Comparative Study of Cement and Lime Stabilized Laterite for Compressed Earth Bricks

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ABSTRACT

The construction technology of compressed earth bricks (CEB) provides a modern use of laterite for walls and buildings to complement the traditional adobe method of earth construction. This research aims at comparing the geotechnical properties of cement and lime stabilized laterite for CEB with a view of establishing their suitability for residential buildings. Preliminary investigations were carried out on laterite to ensure it has good engineering properties. The bricks of the size 295 × 140 × 100mm were mould using hand operated CINVA-ram machine. They were produced using 2%, 4%, 6%, 8% and 10% replacements of laterite with cement and lime as separate mixes. A total of 80 bricks were produced and cured for 7, 14 and 28 days. 60 bricks were used for compressive strength while 20 were used for water absorption. The results of the compressive strength for cement stabilization show that there is a significant increase in all the percentage replacements and they all meet the 2.0N/mm^2 minimum requirement for manually produced blocks (NBRRI, 2006). But for lime stabilization, the minimum requirement is met from 6% replacement due to lime fixation point. Both cement and lime stabilized CEB are found adequate for building construction in terms of water absorption capacity.

Keywords: *CEB, Chemical stabilization, Geotechnical properties, Compressive strength.*

INTRODUCTION

Compressed earth bricks (CEB) are made by compaction of a suitable soil in a mould under pressure. The mould process can be carried out at a range of scales and levels of technology from simple manual process to large integrated brick production plants producing thousands of bricks in a day. The compressed earth bricks became widely used around the world in the last 30 years or more, not only in third world countries but also in developed countries like USA, Canada, France and Australia (Al-Sakkaf, 2009). The soils for CEB may be modified using the chemical form of soil stabilization.

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Chemical stabilization consists of adding other materials or chemicals to soil in order to alter its properties either by physico-chemical reaction between particles of the soil and the added materials or by creating a matrix that would bind or coat the particles of the soil (Patrick, Uphie, Elie and Arlin, 2011). The physico-chemical reaction would cause the formation of a new material made from pozzolanic reaction between clay particles and lime, for instance (Houben and Guilland, 1994). The most often used additives for this soil stabilization are cement, lime, or a cement/lime mixture (Tremblay, 1998).

Lime reacts readily with post plastic soils containing clay minerals (silica, alumina, or iron oxide). The clay could be fine grained clays or the clay gravel type. Such soil should range in Plasticity Index (PI) from 10 to 50 or more (Robert, Clifford, Aviad and Robert, 2011). Lime in its hydrated form (calcium hydroxide) will rapidly cause cation exchange, flocculation/agglomeration and cementitiuos or pozzolanic reaction provided it is intimately mixed with the soil (Robert, Clifford, Aviad and Robert, 2011 and Ramadas, Kumar and Yesuratnam, 2011). Lime must be added in excess of its fixation point for pozzolanic reaction. These reactions begin to occur within an hour after mixing and significant changes are realized within a very few days. The occurrence of these reactions depends on the plasticity of the soil, the mineralogical composition of the soil, the temperature of the surrounding air and the amount of lime used. In the pozzolanic reaction, lime chemically combines with siliceous and aluminious constituents in the soil to cement the soil particles together by forming calcium silicate hydrate (CSH), calcium aluminate hydrate (CAH) or alumino-calcium silicate hydrate (CASH).

$$\text{Lime} + SiO_2 \rightarrow \text{CSH}$$

$$\text{Lime} + Al_2O_3 \rightarrow \text{CAH}$$

$$\text{Lime} + SiO_2 + Al_2O_3 \rightarrow \text{CSH or CAH or CASH}$$

The main reaction in a soil/cement mixture comes from the hydration of two anhydrous calcium silicates; tricalcium silicate ($3CaO.SiO_2$) and dicalcium silicate ($2CaO.SiO_2$), the major constituents of cement, which form two new compounds; calcium hydroxide and CSH, which are the main binder of concrete. (Tremblay, 1998 and Billong, Mello and Ndikontar, 2008)

$$\text{Cement} + H_2O \rightarrow \text{CSH} + Ca(OH)_2$$

The mineralogical composition and the granulometry of cement treated soils have little influence on the reaction since the cement powder contains in itself everything it needs to react and form cementitious products (Patrick *et al*, 2011). Cement will create physical links between the particles of soil, thus increasing the soil strength (Tremblay, 1998 and Kerali, 2001).

EXPERIMENTATION

Lateritic soil: The Laterite sample used for the research was obtained from borrow pits in Rantya housing Low cost area of Jos, Plateau State. The soil was sundried, sieved with sieve size of 10mm and the quantities that passed the sieve size were used for the experiment. Preliminary investigations were carried out on the laterite to determine the mineralogical compositions and some of its geotechnical properties. The tests include chemical analysis, sieve analysis test to determine its granulometry which vary from very fine to gravel according to the origin. Others include specific gravity, bulk density and atterberg limits for liquid limit, plastic limit and plasticity index. The standard descriptions and classifications of the laterite were carried out according to BS 5930. The geotechnical properties of the soil is shown on table 2.

Binders (Cement and Lime): The cement used for the research was ordinary Portland cement, manufactured by Benue Cement Company Plc and bought from a vendor in Jos. It was ensured that the cement was in good condition. The lime used for the research was a commercially available hydraulic lime. It was manufactured in Leicester, United Kingdom by Charmstar Ltd and packaged in 25kg bag. It was bought from a vendor in Jos. The powdered hydraulic lime conforms to ASTM C141-97 standard specification. The specification provides the requirement of the lime to be used as pozzolanic material. The physical properties of the lime were observed and noted (table 2).

Laboratory tests

Preliminary investigations tests were the first set of tests carried out on the laterite to ascertain its properties. The tests include particle size distribution, specific gravity, moisture content, compaction tests, bulk density and atterberg limits test. The sieve analysis test which was carried out to determine the granulometry of the soil was carried out in accordance with BS 812 (1975). The atterberg limits carried out by Casagrande method was done in accordance with BS 1377 (1975) to ascertain the liquid limit, plastic limit and plasticity index of the soil (table 2).

Compressive strength

The compressive strength of the earth bricks depends on the soil type, properties and amount of stabilizer and the compaction pressure used to form the block. The test was carried out in accordance with BS EN12390:2002 by subjecting the bricks to crushing on an ELE compression machine with maximum capacity of 50KN failure load. The Budenberg model machine has serial no 12721421 with the calibration of 0.2KN/div. Two 295 x140 x 100mm bricks were produced for each curing day of every percentage replacement. A total of 60 bricks for 2%, 4%, 6%, 8% and 10% replacements of both cement and lime were subjected to crushing at 7, 14 and 28 days of curing. The crushing forces were all noted and the average compressive strengths were calculated for every 2 cubes of each specimen sample. Table 1 shows the combination scheme for the two stabilizers (cement and lime). S98C2, S96C4, S94C6, S92C8 and S90C10 represent 2%, 4%, 6%, 8% and 10% replacements of cement with laterite respectively; S98L2, S96L4, S94L6, S92L8 and S90L10 represent 2%, 4%, 6%, 8% and 10% replacements of lime with laterite respectively while S100C0L0 which has 100% laterite without any binder serves as the control mix for the other mixes. The same water-solid (laterite + binder) ratio of 0.53 was used for all the mixes. The curing was carried out by moist curing and covered with polythene material to prevent rapid loss of moisture from the specimen.

Compressive Strength = Failure Load (N) Cross-sectional Area (mm^2)

Table 1: Proportioning of the materials used

Designation	**% of Ingredients**		
	Laterite (S)	**Cement (C)**	**Lime (L)**
S98C2	98	2	-
S96C4	96	4	-
S94C6	94	6	-
S92C8	92	8	-
S90C10	90	10	-
S98L2	98	-	2
S96L4	96	-	4
S94L6	94	-	6
S92L8	92	-	8
S90L10	90	-	10
S100C0L0	100	-	-

Source: Laboratory Experimentation, 2014

Water absorption

This durability test which is a test on the porosity of the laterite mixes was carried out to determine the suitability of the mixes for building construction. The test was carried out in accordance with BS 1881 122:1983 with a total of 20 bricks (two bricks for each sample type). The test was carried out after 28 days.

% Water absorption= $(W_{2-}W_1)/W_1$

W_1= initial weight of specimen (kg)

W_2= final weight of specimen (kg)

RESULTS AND DISCUSSION

The various tests carried out under the heading is summarised on table 2. The results of the atterberg limits test shows that the laterite has the liquid limit (LL) of 37%, plastic limit (PL) of 11% and plasticity index of 26%. The plasticity index of 26% for the lateritic soil sample does not exceed the maximum value of 35% stipulated by BS 1377. Thus, this indicates a good laterite soil that is cohesive and hence able to receive proper compaction to enhance the strength and durability characteristics of the laterite. According to the American Association of State Highways and Transportation Officials (AASHTO, 1986), the soil belongs to A-2-6 subgroup meaning that the laterite has gravel, sands with elastic silt or clay fines. The soil can also be classified as low plasticity soil according to the unified soil classification system (USCS) since the L.L < 50 (L.L=37). The summary of the grading curve of the sieve analysis test carried out according to BS 812 (1975) gave D_{10} = 0.212, D_{30} = 1.18 mm and D_{60} = 3.35mm. Therefore, the coefficient of uniformity, (Cu) = $D_{60}/D_{10}/$= 3.35/0.212 = 15.8; and Coefficient of curvature (Cc) = $(D30)^2/(D_{60}\times D_{10})$ = $(1.18)^2/(3.35\times0.212)$ = 2. Therefore, the laterite is well graded since Cu > 6 and Cc is between 1 and 3. The specific gravity of 2.64 is within the range of 2.55 and 4.0 recommended by Maignien (1996).

Table 2: Physical Properties of Laterite and Lime

Basic Characteristics	Laterite	Lime
Colour	Reddish brown	White
Condition of Sample	Sundried	-
Natural Moisture Content (%)	1.71	-
Specific Gravity	2.64	3.6
Liquid Limit (%)	37	-
Plastic Limit (%)	11	-
Plasticity Index (%)	26	-
USCH Classification	LP	-
AASHTO Classification	A-2-6	-
Fineness modulus	4.93	-
Coefficient of curvature, Cc	2.0	-
Coefficient of uniformity, Cu	16	-
Bulk Density (kg/m^3)	1744	-
Fineness Modulus	4.8	-

Source: Laboratory Experimentation, 2014

Compressive strength results

The compressive strength increases with increase in the percentage replacements of both lime and cement. It also increases with increase in curing time (figures 1 to 5). There is considerable increase between the control mix and cement stabilized mixes right from 2% to 10% replacements. This was because cement has everything it needs to react and form cementitious products by creating a physical link between the particles thereby increasing the soil strength. Unlike cement, there is no significant difference between the control mix and lime stabilized mixes at 2% and 4% because lime added at these percentages would not contribute to soil strength increase but would majorly contribute to the improvement of the soil workability. Lime added in excess of the fixation point would be responsible to strength increase. This was noticed for lime replacements at 6%, 8% and 10%.

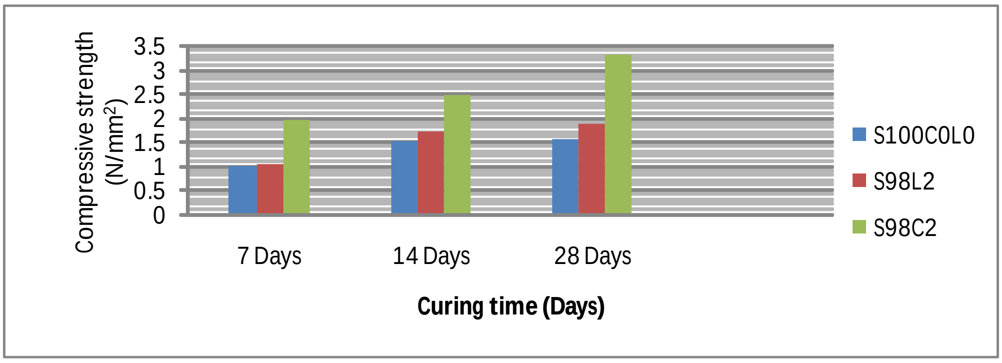

Fig. 1: Compressive strength of the control mix, 2% lime and cement stabilizations

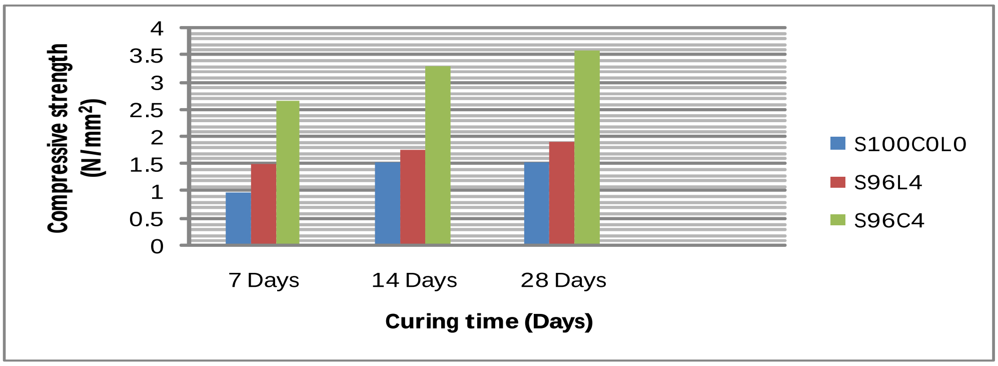

Fig. 2: Compressive strength of the control mix, 4% lime and cement stabilizations

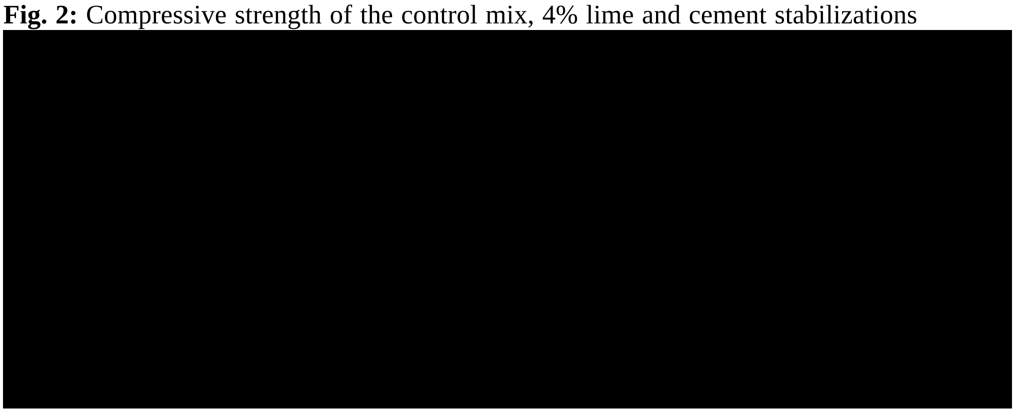

Fig. 3: Compressive strength of the control mix, 6% lime and cement stabilizations

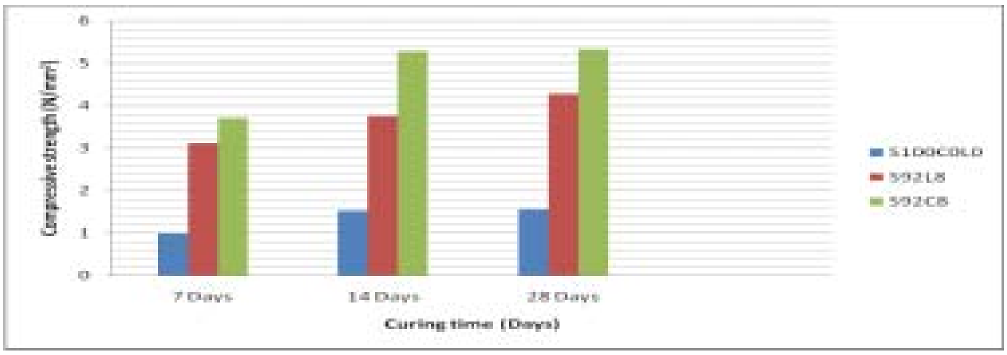

Fig. 4: Compressive strength of the control mix, 8% lime and cement stabilizations

Fig. 5: Compressive strength of the control mix, 10% lime and cement stabilizations

Water absorption

The results of the water absorption test at 28 days for stabilized CEB shown on table 3 give the values that fall within the limit of 20% by weight suggested by Rajput (2006) for building bricks. The control mix (S100C0L0) melted inside the water while carrying out the test.

Table 3: Water absorption result at 28 days

Designation	Water absorption at 28 days (%)
S98C2	5.44
S96C4	6.90
S94C6	7.75
S92C8	10.41
S90C10	11.59
S98L2	4.55
S96L4	7.89
S94L6	8.72
S92L8	9.43
S90L10	10.32
S100C0L0	

Source: Laboratory Experimentation, 2014

CONCLUSION

The results of the physical properties carried out on the laterite show that it has good engineering properties suitable for both building and civil engineering applications. The hydration reactions of cement for all the percentage replacements are faster than those of lime for the corresponding replacements, but the final products in both cases result to the formation of CSH, CAH and CASH. Cement creates physical links between the soil particles when added to the soil to improve the soil strength while lime needs silica and alumina from clay particles in the soil to develop pozzolanic reactions. There is significant increase in strength for cement stabilized mixes at all the percentage replacements but this was noticed for lime stabilized mixes from 6% replacement although the compressive strength increases with increase in percentage replacements of both binders. The results of compressive strength for the cement stabilized CEB at all the percentage replacements meet the minimum requirement of 2.0N/mm^2 for manually produced laterite blocks according to NBRRI (2006) while that of lime stabilization for CEB was noticed from 6% replacement of lime with laterite due to lime fixation point. Both the cement and lime stabilized CEB at all the percentage replacements were found adequate for building construction on the basis of water absorption capacity (durability property).

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