

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

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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 °C. 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 °C, 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).

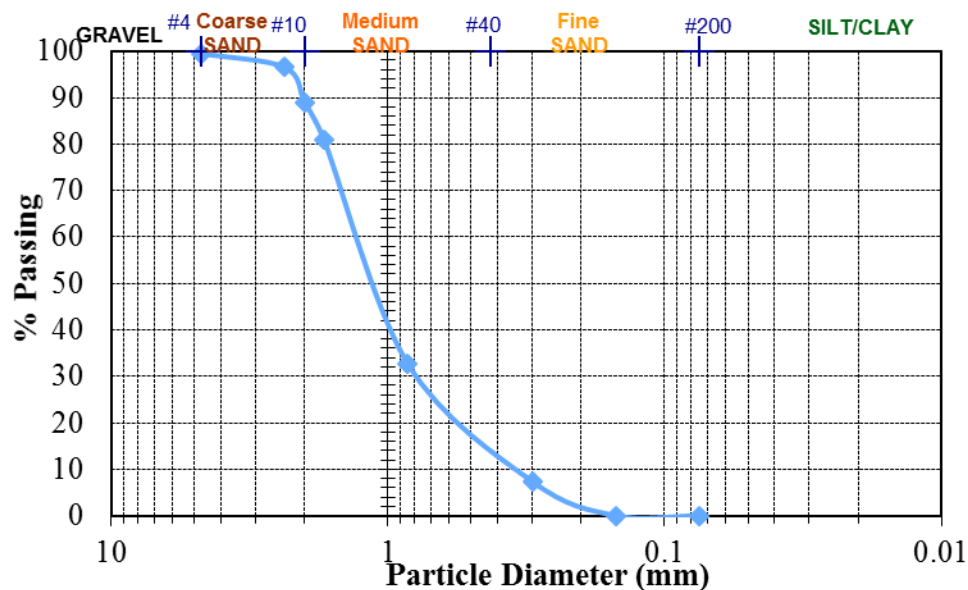


Figure 1: Particle Size Distribution of Fine Aggregates

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/m³ for 150 mm HSB and 1180 – 2024 kg/m³ for 225 mm HSB. Density of the control and 25% RHA meet the recommended 1500 kg/m³ 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/m³. 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).

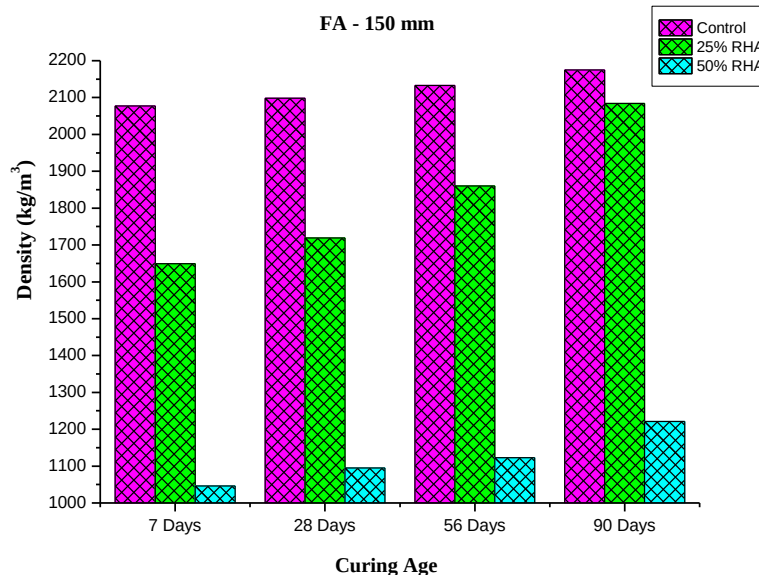


Figure 2: Effect of Fine Aggregate content on Density of 150 mm HSB

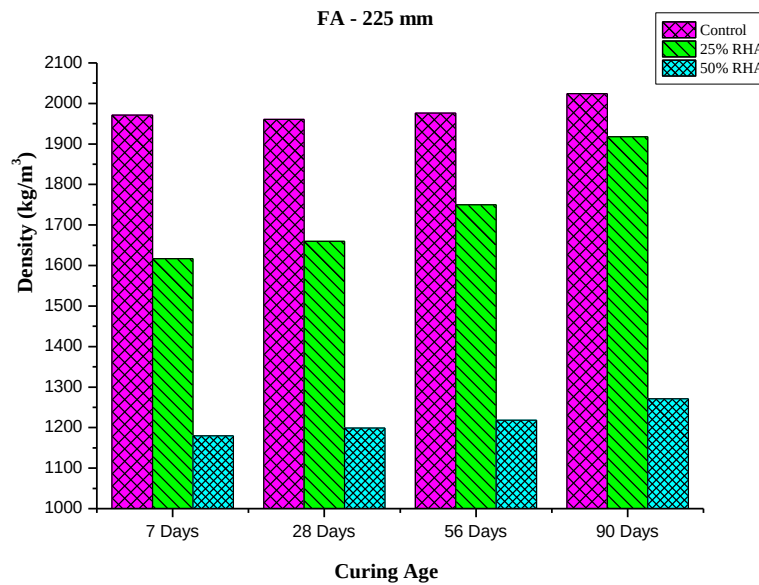


Figure 3: Effect of Fine Aggregate content on Density of 225 mm HSB

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/mm² 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).

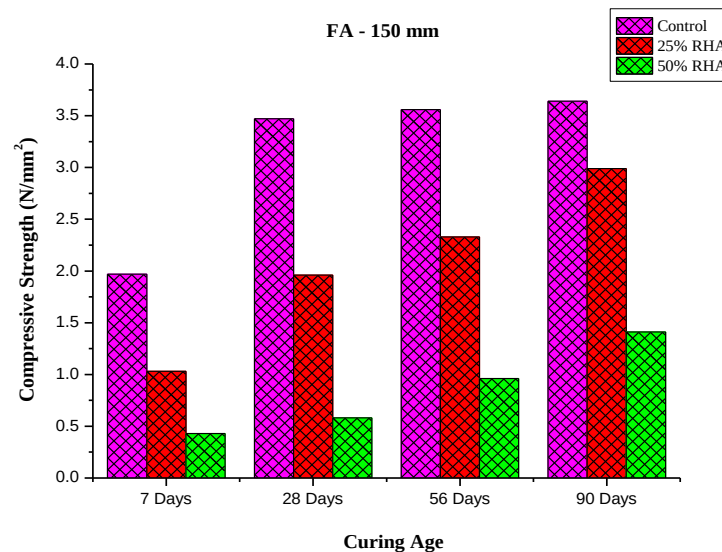


Figure 4: Effect Fine Aggregate content on CS of 150 mm HSB

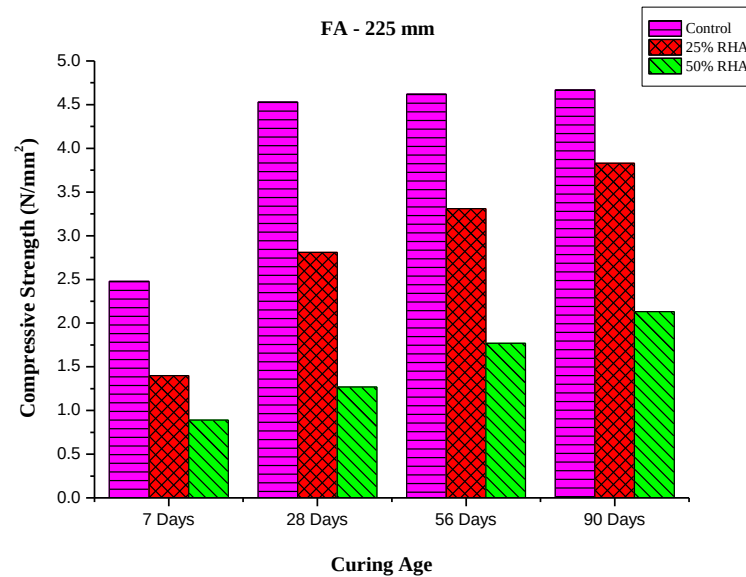


Figure 5: Effect of Fine Aggregate content on CS of 225 mm HSB

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).

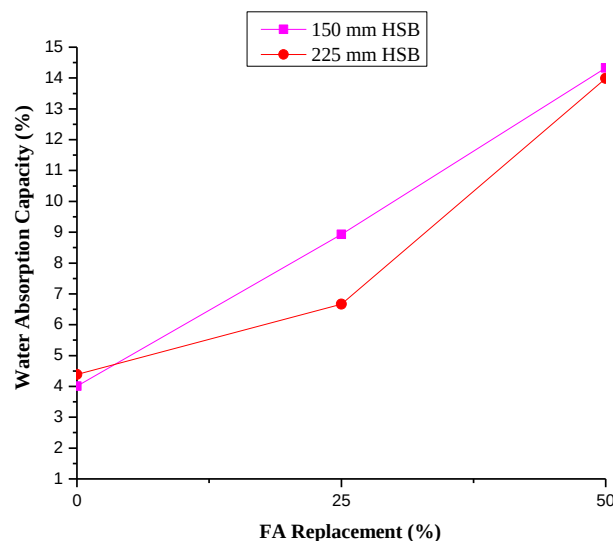


Figure 6: Effect of FA content on WAC of 150 and 225 mm HSB

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).

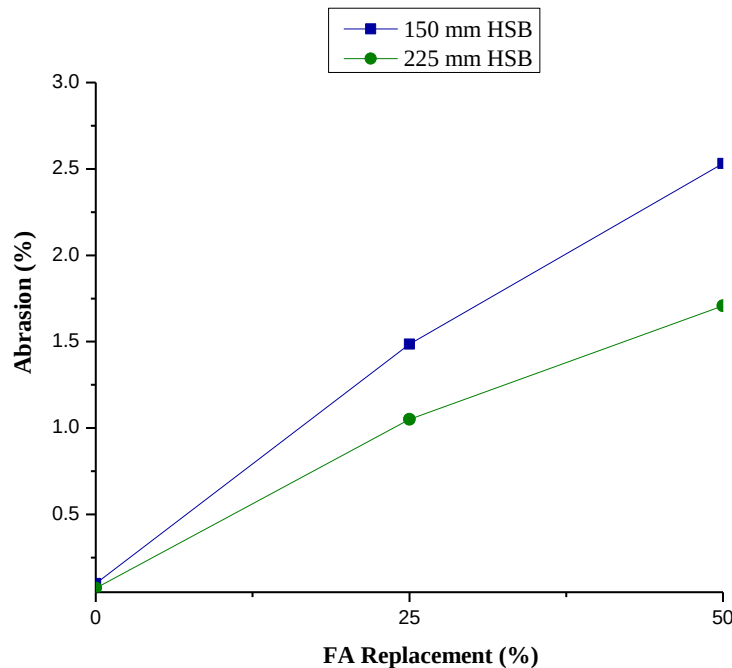


Figure 7: Effect of FA content on Abrasion of 150 and 225 mm HSB

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).

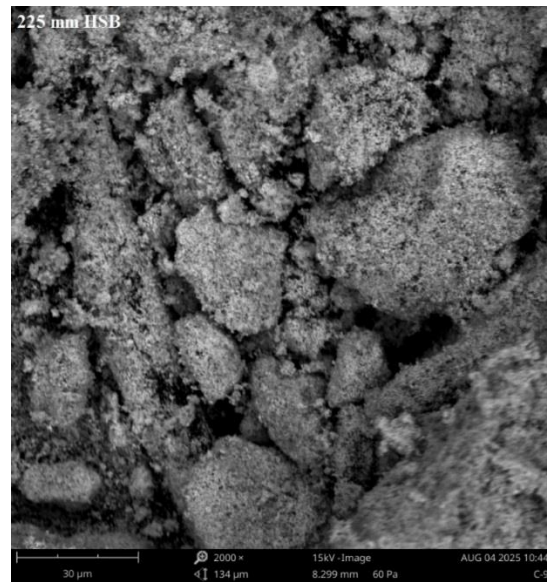
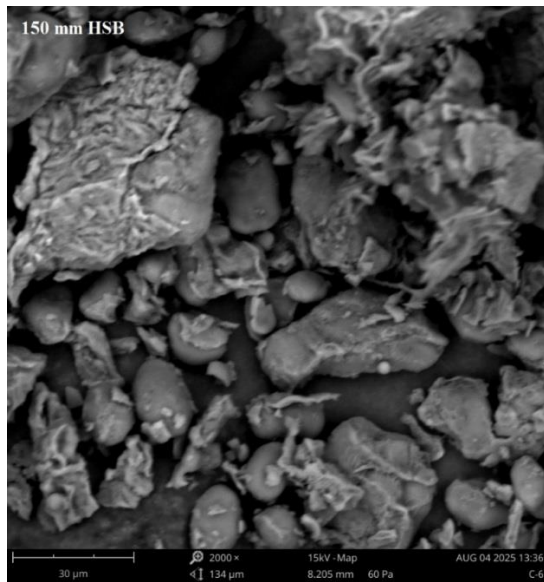


Figure 8: Micrograph of 150 mm HSB Composite **Figure 9:** Micrograph of 225 mm HSB Composite

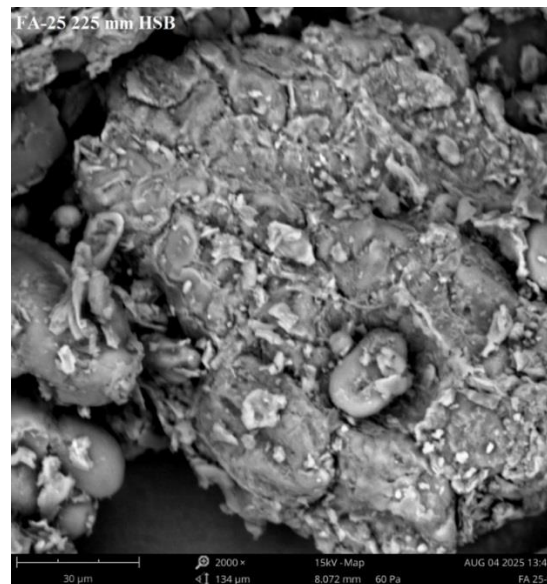
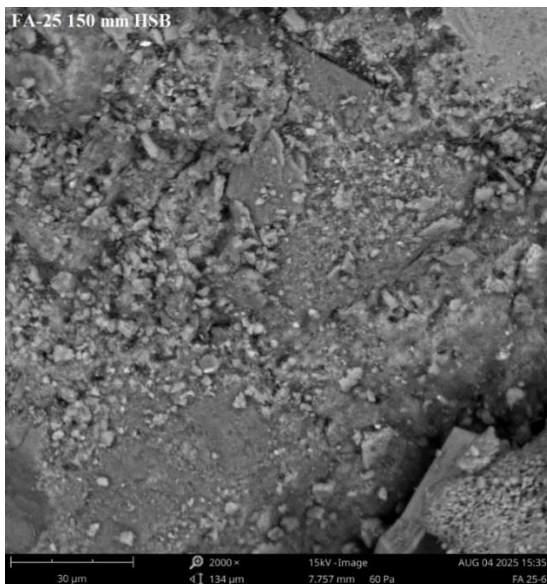


Figure 10: Micrograph of 25% RHA-150 mm HSB **Figure 11:** Micrograph of 25% RHA-225 mm HSB

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).

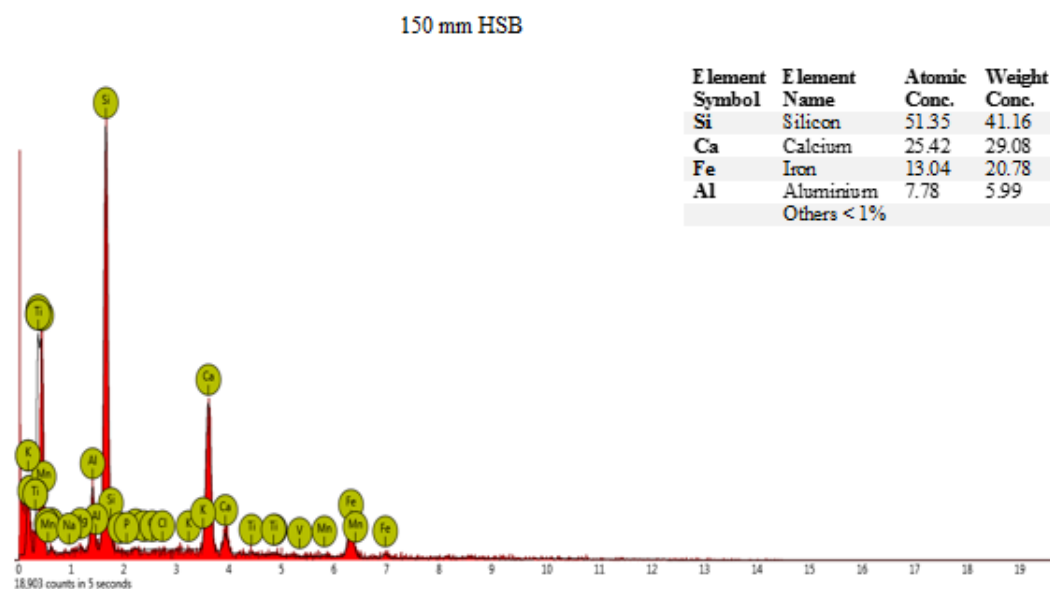


Figure 12: EDS of control 150 mm HSB

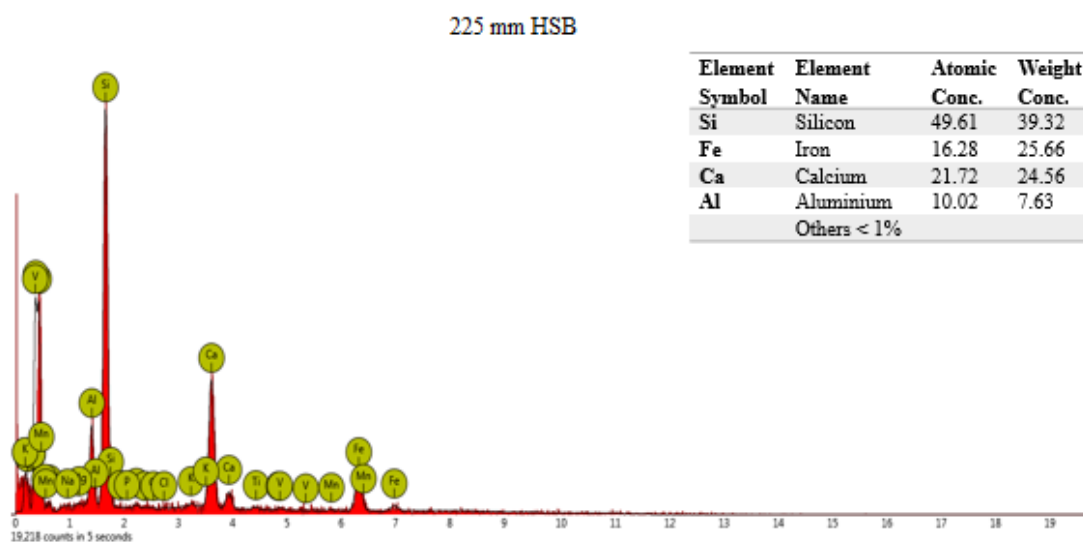


Figure 13: EDS of control 225 mm HSB

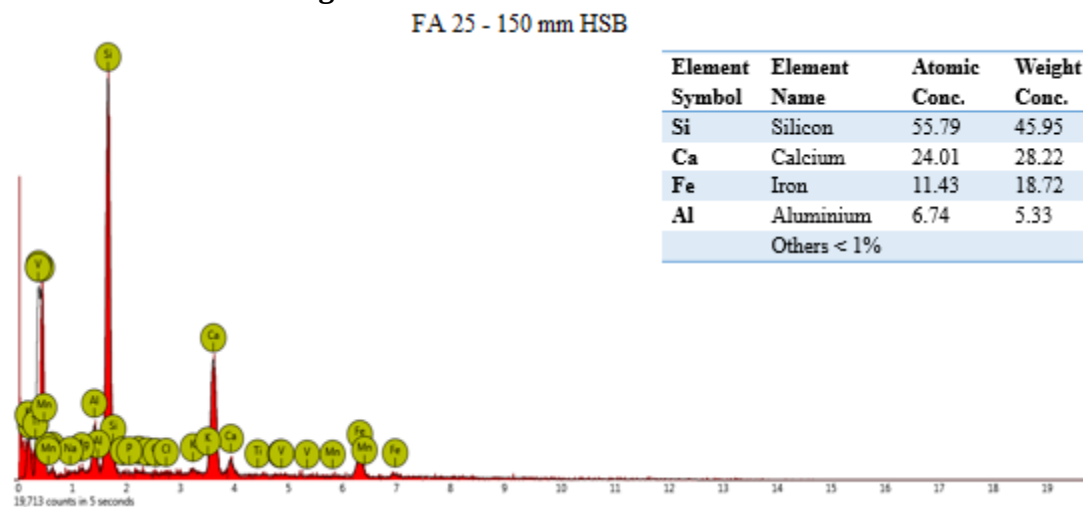


Figure 14: EDS of 150 mm HSB produced with 25% RHA content

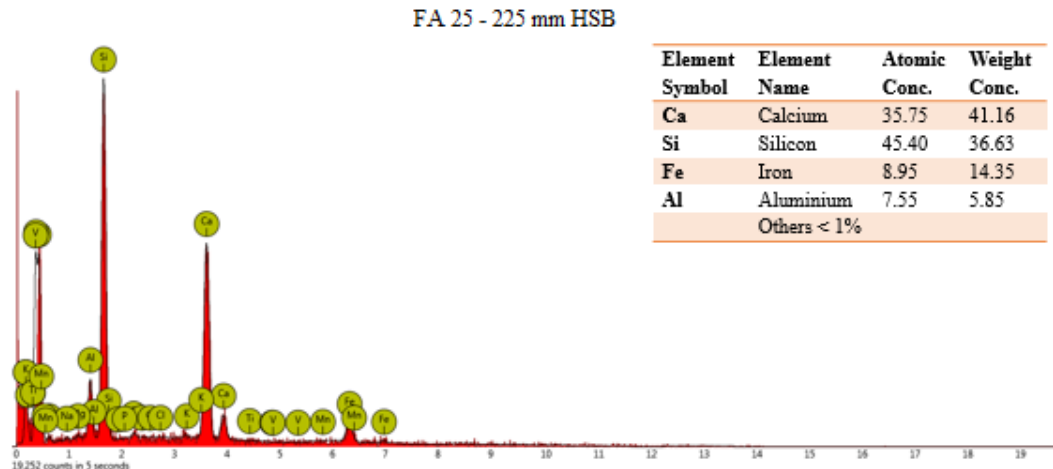


Figure 15: EDS of 225 mm HSB produced with 25% RHA content

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:

- 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.
- 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 (abraziveness) for the RHA-HSB under performs as compared to the control.
- 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/mm² at 90 days than the recommended CS of 2.5 and 3.45 N/mm² by NIS for 150 mm and 225 mm HSB, respectively. While the FA replaced with 50% RHA met minimum standard for lightweight walling material.
- 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.
- 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.

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