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COMPARATIVE STUDY OF CORNCOB ASH-BASED LATERITIC INTERLOCKING AND SANDCRETE HOLLOW BLOCKS

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ABSTRACT: The high cost of conventional walling materials, increase in emission of CO_2 due to cement production and improper disposal of corncob lead to persistent bottlenecks in low-cost and sustainable housing delivery, environmental pollution, and agricultural wastage respectively. This study investigates the use of corncob ash (CCA) as cement additive in producing lateritic interlocking blocks (LIB) and compares its physical characteristics and production cost with Sandcrete hollow block (SHB). Portland limestone cement (PLC) was replaced by CCA in varying percentages 5, 10 and 15%. The density, compressive strength and water absorption of the blocks were determined and compared with the Nigerian standard requirements and specifications. The experimental results showed optimal strength at 3% PLC and 10% CCA with a compressive strength of 4.13MPa, water absorption of 6.60% and density of 1869.47Kgm^{-3} at 28 days curing for LIB. For 450mm × 225mm × 225mm SHB, compressive strength, water absorption and density at 28 days curing were 3.86MPa, 4.69%, and 1849.95Kgm^{-3} respectively. All the blocks produced satisfied the recommendations of both the Nigerian Building and Road Research Institute and the Nigerian Industrial Standards. The cost per square meter of SHB and LIB was 4.62 USD and 2.35 USD respectively. The experimental results indicated that LIBs have better strength and are cheaper than SHBs. Recycling of CCA as a supplement material seems to be a feasible solution not only to the problem of adopting indigenous waste material in the production of LIB but also to the environmental problem.

Keywords: *Portland-limestone cement, Corncob ash, Lateritic interlocking block, Sandcrete hollow block, Compressive strength.*

1. INTRODUCTION

In Nigeria, the astronomical price increases of conventional building materials such as cement, reinforcement bars and concrete blocks and failure to adopt truly indigenous building materials production systems have not solved the persistent bottlenecks created by building materials sector in low-cost housing delivery [1]. The production of cement emits pollution and greenhouse gasses and this has necessitated the search for another means to partially replace them in the construction industry [2].

The use of plastering mortar for coating walls in masonry works further adds significant cost to the total cost of a building, which is already high for low-income earners. A more rational construction process can be established with the introduction of the interlocking block that will allow the elimination of mortar; reduce costs of labor and duration to complete the building. This new initiative asserted by [3] is possible through the use of interlocking masonry and has the advantage of saving time and labor, reducing cost and wastages, thus enhancing sustainable and accelerated housing delivery.

The production of 1kg of Portland cement generates 1kg of CO_2 to the atmosphere [4] and as a result of this, there is need to find alternatives to Portland cement if the contribution of the Portland cement to global warming is to be reduced. According to [3], an economic advantage of a certain percentage of savings is possible with the application of pozzolans to cement in building works. This is propelled by the global concern for the environment, in terms of sustainable development, renewable energy, greenhouse gas emissions and reduction in energy consumption.

A pozzolan requires a minimum of 70% silica, alumina, and ferric oxides; a maximum loss on ignition of 10%; a maximum MgO content of 4%; a maximum SO_3 content of 5% and a maximum moisture content of 3% as a cement binder in concrete [5].

The global corn production in 2015/2016 and 2016/2017 calendar years were 969.69 million metric tons (MMT) and 1070.51 MMT respectively; with Nigeria producing 7.00 MMT and 7.20 MMT respectively [6]. However, most of the corncobs generated worldwide are still disposed of as waste and a result of this, constitute environmental pollution. The emission of CO_2 accompanied with the production of Corn Cob Ash through open-air burning was estimated as 0.27Kg per Kg of ash [7] compare with the corresponding data of 1.020Kg CO_2 stated for Portland cement clinker production [8]. This shows that CCA emits 4 times lesser than PC.

2. LITERATURE REVIEW

Laterite, according to [9] is a red tropical soil, usually derived from rock weathering under strongly oxidizing and leaching conditions that are rich in iron oxide. It is largely deposited in Nigeria and most neighboring African countries and this has made it easily acquired and inexpensive but not adequately maximized in brick production for building purposes.

Laterite interlocking or "dry stack" mortarless block was introduced in masonry construction as a result of easiness in handling and versatility through its development requires efficiency. Sparfil system, Haener system, Spurlock system, Meccano system, and the Solid Interlocking blocks (SIB) or Hydraform blocks are various interlocking blocks developed for use. They have better characteristics compare to the unfired laterite blocks or traditional adobe bricks that were common in some African countries in the 20th century [10].

Hydraform blocks can be produced with a clay content between 5-20% of sandy soil and silt content of 5-25%. They can even be produced with higher clay and silt content, but the plasticity index must be evaluated to see if the soil is desirable and appropriate for block production. In general, it will be difficult to handle soil with low clay and silt portions below 10% during mechanical production. There must be a partial replacement of soil with high clay and silt content above 35%-40% with a sandy soil for workable and durable production [11]. Interlocking block making machine was developed by the Nigerian Building and Road Research Institute (NBRRI) for the production of SIB types with a designed geometric size of 225 x 225 x 112 mm. The machine produces solid blocks of laterite composition, blends with cement in ratio 1:20 [12].

Hydraform blocks are three times as efficient as concrete and almost twice as functionally effective as fired clay bricks in terms of strength property and thermal insulation. Hydraform blocks are also attractive with good face finishes [1]. However, the block strength is impacted by cement content quality, curing days (7 days minimum) and soil characteristics [1]. In addition, [13] estimated the total energy input of interlocking blocks as 657 MJ/ton compared to 4,187 MJ/ton for the common fired bricks. Also, in term of CO_2 emission, interlocking blocks emit 41 kg CO_2/ton compared to 202 kg CO_2/ton for traditional bricks in mainstream construction.

3. MATERIALS AND METHODS

3.1 Materials

Cement: Dangote 3X of Grade 42.5R Portland Limestone Cement (PLC) was used in accordance with the new mandatory industrial standard order for cement classification, manufacturing, distribution, and usage, recommended by the [14] and approved by the [15]

Sand: Sand was obtained from Chelsea area, Ota, Ogun State, Nigeria. It was sharp, clean, and free from clay and organic matter and well graded in conformity to British Standard [16].

Laterite: The lateritic was obtained from a borrow pit in Chelsea, Ota, Nigeria (Latitude 6.00' North and Longitude 3.56' East) and its geotechnical and physical testing were carried out at Geotechnical Laboratory, Covenant University, Ota, Nigeria in accordance to [17]. Natural moisture content, optimum moisture content and maximum dry density were determined as geotechnical and physical properties, AASHTO classification, specific gravity, grain size analysis, the condition of the sample, color and atterberg limit tests and is presented in Table 1.

Water: Laboratory tap water was used for mixing and ensured that it was fit for drinking, free from contaminants either dissolved or in suspension as specified by [18].

Corncob: Corncob was obtained from Agbonle (8° 53' 0" North, 3° 31' 0" East) a major corn producing town in the Derived Savannah Agro-ecological zone of Oyo State in Southwestern Nigeria. The corncob was locally processed and converted into ash (Fig. 1(a)) by open heap village continuous burning method at a temperature, ranging from 400^0C to 450^0C.

The Chemical composition of the CCA was analyzed using SEM/EDS (Model Number- 800-07-334 and Part Number- MFE0224651193) at the Department of Mechanical Engineering, Covenant University, Ota, Ogun State, Nigeria. This makes it be used as a pozzolan. The result is presented in Table 2.

Mixing and Moulding of SHBs: Cement/Sand ratio 1: 10 (1 volume of cement to 10 volume of sand) was mixed in accordance with [19]. A total of 18 sandcrete hollow blocks were molded (Fig. 1(b)) and cured for 7, 21, and 28 days. Batching, Mixing & Moulding of LIBs: The volume method of batching was adopted throughout.

The mold is 225mm×225mm×115mm in dimension and three (3) different types of mixtures were prepared and molded for this study with the aid of locally made interlocking block machine by NBBRI, Ota, Ogun State (Fig. 1(c)).

The water proportion was constant and the replacement ratios between PLC, CCA, and Laterite were taken by the percentage volume in the mix design. All block specimens were produced with (1:0.5) volume ratio for (cementitious materials: water). The PLC was used at constant volume of 3% as control while CCA was added in three varied percentages 5, 10, and 15%.

A total of 54 LIBs (Fig. 1(d)) were molded and cured for 7, 21, and 28 days in accordance with [11].

Fig. 1(a) CCA sample

Fig. 1(b) SHBs produced

Fig. 1(c) NBRRI interlocking block machine used

Fig. 1(d) LIBs produced

3.2 Experimental Test Methods

3.2.1. Density

Specimens were tested according to [20] for as-received density. The specimens were weighed as-received in air and masses M (in Kg) were recorded. Thereafter, the volume of the specimens was determined. Density (D) was determined using the equation:

$$D = \frac{\text{Mass, M (as-received) (Kg)}}{\text{Volume, V } (M^3)} \quad (1)$$

The result of average density is presented in Fig. 2

3.2.2 Compressive strength

The specimens were calculated according to [21]. The dry compression strength was measured with the aid of compressive strength tester. The average compressive strength which is the average of three samples is presented in Fig. 3.

3.2.3 Water absorption

The blocks' water absorption capacity was carried out according to [22] at 23 ± 5^0C for 24 hours. A reliable average was obtained on three specimens of every treatment were tested to obtain. The average water absorption is presented in Fig. 4.

3.2.4 Mixture Data Analysis and Regression Equations

The data was duly analyzed using MINITAB 17 software computer program. The Relationship between density and compressive strength and water absorption for both LIB and SHB at 28 days curing was analyzed with Fit Regression Model. Analysis of Variance and Regression Coefficients for both LIB and SHB were presented in Table 3 and Table 4, and Table 5 and Table 6 respectively. Descriptive statistical Analysis was used to compare relationships between variables. Durbin-Watson Test Statistic Analysis was carried out to determine the normality and correlation coexistence of the test.

Cost analysis of LIB and SHB blocks was calculated and compared in order to derive their economic advantages in terms of unit price per square meter. The calculations were tabulated and the results were presented in Table 7, Table 8, Table 9, Table 10 and Table 11.

4. RESULTS AND DISCUSSIONS

4.1 Geotechnical and Physical Result of Lateritic Sample used

Table 1 shows the Geotechnical and physical testing of the lateritic sample used and therefore suitable for use in conformity with the [11] which stated Plasticity index of 10-15% maximum.

4.2 Chemical Analysis of CCA used

Table 2 shows the Chemical analysis of the CCA used and is suitable as it satisfied [5]

Table 1 Properties of the Sample

Test	Result
Specific gravity (Sg) @20^{0}C	2.69%
(% passing BS 200 sieve (75µm)	24.95%
Natural moisture content (%)	9.05
Maximum dry density (Kgm^{-3})	2045
Optimum moisture content (%)	13.85
AASHTO classification	A-2-7
Condition of sample	Air- dried
Color	Reddish brown
Liquid limit (%)	40.50
Plastic limit (%)	27.05
Plasticity Index (%)	13.45

Table 2 Chemical Analysis

Material	Properties	ASTMC618 Specification
CaO	16.23	
SiO_2	55.50	SiO_2+Al_2O_3+ Fe_2O_3
Al_2O_3	8.78	> 70%
Fe_2O_3	7.13	
SO_3	1.75	≤ 4%
MgO	2.23	≤ 4%
Na_2O	0.90	> 0.70
M.C	1.05	≤ 3%
LOI	6.55	≤ 10%
Sg	2.09	-

Note: M.C = Moisture Content, LOI = Loss of Ignition and Sg = Specific gravity

4.3 Density of LIB and SHB

It can be observed from Fig. 1 below that the dry density of LIBs ranged from 2294.12Kgm^{-3} to 1869.47Kgm^{-3}. The density slightly decreased with ages when adding more CCA because the specific gravity of CCA is less than that of cement. The results at the end of 7 to 28 curing days showed that all the lateritic interlocking blocks produced satisfied the minimum bulk density of 1810 kg/m^3 recommended by the [12]. A Similar trend was observed for SHBs with a density ranging from 1929.46kgm^{-3} to 1849.95kgm^{-3}.

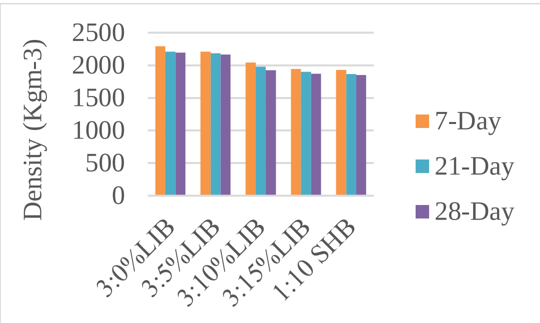

Fig. 2 Graph of density against replacement

4.4 Compressive Strength of LIB and SHB

Comparison of the LIBs' data for 7, 21 and 28 curing days from Fig. 2 below showed that the compressive strength increased with CCA up to 10% and then at 15% CCA, the strength marginally dropped and attained values equivalent to that of 10%. Thus, 10% CCA seemed to be the optimal limit but 7% attained the economic limit. Therefore, 3% PLC: 7%CCA was used as cost analysis.

The increase in strength is due to the pozzolanic reaction as stated by [23] and the presence of predominantly reactive silica in CCA. At 28 curing day, the varied percentage of 3% PLC and 10% CCA (3:10) with 4.13MPa satisfied the minimum compressive strength requirement of 4MPa stipulated by the [12] for blocks produced with Hydraulic Interlocking Block Making Machine. Similarly, 25 number of 225mm blocks were produced from a bag of cement in this study and the compressive strength at 28 curing days was 3.86MPa. This satisfied the minimum 28 days compressive strength of 3.40MPa stipulated by the Nigerian Industrial Standard [19] for 450mm × 225mm × 225mm concrete hollow blocks.

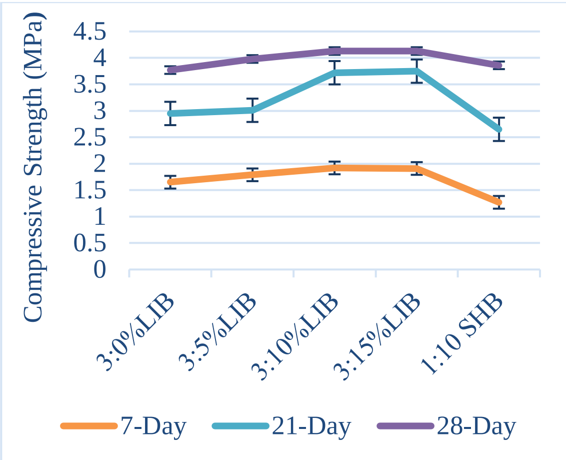

Fig. 3 Graph of compressive strength against replacement

4.5 Water Absorption of LIB and SHB

The Result of water absorption test is shown graphically in Fig. 3 below. Test data showed that water absorption moderately decreases as the CCA addition increases. The decrease supported [23]-[24] that laterite particles have been bonded together by stabilizing agents (PLC and CCA) which reduced the pores through which water could pass into the blocks. Maximum water absorption of the sample was 8.29% for control. The results at the end of 7 to 28 curing days satisfied the maximum water absorption of 12% recommended by the [19] and 12.5% water absorption recommended by the [12]. A Similar trend was observed for SHBs with water absorption ranging from to 7.12% to 4.69%. This met 6% water absorption recommended by [19] for load bearing concrete blocks.

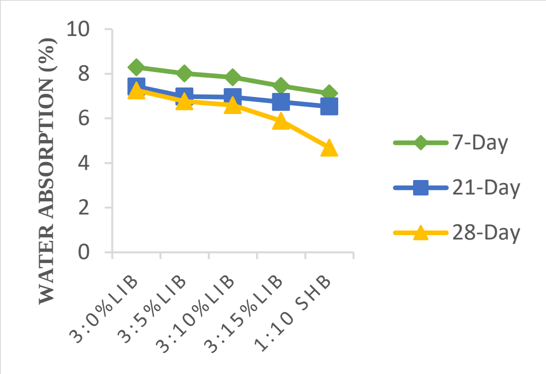

Fig.4 Graph of water absorption against replacement

4.6 Analysis of Variance for LHB and SHB

The analysis of variance table is shown in Table 3 and Table 4 using the p-value to evaluate the regression coefficients with a pre-selected α-level. A commonly used α-level is 0.05.

Table 3 Analysis of Variance for LHB

LIB at 28 days curing				
Source	Adj SS	Adj MS	F-Value	P-Value
Regr.	75498	37749	2.64	0.399
C.S	5438	5438	0.38	0.648
W.S	5521	5521	0.38	0.646
	Model Summary			
	S, R-Sq, R-Sq (adj), R-Sq (pred),			
	119.585, 84.07%, 52.22%, 0.00%			

Table 4 Analysis of Variance for SHB

SHB at 28 days curing				
Source	Adj SS	Adj MS	F-Value	P-Value
Regr.	245.355	122.663	29.22	0.130
C.S	219.296	219.296	52.06	0.088
W.S	0.138	0.138	0.03	0.886
	Model Summary			
	S, R-Sq, R-Sq (adj), R-Sq (pred)			
	2.05244, 98.31% , 94.94% , 30.51%			

From Table 3 and Table 4, the p-values for Regression (Regr.) are 0.399 and 0.130 for LIB and SHB respectively, indicating that all the regression coefficients were significantly different from zero. The model for LIB explains 84.07% of the variation in the data. The adjusted R was 52.22%. R (pred) was 0.00%, which indicates that the model explained 0.00% of the variation in the property when it is used for prediction. The model for SHB explained 98.81% of the variation in the property. The adjusted R was 94.94%. R (pred) was 30.51%, which indicates that the model explained 30.51% of the variation in the property when it is used for prediction.

4.7 Regression Coefficients of LIB and SHB

Table 5 Regression Coefficients of LIB

LIB at 28 days curing				
Term	Coef	SE Coef	P- Value	VIF
Constant	2995	4529	0.628	
C.S	-482	781	0.648	3.71
W.S	146	235	0.646	3.71

Table 6 Regression Coefficients of LIB

SHB at 28 days curing				
Term	Coef	SE Coef	P- Value	VIF
Constant	2057.1	33.7	0.010	
C.S	-52.79	7.32	0.088	1.10
W.S	-1.11	6.11	0.886	1.10

The results of LIB in Table 5 indicate that both compressive strength (C.S) with ($p = 0.648 > \alpha = 0.05$) and water absorption (W.S) with ($p = 0.646 > \alpha = 0.05$) do not have a significant interaction with density. The interaction indicates that the effect of compressive strength (C.S) and water absorption (W.S) on the property of LIB did not depend on the value of density. The VIFs are 3.71 and 3.71 for compressive strength and water absorption respectively (> 1 but < 5). This indicates that the compressive strength (C.S) and water absorption (W.S) are correlated and the regression coefficients were properly estimated.

Similarly, the results of SHB in Table 6 indicate that both compressive strength (C.S) with ($p = 0.088 > \alpha = 0.05$) and water absorption (W.S) with ($p = 0.886 > \alpha = 0.05$) does not have a significant interaction with density. The interaction indicates that the effect of compressive strength (C.S) and water absorption (W.S) on the property of LIB do not depend on the value of density. The VIFs were 1.11 and 1.11 for compressive strength and water absorption respectively (> 1 but < 5). This indicates that the compressive strength (C.S) and water absorption (W.S) are correlated and the regression coefficients are properly estimated.

4.7.1 Regression Equation Models for LIB and SHB

LIB: Density = 2995 – 442 C.S + 146 W.S (2)

SHB: Density = 2057.1 – 52.79 C.S – 1.11 W.S (3)

Equation (2) and Equation (3) shows the models for predicting properties such as density, compressive strength and water absorption of both lateritic interlocking block and concrete hollow block respectively.

4.7.2 Durbin – Watson Statistic for LIB and SHB

The Durbin Watson Test was determined according to [25] with the hypotheses for the Durbin Watson test which are:

- H_0 = no first-order autocorrelation.
- H_1 = first order correlation exists.

From the regression analysis carried out, Durbin – Watson Statistics for LIB and SHB were 2.99629 and 1.19039 respectively. This indicates that the test statistic values were relatively normal and confirmed [26] that values under 1 or more than 3 are a definite cause for concern.

4.8 Volume Computation of LIB and SHB

The cost of walling materials depends on the proportion and type of constituent materials. In other words, the grade of the mix design which affects the compressive strength influences the cost [27]. The current costs of materials are listed below:
Cement (one bag or 50kg) = ₦2, 650;
Laterite (15m^3 of tipper) = ₦15,000; and
Sand (15m^3 of tipper) = ₦40,000.

Density of cement = 1440kgm^{-3};

$$\text{Volume} = \frac{\text{Mass}}{\text{Density}} = \frac{50\text{kg}}{1440\text{kgm}^{-3}} = 0.\ 034722222\text{m}^3$$

Table 7 shows the cost of materials per volume for LIB and SHB production and Table 8 shows the volume of material by proportion for LIB using mix ratio (1: 10) and the total volume is 0.005820880682m^3.

Table 7 Calculation and Output for Materials

Item	Calculation	Output
Cement	₦2650 / 0.0344722222	₦76,320m^{-3}
CCA	Assume15%ofcement	₦11,448m^{-3}
Laterite	₦15,000 / 15	₦1,000m^3
Sand	₦40,000 / 15	₦2,666.67m^{-3}

4.8.1 Volume Computation of Materials used for LIB

Volume of LIB = LWH = 225mm × 225mm × 115mm = 5,821,875mm^3 = 0.005821875m^3.

$$\text{One square meter (1m}^2\text{) of LIB} = \frac{1.00}{\text{Elevation area}}$$

Elevation area = 0.225m×0.115m = 0.025875m^2.

$$\text{Therefore, 1m}^2 \text{ of LIB} = \frac{1.00}{0.025875} = 38.65$$

= approximately 39 blocks.

Table 8 Calculation and Output for Materials

Item	Calculation	Output
Unit ratio	0.00582 ÷ 11	0.0005296m^3
Cement	0.000529 × 0.3	0.000159m^3
CCA	0.000529 × 0.7	0.000370m^3
Laterite	0.000529 × 10	0.00529m^3
Total		0.00582m^3

4.8.2 Volume Computation of Materials used for SHB

Volume of SHB = LWH = 450mm × 225mm × 225mm = 22,781,250mm^3 = 0.022781250m^3.

$$\text{One square metre (1m}^2\text{) of SHB} = \frac{1.00}{\text{Elevation area}}$$

Elevation area = 0.450m × 0.225m = 0.10125m^2.

$$\text{Therefore, 1m}^2 \text{ of SHB} = \frac{1.00}{0.10125} = 9.88$$

= approximately 10 blocks.

The total volume of SHB = volume of the solid block – the volume of hollow block.

Table 9 shows the volume of material by proportion for SHB using mix ratio (1: 10) and Table 10 shows the volume of mortar for SHB (concrete mortar) with a total volume of 0.004055m^3. Table 11 shows cost analysis per square meter wall of LIB and SHB

Table 9 Calculation and Output for Materials

Item	Calculation/Output
The volume of a solid block	0.450m × 0.225m × 0.225m = 0.0228m^3
The volume of the hollow block	2(0.155m × 0.130m × 0.225m) = 0.00907m^3
Actual vol. of block	0.0229m^3- 0.00907m^3 = 0.0137m^3
Unit ratio	$\frac{0.0137\text{m}^3}{11}$ = 0.00125m^3
Cement	0.00125m^3 × 1 = 0.00125m^3
Sand	0.00125m^3 × 10 = 0.0125m^3
Total Volume	0.00125+0.0125m^3 = 0.0137m^3

Table 10 Calculation and Output for Materials

Item	Calculation	Output
Volume of solid block	0.025m×0.450m×0.225m	0.00253125m^3
Volume of hollow block	2(0.155m×0.130m×0.025m)	0.0010075m^3
Volume of mortar (horizontal)	0.00253125m^3 - 0.0010075m^3	0.0015275m^3
Volume of mortar (vertical)	0.050m × 0.225m × 0.225m	0.00253125m^3
Total volume of mortar	(0.0015275 + 0.00253125)m^3	0.004055m^3
Unit ratio	0.004055m^3 ÷ 11	0.0003686363636m^3
Cement	0.0003686363636 × 1	0.0003686363636m^3
Sand	0.0003686363636 × 10	0.003686363636m^3
Total volume	(0.0003686363636+0.003686363636)	0.004055m^3

Table 11 Calculation and Output for Materials

Item	Calculation	Output
Cement	₦76,320 × 0.0001587784091	₦12.12
CCA	₦11,448 × 0.0003704829595	₦4.25
Laterite	₦1,000 × 0.005292613636	₦5.29
Total	₦(12.12 + 4.25 + 5.29)	₦21.66
1m^2 of Wall	39 × ₦21.66	₦844.74
For SHB and Mortar		
Cement	₦76,320 × (0.001246681818 + 0.0003686363636)	₦123.28
Sand	₦2,666.67 × (0.01246681818 + 0.003686363636)	₦43.08
Total	₦(123.28 + 43.08)	₦166.30
1m^2 of Wall	10 × ₦166.36	₦1,663.60

4.8.3 Discussion of cost analysis per square meter wall of LIB and SHB

The unit costs of LIB is ₦21.66 which is 0.060 USD. The cost per square meter of SHB and LIB are ₦1,663.60 (4.62 USD) and ₦844.74 (2.35 USD) respectively. The lower cost of LIB is as a result of the small quantity of cement (3%) in producing the block since cement is the most costly of all material used. Thus, LIB is cheaper both in terms of unit cost and cost per square meter and also, stronger.

5. CONCLUSION, CONTRIBUTION TO KNOWLEDGE AND RECOMMENDATION

5.1 Conclusions

Consequent upon the findings of the comparative study, the following conclusions were stated:

- All the blocks produced satisfied the minimum requirements in terms of compressive strength and water absorption by the NBRRI and the NIS at 28 days curing.
- LIBs are stronger and denser than SHBs.
- LIB is cheaper than SHB in terms of unit cost and cost per square.
-

5.2 Contributions to Knowledge

- The study contributed to the development of greener multidimensional construction technology for lateritic block production towards a sustainable building and infrastructure development project for a low-cost housing estate.
- The study developed models for the relationship among the density, compressive strength and water absorption of the blocks.

5.3 Recommendations

- The inclusion of corncob ash in LIB production should be encouraged as this has been shown to improve virtually all the structural properties of the lateritic interlocking block.
- All tiers of government should facilitate communal effort towards the production of CCA as this would boost the economy of rural dwellers.

6. ACKNOWLEDGEMENTS

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