COMPARISON OF THE EFFECT OF PALM KERNEL FIBRE ASH ON THE COMPRESSIVE EARTH STABILISED BLOCK

[1*]Omotainse P. O., [1]Obamuyiwa O. M., [2]Busari M. A., [2]Igba U. T., [1]Dairo O. U. and [3]Jekayinfa S. O.

[1]*Department of Agricultural and Bio-Resources Engineering, College of Engineering, Federal University of Agriculture Abeokuta. Ogun state*

[2]*Department of Civil Engineering, College of Engineering, Federal University of Agriculture Abeokuta. Ogun state*

[3]*Department of Agricultural Engineering, Faculty of Engineering and Technology, Ladoke Akintola University of Technology, Ogbomoso, Nigeria*

**Corresponding Author: omotainsepo@funaab.edu.ng*

ABSTRACT

Pursuing cost-effective, sustainable building materials remains imperative, particularly for addressing housing deficits in developing nations like Nigeria. This study investigates the influence of one agricultural by-product, palm kernel fibre ash (PKFA), on the compressive and flexural strengths of compressed stabilised earth blocks (CSEBs), aiming to identify optimal proportions for enhanced block strength. Through systematic testing, variations in flexural and compressive strengths are evaluated across different percentages of PKFA replacements (ranging from 0% to 100%). The X-ray Diffraction (XRD) analysis of the PKFA reveals complex crystal structures with various mineral phases, shedding light on the ash's composition and potential structural implications in CSEB production. Results demonstrate a noteworthy impact on the mechanical properties of CSEBs with PKFA incorporation. Flexural strength exhibits improvements with low percentages of PKFA replacement, peaking at certain levels before declining at higher substitution rates. Compressive strength, similarly, showcases enhancements up to a certain replacement percentage, beyond which a decline is observed. The findings suggest an optimal range of PKFA replacement that augments the strength of CSEBs without compromising structural integrity. The study underscores the potential viability of PKFA as a substitute for cement in CSEBs, offering insights into the optimal replacement percentages for enhanced block strength.

Keywords: *Palm Kernel Fibre Ash (PKFA), Compressive Strength, Flexural Strength*

INTRODUCTION

Ensuring the provision of high-quality housing is acknowledged as a crucial duty for the well-being of individuals within any nation. The construction sector holds significant sway in most economies, with its endeavours being pivotal to achieving socio-economic development objectives by providing shelter, infrastructure, and employment opportunities (Anaman and Osei-Amponsah, 2007). Many governments have proposed housing schemes that help facilitate housing ownership for low-income groups. It is essential to find ways to reduce the construction cost, at least for low-income housing. To achieve this, construction materials derived from natural resources are frequently employed (Deboucha and Hashim, 2011). This can be done by focusing on locally available materials for construction purposes with proper and appropriate technology (Danso *et al*., 2014). So many traditional construction materials exist in Nigeria, which have, over the years, proven suitable for a wide range of buildings. These materials have an excellent potential for increased use in the future, and one such material is the Compressed Stabilised Earth Block (CSEB) (Ajayi *et al*. 2019).

Affordable and accessible building materials are necessary to construct low-cost housing in Nigeria. Non-fired laterite bricks are attractive building materials because they are inexpensive to manufacture compared to conventional block and burnt brick commonly used for building houses (Jude *et al*. 2022). In the quest to make building cheap and sustainable, as it is an essential component of human settlement, there is a search for different building materials to be used. Building materials have played an essential role in the construction industry (Akanni *et al.,* 2014). These materials include Cement, Sand, Water, Iron rods, and others. The cost of building materials poses a significant threat to both the construction industry and people aspiring to own houses. Idoro and Jolaiya (2010) affirmed that many projects were not completed on time due to the cost of materials, which has been on the rise. The alternative material used for constructing a building wall in Nigeria is earth brick stabilised with agricultural wastes like rice husk, palm kernel fibre, and palm tree ash, and this is due to the high cost of other building materials to minimise the housing problem in Nigeria. The housing problem seems to be getting worse. According to the Federal Mortgage Bank of Nigeria (FMBN, 2019), Nigeria's housing gap is estimated to be in the region of 17 million units, while home ownership is estimated as low as 25%. This is the result of the high cost of building materials. It has been identified that 75% of the housing deficit in Nigeria is concentrated on families earning less than three times the minimum wage caught in the poverty cycle. Families' incomes are structurally limited, and as a result, they are unable to afford proper housing (World Bank, 2013). Modern technological progress has led researchers to create construction materials that boast enhanced quality and performance. Nevertheless, the depletion of natural resources during this innovation process is a significant and worrisome issue (Elahi *et a*l., 2021).

Palm kernel fibre is a waste obtained from palm fruits after the oil is extracted and has the property of increasing the hardness value of brick (Walid *et al*., 2019). Walid *et al*. (2019) reported that the waste material, palm ash, has been introduced as a competent binder in enhancing mortar and concrete properties.

Compressed stabilised earth block (CSEB) is a construction material that contains earth (laterite) mixed homogenously with a stabilising agent, be it cement, lime, or ash, into a compressed block. In prior studies (Binici et al., 2005; Elahi et al., 2021; Oti & Kinuthia, 2012), it's been unveiled that adopting compressed stabilised earth blocks has garnered increasing attention for providing cost-effective housing. Moreover, as society moves forward, emphasising ecological design in construction and stabilised earth-building materials is anticipated to hold substantial value. This suggests that a mix with higher stabiliser content (such as lime, cement, or ash) results in a superb building material with excellent chemical properties. Conversely, a meticulously planned application of a mixture containing lower stabiliser content aims to achieve a cost-effective and efficient solution for earth building and construction (Solanski *et al.,* 2009). In Anifowose's (2000) discovery, iron in the soil is responsible for low compressive strength in the soil stabilisation process. The strength of the CSEB can be increased by adding natural fibres, which can improve the ductility in tension. The improvement is by retarding the tensile crack propagation after initial formation and the shrinkage cracking (Fetra *et al.* 2013).

The utilisation of oil palm fibre ash, boasting a substantial silica content of 59.1%, presents a promising avenue for its application as a partial substitute for cement (Firdaus *et al.*, 2020).

Noor *et al.,* 2017 delved into the influence of incorporating palm oil kernel shell (PKS) and palm oil fibre (POF) into concrete, focusing on their impact on compressive and flexural strength. The findings highlighted a discernible pattern: substituting PKS decreased compressive and flexural strengths relative to traditional concrete compositions. However, a significant observation emerged at a 25% replacement level of PKS in concrete, where the compressive strength reached an acceptable threshold, falling within the required range for structural concrete.

MATERIALS AND METHODS

Laterite

The laterite used was collected from the abundant deposit of laterite in the Federal University of Agriculture, Abeokuta and air-dried. The laterite samples used were air-dried in a cool, dry place. Air drying was done to enhance the grinding and sieving of the laterite. After drying, stones and other foreign materials were removed; grinding was carried out using a hammer to break the lumps present in the soil. The natural soil samples will be tested for texture or particle size distribution.

Palm kernel fibre

Palm kernel fibre is a natural fibre extracted from the outer part of the palm kernel shell and is primarily used in products such as floor mats, doormats, brushes and mattresses. This material was obtained locally from the FUNAAB palm oil factory, Odeda local government, Ogun State. It was properly kept in a store before it was burnt to ash.

Cement

Cement is a finely ground powdered product that acts as a stabiliser's agent. 50kg (1 bag) of 42.5R ordinary Elephant cement was used, and it was purchased at Camp in Odeda local government, Ogun State.

Water

The water was used for wetting laterite, cement, and fibre ash both during mixing and in the curing of the bricks.

Methods

The study utilised a completely randomised design to investigate the impact of different percentages of fibre ash replacements for cement, spanning six levels (0%, 20%, 40%, 60%, 80%, and 100%) for each factor. Specimens were labelled based on the palm kernel fibre ash percentage and the sample number.

A soil sample of around 500 grams was collected and meticulously cleaned to eliminate any organic matter, roots, or stones that might interfere with the particle size analysis. Subsequently, it was dried in an oven to remove moisture and weighed. The soil was sieved through a 4.75 mm IS sieve using an automatic shaker to eliminate particles larger than 4.75 mm. The retained soil on the 4.75 mm sieve was weighed to assess the mass of the coarse fraction. The soil passing through the sieve was further sieved using a series of standard sieves to classify different particle sizes. Each fraction retained on the sieves was weighed to determine its mass, enabling the calculation of the percentage of soil retained on each sieve and creating a particle size distribution curve.

The mixing process occurred in two stages: dry and wet mixing. Water was added to the dry mix just before compaction to minimise the retention time and maintain the quality of the blocks. The mixing ratio used was 9:1, and various dry mixes were created with different percentages of fibre ash replacements for cement (0%, 20%, 40%, 60%, 80%, and 100%) based on weight.

Laterite cube samples were removed from the mould immediately after casting and left to air dry for 24 hours in a shaded area. Subsequently, they were covered with a polythene sheet to initiate proper curing, which involved sprinkling water on the specimens for about 21 days. This covering was crucial to prevent rapid drying, which could lead to shrinkage and cracking of the blocks. After the curing period, the water evaporated, and the clay fraction was allowed to shrink gradually. To prevent excessive shrinkage, exposure to wind and direct sunlight was minimised, and a drying period of 14 days followed this process to dry out the blocks further.

Compressive strength

The compressive strength of the CSEBs was determined by crushing them under the Universal Testing Machine after 28 days of curing. Two types of compressive strength tests were done: The dry compressive strength test is done by oven drying sample blocks, while the wet compressive strength test is determined in saturated conditions. The process was repeated for the different percentages of PKFA: Cement ratios. The compressive strength was calculated in Equation 1.

$$\text{Compressive strength} = \frac{P}{A} \quad (1)$$

Where,

P = crushing load (kN). A = cross-sectional area (mm^2) of brick.

Fig 1: Produced CSEBs for testing

Fig 2: Testing for the comprehensive strength of the CSEBs

Flexural strength test

The flexural strength is the maximum bending stress that can be applied to the CSEB before it yields. The flexural strength of the CSEBs was obtained using the three-point flexural test technique. The design load and span that the CSEBs were subjected to were determined. The design load is the maximum load that the structure will experience during its intended use, while the span is the distance between the supports on which the CSEBs will be placed. The moment of inertia was a measure of the CSEB's resistance to bending and was calculated using Equation 2.

$$I = \frac{b \times h^3}{12} \quad (2)$$

Where,

I = moment of inertia (mm^4), b = width (mm) of the CSEB, h = height (mm) of the CSEB.

The maximum bending stress that the CSEBs can withstand was calculated using Equation 3.

$$I = \frac{3 \times P \times L}{2 \times \sigma \times h^2} \quad (3)$$

Where,

σ = maximum bending stress, P = applied load (N), L = the span (mm) of CSEB

The maximum bending stress that was calculated was compared with the flexural strength of the CSEBs obtained from the three-point flexural test technique. If the maximum bending stress is less than the flexural strength, the CSEBs should be able to withstand the design load and span without failure. If the maximum bending stress is greater than the flexural strength, the CSEBs may fail in bending, and additional measures may need to be taken to strengthen the structure.

RESULTS AND DISCUSSIONS

Table 1 provides results obtained from the physical properties test of the laterite soil. The moisture content of the laterite soil is within the typical range for stabilised earth block production. However, the liquid and plastic limits indicate that the soil has low plasticity, which may affect its workability during production. The plasticity index of 7.63 is relatively low, which may also affect the strength of the compressed earth blocks. The specific gravity of 2.5 indicates that the soil is relatively dense, which can be a favourable characteristic for compressed earth block production. However, other factors such as soil particle size distribution and clay mineralogy can also affect the quality of the blocks.

Table 1: Properties of the soil considered in the study.

Soil Property	Value
Specific gravity	2.5
Liquid Limit, LL (%)	36.46
Plastic Limit, PL (%)	28.59
Plasticity Index, PI (%)	7.63
moisture content (%)	21.0
Optimum moisture content (%)	22.24
Maximum dry density (g/cm)	1.417

XRD (X-ray diffraction) is an analytical technique widely used to identify crystalline materials based on their unique diffraction patterns. X-rays are diffracted by the atoms in a crystal lattice in specific directions, and the resulting diffraction pattern can be used to identify the type of crystal structure present.

Based on the XRD data provided in Figure 3, the following observations were made about the crystal structure and the potential mineral candidates of the ash:

1. The broad range of diffraction peaks and the variation in peak intensities suggest that the sample is composed of multiple phases or has an imperfect crystal structure. This could indicate the presence of impurities or defects within the crystal lattice.

2. The peak intensities vary widely, suggesting that the crystal is composed of multiple phases or that the crystal structure is not well-ordered.

3. The peaks in the range of 5 to 20 degrees correspond to low-angle diffraction, which is typically associated with large crystal structures. Minerals with larger crystal structures include quartz, feldspars, and micas.

4. The peaks in the range of 20 to 45 degrees correspond to high-angle diffraction, which is typically associated with smaller crystal structures. Minerals with smaller crystal structures include clay minerals, pyrite, and calcite.

5. The peak at 27 degrees is much more intense than the surrounding peaks, which suggests that this peak

corresponds to the dominant crystal phase present, and this could correspond to

6. The peak at 21.2 degrees is extremely intense, which suggests that this peak corresponds to

a very high-order diffraction, likely from a substantial crystal structure. This may indicate the presence of a specific crystal phase or a particular crystallographic orientation.

Based on these observations, we can conclude that the XRD data likely corresponds to a crystalline material composed of multiple phases or with an imperfect crystal structure. The dominant crystal phase appears to be present at 27 degrees, and there is a very intense peak at 21.2 degrees that may correspond to a specific crystal phase or orientation. Some minerals with large crystal structures include gypsum, barite, and halite.

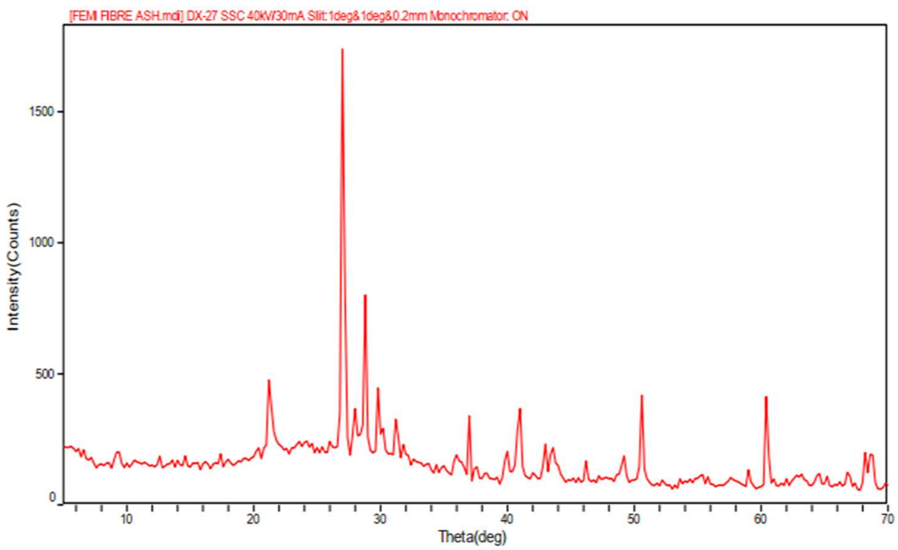

Fig 3: XRD chart for Palm Kernel fibre ash

The results of the chemical composition of the cement used for this study are presented in Table 2.

Table 2: Chemical composition of cement used in the study.

Element	Cement
SiO_2	17.769
Al_2O_3	4.308
Fe_2O_3	2.757
CaO	59.888
MgO	1.378
SO_3	2.295
K_2O	0.125
Na_2O	0.000
P_2O_5	0.136
LOI	9.800
M_2O_5	0.000
TiO_2	0.000

The results presented in Table 3 show the results of the flexural test conducted on six samples. The flexural test measures the material's ability to withstand bending, while the compressive test measures the maximum amount of load that a material can bear before failing. The test results show that using palm kernel fibre ash (PKFA) as a replacement for cement in compressed stabilised earth blocks (CSEBs) has a significant effect on both the flexural strength and compressive strength of the blocks. Table 3 shows that the flexural strength of the CSEBs initially increased as the percentage of PKFA increased, with samples having 20% and 40% PKFA showing higher flexural strength compared to the control sample with no PKFA.

Table 3: Flexural and compressive strengths of CSEBs

Sample	Flexural Test			Compressive Test		
	Initial (mm)	Final (mm)	Flexural strength (N)	Area (mm^2)	Maximum load (kN)	Compressive strength (kN/mm^2)
Cement 100%, 0PKFA1	160	166	15.2	17100	54900	3.2
Cement 80%, 20PKA2	162	168	16.7	17100	59700	3.5
Cement 60%, 40PKA3	163	168	16.34	17100	52200	3.1
Cement 40%, 60PKA4	160	167	6.77	17100	57300	3.4
Cement 20%, 80PKFA5	162	170	5.88	17100	22700	1.3
Cement 0%, 100PKFA6	162	167	7.22	17100	19500	1.1

CONCLUSION

In this study, the investigation into the impact of palm kernel fibre ash (PKFA) as a partial substitute for cement in Compressed Stabilised Earth Blocks (CSEBs) revealed significant insights into the material's flexural and compressive strengths. The results of the flexural tests, reflecting the material's resistance to bending stresses, showcased a noteworthy trend: samples with 20 - 40% PKFA exhibited increased flexural strength compared to the control sample, indicating an optimal percentage range for enhanced performance.

Conversely, higher PKFA percentages (80 - 100%) exhibited a diminishing trend in flexural and compressive strengths, signifying a negative impact on the material's load-bearing capabilities. Despite this decline, even at 100% replacement, the CSEBs demonstrated acceptable strengths. These findings suggest a balance, indicating that 20 - 40% PKFA in the laterite-cement mix enhances flexural and compressive strengths without compromising the blocks' overall performance.

RECOMMENDATION

Encourage using locally available and sustainable building materials for low-cost housing construction, such as compressed stabilised earth blocks and non-fired laterite bricks. This will not only reduce construction costs but also promote the use of eco-friendly materials.

Increase investment in research and development to improve the quality and durability of these local building materials. This will help ensure they meet the required standards and can compete with conventional building materials.

Declaration of Competing Interest

The authors declare that they have no competing interests. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. However, samples with 60%, 80%, and 100% PKFA exhibited a significant decrease in flexural strength compared to the control sample. This trend suggests that there is an optimal percentage of PKFA that can be used in CSEBs to achieve higher flexural strength.

REFERENCES

Ajayi, A. S., Oluwoye, J., Olutoge, F. A., & Coker, A. O. (2019). Impact of palm kernel shell ash (PKSA) on the strength and water absorption properties of earth blocks. *International Journal of Advances in Scientific Research and Reviews*, 04(03), 129-135.

Akanni, P. O., Oke, A. E., & Omotilewa, O. J. (2014). Implications of rising cost of building materials in Lagos State Nigeria.

Anaman, K., & Osei-Amponsah, C. (2007). Analysis of the causality links between the growth of the construction industry and the growth of the macro-economy in Ghana. *Construction Management & Economics*, *25*, 951–961. https://doi.org/10.1080/01446190701411208

Anifowose, A. Y. B. (2000). Stabilisation of lateritic soils as a raw material for building blocks. *Bulletin of Engineering Geology and the Environment*, 58, 151-157.

Binici, H., Aksoğan, O., & Shah, T. (2005). Investigation of fibre reinforced mud brick as a building material. *Construction and Building Materials*, 19(4).

Danso, H., Martinson, B., Ali, M., & Mant, C. (2014). Performance characteristics of enhanced soil blocks: A quantitative review. *Building Research & Information*, 43(2).

Danso, H., Martinson, B., Ali, M., & Mant, C. (2014). Performance characteristics of enhanced soil blocks: A quantitative review. *Building Research &Amp; Information*, *43*(2). https://doi.org/10.1080/09613218.2014.933293

Deboucha, S., & Hashim, R. (2011). A review on bricks and stabilised compressed earth blocks. *Scientific Research and Essays* Vol. 6(3), pp. 499-506, http://www.academicjournals.org/SRE DOI: 10.5897/SRE09.356

Elahi, T. E., Shahriar, A. R., & Islam, M. S. (2021). Engineering characteristics of compressed earth blocks stabilised with cement and fly ash. *Construction and Building Materials*, 277, 122367.

Fetra, V. R., Ismail, A. R., & Ahmad, M. A. (2013). A brief review of compressed stabilised earth brick (CSEB). *UTHM Institutional Repository*. [Link provided is to UTHM Institutional Repository

Idoro, G. I., & Jolaiya, O. (2010). Evaluating material storage strategies and their relationship with construction project performance. *Proceedings of CIB International Conference on Building Education and Research, University of Cape Town*. Retrieved from http://www.rics.org/cobra

ISSN 1992-2248 ©2011 Academic Journals

Jude, K., Igwe, C. O., & Mohammed, B. M. (2022). Effects of Palm Leaf Ash and Palm Kernel Fibre on Properties of Compressed Laterite Earth Brick. *Journal of Sustainability and Environmental Management*, 1(2), 218-223.

Noor, N. A. M., Xiang-ONG, J., Noh, H. M., Hamid, N. A. A., Kuzaiman, S., & Ali, A. (2017). Compressive strength, flexural strength and water absorption of concrete containing palm oil kernel shell. *IOP Conference Series: Materials Science and Engineering*, 271. [DOI link missing]

Oti, J., & Kinuthia, J. (2012). Stabilised unfired clay bricks for environmental and sustainable use. *Applied Clay Science*, 58.

Solanski, P., Zaman, M., and Hhoury, N. (2009). Engineering properties and moisture sustainability of silty clay stabilised with lime, class C fly ash, and cement kiln dust. *Journal of Materials in Civil Engineering*, 21(12), 749.