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COMPRESSIVE STRENGTH AND WATER ABSORPTION OF CEMENT-LOCUST BEAN WASTE ASH BLEND FOR LATCRETE BLOCKS PRODUCTION

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Abstract — This paper investigates the compressive strength and water absorption properties of cement-locust bean waste ash blend for latcrete block production. Locust bean waste was burned in the open air and later calcined at a temperature of 600°C for 3 hours to activate the amorphous content of the ash produced. The locust bean ash was used to replace cement at 5%, 10%, 15%, 20%, 25% and 30% by weight of cement in the production of 9" hollow latcrete blocks. A mix ratio of 1:6 was adopted in the block making. Various tests were carried out on the materials used for the block production to make sure it is up to the required standard. Compressive strength test and water absorption test were carried out on the latcrete blocks. The compressive strength result of the latcrete block with LBWA and the water absorption test conducted gave a promising enhancement after 28 days of curing. This research concludes that latcrete blocks with locust bean waste ash could be utilized in the construction industries for building purposes with better strength and durability properties.

***Keywords*:** Compressive strength, water absorption, locust bean, latcrete, cement

1.0 INTRODUCTION

One of the primary needs of man is shelter and to provide this requires the construction of houses and buildings. The need for cheap locally available materials for construction in developing nations such as Nigeria cannot be overstated. The development of locally manufactured materials is advantageous as it increases manufacturing activities and reduces dependency on imported materials and consequently the cost of construction. Delivering low-cost houses to the masses in Nigeria has been a challenge to the Federal Government [1].

Laterites are reddish-brown or brown residual soils with fine-grained texture usually found in humid zones, they are formed by a process known as laterization which is a weathering process where the disintegration of ferro-alumnino silicate minerals and everlasting deposition of sesquioxides (Al_2O_3 and Fe_2O_3) takes place within the soil profile to form the horizon of laterite [2]. Lateritic soils have been extensively used in roads and highway construction because they are virtually non-swelling and are hence considered a good foundation material [3]. Laterite is a desirable construction material because of its workability at in-situ. Local soils make the construction more suitable, cost effective and environmentally friendly especially in tropical countries [4]. Nigeria is blessed with unlimited deposits of suitable laterite for construction purposes. Locust bean waste ash (LBWA) is the byproduct of locust bean pods obtained after incinerating the material at a convenient temperature [1, 5, 6].

Locust bean tree is available in Nigeria and its environs, and it grows to a height of about 15m with dark and evergreen pinnate leaves. Its tiny red flowers do not have petals. Contained in the leathery pod about 10 -30cm long are seeds with a sweet sticky pulp [6]. Locust bean waste ash is a pozzolanic material. An alternative method of reducing the quantity of cement in concrete, mortar or blocks is by the use of pozzolanic materials. ASTM C618-19 [7] defined pozzolana as siliceous or siliceous and aluminous material which in themselves have no cementitious agents but in finely separated form and in contact with moisture they can react with calcium hydroxide which is obtained during the hydration process of Portland cement at normal temperatures to form compounds that possess cementitious properties.

Otoko et al. [8] experimented on the suitability of lateric soils for block making. In the experiment, laterite soil was chemically stabilized with lime and ordinary portland cement at 0%, 5%, 10%, 15%, 20%, and 25% by weight of the soil. The research aimed at producing interlocking soil lime blocks and soil cement blocks. Strength and durability test was done on the blocks in accordance to National building code [9]. The results of the abrasion test showed an increase in resistance with an increase in lime and cement content from 1.54% and 1.24% at 0% content for cement and lime respectively to 0.13% and 0.38% at 25% for cement and lime respectively. In the water absorption test, there was a decrease in water absorption with increase in cement and lime content, from 6.9% and 10.8% at 5% for cement and lime respectively to 2.4% and 4.2% at 25% for cement and lime respectively. However it was observed that at 0% content of cement and lime the completely dissoved in water as there was no binding medium. The dry compressive strength result at 28 days was reported to be directly proportional to cement and lime content up to 10% and then with continous addition of cement and lime the dry compressive strength was inversely proportional to dry compressive strength. The study conluded that only 10% cement content is recommended for use in interlocks blocks production as 10% lime content did not meet the requirement of [9]. Agbede and Manasseh [10] studied the effect of cement-sand mixture in laterite block production. In the study, laterite was modified by the additon of river sand at 0%(control) and 45% by weight of the dry soil and 9% cement content respectively. The blocks moulded were of dimension 330mm x 150mm x 150mm. the result of the compressive strength test at 7 days with 0% sand content and 45% sand content were 1.03 N/mm^2 and 2.10 N/mm^2 respectively. Similarly the compressive strength test result at 28 days 0% sand content and 45% sand content were was recorded at 0.20% and 3.31% respectively. The study proposed a laterite-cement mixture of 45% sand and 5% cement citing economic reasons. The compressive strength of such mixture was 1.80 N/mm^2 obtained through interpolation from the trend of the results. The study concluded that laterite cannot be effectively stabilized with only 5% cement content at 28 days strength of 1.1 N/mm^2 and therefore the recommend the laterite-sand-cement mixture of 45% sand and 5% cement as it meet the requiremnt of [9].

Akpenpuun et al. [11] examined the mechanical and structural characteristics of cement mortars blended with locust bean pod ash. An X-ray fluorescence (XRF) was conducted on the locust ben pod ash, the combination of Silicon dioxide, Aluminum dioxide and Iron oxide (SiO_2+Al_2O_3 +Fe_2O_3) are above 70% meeting the requirement as a pozzolanic material as stipulated by ASTM C168-01 and observed by the researchers. The experiment evaluated the compressive strength of concrete at 7, 14, 21 and 28 days respectively. In the concrete production locust bean pod ash was used to replace cement at 10%, 15%, 20% and 30%. The reported decrease in workability of the concrete with an increase in locust bean pod ash. The maximum compressive of 65MPa was observed at 15% cement replacement with locust bean pod ash. Microstructural analysis done on the hardened concrete using a Scanning Electron Microscopy (SEM) showed lesser voids and pores, and the presence of dense CSH gels which helped to improve the optimum compressive strength at 15% locust bean pod ash-cement replacement of the mortar.

Osinubi et al. [12] treated Nigeria black cotton soil with locust bean pod waste ash. The experiment was done to determine the suitability of the waste to improve the properties of the soil. Preliminary chemical analysis was conducted on the oxide composition, the waste ash contained Silicon dioxide, Aluminum dioxide and Iron oxide (SiO_2+Al_2O_3 +Fe_2O_3) above 70% meeting the requirement to be used as a pozzolan. The samples were subjected to index compaction using three energy levels (British Standard light, BSL, West African Standard, WAS or 'Intermediate' and British Standard heavy, BSH), shear strength (unconfined compressive strength, UCS), California bearing ratio, CBR and durability tests. the maximum value obtained in the CBR test was at 10% bitumen content and the durability test of the black cotton did not meet the requirement for a material to be used in road construction. The study concluded that locust bean pod waste ash cannot be used as single pozzolan to improve the properties of black cotton soil even though it improved the properties of the soil significantly when compacted with BSL energy. Ndububa and Uloko [13] conducted research on the compressive strength and water absorption capacity of locust bean pod ash concrete. Oxide composition test was done in accordance to ASTM Specification of C618-01 for a material to meet the requirement for pozzolan. The combination of these are Silicon dioxide, Aluminum dioxide and Iron oxide (SiO_2+Al_2O_3 +Fe_2O_3) was greater than 70%, In the experiment locust bean pod ash was used as partial replacement of cement at 0%, 5%, 10%, 15%, 20%, and 25% by weight. In the experiment, the compressive strength of concrete increased at about 1.38% with 25% cement replacement content from 20.9N/mm^2 to 21.2N/mm^2. This meets the requirement by Nigeria Building Specification (NIS) as a concrete to be used for load bearing structures but the water absorption capacity of the mortar did not increase significantly. The study concluded that the compressive strength of the cement-locust bean pod ash concrete is adequate enough for use as a load bearing building material. An experiment on the use of locust bean pod extract (50, 100, 133, 150 and 200g/litre) and cement (0.1, 0.2, 0.3, 0.4 and 0.5kg) to improve the strength and absorption properties of lateritic block validates its use for low housing construction in developing areas of Nigeria [14]. Another study by Akinyemi et al. [15] used red earth, lateritic soils and quarry dust as substitute building materials in block production. The compressive strength presented that the use of quarry dust and lateritic soil and the use of red earth and quarry dust had a good potential as a substitute when related to the adopting of river sand in the production of blocks for developing nations.

A number of studies have been carried out on Locust Bean Waste Ash, but as a form of application, this work seeks to use LBWA combined with Portland cement to produce hollow latcrete blocks and to study its strength and water absorption properties.

2.0 MATERIALS AND METHOD

2.1 Materials

Materials used for this research are ordinary Portland cement, fine aggregate, water and locust bean waste ash. They were all tested to ensure compliance with relevant British code of practice.

2.1.1 Ordinary Portland Cement

The cement used in this research was Ordinary Portland Cement of grade 42.5N and was obtained from open market in Samaru, Zaria, Nigeria which conforms with ASTM C150/C150M [16].

2.1.2 Water

Portable water sourced in department of Civil Engineering laboratory ABU Zaria was used and it complied with standard specification of BS EN 1008 [17].

2.1.3 Locust Bean Waste Ash

Locust bean waste were sourced from farms around Zaria and its environs in Kaduna state, Nigeria. It was burned in open air and later calcined at a temperature of 600°C for 3 hours to activate the amorphous content. Physical test conducted on the locust bean waste ash in accordance with ASTM C136/C136M-19 [18], while the chemical tests to determine the oxides composition was done in accordance with ASTM E1621-13 [19].

2.1.4 Laterite

The Laterite used was collected from an existing borrow pit at a depth of about 1.5 to 2.5 m in Zaria, Nigeria, using method of disturbed sampling.

2.2 Methods

2.2.1 Chemical analysis

The chemical analysis of the materials (locust bean waste ash and cement) used in this research was done in the Chemical Engineering Department, A. B. U. Zaria. The X-Ray Fluorescence (XRF) test is an energy dispersive microprocessor controlled analytical instrument designed for the detection and measurement of elements in a sample (solid, powders and liquids), from sodium to uranium in accordance with ASTM E1621-13 [19].

2.2.2 Setting time of Cement

The setting time of cement is needed to determine the stiffening ability of the cement to a defined consistency. This test was conducted on both OPC and LBWA cement paste as the needle penetration is between 5mm and 7mm for the initial and final setting time. This test was done in accordance to BS EN 196-3 [20].

2.2.3 Particle Size Distribution (Sieve Analysis)

This is the test done on laterite soil to determine the relative proportions of different sizes of soil passing through a set to determined sieves. This was done by air-drying the sample and in accordance with ASTM C136/C136M-19 [18].

2.2.4 Specific Gravity

The specific gravity test was done to measure the weight of a given volume of material (or vice versa). As defined by specific gravity is defined by ASTM D854-14 [21]. is the ratio of the weight of a given volume to the material to the material to the same volume. The test was conducted in accordance with ASTM D854-14 [21] the test was conducted on for laterite soil.

2.3 Production of Blocks

The mix ratio adopted for this research was in accordance to NIS 87 [23], and BS EN 1052-1 [22] which stipulates that the standard cement to sand mix ratio is 1:6. The total number of 42 225x225x450mm blocks were produced with 3 iterations done on blocks for the compressive strength test and 3 iterations for the water absorption test. This was done for all replacement ranging from 0 to 30% at 5% intervals of replacement of the weight of cement with LWBA in the lateritic block production.

3.0 RESULTS AND DISCUSSION

3.1 Chemical properties of LBWA

Table 1 Chemical Composition of Locust Bean Waste Ash

Oxide	SiO_2	Al_2O_3	Fe_2O_3	MgO	TiO_2	CaO	SO_3	K_2O	MnO	LOI
%Composition	51.40	18.18.	15.60	1.63	0.55	5.31	1.48	0.88	0.15	3.33

Table 1 shows the result of chemical composition analysis of locust bean waste ash. It was observed that the chemical composition of LBWA indicate a combined SiO_2, Al_2O_3, and FeO_3 content of 85.18%. This result satisfies the requirement of ASTM C-168 [7] for a material to use as a pozzolan in concrete. As shown in Table 2 the material when compared with ASTM C-168 [7] can be classified as Class F pozzolan, which possess pozzolanic properties.

Table 2 Comparison of test results on Locust Bean Waste Ash with ASTM Standard C-168

Chemical composition	Mineral Admixture Class			Test Result
	N	F	C	85.18
$(SiO_2) + (Al_2O_3) + (Fe_2O_3)$ min (%)	70	70	50	1.48
SO_3, Max (%)	4	5	5	
Loss in ignition (%)	10	6	6	

3.2 Setting time of LBWA Cement paste

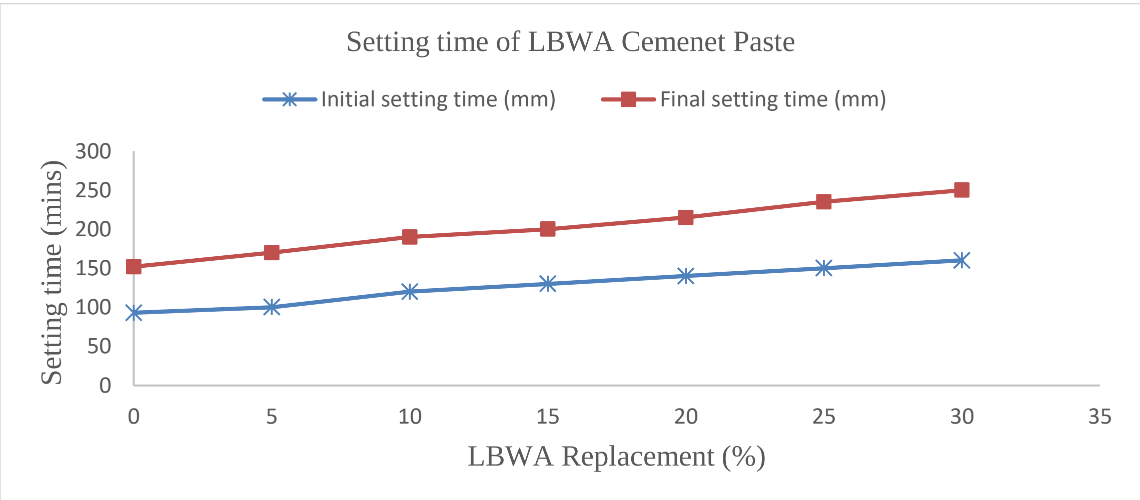

Figure 1 The variation of initial and final setting time with LBWA replacement

The variation in initial and final setting time of LBWA paste is shown in Fig 1. It was observed that the initial setting time with increase in LBWA content (0% to 30%) from 100 mins to 160 mins and final setting times increased from 152 mins to 250 mins respectively.

This increase in the LBWA content increases the amount of heat of hydration by C_3A and strength development by C_3S increases. Pozzolanic reaction between calcium oxides and hydroxides with $Al_2O_3.2SiO_2$ from LBWA produces C-S-H gel and reduces the setting time of the paste.

3.3 Properties of Laterite soil

The laterite soil sample index properties are presented in Table 3. The laterite sample had a moisture content of 13.7%, had a liquid limit and plastic limit of 50.8 % and 32.1and respectively with a plasticity index of 18.7%. The laterite soil was classified using the AASHTO [23] and the Unified Soil Classification System (USCS) systems to belong to the A-2-7 and GW soil groups respectively.

Table 3 Laterite soil index properties

Property	Quantity
Moisture content (%)	13.7
Liquid Limit (%)	50.8
Plastic Limit (%)	32.1
Plasticity Index (%)	18.7
AASHTO classification	A-2-7
USCS Classification	GW
Maximum Dry Density (WAS)Mg/m³	1.90
Specific Gravity	2.63
Percentage passing BS No. 200 sieve (%)	1.11
Condition of soil Sample	Air-dried
Color	Brownish-red

The index properties also showed that the soil meet the required limit of 35% liquid limit and 12% plasticity index for use as a sub base material as specified in the Nigerian General Specifications for Roads and Bridges [24]. The laterite soil had a specific gravity of 2.63, had maximum dry density (MDD) of 1.90 Mg/m^3 using the WAS energy level. The laterite soil sample was air-dried before use for block production.

3.4 Particle Size Distribution of laterite (Sieve Analysis)

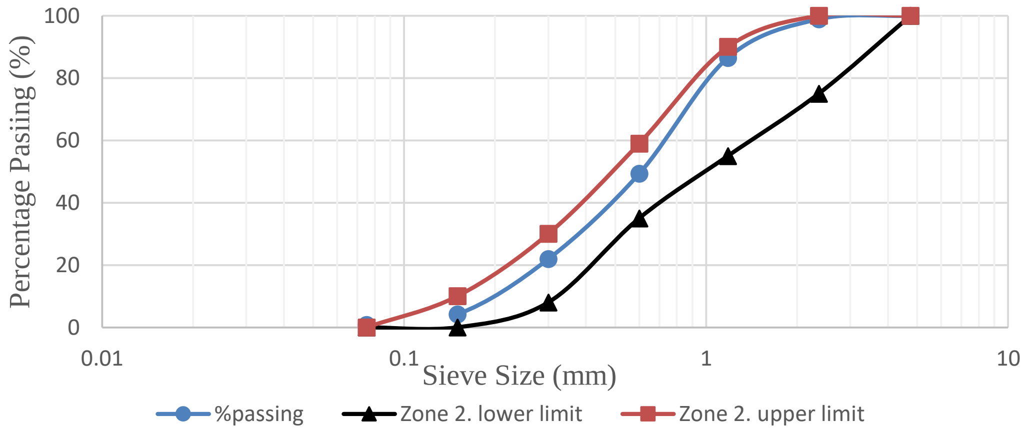

Figure 2 Particle Size Distribution Curve of laterite soil

The particle size distribution was done to determine the gradation of aggregate and often times referred to as sieve analysis. The particle size distribution test result for laterite soil is presented in Figure 2. The test was carried out in accordance to BS EN 933-1[25] and the laterite soil was found to fall within zone 2 in accordance with BS EN 12620 [26] classifications.

3.5 Dry compressive strength test

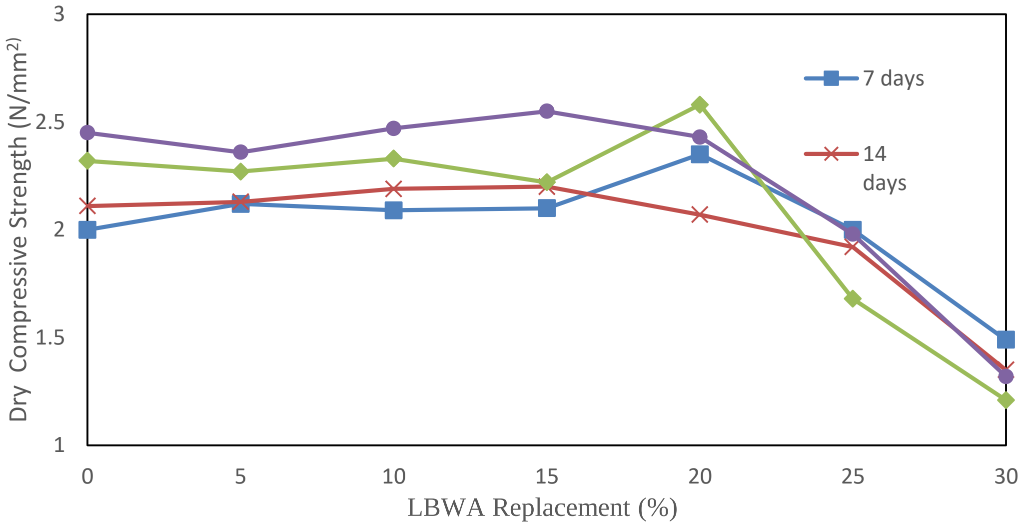

Figure 3 Relationship between Dry Compressive strength and LBWA content

The effect of inclusion Locust bean waste ash on the 28 days compressive strength of latcrete block is shown in Figure 3. The dry compressive strength of the latcrete block at 28 days curing increased from 2.36N/mm^2 for 5% LBWA replacement to 2.58 N/mm^2 for 20% LBWA replacement, after which the continuous addition of LBWA showed a drop-in strength. The gain in strength with increase in LBWA content up to 20% could be attributed to amount of silica-alumina dissolved in the cement matrix. The further addition of LBWA created an excess silica content which did not bond any calcium hydroxide thereby creating pores in the cement matrix. The result of 20% LBWA replacement at 28 days was within the range of minimum strength specified in NIS 87[22] which is between 2.5N/mm^2 to 3.45N/mm^2.

3.6 Water absorption

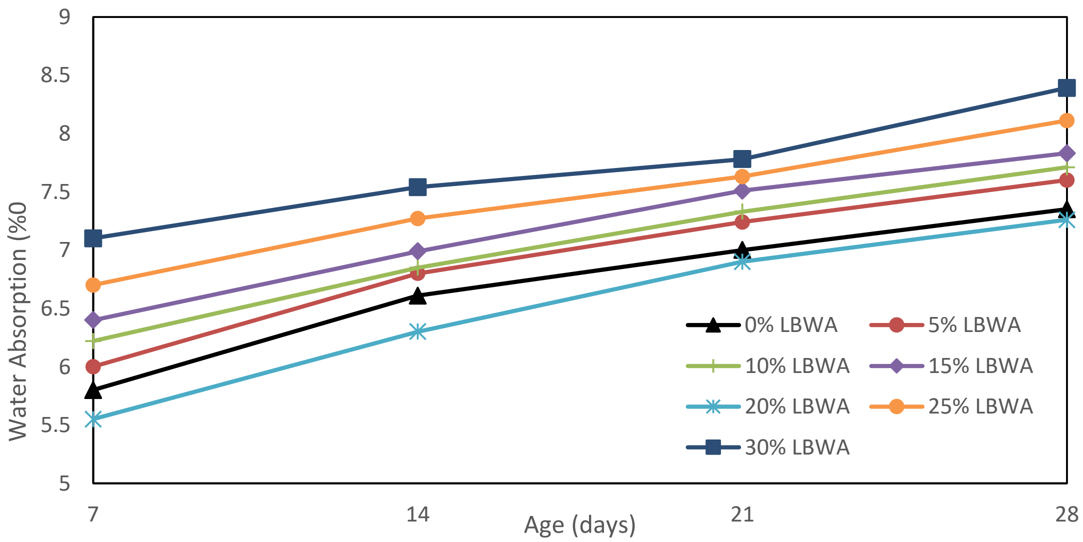

Figure 4 Water absorption with variation in LBWA content and Curing Age

Figure 4 shows the influence of LBWA on water absorption on the hollow block. The water absorption in the hollow block increases from 0% replacement (control) with each curing age. The 28 days minimum water absorption was observed at 20% replacement of about 7.26% when compared to other replacement intervals. The continuous increase of LBWA created higher volume of pores in the block this may be attributed to excess LBWA content which did not successively create a pozzolanic reaction thereby forming spots which necessitated the permeation of water. According to NIS 87 [22], the average water absorption should be maximum of 12%. All values obtained fell below the maximum NIS recommendation. Similar findings of result were reported in other works [26].

4.0 CONCLUSION

The result of the chemical composition analysis of LBWA showed that the material is a class F pozzolan with a combined content of SiO_2, Al_2O_3 and Fe_2O_3 of 85.14% which satisfies the requirement of ASTM C168. The result of the dry compressive strength with 20% LBWA content showed satisfactory compliance with the range of minimum strength specified in NIS 87 which is between 2.5N/mm^2 to 3.45N/mm^2. The result of the water absorption test showed a satisfactory value of 7.26% at 20% LBWA content with 28 days curing age which meets the requirement of a maximum of 12% as stipulated by NIS 870.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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