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Research Article

Improving the Properties of Laterite Bricks With Palm Nut Fibre and Lime for Housing Application

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The high cost of cement and sand has called for research into the use of alternative low-cost building construction materials, such as laterite, for producing bricks and blocks for housing. The aim of the study is to investigate the engineering properties of lateritic bricks that are stabilised with palm nut fibre (PNF) and lime for housing applications. Laterite, 5% lime constant, and PNF of 0.2%, 0.4%, 0.6%, 0.8%, and 1% by weight of laterite were used for preparing the bricks, and their properties were assessed at 7, 14, 21, and 28 days of curing. About 1% PNF and 5% lime at 28-day curing achieved the highest compressive strength of 2.328 N/mm^2 as compared with the control brick strength of 1.022 N/mm^2, representing a strength increase of 127.8% as compared with the control. The maximum tensile strength of 0.514 N/mm^2 was achieved by 1% PNF and 5% lime at 28-day curing as compared with 0.206 N/mm^2 control, which represents 149.5% improved strength. It was found that the higher the fibre content and lime in the brick specimen, the lesser the water absorption. The abrasion resistance of the brick specimens increases with an increase in fibre content. The study concludes that PNF and lime inclusion in lateritic bricks improves the properties of the blocks. About 1% PNF and 5% lime are recommended for use in manufacturing laterite brick for housing applications.

Keywords: abrasion; compressive strength; laterite bricks; palm nut fibre; tensile strength; water absorption

1. Introduction

Construction of houses required high consumption of aggregates and cement, especially at the bricks and blocks moulding stage. The rising cost of sand and cement for building houses has been a great issue affecting people in low-income countries. Therefore, the production of affordable housing with low-cost building and construction materials is a critical need in less developed countries [1–4]. Danso [5] identified that providing decent housing at less cost will help low-income earners to live in decent buildings, reduce the housing deficits in less developed countries, and also reduce the environmental impact of construction activities. The low-income earners' inability to afford decent housing and the expansion of informal settlements are underlined by the necessity to research new building techniques and methods. The use of sustainable building construction materials to build low-cost housing has the potential to address environmental, economic, and social challenges [6].

The continual increase in the cost of conventional building construction materials has prompted researchers, designers, and developers to look for alternative materials for possible use in the construction of houses [7]. Thus, the construction industry offers an ideal method to integrate and utilise several waste materials that are socially acceptable, available, and economical within the buying powers of an ordinary person [8]. The use of agricultural waste for moulding bricks reduces carbon dioxide (CO_2) emissions and the cost of buildings. Extreme dependence on the use of industrially manufactured materials leads to the high cost of buildings, which deter less developed

(a)

(b)

FIGURE 1: Raw materials: (a) sieved laterite ready for use and (b) sample palm nut fibres.

countries from supplying decent housing for underdeveloped communities that constitute a greater percentage of their population [9]. GSS [10] population and housing census (PHC) report indicated that the proportion of houses in rural areas constitutes 57.7%, which is greater than those in urban areas, which is 42.3% in Ghana. An estimate by GSS [10] indicates that Ghana's housing deficit is about 2 million houses. The estimate further indicates that materials used for wall construction in Ghana include landcrete (1.8%), burnt bricks (0.7%), bamboo (0.1%), sancrete blocks (57.5%), stone (0.2%), and earth bricks (34.2%) [10]. The GSS once again noted in its 2021 PHC report that 78.7% of building structures were conventional structures (block buildings) [10]. These statistics prove that, although mud bricks or earth for housing is affordable, the majority of Ghanaians, especially those in urban areas where housing units are in high demand because of rural–urban migration, have been using cement and sand for moulding blocks, which have contributed to the high cost and inadequate housing in Ghana [9].

Sandcrete block walls are currently dominating the building construction industry with their disadvantages of more cement and sand consumption, poor thermal performance, and high cost [11]. Earth-based material buildings are usually affordable as the earth or the soil is cheaper and abundantly available [12]. To solve the issue of insufficient housing units in developing countries, there is a need to tackle the problems of building materials, especially improving the properties of those that reduce construction costs [13]. Obianyo, Onwualu, and Soboyejo [12] expressed that the selection of building materials in communities depends on the availability and cost. Therefore, it is important to identify alternate building materials that are abundantly available and affordable [13]. Several researchers have established that the cause of the high cost of housing is responsible for the gap between the supply and demand of affordable housing. Obeng-Odom and Amadezro [14] identify that the high cost of building materials and poverty are responsible for inadequate housing.

This research is carried out as a result of the gap found in the literature on the use of agricultural waste, laterite, and lime for producing bricks. Previous studies have concentrated on the use of rice husk and cornsilk fibres as soil block reinforcement [8, 15]. Others used materials like jute [16] raw rice husk ash and raw rice husk [17], oil palm fibres, coconut husk fibres, sugarcane bagasse fibres [5], slate tailings [18], oil palm empty fruit bunch fibres [19], rice husk ash and cement [20], sugarcane bagasse ash with lime [21, 22], synthetic waste wig fibre [23], coconut fibres with lime [24]. From the review of the relevant literature, there is a lack of information on the use of laterite, palm nut fibre (PNF), and lime for producing bricks for housing.

As a contribution towards filling this gap, this study was conducted to improve the properties of laterite bricks with PNF and lime for housing applications. The use of PNF, which is usually burnt as waste that contributes to CO_2 in the atmosphere, would rather be useful as a building material. The use of laterite, PNF, and lime as building materials contributes to sustainable construction practices in terms of reduced cost and environmental impact. The study adopted an experimental research design that determined the properties of the bricks manufactured with laterite, PNF, and lime. Laterite, 5% lime constant, and PNF of 0.2%, 0.4%, 0.6%, 0.8%, and 1% by weight of laterite were used for preparing the bricks, and their properties were assessed at 7, 14, 21, and 28-days curing periods. The properties that were determined are abrasion, tensile strength, compressive strength, water absorption, and scanned electron microscopy (SEM) analysis on bricks produced. This study contributes to Target 1 of the Sustainable Development Goal 11 (SDG 11), which seeks to ensure access for all to adequate, safe, and affordable housing. The study investigates alternative materials that can be used to build affordable housing for people in the low-income bracket.

2. Materials and Methods

2.1. Materials. The experimental raw materials deployed for this study are laterite, PNF, lime, and water. The laterite sample used for the production of the bricks was sourced from the Akenten Appiah-Minka University of Skills Training and Entrepreneurial Development (AAMUSTED), Kumasi-Ghana, behind the construction laboratory block. The laterite sample was sieved through a 12.5 mm square sieve for bigger particles and other impurities like tree roots and stones to be removed. The sieved laterite (Figure 1a) was used for the production of the bricks. The PNF samples were collected from Twifu Ayiase oil palm mill, a suburb of Twifu Praso in the Central Region, Ghana. The palm nuts were well boiled and milled, and the oil was then extracted from the milled nuts. The waste fibres were collected and placed in warm water to extract the oil and were then sun-dried for a week to remove the remaining oil (Figure 1b).

Thirty single fibres were randomly selected from the sampled fibres, and their lengths and diameters were measured with a digital calliper and steel rule, respectively. The

Table 1: Material quantity and mix proportions.

Materials	**Quantity**						
Palm nut fibre (%)	**0 (mix1)**	**0.2 (mix2)**	**0.4 (mix3)**	**0.6 (mix4)**	**0.8 (mix5)**	**1 (mix6)**	**Total**
Laterite (%)	100	94.8	94.6	94.4	94.2	94.0	—
Lime (%)	0	5	5	5	5	5	—
Water (%)	6.5	10.2	10.4	10.9	11.3	11.7	—
No. of bricks	24	24	24	24	24	24	144

fibre length ranged between 3.9 and 6.3 mm, and the diameter between 0.18 and 0.55 mm. The average fibre length and diameter were 6.15 and diameter 0.319 mm, respectively. The hydrated lime used for the experimental work was bought from a lime depot at Adum, Kumasi-Ghana. The water used for the mix was clean portable water from the tap of the construction materials laboratory at AAMUSTED, Kumasi-Ghana.

2.2. Brick Specimens' Preparation. Table 1 shows the quantities of materials used and their mix proportions for preparing the brick specimens. The 5% constant lime and palm nuts fibre of 0%, 0.2%, 0.4%, 0.6%, 0.8%, and 1% contents by weight of the laterite were used. The 5% constant lime was used as recommended by a previous study [24]. The lime was used to serve as a binder in the bricks. Control brick specimens were prepared with only laterite and water without lime and PNF. The required quantity of laterite was batched with the aid of an electric weighing balance and spread on the platform, the quantity of lime was batched and spread over the laterite, and the laterite and lime were mixed to obtain a uniform mixture. The PNF was then measured and spread on the laterite–lime mixture (Figure 2a), and the materials were then mixed thoroughly. The quantity of water required was batched and added to the mixture gradually while mixing until a uniform mixture was achieved. The different mixtures were used for moulding the brick specimens of dimension 100 x 100 x 140 mm. The mixture was weighed and poured into the brick-making machine and pressed at 120 bar. The brick specimens were removed and placed on the floor of the laboratory for air drying (Figure 2b) and cured up to 7, 14, 21, and 28 days. The brick specimens were cured by sprinkling water on them in the morning and evening daily. A total of 144 brick specimens were prepared, as shown in Table 1.

2.3. Testing of Brick Specimens. The properties of the brick specimens prepared from laterite, PNF, and lime were assessed through tensile strength, compressive strength, water absorption, and abrasion tests as well as microstructural analysis.

2.3.1. Tensile Strength Test. ELE 2000 kN testing machine was used to conduct the split tensile strength test according to the procedures of BS EN 12,390:6 [25]. Three brick specimens were randomly selected from each mix ratio for testing at 7, 14, 21, and 28 curing days. Each brick specimen was put on a metal jig on top of the base plate of the testing machine; another metal jig was placed on top of the brick specimen and carefully centred. A load of 0.05 kN/s was released continuously until the test brick failed (Figure 3a). The peak load at which the specimen raptured was noted, and the tensile strength was calculated using Equation (1):

$$ft = \frac{2P}{\pi Ld}, \tag{1}$$

where ft = tensile strength (N/mm^2), P = the peak load at which the specimen ruptured (N), L = the length of the specimen (mm), and d = the width of the specimen (mm).

2.3.2. Compressive Strength Test. BS EN 772:11 [26] procedure was followed to perform the compressive strength test. The WAW-1000H Universal compression testing machine with the capacity of 1000 kN was used. Three brick specimens from each mix ratio were tested at 7, 14, 21, and 28 days of curing age. Each test brick was laid on the base plate, and the movable part of the testing machine was brought down gently by hand until it touched the test brick specimen. The load was released on the brick specimen gradually until it ruptured (Figure 3b). The peak load at which the specimen ruptured was noted and the compressive strength was calculated by Equation (2).

$$fc = \frac{F}{A}, \tag{2}$$

where fc = the compressive strength (N/mm^2), F = the peak load at which the specimen ruptured (N), A = the area of the specimen at which the load was exerted (mm^2).

2.3.3. Water Absorption Test. The water absorption test was conducted to assess the rate of water uptake of the brick specimens. BS EN 772:11 [26] procedure was followed to perform the water absorption test. Three-brick specimens were selected from each mix design for testing after 28 days of curing age and then oven-dried at a constant temperature of 106°C for 24 h, and the brick specimens were weighed. The 140 x 100 mm sides of the brick specimens were placed in a container containing water to a depth of 20 mm from the bottom for 1 h. The weight of the absorbed brick specimens was measured and the absorption was calculated by Equation (3).

(a) (b)

Figure 2: Preparation of brick specimens: (a) mixing of mortar and (b) air drying of brick specimens.

(a) (b) (c)

Figure 3: Testing of brick specimen: (a) splitting tensile strength test, (b) compressive strength test, and (c) brick specimens after abrasion test.

$$\mathrm{WA} = \frac{M_2 - M_1}{M_1} \times 100, \tag{3}$$

where WA = water absorption by capillary (%), M_1 = oven-dried weight of the brick specimen (kg), and M_2 = the weight of the partially absorbed brick specimen (kg).

2.3.4. Abrasion Test. ASTM D559-03 [27] procedure was followed to conduct the abrasion test. The brick specimens were cured for 28 days and oven-dried for 106°C for 24 h and were weighed. The brick specimens were placed on a table, and 18 vertical strokes with a wire brush of ~13.3N load were exerted on each side of the brick specimens and 4 strokes were applied to each end side to complete a cycle. In total, 12 cycles were performed to complete the test (Figure 3c). Each brick specimen was weighed for the abrasion resistance to be calculated using Equation (4).

$$\mathrm{AR} = \frac{W_2 - W_1}{W_1} \times 100, \tag{4}$$

where AR = abrasion resistance (%), W_1 = weight of the brick specimen after wire brush (kg), and W_2 = the weight of brick specimen before wire brush (kg).

2.4. SEM Analysis. The SEM analysis was conducted to assess the microstructure of the brick specimen made with laterite, PNF, and lime. A broken piece of a brick specimen was analysed with a Phenom-World ProX SEM analyser to capture and save the image.

2.5. Data Analysis. The data obtained were computed and presented in figures and tables with the help of Microsoft Excel software. An analysis of variance (ANOVA) test was used to assess the significant variations and differences between the test results. To determine the existence of any significant difference in different test groups, Sigma Plot software was used.

3. Results and Discussion

3.1. Compressive Strength. The compressive strength of the brick specimens was assessed after curing at 7, 14, 21, and 28 days, and the result obtained can be seen in Figure 4. It can be observed that as the palm nuts fibre content increased, the compressive strength of the brick specimens also increased. The control brick specimens produced the lowest strength of 0.812, 0.936, 0.958, and 1.022 N/mm^2 at 7, 14, 21, and 28 curing days, respectively, as compared with the brick specimens produced from 1% palm nuts fibre and 5% lime,

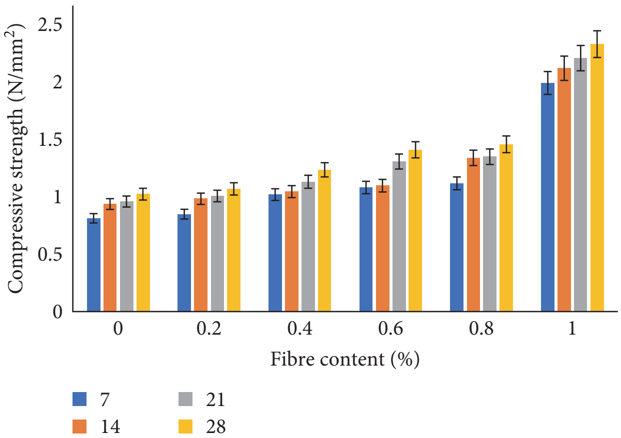


Figure 4: Compressive strength of the brick specimens.

which obtained higher strength of 0.990, 2.118, 2.206, and 2.328 N/mm^2 at 7, 14, 21, and 28 curing days, respectively. The highest compressive strength of 2.328 N/mm^2 represents a strength increase of 127.8% over the control at 28 days of curing. The 28 days cured brick specimens of 0.6%, 0.8%, and 1% fibre content with 5% lime content were found to be higher than the standard strength of 1.4 N/mm^2 requirement specified in the GhBC GS1207 [28] for building and construction. NIS 87:2004 [29] also recommends a strength of 2.8 N/mm^2 for walls subjected to loads and 2.0 N/mm^2 for non-load-bearing walls. The compressive strength result of the brick specimen further indicates that the 1% palm nuts fibre and 5% lime content at 14, 21, and 28 curing days were higher than the required 2.0 N/mm^2 compressive strength for non-load-bearing walls. The findings of this study are consistent with the findings by Sharma, Marwaha, and Vinayak [30], whose compressive strength of Grewia Optiva fibre and cement-reinforced adobe bricks increased with increased fibre addition. Another result of previous studies by Wang, Gan, and Kang [18] and Danso [5] found that additions of fibre content significantly improved the compressive strength of earth bricks. The progressively increased strength can be attributed to the palm nuts fibre and lime in the soil matrix, which enhanced the binding property of the bricks. Another reason for the enhancement of the strength is the fibre addition in the bricks, which prevents cracks development and propagation [5]. The lime content in the brick also contributed to the strength enhancement of the bricks due to the binding characteristics that ensure a good bond between the fibres and the clay matrix. The results of previous studies by Akinyele, Olateju, and Oikelome [8], Obianyo, Onwualu, and Soboyejo [12], Mostafa and Uddin [31], and Cottrell et al. [16] found optimum strength with fibre addition after which the strength declined with further fibre addition. A study by Kang et al. [32] used iron ore tailings supplemented with ground granulated blast-furnace slag in bricks and obtained a very high compressive strength of 31.72 MPa. Such bricks are high performance bricks as compared to the laterite bricks in this current study. In assessing if the difference between the test results was significant or not, an ANOVA test was conducted, and the result, as illustrated in Table 2, shows that there are significant differences ($p = 0.001$) between the test results. To determine which of the treatment pairs recorded the difference, all pairwise multiple comparison procedure (Tukey test) was performed, and the compressive strength results of the 1 vs. 0, 1 vs. 0.2, 1 vs. 0.4, 1 vs. 0.6, and 1% vs. 0.8% pairs were all found to be statistically significant at $p < 0.001$. All the remaining pairs were found to be not statistically significant with $p > 0.05$.

3.2. Split Tensile Strength. The split tensile strength result of brick specimens is illustrated in Figure 5. The result indicates that the highest split tensile strength was obtained by 1% palm nuts fibre-reinforced brick specimens for all the curing days. At 1% fibre and 5% lime addition, the average split tensile strength obtained for the brick specimens were 0.310, 0.416, 0.470, and 0.514 N/mm^2 on 7, 14, 21, and 28 curing days, respectively, as compared with the control brick specimens average split tensile strength of 0.148, 0.164, 0.176, 0.206 N/mm^2 at 7, 14, 21, and 28 curing days, respectively. The result of the current study is in contrast with the previous studies [12, 16], where adobe brick specimens tested attained increased tensile strength at an optimum and declined at further addition of fibres. The continual increase in the tensile strength of the current study can be ascribed to the addition of the lime, which serves as a binder between the fibre and the soil matrix. It is evident from the current results that the laterite brick spacemen made with the addition of 1% palm nuts fibre and 5% lime improved the tensile strength. In assessing if the differences between the split tensile strengths of the brick specimens were significant or not, an ANOVA test was performed, and the result (Table 2) confirms a significant difference ($p = 0.001$) between test results of the brick specimens. To determine which of the treatment pairs obtained the significant difference, all pairwise multiple comparison procedures (Tukey test) were performed, and the split tensile strength results of the 1 vs. 0, 1 vs. 0.2, 1 vs. 0.4, 1 vs. 0.6, and 1 vs. 0.8% pairs were all found to be statistically significant at $p < 0.001$. All the remaining pairs were found not to be statistically significant with $p > 0.05$.

3.3. Correlations Between Tensile and Compressive Strengths. It was found in the current study that the maximum tensile strength was 0.514 N/mm^2, and that of the compressive strength was 2.328 N/mm^2. Both the tensile and compressive strengths achieved their highest strength at 28 days of cured bricks with 1% PNF content and 5% constant lime addition. The correlation between the tensile and compressive strength results of the brick specimens is illustrated in Figure 6. The outcome of the tensile and compressive strength results showed a positive relationship, meaning that both the tensile and compressive strengths of the bricks increase with increased fibres content of the brick specimen. A previous study [33] obtained similar results. Figure 6 shows the coefficient of the determinant (R^2) of 0.8644, 0.7893, 0.97, 0.9633, 0.5829, and 0.9919 for 0, 0.2%, 0.4%, 0.6%, 0.8%, and 1% PNF, respectively, representing moderate to very strong association between the tensile and compressive strength results of the brick specimens. This implies that as the tensile strength of the brick increased the compressive strength also increased.

Table 2: One-way ANOVA for tensile and compressive strengths of the brick specimens.

Source of variance	DF	Compressive strength				Tensile strength			
		SS	MS	*F*	*p*	SS	MS	*F*	*p*
B/t subjects	2	0.0029	0.0014	—	—	0.0029	0.00004	—	—
B/t treatments	5	0.8560	0.1710	25.702	<0.001	0.8560	0.00974	72.127	<0.001
Residual	10	0.0660	0.0066	—	—	0.0666	0.00014	—	—
Total	17	0.9260	0.0545	—	—	0.9260	0.00295	—	—

Note: F (*F* ratio); *p* (significant level = 0.05).
Abbreviations: ANOVA, analysis of variance; MS, mean square; SS, sum of squares.

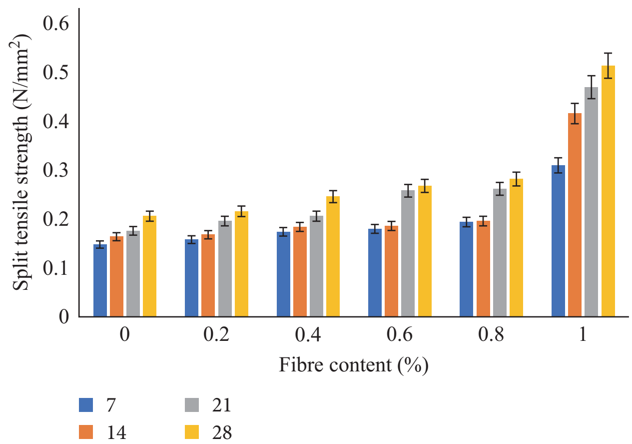


Figure 5: Split tensile strength of the brick specimens.

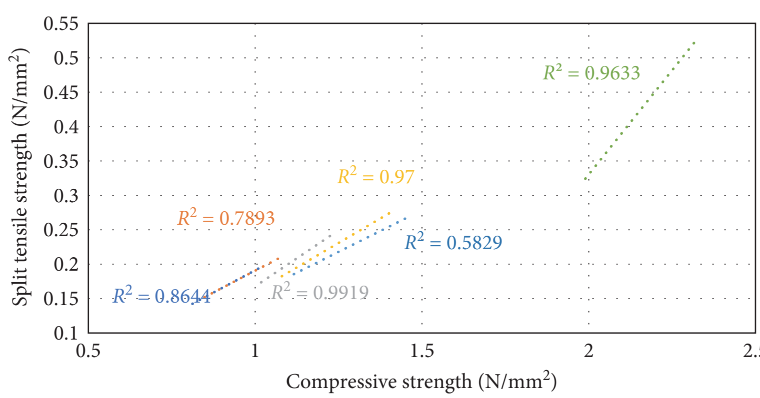


Figure 6: Correlations between tensile and compressive strengths of the brick specimens.

3.4. Water Absorption. Figure 7 illustrates the result of the water absorption test of the brick specimens. The result indicates that the control brick specimens achieved the highest water absorption of 5.7% as compared to the lowest water absorption of 2.76%, which was obtained at the 1% palm nuts fibre and lime. This indicates that the PNF and lime addition to the brick specimens provide better resistance to water uptake. It can be observed that the higher the fibre content in the brick specimen, the lower the water absorption. This result is in contrast with the results of previous works [3, 5, 34], in which the results of water absorption by capillary test revealed that the rate of absorption of the specimens increased with increased reinforced fibre content in the soil matrix. A similar previous study [17] also obtained a rise in the absorption of the specimen with an increase in empty palm bunch fibre. The rise in absorption with increased reinforced fibre in the previous studies was ascribed to the quantity of water uptake by the cellulose of the reinforced fibres, attributed to the amount of cellulose material and the void volume present. The reversed water absorption trend in this study is attributed to the introduction of lime in the soil–fibre mixture, which functions as a binder and improves the bond between the particles of the brick specimens. Therefore, the lower water uptake by the palm nuts fibre and lime brick specimens as against the control is due to the presence of lime in the treated brick specimens. A similar result was achieved in a previous study [24], which used coconut fibre and lime to enhance the

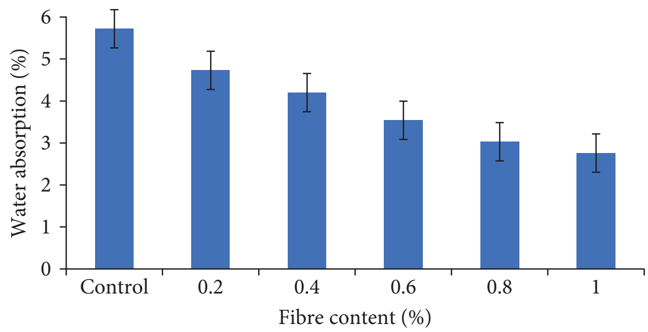


Figure 7: Water absorption of the brick specimens.

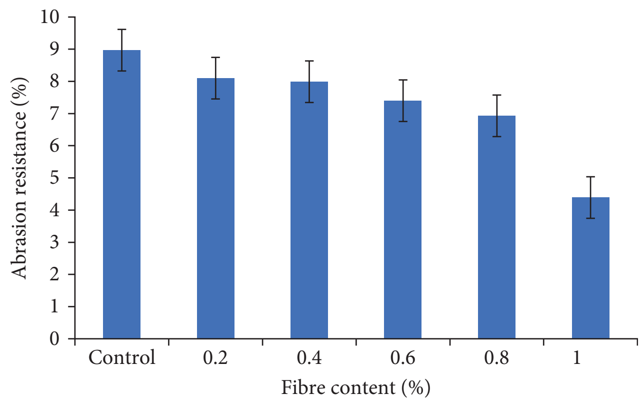
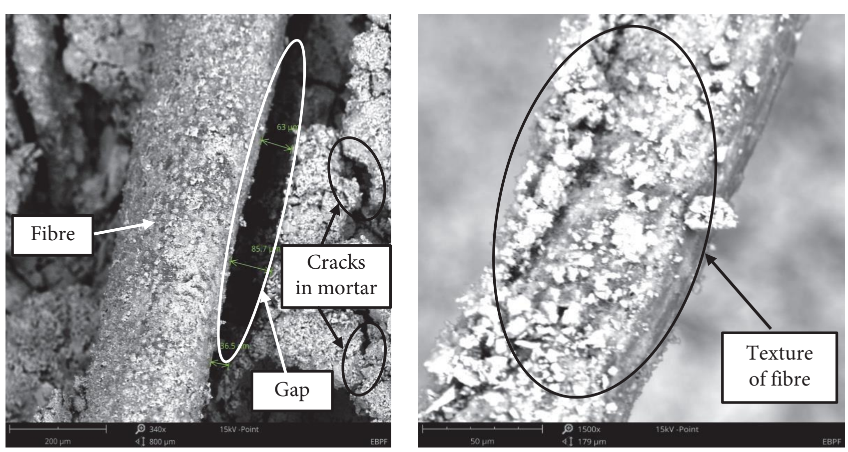


Figure 8: Abrasion resistance of the brick specimens.



(a) (b)

Figure 9: SEM images: (a) micrographic image of a fibre in the brick specimen and (b) image of a single fibre. SEM, scanned electron microscopy.

properties of soil blocks. It must, however, be noted that the absorption percentages (2.76%–5.7%) obtained in this study are better than the 12% required by BS 2028:2000 [35].

3.5. Abrasion Resistance. Figure 8 illustrates the abrasion results of the brick specimens produced with PNF and lime. The control spacemen recorded the highest abrasion of 8.97%, which is followed by 8.10% abrasion for 0.2% PNF brick specimens, and the least abrasion of 4.39% recorded by the 1% PNF brick specimens with constant 5% lime. The result indicates that the abrasion resistance increased with an increase in fibre content, implying that the 1% fibre brick specimens have improved resistance against wearing of the constituent part of the brick specimens. A similar observation was found in a previous study [5] in which the rate of wearing of the block specimens lessened with increased fibre quantity. This indicates that the addition of fibres to the brick specimens improved the resistance of the specimens against wearing triggered by external conditions, such as human activities and wind. The current study result was better compared with that of a previous study [36], which achieved an abrasion result of 9.32 on fired clay bricks. The abrasion resistance of 4.39%, which was achieved by a 1% fibre brick specimen, was better than the values obtained in the above previous studies.

3.6. Microstructural Analysis. The microstructural analysis of the fibre brick specimens was done using SEM. SEM images obtained from the brick specimen are shown in Figure 9. It can be observed from the SEM images that there is the existence of gaps between the fibre and the soil-lime matrix (Figure 9a). The degree of these gaps might be widened during the breakage of the bricks [5]. Figure 7a also shows some micro cracks and voids in the brick specimen, which cannot be seen by the naked eye. The microstructural characteristics in this study are similar to those found in the previous study [25]. The development of cracks and voids usually occurs due to manufacturing and handling deficiencies [25]. The image of the single fibre shown in Figure 9b indicates that the fibre texture is rough. This rough surface of the PNF is facilitate a better bond with the soil-lime matrix. A similar result was observed in previous studies [5, 25]. The rough surface of the fibre contributed to the improved tensile and compressive strengths of the fibre and lime-stabilised soil brick [25]. The improved bond between the fibres and the soil-lime matrix also contributed to the better water absorption and abrasion resistance of the brick specimens.

4. Summary and Conclusion

In this study, brick specimens were prepared from six different mixes of laterite, PNF, and lime, and their properties were assessed. The highest compressive strength of 2.328 N/mm^2 of the fibre lime stabilised reinforced brick specimens was within the recommended compressive strength of the Ghana Building Code [30] for building and construction. The highest split tensile strength of 0.514 N/mm^2 of the fibre lime stabilised brick specimens was better than the control brick specimens. The difference between both the compressive and tensile strengths and the control specimens was found to be statistically significant. A moderate to very strong correlation was found between the tensile and compressive strength results of the fibre lime-stabilised brick specimens. The water absorption percentages (2.76%–5.7%) obtained in this study are better than the 12% required by the BS 2028:2000 [36]. It was also revealed that the abrasion resistance of fibre and lime-stabilised brick specimens improved with an increase in fibre quantity. It was observed from the SEM images that there exist micro gaps between the fibre and the soil-lime matrix. The study, therefore, concludes that the inclusion of PNF and lime significantly and positively improved the engineering properties of the laterite bricks. It is recommended that laterite bricks reinforced with 1% PNF and 5% lime should be used as a building material for non-load-bearing walls such as partitions. Future studies should consider burning the fibre lime-stabilised bricks and compared the properties with the unburnt bricks. It is further recommended that future studies consider assessing factors such as carbon footprint, energy consumption, cost–benefit analysis, environmental impact analysis, and long-term durability of laterite bricks reinforced with PNF and lime.

Nomenclature

AAMUSTED:	Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development
ANOVA:	Analysis of variance
PHC:	Population and housing census
PNF:	Palm nut fibre
SEM:	Scanned electron microscopy.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Ebenezer Aidoo carried out the investigation, experimental work, and prepared the first draft. Humphrey Danso validated, confirmed, supervised, evaluated, and edited the work. The final manuscript was read and approved by both authors.

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