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EVALUATION OF THE COMPRESSIVE STRENGTH AND WATER RESISTING CAPACITIES OF LIME STABILIZED SOIL BLOCKS FOR BUILDING CLIMATE RESILIENT STRUCTURES

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ABSTRACT

The compressive strength and water resisting capacities of lime stabilised soil blocks for use in building climate resilient structures were evaluated. Good laterite material, lime of suitable chemical composition and potable water were used for mixing. Six (6) different mix proportions of soil-blocks were produced i.e., 2%, 4%, 6%, 8%, 10% and 12% lime content in laterite. The dry compressive and wet compressive strengths tests for the blocks produced were measured after the period of 1, 3, 7, 14 and 28 days. Results showed that the 2% lime has an average dry compressive strength ranging between 0.17 to 0.67 N/mm^2 and no wet compressive strength was recorded due to the dissolution of the blocks in water after first day of immersion and 4% lime has an average dry compressive strength ranging from 0.71 to 1.24N/mm^2 and wet compressive strength ranging from 0.76 to 0.49N/mm^2 from day 1 to day 3, while day 7, 14 and 28 dissolved in water. The 6% lime has an average dry compressive strength ranging between 0.58 to 1.96 N/mm^2 and wet compressive strength of 0.67 to 1.47 N/mm^2. A decrease in average dry and wet compressive strengths was observed for 8%, 10% and 12% lime contents. Therefore, the 6% lime-soil mix ratio gave the highest compressive strength of 1.96 N/mm^2 above the weakest average strength of 1.70 N/mm^2, specified by the Federal Ministry of Works and Housing, and minimum requirements of 1.75N/mm^2 by the Nigerian National Building Code. The 6% mix ratio is recommended for use in making lime stabilised soil blocks for building climate resilient structures.

Keywords: blocks, climate resilient, compressive strength, lime, soil, stabilization

INTRODUCTION

During the last 60 years, engineers, scientists, technicians and architects have been investigating various soil stabilization methods (employing mainly cement) and acceptable building products have been made on improved block - making machines (Mekonnen *et al.*, 2020). Other stabilizing materials such as lime, bitumen, cow dung and chemicals have been investigated rather less (Webb, 1992). Research has been carried out and intense research and practical development of stabilization of soils by admixture with other soils or with inorganic and organic products are in progress in Nigeria, U.S.A, Britain etc. (Ozotta and Okeke, 2015). Housing needs of developing countries like Nigeria are growing at a fast rate. To solve the problem of the housing shortages, innovation is needed not only in building technology but also in the materials used in construction (Askhedar and Modak, 1994). The increasing cost of building materials and the increase in population has put a very great stress on housing for the people. More and more people in cities, towns and villages need appropriate roofs over their heads, while prices are sky-rocketing all the time (Dave and Malhotra, 1992). For many types of construction, a binder material is required and lime is one of such material which can find use in small villages, towns and larger conurbations. The cost of production and transportation is low, lime and its products can be available locally and in nearby areas and can also be processed with the help of economic local fuels. As a result, a low - cost binder can be produced, even if it is sometimes below the generally accepted standard. Lime based products can also be used for making blocks of various shapes and sizes and this can be produced at local level and thus a nucleus of low-cost housing construction becomes available (Dave and Malhotra, 1992).

Although lime has more diverse uses than any other material and is probably one of the most highly utilized naturally occurring substances, its first image all over the world is that of a building material and has proved its worth through age-long structures that have triumphantly braved the onslaught of centuries (Dave and Malhotra, 1992). Building with lime is as old as civilization and numerous building structures give evidence of its durability. Lime in combination with pozzolanic materials was antique cement, making it possible to build structures where ordinary concrete of today would fail unless special precautions were taken (Rydeng, 1992). At this time there is no universally accepted design procedure which caters specifically for the design of lime stabilized bases.

The addition of lime to soil generally results in the production of a mixture with adequate mechanical and hydraulic properties for the specific use of that mixture, and that these properties do not change significantly with the action of weathering (Garzón *et al.*, 2016). In lime modified soils, he confirmed the major objective is to minimize its harmful properties such as excessive swelling, very high plasticity and excessive moisture contents. However, the aim of stabilising laterite in this work is to attain adequate structural strength necessary for soil blocks that will be used as walling units either in load bearing or in filled panels (Osinubi, 1998).

The stabilization of Nigerian lateritic soils with cement, bitumen and lime was considered. The results presented shows that, for Nigerian lateritic soils, bituminous stabilization should be used for only sub-base courses. It may however be used a base course on some very lightly trafficked roads, provided there is a restriction on the wheel load, lime stabilization of clays (A-7-6 soil) may be used as directed for bitumen stabilization (Sadeeq *et al.*, 2015). Ordinary Portland Cement (OPC) is capable of stabilizing all lateritic soils provided that, an adequate percentage is applied. The recommended amounts are 3% for A-2-4 and A-2-6 soils and A-7-6 soils (Aderinlewo *et al.*, 2020). Masonry studies in various parts of Nigeria revealed that the major blocks do not meet the minimum standard strength of 1.7 N/mm^2 or the required mean strength of 2.1 N/mm^2. For example, in the

Eastern part of Nigeria (Enugu and it's environ), studies revealed that none of the sandcrete blocks samples selected by random sampling from the twenty-five blocks moulding manufacturers in the city met the twenty-eight-day minimum strength of 1.7 N/mm^2 (Okolie and Akagu, 1994; Florek, 1985; Okpalla and Ihaza, 1987; Manzoor and Yousuf, 2020; Omoregie, 2012).

It was also discovered that the two base course materials commonly used in South Texas-limestone and caliche aggregate were tested extensively to examine the effect of carbonate cementation due to the addition of small percentages of hydrated lime [$Ca(OH)_2$] (Graves *et al.,* 1989). It was concluded that the limestone and caliche aggregate evaluated contain 70 to 80% quartz and 20 to 30% calcite mineral. Low levels of lime (e.g. 1-2%) provided very significant strength and modulus improvements for marginal calcereous aggregates due to calcium carbonate formation (Cao *et al.,* 2019). The calcerous aggregates he used in the study contained significant percentage of quartz minerals. The contamination of parity probably significantly reduced the effect of lime - induced carbonation and bonding with the aggregate particles (Bhuiyan *et al.,* 1995). A purer carbonate aggregate should result in a higher level of strength gain and carbonation when lime is added (Bhuiyan *et al.,* 1995).

The in-situ strengths and performance of heavily stabilized bases in Houston, Texas was evaluated using 5 to 6% lime (Stabiliser), and stressed that the bases with lower levels of stabiliser or that are less rigidly stabilised may perform better than those with higher stabiliser content (Little *et al.,* 1995; Little, 1998; Patel and Patel, 2012; Pourebrahim and Zolfegharifar, 2022).

A comparison was made between rice-hush ash with lime and cement as a stabilizer to laterite soils, in which a recommendation was made for 7% cement for base material, 5% lime for sub-base materials and 18% rice-hush ash for sub-base materials for road construction (Rahman *et al.,* 2017).

Therefore, the main aim of this work is to suggest an appropriate quantity of lime for stabilization of soils to produce of soil blocks that can be used in place of cement stabilized blocks, with highest dry compressive strength and water resisting capacities that can stand the test of time and to exhibit resilience to climate change induced phenomenon.

MATERIALS, EQUIPMENT AND METHODS

Determination of Chemical Composition of Lime

The lime was obtained in bagged powdery form, some portion of the lime was taken to soil science laboratory in the Faculty of Agriculture, Ahmadu Bello University and analysed to find its chemical compositions.

Procedure for the Analysis of Lime

A measured 0.2 g of the sample was weighed into 100ml glass beaker and 20m of Conc. HCl was added. After addition, it is then heated for five minutes in a hot plate to dissolve the content. Then it was allowed to cool down and transfer the digest into 100ml volumetric flask, then made to mark with distilled water and then Ca, Fe, Na, can then be determined from the exact from the atomic Absorption Spectrophotometer (AAS), while sulphate and aluminium can be determined calorimetrically (i.e., turbidity and Aluminium oxide methods), with spectrum of 70 or 20.

Chemical Composition of Lime

The major compositions in lime that are responsible for the important reactions in soil stabilization and in the lime-stabilized soil block production are shown in Table 1.

Table 1: Composition of Lime Used in the Soil Block Production

Compound	CaO	SiO_2	Al_2O_3	NaO	Fe_2O_3	MgO	SO_3
Percentage	74.1	12.2	3.4	3.5	4.0	2.7	0.35

Physical Properties

The physical properties adhered to in this work is stated below:

The Setting Time: Initial = 15 seconds and Final (vicant apparatus) = 25 seconds

Soundness: BS.2, Temperature 20 ^oC (24 hours), with Initial Length = 60mm and Final Length = 65mm and Excess = 5mm.

Heat of Hydration: A value measured as: Heat evolved (^oC)/Weight of lime (g) = (520)/(300) ^oC/g.

The Compressive Strength (Per Unit): Cube Size = (15 x 15 x 15) cm, Surface Area = (150 x 150) mm**,** Weight = 1230g**,** Crushed at MpKN = 100 KN and Strength = 100% 1000/22500 = 4.44 N/mm^2.

Water Retention Value: ASTM C 91 – 71, Initial Flow = 98M^3/S and Final Flow = 105M^3/S i.e., that is Flow = 98/105 x 100 = 93.33M^3/S.

Laterite

The laterite employed was dug from a borrow pit at Shika, Zaria, which is also classified as an A6 - plastic clay soil as obtained from index properties of three samples taken from different locations of the borrow pit. This is a true representation of the laterite, material found all over Nigeria as soil below the vegetable top soil. After the soil was dug and transferred to the laboratory, it was sieved through a 2.36 mm sieve and mixed with proportions of lime and water to produce the blocks. The physical properties of the lateritic soil are shown in Table 2.

Table 2: Physical Properties of Lateritic Soil

Sample Number	**MC %**	**LL %**	**PL %**	**PI %**	**GI %**	**LS %**	**MDD Kg/M^3**	**OMC**	**GS**	**% P35**	**% P200**
A	36.0	37.6	16.06	21.54	6	7.14	1877	12.0	2.43	79	70
B	33.5	35.0	31.58	3.42	6	7.14	1898	13.2	2.40	75	61
C	34.0	36.0	20.90	15.10	6	7.50	1910	12.2	2.35	78	60

Water

The source of water was from the Ahmadu Bello University dam which was pumped to the laboratory from the University's treatment plant. The water is potable and clean and satisfies the required specification for making concrete as desired in BS 3148: 1980 and it is therefore suitable for soil blocks.

Lime

The lime was purchased in a 25 kg bag from the building materials market in powdery form, from Kaduna, and some portion of the lime was taken to Soil Science Laboratory in the Faculty of Agriculture, Ahmadu Bello University, Zaria, for analysis to check its chemical compositions. The hydrated lime was kept safe in the bag to prevent contact with moisture and any other external material of deleterious effects.

Mixing

Batching by weight and hand mixing were adopted. The hand mixing was carried out on a platform which is a clean layer of concrete worked to a flat surface. The measured quantities by weight of each laterite, stabilizer (lime) is poured onto the fiat form as a heap. The dry materials were mixed together with shovels by turning the mixture in and out from side-to-side unit the heap shows an even colour. The mixture at this point is considered homogenous in lime and laterite distribution. Water (about 14% of the total weight of the mix) was added and it gives the mix the required workability.

Moulding, Demoulding and Greasing Of Mould

The manual process used for the production of the blocks consists of three moulds which are of the same dimensions as the moulds but opposite in geometry. The compressor is movable in the vertical direction so that it can either be brought down to rest directly on the mould to effect compaction or push it up to expose the moulds for filling in the soil mix. Oil-borne organic solvent was used to lubricate the sides of the moulds during the process of blocks production. This will enable the prevention of the effects of attack on the blocks by fungi, which also enhanced the blocks to be ejected from the mould easily.

Compaction Pressure

The blocks were produced by "pressing" the wet mix into a compact mass. The amount of compaction pressure applied is taken to be $5N/mm^2$ as supplied by the manufacturer. However, all the blocks produced were adequately compacted.

Strength Determination

The dry and wet compressive strength of all samples were determined in accordance with the standard procedure given in Appendix C of BS 2028, 1364:1968 and amendment No.1:1970 (18). The specimens were tested using an Avery Denison Universal Testing Machine (Fig. 1) in the laboratory.

Figure 1: Avery Denison Universal Testing Machine for Strength Determination of Soil Blocks

SAMPLES

The breakdown of the number of blocks produced (Fig. 2 and Table 3) with different proportions of mix used for conducting the dry and wet compressive strength tests for the period of 1, 3, 7, 14 and 28 days respectively is shown in Tables 4 – 9.

Figure 2: Freshly Molded Blocks

Table 3: The breakdown of the number of blocks produced with different mixed proportions used

S/No	Mix Proportion Produced	Number of Blocks
1	2% lime, 98% laterite	30
2	4% lime, 96% laterite	30
3	6% lime, 94% laterite	30
4	8% lime, 92% laterite	30
5	10% lime, 90% laterite	30
6	12% lime, 88% laterite	30
	Total	**180**

RESULTS, ANALYSIS AND DISCUSSION

Dry Compressive Strength and Wet Compressive Strength

Before any building block can be put into use, it is important to have an idea of the dry compressive strength. So also, it is necessary to confirm the wet compressive strengths for suitability of the blocks when affected by wet conditions, for example during rains, and their full development.

The compressive strength of each block in KN is divided by the gross surface area of the block in mm^2 to have the strength in N/mm for both the dry and wet compressive strengths. Six different mix proportions of soil-blocks were produced i.e., 2%, 4%, 6%, 8%, 10% and 12% lime content in laterite with the same dimensions of 225 mm x 100 mm x 75 mm. The results of tests on the soil blocks are shown in Tables 4 – 9.

The 2% lime has an average dry compressive strength ranging between 0.17 to 0.67 N/mm^2 and no wet compressive strength was recorded, due to the dissolution of the blocks in water after the first day of immersion (Table 4). The 4% lime has an average dry compressive strength ranging from 0.71 to 1.24 N/mm^2 and wet compressive strength ranging from 0.76 to 0.49 N/mm^2 from day 1 to day 3, while day 7, 14 and 28 dissolved completely in water (Table 5).

The 6% and 8% lime have an average dry compressive strength ranging between 0.58 to 1.96 N/mm^2 and wet compressive strength of 0.67 to 1.47 N/mm^2 for 6% lime, while 8% lime has an average dry compressive strength ranging between 0.53 to 1.38 N/mm^2 and wet compressive strength of between 1.11 to 0.44 N/mm^2 (Tables 6 & 7).

The 10% and 12% lime have an average dry compressive strength ranging between 0.40 to 1.00 N/mm^2 for 10% lime and 0.58 to 1.11 N/mm^2 for 12% lime. Wet Compressive strength for 10% is between 0.76 to 0.40 N/mm^2 and the wet compressive strength for 12% lime is between 1.02 to 0.62 N/mm^2 (Tables 8 & 9).

The results of the soil blocks tested with different proportions of lime for this work, showed that 6% lime mix had the highest dry compressive strength of 1.96 N/mm^2 (Table 6) which is the above the minimum weakness average strength of 1.70 N/mm^2, specified by the Federal Ministry of Works and Housing (Okolie and Akagu, 1994; Florek, 1985; Okpalla and Ihaza, 1987; Manzoor and Yousuf, 2020). Also met the minimum requirements of 1.75N/mm^2 specified by the Nigerian National Building Code (NBC, 2006). Substantial resistance to water (wet) of 1.47 N/mm^2, 1.33 N/mm^2, 1.11 N/mm^2 was also recorded in time durations of 1, 3, 7 days (Table 6). Likewise, the mix of 2% lime gives the least compressive strength of 0.17 N/mm^2 (Table 4).

From test results, the material used as stabilizer (lime) has proved to be a good stabilizing agent for the production of durable and standard soil-blocks, that can stand the test of time and climatic induced changes, since they were produced using appropriate percentage of the stabilizers during mixing operation to obtain blocks with maximum strength (Nagaraj *et al.,* 2014). It must be noted however, that lime when used as stabilizing agent develops strength over a long period of time, unlike Ordinary Portland Cement (OPC), the normal day for testing of blocks is 56 days instead of 28 days (Jauberthie *et al.,* 2010; Nagaraj *et al.,* 2014).

Lime has been known to develop strength over the first few days, and therefore, adequate time should elapse before the use of blocks for buildings, so that adequate strength of the blocks would have been attained (Udawattha and Halwatura, 2017). This is the reason why ancient building made of lime soil blocks lasted for centuries (Carran *et al.,* 2012). However, safety measure should be taken when using the soil blocks that were produced using lime as stabilizers, to correctly use the percentage of the stabilizer that will give the adequate wet compressive strength for use in wet environments (Malkanthi *et al.,* 2020).

Table 4: Dry Compressive, Wet Compressive, Water Absorption and Shrinkage for 2% Lime

Strength		Days 1	3	7	14	28	Remarks
Dry compressive strength (N/mm^2)	1	0.15	0.26	0.32	0.42	0.67	Blocks produced were neat with dimension 225 x 100 x 75
	2	0.20	0.28	0.33	0.47	0.67	
	3	0.17	0.24	0.33	0.44	0.67	
	Average	0.17	0.27	0.33	0.44	0.67	
Wet compressive strength (N/mm^2)	Nil	Nil	Nil	Nil	Nil	Nil	Blocks dissolved in water
	Nil	Nil	Nil	Nil	Nil	Nil	
	Nil	Nil	Nil	Nil	Nil	Nil	
	Average	-	-	-	-	-	

Table 5: Dry Compressive, Wet Compressive, Water Absorption and Shrinkage for 4% Lime

Strength		Days 1	3	7	14	28	Remarks
Dry compressive strength (N/mm^2)	1	0.71	0.82	0.89	1.11	1.24	Blocks produced were neat with dimension 225 x 100 x 75
	2	0.69	0.80	0.91	1.11	1.24	
	3	0.73	0.78	0.86	1.11	1.24	
	Average	0.71	0.80	0.89	1.11	1.24	
Wet compressive strength (N/mm^2)	1	0.78	0.67	0.51	Nil	Nil	The 4% lime soil block dissolved in water after 7th day of immersion
	2	0.73	0.67	0.49	Nil	Nil	
	3	0.76	0.67	0.47	Nil	Nil	
	Average	0.76	0.67	0.49	-	-	

Table 6: Dry Compressive, Wet Compressive, Water Absorption and Shrinkage for 6% Lime

Strength		Days 1	3	7	14	28	Remarks
Dry compressive strength (N/mm^2)	1	0.58	0.69	1.29	1.55	1.93	The highest value of dry compressive strength occurs at 28 days of 6% lime soil block
	2	0.58	0.68	1.29	1.55	1.98	
	3	0.58	0.69	1.29	1.55	1.96	
	Average	0.58	0.69	1.29	1.55	1.96	
Wet compressive strength (N/mm^2)	1	1.49	1.33	1.11	0.89	0.64	All blocks produced were neat and with dimension 225 x 100 x 75
	2	1.44	1.33	1.09	0.89	0.67	
	3	1.47	1.33	1.13	0.89	0.69	
	Average	1.47	1.33	1.11	0.89	0.67	

Table 7: Dry Compressive, Wet Compressive, Water Absorption and Shrinkage for 8% Lime

Strength		Days 1	3	7	14	28	Remarks
Dry compressive strength (N/mm^2)	1	0.51	0.73	1.15	1.29	1.38	All blocks were neat with dimension 225 x 100 x 75
	2	0.56	0.69	1.15	1.29	1.38	
	3	0.53	0.71	1.15	1.29	1.38	
	Average	0.53	0.71	1.15	1.29	1.38	
Wet compressive strength (N/mm^2)	1	1.07	0.93	0.82	0. 60	0.47	All blocks produced were neat and with dimension 225 x 100 x 75
	2	1.16	0.98	0.78	0.58	0.44	
	3	1.11	0.89	0.80	0.56	0.42	
	Average	1.11	0.89	0.80	0.58	0.44	

Table 8: Dry Compressive, Wet Compressive, Water Absorption and Shrinkage for 10% Lime

Strength		Days 1	3	7	14	28	Remarks
Dry compressive strength (N/mm^2)	1	0.38	0.42	0.58	0.64	1.00	All blocks were neat with dimension 225 x 100 x 75
	2	0.42	0.44	0.58	0.69	1.00	
	3	0.40	0.46	0.58	0.67	1.00	
	Average	0.40	0.44	0.58	0.67	1.00	

Wet compressive strength (N/mm²)	1	0.73	0.67	0.58	0.49	0.42	All blocks produced were neat with dimension 225 x 100 x 75
	2	0.78	0.67	0.58	0.51	0.38	
	3	0.76	0.67	0.58	0.48	0.40	
	Average	0.76	0.67	0.58	0.49	0.40	

Table 9: Dry Compressive, Wet Compressive, Water Absorption and Shrinkage for 12% Lime

		Days					
Strength		**1**	**3**	**7**	**14**	**28**	**Remarks**
Dry compressive strength (N/mm²)	1	0.58	0.64	0.80	0.89	1.11	All blocks were neat with dimension 225 x 100 x 75
	2	0.60	0.73	0.80	0.98	1.07	
	3	0.56	0.62	0.80	0.93	1.16	
	Average	0.58	0.67	0.80	0.93	1.11	
Wet compressive strength (N/mm²)	1	0.93	0.93	0.82	0.78	0.62	All blocks produced were neat with dimension 225 x 100 x 75
	2	1.07	0.93	0.82	0.76	0.62	
	3	1.07	0.93	0.87	0.73	0.62	
	Average	1.02	0.93	0.84	0.76	0.62	

CONCLUSION

In this research, the dry and wet compressive strength of lime stabilised soil blocks were evaluated using six (6) different mix proportions i.e., 2%, 4%, 6%, 8%, 10% and 12% lime content in laterite to produce soil blocks. The dry and wet compressive strengths were measured after 1, 3, 7, 14, and 28 days and found to attain the highest strength at 6% lime and 94% laterite for dry compressive strength of 1.96 N/mm^2 and wet compressive strength of 1.47N/mm^2 (i.e. water resisting capacity) after immersion in water. Therefore, the soil blocks produced at 6% lime and 94% laterite mix proportions is recommended for use as building blocks that could stand the test of time under climatic induced changes.

RECOMMENDATIONS

Soil blocks in the near future will be the most predominant blocks for building works and other construction projects despite the advert of burnt clay bricks and blocks. The call for further research on this construction material has become indispensable. In addition, there is the need for;

i. More research on the stabilizer (lime) should be carried out to determine whether other organic compounds are present which could be useful for Civil Engineering construction purposes.
ii. Standards and specifications should be formulated for lime, lime-pozzolana and composite cements, and their use should be enforced. Building codes of practice and regulations that are locally produced should also be enforced.
iii. The development of workforce and training to provide managerial and technical skills to cope with requirements of technologies adopted. Also training of skills in the use of indigenous building materials should be undertaken.
iv. The strengthening research co-operation among Building Research Institutes in Africa to facilitate the sharing of experiences in the field of building materials development and utilization.
v. The Federal, States and Local governments should encourage especially rural communities to embark on local production of lime by development of lime kiln with locally available stones and also to use indigenous building materials for constructing schools, offices, clinics, health post and bungalows, etc., to serve as climate resilient and adaptation structures as may be required.

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CONFLICT OF INTEREST

The authors declare no conflict of interest

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