Technoscience Journal for Community Development in Africa 3 (2024) 117-124
ISSN 2659-0573

Research Article

Effect of guinea corn husk ash as partial cement replacement in cement-admixed clay

Samson Olalekan Odeyemi[1,*], Uwemedimo Nyong Wilson[2], Hamzat Olamilekan Abdulganiyu[1], Olawale Oseni[3], Mariam Oyinkansola Salami[1]

[1,]Department of Civil and Environmental Engineering, Kwara State University, Malete, Nigeria
[2]Department of Civil Engineering, Nigerian Defence Academy, Kaduna, Nigeria
[3]Department of Mechanical Engineering, Kwara State University, Malete, Nigeria

Abstract: Soil stabilization involves the incorporation of cement into the soil component of a road pavement to increase its strength. However, the production of cement emits carbon dioxide into the atmosphere leading to greenhouse effect, a major health hazard. A way out is the replacement of some portion of cement with agro-based pozzolanic materials. This study was carried out to find the consequence of using Guinea Corn Husk Ash (GCHA) as a cement replacement in cement admixed clay. The design mix was done with replacement of cement from 10 % - 30 % by weight and GCHA was varied from 5% - 35 % by weight of the cement replacement. X-ray Fluorescence (XRF) was used in obtaining the oxide components of GCHA while a Universal Testing Machine (UTM) was used in determining the Unconfined Compressive Strength (UCS) of the clay. The XRF results reveal that the sum of the oxides of silicon, Aluminium and Iron in the GCHA is 76.92 %. This is greater than the specification by ASTM C-618. The UCS test results indicate that 5 % by weight of GCHA, 20 % by weight of cement incorporation with 200 % by volume of water content had the optimal strength of 7.56 MPa for GCHA incorporation in the admixed clay samples. This strength is higher than the limits specified in IRC: SP 72-2015 for sub-base and base courses for pavement construction. Therefore, GCHA can be incorporated into admixed clay for road construction.

Keywords: Unconfined Compression Strength, Guinea Corn, Ash, Clay, Pavement

1. INTRODUCTION

Prices of materials used in the construction industry are skyrocketing, thus compelling all stakeholders in the sector to investigate indigenous resources and agricultural wastes for rural infrastructure development (Odeyemi et al., 2022). The rising cost of cement continues to be a significant barrier to infrastructural development in developing countries like Nigeria. In 2014, the Nigerian government began a Mortgage Refinance program with the aim of bailing out the construction industry (Andrew, 2014). A possible solution to combating this problem is to replace a fraction of cement with inexpensive and readily available agro-based pozzolanas.

Numerous studies on the utilization of waste products have been done in previous decades. The development and application of agricultural and industrial wastes such as Rice Husk Ash (RHA), blast furnace slag, fly ash, metakaolin, and Bagasse Ash (BA) are fast gaining attention for construction purposes (James and Pandian, 2016).

Guinea corn is a significant food crop that is grown extensively in Nigeria's savannah region and throughout West Africa. It is one of the three principal grain crops in Nigeria, particularly in the northern states of the country. It is generally harvested and processed for consumption, leaving a considerable amount of husk on the land, the majority of which is burnt in preparation for the following farming period (Ndububa and Yakubu, 2015). Guinea corn seeds are small and spherical, appearing in a variety of colours, including red, yellow, brown, and white, depending on the species. It provides the human body with essential minerals

*Corresponding Author:
Email: samson.odeyemi@kwasu.edu.ng;

such as manganese, calcium, iron, and selenium as a staple food (Oyetayo and Ogunrotimi, 2012). Guinea corn husk is a post-harvest agricultural debris that is frequently piled up in Northern Nigeria and most times burnt, posing an environmental hazard '–(Aburime et al., 2020).

Numerous studies on the stabilization of soils using RHA and cement-lime have been conducted to determine its applicability in high-strength admixed clay –(Tastan et al., 2011). However, their work did not extend to the use of GCHA for stabilization of clay soils. The UCS test is the standard method for soil shear testing due to its rapidity in determining shear strength. The technique is basically utilized in recovering saturated, cohesive soils from thin-walled sample tubes. The test is inapplicable to dry sands and crumbly clays, as the soil would disintegrate when there are no lateral confinements(Ismail et al., 2020).

Chompoorat (2012) conducted study on the dynamic properties of clay that was treated with cement. Throughout this investigation, it was discovered that one of the primary elements impacting road settlement is vehicle load. The results revealed that cement admixed clay performed well under dynamic loads. Saadeldin and Siddiqua –(2013) conducted a study on soft clay. Their study revealed that deposits of soft clay are extremely pliable, typically cemented fine-grained soils characterized by a low inherent shear strength. The use of soft clays in conjunction with cement for stabilization has become very popular. The strength of the resulting clay–cement mix was determined by a few variables, most notably the cement quantity, the water-cement ratio, and the curing circumstances. By adding 15% cement, the Unconfined Shear Strength (USS) increased by more than 200 kPa while the Plasticity Index (PI) reduced by 16 %. The decrease in the PI of the mix was discovered to be an effective indicator of the clay's strength enhancement after combining with cement. However, their study did not incorporate GCHA with cement.

Alkamu *et. al* (2018) conducted study on sandcrete block production utilizing GCHA as cement substitute. Three-number sandcrete blocks were cast with GCHA replacing cement at five replacement levels from 0 to 20 %. The blocks were cured and tested for their compressive strengths at 7, 14, and 28 days of curing. The compressive strengths of the blocks were found to be between 2.30 N/mm^2 and 1.3 N/mm^2. Additionally, the outcomes specified that the strength reduced as the GCHA content increased. Density also reduced as GCHA concentration increased, indicating that GCHA is a light substance. A maximum replacement percentage of 5% was recommended, however 10% demonstrated acceptable strength.

Jongpradist et al. (2018) examined the efficacy of Rice Husk Ash (RHA) as a suitable replacement for cement in high strength admixed cement clay. The aim of their work was to find the efficiency and viability of employing RHA to complement or partly replace Portland cement in deep cement mixing techniques. This was carried out using UCS tests on RHA-cement stabilized clay. According to test results, up to 35% of RHA could be added to the mixture to increase its strength if the cement concentration is greater than 10%. The 28th day results revealed that the RHA increased the strength of cement-admixed clay by more than 100%. In comparison with fly ash of comparable grain size, RHA was found to be more effective. This demonstrates that RHA is appropriate for use in high-strength cement admixed soils. The authors reported that the efficiency of RHA is proportional to the quantity of water and cement in the mix, so also is the curing period.

Sani *et al. –(2022)* worked out the increase in UCS value from 186 kN/m^2 for natural lateritic soil gotten from Shika in Zaria to a peak value of 1942 kN/m^2 at 4% cement /0.5% sisal fibre by dry weight of the soil; having treated the sisal fibre with Sodium tetrahydridoborate ($NaBH_4$) (1% wt/vol) for about an hour at room temperature to expunge the cellulose content present in the fibre. The entire composite was compacted using standard Proctor energy. This peak UCS value obtained was determined to be higher than the 1720 kN/m^2 criterion for adequate cement stabilization of base courses.

Odeyemi *et al.* (2020) conducted a study to determine the influence of GCHA as fractional substitute for cement on the properties of lateritic concrete. They evaluated the porosity, workability, corrosion resistance and compressive strength of the lateritic concrete at varying water-cement ratios and at varying percentages of GCHA replacing cement. The central composite approach in Response Surface method was utilized to determine the ideal combination that would result in the lateritic having the highest compressive strength. The best mixture was determined to be 80 % Ordinary Portland Cement (OPC) and 20 % GCHA at a water-cement ratio of 0.51. This combination resulted in a 14.59 percent porosity, a 2.75 mm slump height, and a compressive strength of 18.78 N/mm^2. This is 6.64 percent greater than the strength of the control sample which has a compressive strength of 17.61 N/mm^2 0.7

water-cement ratio. Therefore, the study concluded that GCHA can replace cement in lateritic concrete. Guinea corn husk combined with cow hair (in ratio 5:1) was used as reinforcement to form a hybrid fibre-reinforced cement ceiling board composite with a maximum flexural strength of 22.37 MPa thus satisfying the requirement of BS EN 12467 (2018) specification for ceiling boards (Alomaja et al., 2021).

Though, many of these research findings investigated the effect of RHA in clay stabilization, none considered the use of GCHA for such works. Likewise, some researchers considered using GCHA in concrete and sandcrete blocks, however, GCHA was not considered for clay stabilization. Thus, this study looks at the effect that incorporating GCHA will have on cement admixed clay soil.

2. MATERIALS AND METHODS

Grade 42.5R cement with specific gravity of 2.83 and potable water was used in this study. The fineness of the cement was obtained by sieving the samples in conformity with BS EN 196-3 (2016). The empty pan was weighed with a weighing balance (with an accuracy of three decimal places) and its weight was recorded. 100 grams (g) of the cement was weighed with the pan and also recorded. The weighed cement was then poured unto a 90 µm sieve which was already on the sieve shaker. The sieve shaker was made to sieve the cement for 15 minutes continuously without interruption. After sieving the residue was then weighed and recorded. The standard requires that the weight of the residue should not be more than 10% of the weight of cement used. Equation 1 was used to determine the fineness of cement.

$$\text{Fineness} = \frac{\text{weight of residue } (g)}{\text{total weight of cement } (g)} * 100\% \qquad (1)$$

The clay sample, sourced from Okelele, Ilorin west local government of Kwara State, was pounded with mortar and pestle and passed through 300µm sieve as recommended by Jongpradist *et al.* (2018).

The procedure specified in BS 1377:2 (1996) was followed in determining the specific gravity of the materials. Deleterious materials were manually removed from the test samples before they were screened on BS sieves. An empty bottle was weighed and designated as W_1. W_2 was assigned to the weight of the bottle containing the test samples. Distilled water was added to the samples in the bottle, weighed and recorded as W_3. This bottle was emptied, oven dried and filled with distilled water before weighing and designating it as W_4. The specific gravity was obtained using Equation 2.

$$\text{Specific gravity } (G_s) = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} \qquad (2)$$

The water content, usually expressed in percentage, is the percentage of water to the percentage weight of the solid in a given mass of soil. The water content of the clay used in this study was determined to conform with BS 1377-2:2022 (2022). The weight of empty cans was measured using a sensitive weighing balance and was recorded as W_1, weight of empty can, and wet soil was equally measured and recorded as W_2. The wet sample and can were oven dried for 24 hours in an electric oven at 105 ^{0}C and after which the weight of oven dried sample was weighed with the can and designated as W_3. The weight of dry soil was obtained by subtracting W_1 from W_3 ($W_3 - W_1$) and weight of moisture was obtained by subtracting W_3 from W_2 (W_2-W_3). Equation 3 was used to obtain the water content of the clay.

$$\text{Water content} = \frac{W_2 - W_3}{W_3 - W_1} x\ 100\% \qquad (3)$$

The Liquid Limit (LL) test was conducted on the clay in conformity to ASTM D 4318 (2018). The clay sample was air dried to breakdown the clods and eliminate organic matters. The soil was then sieved using a 300 µm size sieve. 100 g of the soil was measured out of the sieved sample and was mixed with some amount of water. Some portions of the paste were placed and leveled in the cup of a liquid limit device. A grooving tool, held perpendicular to the cup, was drawn through the sample along the symmetrical axis of the cup. The cup was dropped repeatedly, and the number of blows required to close the groove was noted. 10 g of the sample was taken close to the groove and its water content determined. The sample from the cup was transferred to a dish containing soil paste, both were thoroughly mixed after adding some water. The test was repeated by varying the water content of the soil and repeating the test. Five (5) readings were taken within the range of 15 – 45 blows. The LL was found by plotting a flow curve on a semi log graph, with the number of blows on the vertical X-axis and water content on the horizontal Y-axis. A line of best fit was drawn through the plotted points.

The Plastic Limit (PL) is the water content at which a soil sample can no longer be deformed. This test was carried out in conformity to ASTM D4318 (2018). Empty cans were weighed and the weight denoted as W_1. Twenty (20) g of the sample was measured and water was added so that the sample can be easily moulded into ball. The sample was processed by rolling into thread and the thread became thinner and eventually broke. The thread was placed in the can and the weight of empty can and wet soil was recorded as W_2. The sample was oven dried for 24 hours in an electric oven and the combined weight of the dried sample and the can was recorded as W_3. The moisture content was derived from Equation 4.

$$\text{Moisture content} = \frac{w_2 - w_3}{w_3 - w_1} \; x \; 100\% \tag{4}$$

The plasticity index (PI) being the degree of the plasticity of a soil was determined from Equation 5.

$$PI = LL - PL \tag{5}$$

Where PI is Plasticity Index; LL is Liquid Limit and PL is the Plastic limit.

In determining the bulk and dry densities of the clay samples, the weight of the mould, the internal diameter and height of mould were measured and recorded. The sample was filled into the mould in three layers using 27 blows for each layers with the aid of a rod and leveled at the top with a spatula. Then, the weight of the filled sample into the mould was measured. The sample was released from the mould into a pan and was weighed after which the sample was oven dried in an electric oven for 24 hours. Afterwards, the weight of the sample with the pan was determined. Equations 6 and 7 were used to determine the bulk and dry densities.

$$\text{Bulk density} = \frac{Weight\ of\ wet\ soil}{volume\ of\ the\ cylinder} \tag{6}$$

$$\text{Dry density} = \frac{Bulk\ density}{1 + water\ content} \tag{7}$$

The guinea corn husk was locally sourced from a milling store in Ijagbo, Oyun Local Government Area of Kwara State, and calcinated at a temperature of 650 ^{0}C for 4 hours in a rotary furnace as prescribed by Bello et al. '(2018). A milling machine was further used to pulverize the ash into finer particles before passing it through 90 µm sieve. A Skyray EDX 3600B Energy Dispersive X-ray Fluorescence (XRF) Spectrometer was used in obtaining the chemical components of the GCHA. This test was carried out at the National Agency for Science and Engineering Infrastructure (NASENI), Centre of Excellence, Nanotechnology and Advanced Material, Akure, Nigeria. Scanning Electron Microscope (SEM) on GCHA was conducted in the Microstructural laboratory of department of Material Science, Kwara State University. The machine used for this test has a model number ASPEX 3020. The test was conducted at 16.0 kV accelerating voltage so as to obtain a clear and magnified view of the GCHA.

Water contents of 130 %, 160 % and 200 % were considered in this study. The replacement level of cement in the admixed clay were 10 %, 20 %, and 30 % while the replacement level of cement with GCHA were 0 %, 5 %, 15%, 25%, 35 %. The mix design recommended by Jongpradist *et al.* (2018) was adopted. Equation 8 was used in determining the amount of water that was used in remoulding the clay sample to the anticipated water content.

$$w_{t=} w_r (^W/_c) C \tag{8}$$

Where w_t is total clay water content; w_r is the remolding clay water content; $w/_c$ is the water-cement ratio; C is the desired cement content (%).

45 samples were cast, 9 being control samples while the remaining 36 samples contain varying percentages by weight of GCHA at varying water contents. The cylindrical moulds have a height of 100 mm and a diameter of 50 mm in conformity with the requirement of ASTM D2166-16 (2016). The surfaces of the admixed clay in the cylindrical moulds were waxed to prevent moisture lose before storing them in at ambient condition for 28 days. After the curing period, each specimen was tested for their unconfined compressive strength. The mix proportions used are shown in Table 1:

Table 1: Designed mix for cement-GCHA admixed clay

S/N	Cement (%)	GCHA (%)	Water (%)	Duration of curing (days)
1	10	5,15,25,35	130,160,200	28
2	20	5,15,25,35	130,160,200	28
3	30	5,15,25,35	130,160,200	28

1. RESULTS AND DISCUSSIONS

The properties of the cement used in this research are presented in Table 2:

Table 2: Properties of cement used in the study

Properties	Result
Specific gravity	2.83
Fineness (%)	0.79
Consistency (%)	29
Initial setting time (minutes)	103
Final setting time (minutes)	349

The fineness result reveals that the OPC is less than 10 % of the total weight of the sample (100 g) used in conducting the test. This implies that the OPC used for this research meets the requirement of BSEN 196 -3 (2016). ASTM C- 150 (1999) and BSEN 197-1 (2019) stipulated 45 and 60 minutes as the minimum initial setting time for cement respectively. ASTM C-150 (1999) prescribed 375 minutes as the maximum final setting time for cement. The result of the setting time confirms that the OPC used in this study conforms to the minimum initial and maximum final setting times stipulated in ASTM C- 150 (1999) and BSEN 197-1 (2019).

Table 3 shows the properties clay sample used for this study.

Table 3: Properties of clay sample used in the study

Properties	Results
Water content	13.63%
Liquid limit	58.3
Plastic limit	31.65
Plasticity index	26.65
Bulk density	1.67 g/cm^3
Dry density	1.45 g/cm^3
Specific gravity	2.41

Based on the Unified Soil Classification (USC) system, the result in Table 3 depicts that the clay used in this research is an inorganic clay with high plasticity and of high compressibility since the liquid limit is more than 50 %. Fig. 1 shows the plot of the liquid limit.

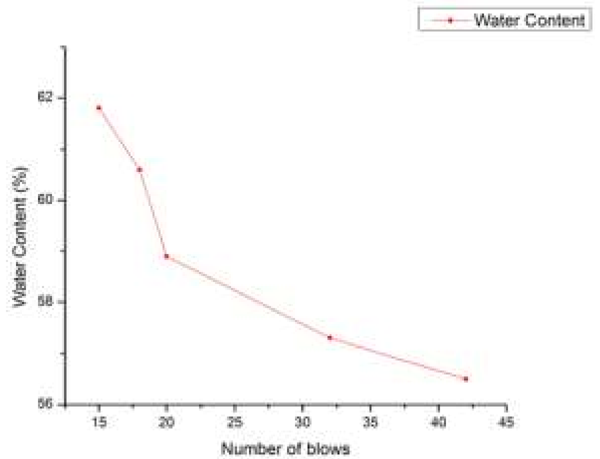

Fig. 1: Liquid Limit of clay sample

Table 4 contains the composition of the oxides of GCHA and OPC. ASTM C-618 specifies that the sum of SiO_2, Al_2O_3, Fe_2O_3 of a supplementary cementitious material should be above 70 %. The sum of SiO_2, Al_2O_3, Fe_2O_3 of the GCHA tested is 76.92 % which is greater than the specification by ASTM C-618 (2001). Moreover, the result further reveals that silicon dioxide (SiO_2) had the largest percentage of oxide composition as expected for such a material. The result also meets the requirement stipulated in BS EN 197-1 (2019) which states that the quantity of SiO_2 shall not be less than 25 % by total mass of the sample. The results are similar to the one presented by Ndububa and Nurudeen (2015), Aburime *et al.* '–(2020) and Odeyemi *et al.* (2020). The result in Table 4 also shows that the SiO_2, Al_2O_3, and Fe_2O_3 present in GCHA are more than that of OPC.

Table 4: Oxide composition of GCHA and OPC

Content	GCHA percentage	OPC percentage
SiO_2	63.8	20.48
Al_2O_3	6.16	5.02
Fe_2O_3	6.96	3.15
CaO	10.72	63.75
K_2O	10.62	0.72
SO_3	1.74	0.18
MgO	0	1.92
LOI	0	4.78

Fig. 2 shows the SEM image of the GCHA. The image presents heterogeneous surface morphology of well distributed white and black patches of irregular shapes. The black patches are the evidence of carbon content in the processed agricultural material, while the ash nature, with elemental evidence, is confirmed with the presence of white patches. The higher coverage of whitish portion further confirms the predominant elemental nature of the pozzolan which makes it suitable as cements alternatives. The highly irregular and angular nature of the structure indicates its high surface porosity and its suitability in this application as previously reported in the open literature (Cheah and Ramli, 2011; Khalid et al., 2018).

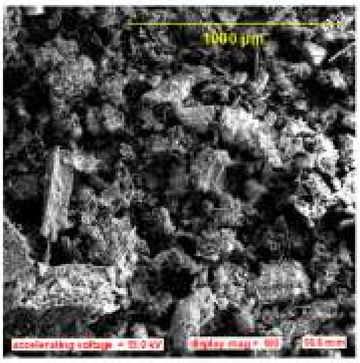

Fig. 2: SEM image for GCHA

Fig. 3, 4 and 5 shows the unconfined compressive strengths for the GCHA cement admixed clay at 130 %, 160 % and 200 % water content respectively. The strength parameters for the samples ranged from 2.48 MPa to 12.76 MPa. These values are within the stipulated limits of 1.7 MPa and 3.0 MPa in (IRC: SP 72 (2015) required for Sub-base and Base courses respectively for road works. However, the highest strength for GCHA inclusion in cement admixed clay was 7.56 MPa obtained at 5 % inclusion of GCHA in 20 % admixed clay at 200 % water content. This was closely followed by 7.55 MPa obtained at 5 % inclusion of GCHA in 30 % cement admixed clay at 130 % water content. These values are higher than the 2500 kPa unconfined compressive strength for RHA-Cement Admixed clay reported by Jongpradist *et al.* (2018). It is evident that apart from the 130 % water content, 20 % cement content produced the highest unconfined compressive strength.

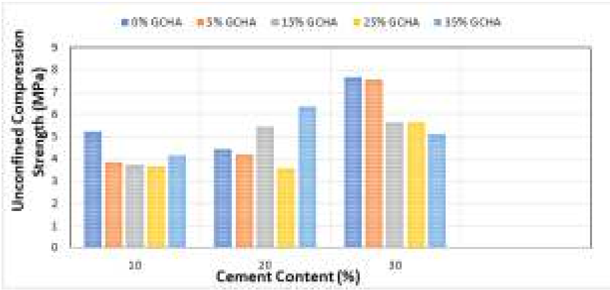

Fig. 3: UCS of cement-GCHA admixed clay with 130% water content at 28 days of curing

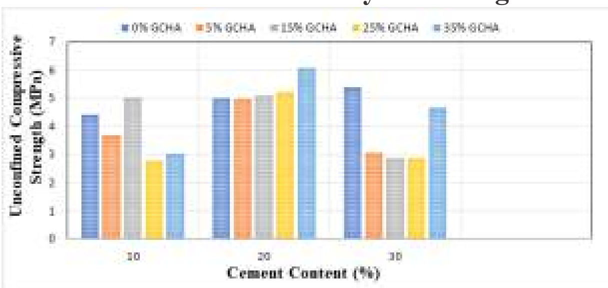

Fig. 4: UCS of cement-GCHA admixed clay with 160% water content at 28 days of curing

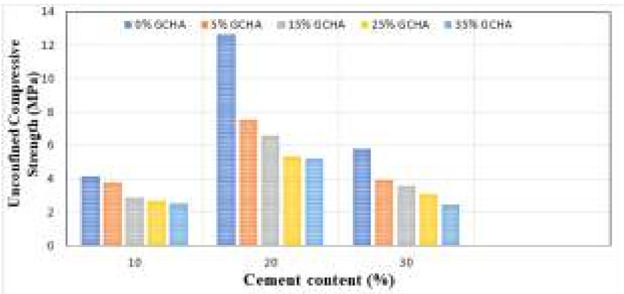

Fig. 5: UCS of cement-GCHA admixed clay with 200% water content at 28 days of curing.

4. CONCLUSION

These following inferences were deduced from the study:

1. GCHA is a suitable pozzolana because the summation of aluminum, silicon and ferric oxides was 76.92 % which is greater than the minimum 70 % specified by BS EN 197-1 (2019) and ASTM C-618(2001).
2. The inclusion of GCHA in cement-admixed clay produced unconfined compressive strengths ranging from 2.48 MPa to 12.76 MPa. These strengths are suitable for sub-base and base course for road constructions.

5. RECOMMENDATION

It is recommended that further studies should consider durability analysis and California bearing ratio test on the cement-admixed clay to further evaluate its strength properties.

6. ACKNOWLEDGEMENTS

The assistance of the Departments of Civil and Environmental Engineering and Mechanical Engineering, Kwara State University, Malete, is highly appreciated for granting access to their equipment.

REFERENCES

Aburime, P. I., Ndububa, E. E., and Kpue, D. O. (2020). The Impact of Guinea Corn Husk Ash as an Admixture for Crack Control in Concrete. *European Journal of Engineering Research and Science*, *5*(10), 1152–1159. https://doi.org/10.24018/ejers.2020.5.10.2171

Alkamu, T., Emmanuel, I., Datok, E. P., and Jambol, D. D. (2018). Guinea Corn Husk Ash As Partial Replacement of Cement in Hollow Sandcrete Block Prodction. *International Journal of Modern Trends in Engineering & Research*, *5*(6),13–19. https://doi.org/10.21884/ijmter.2018.5163.xljy k

Alomaja, J. A., Jimoh, A. A., Wilson, U. N., Joseph, O. P., Akinleye, M. T., and Adeleke, J. A. (2021). Development of Guinea Corn Husk-Cow Hair Hybrid Fibre Reinforced Cement Composite. *Journal of Building Materials and Structures*, *8*(2), 160–167. https://doi.org/https:/doi.org/10.34118/jbms.v 8i2. 1333

Andrew, J. (2014). Nigeria: Jonathan Boosts Housing With N50 Billion Mortgage Refinancing Company. *This Day*.

ASTM C-150. (1999). *Standard Specification for Portland Cement, American Society for Testing and Materials*.

ASTM C-618. (2001). *Standard specification for testing Pozzolanas. American Society for Testing and Materials*.

ASTM D2166-16. (2016). *Standard Test Method for Unconfined Compressive Strength of Cohesive Soil*.

ASTM D4318. (2018). *Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils*.

Bello, M. O., Abdus-Salam, N., and Adekola, F. A. (2018). Utilization of Guinea corn (Sughurm vulgare) Husk for Preparation of Bio-based Silica and it's Characterization Studies. *International Journal of Environment, Agriculture and Biotechnology*, *3*(2), 670–675. https://doi.org/10.22161/ijeab/3.2.48

BS 1377-2:2022. (2022). *Methods of Test for Soils for Civil Engineering Purposes*.

BS 1377:2. 1990. (1996). *Methods of Test for Soil for Civil Engineering Purposes. British Standards, BSI Group Headquarters 389 Chiswick High Road, London, W4 4AL, UK, Standards Policy and Strategy Committee*.

BS EN 12467:2012+A2:2018. (2018). *Fibre-cement flat sheets-Product specifications and test methods*.

BS EN 196-3, B. (2016). *Methods of testing cement part 3: Determination of setting times and soundness*.

BS EN 197-1:2011, B. (2019). *Cement composition, Specifications and conformity criteria for common cements*.

Cheah, C. B., and Ramli, M. (2011). The implementation of wood waste ash as a partial cement replacement material in the production of structural grade concrete and mortar: An overview. *Resources, Conservation and Recycling*, *55*(7), 669–685.

Chompoorat, T. (2012). Dynamic Properties of Cement Treated Clay. *The Seventh Asian Young Geotechnical Engineers Confrence (7AYGEC)*.

IRC: SP 72-2015. (2015). Guidelines for soil the design of flexible pavement for low voume roads. In *The Indian Roads Congress, New Delhi*.

Ismail, B. N., Osman, M. H., and Mohd, M. S. (2020). Estimation of Unconfined Compression Test (UCT) parameters using digital image. *IOP Conference Series*, *476*(1), 1–6. https://doi.org/10.1088/1755-1315/476/1/012041

James, J., and Pandian, P. k. (2016). industrial wastes as auxiliary additives to cement/lime stabilization of soils. *Advances in Civil Engineering*, 17.

Jongpradist, P., Homtragoon, W., Sukkarak, R., Kongkitkul, W., and Jamsawang, P. (2018). Efficiency of Rice Husk Ash as Cementitious Material in High-Strength Cement-Admixed Clay. *Advances in Civil Engineering*. https://doi.org/10.1155/2018/8346319

Khalid, N. H. A., Rasid, N. N. A., Mohdsam, A. R., Lim, N. H. A. S., Ismail, M., Zardasti, L., Mohamed, A., Majid, Z. A., and Ariffin, N. F. (2018). Characterization of palm oil fuel ash and eggshell powder as partial cement replacement in concrete. *IOP Conference Series: Materials Science and Engineering*, *431*(3), 1–9. https://doi.org/10.1088/1757-899X/431/3/032002

Ndububa, E., and Yakubu, N. (2015). Effect of Guinea Corn Husk Ash as Partial Replacement for Cement in Concrete. *IOSR Journal of Mechanical and Civil Engineering*, *12*(2), 40–45. https://doi.org/10.9790/1684-12214045

Odeyemi, S. O., Abdulwahab, R., Akinpelu, M. A., Afolabi, R., and Atoyebi, O. D. (2022). Strength Properties of Steel and Bamboo Reinforced Concrete Containing Quarry Dust , Rice Husk Ash and Guinea Corn Husk Ash. *Iranian (Iranica) Journal of Energy & Environment*, *13*(4), 354–362. https://doi.org/10.5829/ijee.2022.13.04.05

Odeyemi, S. O., Anifowose, M. A., Abdulwahab, R., and Oduoye, W. O. (2020). Mechanical Properties of High-Performance Concrete with Guinea Corn Husk Ash as Additive. *LAUTECH Journal of Civil and Environmental Studies*, *5*(September 2020), 139–154. https://doi.org/10.36108/laujoces/0202/50(0131)

Odeyemi, S. O., Atoyebi, O. D., and Ayo, E. K. (2020). Effect of Guinea Corn Husk Ash on the Mechanical Properties of Lateritic Concrete. *IOP Conference Series: Earth and Environmental Science*, *445*(012034), 1–11. https://doi.org/10.1088/1755-1315/445/1/012034

Odeyemi, S. O., Atoyebi, O. D., and Ayo, E. K. (2020). Effect of Guinea Corn Husk Ash on the Mechanical Properties of Lateritic Concrete. *IOP Conference Series: Earth and Environmental Science*, *445*(012034), 1–11. https://doi.org/10.1088/1755-1315/445/1/012034

Oyetayo, F. L., and Ogunrotimi, A. I. (2012). Guinea Corn (Sorghum vulgare) Leaf, a Potential Source of Nutrients and Phytochemicals. *Food and Public Health*, *2012*(6), 228–230. https://doi.org/10.5923/j.fph.20120206.07

Saadeldin, R., and Siddiqua, S. (2013). *Geotechnical characterization of a clay–cement mix. December*. https://doi.org/10.1007/s10064-013-0531-2

Sani, J. E., Moses, G., Etim, R. K., Wilson, U. N., and Babatunde, O. A. (2022). Stabilisation of Lateritic Soil with Cement and treated Sisal fibre. *ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering*, *15*(1), 41–47.

Tastan, E. O., Edil, T. B., Benson, C. H., and Aydilek, A. H. (2011). *Stabilization of organic soils with fly ash, J. Geotech.* 189–833.