

## Enhancing Properties of Unfired Clay Bricks Using Palm Fronds and Palm Seeds

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### ABSTRACT

The building industry has been thriving all around the world. With global advancement, particularly in technology, real estate development is evolving with the ongoing adoption of new tactics. The current study investigates the performance of palm fronds and palm seeds in enhancing the properties of unfired clay bricks as construction materials. The methodologies used to attain the study's objectives were; determining particle size distribution and Atterberg limits of clay soil, efflorescence, compressive strength, water absorption, and fire resistance of bricks, which were used to give the most appropriate percent of palm fronds and palm seeds for robust bricks. The study required experimental research of the materials used and samples made. Using particle size distribution and Atterberg limits, the soil was classified as clayey soil and low to medium plasticity soil. Batching by weight was achieved using a weighing scale and substitution technique to obtain the proportions of contents in samples. Sample 5, which contained 80% clay, and 20% palm fronds, and sample 6, which contained 65% clay, 25% palm seeds, and 10% palm fronds, passed all the tests. Samples 5 and 6, under efflorescence check, confirmed slight responses where 10% of the brick was covered with a skinny deposit of salts. Under compressive strength, samples 5 and 6 recorded 4.23 N/mm<sup>2</sup> and 3.85 N/mm<sup>2</sup>, respectively, which were more significant than the required minimum compressive strength of fired bricks. For water absorption, they attained a moisture content of 18.1% and 16.1%, respectively, which was in the range of 16–20% under second-class bricks. All bricks passed the fire resistance test, which confirmed that they had a reasonable safety factor. In conclusion, mixes of samples 5 and 6 are recommended to produce robust bricks.

### 1. Introduction

The building industry is a worldwide one with a significant impact on national economies. Organizations and researchers worldwide attempt to develop high-quality, cost-effective, and environmentally friendly building materials and technologies. Although high-quality civil engineering materials are available today, it is evident that their cost and environmental impact are vital issues that must be addressed. When contemplating building design, the environmental impact must be taken into account. Particularly when people become more aware of the terrible effects of destroying nature and the necessity to preserve what is in their environment. It is fundamental to replace actual construction materials and methods with green buildings. Green building is not a new concept, but it is crucial to remember that it is more vital than ever

owing to the difficulties the globe is now facing, such as global warming. The advantages of green buildings include; saving energy and water, reducing waste and emissions, and promoting a healthy indoor temperature [1–3]. According to Mansour et al. [4], the literature reveals that waste management and recycling, as well as the development and potential use of more sustainable, environmentally friendly construction materials, are critical steps in mitigating the environmental implications of construction activities. With the rapidly expanding building sector, there is a tremendous demand for high-quality, low-cost bricks that are environmentally friendly. Studies reveal that most building bricks are formed from clay, a material that has been used for ages and whose qualities are of significant importance [5].

Adobe bricks have been used as a primary building material for decades. In reality, clay is neither expensive nor difficult to work with

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compared to other building materials. However, it is crucial to remember that most buildings' clay bricks are burnt at extremely high temperatures (about 1200 °C), dramatically raising manufacturing costs [6]. Many researchers have attempted to look for more environmentally friendly bricks, and unfired clay bricks seem to meet the performance levels required for calcined bricks [7–10]. Previous studies evaluated the performance of unfired bricks mixed with waste materials, such as agricultural and industrial wastes. The performance was determined in terms of fired bricks' physical and mechanical properties, such as specific gravity, compressive strength, and water absorption. Tiboti et al. [8] utilized quarry dust to produce bricks and achieved promising results. Limami et al. [9] reinforced unfired clay bricks with recycled Typha-fibers waste. Their findings revealed that incorporating higher quantities of Typha-fibers waste in illite soil produced better and more sustainable bricks. Chin et al. [10] utilized recycled paper mill waste, cotton waste, and cement to produce bricks. Their findings showed that the brick meets the strength requirements of the Bureau of Indian Standards (BIS). The study by Turgut & Algin [11] incorporated a combination of cotton waste, limestone powder waste, and a combination of wood sawdust and waste to produce an inexpensive and lightweight composite building material. They concluded that incorporating these waste materials led to increased compressive strength and reduced water absorption that met the relevant international standards.

Other sustainable materials that could be incorporated into clay bricks are palm seeds and palm fronds. Some studies utilized palm oil wood as an insulation material, and the results showed that the palm oil particles enhanced the flexural strength of panels [12]. Alami [13] investigated the effect of palm fronds and date pits on unfired masonry clay bricks' mechanical and thermal properties. Their study found that these materials enhanced the properties of clay bricks. However, studies concerning using palm fronds and palm seeds in engineering works are still limited. For that matter, this study attempts to investigate the properties of unfired clay bricks after adding palm seeds and palm fronds. The study was experimental, and the physical and mechanical

properties of palm seeds and fronds unfired bricks were determined.

## 2. Materials and methods

### 2.1. Materials

The materials used in the current study included clay soil, palm seeds, and palm fronds.

#### 2.1.1. Clay soil

Clay soil used in this investigation was collected from swampy areas in Matugga. The topography of Matugga is seen in Fig. 1. Clay was used as a critical ingredient because of its availability. It was granulated and then filtered to eliminate rocks.

#### 2.1.2. Palm seeds

Palm seeds also known as date pits (see Fig. 2) are seeds obtained



Fig. 2. Palm seeds (saw palmetto).



Fig. 1. Topographical map of Matugga swampy areas.

from a palm fruit. Palm seeds used in this study were collected from swampy areas located in Matugga. Palm seeds were pounded using a mallet and sun-dried for two weeks. They were then filtered using a sieve to eliminate the remaining big grains. The properties of palm seeds were obtained from secondary sources, as seen in Table 1. Palm seeds contain vast quantities of carbon (44.1–45.3%). Carbon and nitrogen keep the soil particles together, hence preventing the shading of soils due to moisture-sucking sunshine, scorching winds, and shuttering by water, which all help in improving the durability of the unfired clay bricks.

2.1.3. Palm fronds

The palm fronds (see Fig. 3) were also obtained from swampy areas located in Matugga. They were cut into small pieces and then burnt for about 5 h at a temperature of about 50 °C in the kiln. Then left to cool for some time. The ash that was obtained from the burning was sieved using a 75 µm sieve before being used for the unfired clay brick production. The palm fronds’ chemical composition based on the literature review is shown in Table 2. The chemical composition in palm fronds was holocellulose, cellulose, hemicellulose, lignin, glucose, xylose, and small ash percentages. These chemical properties are vital in enhancing the strength of unfired bricks.

2.2. Methods

After having all the materials prepared, they were used to manufacture brick samples. Seven samples were made with different percentages using batching by weight through a substitution technique, as shown in Table 3. The percentages used were borrowed from secondary information of past researchers to cover the gap using our additives [13, 22]. This was done not to deviate a lot by using almost the same range. For instance, the study by Limami et al. [22] showed that the inclusion of 10% date pits to 90% clay produced bricks with the best performance results.

2.2.1. Particle size distribution (wet sieving)

The test comprised sieve analysis and was performed in accordance with BS 1377: Part 2:1990 [22]. This involved determining the percentage retained on each sieve after thorough shaking (particle distribution bigger than 0.075 mm).

2.2.2. Atterberg limits

These included using the liquid limit, plastic limit, and linear shrinkage limit in accordance with BS 1377: Part 2:1990 [22]. They were used to determine swelling characteristics of the clay soil to ensure the correct measurements of shear strength and show slight changes in volume through expansion and contraction using varying moisture content. The liquid limit of the clay soil was determined using Casagrande’s method. Plasticity index was obtained from plastic limit and liquid limit using Equation (1).

$$PI = LL - PL \tag{1}$$

2.2.3. Efflorescence test

This test was done in accordance with ASTM C67–02c [23]. This test was performed to check the efflorescence effect of palm seeds and palm fronds in the unfired clay bricks.

2.2.4. Compressive strength test

A compressive strength test machine was used. Compressive strength testing gave an idea about the maximum amount of compressive load



Fig. 3. Palm fronds.

the brick can bear before cracking. This test was carried out in accordance with ASTM C67 [24].

2.2.5. Water absorption test

This test was performed in accordance with ASTM C1403 - 15 [24]. This was done to check the water absorption rate in the unfired clay bricks.

2.2.6. Fire resistance test

This was performed in accordance to BS 476-22-2012 [25]. This was done to check for the ability of the unfired clay bricks to resist fire when exposed to them for a given period.

3. Results and discussions

3.1. Characterization of the clay soil

The properties tested on the clay soil are shown in Table 4. Particle size distribution was obtained from sieve analysis. The particle distribution curve indicated that 63% passed through sieve No. 200, as shown in Fig. 4. This indicates that the soil consists of silts and clays. The soil has liquid limit of 36.91%, plastic limit of 24.7%, and plastic index of 12.21%. Since the value of the plasticity index is 12.21%, it is regarded as low to medium plasticity [26].

3.2. Efflorescence test

In accordance with ASTM C67–02c [23], unfired clay bricks were tested to study the number of salts in them. Samples 1, 2, and 3 were suitable for use as their chemical properties did not cause any reaction due to inconspicuous efflorescence deposits. This was followed by samples 5, 6, and 7, which showed a weak response when less than 10% of the brick exposed area was covered with a thin layer of salt, as in Table 5. This might have occurred due to the low concentration of palm fronds and palm seeds in the unfired clay bricks, which signified the possibility of low soluble salt concentration when low percentages of palm fronds and palm seeds are used. Therefore, no efflorescence occurred on samples 1,2, and 3. For samples 5, 6, and 7, little efflorescence was observed, which results in unfired clay bricks being of good

Table 1  
Chemical composition of palm seeds.

Compound	Carbon (%)	Nitrogen (%)	Oxygen (%)	Sulfur (%)	Hydrogen (%)	Bulk density (kg/m <sup>3</sup> )	References
Value	44.1–45.3	0.9–1	47.2–48.3	0.6–0.8	5.6–6.1	560	[14–17]

**Table 2**  
Chemical composition of palm fronds.

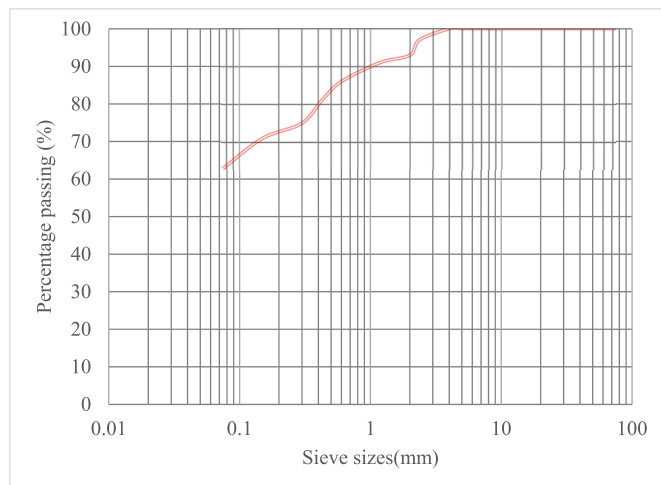
References	Cellulose	Holo cellulose	Compound (%)				
			Hemicellulose	Lignin	Glucose	Xylose	Ash
[18]	40–50	80–83	34–38	20–21	62–67	26–29	2–3
[19]	36	50	30	18			
[20]	46.6	80.5	33.9	18.3	–	–	2.5
[21]	40.21		12.8	32.2			10.54

**Table 3**  
Proportions of the materials used in the production of unfired clay bricks.

Sample No.	Mix ID	Clay (%)	Palm seeds (%)	Palm fronds (%)	Water (kg)
1	100C	100	0	0	19.7
2	50C50PS	50	50	0	22
3	60C40PS	60	40	0	23.7
4	40C60PF	40	0	60	25.2
5	80C20 PF	80	0	20	26.6
6	65C10PS25PF	65	10	25	28.1
7	35C25PS40PF	35	25	40	29.5

**Table 4**  
Summary for the classification of the clay soil.

Parameter	Results
Percentage passing BS sieve No. 200 (0.075 mm) (%)	63
Liquid limit (%)	36.91
Plastic limit (%)	24.7
Linear shrinkage limit (%)	7.7
Plasticity index (%)	12.21
USCS classification	CL



**Fig. 4.** Particle size distribution curve.

**Table 5**  
Results of efflorescence on the unfired clay brick samples.

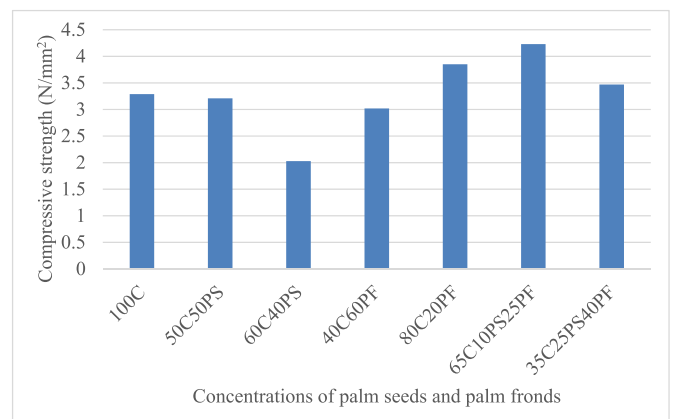
Brick sample	Palm seeds (%)	Palm fronds (%)	Results
1	0	0	Nil
2	50	0	Nil
3	40	0	Nil
4	0	60	Moderate
5	0	20	Slight
6	10	25	Slight
7	25	40	Slight

quality and durable in the long run. Kayalvizhi et al. [27] recorded that in all samples with a low concentration of fibers, precipitation formed was low; hence the bricks were of good quality and durable in the long run.

Sample 4 recorded the highest grade of efflorescence, denoted as moderate. This might have occurred due to the increased concentration of palm fronds in the unfired clay bricks. This also signifies the possibility of increased soluble salt concentration in the mixed palm fronds. Thus, unfired clay bricks indicate white substances on their surfaces which implies that these unfired clay bricks are of poor quality and not durable in the long run.

**3.3. Compressive strength test**

The brick samples' compressive strength is shown in Fig. 5, where compressive strength ranges from 2.03 N/mm<sup>2</sup> to 4.23 N/mm<sup>2</sup> depending on the percentage of palm seeds and palm fronds. After 14 days of curing, unfired brick sample 6 with 25% palm fronds and 10% palm seeds concentration recorded the highest average compressive strength of 4.23 N/mm<sup>2</sup>, probably due to optimum conditions being reached. Beyond this, compressive strength is compromised. Sample 7 with 25% palm seeds and 40% palm fronds recorded a lower average compressive strength than sample 6 of 3.47 N/mm<sup>2</sup>. This showed that a high increase in palm seeds and palm fronds concentration reduces the compressive strength of the unfired clay bricks. For the case of palm seeds concentrations only, sample 2, with a concentration of 50%, recorded a high compressive strength of 3.21 N/mm<sup>2</sup> compared to sample 3, with a concentration of 40% of 2.03 N/mm<sup>2</sup>. This showed that a decrease in the concentration of palm seeds reduces the compressive strength of unfired clay bricks. These findings agree with the study conducted by Limami et al. [9], who also noticed an increase in compressive strength after adding high quantities of date pits. For the case of palm fronds concentrations only, sample 4, with a concentration of 60%, recorded a lower compressive strength of 3.02 N/mm<sup>2</sup> than that of sample 5, with a concentration of 20%, which recorded a compressive strength of 3.85%. This indicated that an increase in the concentration of palm fronds reduces the compressive strength of the unfired clay bricks, as summarized in Fig. 5. Åhnberg [28] reported that the minimum



**Fig. 5.** A graph of compressive strength against samples.

required compressive strength standard of fired clay bricks is 2.73 N/mm<sup>2</sup>. According to the results obtained, most of the samples satisfied the minimum compressive strength since they were more significant than the value and passed the test. Sample 3 recorded 2.03 N/mm<sup>2</sup> hence did not satisfy the required minimum value; therefore, it did not pass the test. The comparison is made since compressive strength is essential to ensure the engineering quality of bricks to withstand loads. Kadir et al. [29] recorded that the decrease in palm fibers increases the compressive strength of the unfired clay bricks. Therefore, similar findings were obtained.

3.4. Water absorption test

The water absorption of the brick samples is represented in Fig. 6, where water absorption values of the samples varied from 16.1% to 100%, depending on the percentage of palm seeds and palm fronds. Samples 1,2,3,4, and 7 could not be taken after 24 h of immersion in water as these wholly dissolved. This meant that water absorption was 100% for the five samples and that bricks were too permeable and hence not durable. This is because high water absorption signifies the high porosity of bricks and a lower resistance of these bricks to deterioration hence low durability. Samples 6 and 5 remained with their shapes after the 24-h immersion in water. The two samples recorded 18.1% and 16.1% water absorption values, respectively. This can be explained by a relatively low concentration of palm seeds and palm fronds in the unfired clay bricks, which provide relatively higher amounts of bonding soil particles due to organic fibers acting as reinforcements in palm seeds and palm fronds. However, samples 1,2,3,4, and 7 recorded high-water absorption values, which were above the recommended limit of 20% water absorption rate, as shown in Fig. 6. This elaborates on why such bricks cannot be used in dump areas. Kadir et al. [29] recorded similar findings where an increase in the percentage of palm fibers from 1% to 10% increased the water absorption rate, and a decrease in palm fibers lowered the water absorption rate. Water absorption rates ranged from 12.84% to 18.76%, and the clay bricks were classified as Engineering bricks B.

3.5. Fire resistance test

After heat exposure at 520 °C on the samples, a compressive strength test was carried out to determine the effect of temperature on bricks. Compressive strength is affected by several factors; some lead to an increase in compressive strength, and others lead to a decrease. These factors include; components of raw materials added and the degree of firing. The compressive strength before firing was lower than after firing, as seen in Fig. 7. The samples did not develop any cracks after exposure to fire. Aldefae et al. [30] recorded that the compressive strength before firing is higher than that after firing. This could be due to

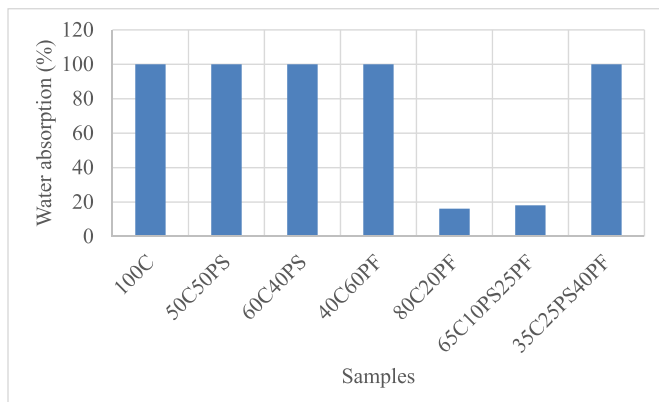


Fig. 6. A graph of water absorption against samples.

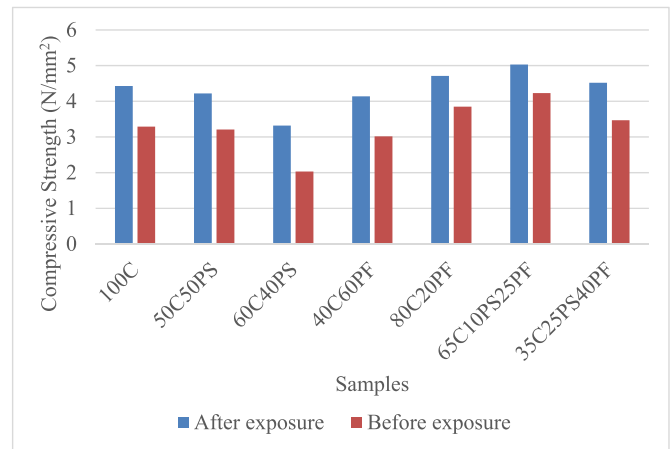


Fig. 7. Relationship between the compressive strength of the sample before and after firing.

the soil’s low water content and low longitudinal shrinkage ratio. A notable observation here is that a high water content ratio induces particle spacing, resulting in decreased compressive strength following firing. Furthermore, rising longitudinal shrinkage generates cracks, resulting in reduced compressive strength after firing. The compressive strength of bricks was shown to diminish at high firing temperatures.

3.6. Determination of optimum percentage of palm fronds and palm seeds

The optimum content percentage of palm fronds and palm seeds was determined after conducting the experiments. The mixture that produced bricks that meet the requirements of the relevant international standards were considered the optimum mixture. Therefore sample 5 and sample 6 had the optimum percentages of palm fronds and palm seeds that produced the strong unfired clay bricks.

4. Conclusions and recommendations

4.1. Conclusions

The current study aimed to investigate the efficiency of palm fronds and palm seeds in enhancing the properties of unfired clay bricks. There is potential in using blended binders to manufacture unfired clay bricks. Both palm seeds and palm fronds improved the strength characteristics of the unfired clay bricks; whose combined action firmly bound the soil particles. The results suggest the potential for the use of blended binders with clay for the manufacture of unfired clay materials within the building industry and for various stabilized soil applications. The following conclusions are therefore drawn from tests carried out;

- Particle size distribution and Atterberg limits of the clay indicated that the soils were clayey (A-6) under the AASHTO classification. For the case of plasticity, the USCS classification showed that the soils were inorganic with low to medium plasticity (CL).
- Six samples passed the efflorescence test, indicating that they can be used for construction since none had a serious reaction (powdering and flaking of the surface). Sample 3 cannot be used during construction due to the high concentration of additives used since it had a moderate reaction.
- After carrying out the compressive strength test, compressive strengths recorded by samples 6,5,7,1,2 and 4 indicated that they could be used for construction only for the internal non-load bearing walls. The compressive strength recorded by sample 3 indicated that it could not be used for construction since its compressive strength did not exceed the least allowable compressive strength of 2.73 N/mm<sup>2</sup>.

- After carrying out a water absorption test, samples 1,2,3,4 and 7 showed that these unfired clay bricks had a high capillarity, so they cannot be used during construction for external walls since they are easily affected by water. Samples 5 and 6 water absorption rates were within the acceptable limits for the durability of stabilized clay masonry units of (16–20) %, which classifies them as second-class bricks. Therefore, these two samples had a low capillarity making them favorable for construction but basically for internal non-load bearing walls.
- All the samples passed the fire resistance test, which indicated that their performance, when exposed to fire under construction, was good since they did not develop cracks after 120 min. Therefore, they had a suitable factor of safety.
- To sum up, according to all the tests, it was concluded that palm seeds and palm fronds are promising additives to use with clay to make strong unfired clay bricks. It was discovered that samples 5 and 6 had low concentrations of palm seeds and palm fronds that produced strong unfired clay bricks, and they passed all the tests carried out. Therefore, they were considered to have the optimum percentage.

#### 4.2. Recommendations

Based on the results, discussions, and conclusions, the following recommendations arose;

- Properties such as creeping resistance and thermal resistance of unfired clay bricks bound with palm fronds and palm seeds and water resistance properties should be investigated in further studies.
- Further research should be done by using soda ash as an additive to improve unfired clay bricks properties and make them more suitable for high load bearings.
- The air-drying method of the curing process should be adopted as a suitable method because constituents of laterite soil cannot withstand the influence of water over a long period.

#### Authorship statement

All the authors agree that they conducted the study entitled “Enhancing Properties of Unfired Clay Bricks Using Palm Fronds and Palm Seeds” together. They were engaged in the conception, reviewal and approval of this manuscript for submission.

#### Authorship contributions

Conception and design of study: JBN, KCN, and JA, Acquisition of data: KCN and JA, Analysis and/or interpretation of data: JBN, KCN, MK and PT, Drafting the manuscript: JBN, KCN, and JA, Revising the manuscript critically for important intellectual content: JBN, PT, and MK, Approval of the version of the manuscript to be published: JBN, KCN, MK, PT, and JA.

#### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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