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Original Article

Mechanical Behaviour of Compressed Earth Block Masonry Wallets Reinforced With Lignocellulosic Coconut Fibre under Diagonal Compression

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Abstract *- This study examines Compressed Earth Block (CEB) masonry wallets manufactured with coconut fibre contents of 0.0%, 0.1%, 0.3%, 0.5% and 0.6% by dry soil mass. Soil from Palián, Huancayo, was used to prepare the units, which were evaluated for mass, water absorption and compressive strength; assembled wallets were assessed under diagonal loading. The recorded compressive strength of the blocks reached 0.441 kgf/cm² at 0.3% fibre, compared with 0.435 kgf/cm² in the control series, while water absorption increased from 10.42% to 10.92%. For the wallets, the mean reported diagonal resistance increased from 7.273 to 7.370 kgf/cm² (+1.33%) between the control and 0.3% series (three specimens per group). Higher fibre contents were associated with lower recorded compressive strength and greater absorption. The 0.3% dosage yielded the highest mean values among the tested configurations; however, the small sample and differences in test geometry and data processing limit broader claims of optimality. The findings document the strength-absorption trade-off and provide a dataset for further evaluation of earth masonry containing locally available natural fibres.*

Keywords *- Compressed Earth Blocks, Coconut fibre, Diagonal compression, Masonry wallets, Sustainable construction.*

1. Introduction

The building industry is facing increasing challenges related to environmental sustainability. These problems come from the large amount of energy needed and the pollution caused when making traditional materials like fired clay bricks and Portland cement. In the Peruvian context, this issue is of particular pertinence.

A multitude of technical reports have demonstrated that the production of fired bricks at a small-scale result in substantial emissions of particulate matter and air pollutants. These emissions have been found to exceed environmental quality standards and have a detrimental effect on public health and the environment.

This has been seen in places like San Jerónimo (Cusco) and Huachipa (Lima) [1-3]. As shown in Figure 1, this is mostly because of the negative effect that air pollution has on the environment, which has a direct and significant effect on the population. Firing at high temperatures uses a lot of energy and releases a significant amount of CO_2 into the atmosphere. This has led to the search for ways to build that are less harmful to the environment.



Fig. 1 Air pollution from brick kilns [1]

In this situation, the use of Compressed Earth Blocks (CEB) is reconsidered as a sustainable option because they require little energy for production and do not need to be fired [2]. As shown in Figure 2, making fired clay bricks causes much higher levels of CO2 emissions and energy use compared to making unfired alternatives. These observations validate unfired earth materials (CEBs) as an option that can indeed the environmental impact of the construction industry [3].

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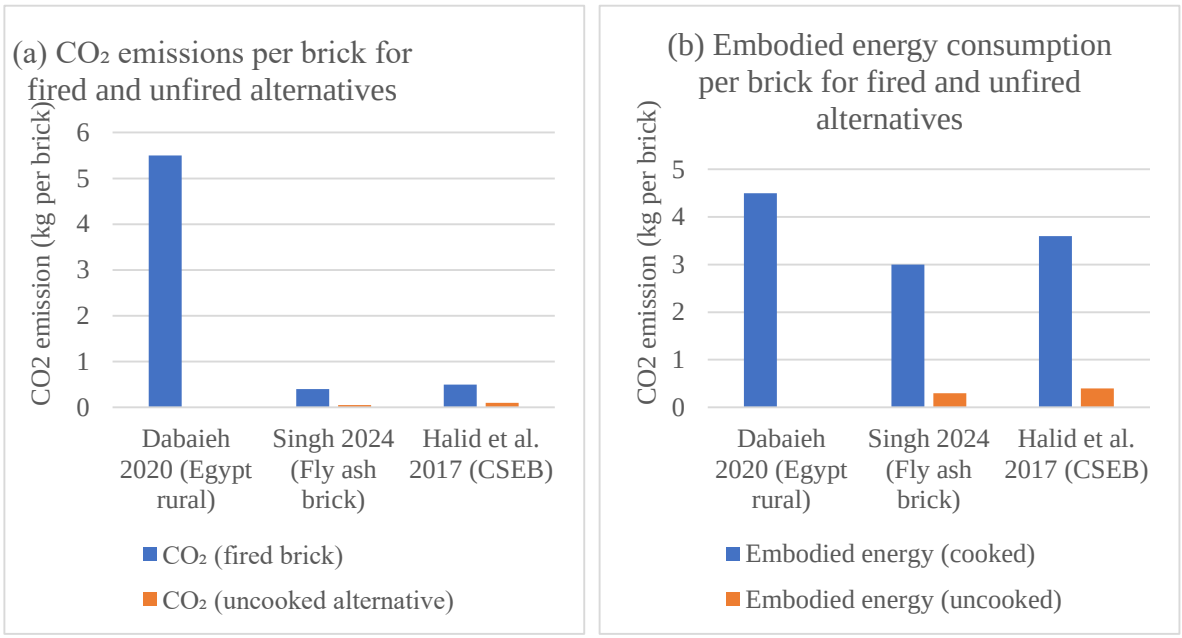

Fig. 2 (a) CO_2 emissions per brick for fired and unfired alternatives, and (b) Embodied energy consumption per brick for fired and unfired alternatives [3].

Nonetheless, there are technical limitations of traditional CEBS and how these can be employed. These limitations are related to their low mechanical strength, their tendency to break when they are subjected under pressure, and their trend to absorb water. All these characteristics have exhibited their effect on reducing the durability and load-bearing capacity of traditional CEBS, especially in Peruvian areas with a high occurrence of earthquakes [4].

On the other hand, many investigations have validated that the addition of natural giver into CEB and CSEB improves their material's resistance against cracking resistance, cracking behavior and boosts their strength. Among these fibres, coconut fibre has attracted a lot of interest because it is readily available, inexpensive, and effective. However, some studies have shown that soil strength increases when the fibre content is reduced. This is typically between 0.3% and 0.6% of the soil's weight. However, higher dosages have been observed to increase porosity and water absorption. Researchers have been studying how to make it stronger by adding natural fibres. Among these, coconut lignocellulosic fibre has shown good results because it is easy to get, cheap, and strong enough to be used. Experimental studies report increases in compressive and flexural strength with optimal fiber content between 0.3% and 0.6% by weight of the soil; however, higher dosages tend to increase porosity and water absorption [5-8]. On top of that, fibre addition can help improve crack control and the post-cracking behaviour of the material [9]. There is a lack of studies that analyze the behaviour of CEB walls reinforced with coconut fibre under shear stress loads. The diagonal compression test is widely used to measure the wall strength and carry out a cracking analysis; this test provides insights into the seismic resistance of walls. However, the effects of coconut fibre dosages and packing density on the wall strengths are still an object of study for researchers [10].

In this regard, this study analyses the response of earth block walls reinforced with coconut fiber under load conditions, measuring the bending and strain. In addition, this study gives insight into the optimal dosage of fiber and its effects on the compressive strength and water absorption of the earth blocks, which are also environmentally friendly.

The bricks made with conventional materials help to reduce environmental impact, and they also make an important contribution to the environment and the rural economy. Compressed masonry bricks require greater attention during their production, because they are made in an artisanal way by local people for personal use. When natural fibers are incorporated into bricks as reinforcement material, poor dosage can be harmful to the stability of the project. There are studies on the addition of coconut fiber that help to improve the properties of the materials that compose them [11].

Recent studies have shown suitable results for coconut fiber. The most relevant point is the improvement of its mechanical and physical properties, obtaining adequate data in flexural behavior, abrasion resistance, and, under certain manufacturing conditions, improvement in compressive strength. These characteristics help to improve the efficiency of artisanal houses built by local people, providing sustainable constructions for their environment [12, 13].

The reviewed studies address the use of components used in masonry bricks individually, because they may present incompatible or harmful characteristics for this alternative construction material. This uncertainty helped to propose the interaction of masonry brick components with natural fibers. Some studies helped to identify the effect of coconut fiber incorporated into the mortar used in clay brick masonry, and variations were observed in compressive, flexural, and diagonal compressive behavior [14]. Materials such as steel and bamboo were also included in masonry, and these offered suitable improvements, as occurred with the use of lignocellulosic coconut fiber incorporated directly into the blocks [15]. The review of recent background studies shows that the use of natural fibers, either as a replacement or as an addition in earth-based materials, has gained greater interest as a strategy to improve mechanical performance for the construction of rural houses and, at the same time, reduce the environmental impact of construction materials in areas where these materials are scarce or very expensive. Recent studies have shown that the behavior of reinforced earth blocks depends on the type, content, and treatment of the incorporated fiber [12]. When areca, coconut, and flax fibers were evaluated, improvements were observed in the mechanical behavior of reinforced soil blocks, highlighting the potential of coconut fiber. Similarly, [10] evaluated the interaction of different plant fibers with masonry walls and found that they can significantly improve the flexural strength of compressed earth blocks, although small reductions were observed in the compressive strength test. This behavior was related to the fiber dosage used and to the behavior of the unified components [16]. It was also observed that different natural fibers can adapt better to the fiber-matrix interaction. This behavior helps to obtain favorable mechanical and water-related properties in the blocks. New studies show the use of earth-based materials reinforced with lignocellulosic fibers. This incorporation works properly, but with some small limitations. Therefore, its evaluation continues to focus mainly on the properties of the units, and a greater characterization of the mechanical behavior of masonry systems is still needed. Experimental evidence verified through the integration of materials compatible with walls and natural fibers, or lignocellulosic coconut fiber, shows suitable improvements under continuous diagonal compression.

The identified research gap is highly relevant because the improvements obtained in individual blocks are not enough to determine the combined behavior of the components in masonry walls subjected to in-plane shear stresses. Therefore, it is necessary to study the block-mortar interaction through crack propagation and the failure mechanisms of the system. For this reason, the present study evaluates the mechanical behavior of masonry wall specimens made with compressed earth blocks reinforced with lignocellulosic coconut fiber under diagonal compression, with special attention to their strength response and cracking and failure mechanisms. Due to this uncertainty, the research seeks to verify, promote, and expand the available evidence, from an individual point of view to an integral point of view of the components with which the masonry wall will interact [11, 14, 15].

Performing a comparison with related studies requires to distinguish the fibre reinforcement of the individual earth units from the diagonal loading of masonry assemblies. Sujatha et al. [12] reported the fibre-dependent performance of blocks, Kamalizad and Morshed [34], on the other hand, studied common-reed-reinforced walls under cyclic lateral loading. In diagonal compression, 48 interlocking CSEB panels were investigated by Kasinikota and Tripura [44], including the effects of coir fibres and also additional steel or bamboo reinforcement. Unlike to those configurations, the present data concern the specified Palián soil, a low coir-dosage series and the coupled block/wallet response, any numerical comparison must account for different stabilisation, geometry and loading protocols.

Existing evidence indicates that the natural fibres can modify the behaviour of earth units, however, block-level results alone do not quantify the mechanical response of their masonry assemblies. What previous studies have already examined are coir-fibre earth panels under diagonal loading [44]. The contribution of the present work is, therefore, narrower: the comparison of five low coconut-fibre dosages by using soil sourced from Palián (Huancayo), combined with block absorption, compressive response and wallet-level diagonal resistance under the reported laboratory conditions. The present study evaluates the response of CEB masonry wallets incorporating 0.0-0.6% coconut fibre, and it compares the recorded strength and absorption values without assuming that one single dosage is universally optimal.

2. Materials and Methods

2.1. Materials used

A comparative experimental program was used in order to examine the effects of the coconut-fibre dosage over the physical and mechanical response of compressed earth blocks and also of the assembled masonry wallets.

2.2. Soil for the Manufacture of CEB

The soil employed to make the Compressed Earth Blocks (CEBs) came from a local deposit in Palian, Huancayo (Junín, Peru). The subsurface material was chosen with the purpose to minimize the presence of organic matter, as illustrated in Figure 3. The soil was later transferred to the laboratory in sealed containers, and then the soil underwent through an air-drying process and manual fragmentation to dislodge roots, clumps of organic matter and oversized part. The performed analysis of the particle size distribution revealed a continuous spectrum of sizes that are favorable for CEB manufacturing, comprising gravel (26.57%), sand (49.55%) and fines (silts and clays, 23.88%), as exhibited in Figure 4. The absence of significant coarse particles indicates that the material is suitable for the compaction processes.



Fig. 3 Soil for Compressed Earth Blocks

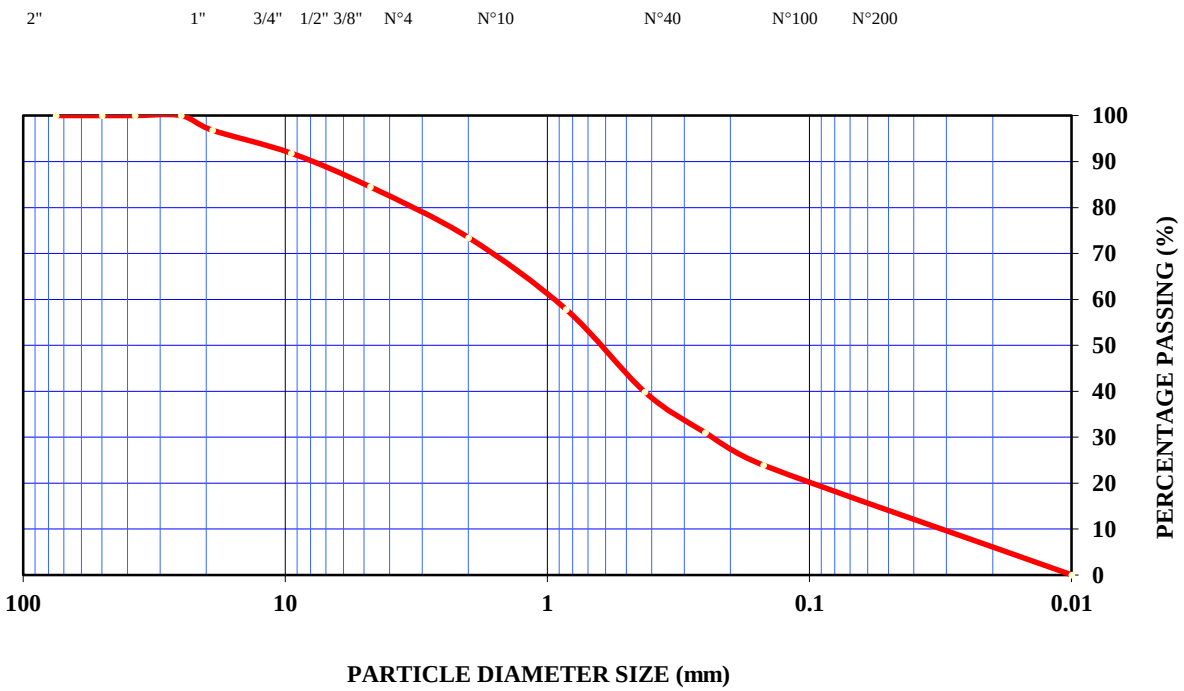

Fig. 4 Particle size distribution chart

With the objective to determine the compaction parameters, a modified Proctor test (method A) was performed, this execution triggeres a maximum dry density of 1.86 t/m³ and an optimum moisture content of 10.1%, as depicted in Figure 5. These parameters were used in order to determine the dosage and manufacturing process for the blocks, which ensured the correct density and resistance.

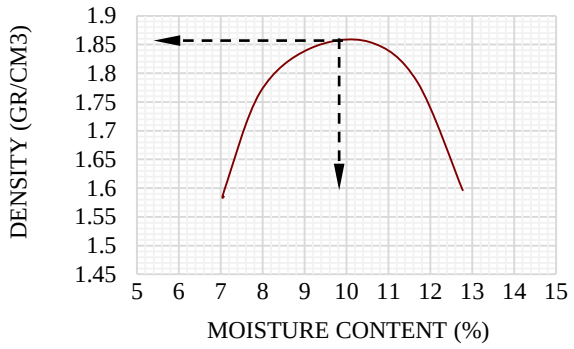

Fig. 5 Density curve

2.2.1. Coconut Fiber

In this study, coconut fibre—a natural lignocellulosic material obtained from the mesocarp of Cocos nucifera—is used as a natural reinforcement for compressed earth materials because of its ability to improve mechanical performance. The fibres are cut to a nominal length of 50 mm and then are added to the soil mixture; a diameter range of 150–400 µm was considered, as reported by previous studies [13]. The elongated shape of the coconut fibre improves the mechanical interaction in the soil matrix and helps bridge cracks [13]. Figure 6 shows the coconut fibre used for the experimental procedure.



Fig. 6 Coconut fiber

Before being added to the mixture, the coconut fiber was prepared by washing it with water to remove surface impurities. It was then air-dried and cut to the required length. This preparation procedure was used to help distribute the fibers more evenly during mixing and to reduce local fiber agglomeration. The main characteristics considered for the coconut fiber are summarized in Table 1. Except for the fiber length and the conditioning procedure applied experimentally in this study, the characteristics taken from previous studies are presented as reference values.

Table 1. General characteristics of the coconut fibre considered in the study

Properties	Description / Value
Origin	Mesocarp of the *Cocos nucifera fruit*
Fiber type	Lignocellulosic natural fiber
Average length	50 mm
Approximate diameter	150 – 400 µm
Fiber status	Natural
Pretreatment	Wash with water, air dry and cut
Usage in the mixture	CEB reinforcement

Note: The fiber length and pretreatment correspond to the experimental procedure used in the present study, while the approximate fiber diameter was taken from previously published literature [13].

Since no independent chemical characterization of the coconut fiber was carried out in this study, the reference physicochemical properties reported in previous experimental research are presented in Table 2 only to provide context for the characteristics of this lignocellulosic reinforcement, according to [17].

Table 2. Reference physicochemical characteristics of coconut fibre reported in the literature

Property	Reported value
Cellulose	47.20 %
Hemicellulose	1.25 %
Lignin	45.25 %
Pectin	6.30 %
Density	1.05 g/cm³
Average diameter	417 µm
Tensile strength	125.45 MPa

The lignocellulosic character of the coconut fibre may influence the moisture uptake and also the fibre-matrix interface. The actual fibre chemical composition was not measured in this study, the values quoted in Table 2 are literature data, and these values should not be interpreted as material-specific laboratory measurements.

2.3. CEB Production

The Compressed Earth Blocks (CEBs) were produced considering two main elements: first, the mixture according to the soil-to-water ratio had to be adjusted; second, the quantity of coconut fiber that had to be employed. The aim was to produce a consistent material with the most suitable physical and mechanical properties, as determined by previous studies of CEBs reinforced with natural fibres [18, 19].

The mixing water was selected in reference to the compaction programme, the reported nominal water content was approximately 10% of the dry-soil mass. The exact compaction optimum and the cited Proctor procedure require confirmation against the laboratory worksheet.

Additionally, the coconut fiber was also added to the soil at 0.1%, 0.3%, 0.5%, and 0.6% by weight. These proportions were selected based on findings from previous studies [5, 6]. These previous studies indicated that small additions of this coconut fiber can improve the strength of the soil under compression and bending.

Nevertheless, adding higher dosages can make the mix more absorbent and can affect its effectiveness and how long it lasts.

The effect of the fiber on CEB properties was evaluated by using these percentages, this permitted the optimal content to be determined with the aim to maximize its strength without compromising compactness or durability. At last, the manufacturing process was broken down into three stages, these three stages are: mixing, compacting and storing. To make things easier to understand, a helpful flowchart in Figure 7 that shows the whole process step by step and highlights the most important factors that influence how well the material works was created.

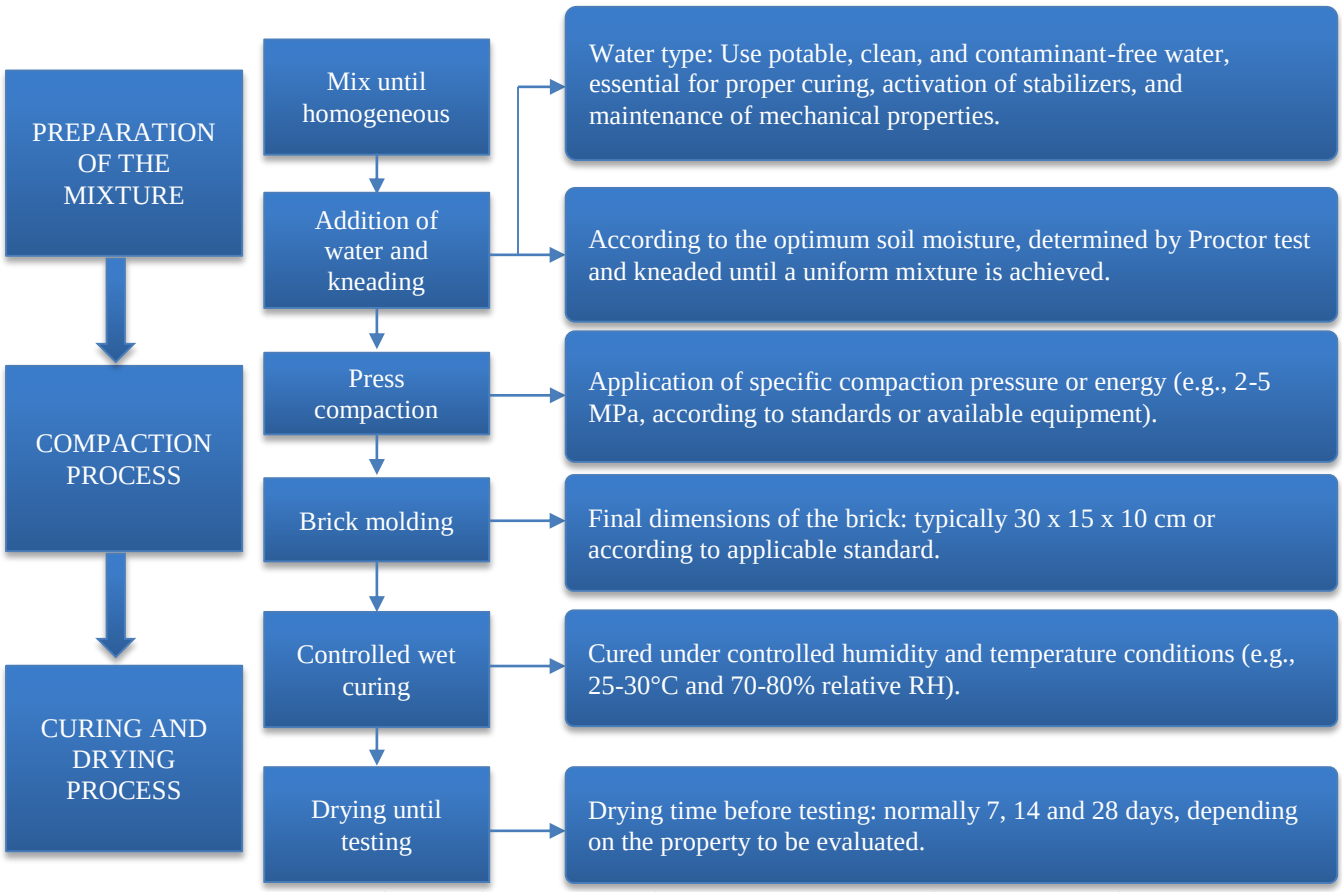

Fig. 7 Flowchart of the manufacturing process of compressed earth blocks reinforced with coconut fiber

The mixture of the brick is made by mixing soil, water and coconut fiber in a 12 x 23 x 9 cm mould. The experiment employed 2,325 g of soil and 300 ml of water. Also, the coconut fiber was added at percentages of 0.1%, 0.3%, 0.5%, and 0.6%, as exhibited in Figure 8.

Soil, water and the coconut fibre were mixed and compacted into the stated moulds. The fibre content was varied by the dry-soil mass, and the resulting specimens were compared in the specified curing ages, the laboratory programme does not establish one universal optimum dosage. The samples were evaluated after curing periods of 7, 14, and 28 days. Three specimens were taken from each mix design, giving a total of nine units per treatment, as depicted in Table 3. This design permitted to notice to asses the evolution of mechanical properties over time.

Table 3. Test wall codes

Item	Description	Curing Time			Amount
		7	14	28	
1	SF-0.0%	3.0	3.0	3.0	9.0
2	SF-0.1%	3.0	3.0	3.0	9.0
3	SF-0.3%	3.0	3.0	3.0	9.0
4	SF-0.5%	3.0	3.0	3.0	9.0
5	SF-0.6%	3.0	3.0	3.0	9.0

Three replicate units were assigned to each one of the combinations of five fibre contents and of three reported curing ages, giving 45 unit-level observations in the planned

experimental matrix. The number of wallets tested for diagonal resistance is reported separately, and this number is not added to this count.



Fig. 8 Compressed earth blocks are categorized according to their dosages

Once the masonry blocks were obtained and cured, they were assembled under the same geometric conditions, using suitable units for each wall specimen. The preparation of the wall specimens was based on ASTM E519/E519M-22, which is a standard used to determine the diagonal tensile or shear strength of masonry assemblages by applying a compressive load along one of their diagonals [20]. This standard allows the test to be used with different dimensions and makes it possible to evaluate variables such as the type of unit, the mortar, and the manufacturing conditions, as long as the specimens are built according to the dimensions established in the standard.

Similarly, [15] evaluated masonry specimens built with compressed earth blocks, including systems joined with mortar and square specimens subjected to diagonal compression. In the present study, all wall specimens were built under equivalent conditions and followed the same procedure before testing. This was done to ensure comparability between the different fiber dosages.

2.4. Tests Performed

2.4.1. Weight of Each Brick and Wall

The bricks were tested after the drying period. Later, a calibrated digital scale (±1 g) was employed with the objective to weigh each unit, while the mass (M) of each brick was recorded in grams. Additionally, each mix was tested using at least three units, from these tests, the mean and standard deviation were then calculated. The walls were built using the same shapes for all mixes. A higher-capacity scale was used to measure the total weight (Mt), which was recorded in kilograms. As a consequence, the evaluation permitted to establish the way in which the weight changes according to the content of fiber, according to the consistency of the results, and according to the comparison between units and wall. Also, it is relevant to mention that these procedures followed the standards for testing masonry, which are outlines in ASTM C140 [21] and NTP 399.613.

2.4.2. Water Absorption Test

Regarding the water absorption test of the blocks, the units were dried to a constant mass (e.g. in an oven at 105 ± 5 °C or following the laboratory procedure). Later on, they were cooled to room temperature, and the dry mass M_d was recorded. After this first process, the blocks were totally submerged into water for a period of 24 hours. After that, surface moisture was carefully removed with a damp cloth, without extracting water from the interior, and the saturated mass M_s was recorded. The water absorption (Abs) was then calculated as follows:

$$Abs(\%) = \frac{M_s - M_d}{M_d} x100$$

In this equation, Ms is the mass of the saturated block (in grams), and Md is the dry mass (also in grams). The results were reported according to fiber dosage, including the mean and standard deviation for each case. The test's objective is clear: to ascertain if increasing the fibre content results in enhanced porosity and absorption. It is clear that these things will affect the duration of the CEB. Absorption was carried out in accordance with NTP 399.613 and ASTM C67/C67M [22]. The latter sets out how absorption in masonry units is determined. The water absorption was calculated from the oven-dry and the saturated mass records, and it was compared across the mixtures. Absorption was used as an indicator of moisture-sensitivity, porosity and long-term durability were not directly determined.

- The more fibre in the material, the more it is absorbed. This is probably because the material has more holes.
- The consistency of the material is measured using a number called CV%.
- The durability of the material is easily estimated through observing at its absorption capacity because a higher absorption level indicates a greater susceptibility to moisture.

2.4.3. Compression Strength Test

The blocks were manufactured and set by following the steps described in Section 2.3. For each mix design, three specimens were first selected and then inspected with the aim to ensure they have a good condition, with no cracks, chipped corners, or other visible defects.

Before testing the specimens, the dimensions of each block were measured in order to determine the load-bearing area (A). Then, the surface was prepared with the objective to ensure a uniform contact with the press plates (e.g. surface sanding or the application of a thin mortar layer or capping, depending on the available resources). The preparation of the surface is the last step, but it is also a critical one because it permits to evade the concentration of stress and premature failure, two issues that are outlined in Peruvian Technical Standard NTP 399.613.

It was necessary to evaluate the performance of the sample blocks over time for the assessment of their strength after a 7, 14, and 28 days of curing. For this process, each block was thoroughly positioned at the centre of the compression machine to ensure the optimal alignment and axial loading. Right after this, the load was steadily and applied with control until failure occurred. The maximum load P_{max} was recorded at the failure time.

The different types of failure were also recorded, among them there were vertical cracking, hear disintegration, crushing, and plane separation, because it was already known that fibers could change the cracking pattern and post-cracking behavior of compressed earth blocks [23]. The compressive strength, also known as f_c, was calculated using the following equation:

$$f_c = \frac{P_{max}}{A}$$

Hence, in this equation, P_{max} is the maximum applied load (in newtons), and A is the loaded area (in millimetres squared).

Data was analyzed according to dosage and curing age in order to determine the mean, standard deviation, and coefficient of variation, and the compression results were evaluated at two levels:

a) Changes over time (7–14–28 days) were analyzed by comparing the mean f_c values for each mixture to evaluate the strength gain during curing
b) Comparing dosages at the same age, the f'_c values of M1, M2, M3, and M4 at each curing age were compared to determine which dosage provided the highest strength with the lowest variability (CV%).

A comparison between dosages for specimens within the same age group was carried out through the evaluation of the f'_c values of M1, M2, M3, and M4 at each curing age to determine which dosage provided the highest strength and the lowest variability (CV%).

2.4.4. Joint Assessment of Strength and Absorption

The compressive strength and the water absorption were compared within each one of the fibre dosages in order to describe the measured trade-off. The criteria were a higher compressive strength and lower absorption, no weighted optimisation function or durability index was calculated.

- High compressive strength.
- Low water absorption.
- Low statistical dispersion (CV%).

The joint interpretation was limited to the properties that were measured in the experimental programme, in particular, an increased absorption was not considered as proof of a quantified change in the pore structure or in the long-term service life [22].

2.4.5. Diagonal Compression of Masonry Wallets

Diagonal compression tests were conducted on the masonry wallets after curing. The loading configuration, failure resistance and the associated deformation records were organised in the experimental spreadsheet for the comparison between the unreinforced and coconut-fibre series. Spreadsheet formulae were used for automated calculations and graphical interpolation, they were not used as additional replicate tests.

During the test, the applied load, deformation response, crack development, and failure behavior were recorded. The experimental setup was established based on the applicable procedures for diagonal compression testing of masonry assemblages.

Statistical treatment: the peak-resistance comparison comprises three wallets for each reported condition. The means, the sample standard deviations and coefficients of variation were used in a descriptive way. Interpolated points in the spreadsheet were not considered as additional replicates, no inferential claim is made on the superiority of the 0.3% dosage.

The workbook records tested wallet dimensions close to 0.61 m by 0.60 m and approximately 0.14 m thickness, these differ from the nominal dimensions that were previously stated in this section. The effective test geometry and the loaded area must be reconciled against specimen sheets before deriving the final stress or modulus values.

Once the curing process finished, the analysis of the walls was performed in order to evaluate their output. Indeed, it was during the evaluation that cracks, collapses, joint separations, and areas of concentrated damage were identified. As a consequence, it was necessary to evaluate the walls based on the different fibre contents. From this assessment, it is concluded that fibers can limit the propagation of cracks in the infrastructure. Nevertheless, the addition of these fiber also increased the porosity and reduced the corresponding strength of the material. These findings go in line with the results reported in other studies on natural fibre–reinforced materials [24].

Crack development, local crushing and joint separation were considered on the qualitative failure assessment, the comparison is restricted to the loading arrangement that was used in the present programme.

- The ease of placement is determined by the workability of the material and its block cohesion.
- Ease of placement, based on workability and block cohesion.
- The alignment and overall stability of the wall must be ensured.
- The presence and pattern of cracks should be noted.

- The material's surface integrity is susceptible to wear and tear, crumbling and similar issues.
- Vertical, diagonal, or joint-oriented patterns characterised the primary form of cracking observed in the structure.

The analysis followed on the general rules for masonry prisms outlined in ASTM C1314 [25] and NTP 399.621 guidelines, as illustrated in Figure 9. The objective was clear to identify the types of cracking patterns and typical failure modes involved.



Fig. 9 Diametral wall test

The diagonal compression test was performed. The peak resistances that are reported are drawn from the laboratory workbook, the effective dimensions and the load-to-stress conversions remain subject to the final unit audit.

3. Results and Discussion

3.1. Weight of Each Brick and Wall

The observed block and wallet masses were compared across the five reported fibre dosages. The small magnitude of the change should be distinguished from the larger changes that are expected in the density or in the structural load for other fabrication conditions.

Along the evaluated dosages, the plotted values in Figure 10 decline from approximately 2999 g to 2982 g, these values do not support an assertion of a substantial weight reduction. [5].

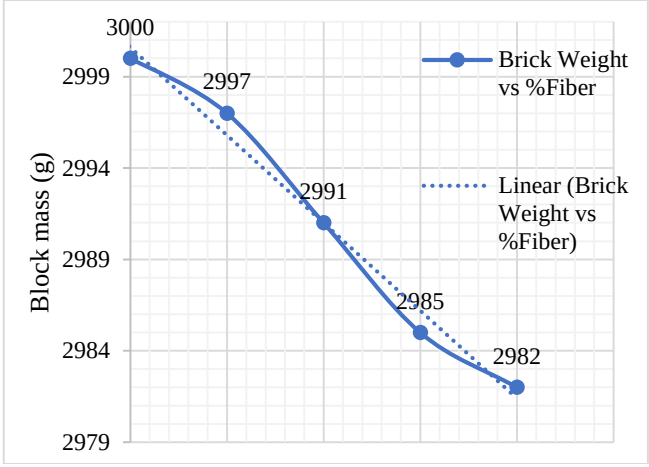

Fig. 10 Weight results for each brick

The corresponding plotted masses of the wallets changed from about 60.00 kg at 0.0% fibre to 59.64 kg at 0.6% fibre, this represents a small difference inside the analysed series, and not evidence of a large reduction in the building loads [5, 26].

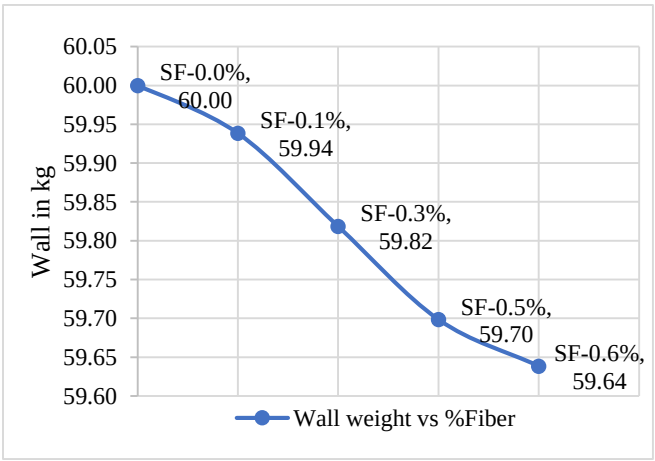

Fig. 11 Weight results for each wall

3.2. Water Absorption Test

Table 4 reports the dry and saturated masses and the resulting absorption percentages for the five mixtures. For the 0.5% fibre, the dry and saturated masses are 25.53 and 28.45, respectively, the corresponding absorption is 11.45% (the 28.45 value is a mass, not an absorption percentage). The control and the 0.3% groups recorded absorption values of 10.42% and 10.92% [27].

Table 4. Absorption of compressed earth blocks

Samples	Ws	Wh	Ps	Percentage
Patron	16.00	17.67	1.67	10.42%
STF-0.1%	19.71	21.80	2.09	10.59%
STF-0.3%	21.19	23.50	2.31	10.92%
STF-0.5%	25.53	28.45	2.92	11.45%
STF-0.6%	27.47	30.85	3.38	12.30%

In Table 4, the variations in water absorption related to the behavior of compressed earth blocks reinforced with coconut fiber can be observed. These differences may be due to small variations in the preparation of each sample, such as moisture content, mold dimensions, compaction conditions, and curing time.

For the mass tests, a calibrated digital scale with an accuracy of ±1 g was used. In the absorption tests, the drying, immersion, and mass recording conditions were kept constant. The variations in absorption or mass may also be influenced by the origin of the coconut fiber, since it can contribute to void formation, moisture absorption, and a heterogeneous soil–fiber matrix.

The results therefore describe a trend of increasing absorption along the evaluated dosages. Because the independent measurements of pore structure were not conducted, the change cannot be attributed exclusively to a measured increase of porosity.

3.3. Compression Strength Test

Table 5 lists the reported nominal values of compressive strength: 0.435, 0.437, 0.441, 0.425 and 0.422 kgf/cm² at the fibre contents of 0.0%, 0.1%, 0.3%, 0.5% and 0.6%, respectively, the largest reported value occurs in 0.3% fibre (+1.38% versus the control). The 3600 cm² area that is printed in Table 5 is inconsistent with the dimensions that were specified for individual units and calls for the verification of the tested element and actual loaded area before these stress units can be considered final [28-30].

Table 5. Compressive strength of compressed earth blocks

Samples	Area cm2	Load Performed kg	Wall Resistance kg/cm2	Trend
Patron	3600	1565.00	0.435	0.435
STF-0.1%	3600	1572.65	0.437	0.437
STF-0.3%	3600	1587.08	0.441	0.441
STF-0.5%	3600	1531.58	0.425	0.425
STF-0.6%	3600	1520.58	0.422	0.422

3.4. Resistance-Absorption Relationship (Equilibrium Criterion)

The combined comparison in Figure 12 indicates that the reported value of compressive strength reached a maximum with 0.3% fibre (0.441 kgf/cm²), whereas the water absorption rose from 10.42% in the control to 10.92% at this dosage. At 0.6%, the corresponding values were 0.422 kgf/cm² and 12.30%, this describes a trade-off inside the experimental series, and not a quantified durability benefit or an independently measured change of porosity.

The original editable chart is retained and its plotted axes and scale must be checked against the verified workbook before final submission [31].

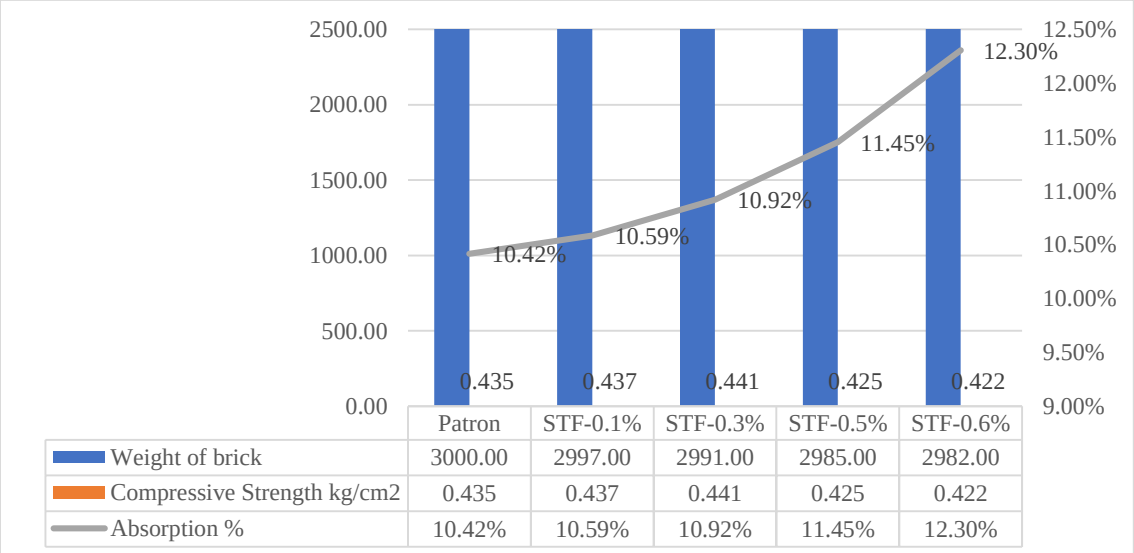

Fig. 12 Resistance-absorption relationship (equilibrium criterion)

3.5. Diagonal Compression Test on Masonry Walls

Figure 13 summarises the processed diagonal-resistance curves for all the fibre dosages, and Figures 14 and 15 show the three curves of the specimens for the control and the 0.3% mixtures. The reported maximum mean diagonal resistance was 7.273 kgf/cm² for the control and 7.370 kgf/cm² for the 0.3% series (+1.33%), other dosages showed lower mean values in the available workbook. Since some of the curve points were interpolated or generated by formulae of the workbook, these are presented as processed curves and not as new independent observations [28].

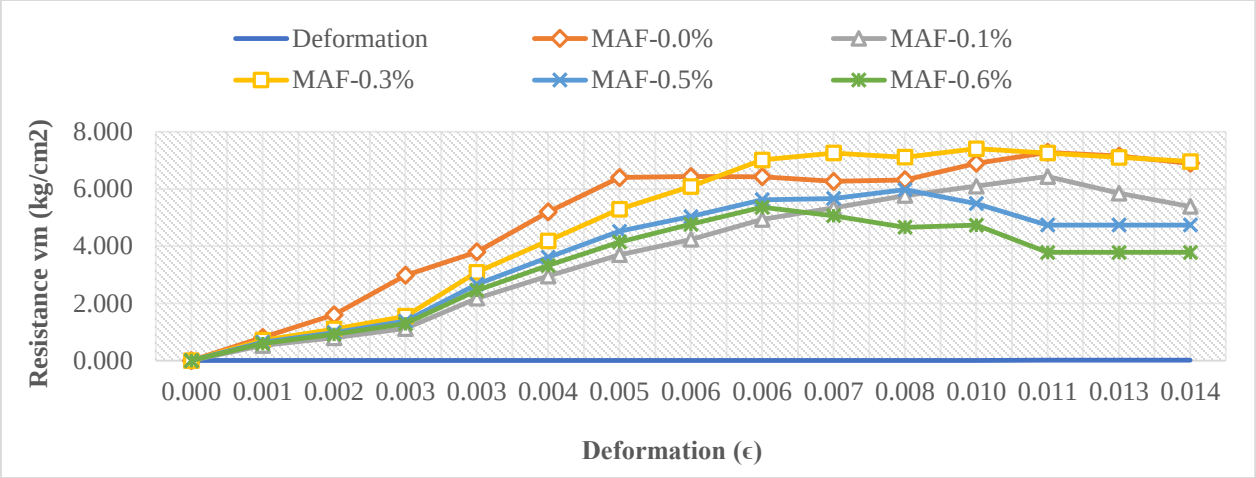

Fig. 13 Masonry test at 0.0%-0.1%-0.3%-0.5%-0.6%

For the control wallets, the individual peak resistances that were reported were 7.29, 7.25 and 7.28 kgf/cm². The response curves in Figure 14 were plotted against the corresponding coordinates of deformation in the workbook, the peak values, and not the interpolated points of the curve, define the number of specimens included in the descriptive comparison [32].

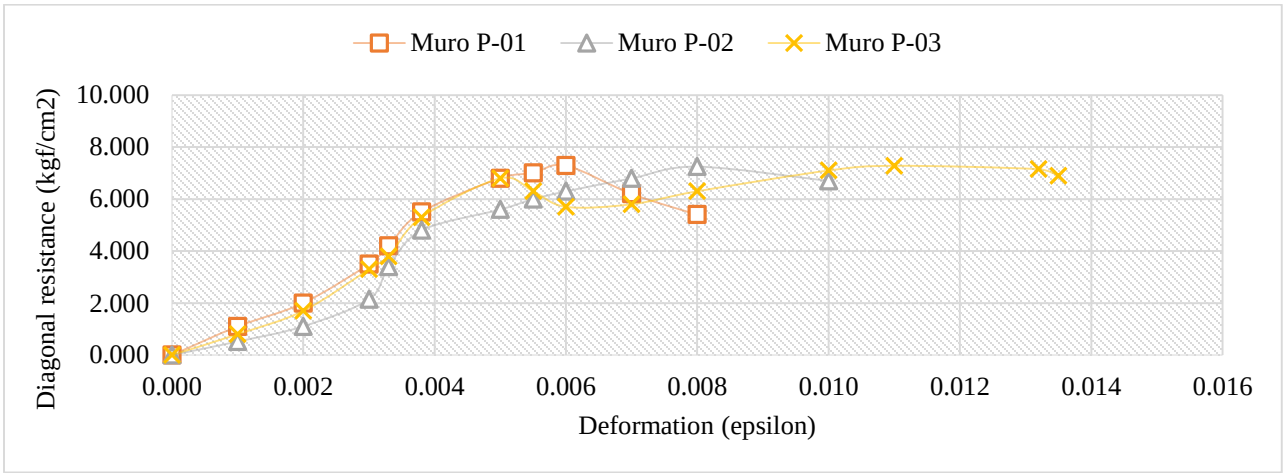

Fig. 14 Diagonal test on masonry walls with 0.0% coconut fiber

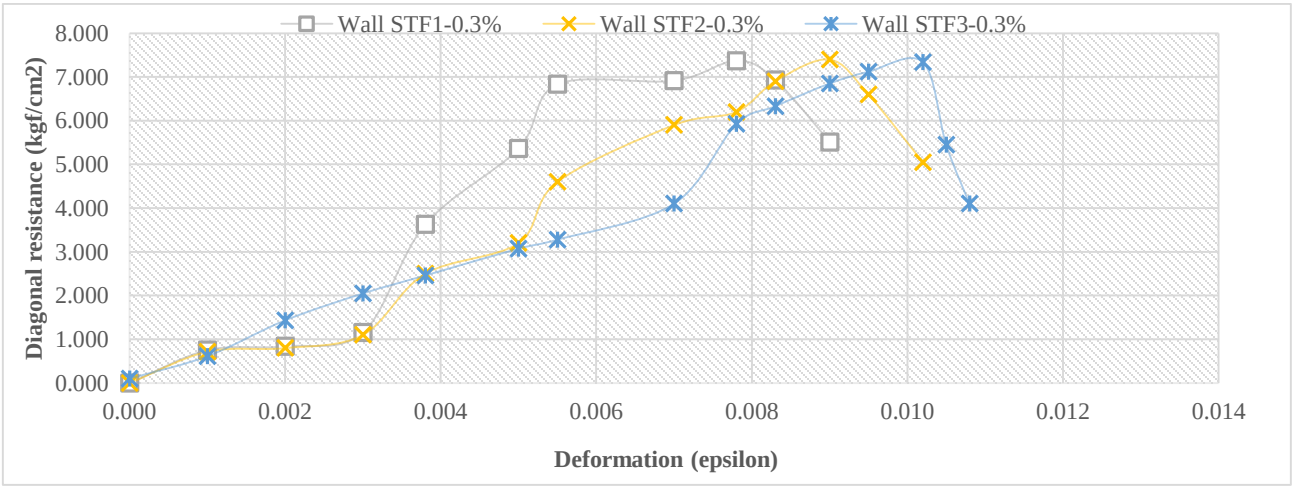

Fig. 15 Diagonal test on masonry walls with 0.3% coconut fiber

The three wallets containing 0.3% fibre reached reported peak resistances of 7.37, 7.40 and 7.34 kgf/cm². Their mean was 7.370 kgf/cm², which was compared with the 7.273 kgf/cm² of the control. The limited difference (+1.33%) is descriptive, it is not reported as proof of statistical superiority or of an enhanced energy dissipation. Changes in post-peak response are discussed qualitatively until the deformation measurement basis, and curve integration can be verified [32, 33].

The photographs and the recorded response were reviewed for diagonal cracks, localised joint separation and the concentration of damage. A possible contribution of fibre-bridging is consistent with the mechanics of the natural-fibre-reinforced earth materials, but this local bridging was not measured directly in this study [12, 36].

No specimen-level ductility index, elastic modulus or absorbed-energy quantity is reported, this is because the required validated displacement gauge length and the complete measured load-deformation histories could not be established from the current manuscript. Those properties should only be calculated after the underlying measurement coordinates and test geometry are confirmed.

For future normalisation, the nominal diagonal stress and strain should be calculated from the verified loaded area, the peak force, displacement-gauge length and the instrumented deformation direction. If measured displacement histories are available, the secant stiffness, deformation at peak and the area below a consistently defined load-displacement curve may be reported, the integration of smoothed or rescaled curves alone is insufficient to demonstrate energy dissipation.

Table 6. Comparative mechanical performance and failure response of unreinforced and 0.3% coconut-fibre-reinforced masonry wallets

Indicator	Control 0.0%	Fiber 0.3%	Interpretation
Mean diagonal strength	7.273 kg/cm²	7.370 kg/cm²	**+1.33%**
Post-peak response	More abrupt	More uniform	Better stability with 0.3%
Deformation capacity	Lower uniformity between specimens	Higher uniformity between specimens	Favorable response with 0.3%
Damage pattern	Cracking and more abrupt loss of capacity	More progressive damage development	Possible fiber bridging effect
Quantitative ductility	Not determined	Not determined	Qualitatively evaluated through deformation
Absorbed energy	Not quantified	Not quantified	Requires integration of the area under the curve

Verified results regarding diagonal compression allow us to observe the interaction of wall specimens under shear stresses and cyclic loads, as well as under exposure to moisture and weathering. According to [34], compressed earth block walls reinforced with reed were evaluated through incremental cyclic lateral displacements and a constant vertical precompression of 0.3 MPa. Their results reported improvements when four vertical reed elements were used in the walls, obtaining an increase of 44% in lateral strength and 76% in displacement capacity compared with the conventional wall. They also obtained smaller improvements in ductility, energy dissipation, and seismic damage. On the other hand, weathering is also a relevant aspect because earth-based materials are sensitive to moisture and erosion processes. According to [35], water action is one of the main deterioration mechanisms of compressed earth blocks. They evaluated this behavior through spray erosion, dripping, capillary absorption, and wetting–drying cycles. More specifically for the reinforcement studied in this research, [36] evaluated cement-stabilized soil blocks reinforced with banana fiber and coconut fiber, observing improvements in post-peak behavior and resistance under durability conditions such as wet–dry cycles, freeze–thaw cycles, and chemical exposure. Likewise, [37] found that stabilized compressed earth blocks reinforced with Juncus fibers could reach satisfactory behavior against erosion and abrasion, although the increase in fiber content also modified water absorption and compressive strength.

The findings characterise the response of the tested wallets under monotonic diagonal loading. They do not establish behaviour under cyclic lateral loading, long-term wetting-drying exposure or earthquake excitation; these require separate tests. Prior studies on common-reed-reinforced CEB walls [34], employed a different loading protocol and reinforcement arrangement, so their improvements cannot be treated as directly comparable effect sizes.

Regarding the results obtained and their comparison with previous studies, it can be observed that the performance of reinforced earth-based materials depends on both the internal nature of the fibers and their adequate dosage. Natural fibers, such as coconut, areca, and palm fibers, have shown the capacity to increase certain mechanical properties of earth blocks, mainly due to the adequate integration of the soil–fiber components. In addition, they offer advantages related to the use of renewable resources or agricultural waste. This aspect can help organic residues or waste acquire added value and contribute to the economic improvement of local people or farmers. According to [12], the results show the improvement offered by coconut fiber by increasing the strength of blocks

reinforced with this fiber. Similarly, [38] determined that a dosage of 0.3% coconut fiber with a length of 6 cm provided the best behavior in dry and wet compression among the configurations studied.

On the other hand, synthetic fibers can provide greater stability and mechanical response under certain conditions. [39], when comparing natural palm fibers with polymeric fibers in earth blocks, found that both systems could improve strength, although the behavior depended significantly on the fiber content. Likewise, [40] observed better mechanical and durability performance of polypropylene fibers compared with natural areca fibers in the blocks studied. In economic and environmental terms, the use of lignocellulosic fibers can be particularly favorable when they come from locally available agricultural waste. However, their selection must consider strength, durability, availability, treatment, and behavior against moisture at the same time. Even so, this does not reduce the economic impact that their use could produce in the agricultural sector, whether at a smaller or larger scale, by promoting their application. The use of plant fibers for the production of adobe blocks represents a sustainable strategy to improve the mechanical and physical properties of this traditional material. This process also promotes a positive socioeconomic impact in rural communities, allowing small farmers to give value to their agro-industrial waste and integrate it into local value chains through the principles of the circular economy [41].

The comparative findings do not indicate that a 1.33% change in diagonal strength exceeds the improvements that are observed for steel-, bamboo- or reed-reinforced systems. Kasinikota and Tripura [44], studied coir-containing panels with additional reinforcement and reported a wide response range depending of the arrangement, the present results are therefore interpreted as configuration-specific and not as evidence of superiority in comparison to these systems.

Table 7. Comparison between coconut fiber and other fibers

Study	Fiber type	Material evaluated	Reported performance	Cost	Sustainability	Relation to the present study
Sujatha et al. (2023) [12].	Coconut/coir, areca, and flax (natural)	Reinforced soil blocks	Coconut fiber showed an appreciable increase in strength; the performance depended on the type and content of fiber.	No direct economic comparison between fibers was presented.	Use of natural fibers as an alternative for sustainable construction units.	Confirms the mechanical potential of coconut fiber, although mainly at the unit scale.
Malkanthi et al. (2024) [38].	Coconut/coir (natural)	Stabilized compressed earth blocks	The best dry and wet compressive performance was obtained with 0.3% fiber and 6 cm length.	For the analyzed conditions, the cost of 1 m² of wall with CSEB was 41.52% lower than fired brick and 8.56% lower than cement blocks.	Uses coconut fiber and earth-based materials; the authors highlight its potential as a low-cost and lower-impact alternative.	It is one of the most directly related background studies to the reinforcement used in this research.
Al-Tamimi et al. (2022) [39].	Palm (natural) and polymeric fibers (synthetic)	Earth blocks	Both natural and polymeric fibers increased strength; the maximum increase was higher than 30% compared with equivalent blocks without fiber. The optimum behavior depended on the dosage.	Not quantified in the study.	Natural fiber is renewable; polymeric fibers offer mechanical advantages, but they have a different origin and end-of-life condition.	Allows a direct comparison between natural and synthetic fibers in earth-based materials.

Manjunath & Annapurna (2026) [40].	Areca (natural) and polypropylene (synthetic)	Stabilized earth blocks	Polypropylene performed better than areca fiber in the evaluated strength and durability indicators, especially with 1% fiber.	No direct economic comparison between both fibers was reported.	Allows the balance between mechanical performance and the selection of a natural or synthetic fiber to be assessed.	A recent and useful reference to compare lignocellulosic fiber with a synthetic fiber.
Present study	Lignocellulosic coconut fiber (natural)	BTC masonry wall specimens subjected to diagonal compression	With 0.3% fiber, a mean diagonal strength of 7.370 kg/cm² was obtained, compared with 7.273 kg/cm² for the control, equivalent to an approximate increase of 1.33%. The reinforced specimens also showed a more uniform and stable post-peak response.	No specific economic evaluation was carried out. A potential benefit is recognized when coconut fiber is locally available as agro-industrial waste.	Potential use of a plant-based lignocellulosic resource and valorization of agricultural waste, with a possible reduction in the dependence on industrialized reinforcements.	Extends the evaluation from the individual block to the integral behavior of the masonry system under diagonal compression.

From an environmental point of view, the integration of plant fibers to improve the properties of a masonry wall or compressed earth block provides durability and safety for a specific use. This supports the implementation of alternative local materials, promotes suitable structures, and indirectly contributes to the rural economy by giving added value to coconut fiber.

Life Cycle Assessment (LCA) studies consider different assumptions about the use of plant fibers. On the one hand, the use of natural fibers, such as coconut fiber, is positive because it promotes the commercialization of these fibers. They are no longer seen only as waste, but acquire added value when they are integrated into masonry walls, also contributing to the reduction of environmental impact. However, this benefit depends largely on factors such as stabilization, processing, and transport distances [42].

When reviewing 22 international background studies on conventional masonry walls and unstabilized earth walls, a reduction in environmental impact due to the use of natural fibers can be observed. This perspective is positive, although it should be considered that obtaining the fiber involves transport, which can modify the evaluation of environmental performance in the case of coconut fiber.

The LCA evaluation of different earth wall systems showed that, in general terms, earth-based solutions combined with suitable insulating materials can generate a lower environmental impact than conventional ceramic block systems [43]. However, prefabricated compressed earth blocks present impacts related to their manufacturing and transport. Therefore, it is important to train the agricultural sector in the proper handling of fibers in order not to alter their composition and to ensure an optimal interaction between both components. This shows that the natural character of the material does not by itself guarantee a low carbon footprint, an aspect also reflected in other reviewed studies with uncertain results.

The incorporation of lignocellulosic coconut fiber represents an alternative to give value to this plant resource as reinforcement in compressed earth blocks. According to [38], the feasibility of using coconut fiber in stabilized compressed earth blocks was demonstrated, achieving favorable mechanical performance and lower construction costs than fired brick and cement block systems evaluated in their study.

Based on these results and on what has been described by other authors, the use of plant fibers can help reduce dependence on industrialized reinforcements. However, the real environmental benefit will depend on factors such as the origin of the fiber, its treatment, transport, dosage, and service life.

The potential environmental contribution of the use of agricultural coir depends on the material preparation, the transport, stabilisation and service life. No life-cycle assessment was performed for the present specimens, reductions in greenhouse-gas emissions or total construction cost are therefore not claimed as the measured outcomes [42, 43].

Table 8. Descriptive statistical comparison between control and 0.3% coconut-fibre specimens

Indicator	Control 0.0%	Fiber 0.3%	Variation
Water absorption (%)	10.42	10.92	+4.80%
BTC compressive strength (kg/cm²)	0.435	0.441	+1.38%
Mean diagonal strength (kg/cm²)	7.273	7.370	+1.33%
Standard deviation – diagonal strength (kg/cm²)	0.021	0.030	—
CV – diagonal strength (%)	0.29	0.41	—

Table 8 consolidates the descriptive comparison, and this table does not imply statistical significance. For the 0.3% fibre dosage, the block strength was 0.441 versus 0.435 kgf/cm² in the control (+1.38%), the absorption was 10.92% versus 10.42%, and the mean diagonal resistance of the wallets was 7.370 versus 7.273 kgf/cm² (+1.33%). The series of diagonal resistance contained three specimens per group. The control values (7.29, 7.25 and 7.28 kgf/cm²) yielded a mean of 7.273 kgf/cm², and the 0.3% series (7.37, 7.40 and 7.34 kgf/cm²) yielded 7.370 kgf/cm².

The replication is limited, the interpretation is restricted to the descriptive statistics. Although the available values show a limited dispersion within the series, n = 3 does not justify general claims that 0.3% fibre is statistically superior. The dependence of the strength on the soil grading, compaction, moisture and block-mortar interface conditions should be addressed by means of a larger experimental programme.

4. Conclusion and Recommendations

Within the experimental series, the incorporation of coconut fibre was associated with a small change in the reported masses of the blocks and walls. The difference should not be generalised as a demonstrated reduction in the structural demand without a building-scale assessment. For the reported block-strength values, the highest nominal result occurred with 0.3% coconut fibre (0.441 kgf/cm², compared with 0.435 kgf/cm² for the control), the magnitudes should not be extrapolated beyond the tested materials. The water absorption increased from 10.42% in the control units to 10.92% at 0.3% fibre and 12.30% at 0.6%. These results indicate a trade-off related to moisture and support the subsequent testing of wetting-drying and erosion, they do not constitute a direct test of the long-term durability. The reported mean diagonal resistance was 7.273 kgf/cm² for the control and 7.370 kgf/cm² for the wallets incorporating 0.3% fibre, the difference of approximately 1.33% is descriptive for three specimens per condition. Neither a significant optimum nor a quantified increase of energy dissipation is established by these data. Further work should verify the effective specimen dimensions and the resistance calculation, increase the number of independent wallet tests and to evaluate the response under moisture cycling and repeated lateral loads. These recommendations concern additional validation and do not imply that such tests were conducted in the present programme. The non-destructive methods could complement the subsequent characterisation. Ultrasonic pulse velocity may assist in the assessment of the uniformity and moisture-sensitive mechanical behaviour of compressed earth units [46], while the rebound-index and ultrasonic measurements have been evaluated jointly for lime-stabilised rammed earth [45]. These techniques require a material-specific calibration against destructive tests and cannot replace the diagonal compression testing of masonry wallets.

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