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IMPROVISED TECHNIQUES OF EARTH BRICKS STABILISATION WITH CASSAVA STARCH

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ABSTRACT
Compressed Earth Bricks technology is anchored in an initial concern to provide a new, economically and socially relevant response to housing production for the World's very poor. As at now the information fully available on stabilisation of Compressed Stabilised Earth Bricks (CSEBs) with alternative materials are on partial replacement of cement but not the use of cassava starch alone. This work is aimed at improvising Earth Brick Stabilisation techniques with cassava starch as the only binder. The adopted techniques are 'Instant Dry Mix (IDM)'; 'Delayed Dry Mix (DDM)'; and 'Cooked Paste Mix (CPM)'. Mechanical properties of the specimens were determined after curing for 7, 14 and 28 days. From the results of Compaction Characteristics and Compressive Strength of samples at 28days, the CPM technique performs best with compressive strength of 2.71N/mm^2, greater than the NBRRI minimum requirement of 1.65 N/mm^2 for compressed earth bricks. The volume of cassava starch increases when cooked, therefore, it is concluded that CPM process is the most appropriate technique of cassava starch bricks (CSBs) stabilisation that can be cost effective in low-cost housing development. Bricks produced using CPM can be applied for the construction of walls in low rise buildings with proper protection from dampness as CS is susceptible to water.

KEYWORDS: *Alternative materials, Brick, Cassava starch, Housing production, Stabilisation*.

INTRODUCTION
Compressed stabilised earth bricks (CSEBs) are compressed earth bricks (CEBs) made up of soil, water, and a binder such as lime or cement to increase strength (Lime, 2001). CSEBs are applicable in various earth structures such as houses, garages, workshops, garden sheds, and a host of others. ILO-WEP (1997), posited that the appropriate stabilisation of CEBs requires soil containing fine gravel/sand as the skeletal frame of the brick, then silt and clay to bind the sand particles together while stabilisers are then added to control expansion, strength and abrasion. Stabilisation of soil with chemical binders such as cement, involves similar technique of mixing soil and binder in dry form first, followed by the addition water to produce sandcrete blocks and earth bricks.

CEB technology, as reviewed by GTZ (1995), is anchored in an initial concern to provide a new, economically and socially relevant response to housing production for the World's poor population. The very low carbon footprint of CSEB, compared to concrete materials and cement stabilised bricks, asserted by MecoConcept (2013), makes it an ultimate environmentally friendly building material. Further stabilisation of CEBs with a binding agent, produces CSEB which minimises linear expansion that occur when water is added to clay fraction and improves strength as well as controls abrasion.

Housing delivery is a major problem confronting the underdeveloped world with several housing policies put in place but without housing delivery. Population growth rate in these parts of the world is higher than the rate of housing provision because the actual housing delivery processes are not sustainable, (Daramola, Alagbe, Aduwo, & Ogbiye, 2013). Challenges of housing in terms of quality and quantity as observed by Ibimilua, (2011), seem to be the same all over the world. The poor have less access to housing while the rich have upper hand in accessing housing. In rural areas of Nigeria, housing is generally inadequate in terms of quality, while in urban areas the major problem is that of quantity. Enhancing the quality of buildings in rural areas requires the upgrading of rural building materials such as earth and local binders like *cassava* starch. In urban areas where shortage in quantity is experienced, developing cheaper but quality materials such as CSEBs would go a long way to ease the problem (Khalil, 2017).

Technological advancement has contributed to greater productivity and lesser construction cost and has even reduced the adverse effects of construction on the environment in many countries. But developing countries are far from the benefits of technology to meet the increasing demand of shelter for even the low-income population. The United Nations Centre for Human Settlements (UNCHS) over the past decades, has been promoting the development of appropriate, energy-efficient and environmentally-sound construction technologies, which heavily rely on locally available resources (HABITAT, 2008). The construction industry is said to be the backbone of national economic and social development as revealed by several studies such as (HABITAT, 1989); (Kerali, 2001) and (Namango., 2006). This is evident during the periods of national economic growth where construction activities grow more rapidly than the economy as a whole.

Earth, as Gernot (2007) posited, is a naturally available material which is easy to use even with low craft and skills. It absorbs and desorbs humidity faster to a higher extent than any other material; produces hardly any environmental waste; and balances indoor climate and moisture movements creating a healthy environment. Earth, according to Anant and Murmu (2018), is abundantly available in nature, has invariably been the major construction material for providing housing and other structures around the world. Globally, it is estimated that one third of the world's population lives in earth buildings acclaimed Little & Morton (2001). These are both modern and traditional buildings, which occur in most cultures and climates. In Nigeria, the basic wall construction material in most traditional architectures asserted by Egenti, Khatib, & Oloke (2014), is earth, usually arranged in simple low-cost and self-help construction methods.

Several simple publications on selecting earth materials and brick presses are available around the globe. Wayne (2011), sited that some of these publications are found with Brick pressing machine manufacturers and that the United Nations (UN) has simple soils testing information, while many universities provide tests for soils as well. In addition, soil engineering has been done in laboratories for road construction materials which are basically the same materials that are good for use in walls, floors and arched roofs. All these are based on cement, lime, and other chemical stabilising agents. As at now no information is fully available on processes of CSEBs stabilisation with cassava starch as an alternative material.

Cassava starch is an abundant and environmentally friendly additive that is used as soil stabiliser in mud walls and mud construction locally in some areas of Nigeria. Khalil (2005), asserted that cassava starch is used in the manufacture of conical mud balls (local walling units) called '*tubali'*, and also in wall rendering as stabiliser in some parts of Northern Nigeria.

According to Pacheco-Torgal & Jalali (2012), earth construction has received an increased attention by the scientific community in the 1990s as illustrated by several published research articles when compared to decades before then. Earth construction has a major expression in developing countries and its importance can be seen in some of the environmental benefits associated with it such as economic issues; renewable resource; little waste generation; energy conservation; minimal carbon dioxide emissions; and proper indoor air quality. Little & Morton (2001), have established that the principal reason for using earth-based materials is the excellent sustainability characteristics exhibited by these materials. These include low carbon emissions, efficient use of finite resources, minimising pollution, waste, and use of benign materials, local sourcing and biodegradability, but cassava starch cannot be applied in much the same way as cement in stabilizing soil for bricks production.

Cement is directly added to soil, mixed thoroughly before water is added to initiate the hydration process that binds soil particles together. Hydration does not occur when cold water gets in contact with cassava starch, therefore it is pertinent that brick stabilisation techniques with cassava starch (CS), are investigated so as to avail scholars and end users with firsthand information on its application as soil stabiliser.

MATERIALS AND METHODS

Materials

The materials for this research include laterite as the primary material; cassava starch as binder; and water.

Plate I: Laterite Soil

Plate II: *Cassava* Starch Powder

The laterite soil was obtained from a borough pit located at Biye in Sabon gari local Government Area of Kaduna State. The laterite was dried; screened pulverised and sieved through the No. 4 sieve (5mm aperture size). *Cassava* starch was obtained in granular form from Sabon gari market in Zaria, Kaduna State, Nigeria. It was washed to remove dirt before pulverising and sieving to powder as shown in plate II.

Methods

Unlike the application of water/cement ratio in the determination of mixing water in concrete or Sandcrete mixes, water requirement for soil stabilisation is determined from Maximum Dry Density (MDD). The MDD for control samples (0% stabilisation level), was achieved by using the proctor mould, 25kg rammer and a digital weighing balance in accordance with (BS1377, 1990). Mixing of the materials for stabilisation of experimental brick samples was conducted in accordance with stipulated standards.

There are no documented records of the methods of brick stabilisation with CS as stabiliser except for cement or lime stabilised bricks. However, three techniques were developed and applied based on soil/binder mixing methods, water/binder ratio, for example (water/cement ratio), workability, placing and brick pressing techniques reviewed from past research works such as [Gooding, (1993) Khalil, (2005); Abejide, (2007); and Khalil, (2017)]. Five levels of stabilisation (0, 5, 10, 15 and 20%) were applied throughout the work.

i. The procedure for compressing cement stabilised CEBs requires mixing of the soil and cement in dry form before adding mixing water and immediately pressing.

ii. In a local application of cassava starch to stabilise soil, the dry starch powder is mixed with the soil and water is sprinkled just enough to wet the mix, which is then covered with polythene material and left to stay overnight. The next day, more water is added to the soil/starch heap and trampled upon by the feet to achieve a consistent sticky mix from which '*tubali*' (local walling units) are rolled out.

iii. The technique applied by Khalil (2005), to stabilise soils with cassava starch, was by cooking the starch into paste.

The three techniques that emanated from these methods are:

A) Instant Dry Mix (IDM)

In this technique, the soil and stabiliser were mixed thoroughly in dry form according to the established proportions of stabilisation levels (5, 10, 15 and 20%). Calculated mixing water was then added, mixed to consistency and instantly pressed.

B) Delayed Dry Mix (DDM)

This technique started as in A. This time, the mix was then covered with polythene material and kept under the sun. Brick pressing was delayed for three days in order to allow the water to soak the CS and soil particles thoroughly.

C) Cooked Paste Mix (CPM)

In the CPM technique, CS was cooked into paste as explained in the next section and added to the laterite soil according to the stabilisation levels, mixed thoroughly and pressed immediately.

Preparation of Stabiliser for CPM.

Cassava Starch Paste Consistency (PC)

Cassava starch when cooked properly, produces a paste with clear appearance (Khalil I. M., 2005). Cold water was introduced into CS powder to produce slurry and stirred to dissolve the powder completely. Hot water at boiling point was then added to the slurry, which reacted by swelling and transforming into paste. The quantities of cold and hot water were varied while the quantity of powder was kept constant in order to achieve consistent paste by using the formulae in equations1 and 2, adopted from Khalil (2005):

$$L_S = S_p + C_w \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

and

$$U_{CP} = L_S + H_w \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where L_S = light slurry,
S_p = starch powder,
C_w = cold water
U_{CP} = uniform clear paste,
H_w = hot water.

Clear, thick and uniform paste with standard viscosity was achieved with a mix ratio of 1: $1^1/_5$: 4; dry starch powder to cold water to hot water at boiling point by weight.

Mix Proportions of materials in a specimen

Table 1: Specimen Mix Proportions by Addition (BS1377, 1990)

S/N	SPECIMEN	L (%)	CS (%)	TOTAL (%)	Remarks
1	L_0	100	0	100	Control specimen
2	LS_5	100	5	105	Cassava
3	LS_{10}	100	10	110	Starch
4	LS_{15}	100	15	115	Stabilised
5	LS_{20}	100	20	120	Specimens

Note: L = Laterite; S = Starch.

Brick pressing was achieved using the (NIBRRI) standard press with a pressure of about 4N/mm^2, (Ramson, 2011). The mould capacity was calculated using the bulk density of the materials and adding 5% in excess to cater for spillages and consolidation. The moulds were filled in three layers of about 30mm by hand so as to ensure uniform distribution of the mix inside the mould. Excess material was scraped off the top of the mould before closing the lid and pressing.

Curing

The method applied in this work was open-air curing under shed, considered as the best method for bricks produced with CS (Khalil, 2017).

RESULTS

Table 1: Moisture Content (MC) and Specific Gravity (SG)

MATERIALS		S	L
TESTS	MC	16.90	16.16
	SG	1.40	2.06

Note: L = Laterite; S = Starch.

Moisture Content

The moisture contents were calculated gravimetrically and the results shown in table 2. The moisture contents of cassava starch and laterite are close, 16.90 and 16.16 respectively.

Specific Gravity

As shown in table 2, the specific gravity of the soil 2.06 is almost twice the specific gravity of cassava starch, 1.40. This is the basis for adopting mix proportions by volume instead of weight.

Table 2: Soil Characterization

MATERIAL			
	(i) SEDIMENTATION TEST		
	Composition		**% Fraction**
	Gravel Fraction: (≤ 5 mm)		46.96
	Sand Fraction: (0.6 – 0.2 mm)		26.96
	Clay Fraction: (≤ 0.002 mm)		15.40
	Silt Fraction: (0.02 – 0.006 mm)		9.57
	(ii) PARTICLE SIZE DISTRIBUTION		
	BS SIEVE NO.	**APARTURE SIZE**	**% RETAINED**
	4	4.76mm	7.5
Laterite Soil	7	2.36mm	14
	16	1.18mm	19.9
	25	600µm	18.7
	52	300 µm	22.1
	100	150 µm	9.1
	200	75 µm	0.6
		Pan	8.1
	(iii) ATTERBERG LIMITS		
LL	**PL**	**PI**	**L_{sh}**
32.38	23.61	8.77	1.86

Note: LL = Liquid Limit; PL = Plastic Limit; PI = Plasticity Index; L_{sh} = Shrinkage Limit

Soil Characterization

i. Sedimentation: From table 3(i), 9.57% silt content is within the required limits; 15.4% clay content is sufficient and the combined sum of clay/silt fractions, 24.97% is greater than the minimum requirement of 10% according to Kenya standard. The coarse and fine sand fractions totaling 73.92% is adequate for limiting shrinkage.

ii. Particle Size Distribution: Table 3(ii) shows the percentages of soil particles retained on each sieve size and pan during sieve analysis. The lateritic soil had falling within zone II and was well graded (BS410 1996).

iii. Atterberg Limits: From table 3(iii), the respective values of LL; PL and PI are 32.38; 23.61 and 8.77. The shrinkage limit 'L_{sh}' recorded for this lateritic soil is 1.86.

The bases of this work is to develop an appropriate technique for brick stabilisation with cassava starch. The parameters deemed adequate in establishing the properties required of CSBs to function as construction bricks are compaction characteristics and compressive strength. The data from these tests were analysed appropriately for the three techniques applied and the results presented in tables, figures and charts.

Compaction Characteristics

The key feature of CEB technology is the compression of soil in a mould using a press with compaction effort ranging from low, medium to high. The medium compaction effort ranges from 2 – 4 MN/m^2 or 2 – 4 N/mm^2. The NBRRI brick press used in this work has a pressure of $4N/mm^2$, (Ramson, 2011), which is the compaction effort constantly applied in producing all samples.

Cassava Starch Stabilised Brick Densities

Unlike concrete samples which must be taken to saturated oven dry conditions before determining density, it is the dry density (DD) that is commonly used for soil samples as specified in (BS1377, 1990). The formula used for calculating 'δ_d' is given by equation 3:

$$\delta = \frac{m}{v} kg/m^3 \quad \text{……………………..…. (3)}$$

Where: δ = density of sample
m = mass of sample
v = volume of sample

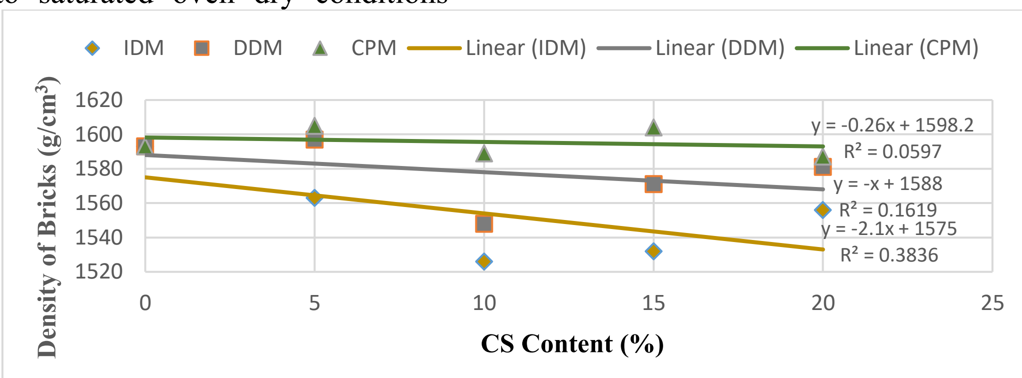

Figure 1: Dry Densities of Compressed Stabilised Bricks at 28 days

From figure 1, IDM technique produced brick samples with the lowest densities ranging downwards from $1575g/cm^3$ to $1535g/cm^3$ as the overall lowest. Higher densities were achieved by the CPM technique with the highest density being $1600g/cm^3$ after 28 days of curing. Density value of the DDM technique fell in-between the former techniques.

Compressive Strength

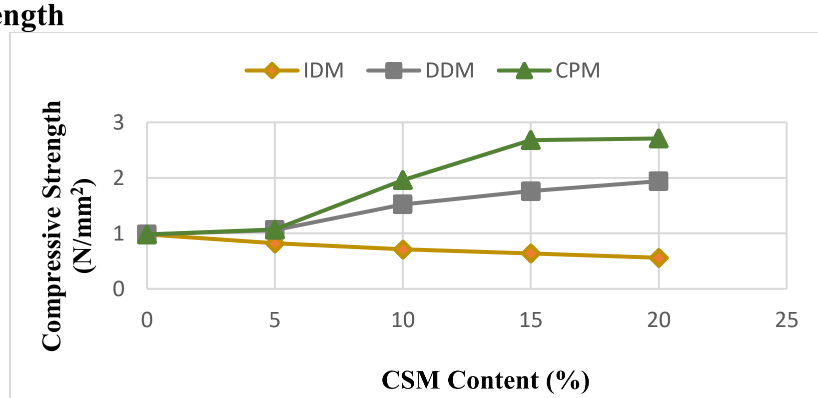

Figure 2: Relationship between Compressive Strength and CS at 28days

Figure 2 depicts the compressive strength of brick samples developed by the three stabilisation techniques at 28 days. The least strength, 0.56N/mm^2 was achieved by the (20%) CS content of the IDM technique where the strength of stabilised samples fell below that of the control sample. Moderate strengths ranging from 1.06N/mm^2 at 5% to 1.94N/mm^2 at 20% CS contents were obtained by the DDM technique. CPM technique developed the highest strengths from 1.07N/mm^2 at 5% to 2.71N/mm^2 at 20% CS content.

DISCUSSIONS

Results of this test were used to compare the three brick stabilisation techniques as shown in figure 1. The relationship between density of bricks and CS content was observed to obey the law of inverse proportionality because, as CS content increased, densities of the samples kept decreasing. This pattern was highest in IDM with R^2 value of 0.38 (the steepest gradient) while the CPM technique displayed a gradual slope with R^2 of 0.06 indicating it as the best for CEBs stabilisation. The simple explanation to this pattern is that firstly during mixing, required mixing water was higher in IDM whereas in CPM the moistened paste was enough to facilitate mixing especially at the 15% and 20% stabilisation levels. Secondly, the soil particles must have been lubricated by the starch paste which aided densification, a phenomenon absent in the dry mix.

Compressive Strength CS is the single most important factor controlling durability which according to Minke, (2000), depends on the quantity and type of clay, grain size distribution of silt, sand and larger aggregates as well as the method of preparation and compaction.

Figure 2 represents the responses of test samples to increase in CS content with respect to strength. The CPM technique of stabilisation is also seen to be the most appropriate as regards strength development because strength gain continued from 5% to 20% CS content. DDM followed with a similar pattern but lower values. The values for IDM kept decreasing as CS increased and all fell below the control level, an indication that this technique is not appropriate. The reason behind this assertion is that no chemical reactions exists when water is added to the dry mix of laterite and cassava starch as compared to the hydration reaction of cement with water. The characteristics of DDM are of special interest in that the qualities exhibited by this method are closer to those of CPM. Although the mix contents of DDM are the same as those of IDM, the explanation to the positive response to stabilisation of the former could be attributed to the delay before pressing as explained earlier.

During the day time, effect of direct sunlight on the covered mix have raised the internal temperature of the soil/starch heap to about 60^{0}C and the absence of air movement had also increased the humidity. This warm moisture within the heap dissolved cassava starch and gradually cooked it into paste. Towards evening time when the temperature outside dropped, the covered heap was still humid. At night when the heat trapped during the day by the earth crust was released upwards, this too acted as a cooking process, thus the DDM turned out to be a better stabilisation technique than the IDM.

CONCLUSION AND RECOMMENDATION

Conclusion

Cassava Starch Bricks (CSBs) produced by CPM as the optimal technique is discovered to achieve compressive strength above the minimum requirement of NBRRI (2.71N/mm^2 to 1.65N/mm^2; CSB to NIBBRI) respectively. This technique is the most appropriate technique because among the parameters tested, CPM samples offered the best results. The technique requires the generation of heat only to about 100^{0}C, which is considered as very low and sustainable compared to the heat needed for the production of cement and burnt bricks, (about 1500^{0}C). This method of bricks production is none toxic therefore, environmentally friendly, requires little skill and costs less as laterite is abundant and cassava starch is very cheap/renewable and applicable even in rural areas for affordable housing.

Recommendations

The optimum level of cassava starch in soil stabilisation for the purpose of bricks stabilisation should not go beyond 20%. Cassava starch stabilised laterite soil could be utilised for load bearing walls, partition walls, cast walls, composite walls; rammed earth/poured earth constructions; and for esthetic designs as the surfaces of the bricks may not require finishing in the form of plastering, cladding or painting. However, CSB walls must be protected from moisture as cassava starch is susceptible to water, perhaps further research on this shortfall of CSBs would proffer a remedy.

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