SSRG International Journal of Civil Engineering
ISSN: 2348 – 8352 /doi:10.14445/23488352/IJCE-V7I3P104
Volume 7 Issue 3, 13-23, March 2020

Critical Review of Structural Characteristics of Stabilised Earth Blocks

Edighoman I. Ewa[1], Barisua E. Ngekpe[2], & Kemejika I. Amadi- Oparaile[3]

[1,2,3] *Rivers State University , Port Harcourt ,Nigeria.*

Received Date: 03 March 2020
Revised Date: 02 April 2020
Accepted Date: 04 April 2020

Abstract

This study investigates the physical, strength, and durability properties of stabilized earth blocks. The literature generally reported that stabilized earth blocks have lower strength and durability properties than conventional mortar blocks. Based on these, several mitigations or improvement measures have been recommended. Notably, the use of both natural and synthetic and Portland cement have been proven to be the most viable. A holistic review has been carried out on the physical, chemical, mechanical, and durability properties of stabilized earth blocks. Results showed that stabilization of earth blocks resulted in improved strength, volume stability, microstructure, and durability. These enhanced properties have made it suitable for use as a replacement for conventional cement-sand blocks. It was also reported that earth blocks had attained a compressive strength that is two or three times greater than the 4.3 mpa compressive strength of vibrated cement sand blocks. Based on these, it was recommended for structural applications.

Keywords: *Earth blocks, stabilization, compressive strength, cement, durability*

I. INTRODUCTION

From the beginning of civilization, earth materials have been the most common and widely used construction materials. In both southern and northern Nigeria, the early forms of earth walls used only earth mixed with water and formed into walls. Temperature variations of day and night and seasonal changes of the harmattan and rainy season caused the walls to deteriorate rapidly, requiring constant maintenance. In the north, straw was added to the wall to strengthen the walls. In the south, sticks were fixed to the ground vertically at intervals then held together with raffia horizontally before compacting the earth around this core to form the wall. Earth walls have been classified as Adobe, Cob, Rammed Earth (RE), Compressed Earth Blocks (CEB), Mud and Wattle, and Daub. However, Egenti(2014) proposed a concept called the Shelled Compressed Earth Blocks (SCEB), a CEB with little or no stabilization in the block's core while stabilizing the block's exterior as an agent.

The soil composition and characteristics vary from place to place. The soil's particle distribution also varies with location and depth(Gelard et al., 2007). According to the Unified soil classification system (USCS), the earth comprises organic or humus, silt, sand, gravel, and clay. The soil may combine in different percentages according to the location. The organic layer is always removed for the compressed earth blocks before obtaining the earth block's soil.

Most researchers use the term Rammed Earth (RE) or Rammed Earth walls for the walls formed by ramming moist earth in layers using steel or wooden formwork in the building then removing the formwork when still wet. Simultaneously, the term Compressed Earth Blocks (CEB) refers to blocks formed in molds, compressed by a manual or mechanical device, and fixed in the building when dry. Compressed stabilized Earth Blocks (CSEB) refers to compressed earth blocks stabilized by any form of binding agent like ordinary Portland cement, lime, or a geopolymer.

There are many environmental benefits offered by earth walls due to lower energy levels, high thermal mass, and availability (Deboucha and Hashim, 2011). Besides the environmental advantages, earth blocks are recyclable, require less energy intensity in manufacturing, and are very inexpensive. This made earth blocks very economical in construction (Hall and Allison, 2009; Melia et al., 2014). Their production is cheap due to high availability and less technicality; they are fireproof, have good sound insulation properties, and good thermal insulation. These advantages of earth blocks necessitated many across the globe to provide shelter for themselves with earth materials. Earth materials were applied for several uses in the construction of structures for various applications.

However, earth wall construction requires more frequent maintenance, and the surface finish of earth buildings do not have beautiful textures. Earth wall structures are often maintained as they are less durable (Blondet and Aguilar, 2007). Though having good geotechnical properties, raw earth used for construction lacks engineering properties needed for durable and highly effective structures. These problems led to the stabilization of earthen materials. Stabilization is a process of mixing admixtures with soil to improve its volume stability, strength, permeability, and durability (Hejazi et al., 2012; Bell, 1993).

Materials such as earthen plasters, stuccoes, tree resins, natural bitumen, Arabic gum, agave juice, opuntia, cactus juice, cowpats, and casein from milk have been in use for stabilization for along all over the world. These are natural fibers and materials obtained from plants, animals, and the earth part. Synthetic materials like PVC, polyvinyl acetate, acrylics, and sodium silicate have been employed in stabilization. In bulk stabilization, asphalt emulsions, hydrated lime, calcined gypsum (plaster of Paris), Portland cement, or supplementary cementitious materials like silica fume, fly ash and ground granulated blast furnace slag are used. These materials provide better bonding strength for the earthen materials. Their fineness also provides good microstructures for the stabilized blocks (Houben and Guillard, 1994; Cristelo et al., 2012). Currently, the two most common stabilizers for earthen materials are cement and lime. However, these two stabilizers have high carbon contents and account for extreme environmental pollution from construction materials. This has become a major global challenge that has drawn the attention of key players in the construction industry to the problems associated with using these stabilizers in the stabilization of earthen materials. Attempts have been made about reducing the effect of these pollutants on the environment by using alternatives. This led to the introduction of green stabilizers, which are used as partial substitutes or admixtures to stabilize earth materials. Lime has been a very good stabilizer for clay due to its drying ability of clay by reducing its moisture content, modifying clay by reducing its plasticity, aid clay compaction, and increasing early strength. Cement, on the other hand, is good for stabilizing sand (Udawatha and Halwatura, 2016).

This study provides a critical review of earth blocks and evaluates mitigation measures adopted so far. This aim is achieved through the following objectives;

- Evaluating the physical, chemical, and microstructural properties of stabilized earth blocks
- Examine the mechanical durability properties of stabilized earth blocks
- Provide useful recommendations on the most appropriate measure.

II. RELATED WORKS

This section presents a critical review of available literature on key structural characteristics of stabilized earth blocks. It reports the works carried out by researchers, including the aim, methods, results, and studies' observations. However, the reviewed properties will be grouped under physical, chemical, mechanical, and durability characteristics.

A. Physical and Chemical Properties of Cement-Stabilised Earth Blocks

Physical properties involve all concrete properties that can be observed and measured without a change in the concrete's compositions. An appropriate measuring instrument measures these properties. They include soil type, particle size, pore sizes, thermal conductivity, optimum moisture content, temperature, density, weight, etc. However, the chemical properties include all properties that are related to the chemical composition of the earth blocks constituent materials.

a) Dry density**:** Many studies have found that the dry density of earth wall materials to be around 1700 – 2200kg/m^3(Jayasinghe 2007, Maniatidis 2003, Van Damme 2017). The dry density depends on the soil type and moisture content and has a lot to do with the compressive strength of the earth wall

b) Soil type/particle size distribution: Laterite is very good for earth walls due to its particle size distribution. Kariyasam et al. (2016) investigated three types of laterite, namely, sandy laterite, clayey laterite, and gravelly laterite with cement stabilizers between 6% - 10% in a 240mm cement stabilized rammed earth wall. The result showed that sandy laterite had an average compressive strength of 2.47N/mm2 = 3.7N/mm2 against clayey laterite with 1.66N/mm2 – 2.3N/mm2 and gravelly laterite soil 2.03 – 2.8N/mm2.

AADAJ and Jayasinghe (2003) investigated cement stabilized earth block strength and found that soil particle distribution plays a role in strength build-up. It was observed that the fine particles from clay and silt (0.06mm) when below 30% produced good results but resulted in a drastic drop in strength when increased above 40%. Other researchers also proposed a range for lower and upper limits as shown

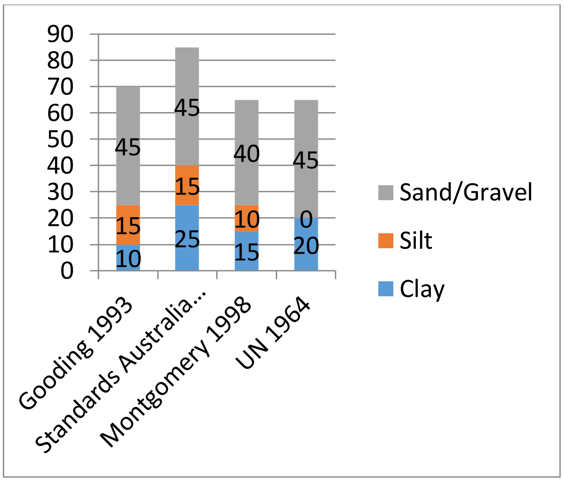

Fig 1. Lower range limit for particle size distribution for stabilization (Vasilios Maniatidis & Peter Walker, 2003)

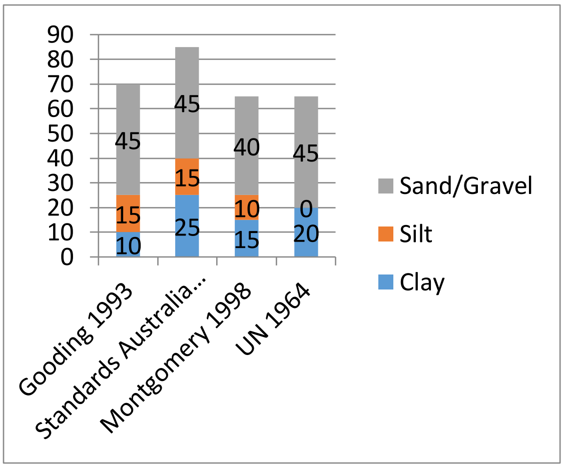

Fig. 2:Upper range limit for particle size distribution for stabilization (Vasilios Maniatidis & Peter Walker, 2003)

c) Pore size: Wang et al. (2018) carried out an experimental investigation into the effects of coal-bearing metakaolin on the mechanisms of a cemented silty soil. X-ray diffraction, mercury intrusion porosimetry, and scanning electron microscopy were the methodologies employed to study the concrete produced mechanism. The LabX XRD – 6000 was used in the x-ray diffraction test. The mercury intrusion porosimetry test was carried out using an Auto Pore IV9500 with a maximum mercury injection of 228MPa. The result obtained revealed that the pore structure was improved, and finer pores were developed. The coal-bearing metakaolin occupied microstructural pores of the concrete leading to denser concrete, which had fewer microstructural pores, leading to a denser concrete production. However, the interfacial bonding was compromised due to less hydration product produced due to the dilution effect. This left widely distributed connecting pores on the surface of the concrete produced.

Sore et al. (2018) investigated the feasibility of applying geopolymer binders that have a less polluting effect than Portland cement on stabilizing compressed earth blocks. The study evaluated the stabilized earth blocks' performance and compared them with those of the Portland cement-stabilized earth blocks. Materials obtained for the study were obtained locally from Burkina Faso. Compressed Earth Blocks (CEBs) stabilized with geopolymers (made from mixtures of metakaolin and sodium hydroxide solution) at varying proportions of 5, 10, 15, and 20% were manufactured. Also, Compressed Earth Blocks (CEBs) with 8% Portland cement and CEBs without stabilizers were prepared. Specimens with geopolymers and without stabilizers were cured for 14 days, while the Portland cement-stabilized CEBs were cured for 21 days. After that, the test was carried out to examine the specimen's physical, chemical, and thermal properties.15% inclusion of geopolymer for the stabilization of CEBs indicated good cohesion of CEBs particles compared to CEBs stabilized by Portland cement. CEBs particles without stabilizer showed poor cohesion. Values of thermal properties of geopolymer-stabilized CEBs. The geopolymer was also observed to emit lower CO2 than Portland cement, making it environmentally viable than Portland cement. This becomes one of the significant advantages for its consideration in the study to investigate its effects on the physicochemical and thermal properties of compressed earth blocks.

***d) Thermal Conductivity*:** Van Damme and Houben (2017)reported that the thermal conductivity for stabilized earth blocks to be between 0.4 – 1.80w/mk.

e) Equilibrium Moisture content: The determination of an equilibrium moisture content of earth block materials as an important characteristic variable in physical simulation led to the making of earth bricks from cohesive soil, cement, and gypsum two natural (wheat and barley straw). The fibers and materials were treated at varying temperatures (10-40^{0}C) and relative humidity (33-95%). Under dynamic equilibrium with environmental conditions, the moisture content was considered. Also, the effects of temperature and relative humidity were investigated. Experimental results showed that the Equilibrium Moisture Content (EMC) increased with increased relative humidity and decreased temperature. CEBs reinforced with barley straws showed higher EMC values than those reinforced with wheat straws. It was also noted that the relative humidity had more effect on moisture content than temperature. The EMC was observed to increase with increased straw content from 1 to 3% for the different mixes. However, the EMC decreased with an increase in gypsum and cement content. Hence, the fibers had greater effects on EMC value than cement and gypsum (Ashour et al., 2015).

Sore et al. (2018) investigated geopolymer as a binder and established the optimum water content of various dry mixes using the proctor compactor test.

Table 1: Optimum Water Content

Material	Optimum water content
Laterite only	16.7%
Laterite + 8% Cement	17.7%
Laterite + 10% Metakaoline	18.5%
Laterite + 15% Matakaoline	21.5%
Laterite + 20% Metakaoline	22.3%

Sitton et al. (2018) concluded that the optimal mix contained 10.91% cement and 11.4% water with an average compressed strength of 15.15 MPa against the ASTM C90 minimum standard 13.79MPa.

f) Chemical Properties: Kaze et al. (2018) investigated the effect of silicate modulus on the setting and microstructure of iron-rich laterite base-geopolymers cured at room temperature. In the study, three sodium silicate solutions with moduli of SiO_2/Na_2O equal to 0.75, 0.92, and 1.04, H_20/Na_2O of9.78, 10.45 12.04 obtained through the addition of 8, 10, and 12M sodium hydroxide solution and sodium silicate were used as activating alkaline solution. The initial and final setting times were measured on the fresh geopolymer paste using Vicat needle apparatus following EN 196 – 3 standard. The dry density was calculated according to EN 12390 – 7. Samples were dried in an oven at 105 degrees Celsius for several days until stabilization of mass. Also, infrared spectroscopy was carried out using an Avatar 330 Thermo Nicolet to analyze surface and bulk areas.

From the result, the initial and final setting times were decreased by the incorporation of silicate modulus. This was due to the increase in the pH of the alkaline solution by the Na_2O concentration. Scan electron microscope test showed that more cohesion and connectivity were found between particles containing activators with lower modulus compared to particles of samples with a higher modulus. Higher alkalinity enhances more dissolution of iron, silica, and alumina during geopolymer reaction. Hence, the absorptivity was improved by higher alkalinity. Similarly, the density of the samples was observed to increase by the addition of silicate modulus.

B. Mechanical Properties

The mechanical characteristics of non-stabilized earth blocks are determined to be dependent on cohesion and friction. The cohesion is generated from inter-particle forces such as van der Waals, capillary, and ionic correlation (Gelard et al., 2007). The strength of non-stabilized earth depends primarily on clay content, nature, and hydration state. However, these blocks' strength does not meet modern demand; hence, the development of stabilization technologies, which include cement to enhance the strengths of earthen concrete (Van Damme et al., 2010).

To improve the mechanical properties, stabilizers are introduced into CEB mixtures infraction. Under this section, a detailed report on how earthen blocks' mechanical properties are affected by different stabilization methods studied by various researchers are highlighted.

a) Compaction: Gonzalez-Lopez et al. (2018) investigated the effect of compaction on stabilized earth blocks' strength. A mixed design with an optimum granulometry of clay with and without stabilizers was prepared, and mechanical tests were carried out in their study. The compressive strength of samples (compressed earth blocks and compressed earth stabilized blocks) was tested for two ways; normal to loading and parallel to the direction of loading, respectively. Before the samples were tested, they were immersed in water for 24 hours, removed, superficially dried, weighed, and placed between 2.5-cm-thick steel plates and tested. More than 200% increment in the compressive strength was observed when the mesh distribution of materials was changed at the same stabilizers. An increment also increased the compressive strength in the compaction force. The samples with ordinary Portland cement stabilizers were observed to have more effective compressive stress. More than 2MPa strength was achieved for samples of all conditions. With 10% of binder and compaction force of 0.98 and 1.96 kN, values of compressive strength more than 6MPa were reached.

Also, at a low amount of stabilizer, the anisotropic tendency of compressive stress increased on increased compaction force whereas, at a high level of stabilizer additions, less anisotropic compressive stress were affected. However, it was found that the direction of compaction did not affect the stability of the blocks.

b) Cement Stabilization: Sofi et al. (2018) researched cement stabilized earth blocks with varying cement mixes from 3% to 18%. The earth consisted of 2% sand, 83% silt, and 15% clay dry weight. Stabilization was done with ordinary Portland cement at 3%, 6%, 9%, 12%, and 18%, and optimum moisture content was obtained for each of the proportions. The result showed that the wet crushing strength peaked at 2.69 MPa at 15% cement content while the dry crushing strength peaked at 4.17MPa at 12% cement content after 28days.

Sitton et al. (2018) also researched compressed earth blocks stabilized with ordinary Portland cement using 14 different mix designs and cured between 7 and 28days. A piece of BP714 equipment was used for the compaction, applying a pressure of 15.5MPa. Results for the unsaturated mix showed strength o 4.92 to 15.72 MPa after 28 days. They concluded that the optimal mix contained 10.91% cement and 11.4% water with an average compressed strength of 15.15 MPa against the ASTM C90 minimum standard of 13.79MPa.

***c) Cement –lime stabilization*:** Guattala et al. (2002) studied the use of lime as a stabilizing agent in earth blocks by preparing a mix of 5%, 8%, and 12% lime. The result showed a dry compressive strength of 9.4MPa, 14.2MPa, 16.2 MPa for 5%, 8%, and 12%, respectively, while the wet compressive strength was 4.4MPa, 8.2MPa, and 9.8MPa for the same mix.

Miqueleiz et al. (2012) did a comparative study of cement and lime using 65mm diameter x 30mm high cylinders using 18% cement and 18% lime, respectively. The CSEB had a dry compressive strength of 18MPa for the 18% cement stabilized, while the 18% lime stabilized had a strength of nearly 13MPa after 90 days of curing. They, however, did not investigate the effect of combining cement and lime.

Raheem et al (2010)alsodid a comparative study of the use of cement and lime at 5%, 10%,15%,20% and 25% in interlocking compressed earth blocks using laterite soil from Olomi, Ogbomosho. The dry compressive strength of cement stabilised after 28 days were 1.63N/mm2, 2.60N/mm2, 2.78N/mm2, 2.82N/mm2 and 3.12N/mm2 while the lime stabilised CSEB were 0.92N/mm2, 1.25N/mm2, 1.15N/mm2, 1.05N/mm2 and 0.94N/mm2 corresponding to 5%, 15%,20% and 25% respectively.

The combined effect of mineralogy and grain size on the technical-economic optimum in the stabilization of earth material was studied by Ammari et al. (2017). Chemical-mineralogical analysis and uniaxial compression tests were carried out on cylindrical specimens of compressed blocks and adobe bricks with three types of earth materials with three cement contents. Results showed that the compressive strength of compressed earth block increases with an increase in cement rate, particularly with lime, which stabilizes the clay constituents. A mathematical model was established to show the relationship between compressive strength and cement rate. The model also allows the determination of the technical-economic optimum of stabilisation which corresponds to the optimum cement rate for specific earth material. The granular fraction in interaction with the mineralogical composition of earth material greatly influenced the cement's technical-economic optimum. The cement's optimum increased with quantities of sands and gravels and its mineralogy with calcite as the binder.

d) GeoPolymers: Udawattha et al. (2018) investigated earth blocks' performance stabilized by natural polymers as an alternative to cement. Seven natural polymers were obtained from Sri Lankan vernacular polymer technologies and mixed with soil at 5, 10, 15, and 20% by dry weight. A compressive strength test was carried out on the samples. The natural polymers (Pines resin, Dawul Kurudu, and Sugarcane bagarse) out of the seven selected polymers were suitable for stabilizing the soil. The soil's strength was improved when these polymers were used with different soil particles, especially at small particle sizes.

The effects of coal-bearing metakaolin on cemented silty soil's unconfined compressive strength were experimentally investigated by Wang et al. (2018). A WDW – 100 microcomputers controlled electronic universal testing machine with 100kN capacity was used to test for the concrete's unconfined compressive strength. From the study, it was observed that the unconfined compressive strength of the silty soil was improved by the incorporation of coal-bearing metakaolin. Under 7 days of curing, coal-bearing metakaolin on the concrete's unconfined compressive strength was not felt effectively; however, from 7 days curing, coal-bearing metakaolin was incorporated effectively influenced the unconfined compressive strength of the concrete. Between 7 and 14 days, the influence of coal-bearing metakaolin on the unconfined compressive strength was due to a combination of the filling effect, the acceleration effect, and the dilution effect. At 28 and 90 days, cemented silty soil's unconfined compressive strength was improved significantly by adding coal-bearing metakaolin. Compared with the control sample (sample with ordinary Portland cement only), the unconfined compressive strength of the concrete was observed to increase by 1.22 - 1.83 times for 28 days curing and 1.27 – 1.73 times for 90 days curing.

Okafor and Ewa (2012) experimented with cement kiln dust (CKD) as a stabilizer on Obudu Earth Blocks. The soil classification was A-7-6(0) or CH, and the Cement Kiln Dust was 20% dry weight. The water content was varied at 12%, 16%, and 20% of earth and CKD dry mix. The study reveals that the compressive strength after 28 days was 3.75N/mm2 at 12% moisture content, 6N/mm2 at 16% moisture content, and 9N/mm2 at 20% moisture content. The strength achieved is higher than the 4.3N/mm2 of vibrated sandcrete blocks.

e) Polypropylene Fibres: Donkor and Obonyo (2015) investigated polypropylene fibers' effect on the strength, ductility, and deformability of compressed earth blocks. The block matrices were produced using different fiber weight fractions. These blocks were tested both under compression and bending. Gilson concrete compression machine with a maximum load capacity of 224KN was used to test for compressive strength under uniaxial compression. Instron Universal testing machine with a maximum load capacity of 150KN was used in running the 3-points bending test.

The result showed that the compressed earth blocks' ductility and deformability were improved by incorporating the fibers. Increment of fiber content to 0.6% by weight, the compressed earth block's strength was improved. Also, there were 22.5% and 22% improvements in compressive strength and 3-point bending strength, respectively, by incorporating 0.4% fiber content. However, it was observed that beyond 0.6% inclusion of fiber, strength began to decline due to difficulty mixing.

Sore et al. (2018) investigated the feasibility of applying geopolymer binders with less CO_2 emission than Portland cement on the stabilization of compressed earth blocks. The stabilized earth blocks' mechanical properties with the geopolymer binders were evaluated compared with those stabilized Portland types of cement. Results showed a significant increase in strengths for Compressed Earth Blocks stabilized with geopolymer binders and heated to about 60^0C.

f) Silicate modulus: Kaze et al. (2018) investigated the effect of silicate modulus on the strength of iron-rich laterite base-geopolymer cured at room temperature. Dry compressive test carried out on samples after 7 and 28 days using Instron 1195 compression machine with a displacement of 5mm/min according to ASTM C 39. The compressive strengths were recorded between 4-10 and 10-18MPa for 7 days and 28 days. It was observed that activators with the highest sodium content and lowest silicate modulus had the highest compressive strength. The optimum compressive strength (18MPa) obtained from laterite and geopolymer with silicate solution of modulus equals 0.75.

The researchers recommended that the laterites developed should be used for construction since they showed acceptable properties. However, they recommended further studies into optimum designs that will yield higher compressive strength of laterite based geopolymer mortar and concrete.

Lemougna et al. (2017), in their study, developed inorganic polymers from laterite, intending to use it for at least non-load bearing building. This they did by investigating the effect of slag and calcium carbonate addition on the development of the geopolymer. In the study, calcite (calcium carbonate) and Ground Granulated Blast Furnace Slag (GGBS) were used as partial replacement of laterite at 2 to 20% and 5 to 50% in mass, respectively. With alkalinity of 1.6 to 2.2, sodium silicate solutions were applied to produce inorganic polymers from laterite calcined at 700^0C.

A compressive test was performed on samples using a DNS100 Universal testing machine with a displacement rate of 0.5mm/min. This test was performed on samples cured for 28 days. The samples were immersed in deionized water for 48 hours before testing for the wet compressive strength test.

X-ray test on laterite showed it contained kaolinite, hematite, and quartz. Mechanical test on the samples showed that on increasing modulus of activating solution (Sodium silicate), the compressive strength increased. The optimum strength was obtained at a modulus of 1.8.

Dry and wet 28 days cured laterite with an activator of modulus 1.6 yielded 36 and 30 MPa respectively when tested. Substitution of laterite by calcite up to 20% did not significantly affect the compressive strength of the sample. However, at different proportions of replacement of laterite with slag, better strength performance was recorded. Optimum strength of 65MPa was observed at 50% replacement of laterite with slag. This was due to the compartment of particles, which reduced microstructural pores in the material.

C. Durability Properties

Gonzalez-Lopez et al. (2018) investigated the durability effects of compaction on stabilized earth blocks. Samples were prepared with an optimum granulometry of clay with and without stabilizers. The water absorption of the blocks was dependent on the amount and type of stabilizer applied. The study observed that the samples stabilized with lime absorbed a similar amount of water under different compacting forces. The absorption coefficient was observed to increase as the content of ordinary Portland cement, and compaction force increased. However, that of the specimen stabilized with lime was related to their surface area.

The durability of compressed stabilized earth blocks stabilized with cement and lime was evaluated by Nagaraj et al. (2014). The lime was used as a substitute for cement infraction. The water absorption test was done on concrete using the Bureau of Indian Standards (IS: 1725, 1982); the blocks were dried completely in the oven, and their mass was recorded accurately. The blocks were later immersed in water for 48 hours. Later, the blocks were weighed again, and an increase in mass was noted to determine the water absorption.

The study observed that the blocks prepared with both lime and cement had better strength even beyond two years after preparation, whereas blocks prepared with only cement showed no strength after six months of preparation.

Moreso, it was observed that the cost of production of stabilized blocks was reduced by the introduction of lime in the stabilization of the blocks. This was due to the freedom of usage of more clay in the block's mix design.

To overcome the problem of less durability for earth structures built through low cost, which lack modern effect, Shelled Compressed Earth Block (SCEB) with a higher ratio of cement stabilization for adequate durability compressed into a single piece was designed (Egenti et al., 2014). Compressed earth blocks were produced with varying cement content from 0 to 15% as a stabilizer. This was done to determine the optimum cement content. Different soil types were evaluated for durable compressed earth blocks, which resulted in a model with an optimum cement content in the outer layer with reduced cement content in the inner core. To achieve this design, a mechanical kit was designed and fabricated. The samples were subjected to a durability test. Drip test was adopted for the test of the durability of concrete. Durability was assessed by subjecting the samples to a simulation of rain of continuous downfall. Jets of water released from a height of 3m impacted samples at a vertical angle of 15 degrees for 6 hours a day for 7 days. This repeated exposure was done to reveal appreciable erosion. The eroded component's dry weight was plotted against the stabilization percentage, as shown in the figure below.

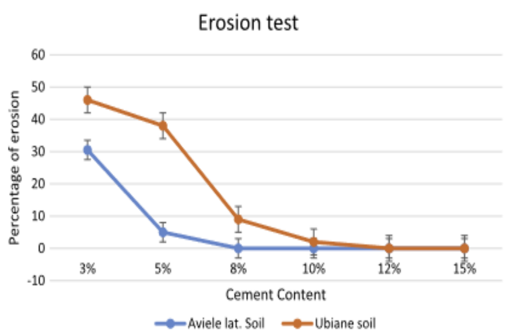

Fig.3: Variation of Erosion of Stabilised Earth Materials with Cement Content (Egenti et al., 2014)

The plot above shows that the number of earth materials eroded decreased with an increasing amount of cement. This was achieved through the improvement of the tensile strength of the shelled portion of the concrete. A better tensile strength that prevented the core's expansion was observed when tested in a worst-case scenario of total immersion in water.

Water absorption was observed to reduce increasing cement content, as shown in the plot below.

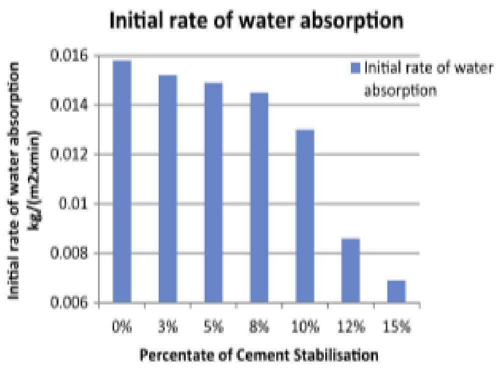

Fig. 4: Variation of Rate of Water Absorption with Cement Content (Egenti et al., 2014)

However, it was recommended that more studies should be carried out on a bigger size shelled compressed earth block with attractive surface texture.

The incorporation of coal-bearing metakaolin reduced the permeability of silty soil. This was shown by the hydraulic conductivity of 90 days, which reduced an order of magnitude. This was revealed through an experimental study done by Wang et al. (2018) on the effects of coal-bearing metakaolin on cemented silty soil permeability. Permeability test was carried out using PN3230 M flexible wall permeameter. The saturated concrete was coated with latex film and mounted on the permeameter. Also, a constant head penetration test was conducted following ASTM D5084 – 10.

So far, all the durability test described here are laboratory-based and conducted over a short period. Bui et al. (2009) investigated more than one hundred small earthen walls size 1000mmx 1100mm x400mm made with different soils. The walls were built using rammed earth, straw earth, compressed earth block, and vibrated compressed earth blocks. These blocks were exposed for twenty years under a wet continental climate with annual precipitation of 1000mm. The material loss due to wall erosion was measured by stereo-photogrammetry, which compared the plastered wall and the exposed earth wall. The result showed a 0.5% degree of erosion for the stabilized earth wall and 1.6% for the unsterilized wall.

a)Shrinkage: Kariyawasam (2016) has reported shrinkage cracks in twenty-five single-story houses constructed with CSRE walls and columns made out of compressed stabilized earth blocks (CSEB). The cracks are measuring 5mm wide are at the wall - column junction. They further experimented with 8% cement stabilization on 1000mm x 160mm x 800mm CSRE wall panel for each soil type temperature ranging between 27-30 degrees Celsius, and relative humidity was in the range of 75 -85%. Results show that sandy soil has a shrinkage strain of 0.003 while gravel has a shrinkage strain of 0.0017, and the shrinkage almost stops after 40 days.

III. STRUCTURAL ADVANTAGES OF CEMENT STABILIZED EARTH BLOCKS

Several improvements have been observed in CSEB produced through cement stabilization from the above-reviewed cement stabilized earth blocks' characteristics. These improvements are significant for the structural demands in constructing modern structures for both domestic and industrial uses.

The following are some of the structural advantages of cement stabilized earth blocks as revealed by reviewed literature.

a) Improved Strength: The compressive strength of earth blocks is significantly improved by stabilizing cement. Cement is made of fine particles that, apart from their bonding abilities, help fill the earth blocks' microstructural pores. This reduction in the pores of concrete help makes the concrete denser. Improved compressive strength enhances the load-bearing ability of concretes. This is a very significant characteristic required in concrete as they are used to construct structures that will be bearing loads.

The cement stabilized earth block's compressive strength and density are observed to increase cement content, as shown in figure 2.3 below.

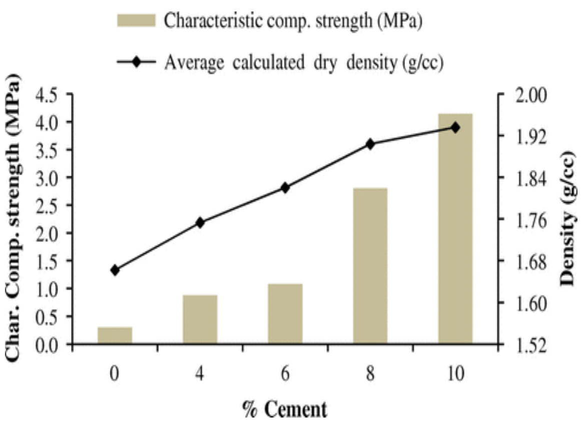

Fig 5: Variation of Compressive Strength and Density with Cement Content (Tripura & Darunkumar, 2015)

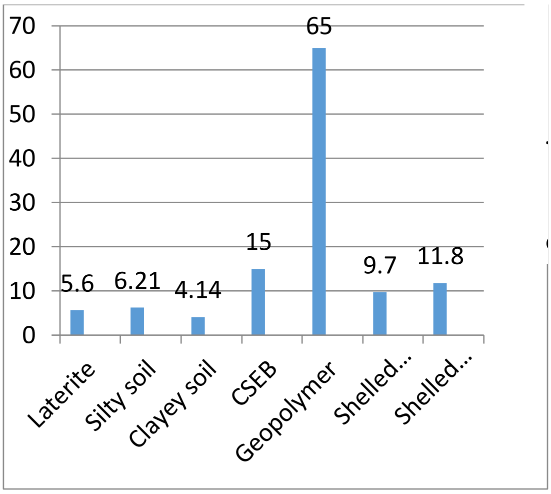

Fig.6: Compressive Strength of CEBs

Fig.6 shows that stabilization with geopolymer holds the key to higher compressive strength, and the implication is that more people in the construction industry will be looking towards

***b) Improved Permeability*:** Incorporation of cement into earthen materials reduces the pores present in the blocks and prevents corrosive agents' penetration that may easily destroy its matrix. Stabilization of earth blocks with cement reduces their permeability.

c) Reduced Microstructural Pores: Cement particles are finer than the earth particle. Their paste helps fill the pores of earthen materials/blocks, reducing the pores present in the concrete blocks.

d) Volume Stability: The dominance of pores in concrete results in shrinkage in most times when concrete is in use. Stabilizing concrete with cement removes this deficiency by filling up these pores with cement particles. This enhances the volume stability of earth blocks and reduces the tendency of the concrete to shrink.

e) Improved Durability: Cement reduces the penetration or absorption of water by earth blocks. This reduces the tendencies of the earth blocks having chemical attacks and abrasion. Penetration of water and other liquid materials gives room for chemical reactive agents that give room for attacks on earth blocks. Stabilizing earth blocks with cement reduces this tendency and improves the durability of the earth block. Also, cement increases the tensile strength of concretes. Improved tensile strength of concretes prevents abrasion of these concretes, thereby enhancing the durability of these concretes. The compressive strength of the earth blocks is also improved by cement. This enhances the load-bearing ability of concrete over a long period.

IV. CHALLENGES ASSOCIATED WITH CEMENT STABILIZED EARTH BLOCKS

Despite the structural advantages of the cement stabilized earth blocks, the reviewed literature revealed the following challenges associated with cement stabilized earth blocks.

a) Pollution: Cement contains a high amount of carbon. Cement stabilized earth blocks emit huge carbon content into the environment. Carbon has been observed to be a very dangerous substance in environmental pollution. The concern on the depletion of the ozone layer by carbonated compounds has led to the call to reduce industrial use of high carbon content materials in production. Consequently, cement being a high carbon construction material, poses an environmental threat, and has become an ecological challenge associated with its usage.

b) Reduced Ductility: Cement increases the compressive strength of concrete but reduces its ductility. Concrete structures are subjected to loads. These loads cause deformation in the concrete. The concrete's ability to still bear loads under deformation is an important structural characteristic needed in construction. Improved ductility of concrete provides this ability for the concrete to deform plastically. Cement stabilized earth blocks lack this ability.

c) High Cost of Production: Production of cement stabilized earth blocks is expensive than the non-stabilized ones. To achieve high strength, more cement is required in the stabilization of earth blocks with cement. This increases the cost of production of these concretes.

d) High Technical Requirement: Unlike the non-stabilized earth blocks such as rammed earth, cob, and compressed earth blocks, which require low technical know-how, the production of cement stabilized earth blocks require high technical knowledge in its production. The mix proportion for the production has to be known to achieve the desired strength, which requires some high level of understanding and experience.

e) Unrecyclable**:** the non-stabilized earth blocks have the advantage of being easily recycled for use, but the cement stabilized earth blocks, on the other hand, are unrecyclable.

f) Poor Clay Stabilisation: Earth materials containing more than 30% clay content are poorly stabilized by cement.

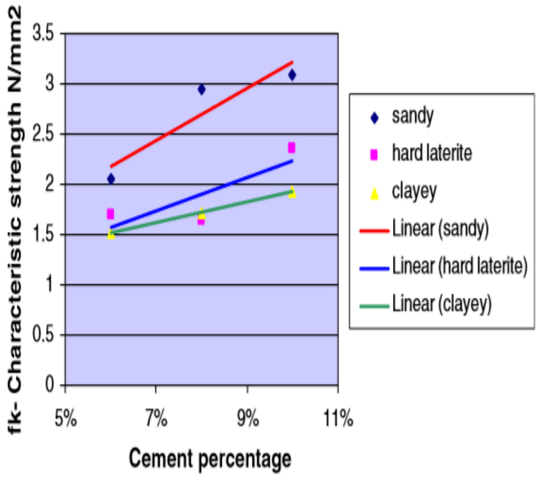

Fig. 7: Variation of Characteristic Strength of Different Earth Materials with Cement Content (Jayasinghe & Kamaladasa, 2007)

The figure above shows the variation of the strength of stabilized earth materials with cement content. From the figure, it is observed that sandy earth materials' strength is greater than those of hard laterite and clayey earth material. The least strengths are observed for clayey materials. This, therefore, shows that cement is a better stabilizer for sandy soil than for clayey soil.

V. CONCLUSION AND RECOMMENDATIONS

A. Conclusion

This study aimed at revealing the impact of stabilization on the structural characteristics of earth blocks. This was carried out through a detailed review of works done on stabilized earth blocks by several researchers.

Stabilization is a technique employed in producing earth blocks to improve strength and other characteristics to meet modern demands. It has been found to employ different materials, both natural and synthetic, among which cement is a major material used. Stabilization of earth blocks with cement is done with partial inclusion of cement into earth matrices. Earth block performance is greatly improved when the blocks are compressed, stabilized, proper grading of the earth's particle sizes is done, pore size is reduced, and optimum water –stabilizer ratio is achieved.

This review has also shown that stabilized earth blocks can be used in load-bearing walls and can therefore be used in story buildings. Durability and Water absorption were considered as a major concern for earth blocks. However, the use of shelled compressive earth blocks performed even better than the existing sandcrete blocks. The aesthetics issue has been addressed with results from the shelled compressed earth blocks, which has made them more acceptable.

Among several benefits, it has been seen from this study that the stabilization of earth blocks provides the earth with improved strength, volume stability, permeability, durability, and microstructure. These improved characteristics are key demands for concrete in the construction of domestic and industrial structures.

B. Recommendations

This work reveals that improved strength, stability, microstructure, and durability of concrete are achieved through stabilization with cement and other stabilizers. Therefore, stabilization is recommended for the construction of high strength structures. However, some challenges were presented in the previous chapter of this work, associated with cement stabilized earth blocks. To address these challenges, the following recommendations are made;

a) To reduce the environment's pollution by reducing carbon emissions into the environment, geopolymers, and other supplementary cementitious materials like Kaolin, Silica fume should stabilize earth blocks. These materials can be used as partial replacement of cement in the stabilization of concrete. This also has been revealed in some reviewed literature in this work.

b) To improve the ductility of concrete stabilized with cement, the inclusion of fibers is recommended. Polypropylene fibers were observed to improve cement stabilized concrete's ductility, as studied by Donkor and Obonyo (2015).

c) To reduce the cost of cement stabilized earth blocks, it is recommended that other cementitious materials that are cheaply available be used in addition to cement in the stabilization of earth blocks. This reduces the quantity of cement to be used in stabilization, thereby reducing the cost of production.

d) Earth materials containing clay are poorly stabilized by cement. To improve the strength of soil containing clay, lime should be incorporated into the concrete mix as lime is very effective in stabilizing clay. Nagaraj et al. (2014), in their study, observed that in a combined stabilization of earth blocks with cement and lime, the clayey fraction of the concrete was greatly stabilized by lime. Hence, with the incorporation of lime into the stabilization of earth blocks, more clay content could substitute for the scarce and expensive sand.

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