Improving the Stability and Durability of Cement Stabilized Earth Blocks Using Local Additives for Quality Low-Cost Houses in Developing Countries

By

Dr. N. A. Nwankwor (nazunwankwor@yahoo.com)
Department of Technology Education,
Modibbo Adama (Federal) University, Yola
Adamawa State, Nigeria

Abstract

The earth material(mud) used for building construction naturally possesses an inherent non-toxic qualities that ensures good in-room quality houses for the occupants. However this wonderful material is also naturally weak to water penetration/erosion and low in compressive strength if unstabilized. This makes it unfit in its natural form for modern housing requirements. To overcome this inherent weakness of the earth material, traditional earth builders usually apply several measures including choice of soil types and use of natural additives to stabilize the material for housing purposes. Recent researches and design changes have resulted in high quality earth-material products which have increased the flexibility and capacity utilization of the earth material in earth building construction. These improvements have resulted in a growing acceptance of these cement stabilised earth buildings by the elite class in many countries were the cement stabilised earth blocks(CSEBs) technologies are wide spread. On the other hand this development has brought with it increases in the cost of these cement stabilised earth blocks(CSEBs). This development has therefore given rise to the need to find other locally available cheaper methods of stabilizing the earth material at minimal cost to the house owner. This research adopted a laboratory-based experiment to investigate the efficacy of the juices from two African shrubs/herbs - grewia mollis (*kelli in fufulde language*) and the shell of Kubewa fruits. These two materials are used traditionally as plasticizers to improve the water resistance capacity of the earth mortar for pottery and rendering of earth building walls. The two additives were mixed with cement at 5% proportion for the entire experiment. This investigation discovered that these two additives actually improved slightly the compressing strength of the earth material but significantly improved the water erosion resistance capacity of the earth material when combined with cement both in single and combined application.

Key Words: Earth Building, African Shrubs/Herbs, Material Improvement, Compressive strength, Erosion Resistance Capacity

Introduction

Research studies and design changes in earth building technologies have continued to add value to the qualities and capacity utilization of earth buildings in many parts of the world. The lapses in our traditional earth building design structures and inherent material weaknesses of the earth material (mud) have also continued to remain focal point in many of these research and design changes, (Gana, Nwankwor & Tika, (2019); Danso & Adu, (2019); Colley & Erdogmus, (2015); Obonyo, Exelbirt & Baskaran, (2010); Nwankwor, (2008) and Kamaladas & Jayasinghe, 2005). In 2014 McGregor et al. also conducted a study on the water absorption characteristics CSEBs in which the effects of different methods of stabilization were clearly explained showing that the study specimen generally satisfied the durability requirements of ASTM Test (1989), at 10% and 6-7% cement content except for those with very high clay content. Walker (1992) also established the same finding through the wire brush test and drying shrinkage test. Danso et al. in 2015conducted a stud on the wearing resistant and erosion only for high clay & silt contents.

One of the major technical advancements in the material quality improvement of the earth material has been mainly through material stabilization and reinforcement, design changes and process modifications and through soil ameliorations to improve the inherent weaknesses of the soil. Some of the notable weaknesses include low structural strength of the natural earth material and its weakness to water penetration and erosion resistance. Cement stabilized earth blocks (CSEBs), which is one of the major advances in material development is fast gaining acceptance in many parts of the world. Today natural(green) buildings using cement stabilized earth blocks (CSEBs) are once again becoming a status symbol among the elite class of several developed societies. This development good as it is for earth builders, is also gradually pricing cement stabilized earth block (CSEB) buildings out of the reach of the low-income earners who were the primary target of these material improvement. This development has made researches in earth building developments to look out for other methods of reducing the cement content of cement stabilized earth blocks (CSEBs) while still improving their natural qualities of strength and durability.

In Nigeria, several local additives have been used by traditional earth builders to stabilize the earth material for different advantages and to improve the material's compressive strength and erosion resistance of the products. These include common selection between soil types, use of straw, cow dung and cement. According to Porteous (2007), the durability of building walls is directly related to their water resistance ability over time. According to Medvey and Dobszay, (2020) for obvious reasons it is undeniable that durability is paramount for any material used for construction It therefore becomes important that improvements in the durability of earth buildings must take into consideration measures that should be taken or techniques that would be developed to improve the water resistance ratio of the earth walls in order to improve on its durability. Medvey and Dobszay, (2020) also agrees that durability in itself has been given many definitions so far and that concerning construction materials and building constructions in general, it is used to refer to the ability of the material or construction to maintain its functionality over time.

In this research durability in earth building construction is defined as the ability of the materials to resist water-induced erosion as it appears to be the most common reason leading to the loss of functionality of earthen walls in this part of the world. In this sense this research is an effort at improving the stability and durability of cement stabilized earth blocks (CSEBs), while at the same time keeping the cost of such buildings within the reach of the average income earner and for the massive rehabilitation of the several Internally Displaced Persons (IDPs) in Nigeria.

Two locally availably additives Grewia mollis juice – locally used as plasticizers in pottery crafts and the juice from soaked shells of kubewa fruits also used locally to improve the plasticity of earth mortar for wall rendering were used as additional stabilizers for cement stabilized earth blocks (CSEBs) in this research. These two additives are commonly available within the North-eastern region of Nigeria. The Grewia mollis also known as *grewia plagiophylla*, is commonly grouped among the tiliaceare family (Himes & Eckman, 1993) while other authors group it under malvaceac family. (Medley, 2007 and Wikipedia 2008). It is a large flowering plant used locally for medicinal and domestic purposes. The back is used to produce rope, while the juice extracted from the leaves and the bark are used for treating various common ailments. It is also used by local earthen pot makers as sealers for rendering the outer surfaces of the earthen pots impervious. The Dorawa tree, which produces the kubewa fruits, is a tall growing plant with a huge trunk found along the arid zones of Nigeria. The shells of the fruits (kubewa) are soaked in water to extract the juice which is used as plasticizers in earth mortar for earth wall rendering (Lawson, 1991). In this experiment, the researcher has taken advantage of the high viscosity level of the juice gum from grewia mollis plants and the juice from the kubewa fruits shells to improve on the water/erosion resistance and compressive strength qualities of the cement stabilized earth blocks.

1. Material Selection and Collation

The soil material for this research was collected from a nearby local earth builders' soil pit at Sangere village near the university compound (see fig. 1). The juice from the Grewia mollis plant was extracted from the plant after soaking it in a clean plastic water drum for 4-days. The juice was then extracted into a clean measuring flask.

For the kubewa fruits, the shells were also soaked for four days and the juice extracted by pressing them in-between two clean polished hard wood surfaces. These methods of extracting the juice followed the method used by the traditional users. The quantity of juices mixed with some minimal quantity of water was measured with a laboratory conical flask. The cement was purchased from a local cement vendor within the locality.

Figure 1: The Researcher collecting the earth material with one of the local earth builders

2. Specimen Production and Sample Selection

All the materials for the experiment were batched by volume. Water was added to achieve workability.

2.1 *Batching and Mixing of the Materials***:** Mixing of the materials was done manually on a clan workshop floor. The soil element which was batched first was thoroughly mixed with the cement and the juice added thereafter. Additional water was added as necessary to make the mix workable for moulding.

2.2 *Specimen Moulding and Curing:* The specimen blocks were manually moulded using a simple block moulding machine exerting an average pressure of 40N/m which was kept constant for the entire block moulding exercise. Each of the experimental and control block specimen were moulded on different days. The experimental specimen blocks were moulded from 15th – 28th March 2021, while the control specimen blocks were moulded from 3rd - 8th April 2021. The blocks were allowed to cure naturally within the workshop hall for the first 7 days and sun-dried for twenty-one days before using them for the experiment.

3. Experimental Procedure

A laboratory based experimental research method employing a value engineering (value analysis) system to compare level of quality improvements achievable with the addition of these juices to CSEBs in different mix proportions was adopted in this research. There were a total of four stabilizer-based groupings in this research. In each of these four (stabilizer combination) groups, three different mix proportions were developed within the groups, both from the experiment and control batches respectively. This mix proportions came in the following order:

i. Cement:*Kubawa fruits shells Juice*:Soil - **1:1:8; 1:1:10; 1:1:20**

ii. Cement:*Grewia mollis plant bark Juice:*:Soil - **1:1:8; 1:1:10; 1:1:20**

iii. Cement:Kubewa fruit juice: Grewia mollis juice:Soil **-** **1:1:1:8;1:1:1:10;1:1:1:20**

iv. Cement:Soil (Control Group) - - - 1:8; 1:10; 1:20

Ten Specimen blocks were produced from each of the mix proportions. A total of thirty specimen blocks were produced from each of the four different groups, based on the stabiliser combination applied. The specimen blocks measured 200mm x 150mm x 100mm. From each of these 12 stabilizer-based mix groups, 5 specimen blocks were selected through a simple drop-test for the laboratory testing. Each of these 5 specimen blocks was further cut into two equal cubes of approximately 100mm x 100mm x 150mm sizes. This gave two pairs of 5 sample blocks cubes x 3(mix proportions) x 4 (stabilizer combinations) for the two laboratory tests of compressive strength and erosion resistance respectively. A total of 15 pairs of these sample cubes were produced from each of the stabilizer-based groups for the two experiments.

4. Test Procedure

The two laboratory tests – erosion resistance and compressive strength - were conducted on each sample cube (i.e. water spray test to measure the erosion resistance ratios and compressive strength test using the cube crushing instrument as follows:

4.1 ***Compressive Strength Test:*** A normal standard medium strength cube-crushing machine was used for the test of compressive strength attained by the samples and calculations followed the standard formulae. The second set of 60 sample cubes made up of 15 sample cubes from the 3- mix proportions of the four differently stabilized earth blocks were subjected to this standard cube-crushing strength test. The cubes were sandwiched in between two smooth hardwood surfaces to avoid direct contact of the sample earth block cubes with the metallic surface of the machine, thereby avoiding unwanted surface breakdown of the samples. The crushing weight was applied at 15kgs at a time until each of the cubes crumbled/disintegrated under load. The readings were recorded accordingly.

[***Formulae for the Calculation***: Compressive Strength = $\frac{\text{Crushing Load P (N)}}{\text{Effective Surface Area (mm}^2\text{)}}$

4.2 ***Erosion Resistance Ratio****:* There have been several researches on the effect of clay & silt content of soils on the compressive strength, but limited studies have been carried out on durability. Danso et al. (2015) have also tested on wearing resistant and erosion only for high clay & silt contents. Rigassi in a study in 1985 gave a beautiful explanation of the effects of clay and silt in Compressed Stabilized Earth Blocks (CSEBs). Other major characteristics of the CSEB such as compressive strength and durability (which contribute to the stability of building walls) as some other important elements of the CSEB is the primary concern of this study as suggested by Rigassi(1985).

A Spray Test Instrument which incorporated a simple modification of the features of Danso(2017) instrument as modified by this researcher was used for the erosion resistance test. This simple modification included a rotating nozzle in place of Danso's steady spray nozzle, to create a turbulence resembling that of the natural rainfall turbulence. The sprayer head was attached to the plastic water pipe connected to a 12.5mm water hose connected to a simple hydraulic water pump, delivering between 50 - 120kPa water pressure. The instrument also retained Danso's water gauge along a plastic pipe, in-between the ends of the water hose and the spray nozzle. The water gauge was used to ensure that the instrument sprays water at a velocity of approximately 12.0m/sec giving a discharge of approximately 51droplets/sec from the nozzle holes of about 3mm in diameter. This gave approximately 2.5mm water droplets per nozzle.

One sample cube from each of the 15 pairs from the sample blocks was placed on a clean platform in the bathtub of the spray instrument in turns. One face of the specimen cubes was placed under a vertically inclined spray at 70kPa for 90minutes delivering a total of 6500 mm spray on the surface of the sample cube. This quantity of water is estimated to be an equivalent of the strongest driving rain for approximately 5 years in most parts of Nigeria. The sample was removed, dried and measured to ascertain the amount of wear. The dried sample was also weighed to check the difference in precipitation. The second face of each of the same sample cubes was subjected to a horizontal spray test for another 90 minutes in turns, dried and readings taken of the mass loss and depth of erosion accordingly. (See calculated mean values as presented in Table 1).

[***Formulae for the Calculation of the Erosion Resistance Ratio*** = $\frac{E_d}{M_b - M_c} \times 100$

(where E_d = Erosion depth; M_b = Mass of block before spray; M_c = Mass of block after the water spray and drying)].

5. Experimental Results

A summary of the Mean values calculated from the readings of the two laboratory test results are presented on Tables 1. A detailed analysis of the data on the table follows immediately thereafter. In all these experiments the proportion of the stabilizers (Cement, Grewia mollis juice and Kubewa shell juice) were kept constant with varying proportion of the soil component as indicated in column 2 of Table 1.

Table 1: Summary of the Mean Values of the Compressive Strength and Erosion Resistance Test Result of the Samples from the Differently Stabilized Earth Blocks

Material-Based Mix Groups	Mix Proportions	Mean Compressive Strength (Mpa)		Erosion Resistance Ratio (%ages)		Remarks
		Mean by Mix Proportion	Group Mean	Mean by Mix Proportion	Group Mean	
Cement-Kubewa Juice Stabilizers	*1:1:18*	5.442	5.622	11.058	10.675	Good for Normal Walls in Earth-Buildings
	1:1:15	5.640		10.738		
	1:1:12	5.784		10.230		
Cement-Grewia mollis Juice Stabilizers	*1:1:18*	5.509	5.691	9.840	9.619	Good for Normal Internal & External Walls in Earth-Buildings
	1:1:15	5.709		9.555		
	1:1:12	5.856		9.461		
Cement-Grewia-mollis & Kubewa Stabilizers Combined	*1:1:1:18*	5.715	5.904	9.003	8.598	Excellent for Normal & External Walls in Earth-Buildings
	1:1:1:15	5.923		8.601		
	1:1:1:12	6.074		78.189		
Cement only-Stabilizer [Control Group]	*1:18*	4.819	5.014	12.026	11.703	Good for Normal Earth-Buildings
	1:15	4.914		11.896		
	1:12	5.282		11.188		

The data under column 3 and 5 in this Table 1 clearly shows that there was a steady improvement in the compressive strength performance and erosion resistance ratio of the CSEBs as the percentage of the soil content is reduced both within and across the stabilizer-based groups. In column 4 of the table the Mean values of the comprehensive strength performance across the groups show a slight improve between the Cement only and Cement + Kubewa juice stabilized group at an average of 12.10%, while the Cement + Grewia-mollis juice stabilized earth blocks improved in compressive strength by approximately at 13.50 over that of Cement only stabilization. The result of the combination of the three stabilizers (Cement + Kubewa juice + Grewia-mollis juice), as indicated in column 4, row 10 at 5.904Mpa shows a clear improvement of the compressive strength performance of the blocks at approximately 17.7% over the cement only stabilized earth blocks.

Based on the data presented on the left hand-side of this Table 1, and the analysed so far, it is safe to conclude that the addition of these local stabilizers (at 5≤8%) irrespective of their combinations, contribute positively to the compressive strength improvement of Compressed

Stabilized Earth Blocks. This compressive strength improvement is a plus in the stability and durability earth buildings in Nigeria.

In the second part of this investigation, the modified Spray Test Equipment was used to test the extent to which these differently stabilized blocks improved in their erosion resistance capacity over the Cement only stabilized earth blocks. The Mean values of the erosion resistance ratios are presented under column 5 of the same Table 1. The data under this column 5 shows that there was noticeable improvement in the erosion resistance capacity of these blocks as the proportion of the soil content was reduced while the percentage of the stabilizers were kept constant. The data under column 6 of the same Table 1 displays the group Mean values of the erosion resistance ratios, in percentages across the stabilizer-type groups. Under this column 6, the data shows that the Cement + Kubewa juice stabilized blocks improved in erosion resistance capacity over the Cement only stabilized blocks by 9.63 per cent. On the other hand the Cement + Grewia mollis juice stabilized blocks improved in erosion resistance capacity by 21.65 per cent above the Cement only blocks, but weaker than a combination of the three stabilizers block by 11.88 per cent. There was a highly significant improvement in the erosion resistance capacity of the 3-in-1 stabilized earth blocks above the Cement only stabilized earth blocks by 36.11 per cent.

A summary of the information presented on the right-hand side of this Table 1 clearly illustrate that the Grewia-mollis juice produces higher erosion resistance capacity than the Kubewa fruit shell juice. The data also shows that there was a quantum improvement in erosion resistance capacity of the blocks by combining the three stabilizers (Cement + Kubewa uice + Grewia-mollis juice) in improving Compressed Stabilized Earth Block (CSEBs) for quality housing. Although there was no laboratory tests on these local additives but their traditional use as pottery sealers and wall mortar plasticizers has been given credence considering the level to which they have improved the erosion resistance capacity of these blocks individually and in combined dosages.

6. Conclusion

This study was a material improvement investigation and it is interesting to note that it has clearly demonstrated that the use of these locally available additives in improving the stability and durability of cement stabilized earth blocks without unduly increasing the overall cost of the blocks is possible. The study has also shown that combining Cement and Grewia mollis has better quality improvement potentials than that of Cement plus Kubewa fruit shells jjuice. The outcome of this study has clearly shown that the combination of these two local additives as material improvement stabilizers to Cement Stabilized Earth Blocks (CSEBs) has varying levels of material improvements between the compressive strength and erosion resistance capacity as follows: a) compressive strength at 12.0%, 13.50% and 17.75% and 6.30%, 21.67% and 36.11% in erosion resistance capacity respectively.

Based on the several findings of this study the researcher is recommending that i) either of these two cheap locally available additives can be used to improve the durability and stability of cement stabilized earth blocks, whichever is readily available with little or no extra cost; ii) a combination of these three stabilizers should be preferred especially for external and load bearing earth building walls; iii) where both additives are available but cannot be used in combination the Cement + Grewia mollis juice should be preferred; iv) it makes economic sense to combine these local additives as stabilizers to improve the material quality of cement stabilized earth blocks instead of increasing the percentage of cement (which is expensive) to attain the same level of quality improvement; v) material improvements such as this (at little or no extra cost on the building owner) should be encouraged in resettling many of the Internally Displaced Persons (IDPs) in Nigeria and other countries whose livelihood has already been devastated; vi) this type of material improvement technique will also make economic sense to normal rural dwellers where these items are wasting away in refuse dumps and at farm locations; and vii) finally there should be a further study on this stabilizer combination to ascertain the exact cost advantage of its use. This will go a long way to encourage higher acceptance/adoption of this technique in earth building material improvement.

REFERENCES

ASTM. Wetting and Drying Compacted Soil-Cement Mixtures: American Society for Testing and Materials, Philadelphia; 1989

Boldizsa´r Medvey . Gergely Dobszay, (2020). Durability of Stabilized Earthen Constructions: A Review. Geotechnical and Geological Engineering. State of the Art Review.

Bui QB, Morel JC, Venkatarama Reddy BV, Ghayad W (2009). Durability of rammed earth walls exposed for 20 years to natural weathering. Journal of Building Environment. 44:912–919. https://doi.org/10.1016/j.buildenv.2008.07.001

Danso, H. and Adu S., (2019). Characteristics of compressed earth blocks stabilized with clay pozzolana. Journal of Civil and Environmental Engineering. Vol. 9 Issue 1. 2019

Danso H, Martinson DB, Ali M, Williams JB. Physical, mechanical and durability properties of soil building blocks reinforced with natural fibres. Construction and Building Materials. vol. 101 pp. 797–809, 2015.

Ebrima Colley and Ece Erdogmus, (2015) Effects of cement stabilization and fibers on the water resistance of compressed stabilized earth blocks. ResearchGate.net retrieved from: https://www.researchgate.net/publication/301869344 on 20th August2021

Erkal A, D'Ayala D, Sequeira L (2012) Assessment of wind driven rain impact, related surface erosion and surface strength reduction of historic building materials. Journal of Building Environment 57:336–348. https://doi.org/10.1016/j.buildenv.2012.05.004

Gregor FM, Heath A, Foddo E, Shea A. Condition affecting the moisture buffering measurement performed on compressed earth blocks. Building and Environment. vol. 75, pp. 11-18, 2014.

Heathcote K. A (1995) Durability of earth wall buildings. Construction Building Materials 9(3):185–189. https://doi.org/10.1016/0950-0618(95)00035-E

Heathcote, K. (2002). An Investigation into the Erosion of Earth Walls; PhD Thesis; University of Technology: Sydney, Australia, 2002

Hines, D.A and Eckman, K. (1993). Indigenous multipurpose trees of Tanzania: uses and economic benefits for people. FAO, Rome (Italy). Forestry Department. Eng:

Jagadish KS, Reddy BVV, Rao KSN. Alternative Building Materials and Technologies New Dilhi: New Age International (P) Limited; 2007.

Medley, K. E. (2007).Enthobotanical knowledge for adaptive collaborative management of Mt .kasgau. Conducted in affiliation with East African herbarium National Museum of Kenya, Grantee Name: Department of Geography, Miami University

Nishantha Kamaladas and Chintha Jayasinghe, (2005). Development of an efficient construction technique for rammed earth. Annual Transactions of Institution of Engineers, Sri Lanka

Obonyo, Esther, Exelbirt, Joseph and Baskaran, Malarvizhi. (2010). Durability of compressed earth bricks: assessing erosion resistance using the modified spray testing. Journal of Sustainability, November 2010. www.mdpi.com/journal/sustainability

Obonyo et al (2010) *Effects of cement stabilization and fibers on the water resistance of compressed stabilized earth blocks*. Available from: https://www.researchgate.net/publication/301869344 [Accessed Aug 31 2021].

Ogunye F (2019) Rain resistance of stabilised soil blocks. Construction and Building Materials. https://doi.org/10.1016/S0950-0618(02)00004-1

Ogunye F. O, Boussabaine H (2002) Development of a rainfall test rig as an aid in soil block weathering assessment. Construction and Building Materials. 16:173–180. https://doi.org/10.1016/S0950-0618(02)00010-7

Ola S. A. and Mbata A (1990) Durability of soil-cement for building purposes: rain erosion resistance test. Construction and Building Materials.***Volume 4, Issue 4*, December 1990, Pages 182-18. https://doi.org/10.1016/0950-0618(90)90038-**

Perera A, Jayasinghe C. Strength Characteristics and Structural Design Methods for Compressed Earth Block Walls. Masonry International. 2003; Vol 16, pp 34-38: p. 34

Porteous W. A.(2007). Classifying building failure by cause: New approach to identifying the causes of building failure avoiding involvement with issues of blame. Journal of Building Research & Information Volume 20, 1992 - Issue 6, pp350-356, Published online May, 2007.

Rigassi Vincent (1985). COMPRESSED EARTH BLOCKS: MANUAL OF PRODUCTION by Volume I. Manual of production A Publication of the Deutsches Zentrum für Entwicklungstechnologien - GATE in: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH in coordination with BASIN - 1985.

Walker PJ. Strength, Durability and Shrinkage Characteristics of Cement Stabilised Soil Blocks. Cement & Concrete Composites (17). pp. 301-310, 1995

Walker P, Standards Association of Australia (2002) The Australian earth building handbook. Standards of Australia International, Sydney

Walker PJ (2004) Strength and erosion characteristics of Earth blocks and Earth block masonry. J Mater Civil Eng16:497–506. https://doi.org/10.1061/(ASCE)0899-561(2004)16:5(497)

Wikipedia (2021). Grewia mollis in Wikipedia. The free internet encyclopedia. Retrieved from www.wikipedia/encyclopedia.org on 15, July,2021.