth blocks reinforced with different thicknesses and proportions of date palm wood chips.

Including stabilizers, such as white cement, significantly impacts the compressive strength of the CEB. Incorporating 10% white Portland cement increased the compressive strength to 17.45 MPa, compared to 3.95 MPa for unstabilized blocks. These results are consistent with previous studies, which attribute this effectiveness to cement hydration. This process produces bonds and solid chemical compounds that fill the pores of the soil mixture particles and bind them together [36–40], thereby increasing the strength of the blocks.

An increase in wood chip proportion reduced the DCS of stabilized blocks when analyzing the effect of varying wood chip content. This decrease in strength was more pronounced with thicker wood chips, showing reductions of 54.06%, 51.39%, and 16.78% for 3 mm, 2 mm, and 1 mm thicknesses, respectively, as wood chip content increased from 0.1% to 1%. These findings suggest that while wood chips can contribute to reinforcement, an excessive proportion

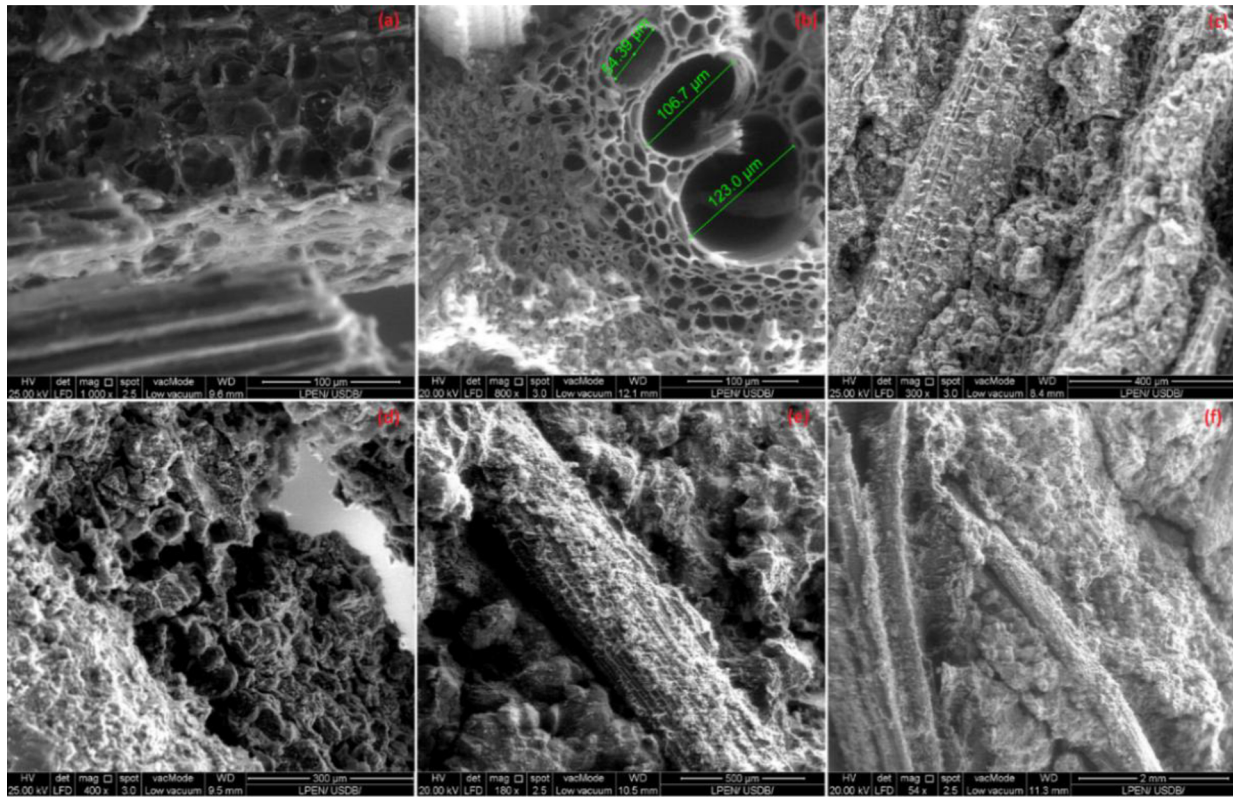


Fig. 7. SEM micrographs: (a) DPWC surface at 100 μm scale; (b) cross-section of DPWC at 100 μm scale; (c) residual stabilized earth on DPWC; (d) residual unstabilized Earth on DPWC; (e) and (f) matrix-fiber interfaces.

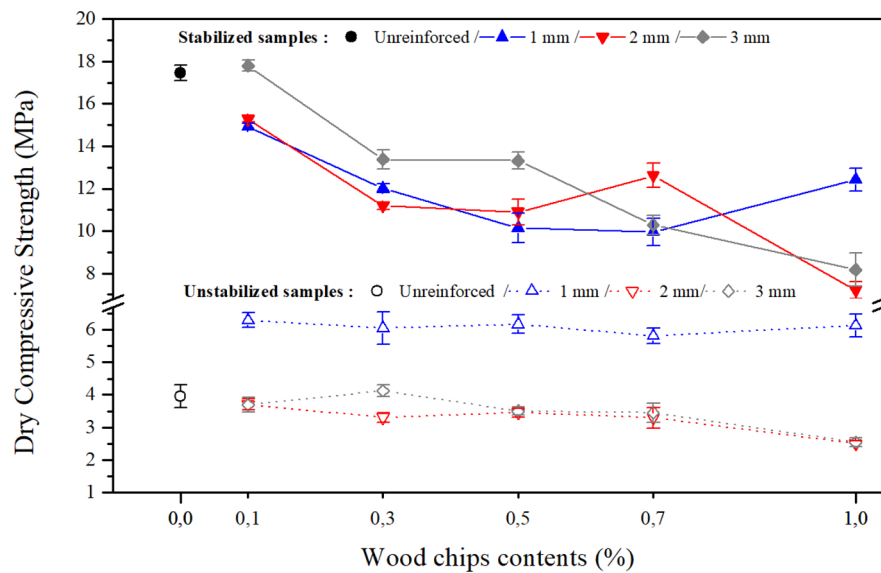


Fig. 8. Compressive strength of stabilized and unstabilized CEB as a function of wood chips thickness and content.

can adversely affect the strength due to the compaction process, which causes the mixture to expand and become more elastic after unloading, thus enlarging the pore network and reducing compressive strength. Similar findings were reported in studies on

sisal, coconut, *Juncus*, and date palm fibers in CEB [15, 20, 41, 42], where increased fiber incorporation led to lower dry compressive strength.

Different behaviors were observed in samples reinforced with wood chips of varying thicknesses.

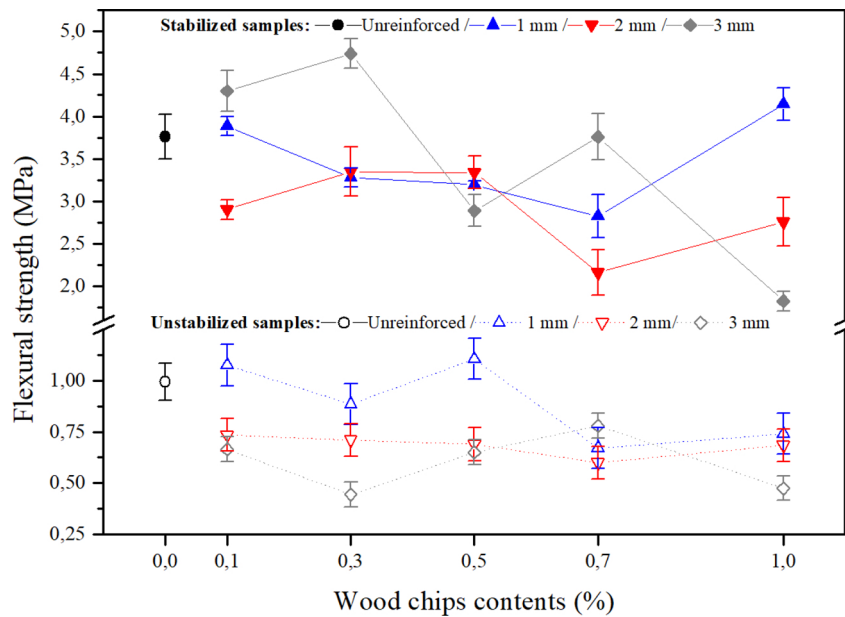


Fig. 9. Flexural strength of stabilized and unstabilized CEB as a function of wood chips thickness and content.

Thinner chips (1 mm) enhanced the compressive strength of unstabilized blocks by 37.17% compared to unreinforced blocks. However, using 2 mm and 3 mm thick chips did not improve the compressive strength of unstabilized blocks. Higher compressive strength was recorded for stabilized blocks with three mm-thick wood chips at 0.1% reinforcement, reaching 17.79 MPa, compared to thinner chips at lower reinforcement contents (0.1%, 0.3%, and 0.5%). Stabilized blocks with cement showed greater stiffness than unstabilized blocks. The improvement in compressive strength with 1 mm chips may be due to their better adhesion with the soil matrix, while their tensile strength complements the lower rigidity of unstabilized samples. This suggests thicker wood chips (3 mm) perform better in rigid, cement-stabilized matrices.

4.3. Flexural strength

The outcome depicted in Fig. 9 represents the dry flexural strength DTS of stabilized and unstabilized compressed blocks reinforced with different thicknesses and percentages of date palm wood chips.

It was observed that stabilized blocks generally exhibited higher flexural strength compared to unstabilized blocks. The flexural strength value without reinforcement was 3.76 MPa and 0.99 MPa for stabilized and unstabilized specimens, respectively. Stabilizers enhance the bonding and filling of the voids between the soil particles, increasing the tensile strength.

The flexural strength of stabilized and reinforced specimens ranged between 1.82 MPa and 4.74 MPa,

depending on the thickness and proportion of wood chips. Specimens reinforced with 1 mm wood chips improved flexural strength by 1%. However, at lower contents (0.1% and 0.3%), the highest flexural strength values were achieved with 3 mm chips compared to 1 mm. No improvement in flexural strength was recorded with 0.5% reinforcement, but two mm-thick wood chips performed better than 1 mm and 3 mm chips at this content. These results disagree with those of Ismail & Yaacob [21], where it was found that increasing proportions of date palm fibers decrease the tensile strength of CEBs.

Thicker wood chips, 3 mm and 1 mm, were found to be more efficient in ameliorating the flexural strength of stabilized blocks compared to thinner chips, 2 mm. The highest bending values recorded were 4.74 MPa for 3 mm chips at 0.3%, 3.34 MPa for 2 mm chips at 0.5%, and 4.14 MPa for 1 mm chips at 1%. Compared to stabilized samples without reinforcement, the improvements in flexural strength for CEBs reinforced with 3 mm and 1 mm chips were 26.06% and 10.10%, respectively. Although the tensile strength of mm-thick wood chips may be weaker than that of 2 mm and 3 mm chips, increasing their numerical density improves the flexural strength of the samples. The unstabilized samples showed an order in flexural strength values of the blocks reinforced with different thicknesses, with better results recorded for 1 mm wood chips. This behavior can be attributed to the compatibility of the fiber strength with the dirt matrix. According to Millogo et al. [48], reinforcing the CEB with natural fibers reduces shrinkage cracks and enhances durability and mechanical performance.

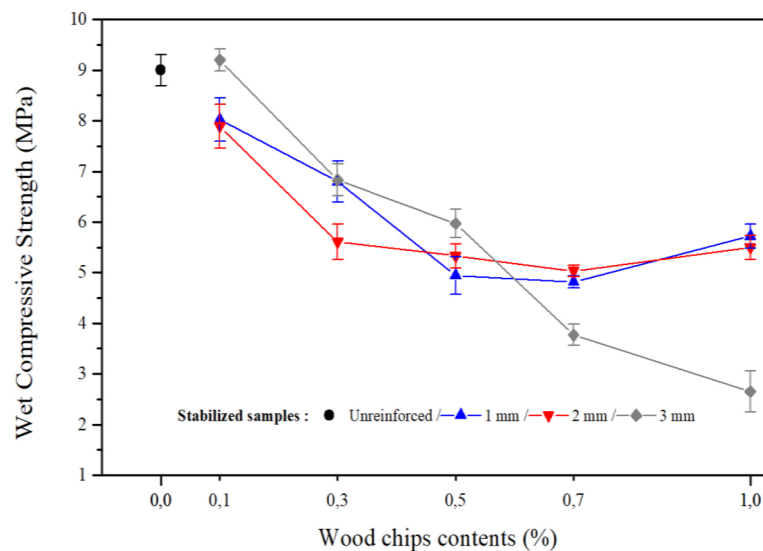


Fig. 10. Wood chip thickness and content on the wet compressive strength of stabilized samples.

Bogas et al. [49] demonstrated that fiber-reinforced blocks have greater bending strength values than unreinforced ones. Furthermore, they noted that this enhancement likely results from the fibers' substantial tensile strength and even distribution and adhesion within the clay matrix.

4.4. Wet compressive strength

Fig. 10 illustrates how varying the thickness of date palm wood chips in different proportions impacts the wet compressive strength of CEBs.

The presence of stabilizers, such as white cement, affects the WCS of the CEBs. Despite the addition of a stabilizer, the WCS decreased as the percentage of wood chips increased, while the stabilizer effectively maintained the cohesion of the soil matrix, in contrast to the unstabilized samples that showed sensitivity and significant damage after being immersed in water, which is consistent with earlier findings [44–48]. These results are in the same context as previous work by other researchers, which suggests that a higher stabilizer proportion improves the wet compressive strength of the blocks [54]. The same tendency was reported by Bastian [43]. WCS of unfilled CEBs values increased from 1.30 MPa to 2.25 MPa, increasing cement contents from 4% to 12%, respectively.

Similar to the results obtained from the dry compressive strength test, the percentage of wood chips in CEB also influences the wet compressive strength. As the proportion of wood chips increased, the WCS of all tested samples decreased compared to the unreinforced blocks. The WCS of samples reinforced with 1 mm, 2 mm, and 3 mm chips decreased by 28%, 30.29%, and 71.19%, respectively, when the

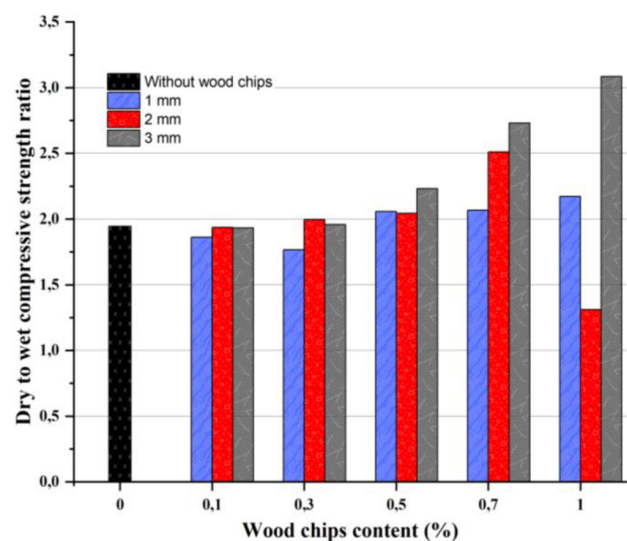


Fig. 11. Dry-to-wet compressive strength ratio of stabilized specimens for wood chips thickness and content.

reinforcement content was raised from 0.1% to 1%. Ismail & Yaacob [21] Observations indicate that higher palm fiber proportion was accompanied by decreased WCS. This decrease can be attributed to the hydrophilic nature of the fibers, which increases water infiltration and moisture content in the samples, thereby affecting WCS [55].

The findings of this study suggest that the thickness of wood chips is an essential element in influencing the wet compressive strength of CEB. Thicker wood chips of 3 mm were found to be more effective in enhancing WCS than thinner chips of 1 mm at lower wood chip proportions. Fig. 11 illustrates the relationship between the dry-to-wet compressive strength

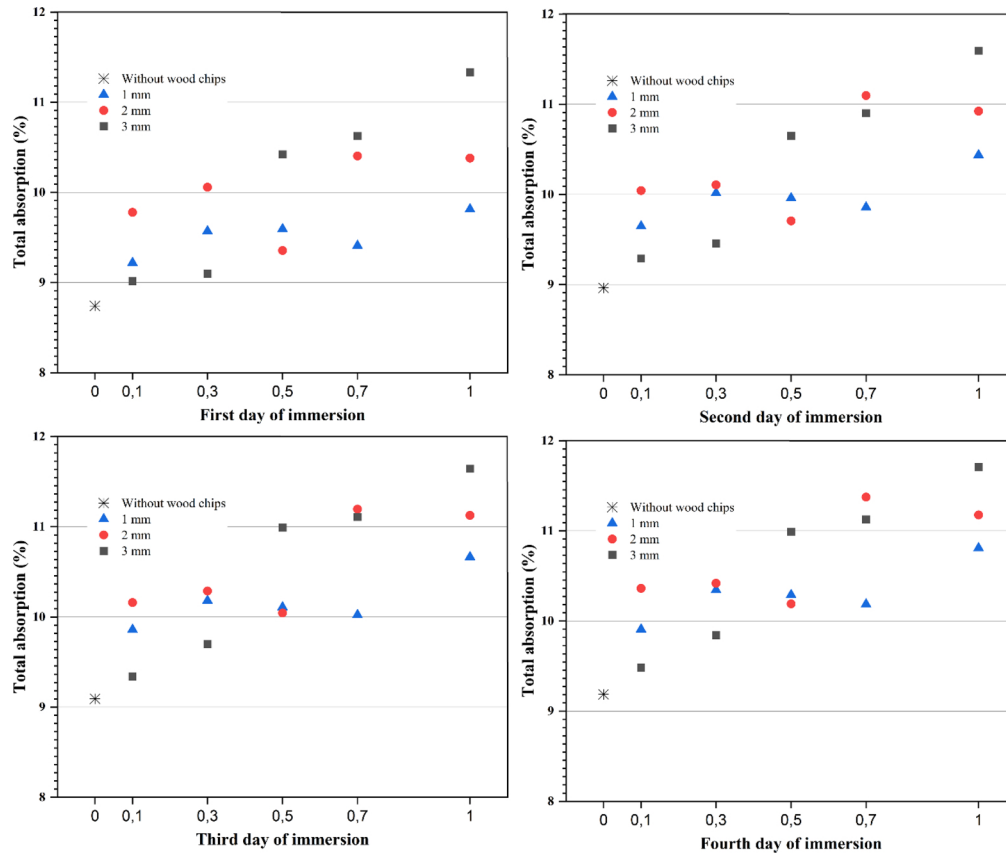


Fig. 12. Effect of wood chips thickness and content on the total water absorption of the stabilized CEB with immersion time.

ratio, wood chips' thickness, and their content in the compressed earthen blocks.

The highest recorded value was 3.08 for 1% wood chips with a thickness of 3 mm. However, the highest DCS/WCS ratio exceeded the recommended limit of two, as proposed by Yusriah et al. [56]. This discrepancy is likely due to differences in the tested specimen dimensions, as water takes longer to infiltrate larger samples than smaller ones. The influence of the lumen size of natural fibers on water uptake was also highlighted, with larger lumen structures allowing fibers to absorb more water [50–52].

4.5. Total water absorption

The total water absorption (TWA) test results during four days of immersion as a function of different contents and thicknesses of date palm wood chips are illustrated in Fig. 12. It can be seen that unreinforced CEB has less absorption than the reinforced samples during water immersion. According to earlier findings, samples that absorb essential moisture tend to degrade rapidly [53, 54]. The values of this test vary from 9.01% to 11.70%. The TWA increased by 8.81%, 13.79%, and 21.03% when the

wood content increased from 0% to 1% for all wood chip thicknesses used in this study, respectively.

The reinforced block with wood chips of 3 mm thickness exhibited less water absorption at wood contents of 0.1% and 0.3%. In contrast, blocks with 1 mm chips and a 1% content showed less water absorption than other thicknesses. These results may be related to the numerical density and distribution of wood chips with different thicknesses in the samples, where a decrease in chip thickness leads to an increase in numerical density. It was observed that all of the unstabilized samples disintegrated during testing, consistent with previous works, which attribute this to the weak cohesion of unstabilized blocks [45, 47, 55–57]. The findings suggest that water absorption experiences a modest rise as the palm wood content increases during the first to fourth day of immersion. The heightened water absorption of the fibers is attributed to their elevated capillarity, porous structure, and hydrophilic characteristics [58–62].

4.6. Thermal conductivity

The thermal conductivity property was studied due to its importance for building insulation, especially

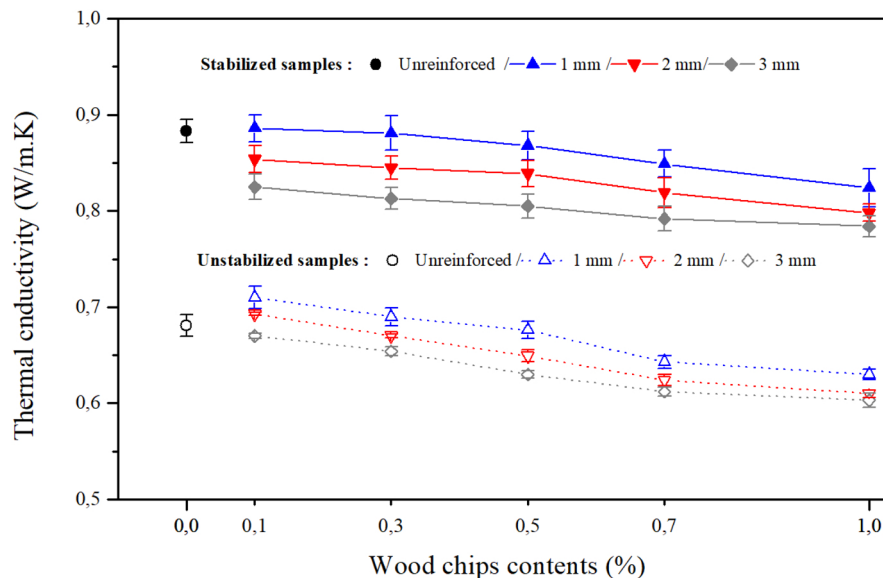


Fig. 13. Effect of DPWC thickness and proportion on stabilized block (CEBs) and unstabilized block (CEB) thermal conductivity.

in hot climates. Fig. 13 presents the thermal conductivity of stabilized (CEBs) and unstabilized (CEB) earth blocks as a function of wood chips content with different thicknesses. The obtained results showed that the thermal conductivity decreased by 6.68%, 9.62%, and 11.21% reinforced with 1% wood chips and thicknesses of 1 mm, 2 mm, and 3 mm, respectively, compared to the unreinforced stabilized earth samples. Presents the thermal conductivity of stabilized (CEBs) and unstabilized (CEB) earth blocks as a function of wood chips content with different thicknesses. The obtained results showed that the thermal conductivity decreased by 6.68%, 9.62%, and 11.21% reinforced with 1% wood chips and thicknesses of 1 mm, 2 mm, and 3 mm, respectively, compared to the unreinforced stabilized earth samples.

It can be seen that raising the content of reinforcement minimizes the thermal conductivity value, which was attributed to the lower conductance of the date palm wood chips compared to the soil matrix. According to Sorea et al. [63], and in line with the results of our research, the presence of the wood, which contains microscopic conduits as shown above, increases porosity while simultaneously reducing the density of compressed earth samples. The thermal conductivity rates vary from 0.71 W/m·K to 0.60 W/m·K for the reinforced and unstabilized samples, where the conductivity of the stabilized and reinforced CEB with different content of wood chips varies between 0.88 W/m·K and 0.78 W/m·K. The unstabilized samples had a lower thermal conductivity than the stabilized samples when cement was used

as a soil stabilizer. These findings are consistent with Bogas et al. [49].

5. Conclusion

This study examined the mechanical, hygroscopic, and thermal properties of stabilized and unstabilized compressed earth blocks (CEBs) reinforced with different thicknesses and ratios of untreated date palm wood chips (DPWC), using chip thickness as a new variable. The findings revealed that 1 mm and 3 mm thick chips significantly enhanced the flexural strength of stabilized blocks at ideal concentrations of 1% and 0.3%, respectively. In contrast, increasing DPWC percentage reduced compressive strength, particularly with larger chips, whereas thinner chips performed better at higher reinforcement levels. Water absorption increased with higher chip content due to the porous, hydrophilic character of the reinforcement, while thermal conductivity reduced, highlighting the potential application of DPWC as a thermal insulator. The interior structure of wood chips contributed to enhanced porosity and fluid transport channels, influencing moisture uptake and heat transfer. These findings indicate that adding 0.3–0.5% of 1 mm or 3 mm chips effectively balances strength and insulation for non-load-bearing or thermally efficient applications in hot areas. Future studies should focus on environmental durability, the combined influence of chip geometry, and field-scale validation to support long-term and practical application.

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Conflict of interest

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Author's contributions

Author #1 Salah Eddine & Mokeddem: Drafted and wrote the manuscript, experimented, and analyzed the results.

Author #2 Abdelmadjid & Hamouine: Assisted in analyzing the structure.

Author #3 Rabia & Abdeldjebar: Assisted in the analysis of the structure and helped in manuscript preparation.

Author #4 Atef & Hamaidi: Supervised the experiment's progress and helped in manuscript preparation.

Ethics

There are no ethical issues with the publication of this manuscript.

References

- Avrami EC, Guillaud H, Hardy M. Terra literature review: an overview of research in earthen architecture conservation. Los Angeles, CA: Getty Conservation Institute, 2008. Accessed: May 27, 2024. [Online]. Available: http://hdl.handle.net/10020/gci_pubs/terra_literature_review.
- Chauhan P, El Hajjar A, Prime N, Plé O. Unsaturated behavior of rammed earth: Experimentation towards numerical modelling. *Construction and Building Materials*. 2019;227:116646. doi:10.1016/j.conbuildmat.2019.08.027.
- Ruiz Valero L, Flores Sasso V, Prieto Vicioso E. In situ assessment of superficial moisture condition in façades of historic building using non-destructive techniques. *Case Studies in Construction Materials*. 2019;10:e00228. doi:10.1016/j.cscm.2019.e00228.
- A B, Mbishida M, Danjuma T. Acoustic Property of NBRRI Interlocking Compressed Stabilized Earth Blocks (ICSEB): A Sustainable Alternative for Building Materials. *Journal of Sustainable Construction Materials and Technologies*. 2025;8(2). doi:10.47481/jscmt.1294558.
- Kerali AG. Durability of compressed and cement-stabilised building blocks. Phd, University of Warwick, 2001. Accessed: May 29, 2024. [Online]. Available: <http://webcat.warwick.ac.uk/record=b1377980~S1>.
- Pacheco Torgal F, Jalali S. Eco-efficient Construction and Building Materials. London: Springer, 2011. doi:10.1007/978-0-85729-892-8.
- Costa C, Cerqueira Â, Rocha F, Velosa A. The sustainability of adobe construction: past to future. *International Journal of Architectural Heritage*. 2018;13:1–9. doi:10.1080/15583058.2018.1459954.
- Pacheco-Torgal F, Jalali S. Earth construction: Lessons from the past for future eco-efficient construction. *Construction and Building Materials*. 2012;29:512–9. doi:10.1016/j.conbuildmat.2011.10.054.
- Rempel A, Rempel A. Frost Resilience of Stabilized Earth Building Materials. *Geosciences*. 2019;9:328. doi:10.3390/geosciences9080328.
- Dayaratne R. Toward sustainable development: Lessons from vernacular settlements of Sri Lanka. *Frontiers of Architectural Research*. 2018;7(3):334–46. doi:10.1016/j.foar.2018.04.002.
- Mazraeh HM, Pazhouhanfar M. Effects of vernacular architecture structure on urban sustainability case study: Qeshm Island, Iran. *Frontiers of Architectural Research*. 2018;7(1):11–24. doi:10.1016/j.foar.2017.06.006.
- Houben H, Guillaud H. Earth construction: a comprehensive guide. In Earth Construction Series. London: Intermediate Technology Publications, 1994.
- Fitzmaurice R. Manual on stabilized soil construction for housing. United Nations. New York: Technical Assistance Programme, United Nations, 1958.
- Baley C. Fibres naturelles de renfort pour matériaux composites. Techniques de L'ingénieur, 2004. doi:10.51257/a-v3-am5130.
- Khedari J, Watsanasathaporn P, Hirunlabh J. Development of fibre-based soil-cement block with low thermal conductivity. *Cement and Concrete Composites*. 2005;27:111–6. doi:10.1016/j.cemconcomp.2004.02.042.
- Scheele S, Harris W. The cultivation, harvesting, and processing of Harakeke (Phormium Tenax) as a source of fibre for inclusion in earth building composites, 1998.
- Ghavami K, Toledo Filho RD, Barbosa NP. Behaviour of composite soil reinforced with natural fibres. *Cement and Concrete Composites*. 1999;21(1):39–48. doi:10.1016/S0958-9465(98)00033-X.
- Alavéz-Ramírez R, Montes-García P, Martínez-Reyes J, Altamirano-Juárez DC, Gochi-Ponce Y. The use of sugarcane bagasse ash and lime to improve the durability and mechanical properties of compacted soil blocks. *Construction and Building Materials*. 2012;34:296–305. doi:10.1016/j.conbuildmat.2012.02.072.
- Danso H, Martinson D, Ali M, Williams J. Effect of sugarcane bagasse fibre on the strength properties of soil blocks, 2015.

20. Taallah B, Abdelhamid G, Guettala S, Kriker A. Mechanical properties and hygroscopicity behavior of compressed earth block filled by date palm fibers. *Construction and Building Materials*. 2014;59:161–8. doi:10.1016/j.conbuildmat.2014.02.058.
21. Ismail S, Yaacob Z. Properties of laterite brick reinforced with oil palm empty fruit bunch fibres. *Pertanika Journal of Science and Technology*. 2011;19:33–43.
22. Mohamed Yusoff MZ, Sapuan S, Ismail N, Wirawan R. Mechanical Properties of Short Random Oil Palm Fibre Reinforced Epoxy Composites. *Sains Malaysiana*. 2010;39:87–92.
23. Laibi A, Poullain P, Leklou N, Gomina M, Sohounhouloué DKC. Influence of the kenaf fiber length on the mechanical and thermal properties of Compressed Earth Blocks (CEB). *KSCE Journal of Civil Engineering*. 2016;168:242–59. doi:10.1007/s12205-017-1968-9.
24. Mostafa M, Uddin N. Experimental analysis of Compressed Earth Block (CEB) with banana fibers resisting flexural and compression forces. *Case Studies in Construction Materials*. 2016;5:53–63. doi:10.1016/j.cscm.2016.07.001.
25. Abdeldjebar R, Hamouine A, Fouchal F, Labbaci B, Zebair A. Effects of treated date palm fiber on durability of stabilized earth blocks (seb). *International Journal of Civil Engineering and Technology*. 2018;9:293–305.
26. Abdelghani I, Hamouine A, Labbaci B, Abdeldjebar R. The Porosity of Stabilized Earth Blocks with the Addition Plant Fibers of the Date Palm. *Civil Engineering Journal*. 2020;6:478–94. doi:10.28991/cej-2020-03091485.
27. Guettatfi L, Hamouine A, Himouri K, Labbaci B. Mechanical and Water Durability Properties of Adobes Stabilized with White Cement, Quicklime and Date Palm Fibers. *International Journal of Architectural Heritage*. 2023;17(4):677–91. doi:10.1080/15583058.2021.1959675.
28. Himouri K, Hamouine A, Guettatfi L. Compressive Creep and Ultrasonic Characterization of Adobe Bricks Stabilized with Quicklime, Portland Cement, and Date Palm Fibers. *International Journal of Architectural Heritage*. 2023;1–20. doi:10.1080/15583058.2023.2262954.
29. Doat P, Hays A, Houben H, Matuk S, Vitoux F. Construire En Terre. Ed. Alternative et Parallèles, 1979. Accessed: May 30, 2024. [Online]. Available: <http://archive.org/details/ConstruireEnTerre>.
30. Mesbah MA, Morel JC, Walker P, Ghavami K. Development of a Direct Tensile Test for Compacted Earth Blocks Reinforced with Natural Fibers. *Journal of Materials in Civil Engineering*. 2004;16. doi:10.1061/(ASCE)0899-1561(2004)16:1(95).
31. Riza FV, Rahman IA, Zaidi AMA. Preliminary Study of Compressed Stabilized Earth Brick (CSEB), 2011.
32. Almi K, Lakel S, Benchabane A, Kriker A. Characterization of Date Palm Wood Used as Composites Reinforcement. *Acta Phys Pol A*. 2015;127(4):1072–4. doi:10.12693/APhysPolA.127.1072.
33. Alshuhail K, Aldawoud A, Junaidi S, Abu-Abdoun I. Enhancing the performance of compressed soil bricks with natural additives: Wood chips and date palm fibers. *Construction and Building Materials*. 2021;295:123611. doi:10.1016/j.conbuildmat.2021.123611.
34. Mesbah MA, Morel JC, Olivier M. Clayey soil behaviour under static compaction test. *Materials and Structures*. 1999;32:687–94.
35. P'Kla A. Caractérisation en compression simple des blocs de terre comprimée (BTC): application aux maçonneries 'BTC-Mortier de terre'. These de doctorat, Lyon, INSA. 2002. Accessed: May 30, 2024. [Online]. Available: <https://theses.fr/2002ISAL0037>.
36. Abdallah R, Carré H, McGregor F. Effect of compaction pressure on the risk of thermal instability of compressed earth bricks. *Mater Struct*. 2024;57(4):84. doi:10.1617/s11527-024-02348-4.
37. Danso H, Martinson DB, Ali M, Williams JB. Physical, mechanical and durability properties of soil building blocks reinforced with natural fibres. *Construction and Building Materials*. 2015;101:797–809. doi:10.1016/j.conbuildmat.2015.10.069.
38. Sadouri R, Kebir H, Benyoucef M. The Effect of Incorporating Juncus Fibers on the Properties of Compressed Earth Blocks Stabilized with Portland Cement. *Applied Sciences*. 2024;14(2). doi:10.3390/app14020815.Art.
39. Taallah B, Guettala A. The mechanical and physical properties of compressed earth block stabilized with lime and filled with untreated and alkali-treated date palm fibers. *Construction and Building Materials*. 2016;104:52–62. doi:10.1016/j.conbuildmat.2015.12.007.
40. Benammar B, Mezghiche B, Guettala S. Influence of atmospheric steam curing by solar energy on the compressive and flexural strength of concretes. *Construction and Building Materials*. 2013;49:511–8. doi:10.1016/j.conbuildmat.2013.08.085.
41. Attoh-Okine NO. Lime treatment of laterite soils and gravels — revisited. *Construction and Building Materials*. 1995;9(5):283–7. doi:10.1016/0950-0618(95)00030-J.
42. Bahar R, Benazzoug M, Kenai S. Performance of compacted cement-stabilised soil. *Cement and Concrete Composites*. 2004;26(7):811–20. doi:10.1016/j.cemconcomp.2004.01.003.
43. Bastian G. Determination of thermophysical characteristics of building materials by the method of the plane source in asymptotic transient regimes. Accessed: May 30, 2024. [Online]. Available: https://www.researchgate.net/publication/368264425_Experimental_and_numerical_study_of_hooked-end_steel_fiber-reinforced_concrete_based_on_the_meso-_and_macro-models.
44. Kenai S, Bahar R, Benazzoug M. Experimental analysis of the effect of some compaction methods on mechanical properties and durability of cement stabilized soil. *Journal of Materials Science*. 2006;41:6956–64. doi:10.1007/s10853-006-0226-1.
45. Namango S. Development of cost-effective earthen building material for housing wall construction, 2006.
46. Oti JE, Kinuthia JM, Bai J. Compressive strength and microstructural analysis of unfired clay masonry bricks. *Engineering Geology*. 2009;109(3):230–40. doi:10.1016/j.enggeo.2009.08.010.
47. Ziegler S, Leshchinsky D, Ling HI, Perry EB. Effect of Short Polymeric Fibers on Crack Development in Clays. *Soils and Foundations*. 1998;38(1):247–53. doi:10.3208/sandf.38.247.
48. Millogo Y, Morel JC, Aubert JE, Ghavami K. Experimental analysis of Pressed Adobe Blocks reinforced with Hibiscus cannabinus fibers. *Construction and Building Materials*. 2014;52:71–8. doi:10.1016/j.conbuildmat.2013.10.094.
49. Bogas J, Silva M, Gomes M. Unstabilized and stabilized compressed earth blocks with partial incorporation of recycled aggregates. *International Journal of Architectural Heritage*. 2018;13:1–16. doi:10.1080/15583058.2018.1442891.
50. Sekhar DC, Nayak S. Utilization of granulated blast furnace slag and cement in the manufacture of compressed stabilized earth blocks. *Construction and Building Materials*. 2018;166:531–6. doi:10.1016/j.conbuildmat.2018.01.125.
51. Millogo Y, Aubert JE, Séré AD, Fabbri A, Morel JC. Earth blocks stabilized by cow-dung. *Mater Struct*. 2016;49(11):4583–94. doi:10.1617/s11527-016-0808-6.

52. Seligmann H, Blake J, Dharni N, Mukherjee A. Rammed earth blocks with improved multifunctional performance. *Cement and Concrete Composites*. 2018;92. doi:[10.1016/j.cemconcomp.2018.04.013](https://doi.org/10.1016/j.cemconcomp.2018.04.013).
53. Lunt MG. Stabilised soil blocks for building. Overseas Building Note no. 184. Building Research Establishment, England: Garston. 1980.
54. Sahari J, Sapuan S, Ismarrubie ZN, Rahman MZA. Comparative Study of Physical Properties Based on Different Parts of Sugar Palm Fibre Reinforced Unsaturated Polyester Composites. *Key Engineering Materials*. 2011;471–472:455–60. doi:[10.4028/www.scientific.net/KEM.471-472.455](https://doi.org/10.4028/www.scientific.net/KEM.471-472.455).
55. Huben H, Rigassi V, Gamier P. Compressed Earth Blocks, Production Equipment. 2nd ed. CDI & CRATerre: Bruxelles, 1996.
56. Yusriah L, Sapuan S, Zainudin ES, Jaafar M. Characterization of physical, mechanical, thermal and morphological properties of agro-waste betel nut (Areca catechu.) husk fibre. *Journal of Cleaner Production*. 2014;72:174–80. doi:[10.1016/j.jclepro.2014.02.025](https://doi.org/10.1016/j.jclepro.2014.02.025).
57. Mokeddem SE, Hamouine A, Abdeldjebar R, Hamaidi A. Mechanical and physical properties of stabilized compressed earth block (CEB) reinforced with date palm wood chips. *Brazilian Journal of Technology*. 2024;7(4):e75934–4. doi:[10.38152/bjtv7n4-036](https://doi.org/10.38152/bjtv7n4-036).
58. Razali N, Salit MS, Jawaaid M, Ishak MR, Lazim Y. A study on chemical composition, physical, tensile, morphological, and thermal property of roselle fibre: Effect of fibre maturity. BioResources. Accessed: May 30, 2024. [Online]. Available: <https://bioresources.cnr.ncsu.edu/>.
59. Wu Z, Xu J, Li Y, Wang S. Disturbed State Concept-Based Model for the Uniaxial Strain-Softening Behavior of Fiber-Reinforced Soil. *International Journal of Geomechanics*. 2022;22:04022092. doi:[10.1061/\(ASCE\)GM.1943-5622.0002415](https://doi.org/10.1061/(ASCE)GM.1943-5622.0002415).
60. Shulley S, Leshchinsky D, Ling HI. Effects of Short Polymeric Fibers on Crack Development in Clays. Fort Belvoir, VA: Defense Technical Information Center, 1997. doi:[10.21236/ADA337814](https://doi.org/10.21236/ADA337814).
61. Yiqun H, Huang J, Zhang W, Liu X. Experimental and numerical study of hooked-end steel fiber-reinforced concrete based on the meso- and macro-models. *Composite Structures*. 2023;309:116750. doi:[10.1016/j.compstruct.2023.116750](https://doi.org/10.1016/j.compstruct.2023.116750).
62. Muñoz P, Letelier V, Muñoz L, Zamora D. Assessment of technological performance of extruded earth block by adding bottom biomass ashes. *Journal of Building Engineering*. 2021;39:102278. doi:[10.1016/j.jobbe.2021.102278](https://doi.org/10.1016/j.jobbe.2021.102278).
63. Sorea S, Messan A, Prud'homme E, Escadeillasc G, Tsobnanga F. Stabilization of compressed earth blocks (CEBs) by geopolymer binder based on local materials from Burkina Faso. *Construction and Building Materials*. 2018;165:333–45. doi:[10.1016/j.conbuildmat.2018.01.051](https://doi.org/10.1016/j.conbuildmat.2018.01.051).