Strength Properties of Stabilised Laterite as Replacement of Sand in Sandcrete Block Production

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compressive strength

ABSTRACT

This research borders on the effect of strength on the replacement of sand with stabilized laterite in the production of sandcrete blocks in Benin City. It involves the stabilization of the laterite with 15% cement before being used in the production of sandcrete block. Lateritic soils were obtained from 1m depth in Dentistry Quarters of the University of Benin while sharp sand were drilled from Okhuahia River, in Benin City. The samples were taken to the laboratory where controlled testing and curing. The stabilised laterite was used to gradually replace sand at the rate of 10%, 20%, 30%, 40%, 50% and then completely at 100% in the production of sandcrete blocks. A total 54 sandcrete blocks were prepared in 0.001 m3 mould and cured for 7, 14 and 21 days, after which the compressive strength of the blocks were determined and compared with the Nigerian Industrial standards (NIS) as well as the British standard (BS 2028) for minimum strength considerations.The results of tests carried out indicate that there was an improvement in the strength of the sandcrete block when there was a complete replacement of the stabilised laterite with sand in the production of sandcrete blocks. The least strength results obtained showed that for each percentage replacement of sand with stabilised laterite, the minimum compressive strength exceeded that specified by NIS for block production. This is quite important in reducing the cost of sand in block production.

1. Introduction

In Nigeria, lateritic soil abounds locally and its use is mainly limited to Civil Engineering works like road construction and land fill operation, but is less utilized in the construction material except as backfill to cover trench in foundations. However, since laterites have no exact technical data, it is not yet a generally accepted constructional material and this contributes to its limited application in building block production (Udoeyo et al., 2006). Studies are currently on-going on the use of lateritic soil in concrete production where laterite is made to partly or wholly replace conventional fine aggregate in the production of concrete known as laterized concrete; and used in the production of brick units such as Compressed Laterized Brick (CLB) usually stabilized with cement. These applications are currently mostly limited to buildings in rural areas or in satellite areas.

Lateritic soil has some advantages which make it potentially good for construction, especially for the construction of rural structures in the developing countries. One of such advantage is the non-requirement of specialized skilled labour in the production of laterized sandcrete blocks for the building structures. Laterized concrete structures are known to have potentially sufficient strength compared with those of normal concrete (Osunade, 1994).

From the literature, there has been many theories on ways to cut down the quantity of sand in construction materials. Scientist have revealed the possibilities of partially replacing sand with variety of naturally existing materials. This works seeks to examine the strength characteristics of sandcrete block when sand is partially or wholly replaced with stabilised laterite as it avail profitable utilisation of the available deposit of lateritic materials in the production of economic building material which can reduce the construction cost. The strength of the lateritic sandcrete blocks shall be compared with the Nigerian Industrial Standards and the British Standards.

2. Laterite and Lateritic Soil

Laterite is a soil group, which is formed during weathering through the process of laterization i.e. decomposition of ferroalumino – silicate minerals, leaching of the combine silica and base; and the permanent deposition of sesquioxide within the profiles (Balogun & Adepegba, 1982). The silica that is left unleached after laterization will form secondary clay silicate minerals. Laterites usually form a poor soil full of concretionary lumps and very unfertile because the potash and phosphate has been removed in solution, while only iron and silicate are left behind (Ola, 1983). Laterites has been used for foundations and other construction purposes in subtropical and tropical regions, where they occur in large deposit. For any soil to be utilized for Civil Engineering works there is need for strength investigation to enable the engineers predict

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their engineering properties and their performance under field conditions, with fairly good degree of accuraccy.

Laterite is a term often used to describe a clinkered siliconized clay material. Villan-Co Chin *et al*., (2003) and Amu *et al*., (2011) described laterite as a red friable clay surface which is a very hard homogenous vescular massive clinker-like material with a framework of red hydrated ferric oxides of vescular infill of soft Aluminum oxides. Villar-Cocina *et al.,*(2003) opined that mechanical stability is an important factor that should be considered in the use of lateritic materials. However, mechanical instability may manifest in form of remoulding and recasting and breakdown of cementation and structure. The mechanical instability can affect engineering properties of laterite, such as particle size, Atterberg's limits, moisture content, grain size among others which in turns affect the strength of laterized (Akintorinwa & Olorunfemi 2012).

McDowell 1959, divided laterite into true laterite, silicate laterite and lateritic clays on the basis of the hydroxides content, and this was developed further by (Martin and Doyne, 1930) with the application of a silica-alumina ratio.

None of the above definitions, however, helped the field identification of this useful engineering material. Most researchers now prefer to use the laterite definition based on hardening, such as “Ferrite” for iron-rich cemented crusts, “Alcrete” or bauxite for aluminium rich cemented crusts, “Calcrete” for calcium carbonate rich crusts and “Silcrete for silica rich cemented crusts” (Fookes, 1997).

2.1 *Chemical Characteristics of Laterite*

Mallet (1883) was perhaps the first to introduce the chemical concept for establishing the ferruginous and aluminium nature of lateritic soils. Fermor (1911) defined various forms of lateritic soils on the basis of the relative contents of the mineral constituents of iron, Aluminum, titanium, and manganese in relation to silica. There are several other attempts by researchers to classify laterite in terms of their chemical compositions, but Fox (1936) demonstrated that such classifications based on chemical composition alone cannot be used to distinguish between indurate and softer formations.

The high content of the sesquioxides of iron or aluminium relative to other components is a feature of laterite. From findings by Osunade, 2002, laterite may contain more than 80% of Fe_2O_3 and little Al_2O_3; while others may contain up to 60% of Al_2O_3 and a little of Fe_2O_3. Although alkaline bases are almost entirely absent in most cases, this is not an absolute criterion (Osunade, 2002). In particular, some ferruginous tropical soils may contain significant amounts of alkali and alkaline bases. Combined silica content is low in sesquioxides. This combined silica is predominantly in the form of Kaolinite, the characteristic clay mineral of most tropic formation. It was on this basis that D'hoore (1954) made a theoretical calculation of free Al_2O_3 content from combined silica content employing the formula in

$$Free\ Al_2O_3 = Total\ Al_2O_3 - (SiO_2 \times 0.85) \text{------------------} (1)$$

The use of this formula leads to the statement that alumina was present principally in combined form in laterite of Buchanan's type. Although alumina is sometimes the main constituent, the sesquioxides of iron are most common and the most frequent.

2.2 *Formation of Lateritic Soils*

Laterization which is the removal of silicon through hydrolysis and oxidation results in the formation of laterite and lateritic soils. The degree of laterization is estimated by the silica sesquioxide (S-S) ratio ($SiO_2/Fe_2O_3+Al_2O_3$). Laterization involves physico-chemical alteration of primary rocks forming minerals into materials rich in Kaolinite (D'hoore, 1954). In the first phase laterite formation Ca, Mg, Na and K are released leaving behind a siliceous framework for the formation of clay minerals. During prolonged alkaline attack, the siliceous framework consisting silica tetrahedral and alumina octahedral is disintegrated. Silica will be leached slowly, while alumina and Ferri-sesquioxides ($Fe_2O_3+Al_2O_3$, and TiO_2) remain together with kaolinite as the end products of clay weathering. The end result is a “reddish matrix” made from kaolinite, goethite, and fragments of the pisolitic iron crust”. (Gidigasu, 1976).

According to Gidigasu, (1976), there are two aspects of the parent rocks that affect the formation of laterite

1. The availability of iron and aluminium minerals, which are more readily available in basic rocks.
2. The quartz contents of the parent rocks, where quartz is a substantial component of the original rock, it may remain as quartz grains.

From the above, three major processes of laterite formation can be identified as follows:

a) **Decomposition:** physic-chemical breakdown of primary minerals and the release of constituent elements (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O, etc.) which appear in simple ionic forms.

b) **Laterization:** leaching under appropriate conditions, of combined silica and bases and the relative accumulation of enrichment oxides and hydroxides of sesquioxides ($Fe_2O_3Al_2O_3$ and TiO_2). The soil conditions under which the various elements are rendered soluble and removed through leaching or combination with other substances depend mainly on the PH of the ground water and the drainage conditions (Pickering, 1962; Loughman, 1969).

c) **Desiccation:** Desiccation or dehydration involves partial or complete dehydration (sometimes involving hardening) of the sesquioxides rich materials and secondary minerals. The dehydration of colloidal hydrated iron oxide involves loss of water and the concentration and crystallization of the amorphous iron colloids into dense crystals, in the sequence; limonite, goethite to hematite (Hamilton, 1964). Dehydration may be caused by climatic changes, upheaval of the land, or may also be induced by human activities (e.g. by clearing of forests). (Loughman, 1969).

2.3 Soil Stabilization

Roger et al. (1996) defines stabilization as any process by which a soil material is improved and made more stable. According to Garber & Hoel (1998): soil stabilization is the treatment of natural soil to improve its engineering properties. Stabilization of soil is employed when it is more economical to overcome a deficiency in a readily available material than to bring in one that fully complies with the requirements of specification for the soil (Ola, 1978). It has been regarded as a last resort for upgrading substandard materials where no economic alternative is available. Although road construction has been the major area of application of soil stabilization techniques, they have also been applied in soil foundation strengthening, though to a limited extent. The principal approach employed to soil stabilization are; first mechanical stabilisation which include compaction with gravel, crushed aggregate, grit and second, chemical stabilisation which makes use of Portland cement, cement-slag blends, Lime (quick - lime, hydrated lime) and gypsum Lime - pozzolan (lime plus fly ash or ground slag) mixtures, bitumen, sand and baggasse stabilization.

The choice of a stabilizing method should be based on the following factors such as General characteristics, Particle-size distribution, Mineralogical composition of the soil and Organic matter, and Physico-Chemical characteristics of the soil.

2.4 Standards for Specification

Two major standards for specifications that will be considered here include the British Standard (BS) and the Nigerian industrial standard (NIS).

2.4.1 British Standard (BS) Specification

The British standard as presented in BS 2028, 1364:1968 relates to the three types of pre-cast solid or hollow blocks. A piece of the code that relates to sandcrete block is presented in table 1. The minimum strenght of the concrete ranged from 2.8 to 5.6N/mm^2.

2.4.2 Nigerian Industrial Standard (NIS)

The Federal Ministry of Works and Housing (FMWI), had specified the same strength requirement as stipulated in BS 2028 for sandcrete hollow blocks i.e. 2.8N/mm^2 or 360 psi. this was also adopted by the Nigerian Industrial Standard N.I.S:74:1976 udc.624).

The proceedings of the conference on Material Testing Control and Research (1978), Federal Ministry of Works and Housing, Lagos, recommended 2.1N/mm^2 or 300 psi as the minimum strength for building blocks. It is worth mentioning that before any cement-sand mix is accepted for use in the field, it must satisfy certain criteria of durability test. In the United Kingdom, the Transport and Road Research Laboratory, in attempt to establish some simple test to take care of all durability tests specified in the A.S.T.M standards, recommended a minimum compressive strength of 1.8N/mm^2 (250*psi*) after 7 days curing. This would correspond to 2.5N/mm^2 at 28 days which is the minimum requirement for sandcrete hollow blocks as per NIS:74. In this study, the maximum period of curing was 21 days which is supposed to give a minimum of 75% of the strength at 28 days curing period i.e. 1.875 N/mm^2.

3.0 Material and Methods

3.1 Collection of material

Soil samples were collected from laterite deposit in Dentistry quarters of the University of Benin Teaching Hospital and sharp sand were collected from Okhuahia River in Benin City. Preliminary tests on several percentage of cement for stabilisation showed that the highest density was obtained at 15% Cement additives. Consequently, all the samples used in the tests were stabilised with 15% cements before being used as replacement for sand in the production of cube sandcrete blocks.

3.2 Preparation of the sample

The sample air dried and particle size distribution tests was carried out on the sharp sand the stabilised lateritic soil. Lump of lateritic soils were grounded using mortar and Pistle to remove void spaces and to facilitate proper mixing with the binding material like cement in the production of the blocks.

3.3 Design of Mix Proportion, Batching and Mixing

The design mix ratio adopted for this study for the production of sandcrete is 1:4. Sand was gradually replaced by stabilised lateritic soil in the order of 10%, 20%, 30%, 40%, 50% and 100%. Curing was carried out for 7, 14 and 21 days after which compressive strength were successively carried out. Six blocks were prepared for each percentage replacement with sand with two blocks each tested for strength at 7, 14 and 21 days curing periods. A total of fifty-four (54) sandcrete blocks were carried out in this project. The steel mould used in the preparation of the sandcrete blocks have a dimension of 100mm x 100mm x 100mm. In all the tests, the water-binder ratio was 0.65 with cement being the binder material.

3.4 Compressive Strength Test.

The Universal Testing Machine was used to test for compressive strength in the blocks after the curing periods of 7, 14 and 21 days and for the all the percentage replacement of sand with stabilised lateritic soil. Two samples were tested for curing interval. The average strength was then recorded. This machine gives the permissible compressive load in (KN) that the blocks can carry. The approach for the computation of the results are presented thus:

$$\text{Density Kg/m}^3 = \frac{\text{Weightofconcretecube}}{Volume(\text{mm}^3)} = \frac{\text{Massofconcrete cube}(kg)}{0.001m^3} \text{ - - - } (ii)$$

$$\text{Compressive strenght} = \frac{\text{CompressiveLoad(KN)}}{Surface\ \text{Area (mm}^2)} \text{ ---------- } (iii)$$

4.0 Results and Discussions

4.1 Sieve Analysis Results

The results of the sieve analysis carried out on the two soil samples are presented in the form of graph shown in figure 1 and 2. The sieve analysis plot for the stabilised lateritic soil and the sharp sand resemble in many respect. Though laterite is composed of clayey minerals, the addition of cement as stabilising agent improved the property of the lateritic soil considerably, making to have sandy soil grain structure.

4.2 *Compressive Test Results*

The results of compressive strength tests carried out on sandcrete block with the sand replaced by at 10%, 20%, 30%, 40%, 50% and 100% stabilised laterite replacement after 7, 14 and 21days period of curing are presented in table 2 to table 4. Scatter plot showing the relationship between the compressive strength and percentage replacement of the stabilised laterite are presented in figure 3.

4.3 *Discussion of Result*

The results of the compressive strength test are shown in tables 2 to 4, while the graphical illustration of the relationship between compressive strength and the variation in the amount of stabilised cement laterite is shown in figure 3. It was observed that the strength curve is not linear with increasing replacement of sand with stabilized laterite. While it is established that the highest compressive strength was obtained when there was 100% stabilised laterite in the sandcrete block, the strength was not progressing normally with the increase in the period of curing. This may affect the long term strength reliability of the block to be produced. The results obtained from 10% stabilised laterite replacement was adequate good long term strength reliability. The results obtained at 40% stabilised laterite replacement was deemed as fair

It was noticed that the higher the lateritic soil replacements, the more water was needed to effectively mould the sandcrete block to shape. This implies that the water content of 0.65 is not static but may require some slight adjustment to achieve a properly mixed mortar. Despite these anomalies, it is evident that the compressive strength of the blocks still meet the minimum strength requirement as per the NIS and BS 2028 for use in building and construction works.

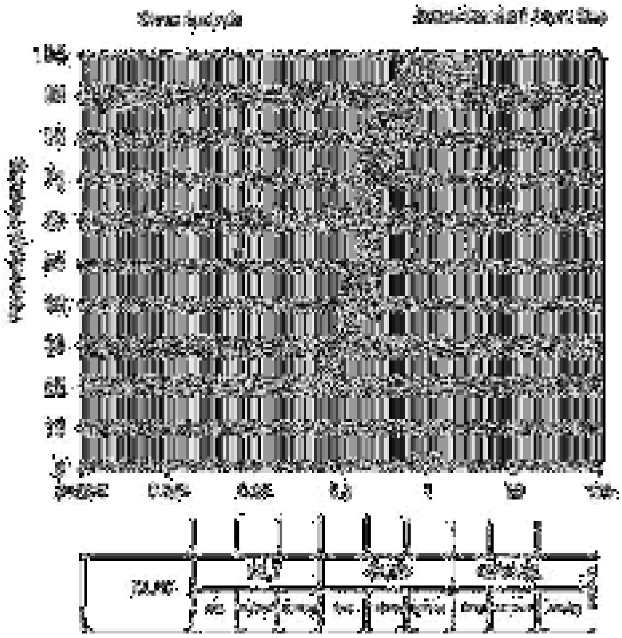

Fig 1:.Graph of sieve analysis of Okhuaihe River Sharp Sand

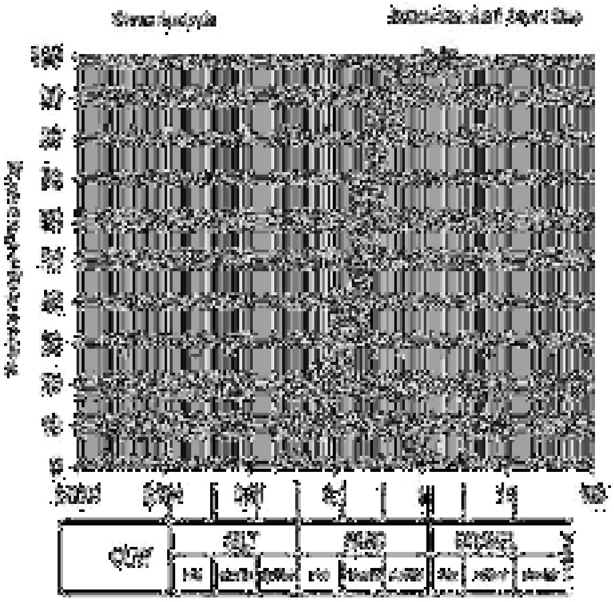

Fig 2: Graph of sieve analysis of lateritic soil in Dentistry quarters

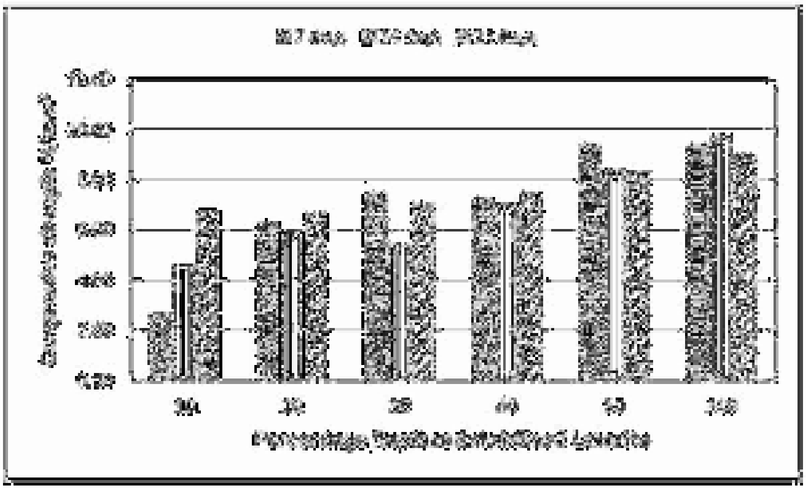

Fig 3: compressive Strength for Different Replacement at 7, 14, and 21days curing period

Table 1: British Standard BS 2028

TYPE	DESCRIPTION	BLOCK DENSITY (Kg/m^3)	AVERAGE COMP. STRENGTH (N/m^2)	MINIMUM COMP. STRENGTH (N/mm^2)
A	Dense aggregate conc. Blocks, for general use in the building	Not less than 500	3.5 7.0 and above	2.8 5.6
B	Light aggregate con. Blocks for load bearing walls for general use in buildings	Below 1500	2.8 – 7.0	2.25 – 5.6
C	Light weight aggregate concrete blocks for internal non-load bearing walls partition	Below 1500	Transverse load is specified	Breaking specified

Table 2: 7days strength of Solid Cement Stabilize Lateritic Block Produced

Percentage Composition%	Block No	Blocks weight (kg)	Size of block (mm^2)	Compressive force (CP) - KN			Average CP	Compressive strength (N/mm^2)
10% stab. laterite + 90% sand	A_{17}	1.90	100X100	32	20	28	26.7	2.67
20% stab. laterite – 80% sand	B_{17}	1.80	100X100	60	68	61	63.0	6.30
30%stab. laterite – 70% sand	C_{17}	1.80	100X100	71	75	80	75.3	7.53
40% stab. laterite – 60% sand	D_{17}	1.90	100X100	78	67	71	72.0	7.20
50% stab. laterite – 50% sand	E_{17}	2.00	100X100	95	97	91	94.3	9.43
100% stab. laterite + 0% sand	F_{17}	2.00	100X100	91	101	90	94.0	9.40

Table 3: 14days strength of Solid Cement Stabilize Lateritic Block Produced

Percentage Composition%	Block No	Blocks weight (kg)	Size of block (mm^2)	Compressive force (CP) - KN			Average CP	Compressive strength (N/mm^2)
10% stab laterite – 90% sand	A_{214}	1.8	100 X100	51	50	38	46.3	4.63
20% stab laterite – 80% sand	B_{214}	1.9	100 X100	68	61	50	59.7	5.97
30% stab laterite – 70% sand	C_{214}	1.8	100 X100	41	58	62	53.7	5.37
40% stab laterite – 60% sand	D_{214}	2.0	100 X100	71	78	61	70.0	7.0
50% stab laterite – 50% sand	E_{214}	2.0	100 X100	91	81	79	83.7	8.37
100% stab laterite – 0% sand	F_{214}	2.1	100 X100	101	99	92	97.3	9.73

Table 4: 21 days strength of solid Cement Stabilize Lateritic Block Produced

Percentage Composition%	Block No	Blocks weight (kg)	Size of block (mm^2)	Compressive force (CP) - KN			Average CP	Compressive strength (N/mm^2)
10% stab laterite + 90% sand	$A3_{21}$	1.9	100x100	61	80	62	67.7	6.77
20% stab laterite + 80% sand	$B3_{21}$	1.9	100x100	51	71	78	66.7	6.67
30% stab laterite + 70% sand	$C3_{21}$	1.9	100x100	68	65	79	70.7	7.07
40% stab laterite + 60% sand	$D3_{21}$	2.0	100x100	70	71	84	75.0	7.50
50% stab laterite + 50% sand	$E3_{21}$	2.0	100x100	81	86	83	83.3	8.33
100% stab laterite + 0% sand	$F3_{21}$	2.1	100x100	85	94	91	90.0	9.00

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5.0 Conclusion and Recommendations

The result of the compressive strength illustrated above shows that all percentage replacement of sand with stabilized laterite meet the minimum standard require by the regulatory bodies to be used for making sandcrete blocks. The addition of cement as a stabilisation agent to the laterite greatly improve it engineering properties as a substitute for sharp sand. The results obtained when all the compressive strengths were accessed as a group showed that there was a drop in strength, especially after 14 days curing period at 20%, 30%, 40% and 50% stabilised lateritic soil replacement. For most cases however, the strength increased slightly for the 21 days curing period. This brings to bear strength reliability in replacing sand with stabilised laterite.

Finally since every replacement of the sand with stabilized laterite surpasses the minimum compressive strength stipulated by NIS and BS standards it should be considered as a veritable replacement of sand for use in sandcrete block production.

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