Effect of corncob ash blended cement on the properties of lateritic interlocking blocks

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Abstract: The increase in carbon dioxide emissions due to cement manufacturing and improper disposal of corncob leads to environmental pollution and agricultural wastage respectively. This study investigates the use of corncob ash (CCA) as cement additive in producing lateritic interlocking blocks (LIB). Portland limestone cement (PLC) was replaced by CCA in varying percentages 5, 10, 15 and 20%. Effect of CCA on compressive strength and water absorption were determined and compared with the Nigerian standard requirements. The experimental findings showed that 3% PLC, 15% CCA with a compressive strength of 4.49MPa and water absorption of 6% at 28 days curing met the recommendations of both the Nigerian Building and Road Research Institute and the Nigerian Industrial Standards. Recycling of

CCA as a promising raw material supplement appears to be a viable solution not only to the environmental problem but also to the problem of adopting indigenous waste material in the production of LIB.

Keywords: Portland limestone cement; corncob ash; lateritic interlocking block; compressive strength; water absorption; density; predictive model; sustainability; indigenous materials; low-cost housing.

Reference to this paper should be made as follows: Oyebisi, S.O., Olutoge, F.A., Ofuyatan, O.M. and Abioye, A.A. (2017) 'Effect of corncob ash blended cement on the properties of lateritic interlocking blocks', *Progress in Industrial Ecology – An International Journal*, Vol. 11, No. 4, pp.373–387.

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This paper is a revised and expanded version of a paper entitled 'Effect of corncob ash blended cement on the properties of lateritic interlocking blocks' presented at *International Conference on Engineering for a Sustainable World*, Covenant University, Ota, Nigeria, 3–7 July, 2017.

1 Introduction

The geometrical increase in the price of conventional building materials in Nigeria such as cement, reinforcement bars and sandcrete blocks and failure to adopt truly indigenous building material production systems have not solved the persistent bottlenecks created by building materials sector in low-cost housing delivery (Adedeji, 2007). Arayela (2005) opined that 65% of the building construction cost originates from the cost of building materials; and this forms the main factor that limits the supply chain of housing (Ogunsemi, 2010). Pollution which associated with the production of cement has necessitated the search for an alternative medium to partially replace them in the construction industry (Aho and Utsev, 2008). The life cycle of a building is widely encouraged through the renewable and recycled sources (Chwieduk, 2003) as this reduced the CO_2 emissions by 30% when it is properly selected (González and Navarro, 2006).

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 implemented with the introduction of technologies that will allow the elimination of mortar; reduce labour costs, and shorten the period of time taken to complete the building. Adedeji (2010) asserted that this new initiative, which is possible through the use of interlocking masonry, has the advantage of saving time and labour, reducing cost and wastages, thus enhancing sustainable and accelerated housing delivery. Therefore to offset the hesitations that do come to mind each time an average citizen thought of having a house of his or her own, researchers have worked and identified the increase in the number of biomass residue identified as pozzolans such as rice husk, groundnut husk, corncob, corn husk, corn stalk, sawdust, coconut shell, etc. The interest in the application of pozzolan is further propelled by the global concern for the environment, in terms of sustainable development, renewable energy, reduction in energy consumption and greenhouse gas emissions.

In the construction industry, the fact that nearly 1 kg of CO_2 is released to the atmosphere for every kilogram of Portland cement produced (United States Department of Energy [USDE], 2003) has further emphasised the need to find alternatives to Portland cement if the contribution of the construction industry to global warming is to be reduced. This is presumed by the fact that an economic advantage of a certain percentage of savings is possible with the application of pozzolans to cement in building works (Adedeji, 2010). ASTM C 618 (2005) specifies that any pozzolan that will be used as a cement binder in concrete 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 SO3 content of 5% and a maximum moisture content of 3%. The global corn production in 2015/2016 and 2016/2017 calendar years were 969.69 million metric tonnes and 1070.51 million metric tonnes respectively; with Nigeria producing 7.00 million metric tonnes and 7.20 million metric tonnes respectively (USDA, 2017). However, most of the corncobs generated worldwide are still discarded as waste. The disposal of this enormous waste can constitute pollution of the environment.

Laterite is a red tropical soil that is rich in iron oxide and is usually derived from rock weathering under strongly oxidising and leaching conditions. Laterite is very abundant in Ceylon, India, Burma, Central Africa, West Africa and Central America (Encyclopedia Encarta Premium, 2009). The large deposition of laterite in Nigeria and most neighbouring African countries have made it easily acquired and inexpensive and is not adequately being maximised in the area of brick production for building purposes.

Hydraform blocks are three times as efficient as concrete and almost twice as efficient as fired clay bricks in terms of the thermal insulation they offer. Attractive, face brick finishes (in a variety of natural colours derived from the soil found at individual sites) is also possible with the use of the material (Adedeji, 2007). However, Adedeji (2007) observed that block strength is affected by cement content quality, curing duration (7 days minimum) and soil type. Moreover, energy input of interlocking blocks are comparable to that of unfired clay bricks, which their total energy input was estimated of 657 MJ/ton as opposed to 4,187 MJ/ton for the common fired bricks, while an equivalent output of CO_2 emission was 41 kg CO_2/ton compared to 202 kg CO_2/ton for traditional bricks in mainstream construction (Oti et al., 2009). In Solid interlocking blocks, substantial cost savings can be achieved due to the elimination of bedding mortar in the superstructure (except in ring beams and in high gables) accelerates construction, thereby reducing workmanship and cost.

By-products such as red mud and metakaolin have been tested to produce lateritic block with good performance but no information is available on the utilisation of CCA. The reduction of cement consumption through the use of more ecologically-friendly material such as corncob ash is thus an ideal way to protect our environment through the reduction of energy consumption and CO_2 emissions. The reduction of CO_2 is of utmost importance as this harmful gas contributes to global warming through the greenhouse effect. Based on this, Nigeria and other parts of the world are tyrelessly evolving various kinds of sustainable and low-cost building adapted from agricultural and industrial wastes, locally available, and environmentally eco-friendly materials in the building construction. This, therefore, forms the objective of this research through the adaptation of interlocking masonry and incorporation of low carbon footprint (corncob ash). In an attempt to reduce the negative impact of cement in building construction and partially replace it with corncob ash, this study thus, limits the cement content to 3% against the 5% content recommended by the Nigerian Building and Road Research Institute (2006), and substitute the remaining 2% with CCA at 5%, 10%, 15%, and 20% because the percentage replacement of PLC with CCA for use in structural applications with an impressive compressive strength according to Price et al. (2014) and Kamau et al. (2016) can be up to 15% and 25% respectively. Mechanical means of vibration was adopted and the sprinkling method of curing was employed.

2 Review of related literature

Introduction of interlocking or ‘dry stack’ mortarless masonry systems in masonry construction requires the development of efficient, easy to handle, and yet versatile blocks. Varied interlocking blocks developed for use include Spurlock system, Meccano system, Sparfil system, Haener system, and the Solid Interlocking blocks (SIB) or

Hydraform blocks, which are an improvement over the traditional adobe bricks or unfired laterite blocks that were prevalent in the 20th century in some African countries (Anand and Ramamurthy, 2003).

In South Africa, hydraform blocks are produced with a sandy soil and clay content between 5–20% and silt content of 5–25%; blending with 5–10% of cement. Blocks can even be produced with higher clay and silt content, but there is need to determine the plasticity index to see if the soil is suitable for block production. Generally, soil with low clay and silt portions, below 10%, will be difficult to handle when coming out the machine. Soil with high clay and silt content, above 35–40%, will need to be blended with a sandy soil (Hydraform Standard, 2015). In Nigeria, the Nigerian Building and Road Research Institute (NBRRI) developed an interlocking block making machine meant to produce SIB types. The blocks have a geometric size of 225 × 225 × 112 mm. This machine produces solid blocks of laterite composition mainly and stabilised with cement material ratio 1:20 (NBBRI, 2006). 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%, the compressive strength of 1.65 N/mm^2 and durability of 6.9% with maximum cement content fixed at 5%.

Watile et al. (2014) in the study titled "interlocking brick for sustainable housing development", investigated the compressive strength, water absorption and density by using a varying percentage of fly ash, stone dust, and sand with different mix proportion. It was found that strength of interlocking bricks with increasing fly ash increases with the age and concluded that interlocking bricks with economically available fly ash in large proportion have sufficient strength for their use in low-cost housing, non-load bearing construction and in regions where good quality burnt clay bricks are not available.

Raheem et al. (2012) carried out the comparative analysis of sandcrete hollow blocks and laterite interlocking blocks as walling elements. Laterite interlocking block was produced using 5% cement stabilisation and 95% laterite. From the results of various tests performed, LIB satisfied the minimum compressive strength of 4.0 MPa recommended by NBBRI (2006) with 5.03 MPa at 28 days curing.

3 Materials and methods

3.1 Materials

The materials for the experimentation of the work include Corncob, Laterite, Portland Limestone Cement and Water which were locally obtained.

3.2 Methods

3.2.1 Batching information

The volume method of batching was adopted throughout. The mould is 225 × 115 × 225 mm in dimension and five different types of mixtures were prepared for this experimentation with the aid of M7 MI SUPER of 4LD 640-Diesel Engine Hydraulic Interlocking Block Making Machine. The water proportion in the mixes was taken as constant and the replacement ratios between PLC, CCA, and Laterite Sample were taken by the percentage volume in the mix design. All block specimens were made with 1:0.55 volume ratios for cementitious materials to water. The PLC was used at constant volume of 3% as control whereas CCA was added in four varied percentages 5, 10, 15 and 20%. Therefore, 3% PLC + 0% CCA, 3% PLC + 5% CCA, 3% PLC + 10% CCA, 3% PLC + 15% CCA, and 3% PLC + 20% CCA are denoted by PCA 1, PCA 2, PCA 3, PCA 4, and PCA 5, respectively.

3.2.2 Materials preparation

The corncob waste was collected from a modern Bodija market in Ibadan, Oyo State, Nigeria. Initially, the corncob was converted into ash by the open heap village burning method at a temperature, ranging from 200°C to 350°C. The uncontrolled fired cob residue ash was black in colour obviously due to excess amount of carbon content (Plate 1). The corn fired cob residue ash was further burnt in an industrial furnace at a temperature of 650°C over a period of 1 h. The temperature of the furnace was increased at a rate of 200°C per hour until it reached the required temperature of 650°C over a period of 3 h and 15 min. At 650°C, the temperature was kept constant for a burning time of 1 h; under controlled condition and then cooled (Adesanya and Raheem, 2009). The material was pulverised to a mean grain size of 90 µm and then its chemical composition was analysed with the aid of X-Ray Fluorescence at Lafarge WAPCO, Ewekoro, Ogun State, Nigeria. The chemical composition is presented in Table 1.

Plate 1 Corncob ash (see online version for colours)

Table 1 Chemical and physical analysis of the CCA used

Material	*CaO*	*SiO_2*	*Al_2O_3*	*Fe_2O_3*	*SO_3*	*MgO*	*Na_2O*	*MC*	*LOI*	*Sg*
Properties (%)	16.23	64.50	6.48	4.03	1.06	1.99	0.90	1.05	5.95	2.05
ASTM C 618Specification	–	$SiO_2 + Al_2O_3 + Fe_2O_3 > 70\%$			≤4%	≤4%	>0.70	≤3%	≤10%	–

Laterite used was locally obtained from L.A. Adisa Borrow Pit at Ojo in Ibadan, Oyo State, Nigeria, and its geotechnical and physical testing were carried out at Civil Engineering Laboratory, University of Ibadan, Ibadan, Nigeria in accordance to British Standard [BS] 1377 (1990). The geotechnical and physical properties that were determined were: natural moisture content, maximum dry density, optimum moisture content, AASHTO classification, specific gravity, grain size analysis, the condition of sample, colour and atterberg limit tests and is presented in Table 2.

Table 2 Geotechnical and physical testing of the lateritic sample used

Test	*Result*
Specificgravity@20°C	2.67%
(% passing BS 200 sieve (75 µm)	32.50%
Natural moisture content (%)	8.50
Maximum dry density (Kg/m3)	950
Optimum moisture content (%)	13.75
AASHTO classification	A-2-7
Condition of sample	Air-dried
Colour	Reddish brown
Liquid limit (%)	41.60
Plastic limit (%)	26.63
Plasticity index (%)	14.97

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 Standards Organization of Nigeria (SON, 2014) and approved by the Nigerian Industrial Standard 444-1 (2014). The Chemical and physical analysis of the cement used is presented in Table 3.

Table 3 Chemical and physical analysis of the cement used

Material	*CaO*	*SiO_2*	*Al_2O_3*	*Fe_2O_3*	*SO_3*	*MgO*	*Na_2O*	*K_2O*	*LOI*	*Sg*
Properties (%)	63.50	20.15	5.42	2.70	2.36	1.45	0.50	0.65	1.95	3.00
BS 12:1996 specification	60–67	17–25	3.0–8.0	0.5–0.6	1.0–3.0	0.1–4.0	0.2–1.3	0.2–1.3	≤3%	–

The water used was fetched from the public borehole and relatively cleaned and conformed to BS 3148 (1980).

3.2.3 Specimen mixing

The mixing was done in a room temperature having an ambient temperature of 23°C and a relative humidity of 54% (BS 1881-Part 125, 1986) on an impermeable surface made free from all harmful materials which could alter the properties of the mix, by sweeping, brushing or scrapping it. The measured laterite sample was spread using a shovel to a reasonably large surface area. Cement was then spread evenly on the laterite and the composite materials were thoroughly mixed with the shovel.

The dry mixture was spread again to receive water which was added gradually until the water-cement ratio of the mixture was attained (Plate 2). The interior of the mould was lubricated with mould oil so as to prevent the lateritic interlocking block from sticking to the sides of the mould and also to give the block a smooth surface. The wet mixture was filled into the mould and then compressed with (EN 837 ITALMANOMETRI) hydraulic pressure of 100 MPa. The excess mixture was scraped off and the top of the filled mould was levelled using a straight edge. After removing the blocks from the machine (see samples in Plate 3), they were first allowed to air dry under a shade for 24 h and protected against shock, vibration, and dehydration at temperature

25°C. Thereafter, curing was continued by sprinkling water morning and evening for seven days at temperature 22°C (BS EN 12390-Part 4, 2000) and covering the blocks with tarpaulin sheet to prevent rapid drying out of the blocks which could lead to shrinkage cracking (Plate 4).

Plate 2 Mixing processes (see online version for colours)

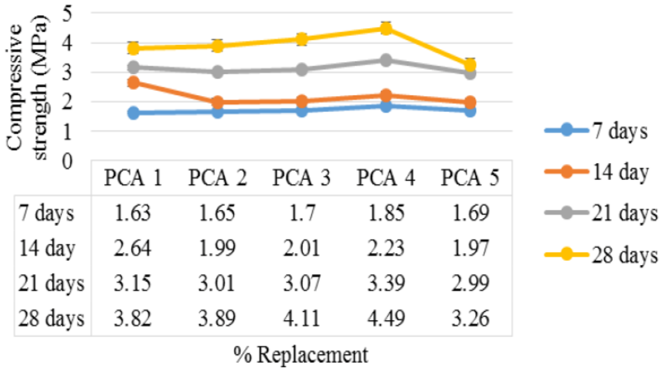
Plate 3 Samples of LIB (see online version for colours)

Plate 4 LIB samples under polythene (see online version for colours)

3.3 Experimental tests

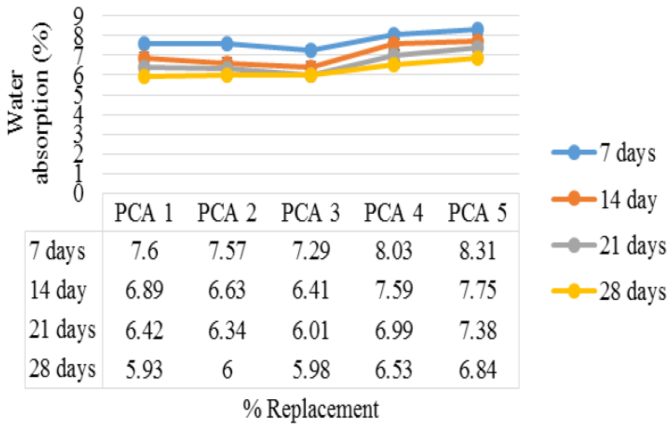
The series of tests were carried out according to BS EN 12390-Part 3 (2000), BS 1881-Part 122 (1983), and BS EN 12390-Part 7 (2000) to determine the compressive strength, water absorption capacity, and bulk density of the block samples respectively. The results of average bulk density, compressive strength, and water absorption of the block samples are presented in Figures 1–3 respectively.

Figure 1 Graph of compressive strength (MPa) against % Replacement (see online version for colours)



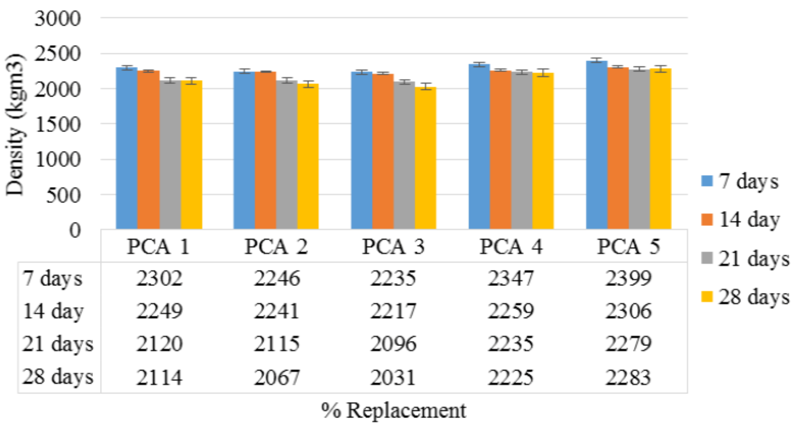
	PCA 1	PCA 2	PCA 3	PCA 4	PCA 5
7 days	1.63	1.65	1.7	1.85	1.69
14 day	2.64	1.99	2.01	2.23	1.97
21 days	3.15	3.01	3.07	3.39	2.99
28 days	3.82	3.89	4.11	4.49	3.26

Figure 2 Chart of water absorption (%) against % replacement (see online version for colours)



	PCA 1	PCA 2	PCA 3	PCA 4	PCA 5
7 days	7.6	7.57	7.29	8.03	8.31
14 day	6.89	6.63	6.41	7.59	7.75
21 days	6.42	6.34	6.01	6.99	7.38
28 days	5.93	6	5.98	6.53	6.84

Figure 3 Chart of density (kg/m^3) against % replacement (see online version for colours)



	PCA 1	PCA 2	PCA 3	PCA 4	PCA 5
7 days	2302	2246	2235	2347	2399
14 day	2249	2241	2217	2259	2306
21 days	2120	2115	2096	2235	2279
28 days	2114	2067	2031	2225	2283

4 Results and discussion

4.1 Chemical and physical analysis of the CCA used

The results of the chemical analysis presented in Table 1 showed a silicon dioxide (SiO_2) content of 64.50% which is greater than the minimum requirement of 25.0% by mass recommended by the ASTM C 618 (2005). And a total of silicon dioxide (SiO_2) + aluminium oxide (Al_2O_3) + ferric oxide (Fe_2O_3) content of 75.01% met the minimum requirement of 70.0% specified by the ASTM C 618 (2005). The sulphur oxide (SO_3) content and the magnesium oxide (MgO) content of 1.06% and 1.99% respectively are below the maximum value of 4.0% specified for class N Pozzolan to which it belongs in ASTM C 618 (2005). The moisture content and the loss of ignition content of 1.05% and 5.95% respectively are below the maximum values of 3% and 10% specified for class N Pozzolan to which it belongs in ASTM C 618 (2005). From the above analysis, it showed that the Corn Cob Ash (CCA) used is a suitable material for use as a Pozzolan as it satisfied the requirements of the ASTM C 6I8 (2005).

4.2 Geotechnical and physical testing of lateritic sample used

The results presented in Table 2 based on AASHTO SOIL CLASSIFICATION SYSTEMS showed that the lateritic sample is classified as “Granular Material of Clayey Gravel and Sand, Group A-2-7”. It is, therefore, suitable for use in conformity with the Hydraform Standard (2015) which stated Plasticity Index of 10–15%.

4.3 Chemical and physical analysis of the cement used

The results of the chemical and physical analysis presented in Table 3 showed that chemical and physical properties of 42.5R Dangote 3X PLC used satisfied the specification of BS 12 (1996).

4.4 Compressive strength

The compressive strengths of CCA blended LIB specimens are shown in Figure 1. Comparison of the data for 7, 14, 21 and 28 days curing time shows that all sample mixes exhibit similar compressive strength at an early age that is from 7 days to 21 days. But at 28 days, the compressive strength marginally increases. This is characterised by a delayed gain in strength of CCA when mixed with water and cement, because, it has a small composition of calcium oxide (CaO) which is important for early strength development (Hannesson et al., 2012). Corncob ash contributes no strength at early age but only acts as a filler, and thus, has to wait for the hydration product of cement such as calcium hydroxide [$Ca(OH)_2$] which react the silicon oxide (SiO_2) of CCA at a later age to form a compound known as Calcium Silicate Hydroxide (C-S-H) (Bapat, 2012). The optimum strength was witnessed at 15% substitution of CCA but at 20% CCA, the compressive strength of block drops and attains values equivalent to that of control block specimen (PCA 1). Thus, 15% CCA seems to be the optimal limit. The specimens made with 15% CCA showed the highest value among the other replacement. This may be due to the fact that the compatibility of the CCA with cement was improved considerably. The increase in strength may also be due partially to the pozzolanic reaction as reported by Adesanya and Raheem (2009) and the presence of reactive silica in CCA. At 28 curing day, the varied percentage of 3% PLC and 15% CCA of 4.49MPa satisfied the minimum compressive strength requirement of 4MPa stipulated by the Nigerian Building and Road Research Institute (2006) for blocks produced with Hydraulic Interlocking Block Making Machine.

4.5 Water absorption

Results of water absorption test are graphically shown in Figure 2. Test data showed that water absorption decreased moderately as the CCA addition increased from 5% to 10% but the higher addition of CCA (that is from 15% to 20%) marginally increased the water absorption capacity. The decrease was due to the fact that chemical reaction between natural pozzolan and calcium hydroxide of hydrated cement paste is lime consuming instead of lime producing (Bapat, 2012; Page and Page, 2007). Secondly, stabilising agents (PLC and CCA) bond the laterite particles together thereby reducing the pores through which water could flow into the blocks.

Moreover, at the higher substitution of CCA, calcium hydroxide was quantitatively insufficient to react with the excess CCA thereby creating voids in the mixture and thus increasing the water absorption. These findings are in line with previous observations of Adesanya and Raheem (2010); Kamau et al. (2017); Khatri and Sirivivathnanon (1997). Maximum water absorption of the sample was 8.31%. The results at the end of 7 to 28 curing days showed that all LIBs produced satisfied the maximum water absorption of 12% recommended by the Nigerian Industrial Standard (2004) and 12.5% water absorption recommended by the Nigerian Building and Road Research Institute (2006).

4.6 Density

The results presented in Figure 3 showed that the dry density ranges from 2302 kg/m^3 to 1998 kg/m^3. It can be observed from the table that the density of the laterite interlocking blocks marginally decreases with age. This signified a possible presence of the pozzolanic reaction which consumes $Ca(OH)_2$ to produce the less dense C-S-H in the mix (Kamau et al., 2016). This finding concurs with the observation of Adesanya (1996) who also reported a decrease in weight with further CCA replacement. The high values witnessed are due to the fact that the blocks do not have hollows in them. They are solid blocks; hence their weights are higher. Also, it can be attributed to the texture of the laterite with widespread of all particle sizes, which allows the particles to be closely packed thereby reducing the voids in the blocks (Raheem et al., 2012). The results at the end of 7 to 28 days curing showed that all lateritic interlocking blocks produced satisfied the minimum bulk density of 1810 kg/m^3 recommended by the Nigerian Building and Road Research Institute (2006).

4.7 Predictive models for the LIB properties

Matlab R2017a was used to determine the relationship between the properties of LIB. Density was normalised by mean 1844 and standard deviation 905.2 while the water absorption was normalised by mean 6.54 and standard deviation 3.224. The relationship between compressive strength and density, and compressive strength and water absorption at 28 days curing are shown in Figures 4 and 5 respectively. With respect to compressive strength, the coefficients of determination (R^2) are 0.941 and 0.942 for density and water absorption respectively. This infers that the model is 94% significantly fit to predict the relationship and also, compressive strength largely depends on the density and the water absorption at 95% confidence bounds.

Figure 4 Relationship between the compressive strength (MPa) and density (kg/m^3) (see online version for colours)

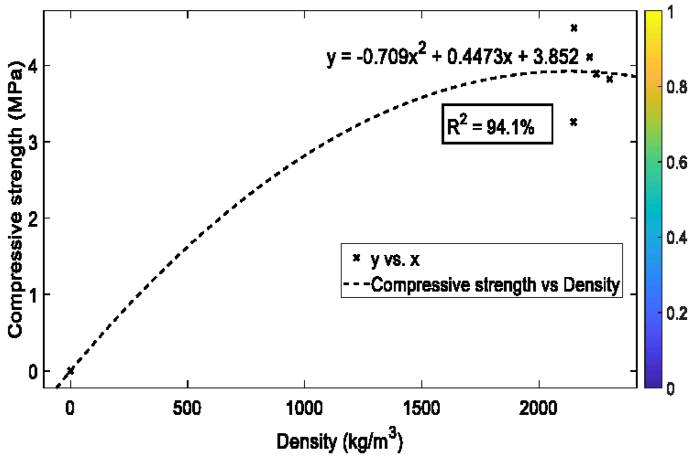
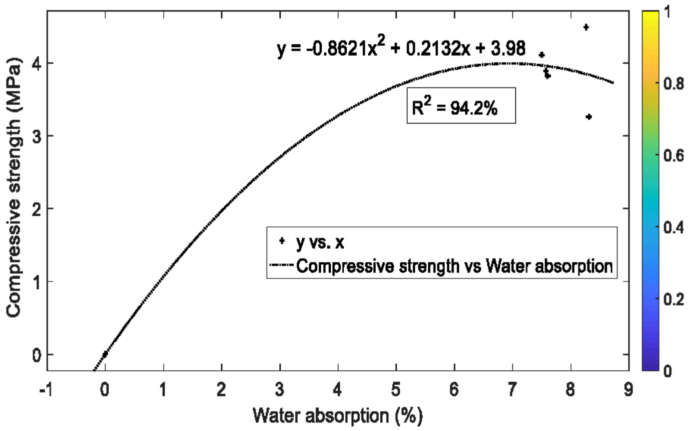


Figure 5 Relationship between the compressive strength (MPa) and water absorption (%) (see online version for colours)



5 Conclusions

Based on the findings of this study, it is concluded that the use of CCA at 15% with 3% PLC has clear effect on the property of the optimal strength of LIB but above 15% substitution, the strength decreases. Moreover, the addition of the CCA reduces the water absorption property of the LIB at the early age but at the later age, it increases. Furthermore, the density property of LIB largely depends on the percentage of CCA substitution because the more the CCA content, the lesser the density. Consequently, the study contributed to the sustainable buildings by recycling and harnessing the agricultural wastes of low carbon footprint for sustainable development of communities and human settlements. It also explored innovation for improved sustainability in the building construction industry. Moreover, the study developed the model equations to predict the relationship between the properties of the block produced. It is therefore recommended that 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. In addition, all tiers of government should facilitate communal effort towards the production of CCA as this would boost the economy of rural dwellers.

Conflict of interest

The authors declared no conflict of interest. The study is novel and has not been published in any journal outlet.

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