Compressive Strength Performance of Concrete Partially Blended with Rice Husk Ash

CHIBUIKEM LUCIUS ANOSIKE[1], IJEOMAH EMMANUEL CHINAZOM[2], ENYA IFEANYICHUKWU OKO[3], IBE JENNIFER CHINYERE[4]

[1, 2, 3, 4] *Department of Civil Engineering Technology, Akanu Ibiam Federal Polytechnic Unwana, Afikpo North L.G.A, Ebonyi State, Nigeria*

Abstract—This study examines the compressive strength performance of concrete partially blended with Rice Husk Ash (RHA) as a supplementary cementitious material. Concrete cubes of dimension 150 mm x 150 mm x 150 mm were produced using a 1:2:4 mix ratio at varying water-cement ratios (0.50to0.70), with RHA replacing cement at 5%, 10%, 15%, 20% and 25% by weight. Materials used include UNICEM Ordinary Portland Cement (Grade 32.5), river sand from Unwana beach, crushed stone aggregate (10to20 mm) from Akpoha, and potable water. Sieve analysis confirmed the fine aggregate falls within BS Zone I. Slump tests were performed on fresh concrete, and compressive strength was determined at 28 days curing age using a 2000 kN compression machine. Results show that workability (slump) increased with increasing RHA content and water-cement ratio, though all mixes exhibited very low workability. Compressive strength decreased progressively with increasing RHA replacement, from 21.8 N/mm2 at 5% RHA to 10.10 N/mm2 at 25% RHA. The 5% RHA blend achieved Grade C20 concrete, making it suitable for use in reinforced concrete construction. This study recommends a maximum of 5% RHA as a partial cement replacement for structural concrete works, and up to 10% for mass concrete applications. The use of RHA as a cement substitute offers environmental and economic benefits by reducing CO2 emissions and the overall cost of concrete production.

Keywords— Rice Husk Ash, Compressive Strength, Partial Cement Replacement, Pozzolan, Concrete, Water-Cement Ratio, Workability

I. INTRODUCTION

Concrete remains the most widely consumed construction material globally, owing to its versatility, economic feasibility and structural reliability. However, the production of its primary binder — Ordinary Portland Cement (OPC) — is a major contributor to global CO_2 emissions, accounting for approximately 5to8% of total anthropogenic carbon dioxide output (Neville, 2003). The growing demand for concrete in infrastructure development, particularly in sub-Saharan Africa, has intensified the need for sustainable, cost-effective alternatives to conventional cement.

Rice Husk Ash (RHA) is an agricultural by-product generated from the combustion of rice husk obtained during the milling of rice paddy. Approximately 600 million tonnes of rice paddy are produced globally each year, yielding about 120 million tonnes of rice husk. Combustion of rice husk at controlled temperatures of 600to700°C for two hours produces RHA containing 90to95% silica (SiO_2), making it a highly reactive pozzolanic material (Houston, 1972). When used as a partial cement replacement, RHA undergoes secondary hydration reactions with calcium hydroxide released during cement hydration, forming additional calcium silicate hydrate (C-S-H) gel that contributes to concrete strength and durability.

The use of RHA offers a dual benefit: it reduces the environmental burden of agricultural waste disposal while simultaneously lowering the cost of concrete production — both critical considerations in developing economies. Previous studies have investigated RHA in concrete at varying replacement levels, with mixed results depending on RHA quality, fineness and replacement percentage. Ashwini et al. (2004) reported a 12% increase in compressive strength using 20% RHA replacement, while Obam (2006) found decreasing strength with increasing RHA content in Nigerian concrete. These contrasting findings highlight the need for context-specific experimental studies using locally sourced materials.

This study therefore investigates the compressive strength performance of concrete incorporating RHA sourced from Afikpo Rice Mill, Ebonyi State, Nigeria, as a partial replacement for UNICEM OPC Grade 32.5, using locally available river sand and crushed aggregate. The work contributes to the body of knowledge on sustainable concrete materials in the Nigerian and West African context.

II. LITERATURE REVIEW

Rice Husk Ash (RHA) has been studied extensively as a supplementary cementitious material (SCM) since the early 1970s. Houston (1972) established that RHA produced by controlled combustion at 600to700°C contains 90to95% amorphous silica, a key requirement for pozzolanic reactivity. The high silica content enables RHA to react with calcium hydroxide (Ca(OH)2) released during cement hydration to form additional C-S-H gel, improving both strength and durability.

Gemma Rodrigue Desensale (2006) reported that the strength development of RHA concrete is slower at early ages but can match or exceed OPC concrete strength at later ages when optimal replacement levels and particle sizes are used. Muhammad Soaib Ismail and Waliuddin (1996) demonstrated that RHA improves the properties of high-strength concrete at replacement levels of 10to20%, attributing the improvement to pore refinement and improved interfacial transition zone (ITZ) quality.

Krishna et al. (2016) studied concrete with 5%, 10%, 15% and 20% RHA replacement and found optimum compressive strength at 10% replacement. Mechanza Akhter (2017) reported that RHA concrete at 10% replacement exhibited higher 28-day compressive strength than the control mix, but strength declined beyond this level. Sourav Ghisal and Moulik (2015) reviewed multiple RHA studies and concluded that 10to15% replacement is generally optimal, provided the RHA is sufficiently fine (passing 150 um sieve) and has low carbon content.

Obam (2006) conducted RHA concrete studies in Nigeria and found that compressive strength decreased with increasing RHA content, recommending 5% as the maximum practical replacement level for reinforced concrete work in the local context. Ologunagba et al. (2015) similarly found that RHA can feasibly replace cement at low percentages without significant strength loss, and highlighted the economic potential of RHA use in developing countries where cement costs are high relative to income.

The present study aligns with and extends these findings by using locally sourced RHA from Afikpo Rice Mill, one of the major rice processing centres in Southeast Nigeria, and testing it with Unwana river sand as fine aggregate — materials characteristic of the local construction environment.

III. MATERIALS AND METHODS

3.1 Materials

The following materials were used for this study:
(a) Cement: UNICEM branded Ordinary Portland Cement (OPC), Grade 32.5, conforming to BS 12 and NIS 441:2003.
(b) Fine Aggregate: Clean river sharp sand obtained from Unwana beach, Afikpo North L.G.A, Ebonyi State. The sand was air-dried and sieved before use.
(c) Coarse Aggregate: Crushed granite aggregate of sizes 10 mm, 15 mm and 20 mm, sourced from Akpoha, Afikpo North L.G.A, Ebonyi State.
(d) Water: Portable water obtained from the student secretariat of Akanu Ibiam Federal Polytechnic, Unwana, conforming to NIS 554:2007.
(e) Rice Husk Ash (RHA): Rice husk was sourced from Afikpo Rice Mill and burnt in a furnace to produce RHA, which was then sieved through a 150 um sieve to remove unburnt carbon and oversized particles.

3.2 Mix Design and Specimen Preparation

A nominal mix proportion of 1:2:4 (cement:fine aggregate:coarse aggregate) by weight was adopted. The density of OPC was taken as 2400 kg/m³. Steel cube moulds of dimension 150 mm x 150 mm x 150 mm were used, giving a cube volume of 0.003375 m³ and a mass of 8.1 kg per cube. Three cubes were cast for each RHA replacement level, giving a total of 15 cubes. RHA was used to replace cement by weight at 5%, 10%, 15%, 20% and 25%, with corresponding water-cement ratios of 0.50, 0.55, 0.60, 0.65 and 0.70 respectively.
The constituent masses per set of three cubes (total mass = 24.3 kg) were:

RHA (%)	RHA (kg)	W/C	Water (kg)	Cement (kg)	Fine Agg. (kg)	Coarse Agg. (kg)
5	0.18	0.50	1.75	3.33	6.9	13.9
10	0.35	0.55	1.93	3.15	6.9	13.9

© SEP 2026 | IRE Journals | Volume 10 Issue 3 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV10I3-1723497

15	0.53	0.60	2.10	2.98	6.9	13.9
20	0.70	0.65	2.28	2.80	6.9	13.9
25	0.88	0.70	2.45	2.63	6.9	13.9

Table 1: Mix Proportions by RHA Replacement Level

3.3 Sieve Analysis
Sieve analysis of the river sand was conducted in accordance with BS 812 Part 18:1995 to determine the particle size distribution and classify the fine aggregate grading zone. A 400 g air-dried sample was shaken through a nested set of sieves for 10 minutes using a mechanical shaker. The mass retained on each sieve was recorded, and cumulative percentage passing was calculated.

3.4 Workability Test (Slump Test)
The slump test was conducted immediately after mixing in accordance with BS 1881 Part 108:1993. The fresh concrete was placed into a standard slump cone (300 mm height) in three equal layers, each tamped 25 times with a 16 mm diameter rod. The cone was then lifted vertically and the slump measured as the difference between the original cone height and the highest point of the settled concrete.

3.5 Casting and Curing
Oiled steel cube moulds (150 x 150 x 150 mm) were filled in three layers with each RHA concrete mix, tamped at each layer, and levelled. After 24 hours, specimens were demoulded, marked and submerged in a curing tank at ambient temperature (20to30°C) until the 28-day test age.

3.6 Compressive Strength Test
At 28 days, specimens were removed from the curing tank, surface-dried and weighed. Each cube was placed on a 2000 kN hydraulic compression testing machine with its smoothest face against the platens. Load was applied at a uniform rate until failure. Compressive strength (f'c) was calculated as:

$$f'c = P / A$$

Where: P = average crushing load (N); A = cross-sectional area of cube = 22,500 mm²

IV. RESULTS AND DISCUSSION

4.1 Sieve Analysis
The sieve analysis results for Unwana river sand are presented in Table 2. The fineness modulus was calculated as 0.42, and the percentage passing at the 600 um sieve was 11.1%, which places the sand in BS Zone I (coarse fine aggregate). The sand was deemed suitable for use in the concrete mix.

Sieve Size	Mass Retained (g)	% Retained	Cumulative % Retained	% Passing	Remark
10 mm	0.00	0	0	100	
4.75 mm	0.00	0	0	100	
2.36 mm	17.7	4.5	4.5	95.5	
1.18 mm	80.4	20.4	24.9	75.1	
600 um	253.0	64.0	88.9	11.1	Zone I
300 um	40.2	10.2	99.1	0.9	
150 um	3.3	0.8	99.9	0.1	
Pan	0.3	0.1	100.0	0	

Table 2: Sieve Analysis Results for Unwana River Sand

4.2 Workability (Slump Test)

RHA (%)	W/C Ratio	Slump Value (mm)	Workability
5	0.50	7	Very Low

10	0.55	9	Very Low
15	0.60	13	Very Low
20	0.65	16	Very Low
25	0.70	21	Very Low

Table 3: Slump Test Results

Slump values ranged from 7 mm to 21 mm, all classified as very low workability (0to25 mm) per BS 1881. This low workability is attributable to the high water absorption characteristic of RHA due to its cellular, porous microstructure. As the RHA percentage increased, the water-cement ratio was increased correspondingly to maintain a workable mix, yet workability remained in the very low range. The increasing slump trend with increasing W/C ratio confirms the dominant effect of water content on fresh concrete behaviour. This is consistent with the findings of Mechanza Akhter (2017) and Krishna et al. (2016), who reported reduced workability in RHA blended mixes at lower W/C ratios.

4.3 Density of Hardened Concrete

Concrete densities ranged from 2311.1 kg/m³ at 5% RHA to 2133.3 kg/m³ at 25% RHA, all within the moderately dense concrete range (2000to2400 kg/m³). The progressive decrease in density with increasing RHA content is consistent with the lower specific gravity of RHA (approximately 2.1) compared to OPC (3.15), which reduces the overall mass of the binder fraction as cement is replaced. This trend has also been reported by Obam (2006) and Ismail and Waliuddin (1996).

4.4 Compressive Strength at 28 Days

RHA (%)	Cube Weights W1, W2, W3 (kg)	Avg. Weight (kg)	Density (kg/m³)	Crushing Loads C1, C2, C3 (kN)	Avg. Load (kN)	f'c (N/mm2)
5	7.70, 8.00, 7.60	7.8	2311.1	500, 485, 485	490.0	21.80
10	7.50, 7.60, 7.60	7.6	2251.9	300, 340, 340	326.7	14.52
15	7.70, 7.90, 7.20	7.6	2251.9	270, 350, 260	293.3	13.04
20	7.70, 7.20, 7.30	7.4	2192.6	255, 250, 215	240.0	10.70
25	7.20, 7.20, 7.20	7.2	2133.3	220, 225, 235	226.7	10.10

Table 4: Density and Compressive Strength Results at 28 Days

Date of casting: 17 November 2022; Date of crushing: 15 December 2022.

The 28-day compressive strength decreased consistently with increasing RHA content, from 21.80 N/mm2 at 5% RHA to 10.10 N/mm2 at 25% RHA, as shown in Table 4. The highest strength of 21.80 N/mm2 achieved at 5% RHA meets the minimum requirement of 20 N/mm2 for Grade C20 concrete (BS 8110), confirming its suitability for use in reinforced concrete structural elements.

The decline in strength with increasing RHA content is attributable to two main factors: (i) the dilution effect — as a greater proportion of the reactive cementitious material (OPC) is displaced, less C-S-H gel is produced in the primary hydration reaction; and (ii) inadequate reactivity of excess RHA beyond the threshold pozzolanic demand — at higher replacement levels, surplus RHA acts as a filler rather than a reactive material, creating weak zones within the cement paste matrix. These findings are consistent with Obam (2006) who reported declining RHA concrete strength in the Nigerian context, and with Ologunagba et al. (2015) who similarly found performance decline beyond 10% replacement.

At 10% RHA replacement, the compressive strength of 14.52 N/mm2 falls below the C20 threshold but satisfies the requirement for mass concrete applications (BS 8110 minimum of 10 N/mm2 for plain concrete). Replacement levels of 15to25%

yielded strengths of 10.10to13.04 N/mm2, suitable only for non-structural or lightly loaded applications. It is noted that the use of OPC Grade 32.5 (a relatively lower grade than the commonly used Grade 42.5 in high-performance studies) likely limited the achievable strength ceiling, particularly at higher RHA replacement levels. As recommended by this study, upgrading to Grade 42.5 cement could improve the compressive strength outcome across all RHA replacement levels.

V. CONCLUSION

This study investigated the compressive strength performance of concrete partially blended with locally sourced Rice Husk Ash (RHA) as a supplementary cementitious material. Based on experimental results, the following conclusions are drawn:

1. Rice Husk Ash obtained from Afikpo Rice Mill is a viable agricultural by-product that can be used as a partial cement replacement in concrete production.
2. Compressive strength decreased progressively with increasing RHA content at 28 days curing age, from 21.80 N/mm2 at 5% to 10.10 N/mm2 at 25% replacement.
3. The 5% RHA blend achieved Grade C20 concrete (21.80 N/mm2) and is recommended for reinforced concrete structural works.
4. The 10% RHA blend (14.52 N/mm2) is suitable for mass concrete applications and non-load-bearing elements.
5. RHA blended concrete exhibited very low workability across all replacement levels, necessitating careful attention to mix design and compaction.
6. Concrete density decreased with increasing RHA content, ranging from 2311.1 to 2133.3 kg/m³ — all within the moderately dense category.
7. The use of RHA offers economic benefits through reduced cement consumption and environmental benefits through diversion of agricultural waste from open burning.

VI. RECOMMENDATIONS

Based on the findings of this study, the following recommendations are made:

1. A maximum of 5% RHA replacement is recommended for reinforced concrete structural elements to maintain Grade C20 performance.
2. Up to 10% RHA may be used for mass concrete works, plain concrete and non-structural applications.
3. OPC Grade 42.5 is recommended instead of Grade 32.5 when using RHA as a partial replacement, to compensate for the strength reduction.
4. Proper attention should be given to RHA fineness — passing the 150 um sieve — and low carbon content (LOI < 6%) to maximise pozzolanic reactivity.
5. Future studies should investigate the effect of extended curing ages (56 days, 90 days) on RHA concrete strength, as pozzolanic reaction is known to continue beyond 28 days.
6. Research should also examine the durability characteristics of RHA concrete, including resistance to chloride penetration, sulphate attack and water absorption, which are particularly relevant to tropical construction environments.

ACKNOWLEDGEMENT

The authors sincerely acknowledge the Department of Civil Engineering Technology, Akanu Ibiam Federal Polytechnic Unwana, for providing laboratory facilities for this study. Special thanks to Engr. Elechi Emmanuel O. and Engr. Attah Gabriel Uchenna for their supervision and technical guidance throughout the research process.

REFERENCES

[1] S. Ashwini *et al.*, “Compressive strength of concrete incorporating Rice Husk Ash at various percentages,” *Journal of Civil Engineering Research*, 2004.

[2] *BS 812 Part 18: Testing Aggregates: Methods for Determination of Particle Size Distribution*. London: British Standards Institution, 1995.

[3] *BS 1881 Part 108: Testing Concrete: Method for Making Test Cubes from Fresh Concrete*. London: British Standards Institution, 1993.

[4] *BS 8110: Structural Use of Concrete — Part 1: Code of Practice for Design and Construction*. London: British Standards Institution, 1997.

[5] S. V. Deodhar, *Civil Engineering Materials*, 6th ed. New Delhi: Khanna Publishers, 2009.

[6] E. O. Elechi, *Introduction to Concrete Technology*. Ibadan: Jeolin Publication Ltd., 2012.

[7] G. Rodrigue Desensale, "Strength development of concrete with rice husk ash," *Cement and Concrete Composites*, vol. 28, pp. 158–160, 2006.

[8] D. F. Houston, *Rice: Chemistry and Technology*. Minnesota, USA: American Association of Cereal Chemists, 1972.

[9] M. S. Ismail and A. M. Waliuddin, "Effect of rice husk ash on high strength concrete," *Construction and Building Materials*, vol. 10, no. 7, pp. 521–526, 1996. ScienceDirect

[10] N. K. Krishna, S. Sandeep, and K. M. Mini, "Study on concrete with partial replacement of cement by rice husk ash," *IOP Conf. Series: Materials Science and Engineering*, vol. 149, no. 1, 2016. IOP

[11] M. Akhter, "Experimental study on the effect of Rice Husk Ash on strength of concrete," *International Journal*, vol. 4, no. 7, pp. 2349–9745, 2017.

[12] A. M. Neville, *Properties of Concrete*, 4th ed. England: Longman Scientific and Technical, 2003.

[13] *NIS 441: Nigerian Industrial Standard for Portland Cement*. Lagos: Standards Organisation of Nigeria, 2003.

[14] *NIS 554: Nigerian Industrial Standard for Potable Water*. Lagos: Standards Organisation of Nigeria, 2007.

[15] S. O. Obam, "Compressive strength of RHA concrete," *Nigerian Journal of Technology*, vol. 25, no. 2, pp. 1–10, 2006.

[16] B. Ologunagba, A. S. Daramola, and A. O. Aliu, "Feasibility of using rice husk ash as a partial replacement for cement in concrete," *International Journal of Engineering Trends and Technology*, vol. 30, no. 5, pp. 267–269, 2015.

[17] M. S. Shetty, *Concrete Technology — Theory and Practice*. New Delhi: S. Chand and Company Ltd., 2003.

[18] S. Ghisal and S. C. Moulik, "Use of Rice Husk Ash as partial replacement with cement in concrete: A review," *International Journal of Engineering Research*, vol. 4, no. 9, pp. 506–509, 2015.