DOI: 10.36108/laujoces/6202.61.0102

Effects of Varying Mix Ratio on the Characteristic Performance of Hollow Sandcrete Blocks Containing Rice Husk Ash as Mineral Filler

[1,3]*Anifowose, M.A. and [2]Raheem, A.A.

1Department of Civil Engineering, The Federal Polytechnic Offa, Offa, Nigeria.
2Department of Building Technology, Ladoke Akintola University of Technology, Ogbomoso, Nigeria.
3Department of Civil Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria.*

Corresponding Author E-mail: mukaila.anifowose@fedpoffaonline.edu.ng; Tel: 08052552927

Abstract

Rice Husk Ash (RHA) had been greatly studied as supplementary cementing material. Incorporating RHA as a mineral filler in block production will further address the challenges that negatively affect rice industries, which has to do with inappropriate use and disposal of rice residue. Hence, this study investigated the effects of RHA as substitute of Fine Aggregate (FA) in the production of Hollow Sandcrete Blocks (HSB). HSB of sizes 450 x 225 x 225 mm and 450 x 150 x 225 mm were produced using a mix proportion of 1:6 and 1:8, respectively. The replacement of the FA with RHA (25 and 50%) was done by reducing the volume of the FA and replacing it with RHA. The HSB were cured by sprinkling for 7, 28, 56 and 90 days. A total number of one hundred and eight blocks were produced. Density, Compressive Strength (CS), water absorption capacity and abrasion of the RHA-HSB were determined. Scanning Electron Microscopy/Energy Dispersive Spectroscopy (SEM-EDS) of the HSB composite was also conducted. The content of FA replaced with RHA lead to a low performance of the HSB properties as against the control. However, the HSB with 25% RHA content meet the recommended CS by NIS for 150 mm and 225 mm HSB at 90 days. Morphologically, the RHA-HSB gain better interfacial bonding at 90 days. The study concluded that HSB produced with 25% RHA as substitute of FA can be used in the application of non-load bearing and load bearing blocks.

Keywords: Fine Aggregate, Rice Husk Ash, Hollow Sandcrete Blocks Properties, Morphology.

Introduction

Sandcrete blocks are predominantly used as walling materials in construction of buildings, drainages and other masonry works. The percentage of walling materials made of sandcrete blocks account for over 95% of all walling materials (Odeyemi *et al.,* 2022a; Atoyebi *et al.,* 2024). Sandcrete blocks are either of solid or hollow rectangular types. Hollow Sandcrete Blocks (HSB) are the common types of sandcrete blocks. They are usually 450 × 225 × 225 mm for load bearing walls and 450 ×150 × 225 mm for non-load bearing walls (NIS 87:2000; Raheem and Sulaiman, 2013; Odeyemi *et al.,* 2019). The quality of sandcrete blocks is influenced by so many factors such as the quality of constituent materials, method of production, duration of curing, forms and sizes of blocks (Oyekan and Kamiyo, 2011; Adewuyi *et al.,* 2013; Quadri and Ijesoh, 2017). The composition of a sandcrete block is Portland cement, fine aggregate (sand) and water (Wilson *et al.,* 2024). Increase in price of walling materials has necessitated the need to find replacement for its components (cement and fine aggregate) either partially or fully. This led to the use of residue such as rice husk ash (Ige *et al.,* 2018; Nduka et al., 2022; Raheem and Anifowose, 2023), guinea corn husk ash (Odeyemi *et al.,* 2020a; Odeyemi *et al.,* 2020b), groundnut shell ash (Ogork *et al.,* 2015; Ige *et al.,* 2017a; Ige *et al.,* 2017b; Sulaiman *et al.,* 2020), bamboo leaf ash (Odeyemi *et al.,* 2022b), palm oil fuel ash (Odeyemi *et al.,* 2021; Hong *et al.,* 2023), metakaolin (Raheem *et al.,* 2021; Jamilu *et al.,* 2023), and iron and steel slag (Adedokun *et al.,* 2024), for sustainable construction.

Rice Husk Ash (RHA) is abundantly available at the dump sites of Hillcrest Agro-Allied Limited – a rice milling company located at Amberi, Irepodun Local Government Area of Kwara State. The RHA is obtained as waste product from the rice husk powered steam engine during rice productions at a combustion rate of 600 ^oC. Hence, it has been reported that the best form of RHA to be used in a cement composite should be combusted at a temperature in the range of 600 to 699 °C (Ogwang *et al.,* 2021: Anifowose and Raheem, 2024). This suggests Hillcrest Agro-Allied Limited RHA as a useful material. There is need for an urgent redress towards the weekly disposal of RHA generated by the company. The present method of disposal is landfill and it is disturbing as a result of acquisition of additional hectares of land for disposal by the company. RHA had been greatly studied as substitute for PLC with no concern on effect of RHA contents as substitute for fine aggregate. The use of RHA improves the micro-filling structure of a composite matrix when compared to conventional composite (Gursel *et al.,* 2016; Prasara and Gheewala, 2017; Shen 2017; Amran *et al.,* 2020). Utilizing RHA as a mineral filler (without sieving to finer size) will further reduce the volume of RHA being disposed Hillcrest Agro-Allied Limited. In this study, the effects of RHA content as replacement of fine aggregate for production of Hollow Sandcrete Blocks (HSB) was investigated.

Materials and Methods

Portland Limestone Cement (PLC) of grade 42.5N that conforms to NIS 444–1 (2014) was used for production of blocks with portable drinking water. Fine aggregate that pass through British Sieve 4.75 mm in conformity to BS EN 12620 (2002+A1:2008) was used. The raw RHA used (without milling and sieving to finer particles) was obtained from Hillcrest Agro- Allied Industries Limited, Amberi, Irepodun Local Government Area of Kwara State (8°14′45.1392″ and 4°32′29.6916″ E). The RHA are being generated from steam engine through the combustion of rice husk in a powered steam engine at a combustion rate of $600\ ^oC$, which are further disposed into landfill, thereby causing environmental threat. Specific gravity of the PLC, RHA and fine aggregate were determined. And particle size distribution were determined on fine aggregate to ascertain its fineness modulus.

In order to minimize the RHA been disposed, raw RHA (without sieving) was used as partial replacement (25 and 50 %) of FA by volume for producing Hollow Sandcrete Blocks (HSB). A mix proportion of 1:6 and 1:8 was adopted. The replacement of the FA was done by reducing the volume of head pan for measurement by quarter (25% FA) and half (50% FA), and replacing it with RHA in each of the mix ratio. The mixture of the composite was then poured into steel mould in the block moulding machine and the blocks were vibrated to ensure adequate compaction. The HSB were cured by sprinkling for 7, 28, 56 and 90 days. A total number of one hundred and eight blocks (fifty-four for 450 x 225 x 225 mm and fifty-four for 450 x 150 x 225 mm) were produced as presented in Table 1. The density, compressive strength, water absorption capacity and abrasion of the RHA-HSB were determined. Scanning Electron Microscopy/Energy Dispersive Spectroscopy of the HSB composite were conducted on the control sample and the 25% RHA-HSB (which met the required standard strength) in order to assess its morphological characteristics.

Table 1: Number of Blocks Samples for Raw Ash and Fine Aggregate Replacements

PLC (%)	Fine aggregate	Raw Ash	Number of Samples per Curing Ages (7, 28, 56, 90)	Water Absorption @ 28 Days	Abrasion @ 28 Days
100	100	0	$3+3+3+3=12$	3	3
100	75	25	$3+3+3+3=12$	3	3
100	50	50	$3+3+3+3=12$	3	3
			Total = 36	**9**	**9**

Results and Discussion

Specific Gravity of Material

The results of Specific Gravity (SG) of PLC, RHA and Fine Aggregate (FA) as obtained were 3.12, 2.43, and 2.71, respectively. Studies conducted by Raman et al. (2011), Marthong (2012), and Fapohunda *et al.*

(2017) indicated that the SG of RHA ranges from 2.05 to 2.53, which is comparatively less than the PLC specific gravity, which ranges from 3.10 to 3.19 (Raheem and Kareem, 2017; Anifowose *et al.,* 2018). This implies that if RHA is used in place of a unit weight of PLC, the volume will increase. As a result, the resulting concrete, mortar or sandcrete will be lighter than the conventional mix (without RHA) and will develop low density as the percentage of replacement increases (Raheem and Kareem, 2017; Fapohunda *et al.,* 2017). The result of the Specific Gravity (SG) of PLC and RHA is in agreement with previous study by Ige *et al.,* (2018) Khan *et al.,* (2021), and Anifowose and Raheem (2024).
The results of the SG of the FA (2.71) in this study is within the specified limit of 2.30 to 2.90 as reported by Neville (2011), ACI (2007) and Abdulwahab *et al.* (2023) for aggregates. SG of aggregates is considered as an indication of strength. Hence, material having higher SG is generally considered as having higher strength. In order to enhance CS, it is more advantageous to utilise materials characterised by a higher specific gravity (Idiata *et al.,* 2024). The result of the FA is in tandem with previous study Adedokun *et al.,* (2019), Anifowose *et al.,* (2021), Adedokun *et al.,* (2021), Serati *et al.,* (2022), Odeyemi *et al.,* (2024) and Abdurrahman *et al.,* (2025).

Particle Size Distribution of Fine Aggregate

The Fineness Modulus (FM) result of the FA from particle size distribution (Figure 1) is 2.9 with corresponding Cu and Cc of 3.69 and 1.30, respectively. The FM obtained from the particle size distribution is within the acceptable limits of 2.3 to 3.1, as specified by ACI (2007) and BS EN 933-1 (2012). The result tandem with the findings by Gashahun (2020), Odeyemi *et al.,* (2024), and Onogwu *et al.* (2024). The FA is considered as poorly graded sand since the value of Cu and Cc does not satisfy the condition stipulated by ASTM D2487 (2017). When Cu of sand > 6.0 and Cc of sand falls within 1 to 3, it indicates the sand is well graded sand. While sand is poorly graded when Cu < 6.0 and/or Cc < 1.0 or Cc > 3.0 (ASTM D2487, 2017; Yusuf *et al.,* 2017; Oriola *et al.,* 2021). The results of this study is an indication that the sand is a poorly graded sand. The better the grading, the less is the void content and higher the workability. A well graded aggregate have least amount of voids in a given volume. In well graded soil, it is assumed that the voids present in the higher size of aggregate are filled up by the next lower size of aggregate, and similarly, voids created by the lower size are filled up by one size lower than those particle and so on (Shetty, 2000; Anifowose *et al.,* 2023).

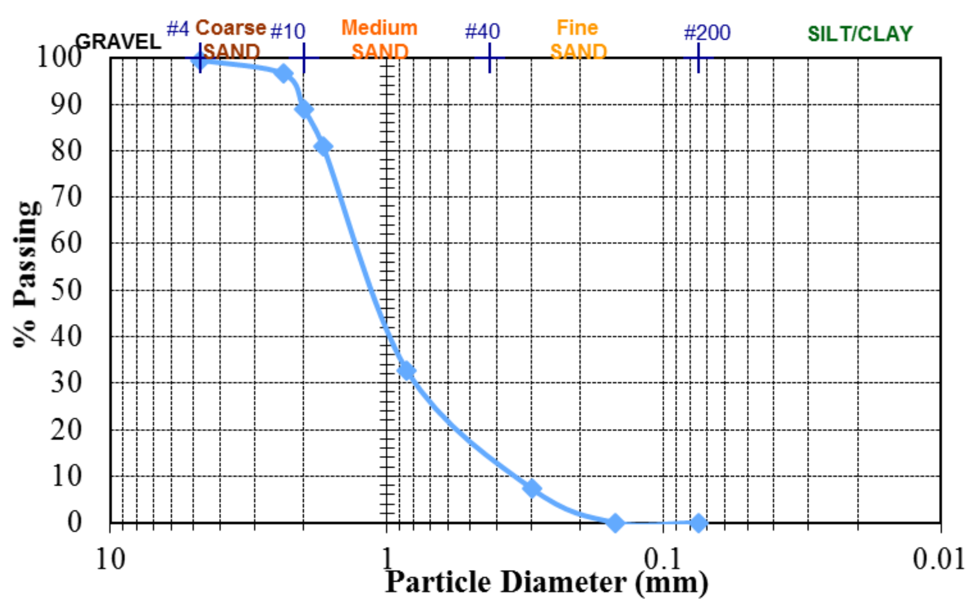


Figure 1: Particle Size Distribution of Fine Aggregates

Effect of Raw RHA on Density of HSB

The density results of the 150 mm and 225 mm Hollow Sandcrete Block (HSB) are as presented in Figures 2 and 3, respectively. The range of the results were, 1046 – 2175 kg/m^3 for 150 mm HSB and 1180 – 2024 kg/m^3 for 225 mm HSB. Density of the control and 25% RHA meet the recommended 1500 kg/m^3 for HSB (Atoyebi *et al.,* 2024; Raheem *et al.,* 2025). The 50% RHA resulted in a low density value, thereby meeting the minimum density of 500 kg/m^3. By implication, the block produced with 50% RHA by Fine Aggregate (FA) replacement is categorized as lightweight block (Ugwuanyi *et al.,* 2018; Popoola *et al.,* 2018). Figures 2 and 3 indicates that with an increase in RHA content as FA replacement, the density of the HSB decreases. Consequently, the HSB with higher RHA content (50%) exhibit lower density in comparison to the control and 25% RHA. This trend is due to the lightweight nature of the RHA particles (having low specific gravity) compared to the relatively heavier FA particles in the control mixture (Mohseni *et al.,* 2019; Wang *et al.,* 2021). The decline in density of HSB with higher RHA content has practical implications. Lower density can be advantageous in lowering the overall weight of the structure, which is particularly advantageous in load-bearing applications where weight reduction can lead to cost savings in structural support requirements (Ramadhansyah *et al.,* 2020; Nassar and Room, 2025).

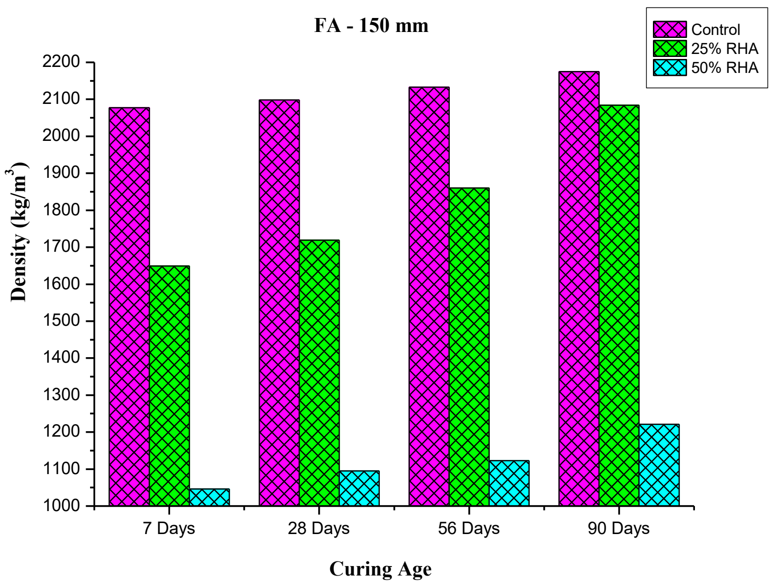


Figure 2: Effect of Fine Aggregate content on Density of 150 mm HSB

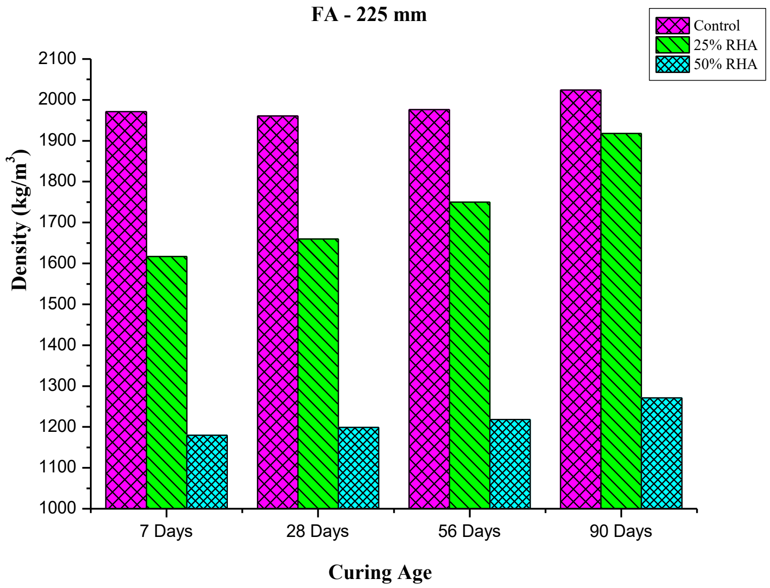


Figure 3: Effect of Fine Aggregate content on Density of 225 mm HSB

Effect of Raw RHA on Compressive Strength of HSB

The Compressive Strength (CS) of HSB reduces as the RHA increases from 25 to 50% in Figures 4 and 5, for 150 mm and 225 mm HSB, respectively. This reduction in CS is observed throughout the curing ages. However, there is increase in CS as the curing age increases from 7 to 90 days. Reason for the low CS is due to reduction in FA volume by weight of RHA. Specific Gravity (SG) of RHA is comparable lower to SG of FA, and SG of aggregates is considered as an indication of strength. Hence, material having higher SG is generally considered as having higher strength. In order to enhance CS, it is more advantageous to utilise materials characterised by a higher specific gravity (Al‑Gburi and Yusuf, 2022). The CS of the control is above the recommended CS for HSB at 28, 56 and 90 days while 25% RHA by weight of FA meet the specified CS of 2.5 and 3.45 N/mm^2 for the 150 mm and 225 mm HSB, respectively at 90 days (NIS 87, 2007; Shittu, 2023). The result of the control and 25% that meet specified CS is however higher than the result of HSB reported by Odeyemi *et al.,* (2018), Wilson *et al.,* (2024) and Raheem *et al.,* (2025).

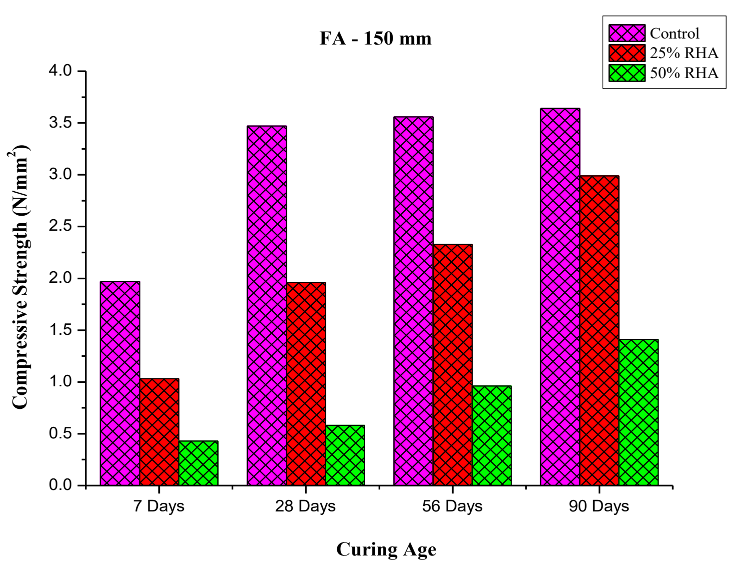


Figure 4: Effect Fine Aggregate content on CS of 150 mm HSB

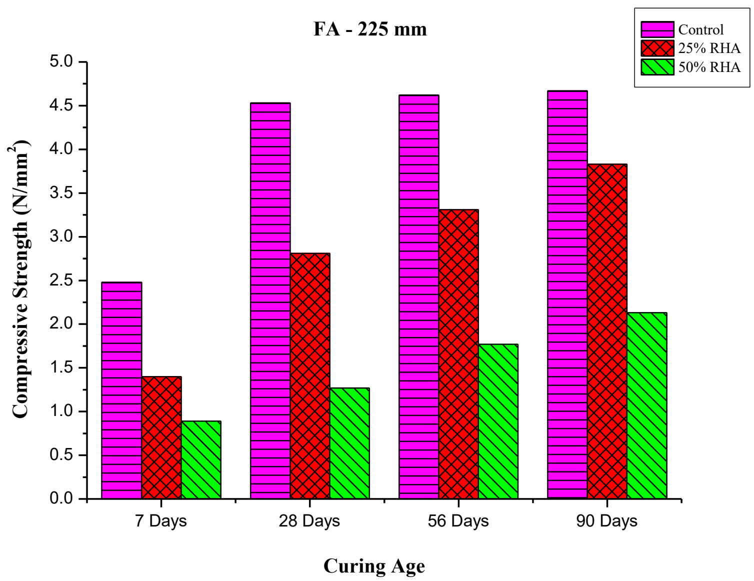


Figure 5: Effect of Fine Aggregate content on CS of 225 mm HSB

Effect of Raw RHA on Water Absorption Capacity of HSB

Results of the Water Absorption Capacity (WAC) ranged from 4.01 – 14.33% and 4.39 – 13.99%, for 150 mm and 225 mm HSB, respectively (Figure 6). The WAC increase with increase in RHA content with the 50% RHA HSB (having 14.33% for 150 mm, and 13.99% for 225 mm) exceeding the recommended 12% WAC by NIS 87 (2007). It is observed that 150 mm HSB absorbs more water than the 225 mm HSB, and this could be attributed to high mix proportion volume of 1:8 for 150 mm HSB as against 1:6 FOR 225 mm HSB. The reason for the high WAC is due to high volume of RHA that replaces Fine Aggregate (FA) in the HSB. RHA significantly influences the water retention and workability of sandcrete mixes due to its high surface area and porous nature. These properties enhance the absorption and retention of water within the mix, which can affect both hydration and consistency (Jamil *et al.,* 2024). As RHA increases, WAC of the HSB begins to dominate, reducing the availability of free water necessary for cement hydration. Excessive RHA in the HSB also limits the formation of the primary binder matrix, which influence the PLC content to become insufficient to fully support the hydration process (Alfanda, 2025).

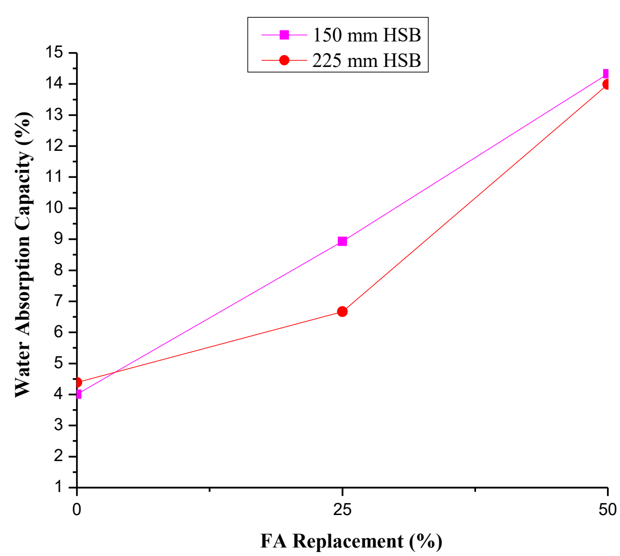


Figure 6: Effect of FA content on WAC of 150 and 225 mm HSB

Effect of Raw RHA on Abrasion of HSB

The abrasion results for the RHA blended FA are as presented in Figure 7. The abraded value ranged from 0.100 to 2.532%, and 0.073 to 1.708% for 150 mm HSB and 225 mm HSB, respectively. The difference in the abraded value could be attributed to the sizes and mix ratio of the blocks. The higher the RA content, the higher the abrasion value as observed in Figure 7. A higher abrasion implies less durable of the HSB to surface wearing. The poor resistance to surface wear and tear can be attributed to the low bonding between the composite (RHA, PLC and FA) and high reduction in FA volume. The lower the value, the better the resistance of the HSB to surface wearing (Olumodeji *et al.,* 2023). The trend of the abrasiveness in this research is similar to the findings of Adewuyi *et al.,* (2013) and Arasa *et al.,* (2017). Meanwhile, it has been reported that a good interfacial bonding of composite will enhance the overall hardness and durability of HSB surface, making it more resistant to abrasive actions (Ambedkar *et al.,* 2017; Witzke *et al.,* 2023).

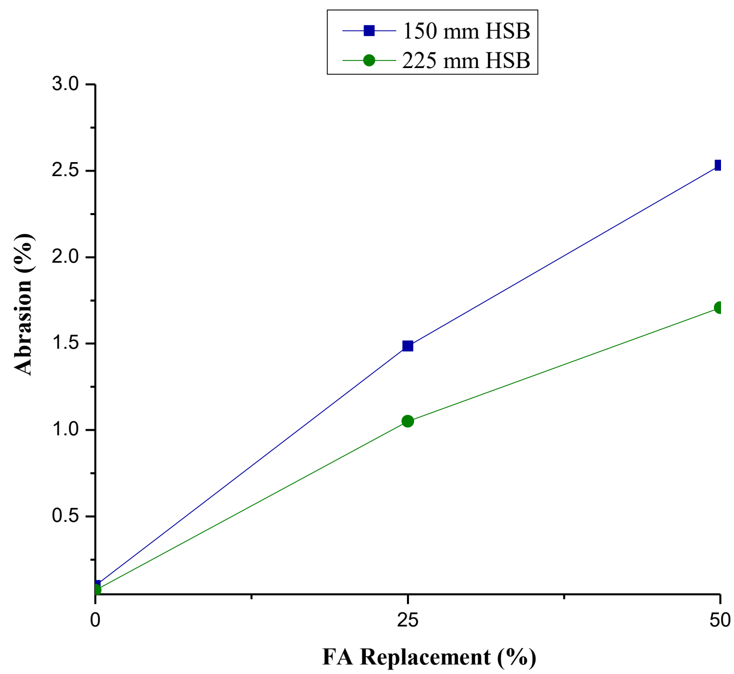


Figure 7: Effect of FA content on Abrasion of 150 and 225 mm HSB

Effect of Raw RHA on Morphology of Sandcrete Composite

The HSB composite micrograph structure are presented in Figures 8 to 11. The micrograph of the control (Figures 8 and 9) depicts properties of a rough and heterogeneous surface with different particle sizes, showing an unequal distribution of the aggregates in the matrix. It depicts the uneven packing density on the surface of the block (Atoyebi *et al.,* 2024). Figures 10 and 11, show the micrograph of the 25% RHA for 150 mm HSB composite and 225 mm HSB composite, respectively. The micrograph of the 25% RHA-150 mm HSB composite in Figure 10 depicts the properties of a rougher surface with a better distribution of the aggregates in the matrix. This is due to the addition of RHA, which was able to gain better interfacial bonding with the matrix (Datchossa *et al.,* 2023; Endale *et al.,* 2023). The 25% RHA-225 mm HSB composite shows an irregular composite with pore structure in Figure 11. The structure has traces of a whitish particle on the surface that may be responsible for the presence of albite. Hence, there is a good bonding in composite matrix. This bonding could be the reason that this samples meet the recommended CS at later age (after 28 days curing).

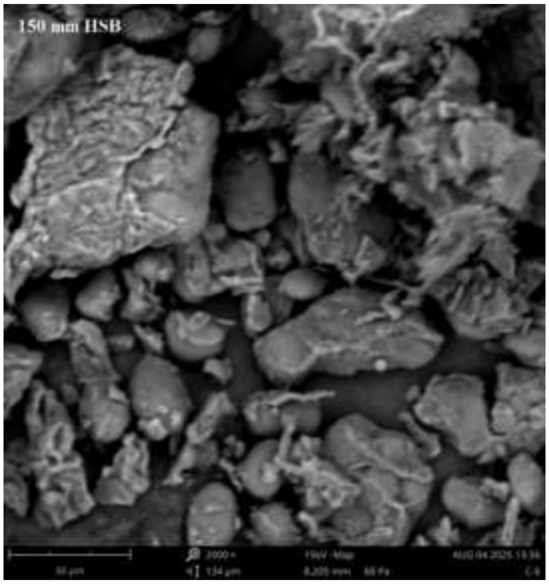


Figure 8: Micrograph of 150 mm HSB Composite

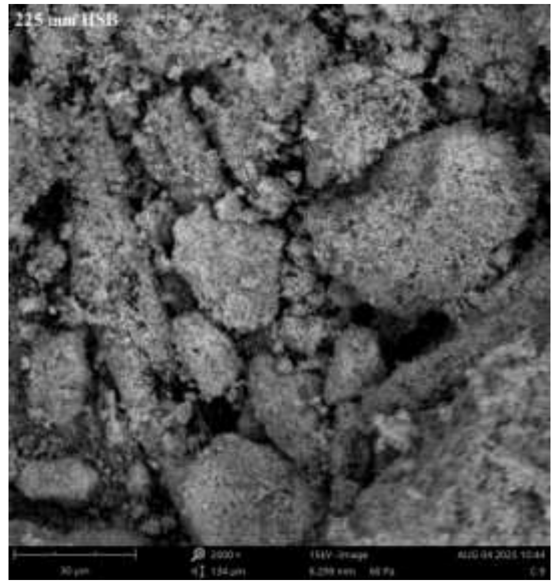


Figure 9: Micrograph of 225 mm HSB Composite

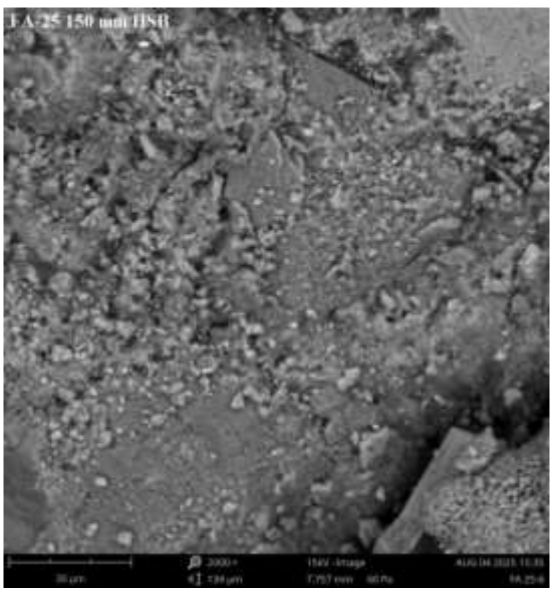


Figure 10: Micrograph of 25% RHA-150 mm HSB

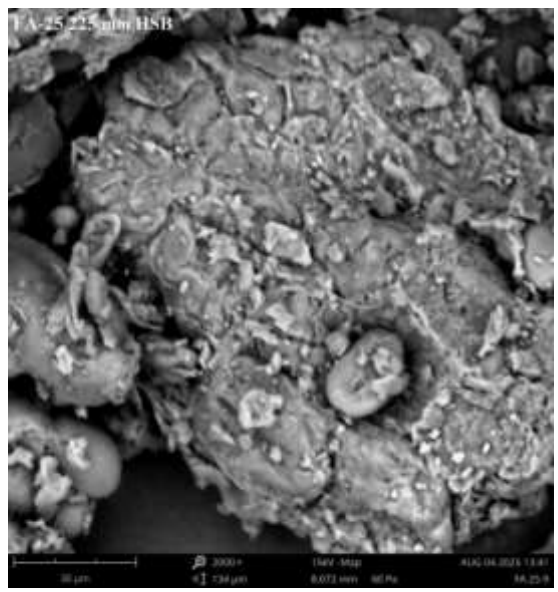
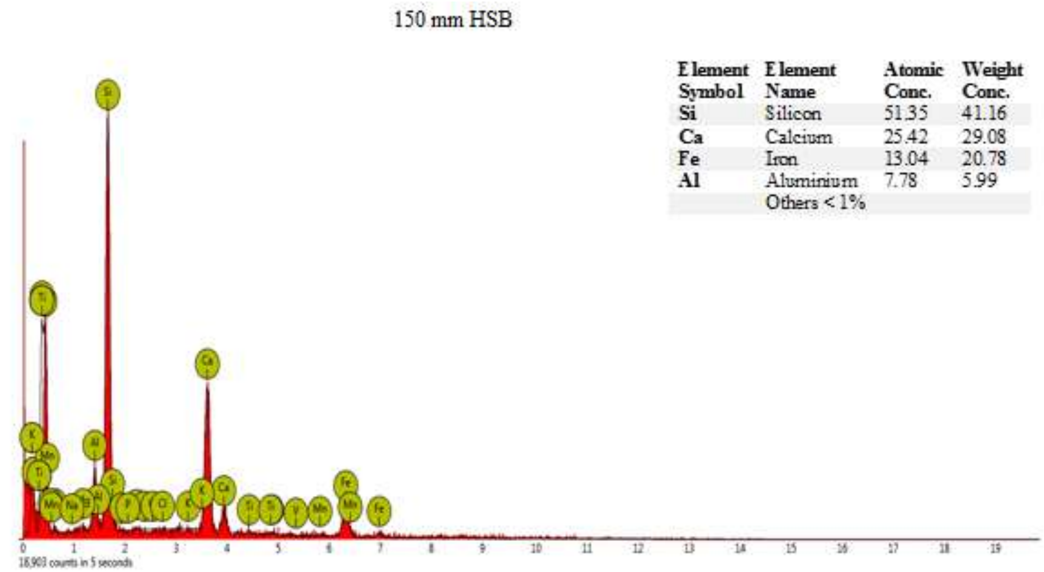


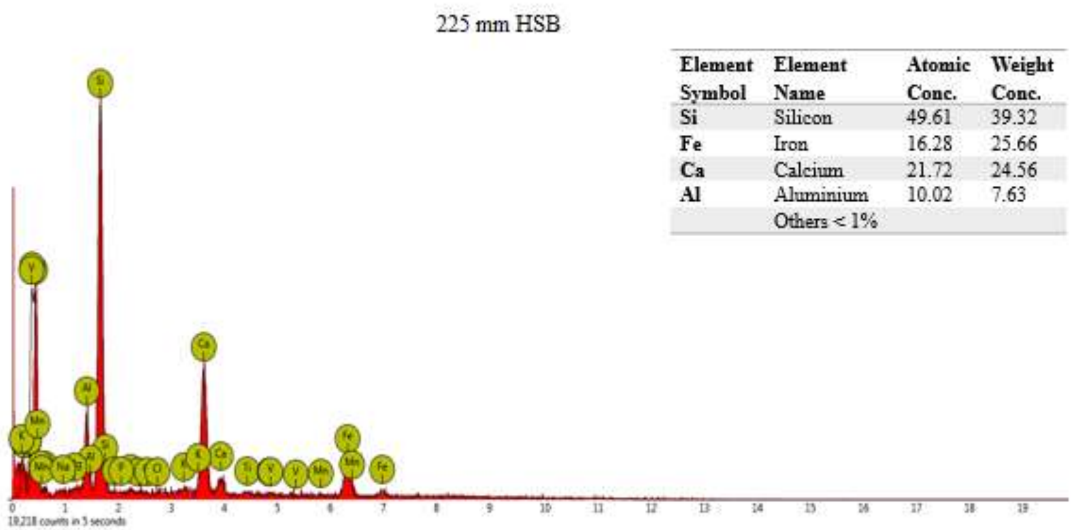
Figure 11: Micrograph of 25% RHA-225 mm HSB

The spectrums and the summarized results of the 150 mm HSB are as presented in Figures 12 and 13. The Energy Dispersive Spectroscopy (EDS) of the control show high content of silicon, followed by calcium, iron, aluminium and presence of other oxides which recorded the weight percent of the significant elements as silicon (51.35%), calcium (25.42%), iron (13.04%), and aluminium (7.78%). The 25% RHA sandcrete composite (Figure 13) also shows high content of silicon, followed by calcium, iron, and aluminium which recorded the weight percent of the significant elements as silicon (55.79%), calcium (24.01%), iron (11.43%), and aluminium (6.74%). The corresponding spectrums and the summarized results of the 225 mm HSB are as presented in Figures 14 and 15. The EDS weight percent shows percent of silicon, calcium, iron and aluminium of 49.61, 21.72, 16.28 and 10.02%; and 45.40, 35.75, 8.95 and 7.55%, representing the major elements for the control, and 25% RHA-HSB composite. The presence of silicon, calcium, iron and aluminium in the RHA blended cement HSB indicate the formation of cementitious compounds that enhance strength of cement composite (Zunino and Lopez, 2017; Qiang *et al.,* 2022; Rao *et al.,* 2023).



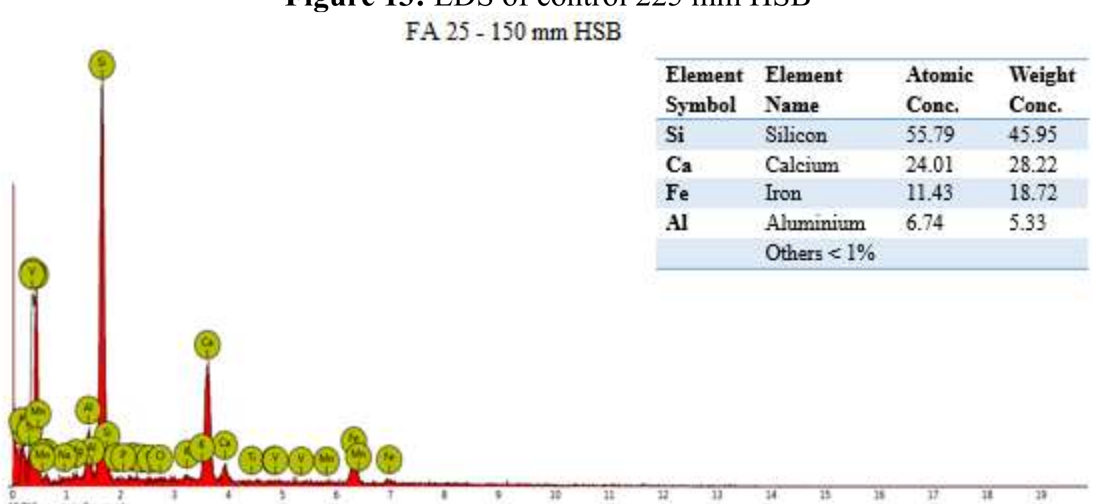
Element Symbol	Element Name	Atomic Conc.	Weight Conc.
Si	Silicon	51.35	41.16
Ca	Calcium	25.42	29.08
Fe	Iron	13.04	20.78
Al	Aluminium	7.78	5.99
	Others < 1%		

Figure 12: EDS of control 150 mm HSB



Element Symbol	Element Name	Atomic Conc.	Weight Conc.
Si	Silicon	49.61	39.32
Fe	Iron	16.28	25.66
Ca	Calcium	21.72	24.56
Al	Aluminium	10.02	7.63
	Others < 1%		

Figure 13: EDS of control 225 mm HSB



Element Symbol	Element Name	Atomic Conc.	Weight Conc.
Si	Silicon	55.79	45.95
Ca	Calcium	24.01	28.22
Fe	Iron	11.43	18.72
Al	Aluminium	6.74	5.33
	Others < 1%		

Figure 14: EDS of 150 mm HSB produced with 25% RHA content

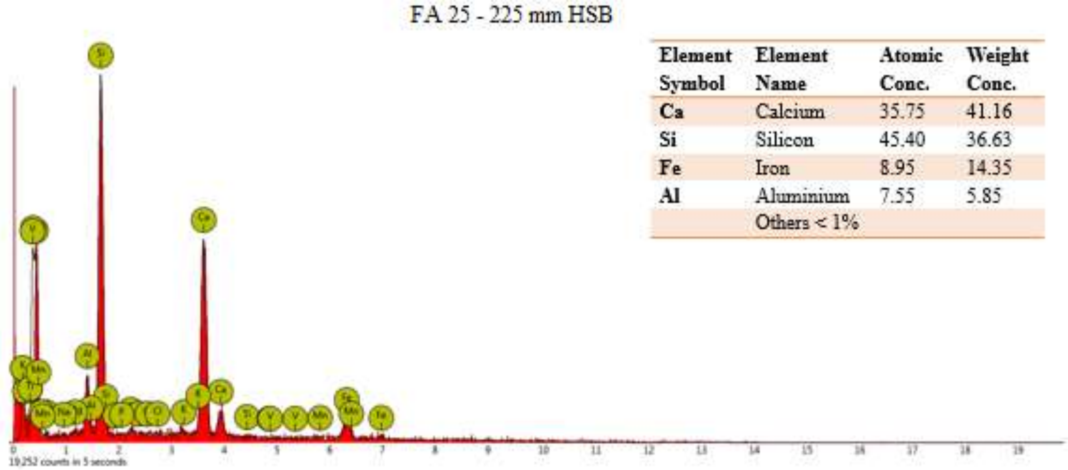


Figure 15: EDS of 225 mm HSB produced with 25% RHA content

Conclusions

The effects of RHA as substitute for fine aggregate in the production of sustainable sandcrete blocks were investigated and the following conclusions were drawn:

i. RHA exhibits lower specific gravity as compared to fine aggregate. By implication the performance of the HSB is low as the RHA content in the HSB increases. The fineness modulus of the fine aggregate from the particle size distribution is within acceptable specified by standards, thereby making it useful for block production.
ii. The density and WAC of the 25% RHA-HSB conforms to the recommended limits by NIS, thereby making the HSB useful for construction purpose. The resistance of the HSB to surface wearing and tear (abrassiveness) for the RHA-HSB under performs as compared to the control.
iii. The content of Fine Aggregate (FA) replaced with RHA content lead to a low performance as against the control at early age. However, the FA replaced with 25% RHA content exhibit higher CS of 2.99 and 3.83 N/mm^2 at 90 days than the recommended CS of 2.5 and 3.45 N/mm^2 by NIS for 150 mm and 225 mm HSB, respectively. While the FA replaced with 50% RHA met minimum standard for lightweight walling material.
iv. HSB produced with 25% RHA can be used in application of non-load bearing blocks and load bearing blocks, provided the curing age of the block is up to 90 days.
v. HSB produced with 50% RHA can be used as light weight material in lowering the overall weight of a structure, which is particularly advantageous in load-bearing applications where weight reduction can lead to cost savings in structural support requirements.

References

Abdulwahab, R., Anifowose M. A., Orogbade, B. O., Olawuyi, M. Y. and Abdulkarim, A. A. (2023) Influence of banana leaves ash on compressive and splitting tensile strengths of concrete, *Proceedings of the Second International Conference on Advances in Cement and Concrete Research (ICACCR 2023),* Ogbomoso, Nigeria, pp 286-293.

Abdurrahman, H., Alfikri, N., Rijaldo, A., Qoryati, M, Marpaung, H. S. M., Wibisono, G. and Olivia, M. (2025) Properties of concrete containing crumb rubber and rice husk ash mixing with peat water, *Applied Materials and Technology,* 6(2): 79-89. https://doi.org/10.31258/Jamt.6.2.79-89.

ACI Education Bulletin E1 (2007) Aggregates for Concrete, Developed by Committee E-701, Materials for Concrete Construction, *American Concrete Institute,* Farmington Hills, Michigan, United States.

Adedokun, S. I., Anifowose, M. A., Oyeleke, M. O., Oduoye, W. O. and Ibiwoye, E. O. (2019) Sustainability of ife steel slag on the split and flexural strengths of concrete, *Proceedings of the 1st International Conference on Engineering & Environmental Science (ICEES 2019),* 862-869. Osogbo, Nigeria.

Adedokun, S. I., Anifowose, M. A., Odeyemi, S. O. and Oluremi, J. R. (2021) Significant levels of steel slag concrete produced with varying water cement ratios, *Journal of Engineering Studies and Research (JESR),* 27(1): 13-19. doi: https://doi.org/10.29081/jesr.v27i1.247

Adedokun, S. I, Oluremi, J. R., Mark, D. O., Anifowose, M. A. and Lawal, A. R. (2024) Effects of substitution of cement with ground granulated slag on concrete produced with different water-cement ratios, *Nigerian Journal of Technology,* 43(3): 400-410; https://doi.org/10.4314/njt.v43i3.1

Adewuyi, T. O., Olusola, K. O. and Oladokun, M. G. (2013) Engineering properties of sandcrete blocks made with blended bamboo leaf ash (BLA) and ordinary Portland cement, *A Multidisciplinary Journal of Graduate School,* 1(3): 48-59.

Alfanda, A. M. (2025) A data-based artificial intelligence for predicting compressive strength of rice husk ash sandcrete blocks, *Academia Engineering,* 2(2): 1-11. https://doi.org/10.20935/AcadEng7673

Al‑Gburi, A. and Yusuf, S. A. (2022) Investigation of the effect of mineral additives on concrete strength using ANN, *Asian Journal of Civil Engineering,* 23: 405-414. https://doi.org/10.1007/s42107-022-00431-1

Ambedkar, B., Alex, J. and Dhanalakshmi, J. (2017) Enhancement of mechanical properties and durability of the cement concrete by rha as cement replacement: experiments and modelling, *Construction and Building Materials,* 148: 167–175. doi: https://doi.org/10.1016/j.conbuild mat.2017.05.022.

Amran, Y. H. M., Alyousef, R., Alabduljabbar, H. and El-Zeadani, M. (2020) Clean production and properties of geopolymer concrete: a review, *Journal of Cleaner Production,* 251: 119679. doi:https://doi.org/10.1016/j.jclepro.2019.119679

Anifowose, M. A. and Raheem, A. A. (2024) Review on application of rice husk ash for production of hollow sandcrete blocks: towards sustainable construction, *International Journal of Engineering Research in Africa (JERA),* 72: 97-116. doi: https://doi.org/10.4028/p-Zqj5YL

Anifowose, M. A., Adedokun, S. I., Adebara, S. A., Adeyemi, A. O., Amototo, I. O., Olahan, A. B. and Oyeleke, M. O. (2021) Influence of water cement ratios on the optimum use of steel slag in concrete. *Journal of Physics: Conference Series (RETREAT 2020),* 1874: 012003. doi:10.1088/1742-6596/1874/1/012003

Anifowose, M. A., Adedokun S. I., Oluremi, J. R., Oyeleke, M. O., Olawuyi, M. Y. and Onadiran S. O. (2023) Effect of slags contents and water contents on properties of fresh concrete, *Proceedings of the Second International Conference on Advances in Cement and Concrete Research (ICACCR 2023),* Ogbomoso, Nigeria, pp 302-308.

Anifowose, M. A., Ige, J. A., Yusuf, A. L., Adebara, S. A. and Abdulkarim, A. A. (2018) Physio-chemical assessment of rice husk ash (RHA) blended calcium chloride ($CaCl_2$) as supplementary cementing materials, *ANNALS of Faculty Engineering Hunedoara-International Journal of Engineering,* 16(4): 111-114.

Arasa, F. O., Onchiri, R. and Abiero-Gariy, Z. C. (2017) Effect of sugarcane bagasse ash on the engineering properties of blended sandcrete blocks, *International Journal of Engineering Research & Technology (IJERT),* 6(12): 327-337.

ASTM D2487 (2017) Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), American Society for Testing and Materials (ASTM International), West Conshohocken, United States.

Atoyebi, O. D., Iwuozor, K. O., Emenike, E. C., Odeyemi, S. O., Joshua, O. O., Abasianwam, B. E. and Adeniyi, A. G. (2024) Strength and durability assessment of nanoquartz sandcrete blocks, *Chemistry Africa,* https://doi.org/10.1007/s42250-024-01122-x

BS EN 933-1 (2012) Tests for Geometrical Properties of Aggregates - Part 1: Determination of Particle Size Distribution - Sieving Method, *British Standards,* London, W4 4AL, UK, Standards Policy and Strategy Committee.

BS EN 12620 (2002+A1:2008) Specification for Aggregates from Natural Sources for Concrete, *British Standards,* BSI Group Headquarters 389 Chiswick High Road, London, W4 4AL, UK.

Datchossa, A. T., Doko, V. K., Kabay, N., Olodo, E. T. and Omur, T. (2023) The Influence of ground and unground rice husk ash on the physico-mechanical and microstructural properties of cement mortars, *Iranian Journal of Science and Technology, Transactions of Civil Engineering,* 47: 2189-2202. https://doi.org/10.1007/s40996-023-01066-1

Endale, S. A., Taffese, W. Z., Vo, D. H. and Yehualaw, M. D. (2023) Rice husk ash in concrete, *Sustainability,* 15: 137. https://doi.org/10.3390/ su15010137

Fapohunda, C., Akinbile, B. and Shittu, A. (2017) Structure and properties of mortar and concrete with rice husk ash as partial replacement of ordinary Portland cement–a review, *International Journal of Sustainable Built Environment*, 6: 675-692. doi:http://dx.doi.org/10.1016/j.ijsbe.2017.07.004

Gashahun, A. D. (2020) Investigating sand quality effect on concrete strength: a case of debre markos and its vicinities, *International Journal of Construction Management,* 22(4): 1-9. doi: 10.1080/15623599.2020.1774838

Gursel, A. P., Maryman, H. and Ostertag, C. (2016) A life-cycle approach to environmental, mechanical, and durability properties of "green" concrete mixes with rice husk ash, *Journal of Cleaner Production,* 112: 823-836. doi:https://doi.org/10.1016/j.jclepro.2015.06.029

Hong, W. C., Mohammed, B. S., Abdulkadir, I. and Liew, M. S. (2023) Modeling and optimizing the effect of palm oil fuel ash on the properties of engineered cementitious composite, *Buildings,* 13: 628. https://doi.org/ 10.3390/buildings13030628

Idiata, D. J., Ngozi, K. O. and Osagie, E. K. (2024) Evaluation of the compressive strength of locally available fine aggregates around usen locality, *Nigerian Journal of Engineering,* 31(2): 80-90.

Ige, J. A., Anifowose, M. A., Odeyemi, S. O., Adebara, S. A. and Oyeleke, M. O. (2018) Assessment of rice husk ash (RHA) and calcium chloride ($CaCl_2$) on compressive strength of concrete grade 20, *International Journal of Engineering Research in Africa (JERA),* 40: 22-29. doi: 10.4028/www.scientific.net/JERA.40.22

Ige, J. A., Anifowose, M. A., Oyeleke, M. O., Bakare, S. B. and Akinjobi, T. F. (2017a) Physio-chemical assessment of groundnut shell ash (GSA) blended calcium chloride ($CaCl_2$) as supplementary cementing material, *ACTA TECHNICA CORVINIENSIS–Bulletin of Engineering Journal,* 10 (3): 155-158.

Ige, J. A., Anifowose, M. A., Amototo, I. O., Adeyemi, A. O. and Olawuyi, M. Y. (2017b) Influence of groundnut shell ash (GSA) and calcium chloride ($CaCl_2$) on strength of concrete, *ANNALS of Faculty Engineering Hunedoara–International Journal of Engineering,* 15(4): 209-214.

Jamil, M. A., Hayano, K., Kassa, A., Sekine, R. and Mochizuki, Y. (2024) Curing effects on geotechnical properties of clays treated with palm kernel shell ash and rice husk ash: insights from water absorption characteristics of stabilizers, *Case Studies in Construction Materials,* 20: e02947. https://doi.org/10.1016/j.cscm.2024.e02947

Jamilu, U., Usman, M., Getso, I. A. and Sanusi, G. (2023) Evaluation of compressive strength of metakaolin-rice husk ash- ternary blended mortar using surface response methodology, *Materials Today: Proceedings*, 86: 73–76. https://doi.org/10.1016/j.matpr.2023.03.120

Khan, W., Fahim, M., Zaman, S., Khan, S. W., Badrashi, Y. I. and Khan, Y. (2021) Use of rice husk ash as partial replacement of cement in sandcrete blocks, *Advances in Science and Technology Research Journal,* 15(2): 101–107.

Marthong, C. (2012) Effect of rice husk ash (RHA) as partial replacement of cement on concrete properties, *International Journal of Engineering Research and Technology,* 1(6): 1-8.

Mohseni, E., Kazemi, M. J., Koushkbaghi, M., Zehtab, B. and Behforouz, B. (2019) Evaluation of mechanical and durability properties of fiber-reinforced lightweight geopolymer composites based on rice husk ash and nano-alumina, *Construction and Building Materials,* 209: 532-540, doi: https://doi.org/10.1016/j.conbuildmat.2019.03.0 67.

Nassar, R. and Room, S. (2025) Strength, durability, and microstructural characteristics of binary concrete mixes developed with ultrafine rice husk ash as partial substitution of binder, *Civil Engineering and Architecture*, 13(1): 595-611. doi: 10.13189/cea.2025.130137.

Nduka, D. O., Olawuyi, B. J., Fagbenle, E. O. and Fonteboa, B. G. (2022) Mechanical and microstructural properties of high-performance concrete made with rice husk ash internally cured with superabsorbent polymers, *Heliyon,* 8(1): e10502. http://dx.doi.org/10.1016/j.heliyon.2022.e10502

Neville, A. M. (2011) Properties of concrete (5th Edition). Pearson Education Limited, Harlow, Essex CM20 2JE, England.

NIS 87 (2000) Specification for standard sandcrete blocks, *Nigerian Industrial Standard:* Standard Organization of Nigeria, Lagos, Nigeria.

NIS 87 (2007) Specification for standard sandcrete blocks, *Nigerian Industrial Standard. Lagos*: Standard Organization of Nigeria, Lagos, Nigeria.

NIS 444-1 (2014) Composition, specifications and conformity criteria for common cements, *Nigerian Industrial Standard:* Standard Organisation of Nigeria, Lagos, Nigeria.

Odeyemi, S. O., Abdulwahab, R., Anifowose, M. A. and Ibrahim, R. J. (2019) Impact of different fine aggregates on the compressive strength of sandcrete blocks, *Arid Zone Journal of Engineering, Technology & Environment (AZOJETE),* 15(3): 611-618.

Odeyemi, S. O. Abdulwahab, R., Giwa, Z. T., Anifowose, M. A., Odeyemi, O. T. and Ezenweani, C. F. (2021) Effect of combining maize straw and palm oil fuel ashes in concrete as partial cement replacement in compression, *Trends in Sciences,* 18(19): 29. doi:https://doi.org/10.48048/tis.2021.29

Odeyemi, S. O., Akinpelu, M. A., Atoyebi, O. D. and Orire, K. J. (2018) Quality assessment of sandcrete blocks produced in adeta, kwara state, Nigeria, *Nigerian Journal of Technology,* 37(1): 53-59. https://doi.org/http://dx.doi.org/10.4314/njt.v37i1.7

Odeyemi, S. O., Anifowose, M. A., Abdulwahab, R. and Oduoye, W. O. (2020a) Mechanical Properties of High-Performance Concrete with Guinea Corn Husk Ash as Additives, *LAUTECH Journal of Civil and Environmental Studies,* 5(1): 139-154. doi: 10.36108/laujoces/0202/50(0131)

Odeyemi, S. O., Anifowose, M. A., Bello, S. A., GIWA, Z. T. and Wilson, U. N. (2022a) Strength properties and microstructure of sandcrete blocks incorporated with maize straws, *Advanced Engineering Forum (AEF)* 46: 71-78. doi:10.4028/p-kgoezq

Odeyemi, S. O., Anifowose, M. A., Giwa, Z. T., Adeniyi, S. O., Osazee, V. S. and Adisa, M. O. (2024) High-performance concrete incorporating almond leave ash as supplementary cementing material, *Covenant Journal of Engineering Technology (CJET),* 8(2): 25-31.

Odeyemi, S. O., Atoyebi, O. D. and Ayo, E. K. (2020b) Effect of guinea corn husk ash on the mechanical properties of lateritic concrete, *IOP Conf. Series: Earth and Environmental Science,* 445: (2020) 012034.

Odeyemi, S. O. Atoyebi, O. D., Kegbeyale, O. S., Anifowose, M. A., Odeyemi, O. T., Adeniyi, A. G. and Orisadare, O. A. (2022b) Mechanical properties and microstructure of high-performance concrete with bamboo leaf ash as additive, *Cleaner Engineering and Technology,* 6: 100352. doi: https://doi.org/10.1016/j.clet.2021.100352

Ogork, E. N., Uche, O. A. and Elinwa, A. U. (2015) Characterization of groundnut shell ash (GSA) admixed with rice husk ash (RHA) in cement paste and concrete, *Advanced Materials Research,* 11(19): 662- 671. http://dx.doi.org/10.4028/www.scientific.net/AMR.1119.662

Ogwang, G., Olupot, P. W., Kasedde, H., Menya, E., Storz, H. and Kiros, Y. (2021) Experimental evaluation of rice husk ash for applications in geopolymer mortars, *Journal of Bioresources and Bioproducts,* 6: 160–167. doi:https://doi.org/10.1016/j.jobab.2021.02.008

Olumodeji, A. O., Ayodele, F. O. and Oluborode, K. D. (2023) Evaluation of compressive strength and abrasive properties of rice husk ash – cement compressed stabilized earth bricks, *Nigerian Journal of Technology,* 42(2): 191-198. https://doi.org/10.4314/njt.v42i2.5

Onogwu C. M., Bukar A. and Magaji, A. (2024) Influence of sulphate attack on compressive strength of millet husk ash as an alternative to silica fume in internally cured high performance concrete, *ETSJ,* 15(12): 37-44. https://dx.doi.org/10.4314/etsj.v15i2.5

Oriola, K. O., Raheem, A. A., Kareem, M. A. and Abdulwahab, R. (2021) Assessment of workability and compressive strength of rice husk ash-blended palm kernel shell concrete, *LAUTECH Journal of Civil and Environmental Studies,* 7(1): 100-115. doi: 10.36108/laujoces/1202.70.0101.

Oyekan, G. and Kamiyo, O. M. (2011) A Study on the engineering properties of sandcrete blocks produced with rice husk ash blended cement, *Journal of Engineering and Technology Research,* 3(3): 88-98.

Popoola, M. O., Apampa, O. A. and Amusan, G. M. (2018) Experimental study and test on light weight foamed concrete solid block, *Nigerian Journal of Engineering,* 25(2): 18-24.

Prasara, A. J. and Gheewala, S. H. (2017) Sustainable utilization of rice husk ash from power plants: a review, *Journal of Cleaner Production* 167: 1020-1028. doi:10.1016/J.JCLEPRO.2016.11.042

Qiang, F., Xu, Z., Zhang, Z., Xu, W. and Niu, D. (2022) Effects of nanosilica on microstructure and durability of cement-based materials, *Powder Technology* 404(8):117447. doi: 10.1016/j.powtec.2022.117447

Quadri, A. I. and Ijesoh, L. I. (2017) Assessment of the mechanical properties of some selected sandcrete hollow blocks in Kogi state, *European Journal of Engineering and Technology Research*, 2(11): 43-48. doi: 10.24018/ejers.2017.2.11.526

Raheem, A. A., Abdulwahab R. and Kareem, M. A. (2021) characterization and effects of nanosilica on consistency and setting times of metakaolin blended cement mortar, *Nano Plus: Science and Technology of Nanomaterials,* 2: 66-75. doi:https://doi.org/10.48187/stnanomat.2021.2.004

Raheem, A. A. and Anifowose, M. A. (2023) Effect of ash fineness and content on consistency and setting time of rha blended cement. *materials Today: Proceedings,* 86(2023): 18-23. doi:https://doi.org/10.1016/j.matpr.2023.02.054

Raheem, A. A. and Kareem, M. A. (2017) Chemical composition and physical characteristics of rice husk ash blended cement, *International Journal of Engineering Research in Africa (JERA),* 32: 25-35.

Raheem, A. A. and Sulaiman, O. K. (2013) Saw dust ash as partial replacement for cement in the production of sandcrete hollow blocks, *International Journal of Engineering Research and Applications (IJERA),* 3(4): 713-721.

Raheem, A. A. Kolawole, F. W., Oguntola, I. O. and Akintola, O. A. (2025) The influence of wood ash fineness on early strength development of hollow sandcrete blocks, *Advances in Cement and Concrete (Materials Research Proceedings),* 51: 39-48. https://doi.org/10.21741/9781644903537-5

Ramadhansyah, P. J., Masri, K. A., Mangi, S. A., Mohd Yusak, M. I., Mashros, N., Mohd Warid, M. N., Satar, M. K .I. M. and Mohd Haziman, W. I. (2020) Strength and porosity of porous concrete pavement containing nano black rice husk ash, *IOP Conference Series: Materials Science and Engineering,* 712(1): 012037. doi: 10.1088/1757-899X/712/1/012037

Raman, S. N., Ngo, T., Mendis, P. and Mahmud, H. B. (2011) High-strength rice husk ash concrete incorporating quarry dust as a partial substitute for sand, *Construction and Building Materials,* 25(7): 3123-3130.

Rao, M. S. C., Packialakshmi, S., Rath, B., Alharbi, S. A., Alfarraj, S., Praveenkumar T. R. and Gavurova, B. (2023) Utilization of agricultural, industrial waste and nanosilica as replacement for cementitious material and natural aggregates – mechanical, microstructural and durability characteristics assessment, *Environmental Research,* 231: 116010. https://doi.org/10.1016/j.envres.2023.116010

Serati, M., Jackson. N., Asche, H., Basireddy, S. and Malgotra, G. (2022) Sustainable shotcrete production with waste glass aggregates, *SN Applied Sciences,* 4: 82. https://doi.org/10.1007/s42452-022-04967-4

Shen, Y. (2017) Rice husk silica derived nanomaterials for sustainable applications, *Renewable and Sustainable Energy Reviews,* 80(C): 453-466. doi: 10.1016/j.rser.2017.05.115

Shetty, M. S. (2000) Concrete Technology; Theory and Practice. S.Chand and Company Ltd., Ram Nagar, New Delhi.

Shittu, S.A. (2023) the effects of coarse sand on sandcrete blocks, *International Journal of Innovative Science and Research Technology,* 8(6): 2880-2893.

Sulaiman, T. A., Aliyu, I., Yau, Y. and Bello, I. (2020a) Assessment of Groundnut Shell Ash and Sawdust Ash as Partial Replacement of Cement in Concrete, *FUTA Journal of Engineering and Engineering Technology,* 14(2): 117-125.

Ugwuanyi, S. E., Adibe, T. N. and Mmonwuba, N. C. (2018) Partial replacement of cement with burnt rice husk ash for low strength concrete production, *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE),* 15(3): 01-05.

Wang, J., Xiao, J., Zhang, Z., Han, K., Hu, X. and Jiang, F. (2021) Action mechanism of rice husk ash and the effect on main performances of cement-based materials: a review, *Construction and Building Materials*, 288: 123068. doi: https://doi.org/10.1016/j.conbuildmat.2021.123 068.

Wilson, U. N., Aliyu, H. I., Odeyemi, S. O., Adediji, O., Durosinlorun, A. O. and Abubakar, P. (2024) Quality evaluation of sandcrete blocks produced in selected local government areas of Kaduna State, Nigeria, *Nigerian Journal of Technology*, 43(4): 628-636. https://doi.org/ 10.4314/njt.v43i4.3

Witzke, F. B., Beltrame, N. A. M., Angulski da Luz, C. and Medeiros-Junior, R. A. (2023) Abrasion resistance of metakaolin-based geopolymers through accelerated testing and natural wear, *Wear,* 530-531: 204996. doi: https://doi.org/10.1016/j.wear.2023.204996.

Yusuf, A., Aminulai, H. O, Abdullahi, A, Alhaji, B. and Alalade, A. I (2017) Dimensional compliance and compressive strength of sandcrete hollow blocks produced in minna metropolis, *Proceedings of the 2nd International Engineering Conference (IEC 2017),* Minna, Nigeria.

Zunino, F. and Lopez, M. (2017) A methodology for assessing the chemical and physical potential of industrially sourced rice husk ash on strength development and early-age hydration of cement paste, *Construction and Building Materials,* 149: 869-881. http://dx.doi.org/10.1016/j.conbuildmat.2017.05.187