Use of Cement-Sand Admixture in Laterite Brick Production for Low Cost Housing

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Abstract

Laterite was modified with 45% sand content by dry weight and stabilized with up to 9% cement content respectively and used in the production of 330 mm × 150 mm × 150 mm bricks through the application of a pressure of 3 N/mm^2 with a brick moulding machine. Results showed that laterite used in this study cannot be stabilized for brick production within the economic cement content of 5% specified for use in Nigeria. However, bricks made with laterite admixed with 45% sand and 5% cement attained a compressive strength of 1.80 N/mm^2 which is greater than the specified minimum strength value of 1.65 N/mm^2. Cost comparison of available walling materials in Makurdi metropolis showed that the use of bricks made from 45% sand and 5% cement resulted in a saving of 30 - 47% when compared with the use of sandcrete blocks while the use of fired clay bricks resulted in a savings of 19% per square meter of wall. The study therefore recommends the use of laterite bricks in Makurdi and other locations because it is more economical and environmental friendly than fired clay bricks.

Keywords

Cement; Sand; Laterite; Brick Production.

Introduction

In many countries, the need for locally manufactured building materials can hardly be overemphasized because there is an imbalance between the demands for housing and expensive conventional building materials coupled with the depletion of traditional building materials. To address this situation, attention has been focused on low-cost alternative building materials.

In Makurdi, the capital of Benue State of Nigeria and its surrounding towns, the most common walling materials are the conventional sandcrete blocks and fired clay bricks. The cost of sandcrete blocks coupled with the low strength properties of commercially available blocks necessitated the search for an alternative that was fired clay bricks. These are smaller than sandcrete blocks and therefore require more bonding mortar. The production of fired clay bricks is labour intensive and the process of firing is usually carried out using given species of trees (*prosopis Africana and melicia excelsa*) which could lead to their extinction and deforestation. Firing of bricks requires great quantities of firewood and energy loss in the form of heat is about 40-50%. In addition to the environmental problem, clay bricks can only be produced in locations where suitable clay soil deposits exist.

In Makurdi and other locations within Benue State, abundant lateritic soil deposits exist which can be harnessed for brick production. This potential is not being maximized. Compared to sandcrete blocks, it is economic to use laterite for brick production because very little cement is required and the cost of transportation is eliminated as production takes place on site. Compared to fired clay bricks, the production of laterite bricks does not involve the firing process. To cure the laterite bricks, they are by covered with tarpaulin and waterproof devices thereby making the process to be more environmental friendly. Laterite bricks are fire resistant and bulletproof.

From experience, laterite bricks of 330 × 150 × 150 mm have proved to be economic and can be easily laid. It is an improvement on the fired clay bricks of 250 × 150 × 100 mm because 22 bricks are required per meter square of wall as against the 33 required for fired clay bricks. Consequently, the mortar required for jointing per square meter of wall is reduced significantly.

Good laterite bricks were produced from different sites in Kano when laterite was stabilized with 3 to 7% cement [1]. The study showed that particle size distribution, cement

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content, compactive effort and method of curing are factors which affect the strength of the bricks.

Laterite bricks were made by the Nigerian Building and Road Research Institute (NBRRI) and used for the construction of a bungalow [2]. From the study, NBRRI proposed the following minimum specification as requirements for laterite bricks: bulk density of 1810 kg/m^3, water absorption of 12. 5%, compressive strength of 1.65 N/mm^2 and durability of 6.9% with maximum cement content fixed at 5%.

Laterite stabilized with cement was used successfully to produce bricks in Sudan [3]. Three pressure ranges: 2 to 4 N/mm^2, 8 to 14 N/mm^2 and 6 to 20 N/mm^2 which were designated low, high and hyper respectively were used in the production of bricks. With cement content of 5 to 8% and a brick size of 290 x 140 x 90 mm, compressive strength ranging from 3 to 3.5 N/mm^2 was achieved using a compactive effort that ranged from 8 to 14 N/mm^2. The study showed that the strength of bricks was dependent on the pressure applied during production, percentage of cement used, and the particle size distribution of the laterite.

Cement stabilized soils are usually evaluated by unconfined compressive strength (UCS) test with a minimum 7-day UCS value of 1720 kN/m^2 as criterion for effective stabilization [4]. The maximum permissible cement content of 5 % was specified by NBRRI [2]. A 7-day UCS value of 1.765 N/mm^2 was recommended by [1] for laterite-cement mixture when it is to be used in the production of laterite bricks.

Several researchers have reported that cement-stabilized laterite can be used in road and building construction [5-8]. Literature is scarce on the engineering properties of Ikpayongo laterite and its use in the construction industry. This objective of this study is therefore to investigate the use of cement and sand admixed with Ikpayongo laterite for brick production.

Materials and Methods

The soil used in this study is a reddish brown laterite soil classified as A-2-7(0) using AASHTO soil classification system [9] and GP by the United Soil Classification system [10]. Disturbed sample of laterite was obtained from Ikpayongo (between latitude $7°30^{P'}$ and $7°35^{P'}$ N and longitude $8°30^{P'}$ and $8°35^{P'}$ E) a distance of 22 km from Makurdi, the capital of Benue

State of Nigeria, along Makurdi-Otukpo road. Sand used for the test was obtained from River Benue in Makurdi. Ordinary Portland cement (Dangote cement produced by Benue Cement company in Gboko) was purchased from the open market and used in this study as the stabilizing agent while portable tap water was employed in the laboratory tests conducted.

Table 1. Test Result of Ikpayongo Laterite

Property	Quantity
Liquid Limit (%)	41
Plastic Limit (%)	24
Plasticity Index (%)	17
Linear Shrinkage (%)	14
Percentage Passing BS Sieve No 200 (%)	7.52
Group Index	(0)
AASHTO Classification	A-2-7
USCS Classification	GW
Maximum Dry Density (WAS)Mg/m^3	1.88
Optimum Moisture Content (%)	12.0
Unconfined Compressive Strength (kN/m^2)	787
Colour	Reddish brown

Atterberg limits tests and Grain size analysis were carried out in accordance with [11]. Compaction was carried out at the West African standard (WAS) energy level. Optimum moisture content obtained from the compaction test was used in moulding UCS specimen. UCS test was performed on laterite mixed with sand and cement in accordance with [11] and [12] for the natural and stabilized materials respectively.

The soil-sand-cement mixtures for specimens were prepared by thoroughly mixing predetermined quantities of air-dried lateritic soil, sand and Portland cement until a uniform colour was obtained. Thereafter an amount of water necessary to give the required moisture content was added to the dry mixtures before compaction at the energy level of the SP and WAS. Specimens for UCS tests were cured in sealed plastic bags for 7 and 28 days. The plastic bags were sealed to prevent loss of moisture by evaporation.

Based on the 7-day UCS results, laterite bricks were produced using soil-sand-cement mixtures with 0 and 45% sand content and 0, 3, 6, and 9 cement content. Laterite and sand were air dried for 24 hours before passing them through 10 mm sieve. Particles passing through the sieve were used for brick production. The required proportions of sand, laterite and cement were mixed manually on a clean and firm platform using a shovel. Cement and sand were mixed together then laterite was added to the mixture. Thereafter water was added and mixing continued until a homogeneous mix was obtained. Trial mix results showed that a water to cement ratio of 0.56 gave the best result, hence this ratio was used for brick production.

The damp mix was poured into the twin steel moulds of a locally fabricated manual press machine, after lubrication with water/oil. A wooden pallet was placed at the bottom of the mould to allow easy removal of the bricks after being pressed. The damp mix was poured into the mould with the aid of a shovel, while tamping was carried out with a 20 mm diameter rod. A hinged mould lid weighing 15 kg was dropped six times from a height of 30 cm onto the exposed top of the mixture in the mould. This is equivalent to a pressure of 3 N/mm^2. The hinged lid was closed at the top of the mould and locked with bolts and nuts to allow for effective pressing from the bottom of the mould, with the aid of the lever arm. The pressed blocks (two in number) were ejected using the single lever arm, thereafter the lid was opened and the bricks removed. The fresh bricks on the wooden pallet were carried carefully to a shade and covered with polythene bags to avoid loss of moisture. The bricks were covered with tarpaulin and left to cure for 7 and 28 days. Ten bricks, made for each sand-cement mixture, were immersed in water for 24 hours before subjecting them to compressive test at 7 and 28 days using an ELE compression machine.

Results and Discussion

Preliminary Tests

Figure 1 shows the curves of grain size distribution for sand, laterite and laterite mixed with sand. The distribution curve for the pure laterite is stepped, an indication of a poorly graded sample, arising from lack of some intermittent particle sizes in the ranges of 1.18 mm, 600 μm and 300 μm. It has specific gravity of 3.10. The curve for pure sand is a smooth curve. Its coefficient of uniformity and curvature are 3.31 and 0.80 respectively. The sand can be classified is poorly graded; its specific gravity is 2.69 and it belongs to zone 2 of [13] sand grading zone. The distribution curve for laterite admixed with sand and cement is smooth implying that the poorly graded laterite soil was greatly improved by the addition of sand (C_u reduced from 47.3 to 13.82). Specific gravity of 2.95 and 2.90 was obtained when laterite was admixed with 30 and 45% sand respectively. The addition of 45% sand to the laterite increased the coarse sand component of the laterite from 30% to 53% while medium sand component or the percentage passing through the 600 μm sieve increased from 20% for natural laterite to 40% when admixed with 45% sand. Sand addition increased the sand component of the laterite thereby correcting the deficient intermittent particle size ranges in the natural laterite.

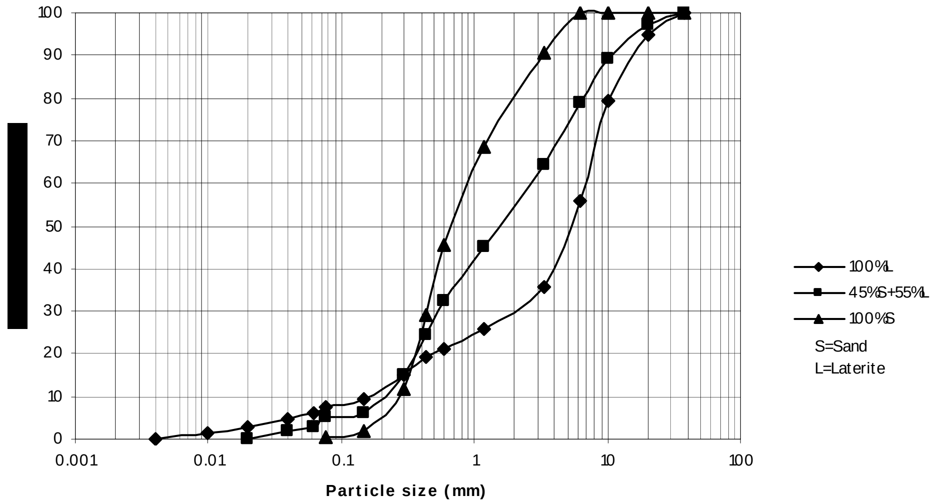

Figure 1. Particle size distribution of sand, laterite and laterite treated with sand

Compaction Characteristics

The effect of cement and sand content on the maximum dry density (MDD) of lateritic soil at the WAS energy level is shown in Figure 2. Generally, MDD increased with the addition of sand alone, cement and their respective combinations. MDD increased from 1.88 Mg/m^3 for the natural laterite to a peak value of 2.00 Mg/m^3 at a sand-cement mixture of 45% sand and 9 % cement. Increase in MDD could be attributed to voids of the natural lateritic soil being filled with sand size particles and cement with a higher specific gravity of 3.15.

The variation of optimum moisture content of stabilized lateritic soil with cement and sand content at WAS compactive effort is shown in Figure 3. Optimum moisture content decreased with sand content but increased with cement and cement-sand mixture. Increase in OMC with the use of cement is probably due to water required for the hydration of cement. Decrease in OMC with the use of sand can be attributed to the reduction in the surface area of the fine component of laterite by the increase in sand size particles. Compaction test was carried out to identify the moisture content that will be used for moulding of UCS specimens for the different combinations.

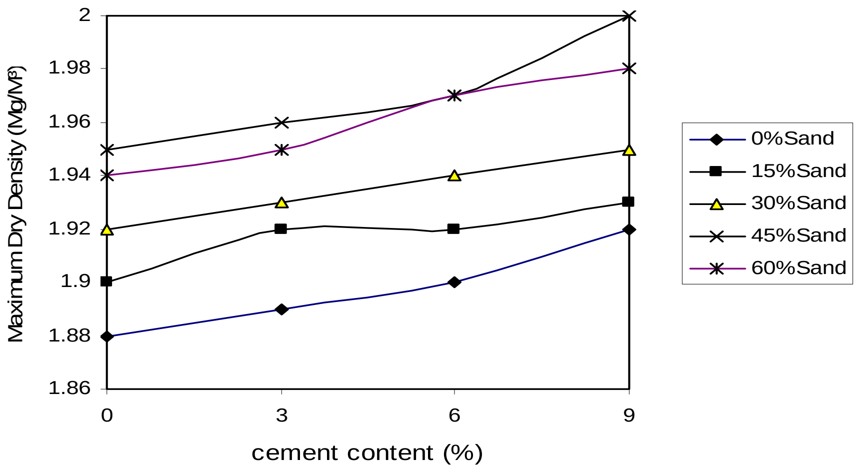

Figure 2. Variation of MDD with cement for soil-sand-cement mixture

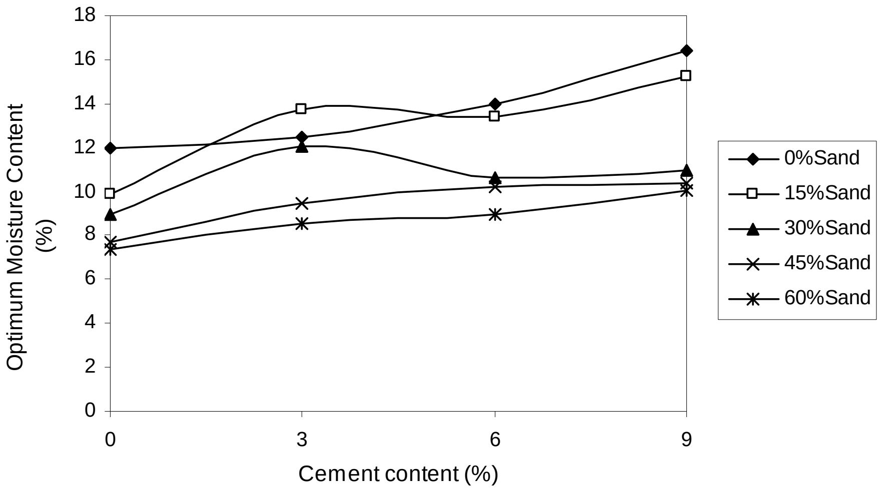

Figure 3. Variation of OMC with cement for soil-sand-cement mixtures at WAS energy level

Shear Strength Characteristics

Figures 4 and 5 show the variation of UCS with cement for the soil-sand-cement mixtures at the WAS energy level for 7 and 28 days respectively. Figure 4 shows that 7-day UCS value increased with sand and cement up to a sand content of 45%, it however decreased at 60% sand content. A similar trend could be observed in Figure 5 for the UCS at 28 days. Based on the peak strength exhibited at 45% sand content for UCS specimens at 7 and 28 days, natural laterite and laterite mixed with 45% sand and cement (3, 6 and 9%} were used in the production of laterite bricks.

Compressive strength at 7 and 28 days of bricks made from laterite treated with cement and cement-sand mixtures is as shown in Tables 2 and 3 respectively.

Table 2. Summary of 7 day Average Compressive Strength Test of Bricks

Cement Content (%)	0	3	6	9
0%Sand Content				
Weight of Bricks(kg)	11.40	12.62	12.56	13.13
Density of Bricks(kg/m^3)	1534.3	1698.5	1690.4	1767.2
Load at Failure (kN)	12.4	14.2	29.4	50.8
Compressive Strength (N/mm^2)	0.25	0.29	0.59	1.03
45%Sand Content				
Weight of Bricks(kg)	11.33	13.24	13.46	13.53
Density of Bricks(kg/m^3)	1524.9	1782.0	1811.6	1821.0
Load at Failure (kN)	10.0	17.80	30.8	104
Compressive Strength (N/mm^2)	0.20	0.26	0.62	2.10

Table 3. Summary of 28 day Average Compressive Strength Test of Bricks

Cement Content (%)	0	3	6	9
0%Sand Content				
Weight of Bricks(kg)	11.40	12.42	12.67	12.82
Density of Bricks(kg/m^3)	1534.3	1671.6	1705.2	1725.4
Load at Failure (kN)	12.4	35.0	63.0	82.0
Compressive Strength (N/mm^2)	0.25	0.70	1.27	1.66
45%Sand Content				
Weight of Bricks(kg)	11.33	13.48	13.59	13.74
Density of Bricks(kg/m^3)	1524.9	1814.3	1829.1	1849.3
Load at Failure (kN)	10	41.0	105.0	164.0
Compressive Strength (N/mm^2)	0.20	0.83	2.12	3.31

Using the optimum cement content of 5% and a 28 day compressive strength of 1.65 N/mm^2 for bricks as the criteria, compressive strength test results show that soil-cement mixtures did not satisfy both requirements. The requirement was met at 9% cement, which is far above the economic cement content. For a laterite-cement mixture of 45% sand and 5% cement, a compressive strength of 1.80 N/mm^2 (obtained by interpolation) was obtained. This value met the requirements.

When the cement content was slightly increased to 6%, laterite-sand-cement mixture of 6% cement and 45% sand met the strength of 2.0 N/mm^2 proposed by [3] where bricks are to be used for one-storey building.

It can be observed that the pressure of 3 N/mm^2 applied in the moulding of bricks in this study fell into the range of low pressure used by [3]. If the higher-pressure ranges were used in moulding the bricks, the expected compressive strength results would have been higher than the values obtained in this study. [14] reported such increase in compressive strength with compactive effort.

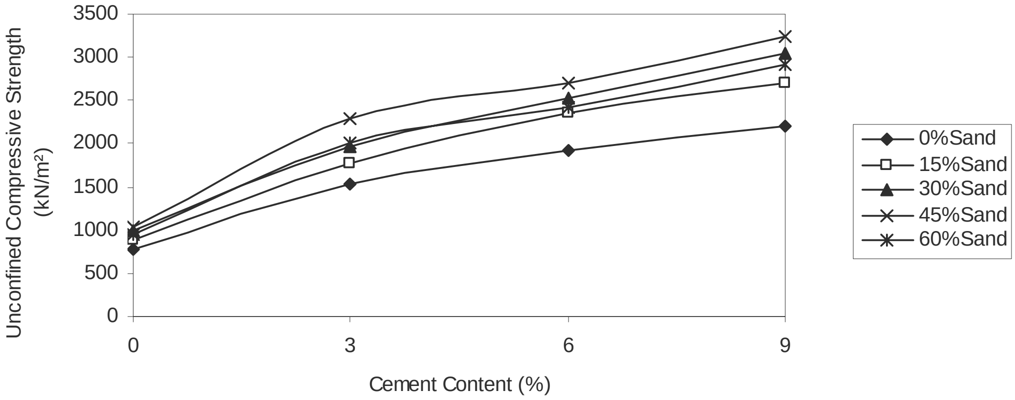

Figure 4. Variation of 7 day UCS with cement for soil-sand-cement mixtures

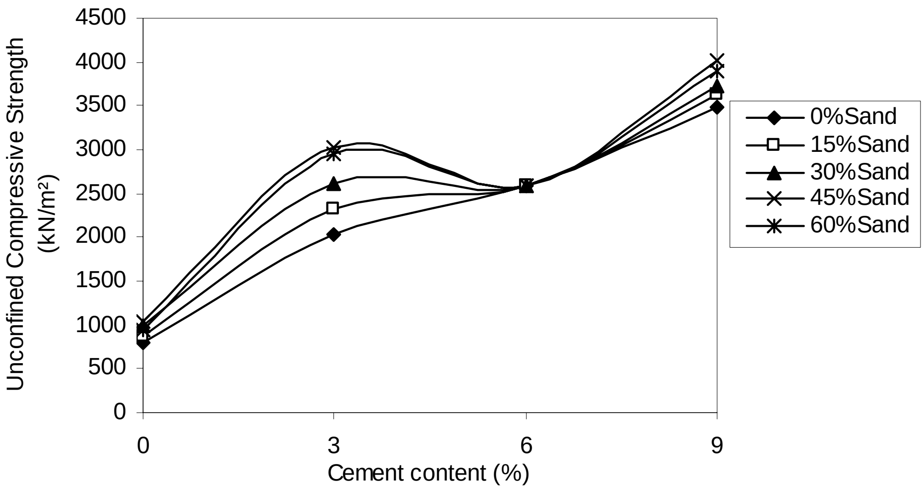

Figure 5. Variation of 28 day UCS with soil-sand-cement mixtures

Cost Analysis

Cost is the basic and starting point of mass housing provision based on bricks; in carrying out cost comparison, it should not be based on the production cost per brick. Utilization cost for comparative purposes should include handling charges, cost of transportation and mortar consumption [15].

Cost analysis of available walling materials in Makurdi metropolis is summarized in Table 4.

Table 4. Comparative Analysis of the Cost of Available Walling Materials per metre square of Walls in Makurdi Metropolis

Item	Fired Clay Bricks	Laterite Bricks[1] A	Laterite Bricks[1] B	Sandcrete Blocks[2]	Sancrete Blocks[3]
No of blocks or bricks/m^2 of wall +10% for damages	35	22	22	10	10
Unit cost of block or brick with transportation (₦)	10	7	17	90	70
Cost of blocks or bricks /m^{2}of wall with transportation (₦)	350	374	374	900	700
Cost of bonding mortar /m^2 of wall + 10% for wastage (₦)	516.67	420	420	220.52	133.95
Cost of labour /m^2 of wall (₦)	245	154	154	250	200
Total cost of a m^2 of wall (₦)	1112	728	948	1371	1034
Price Index	0.81	0.53	0.69	1.0	0.75
Compressive strength (N/mm^2)	1.76	1.80	1.80	2.5	2.5
Savings in cost compared with sandcrete blocks (%)	19	47	30	0	25

A = Laterite was obtained at a distance of 0- 2 km from site
B = Laterite was obtained from a distance of 3- 22 km from site
[1] 330×150×150 brick
[2] 450×230×230 block
[3] 450×150×230 block

The table shows that the use of laterite bricks for walling will result in savings of 30 to 47% and a price index range of 0.53-0.69 per square meter of wall depending on the location of laterite when compared with the use of 450 x 230 x 230 sandcrete blocks. This range is slightly less than the value of 55% reported by [16] that can be attributed to increase in the price of cement from N55 in 1989 to N1,500 in 2007 per 50kg bag. The use of fired clay bricks, which is the most popular alternative walling material in Makurdi metropolis, gave a savings in cost of 19% and a price index of 0.81 when compared with 450×230×230 sandcrete blocks. Based on this analysis, bricks made from laterite and cement is being recommended for building construction in Makurdi and other locations where laterite is readily available.

Conclusions

The following conclusions can be drawn from this study:

1. Particle size distribution curve of the laterite used in this study was poorly graded and addition of 45% sand corrected this deficiency. Since NBRRI did not specify any particle distribution curve for soil to be used in brick production, addition of 45% sand could serve as a guide for the production of bricks in Makurdi metropolis.
2. Ikpayongo laterite cannot be stabilized effectively for brick production within the economic cement content of 5% as the 28-day UCS of 1.1 N/mm^2 did not meet the value recommended by NBRRI (Madedor, 1992).
3. Addition of 45% sand content by dry weight of Ikpayongo laterite enhanced its suitability for use in the production of bricks within the optimum cement content of 5% as the 28 day UCS of 1.8 N/mm^2 for bricks made with a soil-sand-cement mixture of 45% sand + 5% cement met the value specified by NBRRI (Madedor, 1992).
4. Cost analysis of available walling materials in Makurdi metropolis has shown that the use of fired clay bricks for building is not as economical as it is generally believed. The use of laterite bricks offers more savings.
5. In order to provide housing for the greater majority of Nigerians the use of laterite bricks should be encouraged as it is cheaper, more readily available and the production process is environmental friendly.

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