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Compression and Bond Properties of Fired Clay Brick Masonry with Cocopeat Blended Binding Mortar

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Abstract

The production of agricultural, industrial, and demolition trash increases along with global population growth and industrial expansion. They endanger the environment when they are not properly recycled, repurposed, or disposed of. Cocopeat is one such agricultural waste. The use of cocopeat in binder cement is urged to support sustainable construction methods. Because it is seen as trash and discarded in landfills. Cocopeat is an environmentally friendly by-product which can be got during the coconut fibre extraction process. The current study investigates the strength properties of masonry built with binding mortar that incorporates cocopeat as opposed to traditional cement-sand mortar. The mortar prepared with four different integrations of cocopeat as sand replacement of 0, 4, 6 and 8% by weight was used for masonry. Fresh properties of cocopeat binding mortar and their effect on the mechanical characteristics of masonry were investigated. The test results revealed that the mechanical characteristics of masonry were enhanced with increased cocopeat content in the mortar.

Keywords

Masonry, Cocopeat, Binding mortar, Sustainability

1. Introduction

The production of agricultural, industrial, and demolition waste increases along with global population growth and industrial expansion. They endanger the environment when they are not properly recycled, reused, or disposed of. Since cocopeat is a byproduct of the extraction of coconut fiber, it is frequently regarded as waste and disposed of in landfills. Typically, coco husk pieces, coir, and cocopeat are produced when fiber is extracted from coco husk. Although coco husk pieces and coco coir may be utilized to make a variety of goods with added value as shown in Figure 1, coco peat is only employed as a plant-growing medium and the majority of it is disposed of or mixed with nearby water sources. By contaminating the water and the air, these acts put the environment at hazard (Erdogmus 2015).

Cementitious composite materials, such as mortar, are being used more frequently for a variety of construction activities, including masonry blocks, wall finishes, binding mortar, and more. To increase cementitious composite material's ability to provide improved efficiency in construction, there is a growing need for their utilization. Microcracks start to show up along planes that suffer tensile stresses when mortar is subjected to different types of loading. Applying additional loads causes cracks to expand out of control (Chandramouli et al. 2010).

Most of the masonry failure is initiated by the binding mortar itself or the intersection between brick and binding mortar. A good bond between brick and binding mortar has a significant effect on the mechanical characteristic of the masonry wall. This is influenced by many factors such as moisture content, initial water absorption rate, the surface roughness of brick unit and sand grading, composition, consistency, and water retention capacity of the binding mortar. So, improving the performance of binding mortar is one of the optimum ways to im-prove the strength of masonry structures. Generally, by incorporating by industrial waste or fibres are used to improve the performance of binding mortar (Sundaralingam et al. 2021, Thanushan & Sathiparan 2022). Fibers in the mortar mixture serve to counter-act the hydraulic shrinkage, preventing the development of cracks and fissures on the surface of the plaster that has been applied. Also, it was improving the direct tensile strength of the mortar as well as due to roughness, it was improving the bond be-tween the masonry unit and the binding mortar.

Although coconut coir has been continually utilized in cementitious composites such as concrete (Ali et al. 2022), cement mortar (Sathiparan et al. 2017), stabilized earth blocks (Thanushan et al. 2019), surface plaster (Sathiparan & Rupasinghe 2019), etc., the use of cocopeat in cementitious materials is very limited. Priyadarshini et al. (2021) investigate the strength of concrete featuring cocopeat as a partial replacement for sand. Results show that treated cocopeat improved the compressive strength and bonding characteristic of concrete. The strength and durability properties of cement mortar including cocopeat as a substitute for river sand were evaluated by Sathiparan et al. (2022). The findings demonstrated that adding up to 4% of cocopeat content to cement-sand mortar enhances its physical and mechanical characteristics without negatively affecting crucial durability factors. Furthermore, both studies show that using cocopeat as raw materials in construction materials reduces the usage of river sand, so it is a cost-effective and sustainable option. Although these studies show that cocopeat is one sustainable option to reduce sand consumption and value added to cocopeat, still the usage of cocopeat in binding mortar for masonry is one of the areas to explore.

The emphasis of the present study is to investigate the effects of cocopeat-incorporated binding mortar on the mechanical properties of masonry. For that fresh mortar properties, characteristics of hardened binding mortar, and strength characteristics of masonry were investigated through an experimental program.

Fig 1. Derivation of by-products of the Coconut extraction process and its commercial use

2. Methodology

2.1 Materials used

The details about raw materials used for the present experimental program are described below.

- Cement: In this investigation, OPC (Ordinary Portland cement) was used as a binder. OPC was found to have a bulk density of 1,280 kg/m3 and a specific gravity of 3.15.
- Fine aggregate: The river sand had a bulk density and specific gravity of 1,680 kg/m3 and 2.41, respectively. Figure 2a displays the grain size distributions of river sand. According to the grain size distribution, fine aggregate contains 3.8% gravel, 95.6% sand, silt, and

0.6% clay particles, respectively. The uniformity coefficient (Cu), gradation coefficient (Cc) and fineness of fine aggregates were found to be 4.01, 1.10 and 2.89, respectively. Accordingly, according to the unified soil classification system, the fine aggregate may be classified as SP - Poorly graded Sand (SP).

- Cocopeat: The cocopeat was gathered from a coconut coir extraction facility. Cocopeat has a bulk density of 306 kg/m3 and a specific gravity of 1.34, respectively. It is less dense than river sand and can be utilized as a lightweight material. Additionally, a cocopeat with a higher water retention capacity helps shorten the curing process (Shenbaga kumar et al. 2019). To define the particle size distribution for husk particles, a sieve ex-amination was conducted. The particle size distribution of cocopeat is represented in Figure 2a. By weight, the cocopeat is made up of around 60% fiber and 40% tiny husk fragments. The average particle size of the cocopeat was approximately 0.78 mm. Figure 2b illustrates the discrepancy of the frequency with the length of the cocopeat, and Figure 2c shows the discrepancy of the frequency with the diameter of the cocopeat. The fiber found in cocopeat had an average length and diameter of 16.7 mm and 20.2 µm, respectively.
- Brick: Bricks with the dimension of 200×85×60 mm3, which are available in the local market were used. The bricks had a compressive strength of 5.88 MPa and a water absorption rate of 8.3%.

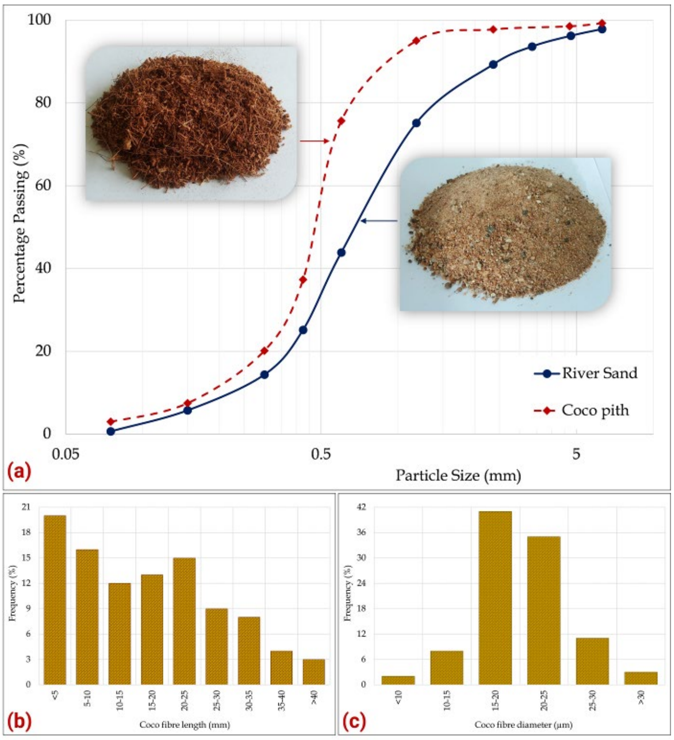

Fig 2. (a) Particle size distribution of cocopeat and river sand, (b) variation of frequency percentage of cocopeat length, and (c) variation of frequency percentage with cocopeat diameter

2.2 Mix design

The objective of this research was to establish whether cocopeat could be used to binding mortar, and it was decided that the mix proportion used on local construction sites was appropriate. As a result, 1:6 by volume of cement to fine aggregates was used to produce mortar. As previously noted, four ratios of cocopeat to cement: 0, 4, 6, and 8% by weight were set. It is not acceptable to replace river sand with cocopeat by weight because cocopeat has a density that is considerably lower than that of river sand. It was so chosen to substitute an equal volume of solid for it. Since the amount of cocopeat in the mix was already determined by the ratio of cocopeat to cement, river sand volume was lowered from the dry mix to make room for the cocopeat.

The quantity of raw materials utilized in each mortar mixture is listed in Table 1. Water requirement was greater for cocopeat due to its hydrophilic nature. The required amount of water needed was decided according to the predetermined slump value of 25-35mm. With the addition of cocopeat to the binding mortar, the amount of required water was increased for the fixed slump.

Table 1. Mix proportion used for binding mortar (for one m^3)

Mix ID	Cocopeat/Cement (%)	Cement (kg)	Sand (kg)	Cocopeat (kg)	Water (l)
C0	0	208.8	1780.0	0.0	281.9
C4	4	208.8	1766.0	8.4	292.3
C6	6	208.8	1758.5	12.5	302.8
C8	8	208.8	1751.0	16.7	313.2

3. Testing

To carry out tests for masonry six masonry prisms, eight masonry triplets, and 8 couplets were prepared to conduct compressive, shear and bond tests respectively as shown in Figure 3. Bricks with the dimension of 200×85×55 mm^3 were used in specimen preparation with the 10mm mortar joint.

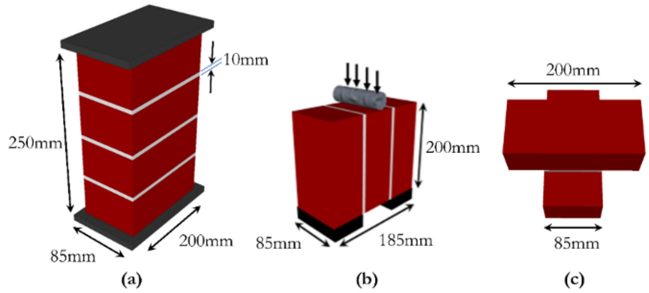

Fig 3. Outline of specimens used for testing; (a) compression test, (b) shear test and (c) bond test

Test on Fresh Mortar

For fresh mortar, slump, slump flow, initial setting time, final setting time and moisture retention capacity were measured. Slump and setting time were measured following ASTM C143 (2020) and ASTM C403 (2016), respectively.

To check the water retention characteristics of fresh mortar, a drying test was done according to CSN EN 16322 (2013). The fresh mortar was filled in the aluminium cylinder (100 mm diameter and 25 mm height) and it was kept in the laboratory environment (humidity of 80% and temperature of 30 °C) to dry out. The weight of the specimen was measured at certain time intervals. The moisture content per unit area at a particular time was given by the function of the mass of the mortar with container after a certain time (mt) and mass of dry mortar with container (md) and area of the aluminium cylinder (A) as Eq. (1).

$$Moisture\ content\ (\%) = (mt - md) \times 100/md \quad (1)$$

The gradient of the preliminary linear section of the moisture content vs. time is defined as the initial drying rate (D1, expressed in %/h). The gradient of the linear section of the moisture content vs. the square root of time is defined as the second phase drying rate (D2, expressed as %/h$^{0.5}$) (Sundaralingam et al. 2022).

Test on Brick and Binding Mortar

Bricks with the dimension of 200×85×55 mm^3 were used to conduct tests on bricks and to carry out tests on mortar 100×100×100 mm^3 cubes, and 200×100×60mm^3 beams were prepared. Compression test flexural tests were done for brick and binding mortar respectively according to ASTM C109 (2020) and ASTM C348 (2020).

Tests on Masonry

A compressive strength test was carried out for masonry prisms made up of 4 blocks and 3 joints of mortar as shown in Figure 3a, according to BS EN 1052-1 (1999). For each composition, the test was performed for six specimens. Spec-miens were cured for 28 days.

The direct shear test is used to test the shear strength of prepared masonry according to BS EN 1052-3 (2002). Eq. (2) was used to calculate the shear strength of the specimens.

$$Shear\ strength = (S + W)/2A \quad (2)$$

Here, S is the maximum shear load, A is the failure surface area and W is the weight of a brick.

Brick couplets cast following ASTM C952 (2012) were used to assess the bond strength. Couplets with distinct mortar designations were manufactured as crosses while maintaining a 10 mm binding mortar thickness and the couplet was created as illustrated in Figure 3c. Specimens were examined on the universal testing machine with a displacement control method with a loading rate of 0.3 mm/min. The failure load and bond area were used to determine the couplet's bond strength. Using Eq. (3), the bonding strength was determined.

$$Bond\ strength = (B + Wc + W)/A \qquad (3)$$

Here, B is the maximum load before bond failure, A is the area of the brick-mortar contact surface, W is the weight of a brick and Wc is the weight of the cap.

4. Results and discussion

4.1 Fresh mortar properties

To find the influence of cocopeat on fresh mortar characteristics, the slump is one of the indicators. Water was added gradually to find the suitable mix design by increasing the w/c ratio by 0.5. Variations of w/c ratio and corresponding slump values for the mixes are presented in Figure 4, which presents the clear identification about, the addition of cocopeat to the mortar, reduced the workability of the mortar mix. During the experiment, when adding cocopeat to the mix the mortar enhanced stiffer. Therefore, the workability of the mortar mix was reduced. These results were similar to the results found by Wongsa et al. (2020) when using coconut and sisal fibre with geo polymers mortar. Rough surfaces, porous structures and irregular stripes of fibre are the reason for the decrease in workability (Lertwattanaruk & Suntijitto 2015). In the present study, water to cement ratio was selected by fixing the slump value as 30±5mm. To achieve that slump, the water-cement ratio requirement was 1.35, 1.40, 1.45 and 1.50 for 0, 4, 6 and 8% cocopeat blended mortar, respectively.

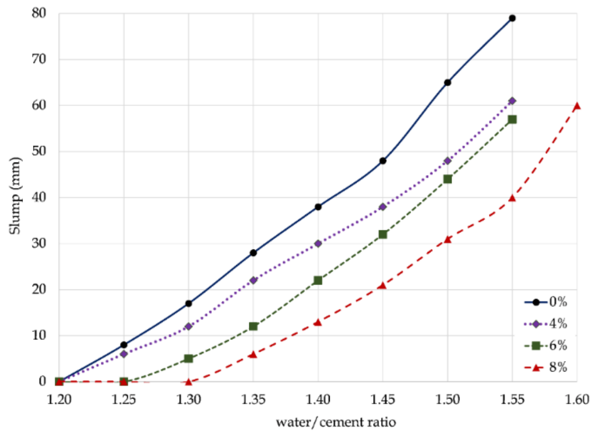

Fig 4. Variation of slump along with water/cement ratio for various mortar mix

Figure 5 depicts the variation of initial and final setting times with the addition of cocopeat to the binding mortar. Fresh mortar can be longer workable with the longer setting time. As per the result, both the initial and the final setting time was increased when adding cocopeat to the mortar, which facilitates the workability of the biding mortar.

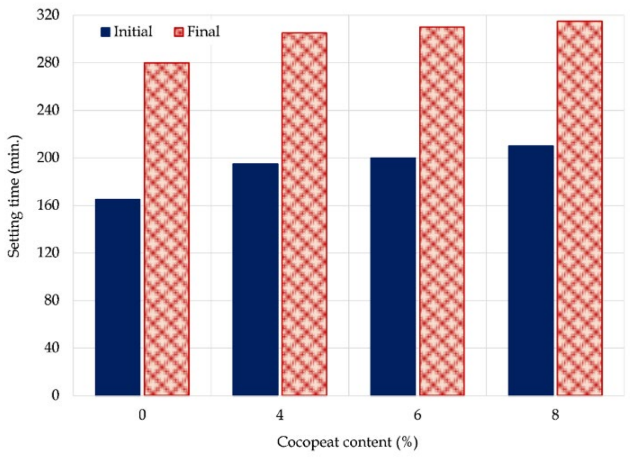

Fig 5. (a) Variation of fresh mortar density for various mortar mix; (b) Initial and final setting time of the various mortar mix

Figure 6 depicts the moisture content variation of mortar with a square root of time. Initial moisture content was observed to be 11.9, 12.1, 12.3 and 12.4% for 0, 4, 6 and 8% cocopeat blended mortar, respectively. It clearly shows that when adding cocopeat to the binding mortar, it keeps the water more. It is necessary to know about the variation of the water retention capacity of mortar with the cocopeat content, as it affects the hydration of cement and the workability of binding mortar.

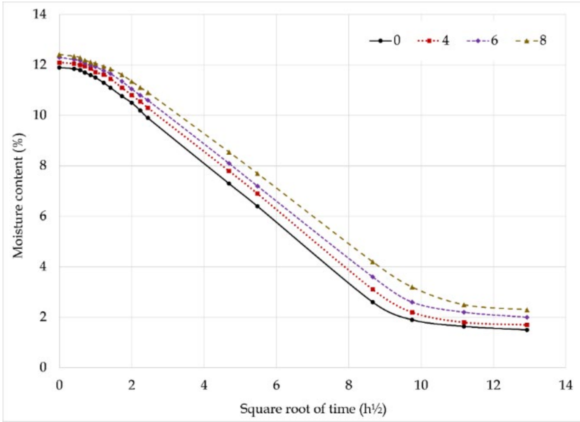

Fig 6. Moisture content variation with elapsed time

The results revealed that the initial evaporation rate reduced with cocopeat in the mortar mix. The initial evaporation rate was 0.40, 0.39, 0.37 and 0.35 % per hour for 0, 4, 6 and 8% cocopeat blended mortar, respectively. A similar trend was witnessed for the second stage as the secondary evaporation rate was 1.18, 1.16, 1.12 and 1.1 %/$h^{0.5}$ for 0, 4, 6 and 8% cocopeat blended mortar, respectively. These results revealed that the incorporation of cocopeat in the fresh mortar improves the water retention capacity.

4.2 Properties of hardened mortar

Table 2 summarizes the density, water absorption rate, compressive strength and flexural strength of brick and binding mortar with different cocopeat content. For all the binding mortar types, the compressive strength of the binding mortar was lesser than brick. But flexural strength of mortars with cocopeat showed higher flexural strength than brick.

The supplement of cocopeat to the mortar affects compressive strength both favorably and unfavorably. On the plus side, the cocopeat's fiber content offers increased tensile strength, which prevents mortar from breaking (Leppänen 2006, Hamidi & Koohdaragh 2011). Thus, improving the mortar's compressive strength as a result. On the other hand, a lower compressive strength was caused by the in-creased porosity that was present in the cocopeat blended mortar (Zhao et al. 2014). When com-pared to the control mortar, the compressive strength of the mortar was raised by 8% when 4% cocopeat was added to it. But cocopeat concentration increased more, and compressive strength declined. Strength decreased by 3 and 25%, for cocopeat contents of 6 and 8%, respectively. The existence of cocopeat in mortar appeared to harm wet compressive strength since there was a drop in compressive strength for the wet condition with a rise in cocopeat content.

When 4% cocopeat was replaced with mortar, the flexural tensile strength increased, but as the cocopeat percentage increased, the strength began to decline. Even when using mortar with an 8% cocopeat content, the flexural tensile strength was higher than that of the control mortar. The connections that the fibers create across the cracks may be responsible for the increase in flexural strength. The force applied to the mortar must be greater than the stress necessary to separate the cement gel-aggregate connection and the friction bond between the fiber and mortar matrix for failure to occur (Donkor & Obonyo 2016). As a result, fibers provide a greater load-bearing capability. Strength decreased after a key threshold (4% cocopeat concentration) because cocopeat is soft and the mortar matrix has more pores.

Table 2. Characteristics of binding mortar with the addition of cocopeat

Properties	Unit (%)	Brick	Mortar			
			0%	4%	6%	8%
Density	kg/m^3	1680	2043	1989	1910	1879
Water absorption rate	kg/m^3	138	196	205	242	255
Dry compressive strength	MPa	5.88	3.94	4.27	3.82	2.94
Wet compressive strength	MPa	4.98	2.79	2.80	2.53	1.77
Flexural strength	MPa	1.75	1.55	2.25	2.09	1.84

4.3 Effect of cocopeat reinforced mortar on mechanical properties of masonry

Compression strength

Figure 7a illustrates the typical compressive failure types of masonry prisms. There is a vertical tensile spitting failure that occurred along the axial loading direction. The crack originated from mortar and it spread through brick.

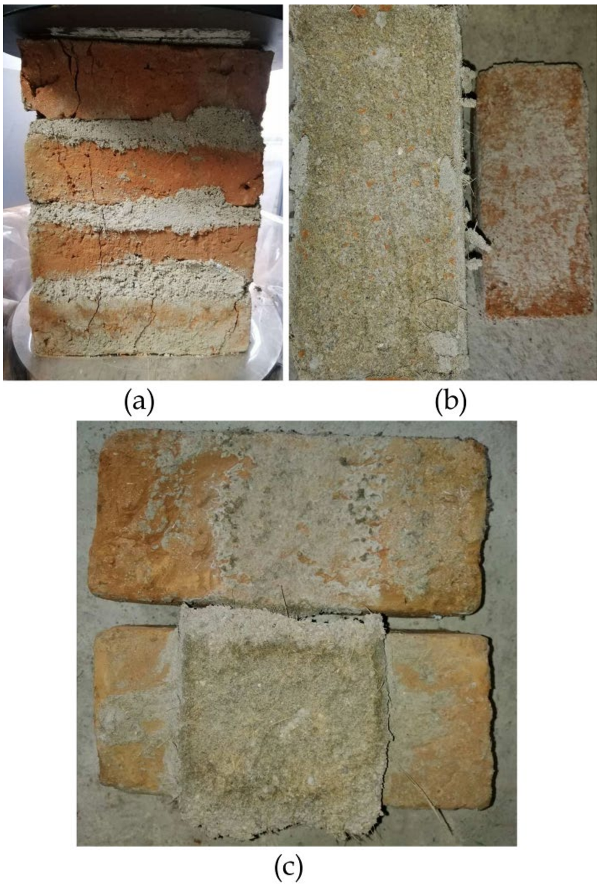

Fig 7. Typical failure modes of masonry prisms under (a) Compression strength; (b) Shear strength; (c) Bond strength

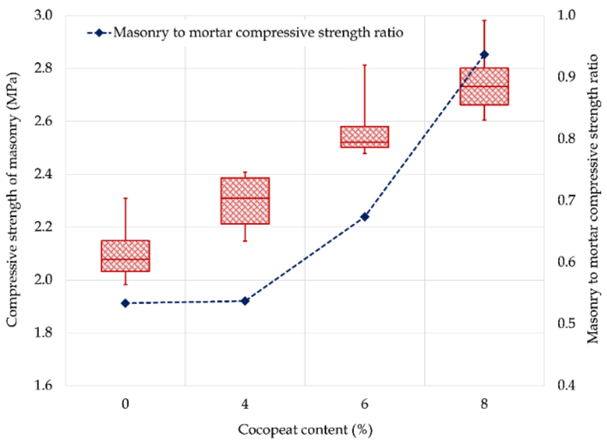

Fig 8. Variation of compressive strength with different binding mortar

Figure 8 illustrates the compressive strength variation of masonry prisms among various types of binding mortar. Results indicated that an increase in the replacement of cocopeat contributed to the higher compressive strength of masonry. Compared with control mortar, the rise in compressive strength was 8.9, 22.1 and 30.7%, respectively for masonry prism with 4, 6 and 8% cocopeat incorporated mortar. The compressive strength of the mortar itself and rough interface surface due to the irregular shape and texture of the cocopeat may attribute to improvement in the overall compressive strength of the masonry. When comparing the masonry strength to mortar strength ratio, the increase rate proportionally increases with mortar strength. The ratio is equal to 0.53, 0.54, 0.67 and 0.94 for 0, 4, 6 and 8% cocopeat blended mortar, respectively.

Shear strength

Figure 7b presents the failure pattern of the interface surface of the masonry triplet observed in shear tests. All the specimens were failing along the interface between brick and mortar. This mainly occurred when bond strength amongst brick and mortar was lesser than the tensile splitting strength of brick and mortar.

Figure 9 illustrates the shear strength variation of masonry triplets with a different type of binding mortar. When stronger brick and weaker mortar are used in masonry, the shear strength depends on mortar strength itself, the water absorption characteristic of the brick and the water retention characteristic of the mortar.

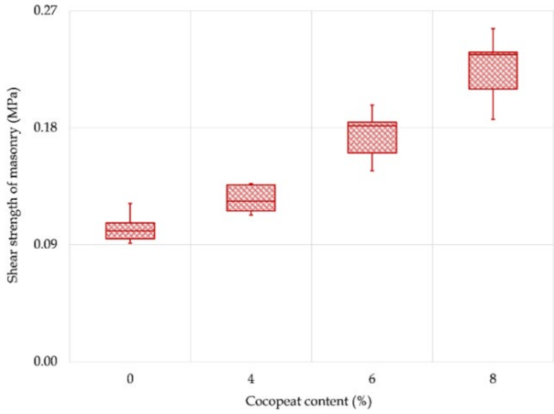

Fig 9. Variation of shear strength with different binding mortar

Since mortars are often spread over absorptive fired-clay bricks, the water retention capability of the fresh mix is very important (Sébaïbi et al. 2003). Namely, these materials readily absorb mixed water from the mortar and this may lead to irregular hardening. In this case, designed properties of the mortar are not achieved. Only by retaining enough water, mortar can preserve adequate plasticity and reach designed properties. Since cocopeat incorporated mortar can absorb more water at the fresh stage, which might be released back to when desiccation occurs and thus affect positively the hydration process of the mortar. It makes a better bond between brick and mortar. In the present study, the same type of bricks was used, therefore shear strength improves with cocopeat quantity. Compared with control mortar, the increase in compressive strength was 22.7, 69.9 and 118.1% for masonry triplet with 4, 6 and 8% cocopeat incorporated mortar, respectively.

Bond strength

All the masonry couplets failed in the brick-mortar interface during the bond test as shown in Figure 7c. This kind of failure happens due to the weak bond strength of the brick-mortar interface compared to the tensile strength of brick-and-mortar.

Figure 10 presents the bond strength variation with masonry cross-couplets with different binding mortar. Similar to shear strength, bond strength also increased with cocopeat content in the mortar. Compared with control mortar, the increase in compressive strength was 24.9, 47.9 and 89.1%, respectively for masonry triplet with 4, 6 and 8% cocopeat incorporated mortar.

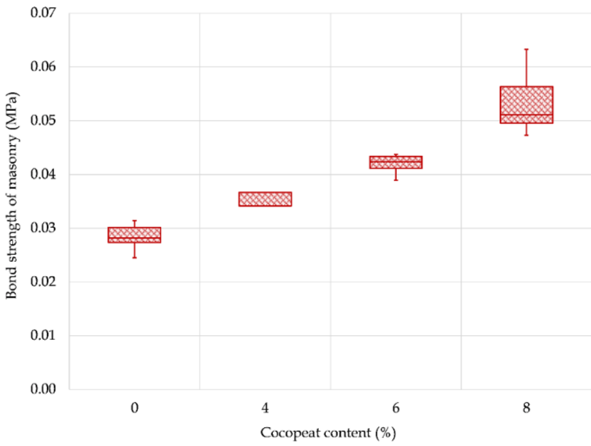

Fig 10. Variation of bond strength with the different binding mortar mix

Relationship between properties

Figure 11 illustrates the relationship between the shear and bond strength of masonry and with compressive strength of masonry. From the research, we have obtained a linear graph for the relationship. The below equations are derived from the test results which give the relationship of characteristic shear strength with characteristic compressive strength as Eq. (4) and characteristic bond strength with characteristic compressive strength as Eq. (5) respectively.

$$fvm = 0.1641fcm - 0.2353 \quad (4)$$
$$fbm = 0.0314fcm - 0.0346 \quad (5)$$

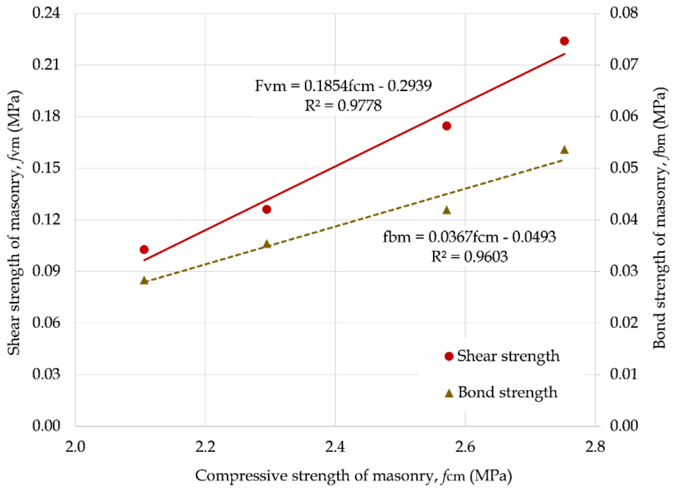

Fig 11. The relationship between characteristic shear, bond and compressive strength of the masonry.

5. Conclusion

The compressive, shear and bond strength of the brick masonry with cocopeat-incorporated binding mortar was studied. The following conclusions are drawn from the current study:

- For mortar mixes including cocopeat, a higher quantity of water is required to obtain the desired slump. However, for a specific slump, adding cocopeat to binding mortar while still fresh demonstrated increased water retention capacity and setting times.
- Mortar containing 4% cocopeat exhibits better compressive and flexural strength after being hardened.
- The compressive, shear, and bond strengths of masonry were increased with binding mortar incorporating greater cocopeat content. Shear, bond, and compressive strength of the brickwork were generally noted to be the sequence in which the influence of cocopeat integrated mortar on masonry strength was noticed.

These findings suggest that cocopeat may be effectively used to create more environmentally friendly binding mortar for masonry. The use of cocopeat as a masonry binder mortar lowers the need for river sand and the environmental damage brought on by the disposal of groundnut shell waste.

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