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Suitability Analysis of Compressed Earth Bricks (CEB) for Sustainable Housing Delivery in Guinea Savannah Zone of Northern Nigeria

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In meeting housing delivery challenges in Nigeria, there is an urgent need to develop materials and technologies that are cost effective, eco-friendly, having good user perception and showcasing cultural heritage. The study evaluated the compressed earth bricks (CEB) and sandcrete blocks sustainability as building materials. Structured questionnaires were administered to professionals (Architects, Structural Engineers and Builders) in Kaduna State to establish the awareness level, application and sustainability qualities of CEB as compared to sandcrete blocks. Laboratory tests were conducted on six soil samples and CEB from three States of Guinea Savannah Zone of Northern Nigeria (Kaduna, Plateau and Niger) to ascertain their suitability for housing development. Findings showed low awareness, acceptability and poor user perception levels of CEB at 12% but high advantage as regard cost, environmental friendliness (energy efficient) and cultural heritage. CEB were manually and dynamically compressed at medium pressure and cured for 7 and 28 days respectively with five different cement ratios. The maximum compressive strength in 28days for Kaduna State was Damashi with 2.67 N/mm^2, at 6% stabilisation; Plateau State, both Bassa and Jos South had 2.82 N/mm^2 at 6% cement content and Bosso in Niger State was 4.42 N/mm^2 at 8% cement content. The bricks from each of the sites indicated appropriate for use at either 2% or 4% but averagely 6% and all at 8% cement stabilisation. CEB has sustainable advantage over sandcrete blocks by approximately 70%. The paper recommends that developers, Non-governmental organisations (NGOs), Governments housing development agencies commence the use of optimised CEB for sustainable large scale housing production in Nigeria.

Keywords: Comparative Analysis, Compressed Earth Bricks (CEB), Sandcrete Blocks, Housing, Sustainable Technology, Nigeria

INTRODUCTION

The provision of adequate and well maintained housing in any country is a stimulant to its economy (Uwatt 2019; Oladapo & Olotuah, 2010; Omole, 2010). Quite a lot of issues have been identified by several studies as hampering sustainable (adequacy and quality) housing provisions and delivery in Nigeria such as land (Federal Ministry of Works and Housing Nigeria [FMWHN], 2012); housing finance (Moore, 2019; Olotuah & Ajenifujah, 2009); land tenure system (Moore, 2019; Ayedun & Oluwatobi, 2011); provision of social infrastructures (Ajayi & Omole, 2012); building materials (Eromobor & Das, 2013; Adedeji & Ogunsote, 2012; Ademiluyi 2010). In a related development, others including lack of political will, lack of consistency and continuity in housing policy formulation and poor implementation of strategies, unfavourable political environment and declining population of tradesmen in the construction industry are hindrances bedevilling adequate housing in the country (Ibem *et al*., 2011).

Most housing challenges especially in urban centres are characterised by poor infrastructure, low quantity and poor quality of housing stock/units as observed in the

2012 National Housing Policy (FMWHN, 2012). FMWHN (2012) also opined that these challenges are basically as a result of the high number of low income groups which makes up 90% of the total population of the country. Kumo (2014) avowed that housing challenges in Nigeria are as a result of combination of factors such as high rates of population growth and urbanisation, high cost of housing development, mortgage and infrastructural financing and inadequate stock of decent and affordable housing. Housing challenges have resulted into several factors such as overcrowding, increasing pressure on infrastructural facilities and rapidly deteriorating environment (Moore, 2019; Ekpo, 2019; FMWHN, 2012; UN-Habitat, 2012).

In housing construction, the input of building materials accounts for as much as 60% to 75% of low-cost housing (Eromobor & Das, 2013; Adedeji & Ogunsote, 2012). It has also been argued that the built environment is an immense contributor to global warming accounting for 48% (41% operating and 7% embodied) of total energy consumption and share of greenhouse gas (GHG) emissions (Architecture 2030, 2014). The building sector produces about 50% of greenhouse gas (GHG) emissions, chlorofluorocarbons (CFCs) and also comprise 40% of acid-rain producing sulphur dioxide and nitrogen oxides causing major environmental crisis more than other sectors put together (Yuefeng, 2011; Green Play Book (GPB), 2010). Figure 1 depicts the U.S. energy consumption by sectors which indicates that the building sector has the highest level and in Figure 2, building operations and construction of buildings and infrastructures is at 50.7%.

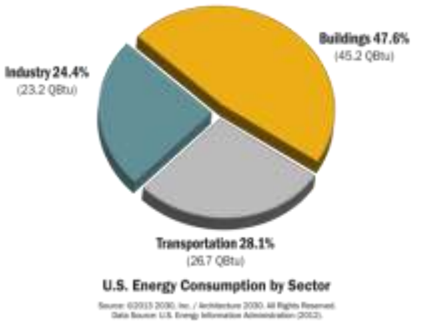

Figure 1: U.S. Energy Consumption by Sector Source: Architecture 2030 (2014).

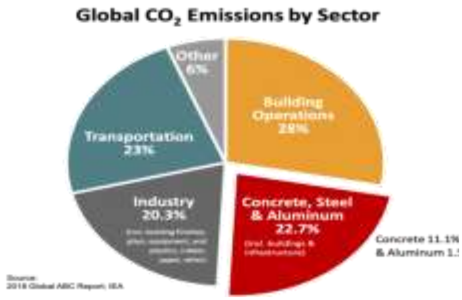

Figure 2: Global Emissions by Sector Source: Global ABC Report, IEA (2018)

The effect of global warming and climate change resulting from fossil fuels use and deforestation which produce greenhouse gases can be reduced or eliminated through sustainable housing (UN-Habitat, 2012). According to Buys and Hurbissoon (2011), sustainable housing is cheaper because it pays for itself, heats and cools itself, easier to maintain and is more often aesthetically pleasing. Also sustainable buildings have both tangible (reduction of power consumption by 20%-40% and reduction of potable water consumption by between 30% and 40%) and intangible (health, comfort and safety of the building occupants, higher productivity and better practices) qualities from inception. Hanafi (2021) and Merwe (2011) averred that focusing on the energy efficiency of a building will drastically reduce or eliminate the negative impact of buildings on the environment and its occupants. Energy efficiency can be achieved through the choice of material utilised for construction and operation of the building.

If an environment is to last a lifetime, conserve energy and save money, be healthy and comfortable, sustainable building materials should be used (Little, 2015). It is then imperative that sustainable building materials and technologies are utilised for the construction of buildings so as to reduce the adverse effects of huge energy consumption, of gas emissions and achieve users requirements without compromising the ability of future generations to have their own needs met. Quite a lot of studies have shown that contemporary earth construction is sustainable and has the potential to address the urban housing crisis in developing countries (Brown, 2014; Egenti *et al*., 2014; Openator, 2014; Auroville Earth Institute (AEI), 2012; Deboucha & Hashim, 2011; Riza, *et al.*, 2011; Zami & Lee, 2011; Guillaud *et al.*, 1995; Rigassi & CRATerre-EAG, 1985). Due to its traditional thermal mass properties that allow for natural warming and cooling, external walls are regarded as contributor to the energy efficiency of buildings (Merwe, 2011).

The study identified features of sustainable housing, established the awareness levels of CEB and sandcrete blocks for building, compared sustainability concepts in both CEB and Sandcrete blocks and established CEB suitability for housing provision.

MATERIALS AND METHODS

Combination of questionnaire survey and observation (based on laboratory tests) were adopted to collect data for the study. Purposive sampling technique was used to determine the professionals (Architects, Builders and Structural Engineers) that responded to the survey within Kaduna Metropolis in order to establish awareness level, applicability/sustainability of CEB and sandcrete blocks. Based on this, 33 well-structured questionnaires were self-administered to these professionals and 29 completed questionnaires were retrieved.

In a related development, experiments (laboratory tests) were conducted so as to validate the suitability of CEB for building in three States (Kaduna, Plateau and Niger) in Guinea Savannah Zone Northern Nigeria. Two types of laboratory tests were carried out; the preliminary tests (grain size distribution, plasticity, compaction and particle density) on the soil samples and the mechanical tests (water absorption, compressive strength and density) on CEB to ascertain its strength for housing development. The soils were obtained from laterite borrow pits and other sites from the study areas as presented in Table 1. The tests were carried out in three different laboratories namely the Nigerian Building and Road Research Institute (NBRRI) Abuja, the Civil Engineering and Building Departments, Federal University of Technology, Minna. The tests were carried out in accordance with BS 1377-2:2022.

The data collected were analysed frequency count and percentages with the aid of SPSS 20.

Table 1: Brick Production Description

Group	Laboratory	Soil Extraction Location	Description	Quantity of bricks	Size of bricks
1	Civil Engineering and Building Dept FUT, Minna	Bosso, Niger State- Gidan Kwano	Soil; water and 0% cement	6 bricks	222x190x150mm
2		Bida, Niger State – Edokota borrow pit Bida	Soil; water and 2% cement	6 bricks	
3		Chikun, Kaduna State - Damashi	Soil; water and 4% cement	6 bricks	
4		Jaba, Kaduna State – Nok	Soil; water and 6% cement	6 bricks	
5			Soil; water and 8% cement	6 bricks	
1	NBRRI, Abuja	Bassa, Plateau State - Rukuba	Soil; water and 0% cement	6 bricks	222x190x150mm
2		Jos South, Plateau State – Rayfield borer pit	Soil; water and 2% cement	6 bricks	
3			Soil; water and 4% cement	6 bricks	
4			Soil; water and 6% cement	6 bricks	
5			Soil; water and 8% cement	6 bricks	

RESULTS AND DISCUSSION

Awareness/Application and sustainability qualities of CEB and sandcrete blocks

Table 2 shows the demographic information of the respondents. The respondents that fell 41 years and above with highest percentage at 51.5%; the Architects the highest respondents at 45.5% and 16 people 21years and above at 48.5%.

Table 2: Demographic information of respondents

S/N	Respondent Data		Frequency	Percent
1	Age	18-30yrs	5	15.2
		31-40yrs	11	33.3
		41yrs – above	17	51.5
2	Profession	Architect	15	45.5
		Structural/Civil Engineer	10	30.3
		Builder	8	24.2
3	Years of practice	0-10yrs	7	21.2
		11-20yrs	10	30.3
		21yrs and above	16	48.5

The result in Table 3 displays the level of awareness of both CEB and sandcrete blocks by the respondents. 88.48% indicates the highest level of awareness which is sandcrete block. 100% of respondent said that they had seen more of building made from sandcrete blocks than CEB while 30.3% have read of CEB.

Table 3: Awareness Level of CEB and Sandcrete Blocks

Which of the Materials are you More Aware of and how?

s/no	**Item**	**Compressed Eartl Bricks**		**Sandcrete Blocks**	
		Freq	**Percent**	**Freq**	**Percent**
i.	Heard of it more	1	3.0	32	97.0
ii.	Read/Studied about it more	10	30.3	23	69.7
iii.	Seen it more	0	0.0	33	100.0
iv.	Applied it in project(s) more	3	9.1	30	90.9
v.	Inhabit(ed) a structure made of it	5	15.2	28	84.8
	Cumulative Percentage		11.52		88.48

Table 4 shows the sustainability qualities of building materials and indicates which of CEB and sandcrete blocks exhibits more of these qualities. The table indicates that for economical sustainability CEB have a cumulative percentage of 74.99 while sandcrete blocks are lesser at 25.01. CEB is more environmental sustainable as is indicated with 79.10% while sandcrete blocks is more socio-cultural sustainable having 53%. The cumulative percentage of 67% indicates that CEB is a more sustainable building material.

Findings from the study indicates that CEB is relatively cheaper than sandcrete blocks arising from factors such as plastering, painting, less mortar, low maintenance, energy efficient (reducing cost of achieving mechanical ventilation since it produces conducive space).

The responses from the questionnaires reveal that sandcrete block building material is more known, popular, accepted and applied in the study area. The sustainability qualities such as economical (affordable, marketable, easy technique/skill production, employment opportunity and continuity quality in production) has high percentages for CEB above 70. In line with Hanafi (2021) and Saad *et al.* (2020), CEB environmental sustainability is high at above 70% including constituent material availability, strong to withstand forces, energy efficient (conserves and/or generates), non-toxic, thermal comfort and biodegradable while socio-cultural sustainability sandcrete blocks has good users-perception at 60.6% and acceptability at 81%.

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Table 4: Sustainability Qualities of CEB and Sandcrete Blocks

Which of CEB or Sandcrete Blocks do you think have the following Application and Sustainability Qualities?					
s/n	**Item**	**Compressed Earth Bricks**		**Sandcrete Blocks**	
		Freq	**Percent**	**Freq**	**Percent**
Economical Sustainability					
i.	Affordable	28	84.8	5	15.2
ii.	Marketable	24	72.7	9	27.3
iii.	Time saving in production	23	69.7	10	30.3
iv.	Easy to Use	21	63.6	12	36.4
v.	Easy Technique/Skill production	28	84.8	5	15.2
vi.	Employment Opportunity	27	81.8	6	18.2
vii.	Modern material	22	66.7	11	33.3
viii.	Continuity quality in production	25	75.8	8	24.2
			74.99		**25.01**
Environmental Sustainability					
ix.	The constituent material is readily available	28	84.8	5	15.2
x.	Durable	20	60.6	13	39.4
xi.	Strong to withstand forces (weather, natural)	27	81.8	6	18.2
xii.	Energy efficient (conserves and/or generates)	33	100.0	0	0.0
xiii.	Non-toxic	32	97.0	1	3.0
xiv.	Recyclable	26	78.8	7	21.2
xv.	Thermal comfort qualities	33	100.0	0	0.0
xvi.	Biodegradable	31	93.9	2	6.1
xvii.	Flexible in use	18	54.5	15	45.5
xviii.	Aesthetical	19	57.6	14	42.4
			79.10		**20.90**
Socio-cultural Sustainability					
xix.	Good users-perception	13	39.4	20	60.6
xx.	Encourages Community participation	19	57.6	14	42.4
xxi.	Acceptable	6	18.2	27	81.8
xxii.	Showcases Cultural heritage and identity	27	81.8	6	18.2
			47		**53.0**
	Cumulative Percentage		**67.03**		**32.97**

Laboratory Test Results and Analysis

Texture/grain size distribution test: From the grading curves in Figure 3, soils from all the sites had fine graded soils except for that from Bida and Jos South. The particle sizes of the soils tested were at right proportions required for use in construction of buildings following the generally accepted grades of soil proportion for use: Gravels, 0-40%; Sands, 25-80%; Silts, 10-25% and Clays, 8-30%.

Plasticity (Atterberg Limits) test: In Figure 4, Bida and Nok soil samples conformed to A-3 of AASTHO classification, which is fine grained soil and had liquid limits of 31%; 39% while the plasticity indexes are 16%; 18% respectively. Bosso, Damashi, Jos South and Bassa soil samples conformed to A-7-6 of AASTHO classification which is clayey soil and they had 43%; 49%; 46% and 43% liquid limits and 13%; 21%; 15%; 15% plasticity indices respectively.

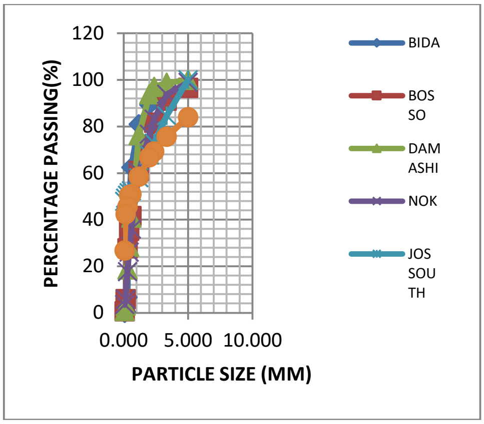

Figure 3: Sieve Analysis of the soil samples

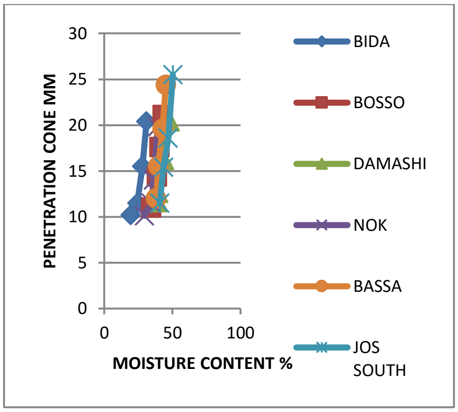

Figure 4: Atterberg limit of the soil samples

According to Riza *et al.* (2011), the recommended plasticity index for suitable soils should fall within the range of 15-25%. The soils investigated had plasticity indices within 15% to 21% with exception to Bosso, Niger State with 13 % which can be taken as negligible.

*Specific gravity test***:** In Table 5, the Particle Density results obtained from the soil samples of Bida, Bosso, Nok, Damashi, Jos South and Bassa have average specific gravity of 2.55kg/m^3, 2.39kg/m^3, 2.44kg/m^3, 2.32kg/m^3, 2.49kg/m^3 and 2.46kg/m^3 respectively. This value classifies the Bida soil sample as a coarse aggregate at above 2.50kg/m^3 and will not produce bricks having as much strength as other sites.

Table 5: Summary of Specific Gravity (Particle Density) Test

Summary of Specific Gravity (Particle Density) Test				
Site	Specific (Kg/m^3 gravity	Particle density	Average particle density (Kg/m^3)	Particle remark
Bida	2.65	2.45	2.55	Coarse aggregate
Bosso	2.38	2.40	2.39	Fine aggregate
Nok	2.67	2.22	2.44	Fine aggregate
Damashi	2.56	2.08	2.32	Fine aggregate
Jos South	2.50	2.47	2.49	Fine aggregate
Bassa	2.45	2.47	2.46	Fine aggregate

Compaction test: From Figure 5, Bida, Nok, Damashi soil samples are inorganic clay of medium plasticity and for each samples their Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) are minimum 15.5% and 1.9g/cm^{3}respectively. While, soil samples from Bosso is organic silt clay of low plasticity; Jos South is organic clay of low plasticity and Bassa inorganic clay of low plasticity.

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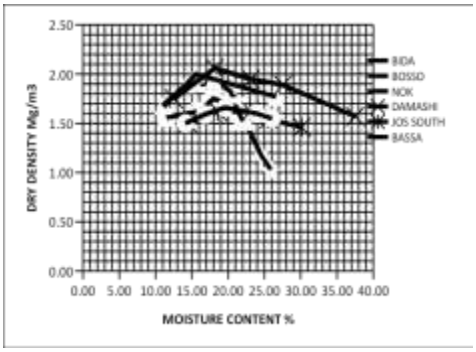

Figure 5: Compaction test of the soil samples

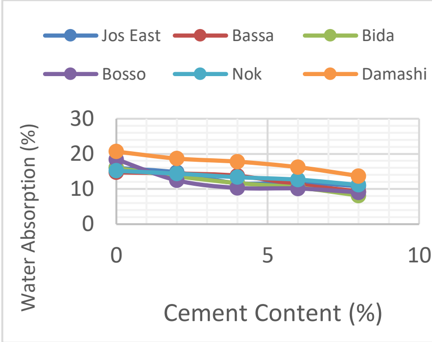

Figure 6: Water absorption test of the soil samples

Water absorption test: Figure 6 depicts the percentage of water absorption ratio to cement content for bricks produced from soils collected from all the sampled sites. It shows that Bosso, Bida, Nok, Damashi, Jos South and Bassa soils had water absorption at 18.4%, 16%, 15.2%, 19.7%, 16% and 14.7% respectively at control level of 0% cement content. The water absorption rate kept dropping at the addition of cement and reached the minimum at varying percentages with the least at 8% cement content each. Only Bosso at 10.27% and Jos South at 11.15% attained the appropriate minimum water absorption require for the use of CEB with 4% cement content. With 6% cement content, Bida, Bosso, Nok, Damashi, Jos South and Bassa reached 10.4%, 10.1%, 12.1%, 14.2%, 10.9% and 11.3% respectively; putting all at appropriate water absorption rate except for Damashi. At 8% cement mix, all samples attained the required minimum water absorption in the following ratio Bosso at 9.0%, Bida 8.1%, Nok 11.2%, Damashi 11.7%, Jos South 9.8% and Bassa at 9.3%. The result indicates that all the bricks tested were suitable for building but at varying cement mixtures with minimum of 4% and maximum of 8%.

For the percentage of cement added from 2%, 4%, 6% and 8% with a control of 0% the water absorption for Niger, Kaduna and Plateau States were found to be in the range of 9-12% after seven days curing, a percentage within the recommended 12% maximum in the African Regional Standards [ARS-674] (1998).

Density test

The density of the CEB is within the range of 1600kg/m3-1800kg/m3. There was also an indication of density is direct proportionate to compressive strength, the higher the density the higher also the compressive strength in line with BS-1377-4 (1990) and BS=1377-2(2022).

Table 6: Summary of Density Test Result

Summary of Density Test Result						
Cement Content (%)	**Bida Density (kg/m³)**	**Bosso Density (kg/m³)**	**Nok Density (kg/m³)**	**Damashi Density (kg/m³)**	**Jos South Density (kg/m³)**	**Bassa Density (kg/m³)**
0	1728.00	1728.00	1728.00	1728.00	1744.9	1744.9
2	1704.00	1704.00	1704.00	1704.00	1753.8	1753.8
4	1752.00	1760.55	1752.00	1760.55	1752	1760.6
6	1797.33	1792.00	1797.33	1792.00	1797.33	1792
8	1829.00	1820.28	1829.00	1820.28	1829	1820.3

Compressive strength test: CEB was produced in cement percentages of 0; 2; 4; 6; and 8% from samples collected; the bricks were produced into five groups depending on the percentage of the cement added; these were manually and dynamically compressed at medium pressure and cured for 7days and 28days respectively.

Figures 7 and 8 show the compressive strength of CEB at varying cement content ratios at 7 and 28 days curing periods respectively. The minimum compressive strength for Bida and Bosso were at 0% cement content and consist of 0.47 N/mm^2, 0.71 N/mm^{2}for 7days and 0.56 N/mm^2, 1.28 N/mm^2 for 28days respectively while the maximum compressive strengths were at 8% cement content with 1.83 N/mm^2; 2.57 N/mm^2 for 7days and 28days at 3.01 N/mm^2; 4.42 N/mm^2. The significant increase was on 6% cement stabilisation with Bida at 1.59 N/mm^2 and 2.67 N/mm^2 from 1.04 N/mm^2 and 1.29 N/mm^2 respectively in 4% stabilisation while Bosso increased majorly between 6% and 8% from 1.47 N/mm^2 to 2.57 N/mm^2 and 3.0 N/mm^2 to 4.42 N/mm^2 for 7 and 28 days respectively. The result therefore indicates that for Bida the compressive strength of the soil at both 7 and 28 days is appropriate at 6% cement stabilisation while Bosso is best at 8% for 7days and 2% at 28days given that the African Regional Standards [ARS-674] (1998) specified that the minimum compressive strength for CEB should be 1.6N/mm^2 (240psi).

The Nok mould bricks attain higher and quicker compressive strength both at increase in cement content and curing days as compared to Damashi with gradual increase. The appropriate compressive strength of the bricks made from both soil samples of Nok and Damashi are at 1.97, 2% for 7days; 2.67 N/mm^2, 6% for 28days and 2.41, 8% for 7days and 1.71, 6% for 28 days respectively. Therefore, the stabilisation of the soil samples with 6% of cement is adequate for both bricks. The Bassa LGA bricks have the highest compressive strength with considerably increase at 28 days as compared to Jos South. In 7days both Jos South and Bassa bricks were suitable for use at 1.59 N/mm^2, 6% and 1.6 N/mm^2, 4% while in 28days they had appropriate compressive strength of 1.64 N/mm^2 at 4% and 1.6 N/mm^2 at 2% cement contents respectively and in 28days at 6% cement content they both had 2.82 N/mm^2.

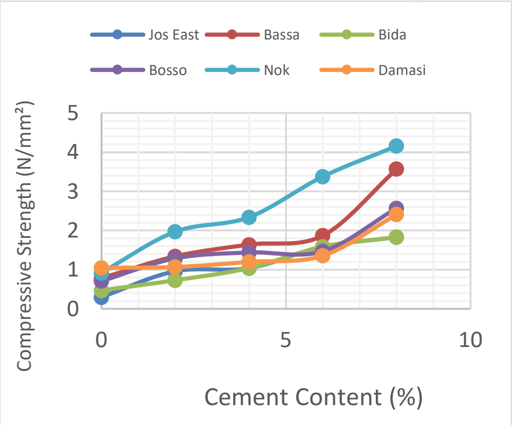

Figure 7: Comparative Compressive Strength at 7days of CEB

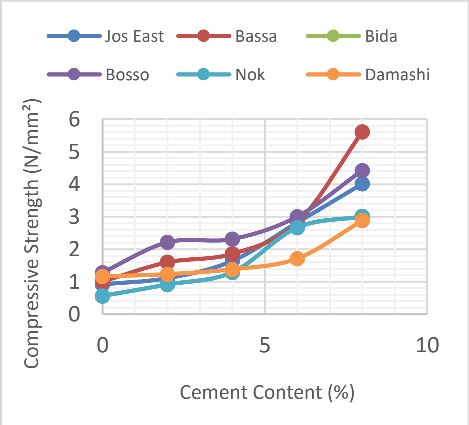

Figure 8: Comparative Compressive Strength at 28days of CEB

The results indicate that in 7days, bricks from Nok have the highest compressive strength and Bida has the least. While in 28days the maximum compressive strength is Bosso but dropped at 8% cement content and the minimum is Nok but picked up considerably at 6% cement stabilisation. Following the African Regional Standards for CEB (ARS-674:1998) and National Building Code (2018) which permits that the minimum compressive strength for CEB be 1.6N/mm^2 and 12% minimum for water absorption; the bricks from each of the sites indicated appropriate for use at either 2% or 4% but averagely 6% and all at 8% cement stabilisation. The charts also indicate that addition to cement substance and days of curing increases the strength of the bricks.

The bricks produced from the sample soils have average compressive strengths at varying cement ratio meeting the minimum strength at worse condition 1.6N/mm^2 (240psi) as is recommended in African Regional Standards [ARS- 674] (1998) for CEB. The results clearly shows that the compressive strength of bricks increases as the proportion of cement was added; decrease in compressive strength of the earth bricks is as a result of increase in percentage of soil quantity and increase in water content as also agreed by UNHabitat (1992), Rigassi and CRATerre-EAG (1985) Minke (2009) and BS1377-2:2022.

CONCLUSION

Sustainable housing eliminates or reduces the effect of global warming and climate change; it is cost effective, giving rise to affordable housing; easy to maintain; healthy and safer. Sustainable housing features consider sites, energy, material and water efficiency; users' health and safety and building design, operation and maintenance. The comparative analysis carried out indicated that CEB is economical and sustainable in the sense that the constituent materials are easily available, cheaper production cost, production skill and techniques easier and with more employment opportunities. Environmentally, CEB is energy conserving and non-toxic, recyclable, with high thermal qualities while sandcrete blocks is said to be more durable. Socio-culturally, CEB promotes and preserves culture more. The results from the laboratory analysis indicated that the soils were suitable for brick production and the compressive strengths appropriate for construction. The study invariably implies that if CEB is used for all or most of the building elements from foundation to roof it will further reduce cost of mass housing development in Nigeria. The paper recommends that developers, Non-governmental organisations (NGOs), Governments housing development agencies commence the use of optimised CEB for sustainable large scale housing production in Nigeria.

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