Journal of Sustainable Development Studies
ISSN 2201-4268
Volume 8, Number 1, 2015, 193-208

Investigation of the Effect of Bamboo Leaf Ash Blended Cement on Engineering Properties of Lateritic Blocks

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Abstract: Laterite is the commonly used building materials in rural Nigeria. It has been observed that it became the traditional building construction material due to its availability, low processing cost and ease of handling with little or no equipment and skill requirements. However, studies have shown that lateritic soils are generally weak in compression and tend to absorb moisture and become soften. Consequently, walling materials such as lateritic blocks has been the subject of investigation for decades; partly, to serve as an alternative to the conventional sand Crete blocks. Such effort is especially desirable as it is well known that the production processes of cement; which is the main binder employed in the production of sand Crete blocks is associated with huge energy consumption and emission of harmful gases such as CO_2. This study investigated the effect of bamboo leaf ash blended with cement on some engineering properties of lateritic blocks. The bamboo leaves used for this study were collected in the campus of the University of Uyo and the laterite was obtained from a borrow pit in Itu L.G.A. of Akwa Ibom State, Nigeria. The leaves were sun-dried, burnt in an open atmosphere and then heated in a muffle furnace at 600^oC for 2hours to obtain the bamboo leaf ash (BLA). Tests on the physical and chemical properties of bamboo leaf ash blended with cement were conducted in accordance with BS 4550: 1978 and BS 12: 1996. The chemical analysis of the BLA showed that the combined Silica Oxide (SiO_2), Aluminum oxide (Al_2O_3) and Ferrous oxide (Fe_2O_3) content was above the 70% minimum standard requirement specified by ASTM (ASTM C 618, 2008) for pozzolanic materials. Varying levels of percentage replacement of cement with bamboo leaf ash was obtained at 0%, 5%, 10%, 15%, 20% and 25%. A total of 72 blocks comprising of 12 blocks for each percentage replacement of the lateritic block size of 225mm x 113mm x 75mm of mix ratio 1:20 and water-cement ratio of 0.8 were cast, cured and crushed at 7, 14, 28, and 56 days curing respectively. Analysis of the compressive strength, moisture absorption resistance and the abrasion resistance of the lateritic blocks produced from cement blended with bamboo leaf ash (BLA) showed that the 5% and 10% cement replacements is suitable for load bearing outer walls whereas the 20% and 25% substitution was found more suitable for non-load bearing indoor walls. The 15% substitution was however found to be suitable for non-load bearing outer walls.

Keywords: pozzolana, bamboo leaf ash (BLA), lateritic blocks, compressive strength.

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1.0 Introduction

Housing for the poor remains a major challenge for most developing nations like Nigeria where majority of the population still live in sub-standard houses. According to Anthonio (2003), housing can be described as an essential component of human settlement that ranks comparably with the provision of food and clothing in the hierarchy of the basic primary elements required for human existence. At its most elemental level, it addresses the basic human needs by serving as shelter, offering protection against excessive cold, heat, rain, high winds and any other form of inclement weather as well as protection against unwanted aggression. As observed by Mustapha (2004), homelessness and the incidence of people living in poor housing and unhealthy neighborhoods are rapidly growing. The housing problem is acute especially in the urban areas due to shortage of affordable housing for low-income earners and the poor who constitute over 70% of the urban population.

Laterite is the commonly used building materials in rural Nigeria. Some lateritic soils are suitable for use in their natural state, while others require additives in order that they satisfy certain requirements to make them suitable for the intended application (Kamang 1998, UNCHS 1986). According to Abalaka (2006) the reason for the popularity of lateritic soil as a traditional building construction material is its availability, low processing cost and ease of handling with little or no equipment and skill requirements. However, lateritic soils are generally weak in compression and tend to absorb moisture and become soften. Any improvement in the compressive strength of the materials will enhance its performance as building construction materials. He also stated that the compressive strength of lateritic blocks could be greatly increased by either mechanical compaction of laterite or the use of binder such as cement with low compaction, or by employing both methods. A high percentage of the bond is believed to be achieved by particle interlock in the damped soil depending on the particle size distribution and clay content of the laterite. The remaining strength is gained by pozzolanic reaction between hydrated ferric oxide and silica. Compressive strength of lateritic blocks could equally be improved by fixing the blocks in kilns designed for that purpose.

Traditionally, vegetable straws have been used for the stabilization of lateritic soils for block making in rural Nigeria and elsewhere (Roach 1993, Adesanga 2000, Abalaka 2006). Straws were found to reduce shrinkage of lateritic blocks and improve their quality and strength. However, the strength of such blocks depends upon the quality and quantity of straws added. Other materials had also been used in stabilizing laterite. Apart from cement which is the most predominantly used material, others such as lime, bitumen, gypsum, meta-kaoline, carbide, silica fume, burnt clay and ash from agricultural waste; including palm kernel shell, coconut fibre/shell, rice husk, sugar cane leaf, sugar cane bagasse etc. have been tested and found suitable for lateritic soil stabilization (Adams and Agib 2001, Okoli 1998).

The high cost of building materials has been observed to be the major factor besetting housing delivery in Nigeria (Okoli, 1998). This has been partly traced to the rising cost of cement; which is commonly used in the production of sandcrete blocks, concrete and as stabilizing admixture in soil blocks. In addition, there are also issues arising from the production processes of cement which ranges from huge energy consumption to large emission of CO_2; a major greenhouse gas. Hence, for a nation which is faced with what can be described as an unprecedented energy crisis and with the global campaign against the emission of greenhouse gasses to curb warming of the environment, it is only appropriate to seek alternative means to the use of cement in the effort to achieving the goal of housing delivery.

All over the world, Pozzolans have been discovered to be viable alternative binder to cement, especially in the realm of partial replacement. Pozzolans are fine silica and alumina rich materials which when mixed with hydrated lime produce cementitious materials suitable for stabilization and construction needs. Recently, it was reported that bamboo leaf ash is an equally good pozzolanic material which reacts with calcium hydroxide to release additional calcium silicate hydrate (C-S-H); the main cementitious component (Dwivedi et al. 2006, Singh et al. 2007, Frias et al. 2012) . The chemical characterization of the bamboo leaf ash (BLA) in comparison with those of the ordinary portland cement (OPC) using X-ray fluorescense (XRF) and scanning electron microscopy techniques (SEM) is as shown in Table 1. It should be noted that the chemical characterization of BLA is generally dependent on the specie of bamboo that produces the ash (Frais M. et al. 2012).

In this effort, the effect of bamboo leaf ash blended with cement on the engineering properties of lateritic blocks has been investigated so as to establish the optimum bamboo leaf ash content suitable for stabilizing lateritic block for building construction. Since these materials are readily in abundance, it is expected to impact positively on the building industry in Nigeria; particularly in the area of cost of housing delivery and environmental protection from harmful gases.

2.0 Materials and Methods

Bamboo Leaf Ash (BLA): The bamboo leaves used for this study were collected in the campus of the University of Uyo, Akwa Ibom State. The leaves were dried in the sun, burnt in an open atmosphere and then heated in a muffle furnace at $600^{o}C$ for 2 hours to obtain the BLA. After which they were allowed to cool and then sieved through a sieve size of 300μm to obtain the ash. The ash was kept in sealed polythene bag to prevent moisture absorption (see plate 1-3). The chemical characterization of the BLA was carried out by X-Ray fluorescence (XRF), using a Philips PW 780 instrument, with an anticathode tube of rhodium of 4 KW and the result is as shown in Table 1.

Cement: Ordinary Portland Cement (OPC) of Unicem brand was used with properties conforming to BS12: (1971) and produced in accordance to NIS 444:2003 Part 1 (see Table 1). This "Unicem" brand of cement was obtained from Ewet market in Uyo and was kept in an airtight bag to prevent exposure to moisture.

Laterite: The laterite used for the production of the blocks was obtained from a borrow pit in Itu L.G.A. The lumps in soil samples were broken down into smaller pieces and the soil sample was made to pass through a 4.75mm sieve to achieve a fine graded soil that can be efficiently mixed with the stabilizer (i.e. cement blended with bamboo leaf ash).

Water: The water used in this study was fresh portable water obtained from the water tap in the University of Uyo, Annex campus.

Experimental procedure

Preliminary tests: The lateritic soil type used in this study was determined by performing the following tests on the lateritic soil samples in accordance with BS 1377-1990: 1-8; standard proctor test, liquid limit test, plastic limit test and specific gravity test. In addition, physical properties test such as the specific gravity test, bulk density and porosity test, initial and final setting time test were equally conducted on the BLA and the BLA blended cement.

Production of lateritic block samples: A total of 72 solid blocks comprising of 12 blocks for each percentage replacement of the lateritic block size of 225mm x 113mm x 75mm of mix ratio 1:20 and water/cement ratio of 0.8 were cast and cured at

7, 14, 28, and 56 days respectively(see plate 4). Curing was done by placing the blocks on the floor of the laboratory as close together as possible and was kept damped daily throughout the period of curing. The percentage replacement of cement with bamboo leaf ash in this study were 0%, 5%, 10%, 15%, 20% and 25%. The 0% replacement was introduced to serve as the control.

Tests conducted on the block samples: The compressive strength test, water absorption test, and the abrasion test were conducted on the BLA blended cement blocks to measure the performance of the BLA at the different levels of cement substitution.

3.0 Results and Discussion

Presented in Table 2 are the results of the tests conducted on the lateritic soil samples and the BLA used for the production of the BLA blended cement stabilized lateritic blocks. The result of the particle size analysis revealed that only 2% of the lateritic soil particles were smaller than 0.150mm in size. The specific gravity was found to be 2.57; which falls within the range specified by for lateritic soil. The Atterberg's Limit test yielded a plasticity index (PI) of 14.7%; and the fact that the Liquid Limit fell between 35% and 50% showed that the laterite has intermediate plasticity. The PI value falls within the range for lateritic soil suitable for block making (Graham & Burt, 2002); and also conforms to the specification of BS 1477, (1975). This confirms that the laterite is cohesive and able to receive proper compaction to enhance its strength. Again, the laboratory compaction test of the laterite showed that a water content of 12% gave a maximum dry density of 2.04kg/m^3 (MDD). This measure of water content was taken as the optimum moisture content (OMC) and falls within the range of 8 – 12% by weight of lateritic soil recommended for block making (BS 1377, 1975).

The specific gravity of the BLA was found to be 2.69. This is higher than the 2.13 and 2.04 obtained for Rice Husk Ash and earthworm cast (Kamang, 1998) respectively; but was less than the 3.15 for cement (BS 1377, 1975). The BLA had an un-compacted bulk density of 653.31kg/m^3 and compacted bulk density of 755.20kg/m^3.The porosity of the ash was found to be13.5%. This indicates low presence of internal pores in the ash and hence buffers the compressive strength.

The initial and final setting times in the presence of different amount of BLA were determined with vicat apparatus at consistency limits of 32, 36, 42, 48, 56 and 63 percentages of water to cement and the result is presented in Table 3. It can be observed that the setting times of the blended cement at 5% substitution level was almost unchanged compared with those of the control. However, higher substitution levels witnessed a marked increase in setting times especially as you attain the 15% level and above.

Figure 1 depicts the effect of the BLA at different substitution level on the compressive strength of the lateritic blocks at varying curing duration. At 7 days curing, there was no appreciable difference between the compressive strength of the control and those of the 5% and 10% substitution levels. Specifically, the compressive strength of the 5% substitution lagged behind the control by about 5.3% whereas the 10% substitution lagged by about 7.1%. At 14 days curing, appreciable difference in compressive strength between the control and the BLA blended cement at all levels of cement replacements was observed. A marked reduction of 17.5% was observed for the 5% level with other levels of substitution recording even higher reduction in compressive strength. However, at 28 and 56 days of curing, the strength development of the blocks for the 5% and 10% were again relatively closer to that of the control. As shown in Table 4, the compressive strengths obtained for the 5% to 25% replacement at 56th day were relatively higher with the value of 10.5N/mm^2, 9.6N/mm^2, 9.0N/mm^2, 8.3N/mm^2 and 7.4N/mm^2 for 5%, 10%, 15%, 20%, and 25% replacement of cement with BLA respectively. The result suggests that 5% and 10% replacements are adequate to produce lateritic blocks for load bearing walls whereas 15% to 25% replacement can be used for non-load bearing walls.

Depicted in figure 2 is the moisture absorption profile of the BLA blended cement lateritic blocks at different percentages of cement replacements. It can be observed that at the 5% and 10% replacements, there were slight improvements in water absorption relative to the control. However, water transport resistance through the blocks began to deteriorate slightly at the 15% substitution and worsens with higher levels of substitution. This suggests that resistance to moisture transport through the blocks is excellent up to 10% cement replacement and within reasonable tolerance level at the 15% substitution. The result at 20% and above showed a relatively poor performance in terms of moisture resistance.

The abrasive strength of the lateritic blocks was calculated and the result is shown in figure 3. Results showed that resistance to surface friction quantified by the abrasive coefficients deteriorates sharply with increasing percentage of cement substitution. For instance, at the 5% replacement, the abrasive coefficient deteriorated up to about 50% of the abrasive coefficient of the control. This observation was found to be consistent with those of EKO et al (2006); who opined that stabilization of compressed earth block using cement increases the abrasive strength of the block.

Table 1: Chemical composition of BLA and OPC by percentage weight (After *Matawal and Ze Gyang, 2012)

Material	**Composition (wt. %)**										
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	SO_3	IR	LOI
OPC (Unicem)*	17.76	4.47	3.16	63.47	2.37	0.60	0.24	0.27	3.0	0.74	2.56
BLA	51.99	10.10	6.85	12.51	2.10	3.39	1.69	0.20	2.74	-	0.09

Table 2: Index properties of the lateritic soil sample and the BLA used for production of the BLA blended cement stabilized lateritic blocks.

<table>
<tr><td colspan="2">Property</td><td>Quantity</td></tr>
<tr><td colspan="2">Liquid limit (%)</td><td>37</td></tr>
<tr><td colspan="2">Plastic limit (%)</td><td>22.4</td></tr>
<tr><td colspan="2">Plasticity index (%)</td><td>14.7</td></tr>
<tr><td colspan="2">Specific gravity</td><td>2.57</td></tr>
<tr><td rowspan="2">Standard proctor test</td><td>Max. dry density (kg/m^3)</td><td>2.04</td></tr>
<tr><td>Optimum moisture content (%)</td><td>12</td></tr>
<tr><td colspan="2">Specific gravity (BLA)</td><td>2.69</td></tr>
<tr><td rowspan="2">Bulk density of BLA (kg/m^3)</td><td>uncompacted</td><td>653.31</td></tr>
<tr><td>compacted</td><td>755.20</td></tr>
<tr><td colspan="2">Porosity of BLA (%)</td><td>13.5</td></tr>
</table>

Table 3: Initial and Final Setting Time of the control and the blended cement

% Replacement	Initial setting time (hrs)	Final setting time (hrs)
0	2:01	3:24
5	1:50	3:24
10	2:20	3:54
15	2:36	3:52
20	2:58	4:09
25	3:00	4:20

Table 4: Shows the Result of the Compressive Strength Test of Lateritic Blocks produced with BLA blended cement (0 - 25% levels of cement replacement) at 7, 14, 28, and 56 days of curing.

Percentage replacement (%)	**Average compressive strength (N/mm^2) at different curing duration of 7, 14, 28 and 56 days.**			
	7th	14th	28th	56th
0	5.6	6.8	8.7	11.2
5	5.3	5.7	8.4	10.5
10	5.2	5.5	8.0	9.6
15	4.3	4.7	7.5	9.0
20	4.2	4.3	6.6	8.3
25	3.9	4.0	6.1	7.4

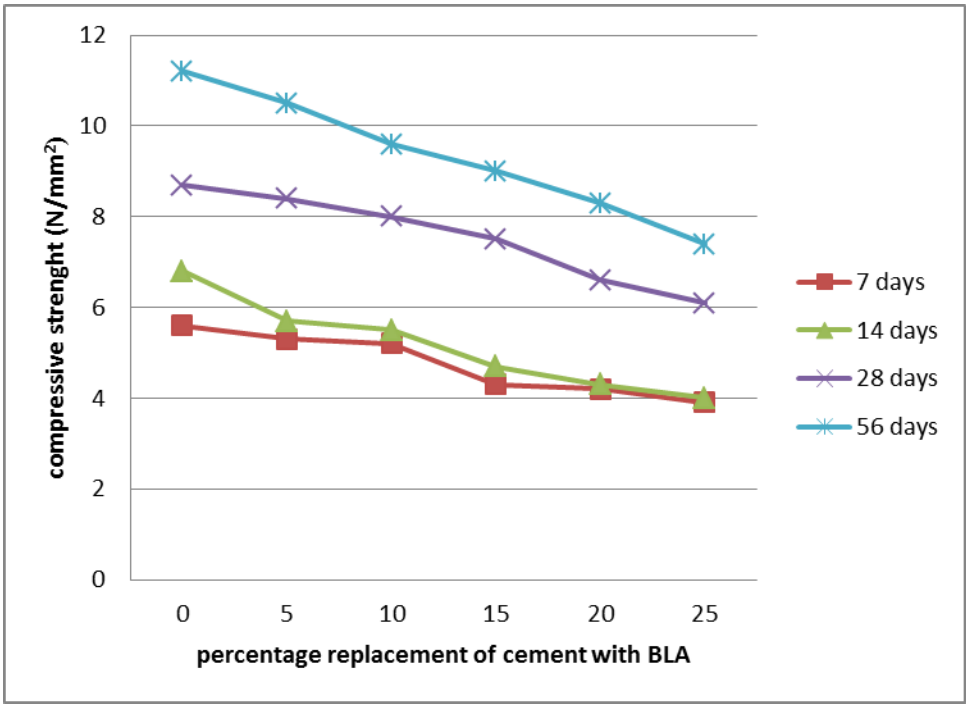

Figure 1: Variation of compressive strength with respect to percentage replacement of cement with BLA at varying curing duration.

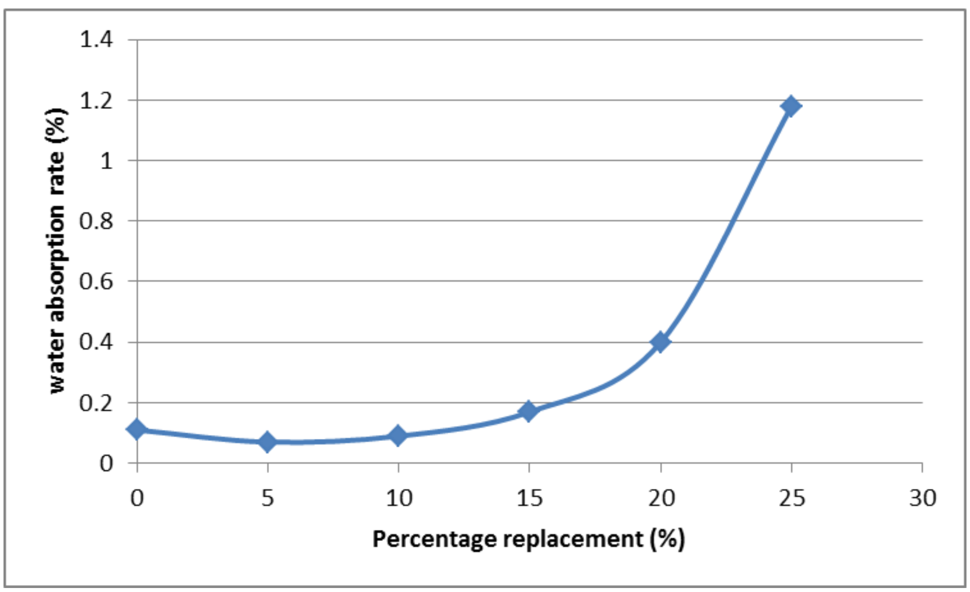

Figure 2: variation of water absorption coefficient of lateritic blocks at different levels of cement replacements by BLA.

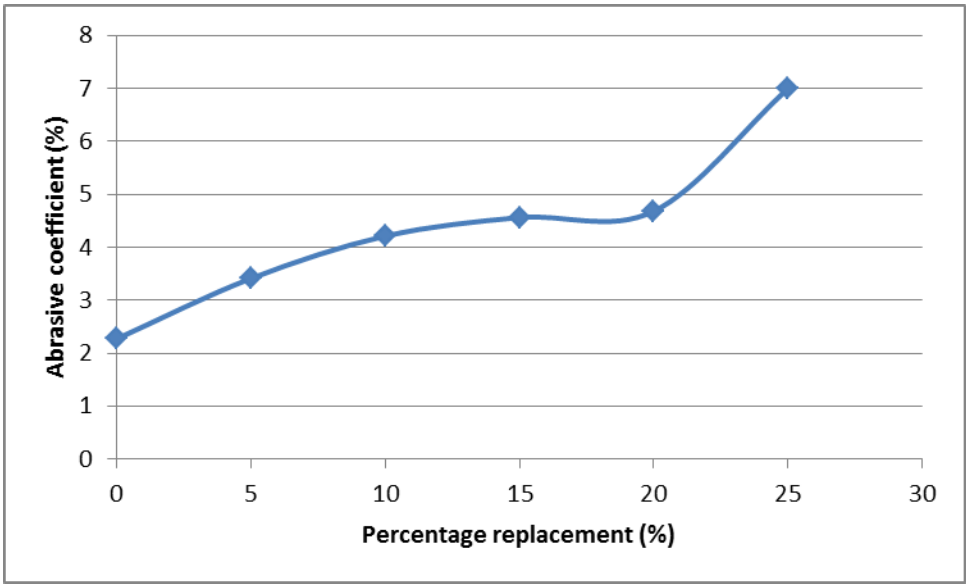

Figure 3: variation of the abrasive coefficient of lateritic blocks at different levels of cement substitution by BLA.

4.0 Conclusion

The compressive strength of the lateritic blocks produced from the BLA blended cement revealed that there is a strong relationship between compressive strength and the percentage replacement of bamboo leaf ash (BLA) with cement. An increase in percentage replacement brings about a reduction in the strength. The compressive strength values obtained between 5% to 25% replacement at 56th day was high with the value of 10.5N/mm^2, 9.6N/mm^2, 9.0N/mm^2, 8.3N/mm^2 and 7.4N/mm^2 for 5%, 10%, 15%, 20%, and 25% replacement of cement with BLA respectively. We conclude then that the 5% and 10% replacements would be suitable for the production of lateritic blocks for load bearing walls while 15% to 25% replacement can be used for non-load bearing walls. The fact that resistance to water penetration was good with the lateritic blocks produced with the 5% to 15% cement substitution but not so good for higher levels of substitution causes us to conclude that blocks produced with 5% to 15% replacements should be used for outer walls while the interior walls could be produced with higher levels of cement substitution.

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Plate 1: Bamboo Leaf Ash Burnt in an open Atmosphere

Plate 2: Bamboo Leaf Ash in Solid State

Plate 3: Bamboo Leaf Ash Burnt in Furnace.

Plate 4: Picture of block samples produced with the BLA blended cement arranged on the floor of the laboratory undergoing curing.