Nigerian Journal of Technology (NIJOTECH)
Vol. 42, No. 2, June, 2023, pp.191 - 198
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
https://doi.org/10.4314/njt.v42i2.5

EVALUATION OF COMPRESSIVE STRENGTH AND ABRASIVE PROPERTIES OF RICE HUSK ASH – CEMENT COMPRESSED STABILIZED EARTH BRICKS

A. O. Olumodeji[1], F. O. Ayodele[1, *] and K. D. Oluborode[1]

[1]Department of Civil Engineering, The Federal Polytechnic Ado-Ekiti, Nigeria

*corresponding author (Phone Number: +234-806-139-4021. Email: ayodele_fo@fedpolyado.edu.ng)

Article history: Received 15 January, 2023. Revised 12 April, 2023. Accepted 13 April, 2023. Published 31 July, 2023.

Abstract
Cement, the most utilized building material in developing countries like Nigeria, is rising daily, making it hard for low-income people to acquire a home. This study aimed at producing compressed stabilized earth bricks (CSEBs) from Rice Husk Ash (RHA) and cement. After uncontrolled calcination of rice husk, the RHA oxide compositions were assessed by X-Ray Fluorescence. Design Expert (RSM) designed mix proportions for seventeen earth brick variables. Cement-RHA-Soil was blended with 0-5% cement and 20-25% water. Box Behnken Design (BDD) of Response Surface Methodology (RSM) in Design Expert Version 6 was used to generate seventeen (17) design mix proportions (variables) for the CSEBs. After damp curing for three days, compressed stabilized earth bricks (CSEBs) were evaluated for compressive strength and abrasion at 28, 56, and 108 days. RHA was pozzolanic because its major oxides (SiO_2, Al_2O_3, and Fe_2O_3) yielded 75.27%. CSEB compressive strength improved with age. RCB16- CSEBs with 2.5% RHA+2.5% Cement+21.25% WC - exhibited the best compressive and abrasion strength. Thus, RHA is a good cement replacement in CSEB production for cheaper and sustainable building.

Keywords: Earth bricks, Building, Compressive strength, Abrasion, Sustainability.

1.0 INTRODUCTION

Shelter is a basic human need but owning a house is a long-life struggle for low-income earners in developing countries because they find housing cost unaffordable because of the cost of building materials [1]. In the olden days, dating back to 7000 BC, construction was done with earth bricks [2]. These earth bricks also known as mud bricks can either be unfired or fired [3], comprising clay, water, and binding material. The common methods of this earth construction are rammed earth, straw, clay, wattle and daub, shaped earth, extruded earth, cob and compressed earth, and adobe (mud) bricks [4]. The bricks have also found their application useable as pavement materials. Although they are low-cost, versatile, and durable building construction materials with good load-bearing properties, high thermal mass, and low energy impact [5], they mostly suffer deterioration at an alarming rate due to weather conditions and high rates of flood. Also, the dearth of information about its mechanical properties and no accurate design code for producing these bricks are huge drawbacks [1]. An improved form of earth bricks (mud bricks) is compressed stabilized earth bricks (CSEBs) which are produced by compressing a mixture of water, ordinary Portland cement (OPC), soil, and sand. It is a widely-known and sustainable material with good strength and improved insulation properties [6]. Also, its ease of production, reduction in transportation cost, utilization of local materials, aesthetics, low emission (environmental friendliness), durability, better fire resistance, sound-proofing property, and better energy efficiency gives it an edge over other masonry products/materials.

Cement is the most common binder used to improve the strength properties of earth bricks but due to its high cost, there is a need for locally manufactured supplementary building material with low cost which will also be locally available and affordable to improve the strength of the earth bricks. This will allow low-income earners in developing countries like

Nigeria the opportunity to own a house. The use of alternative but locally available materials will also reduce environmental problems such as the emission load of about 2070×10^6 tons of CO_2 [2] and address the depletion of resources associated with the production of cement and other building materials [7]. These alternative construction materials may be fibres, shells, ashes (Pozzolanic or Non-pozzolanic), etc. [8]. Pozzolans are supplementary cementitious materials that when added to Portland cement, contribute to the properties of the hardened concrete through hydraulic or pozzolanic activities or both. Pozzolans are also notable additives in soil stabilization and earth bricks production. Pozzolans include fly ash, and raw or calcined natural pozzolans which include among others; volcanic ashes, diatomaceous earth, opaline cherts, tuffs, shales, and various materials requiring calcination to induce satisfactory properties. Pozzolanic materials play an important role in terms of cost reduction and other technical benefits such as enhanced strength development, mitigation of thermal effect from cement, etc. Pozzolanic waste materials are noted to be efficient in reducing CO_2 emissions of cement and construction industries as well as wastes [9].

Several additives (Pozzolanic or Non- Pozzolanic) have been assessed in developing countries with a view of using them for civil engineering construction. They include rice husk ash, locust bean waste ash, ash, marble dust, palm bunch ash, natural Pozzolana, fly ash, palm kernel shell ash, corn cob ash, eggshell, bamboo leaf ash, wood ash, quarry dust, sawdust ash, coconut shell ash, waste paper ash, cow bone powder, palm oil fuel ash [10]. The pozzolanic materials are mainly from agro-based resources because of the agrarian nature of their economy and livelihood. Nigeria in particular is known for growing crops including rice, maize, oil palm, cassava, etc. Rice is grown heavily in Nigeria, both within the Southern and Northern parts of Nigeria. Rice grain contains about ten percent (10%) husk and twenty percent (20%) resultant rice husk ash (RHA) is obtained after combustion [11]. Rice husk ash has been used for partial replacement of cement in civil engineering constructions which has now drastically reduced the level of pollution of this agricultural waste in the environment. However, there is little information about the mechanical properties of CSEBs modified with combined RHA and Cement. Hence, this study is significant as it will provide baseline data on the use of RHA + Cement in modifying properties of CSEB and ultimately expand frontiers on the useability and performance of the RHA-Cement-CSEBs. The objectives of this study are to (i) determine some geotechnical properties of the lateritic soil (ii) assess the chemical properties (oxide composition) of the binders (RHA and Cement) (iii) evaluate compressive strength and abrasion properties of the RHA – cement – modified earth bricks.

2.0 MATERIALS AND METHODS

2.1 Materials Sampling

The rice husk was obtained from a rice mill in Igbemo-Ekiti, Ekiti State in Nigeria, sun-dried and burnt openly. It was allowed to cool after which it was sieved through a 300µm sieve. The rice husk and RHA are shown in Figure 1. Portland limestone cement CEMII/A-L was also obtained from a local retail store. Lateritic soil was obtained from a borrow pit along CBN, new Iyin road, Ado-Ekiti. The Oxide composition of the RHA was carried out at Lafarge Cement Laboratory (Lafarge Readymix Nigeria Limited) Oregun, Lagos, Nigeria.

Figure 1: Rice husk and RHA

2.2 Methods

Oxides present in the Rice Husk Ash were determined using X-Ray fluorescence (XRF). Particle size distribution, Specific gravity, and Atterberg limits were performed on the lateritic soil following [12] and the soil was classified according to Unified Soil Classification System (USCS) standard. The CSEBs were mixed in proportion. These proportions were generated using RSM of Design Expert, Version 6. RSM is a proficient statistical tool useful in experimental design, particularly in generating varied runs (variables) [13]. Binder (RHA and cement) in the range of 0 – 5% was adopted based on literature findings that CSEBs are typically made with 5 - 10 % cement (a conventional binder) [14 – 18]. The conventional binder' proportioning was then structured by replacing partially with RHA. The water content range of 20 – 25% of the total dry mass of the total constituents, obtained after a series of trial mixes and procedures was the range structured by RSM. The obtained mix details are shown in Table 1. The bricks were produced with a brick moulding machine by mixing 4.5 kg of the soil, water, rice husk ash, and cement in varying proportions manually and fed into the machine which compresses the mixture to form the bricks. The bricks were compressed mechanically by the brick moulding machine rammer. The CSEBs were first subjected to damp curing for three days by covering them with plastic bags after which they were air dried to complete 28 days, 56 days, and 108 days. The compressive strength of the CSEBs was done using a compression testing machine while the abrasion resistance was conducted following the method prescribed by [19]. Analysis of Variance (ANOVA) was done to determine the effect of the binder (RHA and Cement) and the addition of water on the strength and abrasion resistance of the CSEBs. Figure 2 presents the research framework.

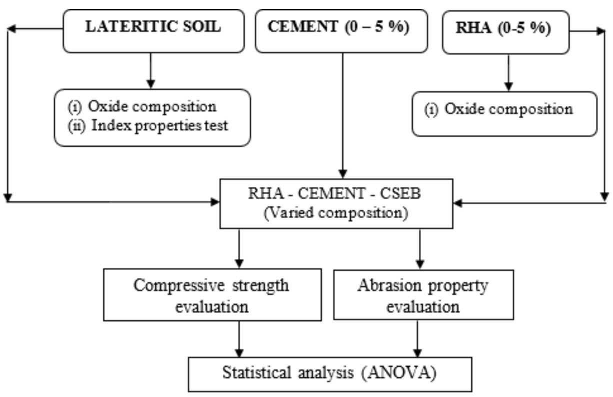

Figure 2: The research framework

Table 1: Mix proportions for samples of the CSEBs

Variables	Material Proportioning			Sample ID
	RHA (%)	Cement (%)	Water Content (%)	
1	3.75	1.25	21.25	RCB1
2	0	5	20	RCB2
3	1.25	3.75	22.50	RCB3
4	1.25	3.75	21.25	RCB4
5	5	0	20	RCB5
6	0	5	25	RCB6
7	3.75	1.25	22.50	RCB7
8	1.25	3.75	23.75	RCB8
9	5	0	25	RCB9
10	3.75	1.25	23.75	RCB10
11	0	5	22.50	RCB11
12	2.50	2.50	22.50	RCB12
13	5	0	22.50	RCB13
14	2.50	2.50	23.75	RCB14
15	2.50	2.50	25	RCB15
16	2.50	2.50	21.25	RCB16
17	2.50	2.50	20	RCB17

3.0 RESULTS AND DISCUSSION

3.1 Oxide Composition Of Rice Husk Ash (Rha)

The oxides of silicon, iron, and aluminium present in the ash are shown in Table 2. The sum of the three oxides (SiO_2, Fe_2O_3, Al_2O_3) is greater than 70 percent and it, therefore, indicates that the rice husk ash is pozzolanic according to [20].

3.2 Physical Properties of the Lateritic Soil

The properties of the soil indicated that it is coarse-grained according to USCS. It contains gravel of 2.3%, sand of 51.5%, and fines of 46.2% (silt is 41.0% while the clay fraction is 5.2%). The soil is classified as SM, coarse-grained soil. The Atterberg limit result of the lateritic showed that the soil has a liquid limit (LL) of 43.1%, a plastic limit (PL) of 27%, and a resultant Plasticity Index (PI) of 16.1%. [19] reported that the manufacturing of good quality, durable compressed stabilized earth bricks requires the use of soil containing fine gravel and sand for the body of the brick, together with silt and clay to bind the sand particles together. The LL and PI of the soil sample showed that the soil can be used for earth bricks production since it falls within the limit of 25-50 and 3-29 respectively as specified by [21]. The summary of the soil properties is presented in Table 3.

Table 2: Oxide composition of RHA

Parameter	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	M_2O_5	P_2O_5	TiO_2	LOI	Total
%	71.4	0.5	3.4	2.8	2.1	0	1.3	0	0	4.3	0	19.0	104.8

Table 3: Summary of soil properties

Properties	Soil Sample
Colour	Reddish Brown
% Passing 0.075 mm sieve	46.2
Liquid limit (%)	43.1
Plastic limit (%)	27.0
Plasticity index (%)	16.1
Specific gravity	2.6
USCS	SM

3.3 Compressive Strength of Compressed Stabilized Earth Bricks

Compressive strength measures the ability of a brick to withstand compression. It is the most universally accepted value for determining the quality of bricks. Nevertheless, it is instenselyrelated to the soil type and the content of the stabilizer. The results of the compressive strength of brick at ages 28, 56, and 108 days are shown in Figure 3. The observed trend is consistent with the findings of [22] that an increase in curing age will result in a corresponding increase in strength. The results obtained satisfied the minimum requirement of 1.65 N/mm^2 according to Nigeria Building and Road Research Institute (NBRRI) standards. CSEBs with same proportion of binder (2.5:2.5) – RCB12, RCB14, RCB15, RCB16, RCB17 - also had their compressive strength greater than 1.65N/mm^2 specified by NBRRI. CSEBs codenamed RCB3, RCB4, and RCB8 are samples with a higher percentage of cement. They all meet up with the minimum requirement of 1.65 N/mm^2. It was observed from the result obtained that the compressive strength of the CSEBs without cement except for RCB5 which had 1.63 N/mm^2 conforms to the minimum requirements of 1.65 N/mm^2 compressive strength for bricks for building construction by NBRRI standards. At 28 days, 56 days, and 108 days, the optimum compressive strength values were obtained from RCB6 (5% Cement + 25 % water), RCB11(5% Cement + 22.5% water), and RCB16 (2.5 % Cement + 2.5 % RHA + 21.25 % water respectively. The strength behaviour of the CSEBs can be attributed to the chemical reaction (hydration and pozzolanic reaction) between the binder (Cement and (or) RHA), lateritic soil samples, and water [23]. The compressive strength behaviour of CSEBs is consistent with the findings of authors [23 - 25] that averred that 5 % addition of binder to earth bricks improves compressive strength.

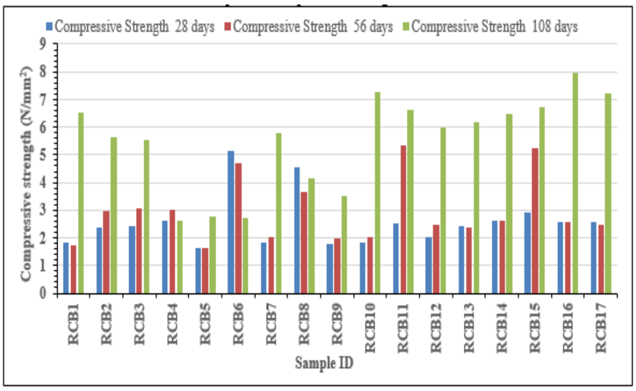

Figure 3: Compressive strength behaviour of the CSEBs

3.3.1 Effect of water content on compressive strength properties of CSEBS

As shown in Figure 4, it was observed that the compressive strength of 5 % RHA with 20 % water content remained at 1.63 N/mm^2 at 28 days and 56 days and then increased to 2.75 N/mm^2 at 108 days. The compressive strength with the same percentage of RHA having 25% water content increased from 1.79 N/mm^2 at 28 days to 1.98 N/mm^2 at 56 days and 3.51 N/mm^2 at 108 days. As for RCB13 with 22.50% water content, the compressive strength dropped from 2.42 N/mm^2 at 28 days to 2.38 N/mm^2 at 56 days but then increased to 6.18 N/mm^2 at 108 days. The effect of water content on the compressive strength properties of 5% cement content CSEBs is also shown in Figure 4. The CSEBs with 20 % water content have a good performance of compressive strength compared to CSEBs with 25% water content. It increased with an increase in curing ages, unlike the CSEBs with 25% water content which decreased with an increase in curing ages. The CSEBs with 22.50 % water content have a better performance with higher compressive strength with an increase in curing ages.

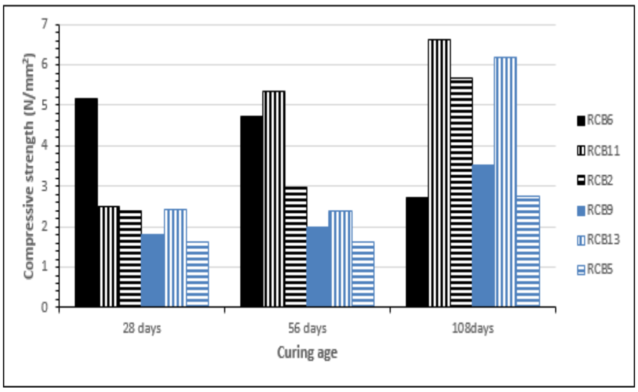

Figure 4: Effect of water content on compressive strength behaviour of CSEBs made with 5% cement and 5% RHA

The effect of water content on the compressive strength properties of CSEBS made with 3.75 % RHA + 1.25 % cement (RCB1, RCB7, and RCB10) is presented in Figure 5. There is an increase in the compressive strength of CSEBs partially replaced with 3.75% RHA at water proportions of 21.25% (RCB1), 22.50 % (RCB7), and 23.75 % (RCB10). The compressive strength of RCB1 increased from 1.81 N/mm^2 at 28 days of curing age to 1.74 N/mm^2 at 56 days and 6.51 N/mm^2 at 108 days. It was also observed for RCB7 which increased from 1.82 N/mm^2 at 28 days to 2.05 N/mm^2 at 56days then to 5.78N/mm^2 at 108 days and also for RCB10 which also increased from 1.85 N/mm^2 to 2.01 N/mm^2 at 56 days and finally to 7.29 N/mm^2 at 108 days. Also, the effect of water content on the compressive strength properties of CSEBs made with 1.25 % RHA + 3.75 % cement (RCB3, RCB4, and RCB8) is presented in Figure 3, there is a better performance of compressive strength of the RCB3. The compressive strength increased from 2.41 N/mm^2 at 28 days of curing age to 3.09 N/mm^2 at 56 days of curing age, then to 5.56 N/mm^2 at 108 days of curing age. As for RCB4 with 21.25 % water content, the compressive strength increased at

56 days of curing ages and then decreased at 108 days. Also, for RCB8, the compressive strength decreased at 56 days of curing age and then increased at 108 days of curing age.

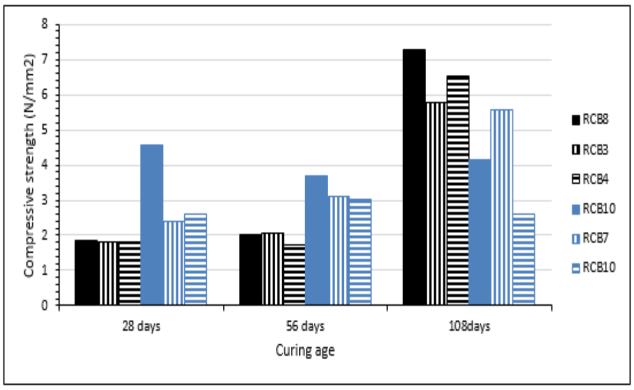

Figure 5: Effect of water and RHA on compressive strength of CSEBs made with 1.25:3.75 binder

The effect of water content on compressive strength properties of CSEBs made with 2.5 % RHA + 2.5 % cement (RCB12, RCB14, RCB15, RCB16, and RCB17) is presented in Figure 6. Their compressive strength values increased with an increase in curing ages except for RCB17 whose compressive strength was reduced at 56 days but later increased at 108 days.

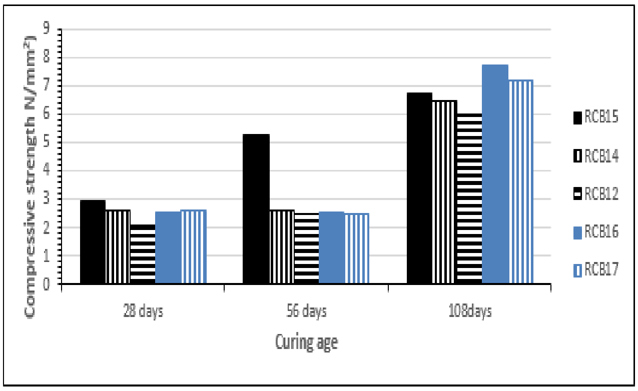

Figure 6: Effect of water and RHA on compressive strength of CSEBs made with 2.5:2.5 binder

3.4 Abrasion Strength of CSEBS

Abrasion strength is the measure of resistance to wear of the bricks from external factors. It is closely linked to soil properties and the stabilizer. The abrasion test determines the abrasive strength of CSEBs used in facing masonry. The higher the value, the poorer the resistance of the CSEBs to wearing. The average results are presented in Figure 7. It was observed that the % mass of abraded soil of the CSEBs with higher content of RHA is higher than the ones with higher content of cement. This is because the bonding between the soil and RHA is low and vice-versa. Also, there is an increase in abrasive strength values with an increase in curing ages of the compressed bricks except for RCB1, RCB5, RCB9, RCB10, RCB12, RCB14, RCB15, RCB16 which didn't follow the trend.

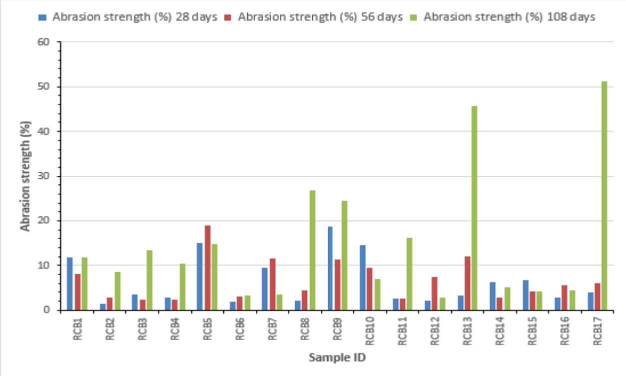

Figure 7: Abrasion strength of the CSEBs

3.4.1 Effect of water content on abrasive strength of CSEBS

From Figure 8, it was observed that RCB5, RCB9, and RCB13 which have 5% RHA with 20 %, 25 %, and 22.50 % water content respectively perform differently. RCB5 with 20 % water content increased at 56 days and then reduced at 108 days curing ages. As for RCB9, the abrasive resistance reduced at 56 days but increased at 108 days curing ages. RCB13 increased from 3.20 % at 28 days to 12.13 % at 56 days and finally to 45.57 % at 108 days curing ages. From all indications, RCB6 had the best resistance to wear. Although it was generally observed that CSEBS with 5 % cement (RCB2, RCB6, and RCB11) performed better than others at all curing ages. This is due to the cementing property of the cement that had engendered a strong bond among the composite.

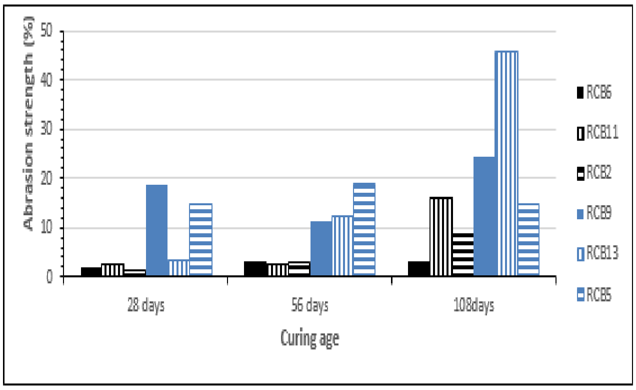

Figure 8: Effect of water content on abrasion strength of CSEBs made with 5:0 % binder

The wear resistance of RCB7 reduced from 9.49 % at 28 days to 11.46 % at 56 days but later improved at 108 days where 3.45 % was obtained. On the contrary, the wear resistance of RCB1 improved to 8.03 % after

56 days of curing from 11.82 % at 28 days but there was a decline again to 11.84 % at 108 days of curing ages. While, for RCB10, the wear resistance improved with an increase in curing age i.e., from 14.48 % at 28 days to 9.45 % at 56 days and optimally to 6.94 % at 108 days. This is shown in Figure 9.

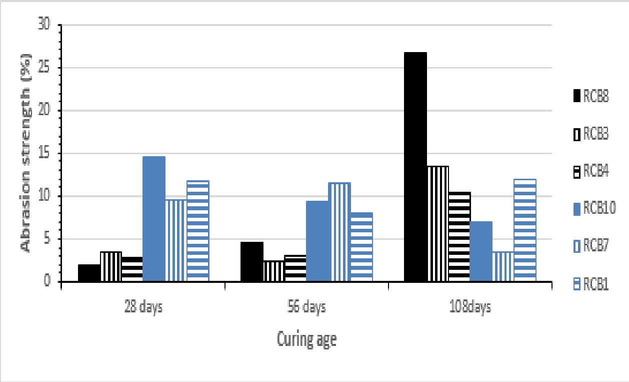

Figure 9: Effect of water content (WC) on abrasion behavior of CSEBs made with 3.75:1.25 % binder

Also, RCB8 had a reduction in their abrasive strength from 2.07 % at 28 days to 4.53 % at 56 days then to 26.68 % at 108 days of curing age. Similarly, RCB3 improved in their abrasive strength from 3.51 % at 28 days to 2.34 % at 56 days but decreased to 13.37 % at 108 days. For RCB4 , there was an improvement in the wear resistance from 2.77 % at 28 days to 2.26 % at 56 days then decreased to 10.47 % at 108 days.

On other hand, Figure 10 shows the abrasive strength of RCB15, RCB14, RCB12, RCB16, and RCB17 which had an equal proportion of cement and RHA (2.5:2.5) but varying water content. Comparatively, their wear resistance values were lower. RCB12 and RCB16 had better wear resistance at 108 days compared with 56 days whereas RCB14 improved at 56 days compared with its 28 days and 108 days performance. RCB15 distinctively had an improved wear resistance with an increase in curing age.

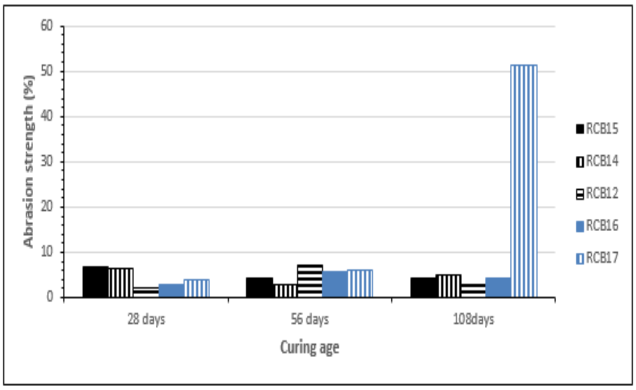

Figure 10: Effect of water and RHA on abrasion behavior of 2.50% cement content CEBs

3.5 Results of Statistical Analysis

The descriptive statistics of the analysis is shown in Table 4 while the ANOVA summary is presented in Table 5.

Table 4: Descriptive statistics analysis

	N	Mean	Std.Deviation	Std.Error	95 % Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
RHA	17	2.5000	1.71163	.41513	1.6200	3.3800	.00	5.00
Cement	17	2.5000	1.71163	.41513	1.6200	3.3800	.00	5.00
Water Content	17	22.5000	1.71163	.41513	21.6200	23.3800	20.00	25.00
Total	51	9.1667	9.66846	1.35386	6.4474	11.8860	.00	25.00

Table 5: ANOVA summary

Source	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4533.333	2	2266.667	773.689	.000
Within Groups	140.625	48	2.930		
Total	4673.958	50			

Table 6: Multiple comparisons analysis (Lsd Method) results

(I) Factors	(J) Factors	Mean Difference (I-J)	Std. Error	Sig.	95 % Confidence Interval	
					Lower Bound	Upper Bound
RHA	Cement	.00000	.58709	1.000	-1.1804	1.1804
	Water Content	-20.00000*	.58709	.000	-21.1804	-18.8196
Cement	RHA	.00000	.58709	1.000	-1.1804	1.1804
	Water Content	-20.00000*	.58709	.000	-21.1804	-18.8196
Water Content	RHA	20.00000*	.58709	.000	18.8196	21.1804
	Cement	20.00000*	.58709	.000	18.8196	21.1804

*. The mean difference is significant at the 0.05 level.

The p-value is 0.000 which depicts that there is a significant contribution of water and the binder (cement and Rice Husk Ash) on the chosen properties (compressive strength and abrasion resistance) of the

CEBs. Also, the result from the post-hoc test (Table 6) shows that water content contributes more to the significance of the test while the mean plot presented in Figure 9 shows the movement of the significance of the materials. The binders are on the same level while the water content is the highest. These statistical analyses imply that water addition plays a vital role in the compressive strength and abrasion resistance performance of the CSEBs.

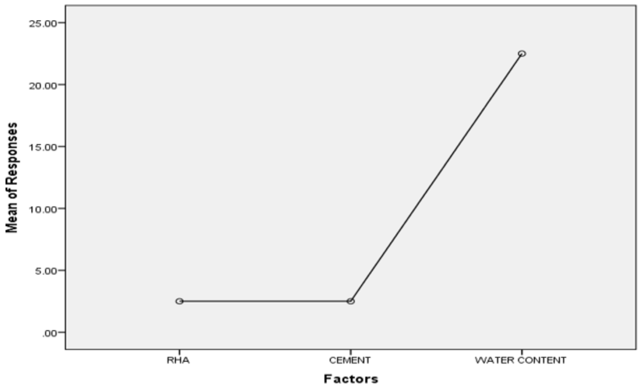

Figure 11: Mean plot of the analysis

4.0 CONCLUSIONS AND RECOMMENDATIONS

The compressive and abrasive strength properties of CSEBs produced with cement and RHA were studied. From the results of the various tests performed, the following conclusions can be drawn. The soil sample is said to be silty-sand since the percentage of fines is less than 50 %. Its clay content makes it good for the production of bricks. Also, RHA-the alternative binder is a good material for use as a pozzolan, a viable partial replacement for cement, and ultimately proficient in producing low-cost earth bricks. The compressive strengths of bricks reduced as the percentage of RHA replacement increased. Water plays a vital role in the compressive strength and abrasive strength properties of the CSEBs. The peak performance of compressive strength (7.96 N/mm^2) and abrasive strength (4.11 %) was obtained from RCB16 (CEB with 2.5 % of Cement + 2.5 % RHA + 21.25 % WC). CSEBs can be produced by blending RHA and cement as binder for low-cost buildings. However, it is recommended that more durability tests should be performed on these bricks as this will enhance technical investigation and reliable recommendations

REFERENCES

[1] Oskouei, A. V., Afzali, M., and Madadipour, M. "Experimental investigation on mud bricks reinforced with natural additives under compressive and tensile tests," Constr. Build. Mater., vol. 142, pp. 137–147, 2017, doi: 10.1016/j.conbuildmat.2017.03.065.

[2] Murmu, A. L., and Patel, A. "Towards sustainable bricks production: An overview," Constr. Build. Mater., vol. 165, pp. 112–125, 2018, doi: 10.1016/j.conbuildmat.2018.01.038.

[3] Kanna, G. V., and Dhanalakshmi, G. "Experimental investigations on bricks with the replacement of coconut fibre," Int. Res. J. Eng. Technol., vol. 5, no. 2, pp. 199–204, 2018.

[4] Bock-hyeng, C., Ofori-boadu, A. N., Yamb-bell, E., and Shofoluwe, M. A., "Mechanical properties of sustainable adobe bricks stabilized with recycled Sugarcane fiber waste," Int. J. Eng. Res. Appl., vol. 6, no. 9, pp. 50–59, 2016.

[5] Ugwuishiwu, B. O., Echiegu, E. A., Okoye, N. M., and Chukwuma, G. O. "Natural fibre induced properties on stabilized earth bricks natural fibre induced properties on stabilized earth bricks," PARIPEX - Indian J. Res., vol. 2, no. 9, pp. 1–4, 2013.

[6] Salim, R. W., Ndambuki, J. M., and Adedokun, D. A. "Improving the bearing strength of sandy loam soil compressed earth block bricks using sugercane bagasse ash," Sustainability, vol. 6, pp. 3686–3696, 2014, doi: 10.3390/su6063686.

[7] Ashour, T., Korjenic, A., Korjenic, S., and Wu, W. "Thermal conductivity of unfired earth bricks reinforced by agricultural wastes with cement and gypsum," Energy Build., vol. 104, pp. 139–146, 2015, doi: 10.1016/j.enbuild.2015.07.016.

[8] Ayodele, F. O., and Popoola, O. O. "Potential of snail shell and palm kernel shell powders in improving engineering properties of clay," J. Appl. Sci. Environ. Manag., vol. 23, no. 8, pp. 1437–1444, 2019.

[9] Sojobi, A. O., Awolusi, T. F., Aina, G. B., Oke, O. L., Oladokun, M. and Oguntayo, D. O. "Ternary and quaternary blends as partial replacement of cement to produce hollow sandcrete blocks," Heliyon, vol. 7, no. 6, p. e07227, 2021, doi: 10.1016/j.heliyon.2021.e07227.

[10] Ayodele, F. O., Alo, B. A., and Adetoro, A. E. "Influence of rice husk ash fines on geotechnical properties of lime stabilized lateritic soil," Int. J. Eng. Res. Africa, vol. 61, pp. 217–230, 2022.

[11] Waziri, B. S., Lawan, Z. A., and Mala, M. "Properties of compressed stabilized earth

blocks (CSEB) for low- cost housing construction: A Preliminary Investigation Literature Review," Int. J. Sustain. Constr. Eng. Technol., vol. 4, no. 2, pp. 39–46, 2013.

[12] British Standard. BS 1377: 2. "Methods of test for soils for civil engineering purposes",1990.

[13] Awolusi, T. F., Oke, O. L., Akinkurolere, O. O., and Sojobi, A. O. "Application of response surface methodology: Predicting and optimizing the properties of concrete containing steel fibre extracted from waste tires with limestone powder as filler," Case Stud. Constr. Mater., vol. 10, p. e00212, 2019, doi: 10.1016/j.cscm.2018.e00212.

[14] Aguwa, J. I. "Performance of laterite-cement blocks as walling units in relation to sandcrete blocks,". Leonardo Electron. J. Pract. Technol., vol. 16, pp.189–200, 2010.

[15] Riza, F. V., Rahman, I. A., Mujahid, A., and Zaidi, A. "A brief review of Compressed Stabilized Earth Brick (CSEB)," CSSR 2010 - 2010 Int. Conf. Sci. Soc. Res., no. Cssr, pp. 999–1004, 2010, doi: 10.1109/CSSR.2010.57 73936.

[16] Raheem, A. A., Momoh, A. K., and Soyingbe, A. A. "Comparative analysis of sandcrete hollow blocks and laterite interlocking blocks as walling," Int. J. Sustain. Constr. Eng. Technol. vol. 3, no. 1, pp. 79–88, 2012.

[17] Ojo, E. B., Matawal, D. S., and Katagum, A. I. "Assessment of the suitability of some lateritic soils for the production of compressed stabilised earth blocks in Nigeria," Int. J. Civ. Environ. Eng., vol. 37, no. 2, pp. 1416–1422, 2015.

[18] Mostafa, M. and Uddin, N. "Experimental analysis of Compressed Earth Block (CEB) with banana fibers resisting flexural and compression forces," Case Stud. Constr. Mater., vol. 5, pp. 53–63, 2016, doi: 10.1016/j.cscm.2016.07.001.

[19] Adam, E. A., and Agib, A. R. A., "Compressed stabilized earth block manufacture in Sudan," 2001.

[20] American Society of Testing and Materials. ASTM C618-05. "Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use", 2005.

[21] African Regional Standard. ARS 680. "Compressed Earth Blocks-Code of Practice for the Production of Compressed Earth Blocks", 1996

[22] Obianyo, I. I., et al., "Performance of lateritic soil stabilized with combination of bone and palm bunch ash for sustainable building applications," Cogent Eng., vol. 8, no. 1, pp. 1–19, 2021, doi: 10.1080/23311916.2021.19 21673.

[23] Obianyo, I. I., Onwualu, A. P., and Soboyejo, A. B. O., "Mechanical behaviour of lateritic soil stabilized with bone ash and hydrated lime for sustainable building applications," Case Stud. Constr. Mater., vol. 12, pp. 1–12, 2020, doi: 10.1016/j.cscm.2020.e00331.

[24] Yaw, M. I., Emmanuel, A., Y. P. P. K, and Senyo, D. K., "Feasibility of using Cocoa Pod Husk Ash (CPHA) as a stabilizer in the production of Compressed Earth bricks," Int. J. Eng. Res. Gen. Sci., vol. 3, no. 6, pp. 514–524, 2015.

[25] Salim, R. W., Ndambuki, J. M., and Adedokun, D. A., "Improving the bearing strength of sandy loam soil compressed earth block bricks using sugercane bagasse ash," Sustainability, vol. 6, pp. 3686–3696, 2014, doi: 10.3390/su6063686.