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Stabilized Lateritic Bricks as Alternative To Mud Housing In Bauchi, North East Nigeria

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Abstract: *Samples of laterites from borrow pits in mud house construction locations of Bauchi, North East Nigeria were investigated. The laterites had particle components of 22.0% clay, 16.8% silt and 61.2% sand. They were stabilized with cement, lime and bitumen respectively and tested for compressive strength, water absorption capacity, linear Shrinkage and permeability. The stabilizers were introduced to the laterite in ratios of 3%, 5% and 7% respectively before testing. They were cured for 7, 14, 28 and 42 days respectively. After 28 days of curing, cement stabilized laterites (CSL) possessed compressive strengths of 1.98N/mm^2, 2.83N/mm^2 and 3.48N/mm^2 respectively. Zero stabilized laterite (ZSL) had a maximum value of 1.27 N/mm^2 after 42 days. The water absorption capacities were 6.65%, 5.23% and 4.88%. Lime stabilized laterite (LSL) had compressive strengths of 0.84N/mm^2, 0.94N/mm^2 and 1.02N/mm^2 and water absorption capacities of 10.3%, 9.48% and 9.14%. ZSL had 16.41% value. Compressive strength for bitumen stabilized laterite (BSL) were 0.92N/mm^2, 1.03 and 1.11N/mm^2 with water absorption capacities of 3.13%, 1.73% and 1.49%. Further results showed that 7% CSL had a permeability of 4.47 x 10^{-9} m/s at 20^{o}C and 7% LSL had a permeability of 7.30 x 10^{-9} m/s. Generally the bricks experienced less linear shrinkage with increase of % stabilizers, however CSL had least shrinkage of 0.47% while BSL had highest of 1.33%. The results showed that stabilized laterites produced superior performance than ZSL. Cement was the best characteristic performer except in water absorption where BSL absorbed least water. Combinations of the stabilizers is suggested for further investigation to obtain optimum performance.*

Keywords: *Laterite, Strength, Soil, Cement, Lime, Bitumen.*

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I. Introduction

Bricks made from plain soils for centuries have been used in building mud houses (Baher, Benazzoug, & Kenai, 2004). The most consistent of these soil types are laterites. Laterite is an old and popular construction material that has served humanity for centuries now. According to a UN report (ESCAP, 1989), it is a highly weathered tropical soil containing varying proportion of iron and aluminum oxides. In addition to mud houses, it is used for the construction of highways. When used alone, it depreciates in strength fast under load and ambient weather. In another report (Kasthurba, Krishna, & Venkat, 2014), laterite was described as a type of soil found in hot and wet tropical regions of the world, formed from weathered rocks under high temperature and rainfall with wet and dry spells. The high rainfall leached away the silica component and thereby making it rich in iron and aluminium oxides. Due to the presence of iron oxide, it varies in colour from red to brown and yellow. It becomes hard when exposed to the atmosphere and have become a popular building material utilized in these regions of the world because of its availability and economical benefit compared to other natural earth materials. In addition to its cost effectiveness, it is also considered to possess better energy efficiency when compared to conventional modern building materials in tropical countries.

Many people in Bauchi, North East Nigeria and in deed a lot of low income earners in Africa live in mud houses. A major disadvantage associated with mud houses is the ease at which they were destroyed by the perennial floods that accompanied the yearly seasonal rains. In Kano, North West Nigeria a few hours of rainfall on August 8, 2016 resulted in the collapse of 5,300 mud houses due to the floods so generated (Odogwu, 2016).
According to the report of a study of mud house failures in Bauchi, North East Nigeria (Ndububa & Mukkadas, 2016), house failures through wall collapses in buildings constructed with plain earth bricks without plastering was 100%. What this meant was that all the mud houses had at least a portion of the mud wall that collapsed. These failures occurred during the rainy seasons of June to August each year. Consequently stabilization of the lateritic soils used for the mud houses was a strong option. The Federal Government of Nigeria in 2016 announced a plan “to do away with mud houses in a not too distant future” and threw the challenge to the Nigerian Building and Road Research Institute (Guardian Editorial Board, 2016). One of the areas of research will have to be on stabilizing the local occuring laterites for better and superior performnace.

Mechanical stabilization through compaction is one way. This approach has produced better performance when machines were used. Compressed Earth Bricks (CEB) so produced have been used to construct strong and durable buildings (Ogunsusi & Kolawole, 1994).

Chemical stabilization involves the mixing of chemical material to the lateritic soil without removing the element of compaction to derive maximum performance. A paper on flexural strength of compressed stabilized earth (CSE) with cement as the stabilizing chemical agent presented a result that indicated that the minimum flexural strength was 0.25 N/mm^2 which is comparable with conventional masonry such as burnt clay brickwork (Jayasinghe & Mallawaarachichi, 2009). Other common chemical stabilizers for lateritic soils are lime and bitumen or combinations of these with cement. Pozzollanas, processed agro-waste materials like Rice Husk Ash (RHA) and bio-degradable materials like straw may also pass for chemical stabilizers. Many research efforts on these stabilizers in the past show that they improved the performance characteristics of lateritic soils. For example, lateritic soil stabilized with RHA gave an optimum unconfined compressive strength (UCS) of 0.298N/mm^2 at 8% RHA which was marginally above 0.290N/mm^2 value obtained from the plain sample (Alhassan, 2008). When cement was introduced into the mix at 4, 6 and 8%, the optimum UCS values were 0.65, 1.75 and 2.3N/mm^2 respectively (Alhassan & Mustapher, 2007). Similarly stabilizers of cement, lime and termite-hill produced results of 2.3N/mm^2, 1.57N/mm^2 and 1.44N/mm^2 at 8% (Awoyera & Akinwunmi, 2014). Also an earlier report on laterite that was stabilized with straw and wood shavings showed an improvement of the compressive strength over the plain laterite by as high as 220% with 5% straw laterite and 280% with 5% wood shavings laterite (Ndububa, 1996). All reported strengths were given after 28 days of curing. The results showed improvements in strength over the plain samples.

The need to find a better alternative to the plain mud bricks used by the locals becomes imperative due to the very high failure rate under flooding. Research efforts over the years in Bauchi has come up with certain results that assured that replacing the plain bricks with stabilized ones is the way to go because of the strength as shown by previous reports (Ndububa & Malgwi, 2016) and (Ndububa & Mukaddas, 2016).

In this paper report, the laterites in the Bauchi area were stabilized with cement, lime and bitumen at different percent ratios of 3, 5 and 7%. The cement, lime and bitumen used were readily available in the Bauchi area. The ordinary portland cement is well known to the locals as they used it in some cases as rendering materials over the mud houses when mixed with sand and water. Lime is dry Cementations product obtained by calcining a limestone containing silica and alumina to a temperature short of incipient fusion, so as to form sufficient free lime (Calcium Oxide) to permit hydration and at the same time leaving un-hydrated sufficient calcium silicates to give the dry powder. Bitumen on the other hand is composed mainly of high molecular hydrocarbons. They are usually black and used as binding materials (adhesives) and water proofing agents in civil and building constructions.

In addition to compressive strengths determination, other performance parameters were determined and evaluated. This included water absorption capacity, linear shrinkage and permeability of the bricks.

II. Materials And Methods

2.1 Preparation of Materials

Ordinary Portland Cement (OPC) was used. It exhibited all the qualities of good cement by visual means, touch and hydration. A good quality brand of lime was also used, they were ground to avoid granules. The bitumen used was heated for 35 minutes with a volatile solvent (kerosene) until it was fluid enough to be mixed with the laterite soil. The laterite was collected from locations within and around Bauchi town where local mud house developers sourced laterite. Clusters of them were broken down into simple particles for ease of mixing and to maximize surface area contacts during mixing. Soil suitability, that is, a hydrometer test was conducted to ascertain the relative proportions of sand, silt and clay for the purpose of comparing with acceptable limits for building purposes (Norton, 1986).

Three specimen were used for each test and the average determined. The water was clean and free from impurities.

2.2 Mixing

The “dry mix process” (Ndububa, 1995) was adopted. It involved thorough mixing of any of the cement and lime stabilizers with laterite in their dry states before gradually adding water while the mixing process continued to a required consistence. In the case of bitumen, it was heated to a liquid state before the mixing with laterite. The percent mix proportions used for the stabilizers were 3%, 5% and 7% of the total mix respectively. The mixing was done mechanically to avoid segregation.

2.3 Compaction and Curing

Compaction was done in accordance to British Standards (BSI, 1983). The mixed materials were introduced into 150x150x150mm cube moulds in three layers with hand trowel; each layer was compacted using the 2.4kg rammer. Three samples were prepared for each experiment from which averages were determined. The specimen were demoulded after 24 hours and cured by plastic sheeting with black polythene bag to ensure air tightness and prevent evaporation of water for the number of days of curing.

2.4 Testing

The Compressive Strength test was carried out in accordance with British Standards Specifications (BSI, 1983) with a compression machine. The cubes were crushed after 7, 14, 21, 28 and 42 days respectively. The compressive strength is the ratio of the crushing force and the cross sectional area of the sample. Also weighing of specimen was conducted before crushing to determine the densities.

The Water Absorption Capacity test was conducted by weighing 28-day samples after which they were re-weighed again after soaking in water for 24 hours. The water absorption capacity is the ratio between the difference in weight and the initial weight, expressed in percent.

The Falling Head Permeameter was used in the permeability test. The coefficient of permeability was determined from the equation:

$$K_T = 3.84 \frac{al}{At} \log_{10}(h_1/h_2) 10^{-5} m/s$$

where a = area of standpipe in mm^2

A = Area of core cutter of the cell in mm^2

t = Time taken in running the test

h_1/h_2 = Height ratio

L = Sample length

D = Diameter of the core cutter

The Linear Shrinkage test was carried out by first measuring the length of a sample after demoulding and remeasuring after 28 days of curing. The Linear Shrinkage is the ratio of the difference in length and the initial length and expressed in percent.

III. Results And Discussions

The percent soil proportions are shown in Table 1. The laterite fits within the specified fractions that is recommended for building purposes (Norton A. , 1986)

The results of the Compressive Strength, Density, Water Absorption Capacities, Linear Shrinkage and Permeability tests are presented in Tables 2 to 7. The results show that compressive strength increased with curing days and percent of stabilizers. The increase of compressive strength with age is expected as most building materials show the same trend. The densities however decreased with age indicating that the rate of mass reduction of sample materials as a result of loss of moisture is greater than the rate of volume loss as a result of shrinkage. The exception is in BSL which presented slightly higher densities (Table 4 and Figure 5). The reason for this may be due to the liquid state of bitumen at mixing stage which after then reduced in volume as the viscosity increases at higher temperatures exceeding 20^0C. At the same time, weight loss may not have been significant as moisture evaporation is hindered by the water proofing nature of bitumen.

All the results show that increase in percent stabilization improved the performance characteristics in all of the materials, i.e. higher compressive strengths, lower water absorption capacities and lower linear shrinkage. These trends are presented in Figures 1- 5.

The results show that cement is a better stabilizer of laterite over lime and bitumen with respect to compressive strength. The 28-day strength of 2.83N/mm^2 for 5% CSL exceeded the recommended strength of 2.5N/mm^2 for sandcrete blocks (NSO, 1975) and the 3% CSL strength of I.68N/mm^2 also exceeded the minimum recommended strength of 1.5N/mm^2 for building bricks (Ndububa, 1995). The compressive strength of 5% and 7% CSL were found to have met the standards for interior load bearing partition and the 3% met the standard for interior non-load bearing partition for low-cost housing (ASTM, 1974).

Apart from its higher compressive strength, the 5% CSL for example is far more affordable because its 95% laterite component is cheaper, much available and abundant when compared to the 14 – 17% cement and the 83 – 86% fine aggregate that constitute hollow sandcrete blocks. Cement and fine aggregates are relatively more expensive in Bauchi, North East Nigeria

It is observed that ZSL possessed almost as much compressive strength as BSL. This shows that BSL may not improve compressive strength but may be used as a plastering material due to its low water absorption capacity, less shrinkage to ZSL and the well-known water proofing properties of bitumen constituent. The BSL values are higher than those obtained from laterite stabilized with vegetable fibres based on earlier report (Ndububa & Malgwi, 2016). The higher strength by CSL is not unconnected with the relatively higher sand content in the laterite with which cement binds well. With longer period of curing and a higher clay content, LSL would have possibly gained higher strength because of the slower curing rate since it binds better with the smallest granular clay.

The permeability results showed that CSL was least in permeability while ZSL was most permeable. This again underscores the need to always stabilize ZSL whenever its use may result in the continuous contact with water or moisture.

Generally, the results do reinforce the need to stabilize plain lateritic soils for better performance in mud house construction.

Table 1: Percentage Proportions of Laterite Samples from the Bauchi Borrow Pit as given from Hydrometer Soil Tests.

Location of Borrow pit	**Sand Fraction (0.06-2.00mm) %**	**Silt Fraction (0.002-0.06mm) %**	**Clay Fraction (≤0.002mm) %**	**Total %**
Bauchi	61.8	16.8	22	100
Specified Fractions (Norton, 1986)	40-75	10-30	15-30	

Table 2: Compressive Strengths and Densities of CSL for Different Curing Periods and Stabilizer Percent.

Curing Period (days)	**Percent Stabilizer (%)**				**Average Cube Density (kg/mm^3)**	
	0	3	5	7	Stabilized Laterite	ZSL
7	0.53	1.01	1.62	2.19	2033	2045
14	0.64	1.27	2.20	2.59	1998	1995
28	0.81	1.68	2.83	3.48	1896	1966
42	1.27	2.21	3.27	4.03	1853	1926
Average Cube Density (kg/mm^3)	1983	1960	1951	1917		

Table 3: Compressive Strengths and Densities of LSL for Different Curing Periods and Stabilizer Percent .

Curing Period (days)	**Percent Stabilizer (%)**				**Average Cube Density (kg/mm^3)**	
	0	3	5	7	Stabilized Laterite	ZSL
7	0.53	0.35	0.46	0.56	2084	2045
14	0.64	0.47	0.67	0.73	2011	1995
28	0.81	0.84	0.94	1.02	1916	1966
42	1.27	1.10	1.16	1.30	1844	1926
Average Cube Density (kg/mm^3)	1983	1988	1980	1924		

Table 4: Compressive Strengths and Densities of BSL for Different Curing Periods and Stabilizer Percent

Curing Period (days)	**Percent Stabilizer (%)**				**Average Cube Density (kg/mm^3)**	
	0	3	5	7	Stabilized Laterite	ZSL
7	0.53	0.23	0.30	0.41	1870	2045
14	0.64	0.61	0.64	0.84	1877	1995
28	0.81	0.92	1.03	1.11	1890	1966
42	1.27	1.19	1.24	1.43	1904	1926
Ave. Cube Density (kg/mm^3)	1983	1790	188 7	1901		

Table 5: Water Absorption Capacity Values for Stabilized Laterite for 28 days Curing Period.

Type of Stabilized Laterite		**Percent Stabilizer (%)**		
	0	3	5	7
ZSL	16.41			
CSL		6.65	5.23	4.88
LSL		10.30	9.48	9.14
BSL		3.13	1.73	1.49

Table 6: Linear Shrinkage Values for Stabilized Laterite for 28 days Curing Period.

Type of Stabilized Laterite	**Percent Stabilizer (%)**			
	0	3	5	7
ZSL	3.53	-	-	-
CSL	-	1.00	0.53	0.47
LSL	-	1.67	1.33	0.80
BSL	-	3.40	2.5	1.33

Table 7: Permeability Test Results for 28 days Curing Period for 7% Stabilizer

Type of Stabilized Laterite	**Permeability (m/s)**
ZSL	1.768×10^{-7}
CSL	4.47×10^{-9}
LSL	7.30×10^{-9}

Fig. 1: Compressive Strengths of 28-day Stabilized Laterites

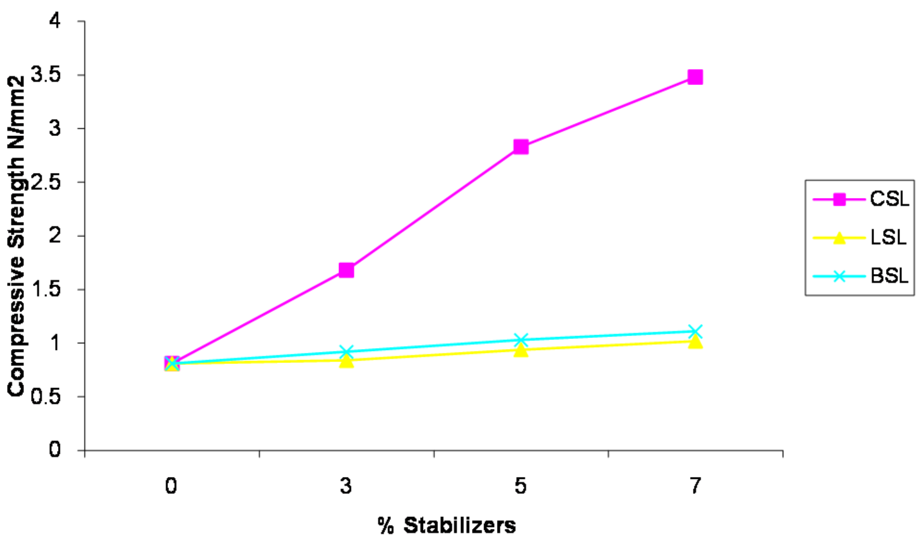
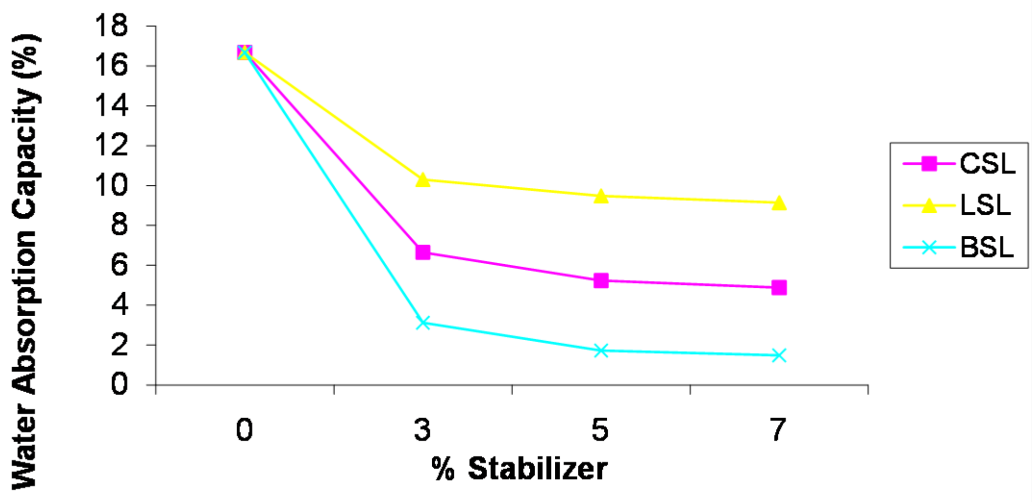
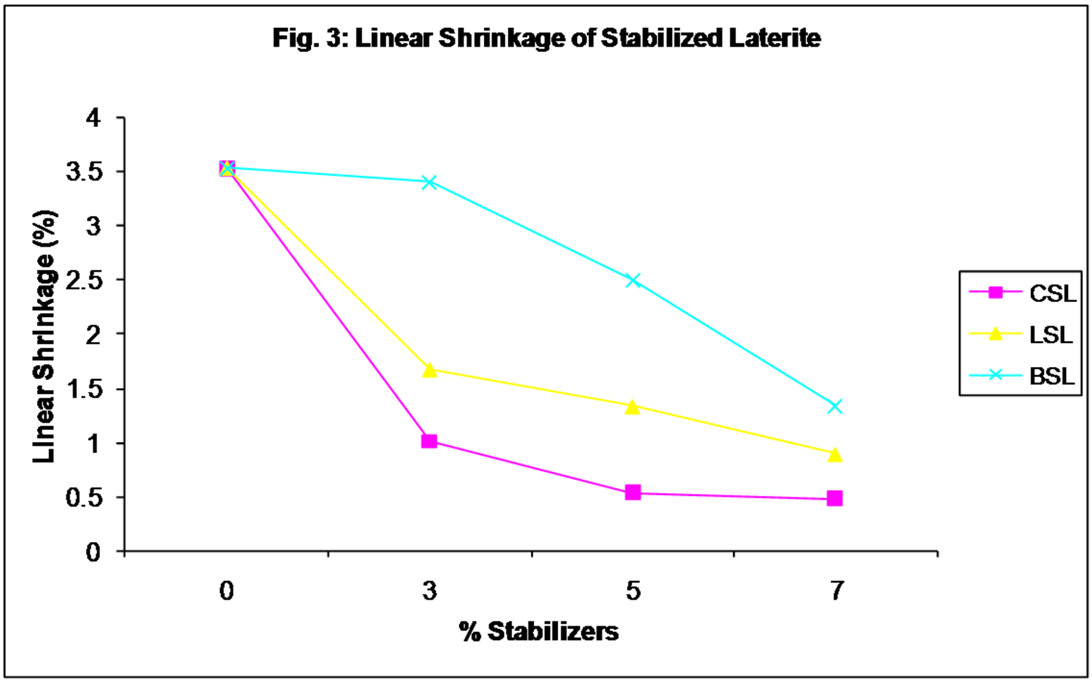
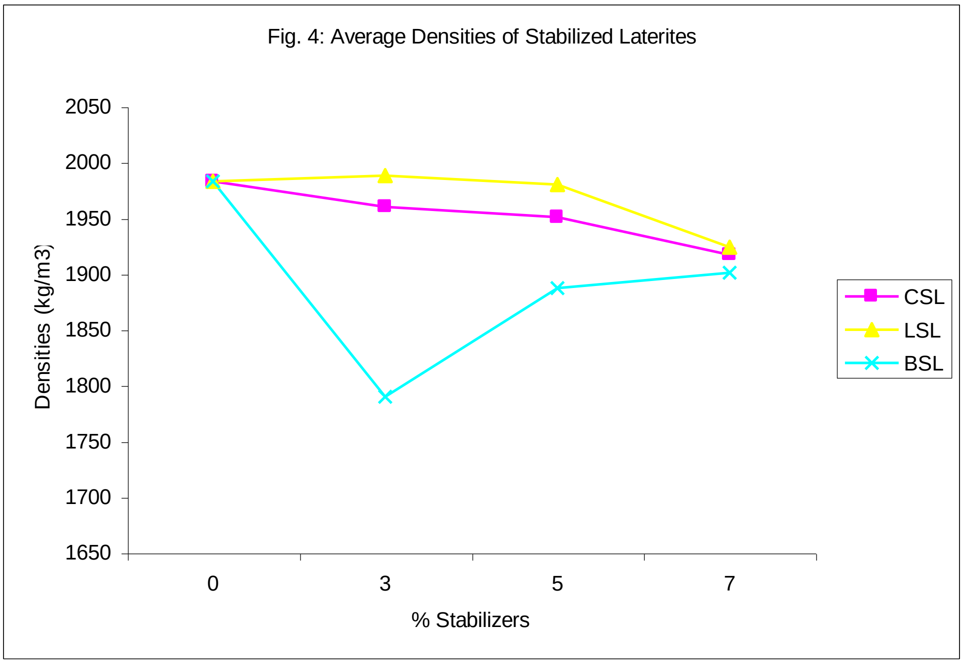


Fig. 2 :Water Absorption Capacity of Stabilized Laterite







IV. Conclusions And Recommendations

CSL and LSL at percent proportions 3% and above compares well with sandcrete blocks and possess enough strength for load bearing partition walls. This is not the same with ZSL, hence multiple wall failures with almost all plain mud houses in Bauchi, North East Nigeria.

Another advantage of the stabilized materials with respect to weight is the reduced densities. In view of its relatively low water absorption capacity, the BSL may serve better as rendering material.

The use of stabilized laterites should replace plain laterites in mud housing projects due to superior characteristic performance and economics. Also combinations of the stabilizers is suggested for further investigation to obtain optimum performance.

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