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Experimental Analysis of Early Compressive Strength of Sandcrete Block Blended with Rice Husk Ash and Activated with Soda Ash

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Abstract
Sandcrete blocks are widely used masonry units in construction, and partial cement replacement with agricultural waste materials has been investigated as a means of reducing cement consumption, production cost, and environmental impact. Rice husk ash (RHA), a silica-rich pozzolanic material, and soda ash (Na_2CO_3), an alkaline activator, have potential to modify the hydration and strength development of cementitious materials. This study experimentally analysed the early compressive strength and water absorption of 150 mm (6-inch) hollow sandcrete blocks produced by partially replacing ordinary Portland cement (OPC) with RHA at 10–50% and activating the blends with soda ash at 0.5–3.0%. The physical properties of the fine aggregate were determined in accordance with BS EN 933-1 and BS EN 1097-6, while the chemical composition of RHA was determined using X-ray fluorescence (XRF) analysis. A total of 54 sandcrete-block specimens were produced from the experimental programme and cured for 7 days before testing for wet mass, dry mass, water absorption, and compressive strength in accordance with BS EN 772-1 and NIS 87. The sand had a fineness modulus of 1.93 and a specific gravity of 2.56. XRF analysis showed that the combined $SiO_2 + Al_2O_3 + Fe_2O_3$ content of the RHA was 85.84%, indicating strong pozzolanic potential. Compressive strength increased at low RHA and soda ash contents but declined at higher replacement levels. Water absorption increased with RHA content but remained below the 12% limit reported in NIS 87. The optimum combination within the tested range was 10% RHA with 1.0% soda ash, which achieved 1.76 N/mm^2 at 7 days, compared with 1.23 N/mm^2 for the control. The novelty of the study is the experimental evaluation of combined RHA replacement and low-dose soda ash activation for improving early-age performance of 150 mm hollow sandcrete blocks. The findings identify a practical blend that meets the stated 1.50 N/mm^2 minimum for non-load-bearing blocks and provides a basis for further optimisation at lower RHA replacement levels.

Keywords: *Sandcrete blocks, rice husk ash, soda ash, compressive strength, water absorption.*

1.0 Introduction

Sandcrete blocks are composite masonry units produced from sand, cement, and water, with cement serving as the primary binder. The materials are mixed, placed in moulds, compacted, and cured for use in the construction of walls and partitions (Awolusi et al., 2021; Alejo, 2020). Because sandcrete blocks are widely used in building construction, improving their strength, durability-related properties, affordability, and environmental performance remains important. Recent studies have investigated the incorporation of agricultural and industrial waste materials in sandcrete blocks, with cost reduction and environmental sustainability identified as important drivers for such applications (Adebanjo et al., 2024). Modified sandcrete blocks have also been reported to exhibit improved strength and satisfactory durability-related performance when appropriate replacement materials and proportions are used (Khan et al., 2023; Robert et al., 2020).

A pozzolanic material reacts with calcium hydroxide in the presence of water to form compounds with cementitious properties (Berenguer et al., 2021). When used as a partial replacement for cement, a suitable pozzolanic material can contribute to strength development and durability-related performance while reducing the quantity of Portland cement required. Rice husk ash (RHA) is a promising pozzolanic material because of its high reactive silica content. Its silica can react with calcium hydroxide released during cement hydration to form additional calcium silicate hydrate (C–S–H), which contributes to strength development. Tulashie et al. (2021) reported improved performance at a 10% RHA replacement level, while other studies have demonstrated the potential of RHA as a sustainable supplementary cementitious material (Pandit, 2025; Owamah et al., 2024). The use of agricultural ash in cementitious materials also provides a means of reducing waste accumulation and the demand for conventional cementitious materials (Premalatha et al., 2022).

Alkali-activated materials (AAMs) are produced through reactions between aluminosilicate-rich precursors and alkaline activators, with the resulting reaction products depending on the precursor composition and calcium content (Marvila et al., 2021). Alkaline activation can enhance the dissolution of reactive silica and alumina and thereby influence the formation of cementitious reaction products. Soda ash is sodium carbonate (Na_2CO_3), and its use in cement-based systems has been investigated because sodium carbonate can modify hydration reactions

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and early-age strength development (Rahimpour et al., 2024; Zhang et al., 2022). Wang et al. (2022) reported that sodium carbonate can influence the engineering properties of cementitious blends, demonstrating its potential as an activator at appropriate dosages. Therefore, combining RHA with a controlled dosage of soda ash provides a potential route for improving early strength while reducing cement content. The objective of this study is to experimentally analyse the early compressive strength and water absorption of 150 mm (6-inch) hollow sandcrete blocks produced by partial replacement of cement with RHA and activation with soda ash.

The novelty of this research is the combined experimental assessment of RHA as a partial cement replacement and soda ash as an alkaline activator for the early-age performance of 150 mm (6-inch) hollow sandcrete blocks. The study contributes to knowledge by identifying the optimum combination within the tested ranges and by relating the observed strength response to water absorption. Within the experimental matrix, 10% RHA with 1.0% soda ash produced the highest 7-day compressive strength of 1.76 N/mm², providing a specific dosage basis for further optimisation.

2.0 Materials and Methods

2.1 Materials

This study investigated the early compressive strength and water absorption performance of sandcrete blocks produced by partially replacing ordinary Portland cement (OPC) with rice husk ash (RHA) and activating the blends with soda ash (Na_2CO_3). Sokoto cement conforming to BS EN 197-1:2011 (BSI, 2011) was used as the primary binder. Rice husk ash was obtained by burning rice husk at approximately 550 °C and was used as a supplementary cementitious material. Soda ash was used as the alkaline activator, while fine aggregate (sand) conforming to BS EN 12620:2002+A1:2008 was used to provide bulk and workability. Clean, potable water complying with BS EN 1008:2002 was used for mixing and curing.

2.2 Physical Characterisation of Fine Aggregate

Sieve analysis was performed in accordance with BS EN 933-1:2012 to determine the particle-size distribution of the fine aggregate. A 500 g air-dried sand sample was passed through sieves with apertures of 4.75, 2.36, 1.70, 1.40, 0.30, and 0.075 mm, arranged in descending order, and the mass retained on each sieve was recorded using an electronic weighing scale. The fineness modulus was calculated from the cumulative percentage retained using Equation (1).

$$\text{Fineness Modulus} = \Sigma(\text{Cumulative retained weight on sieves})/(\text{Total weight of sand sample}) \quad (1)$$

The specific gravity of the fine aggregate was determined using a 50 mL pycnometer in accordance with BS EN 1097-6:2022 (BSI, 2022). The masses of the empty pycnometer, the pycnometer with sand, the pycnometer with sand and water, and the pycnometer with water alone were recorded, and the specific gravity was calculated using Equation (2).

$$\text{Specific Gravity} = (W_2 - W_1)/[(W_2 - W_1) - (W_3 - W_4)] \quad (2)$$

where W_1, W_2, W_3, and W_4 represent the masses of the pycnometer, the pycnometer with sand, the pycnometer with sand and water, and the pycnometer with water, respectively.

2.3 Chemical Analysis of Rice Husk Ash

The oxide composition of the rice husk ash was determined by X-ray fluorescence (XRF) spectroscopy. The ash was oven-dried, ground to a fine powder, and sieved through a 75 µm mesh before being prepared as a pressed pellet. The pellet was analysed using a calibrated XRF spectrometer to quantify the major constituent oxides, including SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, and SO_3. The combined SiO_2–Al_2O_3–Fe_2O_3 content was used as an indicator of the pozzolanic potential of the ash.

2.4 Mix Design and Preparation of Sandcrete Blocks

A target mix ratio of 1:8 (binder to sand) was adopted in accordance with NIS 87:2007 (NIS, 2007), with a water-to-binder ratio (w/b) of 0.5 and a target 7-day compressive strength of 2.5 N/mm². For the control mix, 1.6 kg of cement, 14 kg of fine aggregate, and 0.8 kg of water were batched per six-inch hollow block. Rice husk ash was used to replace cement at 10%, 20%, 30%, 40%, and 50% by mass, while soda ash was incorporated at 0.5%, 1.0%, 1.5%, 2.0%, 2.5%, and 3.0% by mass of binder, both independently and in combination. The experimental matrix comprised twenty mix variations, and a total of 54 block specimens were produced. All materials were batched by weight, mixed manually, cast into lubricated moulds, and compacted. The cast blocks were demoulded after 48 hours of undisturbed open-air setting, labelled, and cured in a water tank for 7 days before testing. The RHA range of 10–50% was selected to provide low, intermediate, and high cement-replacement levels and to identify the point at which dilution of the cementitious phase begins to outweigh the benefits of pozzolanic contribution. The soda ash range of 0.5–3.0% was selected as a controlled low-dose activation range intended to identify an effective dosage without introducing excessive alkali content into the binder system. The combined matrix was therefore designed to identify an optimum early-strength combination within the selected experimental limits.

2.5 Testing of Hardened Sandcrete Blocks

Water absorption was determined in accordance with NIS 87:2007. Oven-dried block specimens were weighed to obtain the dry mass (W_1), fully immersed in clean water for 24 hours, surface-dried with an absorbent cloth, and reweighed to obtain the saturated mass (W_2). Percentage water absorption was calculated using Equation (3), with a maximum permissible limit of 12% by weight as reported in the manuscript from NIS 87.

$$\text{Water Absorption (\%)} = (W_2 - W_1)/W_1 \times 100 \quad (3)$$

Compressive strength was determined in accordance with BS EN 772-1:2011 (BSI, 2011) using a compression testing machine. After the 7-day curing period, the dimensions of each specimen were measured to determine the loaded cross-sectional area, and a compressive load was applied continuously until failure. Compressive strength was calculated using Equation (4), and the average value for each mix proportion was reported.

$$\text{Compressive Strength (N/mm}^2\text{)} = \text{Failure Load (N)/Cross-Sectional Area (mm}^2\text{)} \quad (4)$$

3.0 Results and Discussion

3.1 Physical Properties of Fine Aggregate

3.1.1 Sieve Analysis

The particle size distribution of the fine aggregate is presented in Figure 1.

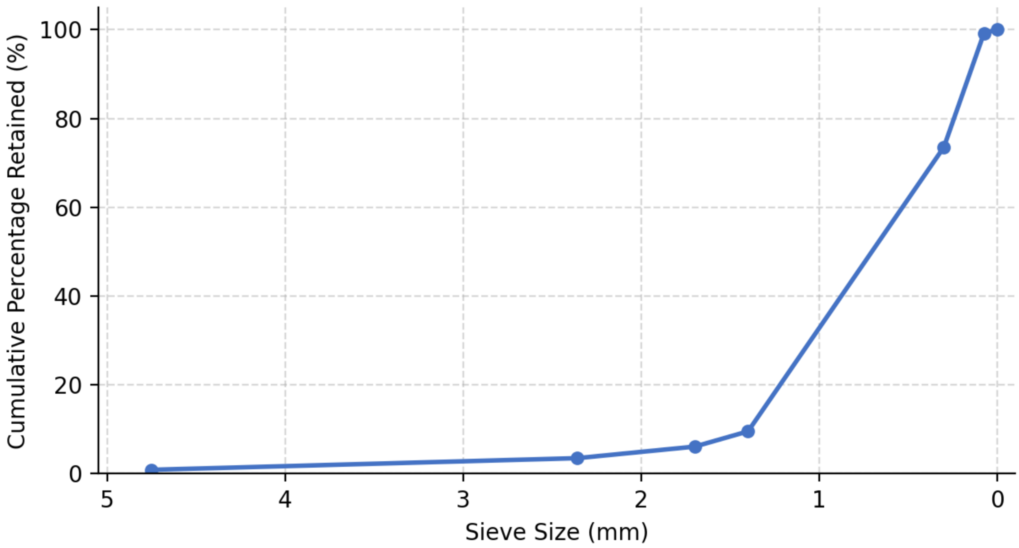

Figure 1: Particle size distribution curve for the fine aggregate

The sieve analysis yielded a fineness modulus (FM) of 1.93, with 73.53% of the material retained on the 300 μm sieve, 99.13% passing the 4.75 mm sieve, and only 0.69% passing the 75 μm sieve. The results indicate that the aggregate is predominantly fine sand with a low proportion of material passing the 75 μm sieve. Although the FM of 1.93 indicates a relatively fine grading compared with commonly used concrete sands, the aggregate can be considered suitable for the present sandcrete-block mixtures based on the observed grading and the successful casting of the specimens. The relatively fine grading may improve workability and surface finish but can increase specific surface area and water demand; consequently, control of the water-to-binder ratio is important for maintaining strength. This interpretation is consistent with studies reporting that aggregate grading influences workability, density, and strength development in cement-based masonry units (Wilson et al., 2024; Oyelami et al., 2025).

3.1.2 Specific Gravity

Table 1: Average specific gravity test results

Trials	W1 (g)	W2 (g)	W3 (g)	W4 (g)	S.G
1st Trial	31.3	59.3	100.0	83.0	2.55
2nd Trial	31.4	65.4	103.9	83.3	2.54
3rd Trial	31.3	71.1	107.7	83.2	2.60

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Trials	W1 (g)	W2 (g)	W3 (g)	W4 (g)	S.G
Average	31.3	65.3	103.9	83.2	2.56

Note. W_1 = *mass of pycnometer;* W_2 = *mass of pycnometer and sand;* W_3 = *mass of pycnometer, sand and water;* W_4 = *mass of pycnometer and water.*

The average specific gravity of the fine aggregate, determined from three pycnometer trials, was 2.56. This value is within the commonly reported range for natural fine aggregates and indicates that the sand does not contain an unusually high proportion of lightweight or highly porous particles. The result is comparable with values reported in previous studies and supports the use of the aggregate in the sandcrete-block mixtures investigated.

3.2 Chemical Composition of Rice Husk Ash

Table 2: Rice husk ash chemical composition

Constituent	Composition (%)
Fe_2O_3	6.086
SiO_2	74.988
CaO	4.767
Al_2O_3	4.762

The oxide composition of the rice husk ash, determined by X-ray fluorescence (XRF) analysis, is presented in Table 2. The ash was predominantly composed of silicon dioxide (SiO_2, 74.99%), followed by iron oxide (Fe_2O_3, 6.09%), calcium oxide (CaO, 4.77%), and aluminium oxide (Al_2O_3, 4.76%). The combined $SiO_2 + Al_2O_3 + Fe_2O_3$ content was 85.84%, which is above the 70% oxide-content criterion commonly used in ASTM C618 to assess pozzolanic materials. This result indicates strong pozzolanic potential; however, oxide content alone is not sufficient to establish complete compliance with a pozzolan classification because other requirements, such as loss on ignition and reactivity-related criteria, must also be considered. The high silica content is consistent with reported characteristics of Nigerian rice husk ash (Raheem & Bello, 2025) and with the silica-dominant composition reported by Sawasdee and Pisutpaisal (2022). The chemical composition therefore provides a sound basis for investigating RHA as a supplementary cementitious material in the present study.

3.3 Physical Properties of Sandcrete Blocks

3.3.1 Wet Mass

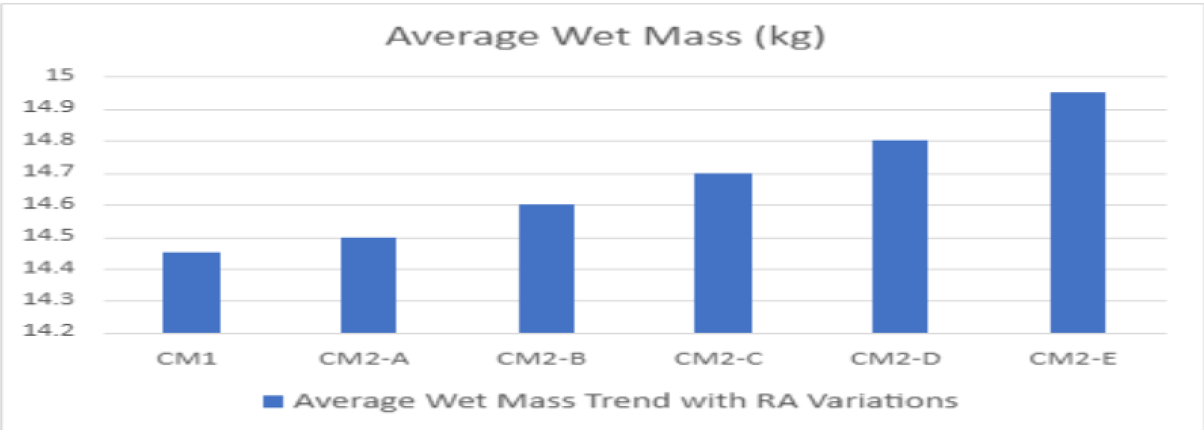

Figure 2: Wet mass test of rice husk ash (RHA) variations

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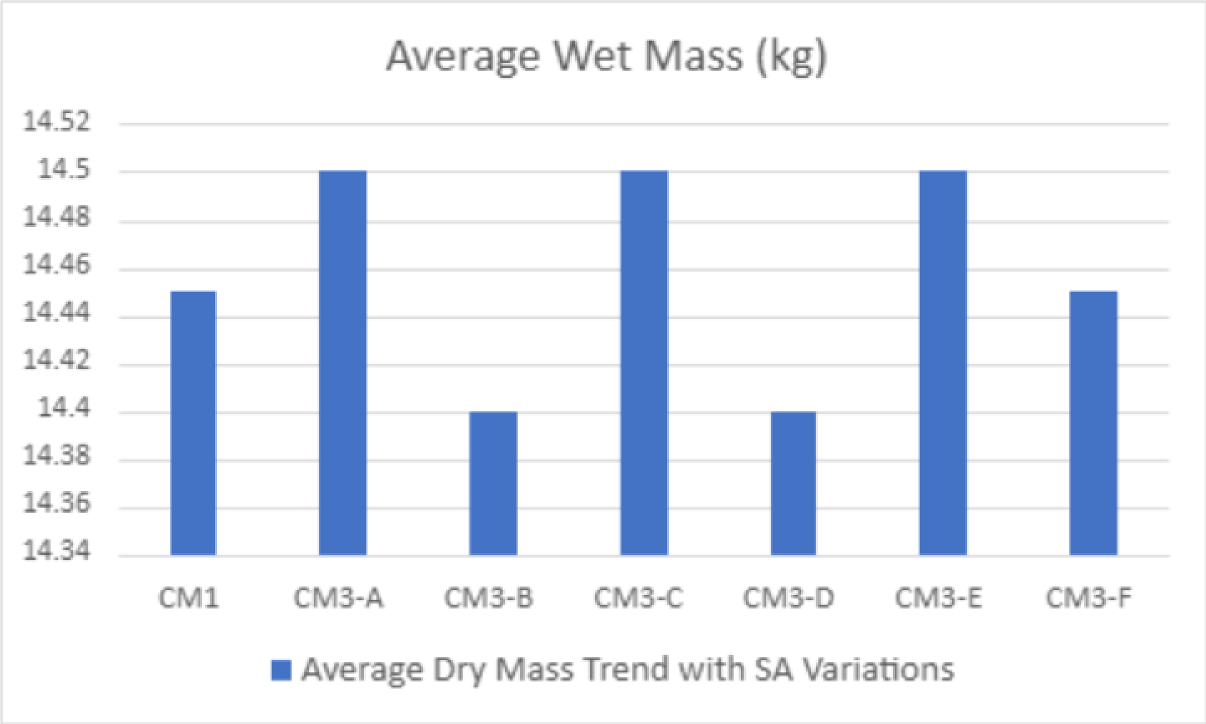

Figure 3: Wet mass test of soda ash (SA) variations

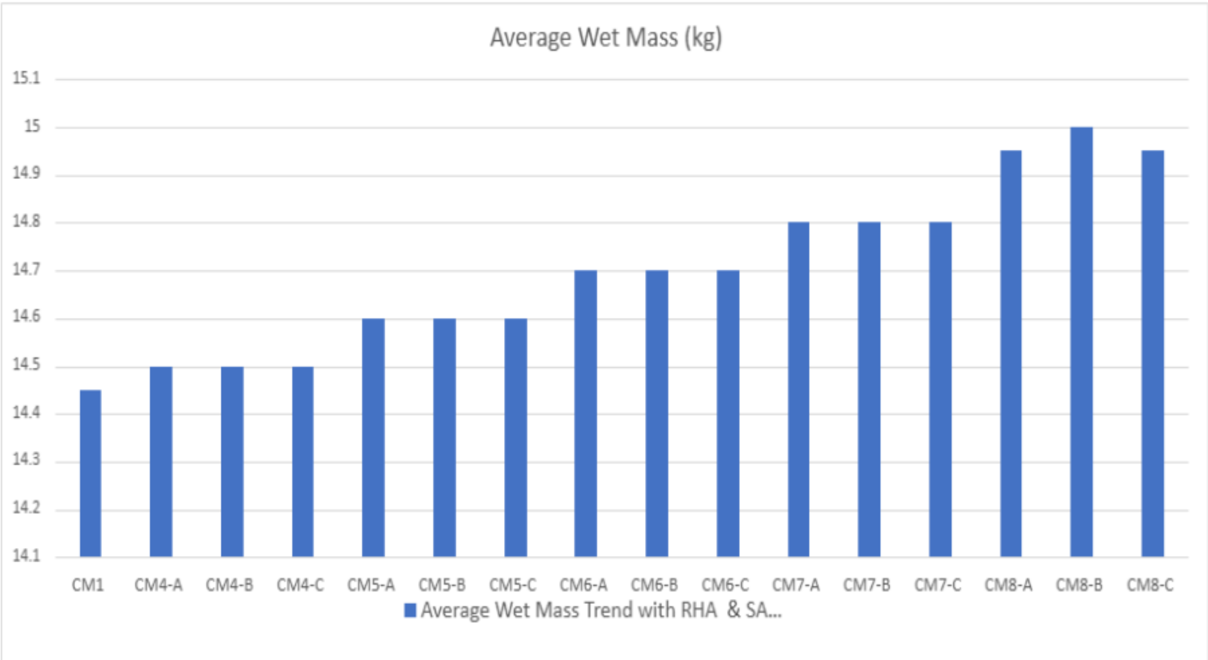

Figure 4: Wet mass test of combined rice husk ash (RHA) and soda ash variations

The wet mass of the sandcrete blocks increased progressively with RHA content, from 14.45 kg for the control mix (CM1) to 14.95 kg at 50% RHA replacement. This increase is plausibly associated with the high specific surface area and porous texture of RHA, which can increase water demand and the amount of water retained within the fresh mixture. Soda ash addition, by contrast, had only a small effect on wet mass (14.40–14.50 kg across 0.5–3.0% SA), while the combined RHA–SA mixes followed the RHA-dominated trend, rising from 14.50 kg at 10% RHA to 15.00 kg at 50% RHA. The observed trend is consistent with reports that porous agricultural ashes can increase water demand and alter the mass of fresh cementitious mixtures (Raheem et al., 2025; Oyekan & Kamiyo, 2020).

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3.3.2 Dry Mass

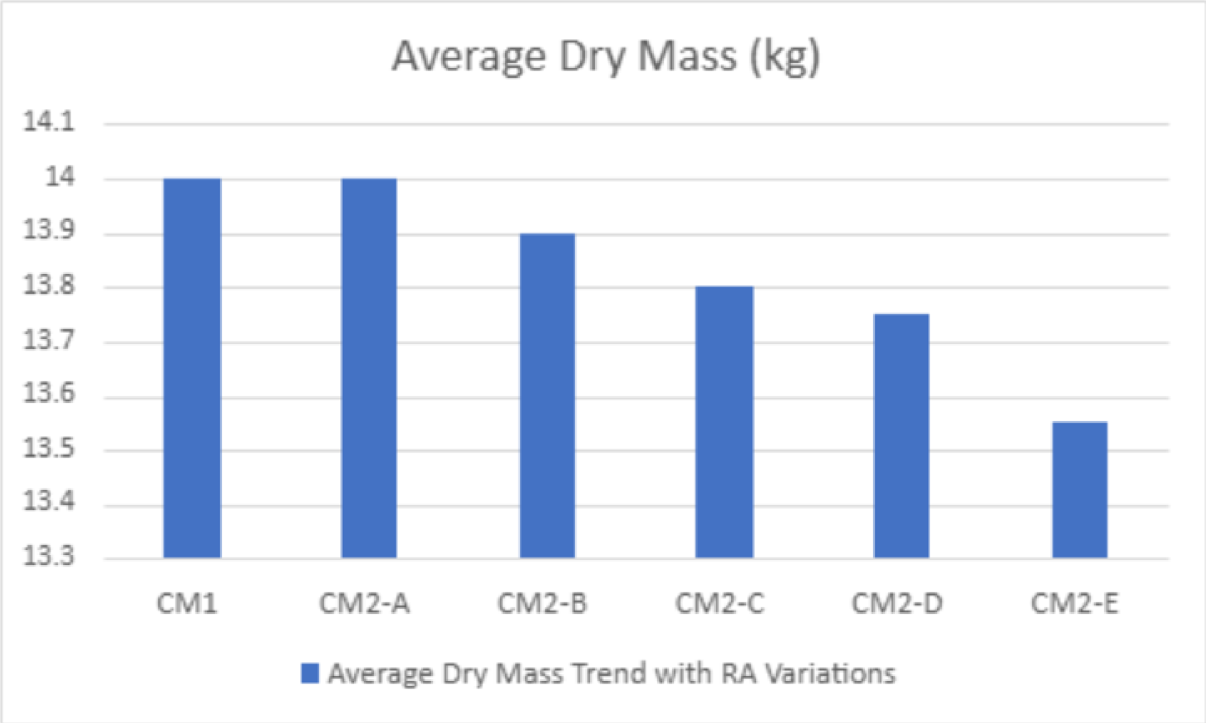

Figure 5: Dry mass test of rice husk ash (RHA) variations

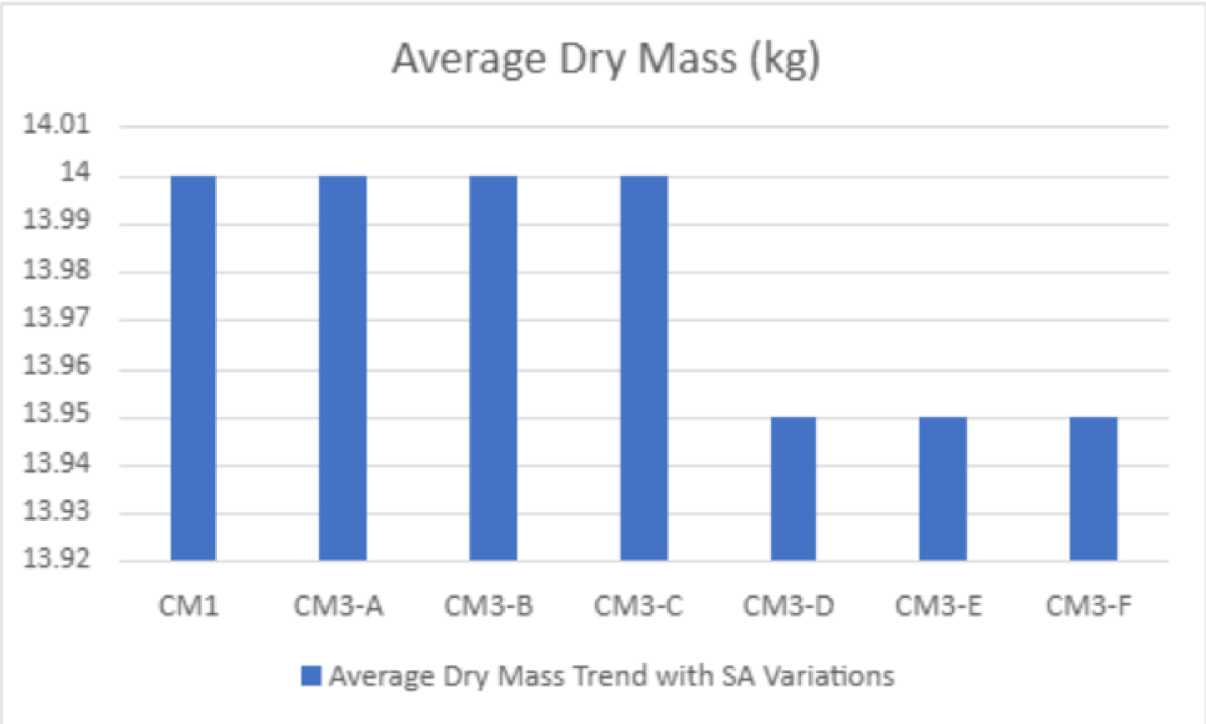

Figure 6: Dry mass test of soda ash (SA) variations

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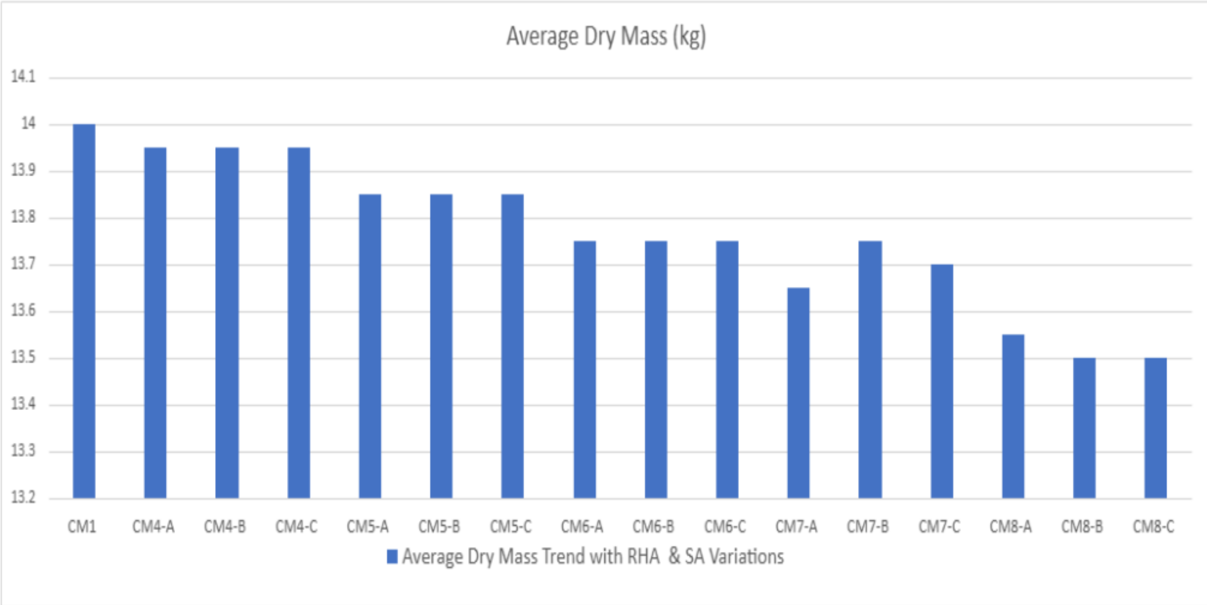

Figure 7: Dry mass test of combined rice husk ash (RHA) and soda ash variations

Dry mass showed an inverse trend to wet mass, decreasing from 14.00 kg for the control mix to 13.55 kg at 50% RHA. This reduction is consistent with the lower particle density and bulk density of RHA compared with Portland cement, so replacing cement with RHA reduces the mass of solid material at a given volume. Soda ash incorporation produced only a marginal reduction in dry mass, from 14.00 kg to 13.95 kg across the tested range, whereas the combined RHA–SA mixes decreased from 13.95 kg at 10% RHA to 13.52 kg at 50% RHA. These observations agree generally with studies reporting reduced density or mass in cement-based composites containing higher proportions of RHA (Raheem et al., 2025; Singh et al., 2023; Tulashie et al., 2021).

3.3.3 Water Absorption

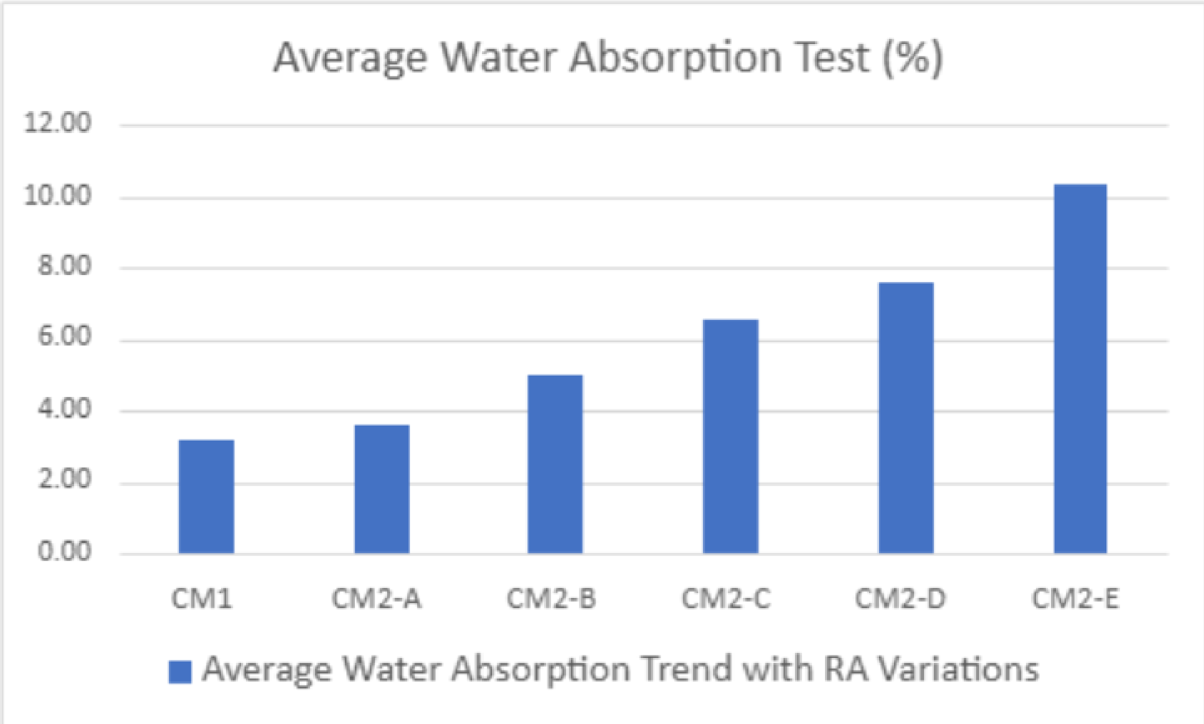

Figure 8: Water absorption test of rice husk ash (RHA) variations

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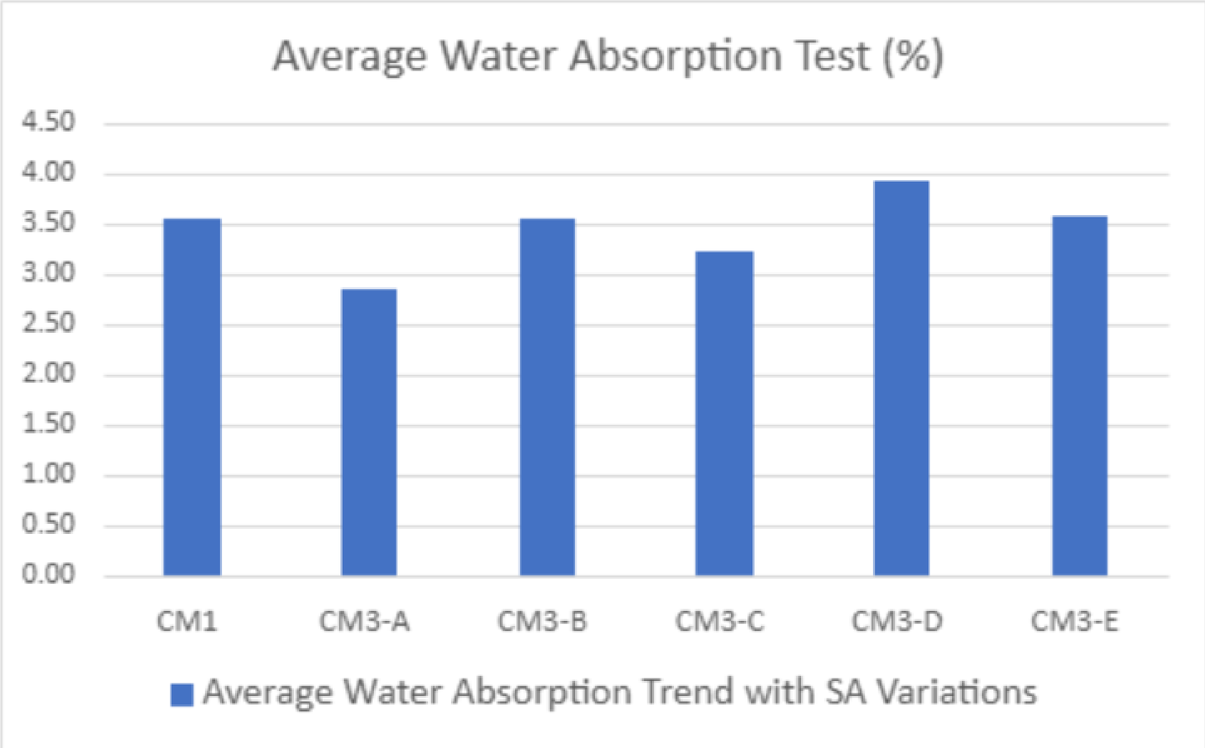

Figure 9: Water absorption test of soda ash (SA) variations

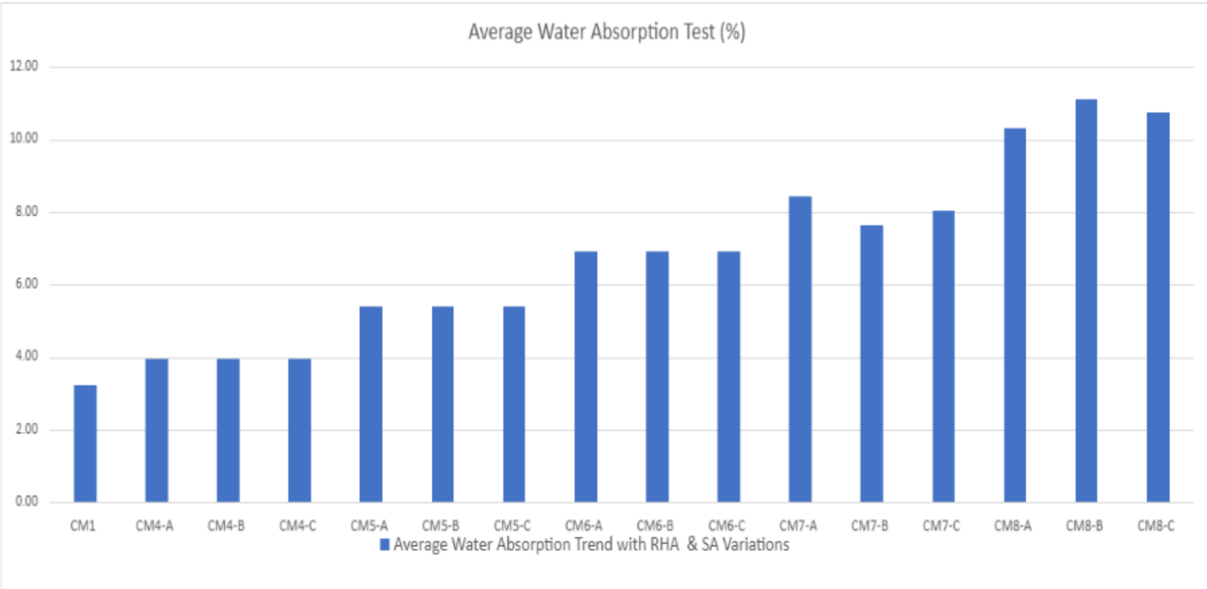

Figure 10: Water absorption test of combined rice husk ash (RHA) and soda ash (SA) variations

Water absorption increased progressively with RHA content, from 3.21% for the control mix to 10.33% at 50% RHA replacement. The increase can be attributed to several related mechanisms: RHA has a porous structure and high specific surface area, which increase water demand; higher RHA contents also reduce the proportion of cement paste available to fill and refine the pore network; and incomplete filling of capillary pores can increase connected porosity after curing. Consequently, more water can enter and be retained within the hardened block during the absorption test. Soda ash incorporation had only a limited effect on water absorption, with an overall average of 3.46% across 0.5–3.0% SA. The combined RHA–SA mixes followed the RHA-dominated trend, increasing from 3.94% at 10% RHA to 10.74% at 50% RHA. All tested mixes remained below the 12% maximum water absorption limit reported in NIS 87, indicating acceptable water-absorption performance within the experimental range. However, water absorption alone should not be interpreted as a complete measure of long-term durability. The observed increase with RHA content is consistent with reports of increased pore volume and water absorption at higher pozzolanic-ash replacement levels (Raheem et al., 2025; Naghizadeh et al., 2022).

3.3.4 Compressive Strength

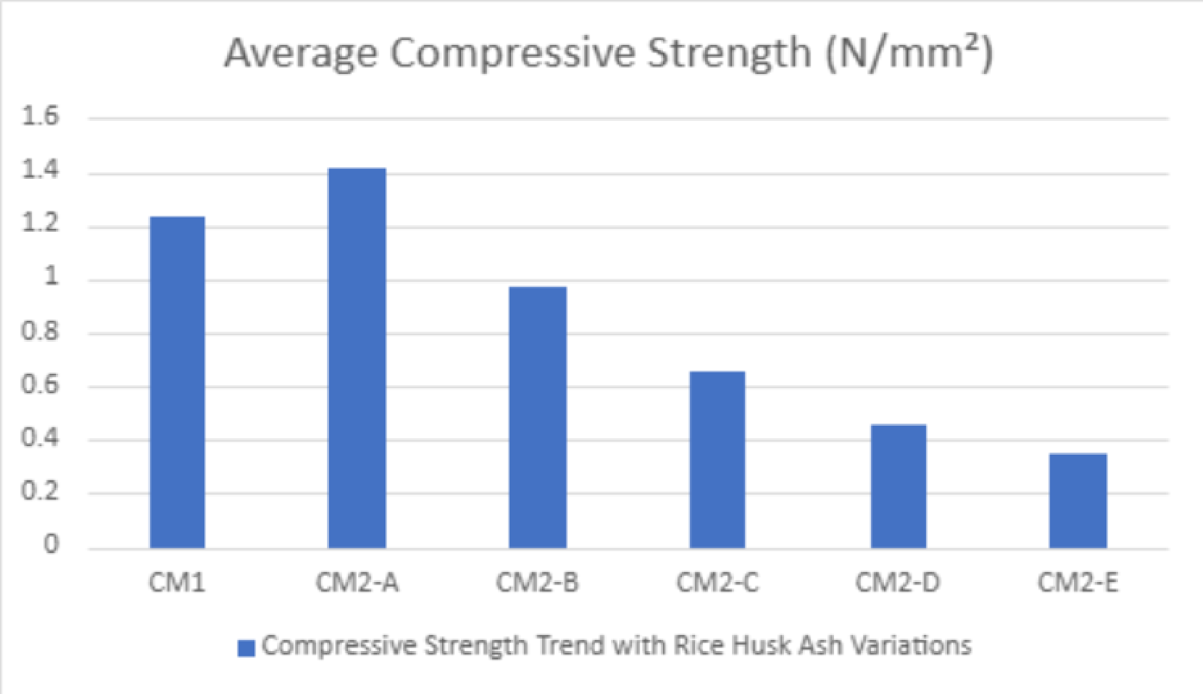

Figure 11: Compressive strength test of rice husk ash (RHA) variations

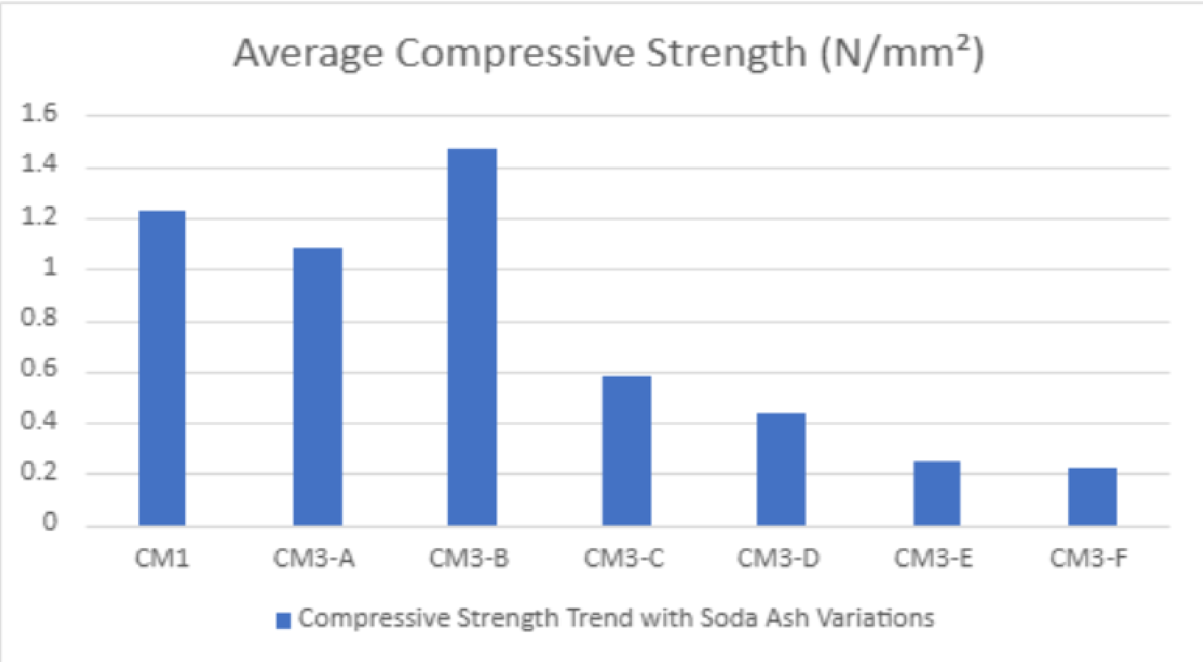

Figure 12: Compressive strength test of soda ash (SA) variations

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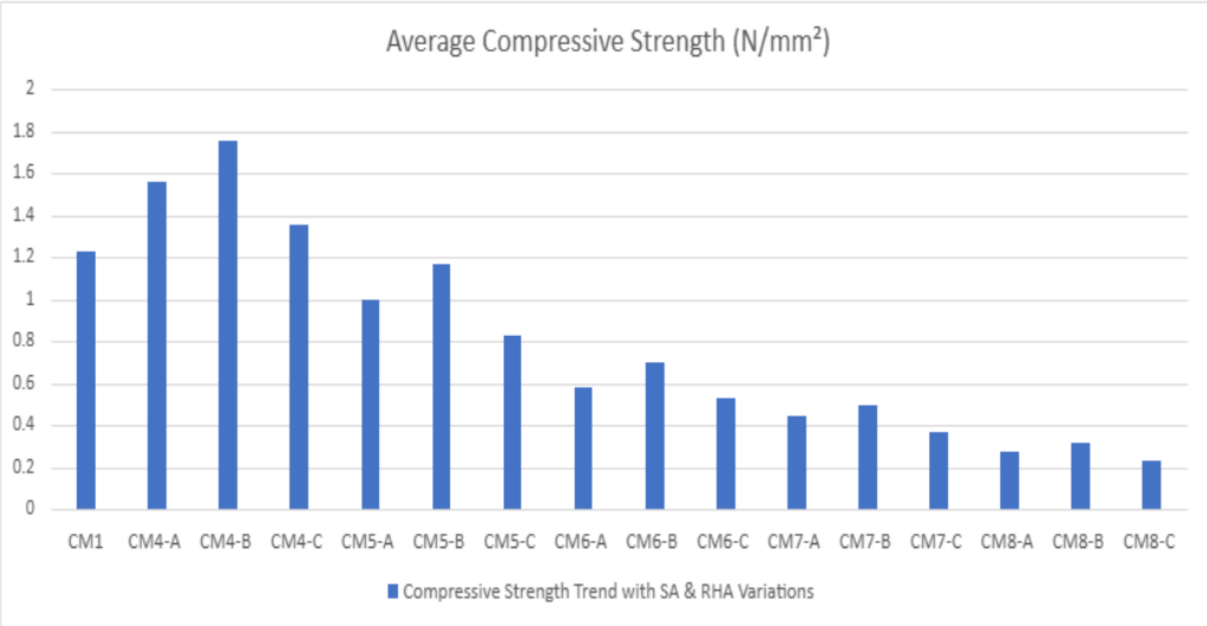

Figure 13: Compressive strength test of combined rice husk ash (RHA) and soda ash (SA) variations

The control mix (CM1) achieved an average 7-day compressive strength of 1.23 N/mm^2. For RHA-only mixes, strength increased to 1.41 N/mm^2 at 10% replacement, representing an improvement of approximately 14.6% over the control, before declining progressively to 0.35 N/mm^2 at 50% RHA. Soda-ash-only mixes exhibited a similar non-linear response, rising to a maximum of 1.47 N/mm^2 at 1.0% SA before falling to 0.22 N/mm^2 at 3.0% SA. In the combined RHA–SA series, the highest strength recorded was 1.76 N/mm^2 at 10% RHA with 1.0% SA, representing a 43.1% improvement over the control; the 10% RHA + 0.5% SA combination also achieved 1.56 N/mm^2. Strength declined beyond the optimum low-replacement region, reaching as low as 0.23 N/mm^2 at the highest combined replacement levels. The increase at 10% RHA can be explained by a balance between two mechanisms. First, the reactive silica in RHA can participate in pozzolanic reactions with calcium hydroxide released during cement hydration, producing additional C–S–H and improving the density of the binder matrix. Second, the alkaline environment created by the soda ash can promote dissolution of reactive silica and modify early hydration, thereby increasing the availability of species that contribute to cementitious reaction products. At higher RHA replacement levels, however, the reduction in OPC content becomes dominant: less cement is available to provide primary hydration products, while the higher RHA content can increase water demand and porosity. Similarly, excessive soda ash can disturb the hydration balance rather than continue to increase strength. The results therefore indicate that the 10% RHA + 1.0% SA combination provided the most favourable balance between cement dilution, pozzolanic contribution, and alkaline activation within the tested range. This interpretation is consistent with previous reports identifying low RHA replacement levels as more favourable for strength development than high replacement levels (Raheem et al., 2025; Naghizadeh et al., 2022).

Based on the NIS minimum requirement of 1.5 N/mm^2 for non-load-bearing six-inch hollow sandcrete blocks as cited in this manuscript, only the 10% RHA + 1.0% SA and 10% RHA + 0.5% SA combinations met or exceeded this threshold. The 10% RHA + 1.0% SA combination was therefore identified as the optimum mix within the tested experimental range. This result supports the objective of identifying a blend capable of improving early-age compressive strength while maintaining acceptable water absorption.

4.0 Conclusion

This study experimentally analysed the early compressive strength and water absorption performance of 150 mm (6-inch) hollow sandcrete blocks produced by partial replacement of ordinary Portland cement with rice husk ash (RHA) and activation with soda ash (Na_2CO_3). The fine aggregate had a fineness modulus of 1.93 and a specific gravity of 2.56. X-ray fluorescence analysis showed that the RHA contained 85.84% combined SiO_2, Al_2O_3, and Fe_2O_3, indicating strong pozzolanic potential.

The 7-day compressive-strength results demonstrate that the effect of RHA and soda ash was dosage-dependent. The control mix recorded 1.23 N/mm^2, while the optimum combination of 10% RHA and 1.0% soda ash achieved 1.76 N/mm^2, representing a 43.1% increase relative to the control. This improvement is attributed to the combined effect of RHA's reactive silica and the activating influence of soda ash, which can promote the formation of additional cementitious reaction products at appropriate dosages. At higher RHA replacement levels, the reduction in cement content and the associated increase in water demand and porosity outweighed the benefits of pozzolanic reaction, resulting in lower strength. Water absorption increased from 3.21% for the control mix to

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10.33% at 50% RHA, but all tested mixes remained below the 12% limit reported in NIS 87. Thus, the results support acceptable water-absorption performance within the tested range, but they do not by themselves establish long-term durability.

The major contribution to knowledge is the identification, within the experimental matrix, of 10% RHA activated with 1.0% soda ash as the combination that produced the highest 7-day compressive strength of 1.76 N/mm² and exceeded the stated 1.50 N/mm² minimum for non-load-bearing six-inch hollow sandcrete blocks. The study also demonstrates that increasing RHA beyond the optimum level does not necessarily improve performance; instead, the benefit of pozzolanic addition is limited by cement dilution and increased pore-related water demand. The novelty lies in evaluating the interaction of RHA replacement and soda ash activation specifically for the early-age performance of 150 mm hollow sandcrete blocks, thereby providing an experimentally defined optimum within the tested ranges. These findings provide a basis for targeted optimisation of low-RHA, low-soda-ash mixtures rather than assuming that higher replacement or activator contents will produce higher strength.

Based on the findings of this study, the following recommendations are made. (i) Future studies should investigate RHA replacement levels below 10%, preferably at smaller increments, to determine whether a lower replacement level can further improve early and later-age strength. (ii) Soda ash dosages around the observed optimum should be investigated using smaller increments to define the activation threshold more precisely. (iii) The blocks should be tested at 3, 7, 14, 28, and longer curing ages to establish strength development and confirm whether the early-age optimum remains beneficial at later ages. (iv) Durability assessment should be expanded beyond water absorption to include sorptivity, drying shrinkage, wet–dry cycling, and, where relevant, chemical exposure. (v) Future work should characterise the RHA further, including particle-size distribution, specific surface area, loss on ignition, and reactive silica, to improve reproducibility and relate ash characteristics to performance. (vi) Replicate specimens and statistical analysis, such as analysis of variance (ANOVA) or response surface methodology, should be used to quantify experimental variability and confirm the significance of the observed optimum. (vii) Full-scale block production and field trials are recommended to assess batching, compaction, curing, dimensional consistency, and practical constructability before large-scale application. (viii) The economic and environmental benefits should be quantified through a cost analysis and, where feasible, a life-cycle assessment.

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