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Compressed Stabilised Earth Brick strength development

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ABSTRACT: Mudbricks have been used in shelter construction for decades and are from a mixture of clayed material and water sometimes mixed with other binders with pozzolanic properties. Over 30% of the world's populace live in earthen structures, which is substantial though faced with strength and durability challenges especially. To salvage these challenges, an understudy was carried out to identify the local stabilization techniques adopted in some selected local government areas and how best to improve the practice while considering global standards. This study explores additional strength stabilizers (cement) in the existing local practice and comparatively analyses the strength and other vital behaviors between Stabilized Earth Brick (SEB) and Compressed Stabilized Earth Brick (CSEB). The CSEB's strength properties reveal that the location with higher clay content, where the sand was not added fails to yield the desired result while the location with sand stabilization shows otherwise. Similarly, Jere soil with 12.2% clay content higher than the upper clay threshold fails the Nigerian building code requirement but the lateritic soil satisfactorily performs much better with the 5% cement stabilization, and this led to sand stabilization index development for soil with clay content above the recommended threshold.

1. Introduction

Majority of the conventional buildings and to be built houses in Borno state remote communities especially the Local Government Area's (LGA's) are made from Mudbricks and has been suffering from high cost due to the insurgency, poor quality of work, low quality or near absence of ongoing maintenance and relatively shorter lifespan [1]–[4]. Mudbrick shelters has been a trending feature in both the developed and developing countries construction industry due to its cost-effectiveness despite other challenges [1]. The satisfactory behaviour of Mudbricks structures made from clay and claylike materials is documented since the nineteenth century despite its many challenges [5].

Provision of adequate and affordable shelter is one of the most significant fundamental human needs [6]. Presently, several developing countries are faced with serious problems of delivering adequate and cheap shelters in sufficient quantities. In the last few decades, shelter conditions have been worsening resources have remained scarce, housing demand has risen and the urgency to provide immediate practical solutions has become more sensitive. The need to address this humanitarian need is of paramount importance and cannot be overemphasized.

Thus, in line with the USAID/BHA funded program aimed at addressing Diverse and Acute Primary Threats (ADAPT) to human security in North-eastern Nigeria especially alleviating human suffering among the displaced, returnees and household in Borno State, the humanitarian response strategy that included timely and integrated multi-sectoral assistance through unhindered and equitable access that would help and strengthened the resilience of the affected communities. Provision of shelter is no doubt will promote early recovery and safe durable solutions to the displaced. However, most of these local communities depend on local technologies and practices in providing shelters for themselves. These local practices are marred with several challenges especially the issue of sustainability of the provided shelter that are mostly made from mudbricks [5], [7]. A goofy mixture made by blending mud and water yields Mudbrick. This medium tensile strength is enhanced traditionally with the addition of straw to prevent the mudbrick from cracking [8].

Strength of Mudbrick structures has been a major concern and several scholarly articles are available [1], [9], [10]. This becomes necessary in addressing the known major drawback associated with the mudbrick durability which is highly corelated to its strength [11] there are several techniques available to enhance the mudbrick durability through either mechanical, physical, or chemical stabilization methods [12], [13].

The composition of sand and clay content plays a significant role in adopting the type of stabilizers for the strength enhancement [10]. For example, lime (6 – 10% of cement content) was known to enhance the pozzolanic reaction thus subduing the negative effect of clay soil with high silt [14], [15]. Similarly, cement was found to be suitable for sandy soil (15% gravel, 50% sand, 15% silt and 20% clay) with minimum cement content of 3% and average of 5% [10]. Another experiment indicates that the cement content could be as low as 4% and maximum value of 16% by volume [16]. Moreover, clay plasticity index that was normally within the range of 15 – 25 plays an important role also [17].

The under-study to provide to solution in improving local technologies and practice for the sustainability of the on-going shelter project especially the use of Compressed Stabilised Earth Brick's (CSEB's) as structural alternatives is timely and apt. Hence, this research explores the various types of soils in Borno with special interest on addressing the challenges on mudbricks strength enhancement using different stabilizers and mixing ratios, environmental aspects (environmental Impact analysis), existing practices in the country and potential institutional / investment partners that will frontier the new discoveries for the betterment of all in the state. No doubt, the study findings will greatly enhance the local artisan skills and mudbricks producers in achieving a new low-cost mudbrick with increased longevity that will significantly improve the shelter sustainability in pilot-remote areas of Borno State that included Dikwa, Damboa, Jere and Monguno Local Government Areas (LGA). The objectives were to identify the local mudbrick production and stabilization techniques and compare strength analyses of Compressed Stabilised Earth Blocks (CSEB) and Stabilised Earth Blocks (SEB) using different stabilisers and mixing ratios based on the existing local practices identified. Moreover, Borno state is one of the 36-states of the Federal Republic of Nigeria located in the North-eastern part with co-ordinates 11°30′N 13°00′E and 350 m above sea level covering a total land mass area of 70,898 km^2 (Figure 1).

Figure 1. Study Area locations

2. Mudbrick strength enhancement review

Significant research effort has been carried out to address some known challenges associated with Mudbrick like the strength related issue, durability, and susceptibility to water damage [6]. Consequently, Compressed Stabilized Earth Blocks developed (

Figure **2**), which is in the form of rammed and unfired [18] earth bricks modified with strength enhancer's [19], [20]. Extensive effort to improve stabilised mudbrick in to a reliable and close substitute to the existing conventional building bricks span more than 6 decades [21], [22].

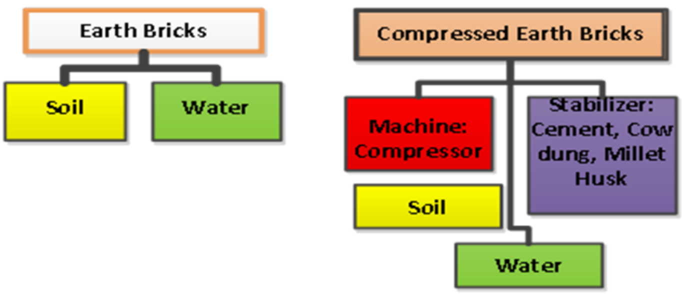


Figure 2. Difference between ordinary Mudbrick and Compressed Stabilised Earth brick (CSEB)

Literally, a scholarly investigation on Mudbrick with cement stabilizer establishes a mix proportion with 4% cement as minimum, the soil composition was fine sand ≤ 10% (≤ sieve opening 0.425 mm), Sand 55–60% (sieve opening 0.425mm ≤ sand ≤ 4.75 mm), gravel 30–35% (sieve opening 4.75mm ≤ gravel ≤ 20 mm) and water 18% to 20% [23]. The ideal clay content should be between 30 – 40 % but greater than 40% is not suitable for stabilised mudbrick production unless modified with sand content [24]. However, clayed soil with 15% gravel, 30% sand, 20% silt and 35% content lime stabilization was proposed [10].

Rahman et al., (2016), conducted experiment on compressed stabilised earth block (CSEB) with several additives as a fire-burned clay moulded brick alternative. The study results indicates that CSEB's strength increases over the reference block with 5 – 8% lime addition. Conversely, the experiment also found out that 30% sand additives with 4% as stabilizer had no effect on the CSEB's strength and compressive strength of clayed modified with 30% had lower strength value in comparison with the original clayed brick without any additives. Similar experiment by Al-Ajmi et al., (2016), that uses different additives to enhance mudbricks strength shows increasing cement ration will lead to increase in optimum mudbrick strength. Interestingly, the measure of cement content would yield satisfactory strength behaviour should at most be below 10% else uneconomical [12]. On the other hand, CSEB mixture will be difficult to handle if the cement content falls below [25].

Calatan et al., (2016) experimental investigation on natural fibres effectiveness in enhancing mudbricks strength showed an improved strength behaviour with better thermal conductivity. A closely related experimental investigation on the potentials of fibre in improving mudbrick strength further collaborates the previous finding [26]. Compressed earth block optimization with two different sediments treated with 4% glass waste and 10% blast furnace slag dissolved in NaoH solution yielded high CEB strength, low porosity, and good water resistance [27]. Similar experiments on both unstabilised and CSEB water vapour absorption by adding cement or biopolymer guar gum to the earth material shows identical mechanical behaviour and improvement in liquid water durability with reduced water vapour absorption in comparison to unstabilised earth brick [28].

Narayanaswamy et al., (2020) work indicates the promising potentials of alkali-activated compressed earth block in reducing the global warming effect. Similarly, CSEB mixture with sodium hydroxide solution showed significant improvement in the mechanical properties of CSEB [30].

3. Materials and Methods

3.1 Materials

The materials for this study included the soil samples collected from the four (4) LGA's as earlier mentioned, Cow dung, Millet husk and Ordinary Portland Cement (OPC). Figure 3 shows the typical samples collection points that was carried out during the peak raining season in the month of August at the various LGA's. Moreover, the choice of those stabilizer was guided by common local practice in those LGA's to produce their shelter mudbrick.

Figure 3. Soil samples collection at various LGA's in Borno State

(a) (b)

Figure 4. Additives materials (A) Cow dung (b) Millet Husk

Figure 4 (a and b) indicates the respective Cow dung (CD) and Millet Husk (MH) which were locally obtained within Maiduguri metropolis market at Kasuwan Shahu.

The former is an agricultural waste from grain millet which is available in large quantity and Nigerian contribute about 40% of the global 28.38 million tons [31] . The cow dung is also a biodegradable waste from cow dropping, black in colour with fair pungent smell.

3.2 Methodology

3.2.1 Soil materials selection

Soil sample from the four LGA's were collected from where the local artisan normally moulds their mudbricks, and all are at the outskirt of the town. Most of the sites look like an abandoned borrow pits site except for the Monguno's fine sand material that was collected from an open field.

3.2.2. Soil suitability determination

Suitable strength stabilizer selection remains a critical work in producing CEB and its directly related to the soil under consideration [10]. Hence, the soil suitability determination through its composition determination was the foremost activity after soil collection and this was achieved through Hydrometer testing. This test method will indicate the soil behaviour whether it is clayed or sandy [21].

3.2.2.1 PH test

The pH value determination plays an important role especially when cement will be used for any soil type stabilization except if the soil pH is below 5.3 [16], [25]. Hence, the respective soil samples were agitated in a clean glass with distilled water. The sample were drained, and pH test strips was used to obtain the pH values for all the 4 LGA's soil.

3.2.2.2 Hydrometer and sieve analysis test

To make the soil sample homogenous, the air-dried soil sample was ground manually using ceramic mortar and pestle and sieve through 2 mm sieve for all the respective 4 LGA's and the procedure was in accordance with British standard (BS 1377 -part 2). 50g sieved soil sample was dispersed through a demineralised Amyl alcohol medium consisting of 4g Sodium Phosphite (Na_3PO_3) and 10 g Sodium Carbonate (Na_2CO_3)

as shown in Figure 5. After suspending the medium for 40 sec and 2 hrs, hydrometer readings were recorded for the computation of sand, silt, and clay quantity. The principle of stokes law applies in computing the quantity of each where the denser particles will settle first at the bottom before the less dense particles (silt and clay) will layer on top. Thus, examining the thickness of each layer, the approximate values for the respective soil are obtained.

Figure 5. Prepared sample for hydrometer testing

Additionally, the particle size distribution for the coarse fraction (> 0.075 mm) was conducted using sieve analysis in accordance with the BS 1377 (Part 2 – clause 9.2 – 9.5). the sample specimens were oven dried at 105°C and weight 500 g, soaked and stirred well after 1 hr to separate the clay particles. The pulverised medium was sieved through 0.075 mm sieve size to collect the clay-silt content. The retained soil on sieved 0.075 mm was oven dried and sieved through standard sieve size (Figure 6) and the fraction retained on each sieve was recorded for the computation of the particle size distribution.

Figure 6. Sieve analysis experiment

3.2.2.3 Atterberg limit test

The Atterberg limits in other words called the consistency limits is used to classify the soil cohesive nature. The consistency limits of much importance are the liquid (LL) and plastic (PL) limits. The soils liquid limit was determined using Casagrande apparatus in accordance with the BS 1377:1990 – part 2, clauses 4.3, 4.5. Soil sample oven dried and sieved through sieve NO. 40 and collected 250g further mixed with distilled water on glass plate. Casagrande base cup was filled with 80g soil sample and a groove through the base cup. The Casagrande metal cup was raised and dropped repeatedly at 10 mm at constant rate of 2-drops per second until grooving closure. Moisture determination can were used to collect wet sample and oven dried at 110^{o}c. the recorded values are used for the computation of the liquid limit that corresponds to moisture content when 25 blows cause a 13 mm grove closure at the cup base. A total of six different reading was recorded, and average value obtained was considered as respective LGA's soil LL in this experiment.

Figure 7. Casagrande instrument used

Furthermore, the soils PL indicates the moisture content of the soil when remoulded and rolled between fingers tips on a glass plate such that 3 mm diameter rolled sample will indicates longitudinal and transverse crack showing a stiff consistency. Hence, 20g of sieved soil sample (passing sieve No. 40) thoroughly kneaded after mixing with distilled water and placed on glass plate and made a thread of 6 mm. applying gentle pressure, the 6 mm thread was rolled further to 3 mm and the procedure was repeated until shearing (both longitudinally and transversally) at the 3 mm thread. The crumbled sample were collected in container, weighted, and oven dried for further computation of moisture content. Thereafter, the respective soil Plasticity Index (PI) was determined using Eq. 1.

$$PI = LL - PL \quad \text{Eq. 1}$$

3.2.2.4 Compaction test

The compaction test that was conducted at the Eighteen Engineering Company laboratory was aimed to determine the Optimum Moisture Content (OMC) at the corresponding maximum dry density. The test was carried out in accordance with the BS 1377 – 1990 part 4 using 2.5 kg rammer method. The mould (105 mm in diameter and 115 mm high) was filled with moist soil in three approximate equal layers and compacted by 25 blows with a rammer falling from an approximate height of 305 mm. after the third layer filling, the mould top, trimmed, and the wet soil was measured, and moisture content determined after over drying collected sample. This process was repeated with increasing added up water. The OMC and maximum dry density are further computed after plotting a smooth curve of soil dry density (g/cm^3) against moisture content (%).

3.2.2.5 Mudbricks Production

This study experiment consists of two (2) distinct types of mudbricks; Uncompressed mudbrick and Machine compressed mudbrick. For either of these types, both normal and strength modified considerations were considered in this study. The choice for the strength modifiers in this study were guided by literature and the current existing practice at the localities in producing uncompressed mudbrick.

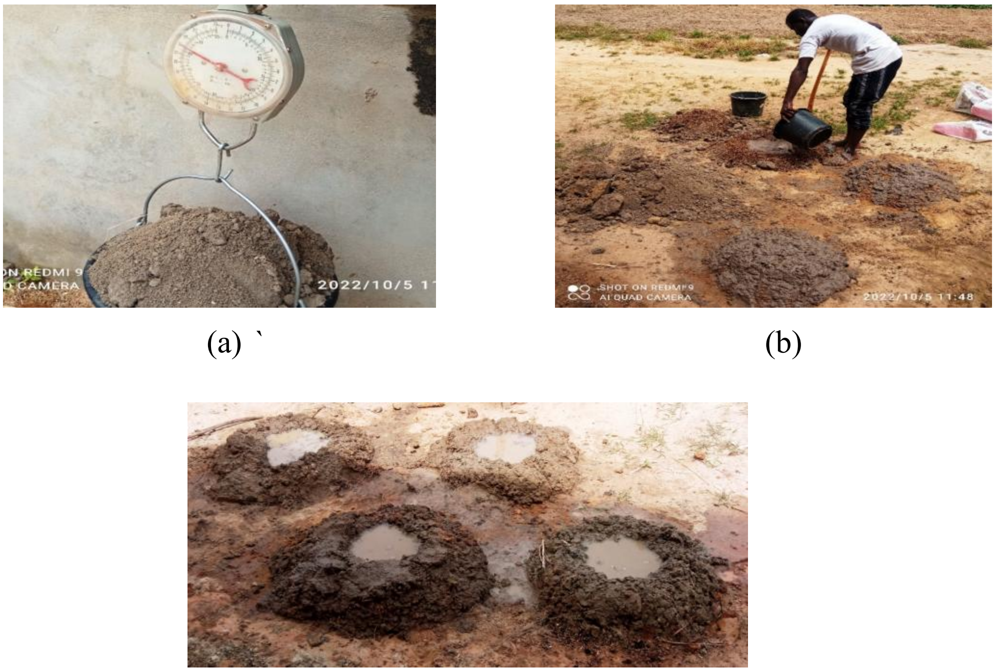
Uncompressed Mudbricks

Sample preparation for the uncompressed mudbrick production was carried out in batches of 21 kg of the soil sample with the composition given in Table 1 for the Three (3) LGA's except for Monguno LGA. However, the current practice for the local stabilization used in Monguno LGA was the use of fine sand in equal measure with the soil quantity. Hence, this study similarly, adopted the same approach by adding a uniform 7 kg of fine sand for all consideration. Incidentally this choice for the equal measure is in line with literature finding that shows an ideal mudbrick recipe contains 50% sand [32] and 25-40% clay [33].

Table 1. Strength enhancement composition (Uncompressed)

S/No.	No additives (N)	Cement content (C), kg (%)	Composite (CO), kg (%)		
			Cement	Cow dung	Millet husk
1	Normal sample for control	0.63 (3)	0.63 (3)	0.90 (4.3)	0.17 (0.8)
2		1.26 (6)	1.26 (6)	1.80 (8.6)	0.34 (1.6)
3		1.89 (9)	1.89 (9)	2.71 (12.9)	0.51 (2.4)

Although no standard method was followed in the sample preparation for the uncompressed mudbricks, but rather the artisan employed for the work is an experienced village level mudbrick worker. Firstly, the soil samples were beaten for ease of work, thereafter the other additives were added and mix thoroughly with the addition of water that ranges from 1 – 7 ltrs depending on the mix consistency. The medium was left in moist condition for three days to have proper mix and good composite action between the soil and the other additives. The cement due to its setting time, its addition was delayed till on the fourth day, where the appropriate proportions were added and mix thoroughly again in preparation for moulding.



(a) `

(b)

(c)

Figure 8. Sample preparation (A) Batch weighing (B Mixing (c) Mixed and left to reach composite action

Figure 8 shows the sample preparations for the uncompressed mudbricks casting. For clarity, the samples are designated with N – for Normal sample, C – for cement only and CO – for the composite; for example, C (6%) and CO (3%) represent the respective sample with 6% cement only and 3% cement composite.

Uncompressed Mudbricks production

The fermented mixed constituent was thoroughly match by foot after the addition of adequate water and moulded using a fabricated rectangular-wooden mould of size 290 x 140 x 90 mm.

(a) (b)

Figure 9. Uncompressed Mudbrick production (a) Foot matching and (b) Moulding

(c)

Figure 10. Wooden fabricated mould

Machine compressed Mudbrick

OSKAM V/F machine (Figure 11) was the intended medium to produce the Compressed Earth block (CEB). Consequently, as such the machine has it own requirement in terms of sample preparation and subsequent feeding to the machine for production; for example the maximum soil weight per the standard mudbrick type (295 x 140 x 90 mm) is 8 kg. hence, the soil sample for the respective Three (3) LGA's with exception of Monguno LG were batched (Figure 2) in quantum of 24 kg (about 8 kg / mudbrick) after proper sorting for foreign objects and irregular sized soil mass. However, in addition to the existing composition as indicated in Table **2**Table 2, for Monguno LG, an additional 8 kg fine Sand was added stabilizer, and this indicates a soil / sand ratio of 1:1.

indicates the different mix ratios for the batched production. Similarly, as previously index sample differentiability, the machine compressed sample are assigned with mN – for Normal sample, mC – for cement only and mCO – for the composite; for example, mC (9%) and mCO (6%) represent the respective sample with 9% cement only and 6% cement composite.

Table 2. Strength enhancement composition (Machine compressed)

S/No.	No additives (mN)	Cement content (mC), kg (%)	Composite (mCO), kg (%)		
			Cement	Cow dung	Millet husk
1	Normal sample for control	0.72 (3)	0.72 (3)	1.03 (4.3)	0.19 (0.8)
2		1.44 (6)	1.44 (6)	2.06 (8.6)	0.43 (1.6)
3		2.16 (9)	2.16 (9)	3.09 (12.9)	0.58 (2.4)

Thereafter, the earth material including the strength additives was poured into the mixing drum (see Figure 11) while the machine was powered to provide a homogenous mixture. While the machine turns the mixture, the automatic sprayer sprinkles measured water for about 100 sec (controlled from the water timer switch) until the mixture was saturated enough. It is pertinent to note that the amount of water being sprinkled was considerably lower than the water used in the production of the equivalent batched uncompressed mudbrick.

Figure 11. OSKAM Machine showing the various component.

Machine CEB production

The digital electronic weighing balance attached as one of the OSKAM machine accessories was used to measure exactly 8 kg of the mixed constituents from the mixing drum using sample collection buckets. The measured quantity was filled into compressing machine pre-filling chamber and was conveyed into the compression chamber where it was compressed to a pressure of about 150 bar (Figure 12 a). The CEB was then removed from the machine outlet unto the collection rail attached to machine for onward staking and open drying using specially designed hand jack as shown in Figure 12 (d). The mudbrick production was seamlessly carried out in well organised manner in such that mCO, mC and mN are considered in their respective composition as shown in Table 2.


(a)


(b)


(c)


(d)

Figure 12. CEMB production (a) Pressure gauge, (b) Operation, (c) Typical CEMb and (d) Handle for carrying

Compressive strength test

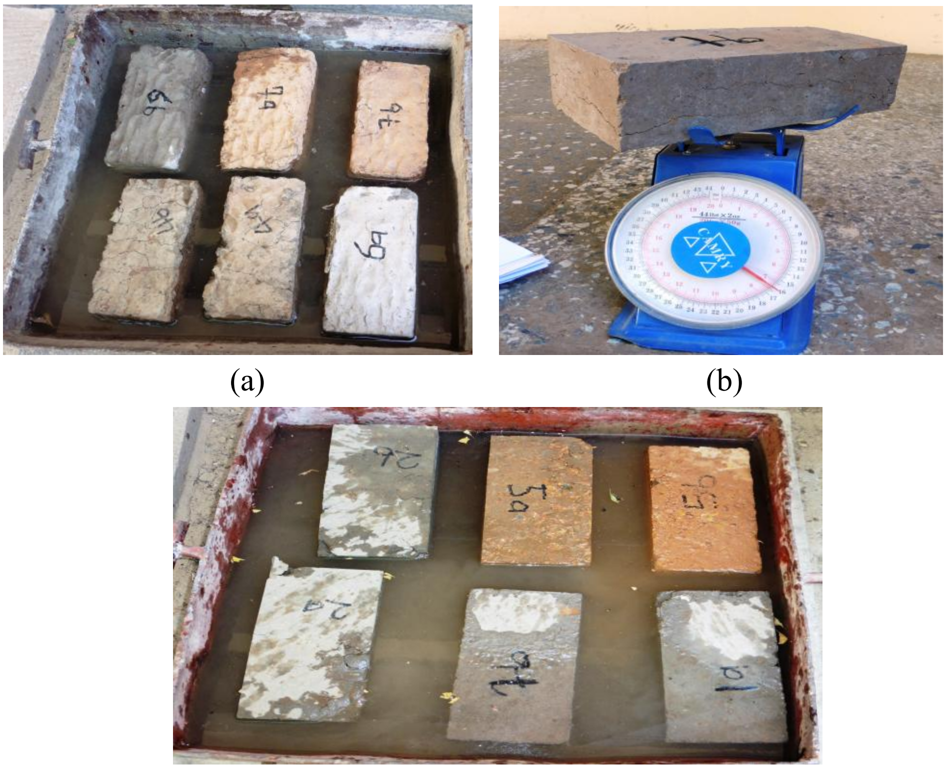
The mudbricks compressive strength test was conducted on the cured specimens using Compression machine DY 2000 (Figure 13) at EEC in accordance with BS 3921. Before crushing, the sample specimens are weighted using electronic weigh balance for their respective densities' (mass weight / volume) computations. The respective testing included both uncompressed and CSEB's after 7, 14, 21 and 28 days. However, most sample couldn't be carried to the crushing machine due to self-crumbling after curing especially the composite mixes.

Figure 13. Compressive strength test (A) Compression machine, (B) Curing Bay, (C) Sample ready for weighing and crushing (D) failed sample which cannot be carried after curing, eg.. some composite mix

Water absorption test

Water absorption test (Figure 14) is key in determining mudbrick durability and this is the main reason for the use of stabilizers which are to prevent mudbrick softening on moisture absorption (Harison and Sinha, 1995). Hence, after 28-days curing age, the unsoaked mudbrick weight (w_a), and the equivalent soaked weight (w_b) after 24 hrs in the water absorption basin are used to obtain the specimen water absorption rate using Eq. 2. Importantly, the water absorption for building bricks shall not be more than 25% weight after 24 hrs immersion as found in the national building code and that will serve as basis for the brick's performance.

$W = (w_b - w_{a)}/w_a * 100$ -------------------------- E.q. 2



(a) (b) (c)

Figure 14. Water absorption test (a) soaked SEB samples, (b) sample weighing, and (c) soaked CSEB samples.

4. Results and discussion

4.1 Particle size and Atterberg limits

The soil hydrometer and sieve size particle distributions are presented on Table 3 and Figure 16. The particle size distribution for Dikwa and Jere LGA's shows gravel (9%, 7.4%), Sand (22, %, 37.9%) and clay (69% and 54.72%), respectively. Similarly, a corresponding value of gravel (1.8%, 56.1%), sand (18.1%, 17.35%) and clay (80.1% and 27%) were obtained for Monguno and Damboa LGA's. interestingly, the hydrometer analysis indicated the respective clay contents for Monguno, Damboa, Jere and Dikwa as 67.2%, 49.7%, 52.2% and 72.2% respectively. Although it is obvious that sieve analysis gives correct gradation for particle size > 0.075 mm and hydrometer test for better soil gradation of particles < 0.075 mm. Although clay content for ideal mudbrick can vary between 25-45% and as little as 5% but cracks are likely to develop if former upper threshold exceeded [33]. As envisage, cracks were so pronounced on the casted mudbrick especially the uncompressed type as shown in Figure 14.

Figure 15. Cracks propagation due to high clay content

Table 3. Hydrometer analysis

S/No.	Location	pH value	Soil content (%)			LL	PI	Textural Class	Remark
			Clay	Sand	Silt	(%)	(%)	(AASHTO)	
1	Monguno	7.36	52	32.8	15	33	17	Clay (A-4)	Clay > 40
2	Damboa	7.23	36	50.3	14	27	7.2	Clay-gravel and Sand (A-2-4)	clay ok
3	Jere	7.07	32	47.8	20	21	4.3	Silty soil (A-4)	Clay ok
4	Dikwa	6.69	57	27.8	15	27	6.2	Silty soil (A-4)	Clay > 40

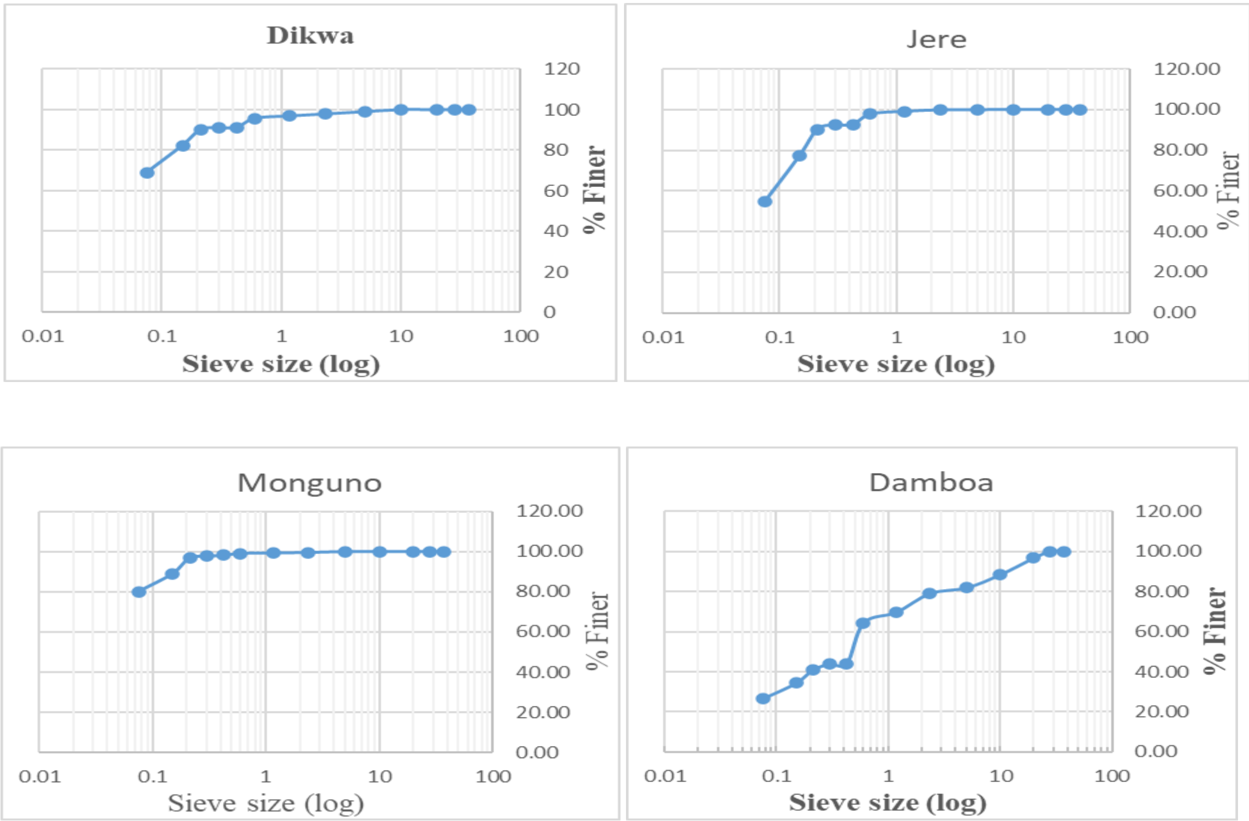


Figure 16. Particle size distribution for the Four (4) LGA's

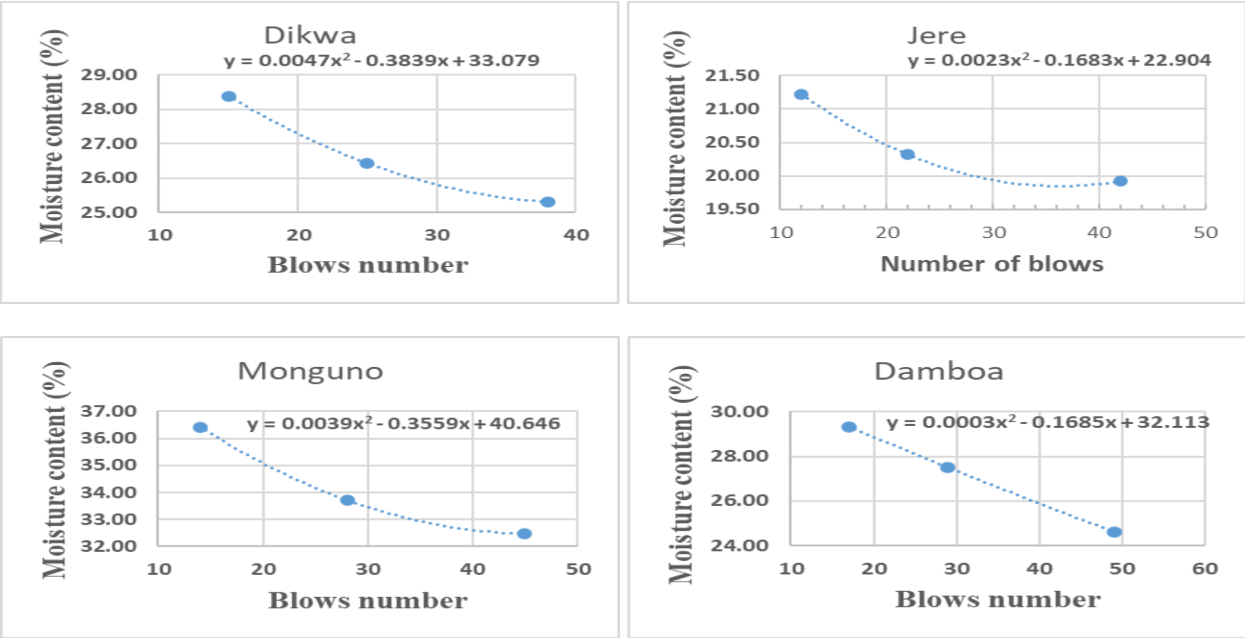


Figure 17. Liquid limits chart

The LL and PI of test soil ranges from 27.1 – 33.2 and 4.3 – 16.9 with Monguno soil showing high LL (Figure 17) and PI (Table 3) values and Jere exhibiting the lowest characteristics. Generally, soil with LL < 35% indicates low plasticity, intermediate if LL is between 35% - 50%, high and higher plasticity if the respective LL are between 50% - 70% and 70% - 90% but greater than 90% is considered as extremely high plasticity [34]. Furthermore, based on AASTHO soil classification, all the soil are A-4 (clay / clayed – silt soil) except Damboa which was classified as A-2-4 (clay-gravel and sand soil). It is not surprising because the latter is majorly used for road construction within the state and beyond for its good geotechnical properties.

4.2. Soil suitability for Mudbricks production

To establish the soil suitability in its existing form, a curve envelop for gravel, sand and clay content is developed in relation with literature recommendation for those constituents for mudbricks production [23]. Figure 18 shows the respective soil envelop curve for the locations under consideration using the particle size analysis (S.A.) results. The result indicates that none of the soils passes through curve envelop bounded by the upper and lower limits for the gravel, sand, and clay constituents. For example, Damboa's soil indicated an excess gravel (60%) and falls short of sand (50%) above the upper limit when compared with Dikwa's that falls short of both gravel (233%) and sand (98%) lower than the minimum threshold. This clearly indicates that the respective soil needs to be stabilised to have effective result in producing mudbrick. This perhaps explain the reason why there is persistent case of low durability associated with those mudbricks in those localities. Thus, this justifies the need for their stabilization with cement and sand as the case of Monguno. The choice for the cement agrees with literature [35], which showed that cement is more suitable stabilizer for soil with PI below 15 though Monguno soil PI is marginally above 15 but further sand was added. Blending clay soil with Portland cement, hydration ensured where the compound C3S and C2S in cement will react to form Calcium Silicates Hydrates in presence of water [22]. This complex compound has beneficial deleterious reduction effect in clay material.

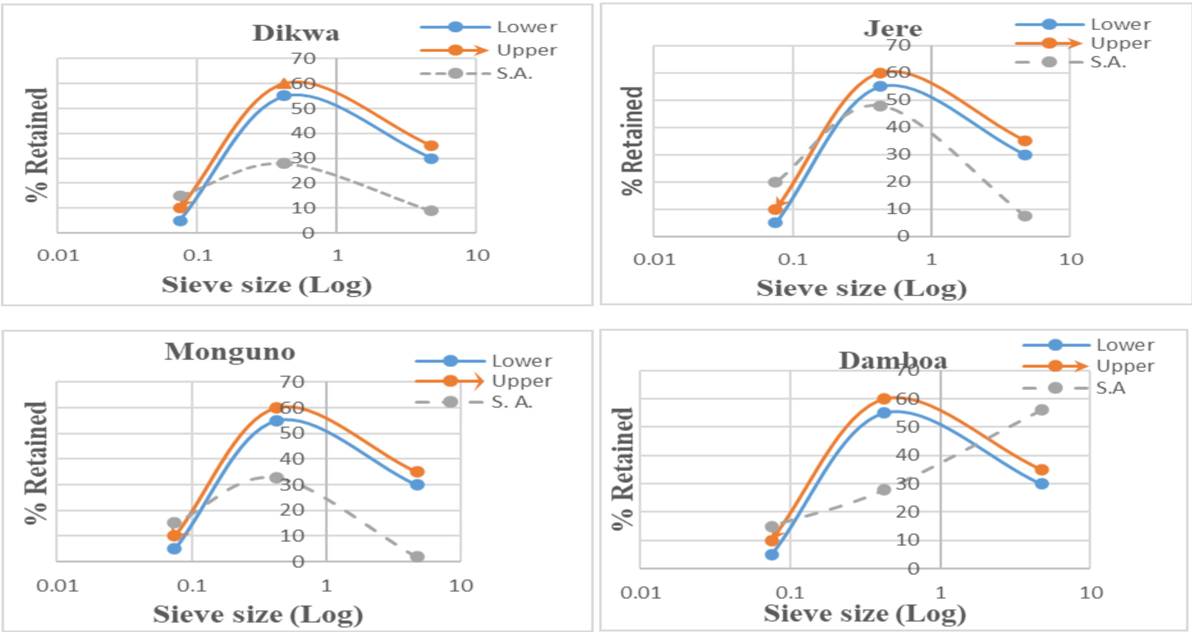


Figure 18. Soil envelope curve

4.3 Optimum moisture content and MDD

The soils Maximum Dry Density (MDD) varied between 1.9 – 2.1 g/cm^3 with the Optimum Moisture content (OMC) ranging from 7.5 – 9.5%. Adopting O'Flaherty, (1988) classification for standard proctor value range for clay soil are: MDD and OMC within 1.44 – 1.685 g/cm^3 and 20 – 30% is clay. While the MDD and OMC within 1.6 – 1.85 g/cm^3 and 15 – 25% is silty-clay but if MDD and OMC ranges between 1.76 – 2.165 g/cm^3 and 8 – 15% is sandy-clay. The soils constitute an element of sandy-clay properties.

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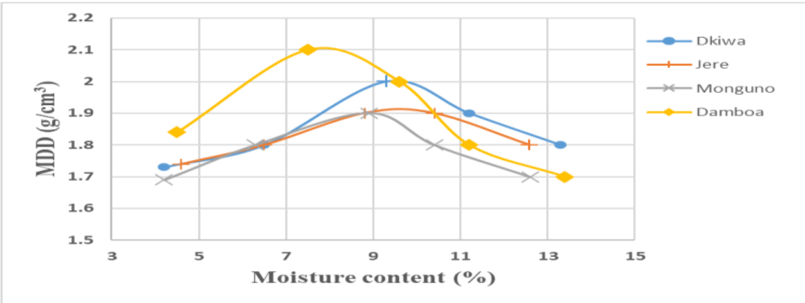


Figure 19. OMC and MDD determination curve

4.4 Water absorption

Table 4 shows the water resistance capacity for both SEB's and CSEB's for the respective locations as indicated. Although failed after soaking (Figure 20), generally higher water absorption rate was recorded with the clayed medium bricks (SEB) than its counterpart from sand stabilized and lateritic soil from the respective Monguno and Damboa. The CSEB's water absorption resistance increases with increasing cement content [6] and the values are well within the limiting 25% as found in literature. Interestingly, the average water resistance performance from SEB's against CSEB's ranges between 12.95% - 17.58% with the lateritic soil based CSEB's showing better performance of 13.4%. the latter behaviour could be attributed due to the presence coarser material which enhances effective bonding between the soil particles in contact with cement which ultimately led to reduced voids.

Figure 20. Failed sample during water absorption test

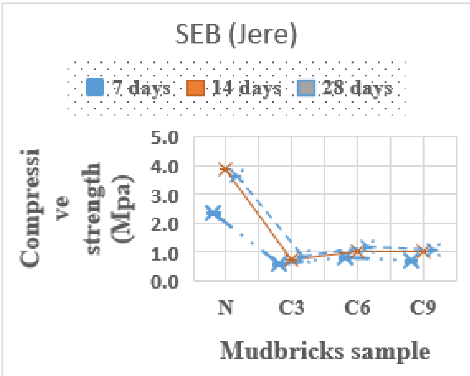
Table 4. Water resistance capacity

S/no.	LGA	Cement content	SEB (water absorption)			CSEB (water absorption)			Water resistance (%)	
			W_a (g)	W_b (g)	W (%)	W_a (g)	W_b (g)	W (%)	SEB - CSEB	Average
1	Jere	0%	7400	-	-	6755	-	-	-	12.95
		3%	7250	9135	26	6850	-	-	-	
		6%	6750	8370	24	6700	8113.7	21.1	13.7	
		9%	7500	9225	23	6800	8194	20.5	12.2	
2	Monguno	0%	5650	6904.3	22.2	7250	8609.4	18.8	18.4	17.58
		3%	6100	7417.6	21.6	7200	8488.8	17.9	20.7	
		6%	6150	7287.8	18.5	7150	8310.4	16.2	14	
		9%	5950	7027	18.1	7300	8427.9	15.5	17.2	
3	Damboa	0%	7200	8445.6	17.3	7150	8236.8	15.2	13.8	13.4
		3%	7550	8841.1	17.1	7250	8301.3	14.5	17.9	
		6%	7600	8869.2	16.7	7300	8300.1	13.7	21.9	
		9%	7450	8656.9	16.2	7250	8156.3	12.5	29.6	

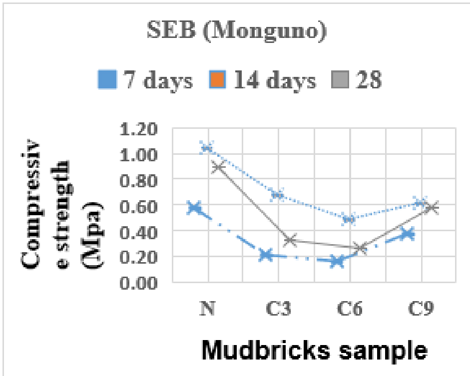
4.5 Mudbricks Compressive strength

Figure 21 (i – iii) presents the compressive strength for the stabilised earth bricks (SEB) for the locations as indicated. Unfortunately, Dikwa's wasn't possible to produce SEB due to its high clay content, and that's makes it impossible to achieve the desired mix like the others. Although, Monguno's soil had high clay content, but the addition of the fine sand significantly enhanced the production of its SEB for this experiment. The results in Figure 21 (i and ii) shows a strength decline with 3% cement addition and marginal strength gain as cement content increases. Additionally, there is insignificant strength difference between 14- and 28-days values for Jere, but 28 days strength was lower than 14 days value for Monguno. The latter behaviour could be attributed to possible de-bonding between the sand particles, clay and cement with age and this could be true because of the low compactive effort in producing SEB in general.

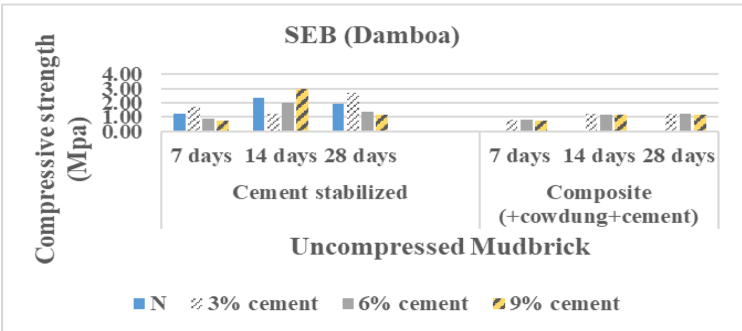
On the other hand, Figure 21 (iii) showed the compressive strength behaviour for Damboa soil type that included both cement only and composite (cement+cowdung+millet husk) stabilized soil. Principally, the composite stabilised component was prepared for all the other locations but only Damboa's was possible for testing because the sample lacks compactness during and after curing period as shown in Figure 22. The possible reason could be because of higher millet husk content (1%) which made it impossible for the clay matrix to cover the fibres for effective bonding [5]. Some other cases are as result of excessive shrinkage on drying and example is shown with Figure 23. The lateritic soil from Damboa shows a promising 28-day strength with 3% cement content. However, the composite stabilization shows insignificant strength variations from 0 – 9% cement increment.



i.



(ii)



(iii)

Figure 21. SEB compressive strength values (Jere), (ii) Monguno and (iii) Damboa

(a)

(b)

Figure 22. Failed bonding on drying for some composite samples

Figure 23. Excessive shrinkage

Conversely, Figure 24 indicates compressed stabilised earth bricks (CSEB) compressive strength tests values for the respective LGA's soil types. The compressive strength for the clayed soil increased marginally from zero to 3% cement increase and no meaningful gain thereafter (Figure 24 i). However, the modified clay matrix with sand is much higher comparatively with the un-modified clay compressive strength (87% strength gain at 28 days at 9% cement). The same strength variation is observed with 3% cement content (80% gain) as stabilizer. Similar behaviour was exhibited using lateritic soil in the production of CSEB that also indicated that the higher the cement content the more the strength gain at 28 days period (Figure 24 iii). This gain in strength property is solely due to the altered clay soil matrix [10]. Moreover, the compressive strength behaviour for composite matrix is insignificant between zero to 9% cement.

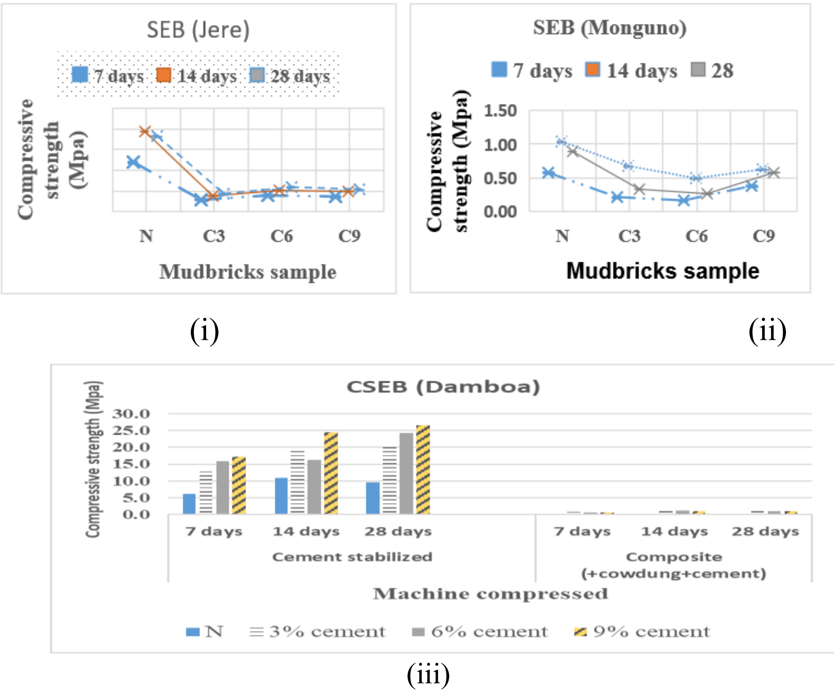
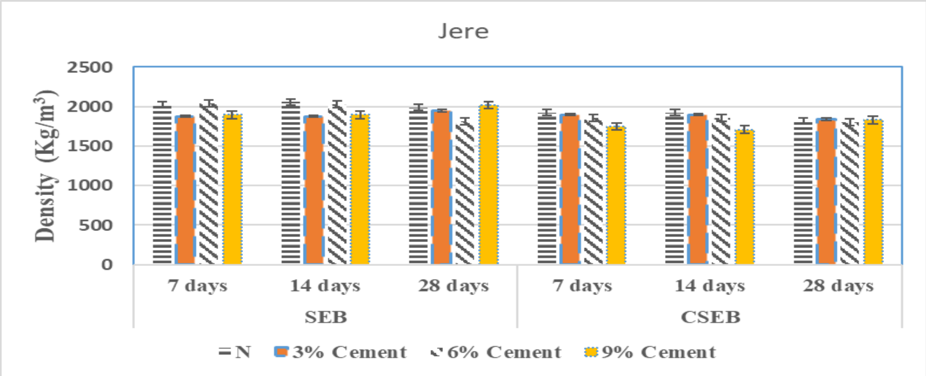
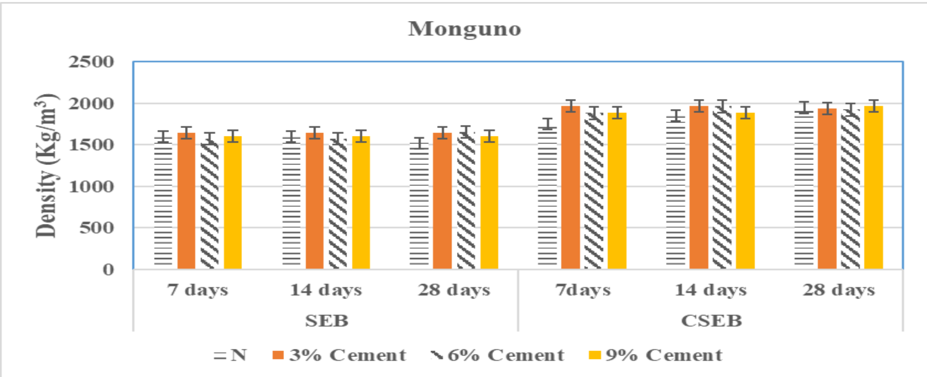


Figure 24. CSEB compressive strength values (Jere), (ii) Monguno and (iii) Damboa

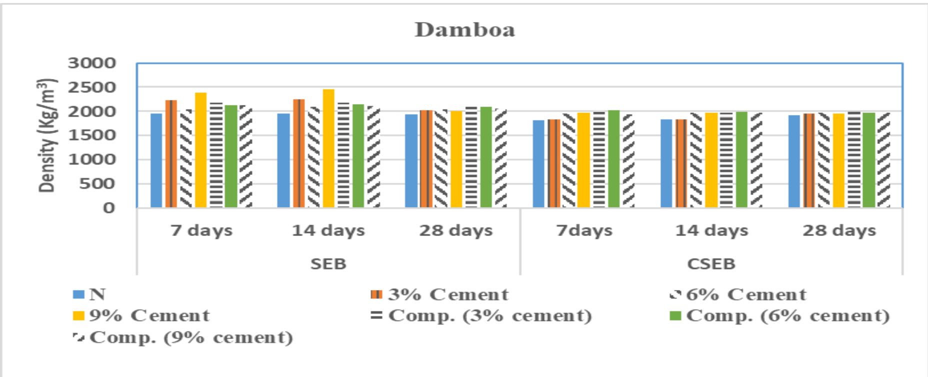
The acceptable density value for effective thermal insulation for mudbricks is between 1800 – 2000 kg/m^3 [5]. Figure 25 densities results indicates that all the respective locations CSEB are well within the acceptable limit as found in literature. However, SEB densities values are found to be varying significantly both above and below the required limits for effective thermal insulation.



(i)



(ii)



(iii)

Figure 25. Densities values

Stabilization recommendation

The CSEB's strength properties presented reveals intriguing behaviour for the various soil types used from the different locations. It was established that the location with higher clay content, where sand was not added fails to yield a result while the location with sand stabilization shows otherwise. Similarly, Jere soil with 12.2% clay content higher than the upper clay threshold fails the Nigerian building code requirement for 28-days strength value. However, the lateritic soil from Damboa, satisfactorily performs much better than all with the 5% cement stabilization as shown in Table 5.

Table 5. CSEB general condition and recommended remedies

S/no.	Soil location (LGA)	Clay content (%)	NBC requirements		Remark
			7 days strength ≥ 1.6 N/mm^2	28 days strength ≥ 3 N/mm^2	
1	Dikwa	72.2	Fail	fail	Soil needs sand stabilization
2	Monguno	67.2	Ok	ok	Favourable condition because of added sand
3	Jere	52.2	Ok	Below limit (av. Is 2.67)	Soil needed sand stabilization due to higher clay content
4	Damboa	35.5	Ok	ok	Lateritic soil and favourable CSEB

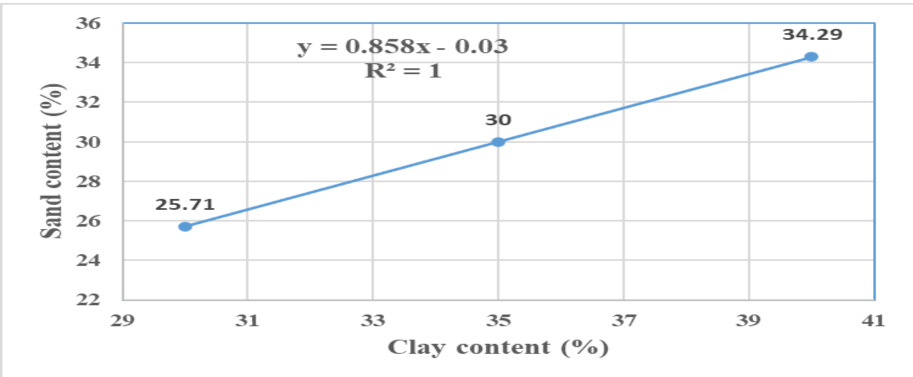


Figure 26. optimum sand component determination

To achieve effective CSEB's for any location based on the clay content, a sand content addition to the clayed material will favourably alter the clay matrix for better cohesion and enhanced CSEB strength [24]. Generally, for a soil with 35% content, a 30% sand was proposed as found in literature [24] and Figure 26 indicates the linear relationship between clay and sand contents for effective stabilization. The equation of best fit shows that for a clay content value of x %, the required sand is y %. For example, a typical Dikwa soil type with 72.2% clay requires 62% sand content for the equivalent clay weight measure.

5. Conclusions

This research that works on the strength enhancement of Mudbrick production for the provision of low-cost housing for the rural dwellers in some selected pilots LGA's in Borno state that included Dikwa, Monguno, Jere and Damboa. The study identifies that most of the locations practice stabilised earth brick (SEB) production but uncompressed. The local stabilizers used included millet husk and cow dung, and this was marred with strength and durability issues. This study explores additional strength stabilizer (cement) on the existing local practice and comparatively analyses the strength and other vital behaviour between SEB and compressed stabilised earth brick (CSEB). The latter involves the use of hydraulic powered machine for compressing the earth brick.

The CSEB's strength properties reveals intriguing behaviour for the various soil types used from the different locations. It was established that the location with higher clay content, where sand was not added fails to yield a result while the location with sand stabilization shows otherwise. Similarly, Jere soil with 12.2% clay content higher than the upper clay threshold fails the Nigerian building code requirement for 28-days strength value. However, the lateritic soil from Damboa, satisfactorily performs much better than all with the 5% cement stabilization. The study further develops sand stabilization index formular for soil with clay content above the recommended threshold.

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Conflicts of interest

The authors declare no conflict of interest.

Authors contribution statement

K. Mohammed: Conceptualization, project design and grant application, Data analysis, report writing; Umar A. Jidda: Grant facilitation and implementation, project locations facilitation and investigation and review work analysis; Ridwan A. Muhammad: field and laboratory works analysis.

References

1. V. Sumanasena, A. Rajabipour, M. Bazli, C. Kutay, and D. Guo, "Strength and erosion resistance of mudbrick as an alternative local material for Australia's Northern Territory remote housing," *Case Studies in Construction Materials*, vol. 16, p. e01023, 2022.

2. R. S. Bailie and K. J. Wayte, "Housing and health in Indigenous communities: Key issues for housing and health improvement in remote Aboriginal and Torres Strait Islander communities," *Australian Journal of Rural Health*, vol. 14, no. 5, pp. 178–183, 2006.

3. A. Lowell *et al.*, "The 'invisible homeless'–challenges faced by families bringing up their children in a remote Australian Aboriginal community," *BMC Public Health*, vol. 18, no. 1, pp. 1–14, 2018.

4. J. Fien and E. Charlesworth, "'Why isn't it solved?': Factors affecting improvements in housing outcomes in remote Indigenous communities in Australia," *Habitat Int*, vol. 36, no. 1, pp. 20–25, 2012.

5. G. Calatan, A. Hegyi, C. Dico, and C. Mircea, "Determining the optimum addition of vegetable materials in adobe bricks," *Procedia technology*, vol. 22, pp. 259–265, 2016.

6. V. Prakash, A. S. Amal Raj, B. Mathew, and V. R. Sumith, “Studies on stabilized mud block as a construction material,” *International Journal of Innovative research in advanced engineering*, vol. 1, no. 3, 2016.

7. A. I. Amadi and K. C. Amadi, “Uncertainties surrounding the economic potential of locally available laterite deposits in promoting environmentally sustainable housing in Nigeria,” *American Journal of Civil and Environmental Engineering*, vol. 3, no. 3, pp. 43–51, 2018.

8. F. Al-Ajmi, H. Abdalla, M. Abdelghaffar, and J. Almatawah, “Strength Behavior of Mud Brick in Building Construction,” *Open Journal of Civil Engineering*, vol. 06, no. 03, pp. 482–494, 2016, doi: 10.4236/ojce.2016.63041.

9. K. A. Heathcote, “Durability of earthwall buildings,” *Constr Build Mater*, vol. 9, no. 3, pp. 185–189, 1995.

10. M. Rahman, M. Rashiduzzaman, F. Z. Akhand, and K. B. Kabir, “Compressed stabilized earth block: a green alternative for non-load bearing building block in developing countries like Bangladesh,” *American Chemical Science Journal*, vol. 12, no. 3, pp. 1–10, 2016.

11. A. Guettala, H. Houari, B. Mezghiche, and R. Chebili, “Durability of lime stabilized earth blocks,” 2002.

12. P. J. Walker, “Strength, durability and shrinkage characteristics of cement stabilised soil blocks,” *Cem Concr Compos*, vol. 17, no. 4, pp. 301–310, 1995.

13. N. Billong, U. C. Melo, F. Louvet, and D. Njopwouo, “Properties of compressed lateritic soil stabilized with a burnt clay–lime binder: effect of mixture components,” *Constr Build Mater*, vol. 23, no. 6, pp. 2457–2460, 2009.

14. S. N. Malkanthi, N. Balthazaar, and A. Perera, “Lime stabilization for compressed stabilized earth blocks with reduced clay and silt,” *Case studies in construction materials*, vol. 12, p. e00326, 2020.

15. K.-L. Lin, B.-Y. Chen, C.-S. Chiou, and A. Cheng, "Waste brick's potential for use as a pozzolan in blended Portland cement," *Waste Management & Research*, vol. 28, no. 7, pp. 647–652, 2010.

16. L. Wang, *Cementitious stabilization of soils in the presence of sulfate*. Louisiana State University and Agricultural & Mechanical College, 2002.

17. F. V. Riza, I. A. Rahman, and A. M. A. Zaidi, "A brief review of compressed stabilized earth brick (CSEB)," in *2010 International Conference on Science and Social Research (CSSR 2010)*, IEEE, 2010, pp. 999–1004.

18. F. V. Riza, "Application of RHA's Pozzolanic Properties in the Making of CEB," *International Journal of Sustainable Construction Engineering and Technology*, vol. 2, no. 2, 2011.

19. HB. Nagaraj, M. Sravan, TG. Arun, and KS. Jagadish, "Role of Lime with cement in long-term strength of Compressed Stabilised Earth Block," *International Journal of Sustainable Built Environment*, vol. 3, no. 1, pp. 54–61, 2014.

20. A. YMXD, I. PACHOUKOVA, K. E. AGBO, and K. : BEDJA, "Study of Improvement of Mud Bricks Stabilized with Cement Characteristics by Addition of Rice Husks Ashes," *Research Journal of Material Sciences*, vol. 5, no. 7, pp. 1–4, 2017.

21. R. B. Brown, "Soil Texture, Soil and Water Science Department," *Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL*, pp. 32–611, 2007.

22. D. Sadek and H. Roslan, "A review on bricks and stabilized compressed earth blocks," *Scientific Research and Essays*, vol. 6, no. 3, pp. 499–506, 2011.

23. F. R. Arooz and R. U. Halwatura, "Mud-concrete block (MCB): mix design & durability characteristics," *Case studies in construction materials*, vol. 8, pp. 39–50, 2018.

24. M. Edgar, “PRODUCTION OF COMPRESSED STABILIZED SOIL BLOCKS (SSB) - Process Analysis),” Mzuzu University, Luwinga, 2015.

25. S. Garg, *Soil mechanics and foundation engineering*. Delhi, India.: Khanna Publishers, 2001.

26. O. O. Joseph and J. A. Adeniran Jolaade Adeala, “Properties of Mud Brick Stabilized with Sugarcane Peel Ash,” *International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS)*, vol. 8, no. 6, pp. 45–48, 2019.

27. S. Larbi, A. Khaldi, W. Maherzi, and N.-E. Abriak, “Formulation of Compressed Earth Blocks Stabilized by Glass Waste Activated with NaOH Solution,” *Sustainability*, vol. 14, no. 1, p. 102, Dec. 2021, doi: 10.3390/su14010102.

28. A. W. Bruno, B. Scott, Y. D’Offay-Mancienne, and C. Perlot, “Recyclability, durability and water vapour adsorption of unstabilised and stabilised compressed earth bricks,” *Mater Struct*, vol. 53, no. 6, p. 149, Dec. 2020, doi: 10.1617/s11527-020-01585-7.

29. A. H. Narayanaswamy, P. Walker, B. V. V. Reddy, A. Heath, and D. Maskell, “Mechanical and thermal properties, and comparative life-cycle impacts, of stabilised earth building products,” *Constr Build Mater*, vol. 243, p. 118096, 2020.

30. S. O. Sore, A. Messan, E. Prud’Homme, G. Escadeillas, and F. Tsobnang, “Stabilization of compressed earth blocks (CEBs) by geopolymer binder based on local materials from Burkina Faso,” *Constr Build Mater*, vol. 165, pp. 333–345, 2018.

31. A. Kuhe, A. V. Terhemba, and H. Iortyer, “Biomass valorization for energy applications: A preliminary study on millet husk,” *Heliyon*, vol. 7, no. 8, p. e07802, Aug. 2021, doi: 10.1016/j.heliyon.2021.e07802.

32. V. L. Emery, “Mud-brick architecture,” *UCLA Encyclopedia of Egyptology*, vol. 1, no. 1, 2011.

33. A. M. Rosen, *Cities of clay: the geoarcheology of tells*. University of Chicago Press, 1986.

34. R. Whitlow, “Basic Soil Mechanics. Essex.” Longman, 1995.

35. D. O. A. Osula, “A comparative evaluation of cement and lime modification of laterite,” *Eng Geol*, vol. 42, no. 1, pp. 71–81, 1996.

36. C. A. O’Flaherty, *Highway Engineering*, vol. 2. London, U.K: Edward Arnold , 1988.