
EFFECT OF SUPERPLASTICIZER DOSAGE ON THE WORKABILITY AND COMPRESSIVE STRENGTH OF RICE HUSK ASH MODIFIED CONCRETE

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ABSTRACT

Concrete production contributes approximately 5–8% of global anthropogenic greenhouse gas emissions. Using agricultural waste as supplementary cementitious material offers a sustainable approach to reducing cement consumption. This study investigates the effect of superplasticizer dosage on the workability and compressive strength of concrete containing varying proportions of rice husk ash (RHA). RHA was produced by controlled calcination of rice husk at 650°C for 4 hours and characterized using XRF, XRD, and SEM. Concrete mixes contained 0%, 5%, 10%, 15%, 20%, and 25% RHA replacement by cement weight and 0%, 1%, 2%, 4%, 6%, and 8% Conplast SP430 by binder weight. A total of 432 cube specimens (100 mm × 100 mm × 100 mm) were cast and tested at 7, 14, 28, and 56 days in accordance with BS EN 12390-3, while workability was assessed using the slump test (BS EN 12350-2). XRF results confirmed that RHA meets ASTM C618 requirements for Class N pozzolan, with 77.50% combined SiO₂+Al₂O₃+Fe₂O₃ and 4.02% loss on ignition. RHA significantly reduced workability, with slump decreasing from 45 mm to 5 mm at 25% RHA without superplasticizer. Superplasticizer improved workability by up to 287% at 8% dosage. RHA reduced early-age compressive strength, but pozzolanic activity enhanced long-term strength development. The optimum superplasticizer dosage was 6%, beyond which strength declined. The recommended sustainable mix is 10–15% RHA with 4–6% superplasticizer, achieving 28-day strengths of 28.0–31.2 N/mm², suitable for structural applications. The findings provide practical guidance for sustainable concrete production in Nigeria using locally available agricultural waste.

Rice Husk Ash (RHA); Superplasticizer; Compressive Strength; Workability; Sustainable Concrete; Supplementary Cementitious Materials;

1. INTRODUCTION

Concrete is the most widely used construction material due to its versatility, durability, and low cost, with global consumption estimated at about 25 billion tons annually (Neville, 2011; Mehta & Monteiro, 2014; Monteiro et al., 2017). However, cement production contributes about 5–8% of global anthropogenic CO₂ emissions, creating a need for sustainable alternatives (Schneider et al., 2011; Kajaste & Hurme, 2016; Habert et al., 2020). Partial cement replacement with supplementary cementitious materials (SCMs), including agricultural wastes, can reduce cement use and emissions while forming additional C-S-H through pozzolanic reactions (Juenger et al., 2019; Paris et al., 2016; Snellings et al., 2012). Rice husk ash (RHA) is particularly promising because of its high amorphous silica content and availability. Rice milling produces about 20–22% husk, which is often dumped or openly burned, causing environmental problems; controlled combustion at 550–800°C produces silica-rich ash suitable as a pozzolan (Della et al., 2002; Pode, 2016; Zareei et al., 2017; Beidaghy Dizaji et al., 2022). Nigeria's substantial rice production therefore provides opportunities to convert RHA into a useful construction material while reducing agricultural waste and cement consumption (Federal Ministry of Agriculture and Rural Development, 2019; FAO, 2020; Raheem et al., 2017; Fapohunda et al., 2017). However, RHA's porous, irregular particles increase water demand and reduce workability, which can be addressed using superplasticizers (SPs) to improve flowability and strength without increasing the water-cement ratio (Aslon et al., 2023; Vincent-Uzogbo & Ogorigbo, 2023; ACI Committee 212, 2010).

The interaction is complex because RHA can adsorb SP, reducing its effectiveness and making dosage optimization necessary (Ojo et al., 2023; Abbas et al., 2021). Previous studies generally report reduced strength at high RHA contents but improved performance at moderate levels and with SP. However, limited research has systematically examined varying RHA and SP combinations using locally available Nigerian materials. This study therefore addresses the need to determine suitable RHA-SP combinations and the optimum SP dosage for sustainable concrete production.

The aim of this study is to examine the effect of different superplasticizer dosages on the workability and compressive strength of concrete containing varying proportions of RHA, with a view to optimizing their use in sustainable concrete production. The specific objectives are to: **(i)** assess the influence of different SP dosages on the workability of concrete containing varying RHA proportions; **(ii)** investigate the effect of SP dosage on the compressive strength of RHA-modified concrete; **(iii)** determine the optimum SP dosage for achieving the best compressive strength performance.

2. METHODOLOGY

2.1 Materials

The materials represented those commonly available in Nigeria. Dangote Portland limestone cement (42.5R), conforming to NIS 444-1 (2014) and BS EN 197-1 (2011), was used with Zaria river sand and 20 mm crushed granite from Abdul Kwari Quarry Company, Zaria; both aggregates met BS EN 933-1 (2012) and BS EN 1097-2 (2010). Rice husk from a Kano rice mill was cleaned, washed, sun-dried for 48 hours, and calcined at 650°C for 4 hours, then cooled, ball-milled, and sieved through 75 µm (BS No. 200) (Zareei et al., 2017; Beidaghy Dizaji et al., 2022). Conplast SP430, an SNF-based superplasticizer, was used at varying dosages, while potable water from Ahmadu Bello University, Zaria, was used for mixing and curing. RHA properties are presented in Table 2.1.

Table 2.1: Physical Properties of Rice Husk Ash

Property	Value
Color	Grey
Specific Gravity	2.10
Fineness (Passing 75 µm)	85%
Loss on Ignition (LOI)	4.02%*

* Well below the 10.0% maximum permitted for ASTM C618 Class N pozzolans.

Table 2.2: Physical Properties of Conplast SP430 Superplasticizer

Property	Value
Appearance	Dark brown liquid
Specific Gravity	1.20 ± 0.02
pH Value	7.0–9.0
Chloride Content	Nil
Solid Content	40–45%
Dosage Range	0.5–3.0% by weight of cement

2.2 Characterization of Materials

The characterization of materials was conducted to ensure that all materials met the required standards for concrete production and to provide baseline data for interpreting the results of the study.

2.2.1 Characterization of Cement

Cement was characterized in accordance with BS EN 196-3 (2016) and BS EN 196-6 (2010) for fineness (Blaine air permeability method), consistency (Vicat apparatus), setting time (initial and final), and soundness (Le-Chatelier apparatus).

2.2.2 Characterization of Aggregate

Aggregates were tested for particle size distribution (BS EN 933-1, 2012), specific gravity, water absorption, aggregate crushing value (ACV), and aggregate impact value (AIV) (BS EN 1097-2, 2010).

2.2.3 Characterization of Rice Husk Ash

RHA was comprehensively characterized using X-Ray Fluorescence (XRF) spectrometry for chemical composition (BS EN 196-2, 2013), X-Ray Diffraction (XRD) for mineralogical analysis, and Scanning Electron Microscopy (SEM) for morphological examination. Loss on ignition (LOI), specific gravity, and fineness were also determined.

2.2.4 Characterization of Superplasticizer

The superplasticizer was characterized based on the manufacturer's technical data sheet (Table 2.2). Compatibility with cement and RHA was assessed through preliminary tests on cement paste and mortar, evaluating the effect on consistency, setting time, and flow.

2.3 Concrete Mix Design

A 1:2:4 mix ratio with a constant water-cement ratio of 0.50 was adopted, targeting 30 N/mm² at 28 days (Neville, 2011). The water content was deliberately held constant at 25 kg per mix across all superplasticizer dosages to isolate the pure plasticizing/dispersing effect of the SP, rather than its water-reducing capability. This design choice allows for a direct comparison of SP's influence on workability and strength without the confounding variable of a reduced water-cement ratio. RHA replaced cement at 0–25% (0%, 5%, 10%, 15%, 20%, and 25%), while Conplast SP430 was used at 0–8% (0%, 1%, 2%, 4%, 6%, and 8%) by binder weight. The 36 mix combinations produced 432 cubes (100 × 100 × 100 mm) for compressive strength testing at four curing ages, with three replicates per mix. Mix proportions are presented in Table 2.4.

Table 2.4: Mix Proportions for All Concrete Mixes

Mix ID	Cement (kg)	RHA (kg)	RHA (%)	SP (kg)	SP (%)	FA (kg)	CA (kg)	Water (kg)
0% SP Series (0% SP)								
M1	50	0	0	0	0	100	200	25
M2	47.5	2.5	5	0	0	100	200	25
M3	45	5	10	0	0	100	200	25
M4	42.5	7.5	15	0	0	100	200	25
M5	40	10	20	0	0	100	200	25
M6	37.5	12.5	25	0	0	100	200	25
1% SP Series (1% SP)								
M7	50	0	0	0.5	1	100	200	25

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Mix ID	Cement (kg)	RHA (kg)	RHA (%)	SP (kg)	SP (%)	FA (kg)	CA (kg)	Water (kg)
M8	47.5	2.5	5	0.5	1	100	200	25
M9	45	5	10	0.5	1	100	200	25
M10	42.5	7.5	15	0.5	1	100	200	25
M11	40	10	20	0.5	1	100	200	25
M12	37.5	12.5	25	0.5	1	100	200	25
2% SP Series (2% SP)								
M13	50	0	0	1	2	100	200	25
M14	47.5	2.5	5	1	2	100	200	25
M15	45	5	10	1	2	100	200	25
M16	42.5	7.5	15	1	2	100	200	25
M17	40	10	20	1	2	100	200	25
M18	37.5	12.5	25	1	2	100	200	25
4% SP Series (4% SP)								
M19	50	0	0	2	4	100	200	25
M20	47.5	2.5	5	2	4	100	200	25
M21	45	5	10	2	4	100	200	25
M22	42.5	7.5	15	2	4	100	200	25
M23	40	10	20	2	4	100	200	25
M24	37.5	12.5	25	2	4	100	200	25
6% SP Series (6% SP)								
M25	50	0	0	3	6	100	200	25
M26	47.5	2.5	5	3	6	100	200	25
M27	45	5	10	3	6	100	200	25
M28	42.5	7.5	15	3	6	100	200	25
M29	40	10	20	3	6	100	200	25
M30	37.5	12.5	25	3	6	100	200	25
8% SP Series (8% SP)								
M31	50	0	0	4	8	100	200	25
M32	47.5	2.5	5	4	8	100	200	25
M33	45	5	10	4	8	100	200	25
M34	42.5	7.5	15	4	8	100	200	25
M35	40	10	20	4	8	100	200	25
M36	37.5	12.5	25	4	8	100	200	25

Note: Water content was held constant at 25 kg for all mixes to isolate the pure plasticizing effect of the superplasticizer.

Batching was done by weight with aggregates at SSD condition. Mixing involved 3 minutes of dry mixing, SP solution preparation in 60% of the mixing water, 4 minutes of wet mixing, and visual quality checking (Pavithra et al., 2016; Zareei et al., 2017). Concrete was cast in 100 × 100 × 100 mm

moulds conforming to BS EN 12390-1 (2012), filled in three layers and compacted with 25 strokes per layer (BS EN 12390-2, 2009). Specimens were demoulded after 24 hours and water-cured at $27 \pm 2^\circ\text{C}$ for 7, 14, 28, and 56 days.

2.4 Experimental Program

2.4.1 Workability Test (Slump Test)

Workability was assessed using the slump test in accordance with BS EN 12350-2 (2009). Fresh concrete was placed in a standard Abrams cone (100 mm top, 200 mm bottom, 300 mm height) in three layers, each tamped 25 times. The cone was lifted vertically, and slump was measured as the vertical difference between the cone height and the highest point of the slumped concrete. Three measurements were taken per mix, and the average was reported. All slump tests were performed in triplicate, and the mean and standard deviation were calculated for each mix to assess test repeatability.

2.4.2 Compressive Strength Test

Compressive strength was determined on 100 mm cube specimens in accordance with BS EN 12390-3 (2009). Specimens were tested at 7, 14, 28, and 56 days using a 3000 kN compression testing machine conforming to BS EN 12390-4 (2000). The load was applied at a constant rate of 0.5 N/mm²/s until failure. The compressive strength (f_c) was calculated using Equation 1:

$$f_c = P / A \quad (1)$$

Where:

f_c = Compressive strength (N/mm²)

P = Maximum load at failure (N)

A = Cross-sectional area of the specimen (mm²)

Three specimens were tested per mix at each curing age, and the average value was reported.

"For each mix and curing age, the mean compressive strength and standard deviation (SD) were calculated from the three replicate specimens. The coefficient of variation (CoV) was computed as the ratio of the standard deviation to the mean, expressed as a percentage. To evaluate the statistical significance of the effects of RHA content and SP dosage on compressive strength, a two-way analysis of variance (ANOVA) was performed on the 28-day compressive strength data using Microsoft Excel (Data Analysis Toolpak), with a significance level set at $\alpha = 0.05$. Where significant differences were identified, Tukey's Honestly Significant Difference (HSD) post-hoc test was conducted to determine which specific groups differed significantly.

3. RESULTS AND DISCUSSION

3.1 Characterization of Materials

3.1.1 Properties of Cement

The physical properties of Dangote Portland limestone cement (42.5R) were determined in accordance with BS EN 196-3 (2016) and BS EN 196-6 (2010). The results are presented in Table 3.1.

Table 3.1: Physical Properties of Cement

Property	Sample A	Sample B	Sample C	Average	BS EN 196-3 (2016) Requirement
Consistency (%)	30	28	26	27.67	26–33
Initial Setting Time (min)	126	131	138	131.67	≥ 45
Final Setting Time (min)	188	194	204	195.33	≤ 600
Soundness (mm)	0	6	4	3.33	≤ 10

Cement consistency ranged from 26–30%, averaging 27.67%, within the BS EN 196-3 (2016) limit of 26–33%. Initial and final setting times averaged 131.67 and 195.33 minutes, meeting the 45–600 minute requirements, while soundness expansion averaged 3.33 mm, below the 10 mm limit. Thus, the cement met all standards and was suitable for concrete production, with consistency results agreeing with Çelik et al. (2023) and Hawkins et al. (2003) (Neville, 2011; Shetty, 2000).

3.1.2 Properties of Aggregates

The physical and mechanical properties of the fine and coarse aggregates were determined in accordance with BS EN 933-1 (2012) and BS EN 1097-2 (2010). The results are presented in Table 3.2.

Table 3.2: Physical and Mechanical Properties of Aggregates

Property	Fine Aggregate	Coarse Aggregate	Standard Requirement
Fineness Modulus	2.72	-	2.3–3.1
Specific Gravity	2.67	2.69	2.30–2.90
Water Absorption (%)	1.2	0.8	< 3.0%
Aggregate Crushing Value (%)	-	22.5	< 30%
Aggregate Impact Value (%)	-	18.7	< 30%
Bulk Density (kg/m ³)	1650	1550	-

The fine aggregate had a fineness modulus of 2.72, within the 2.3–3.1 range, indicating suitable grading (ACI Education Bulletin E1, 2007). Specific gravities of 2.67 (fine) and 2.69 (coarse) were within the 2.30–2.90 range, while water absorption of 1.2% and 0.8% was below the 3.0% limit, indicating low porosity (Neville, 2011; BS EN 1097-2, 2010). ACV (22.5%) and AIV (18.7%) were below 30%, confirming good aggregate strength and toughness for structural concrete (Kosmatka et al., 2016; Shetty, 2000).

3.1.3.1 Chemical Composition (XRF Results)

The chemical composition of RHA was determined using X-Ray Fluorescence (XRF) spectrometry in accordance with BS EN 196-2 (2013). The results are presented in Table 3.3.

Table 3.3: Chemical Composition of Rice Husk Ash

Constituent	Composition (%)	Constituent	Composition (%)
SiO ₂	60.10	MgO	5.19
Al ₂ O ₃	15.10	SO ₃	0.62
Fe ₂ O ₃	2.30	Na ₂ O	0.45
CaO	10.55	K ₂ O	0.50
P ₂ O ₅	2.75	TiO ₂	0.07
LOI	4.02	—	—

XRF results showed SiO_2 (60.10%) as the dominant oxide, followed by Al_2O_3 (15.10%) and CaO (10.55%). The combined $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$ content of 77.50% exceeded the ASTM C618 (2019) minimum of 70%, confirming RHA as a Class N pozzolan suitable as a supplementary cementitious material. The LOI of 4.02% was well below the 10.0% maximum limit specified for Class N pozzolans under ASTM C618 (and also satisfies stricter 6.0% internal requirements), indicating good combustion and low carbon content (Raheem & Anifowose, 2023; Singh et al., 2019; Beidaghy Dizaji et al., 2022; Zareei et al., 2017).

3.1.3.2 Mineralogical Composition (XRD Results)

The XRD pattern of RHA (Figure 3.1) shows a broad hump at $2\theta \approx 22^\circ$, confirming predominantly amorphous, reactive silica. The absence of cristobalite and tridymite peaks indicates that 650°C calcination preserved the amorphous structure, as crystallization generally occurs above 800°C . Minor peaks at $2\theta = 20\text{--}30^\circ$ indicate trace quartz and impurities. Overall, the RHA was confirmed as a silica-rich pozzolanic material (Beidaghy Dizaji et al., 2022; Della et al., 2002; Singh et al., 2019; Zareei et al., 2017).

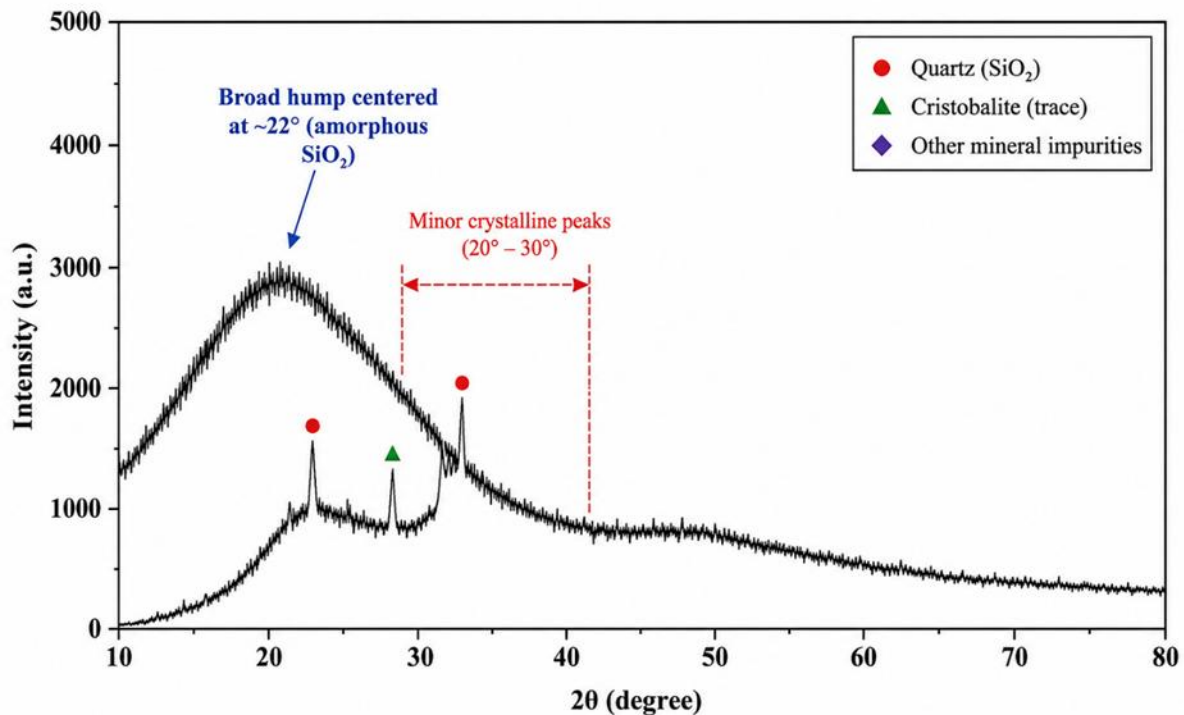


Figure 3.1: XRD Pattern of Rice Husk Ash

3.1.3.3 Morphology (SEM Results)

The SEM images in Figure 3.2 show RHA particles with irregular, angular, porous, and fibrous structures of varying sizes (Beidaghy Dizaji et al., 2022; Della et al., 2002). The pores result from combustion of cellulose, hemicellulose, and lignin, forming a silica-rich skeleton with high specific surface area (20–50 m^2/g) and water demand, which reduces workability (Singh et al., 2019; Aslon et al., 2023; Vincent-Uzogbo & Ogirigbo, 2023). The ash exhibited a grey colouration, consistent with the low LOI of 4.02%, confirming good combustion and low residual carbon content. The porous structure also increases SP adsorption, potentially reducing its effectiveness (Ojo et al., 2023; Kanthe, 2021).

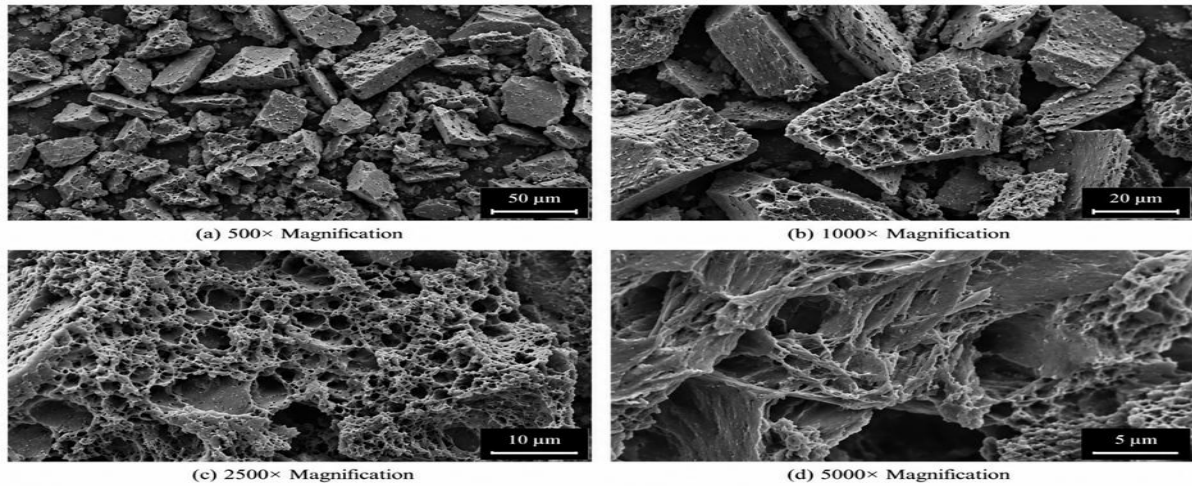


Figure 3.2: SEM Images of Rice Husk Ash at (a) 500×, (b) 1000×, (c) 2500×, and (d) 5000× Magnification

3.2 Workability of Fresh Concrete

The workability of fresh concrete was assessed using the slump test in accordance with BS EN 12350-2 (2009). The slump test results for all concrete mixes are presented in Table 3.4 and Figure 3.3.

Table 3.4: Slump values (mm) for all concrete mixes (mean $\pm$ standard deviation, $n = 3$)

RHA (%)	SP 0%	SP 1%	SP 2%	SP 4%	SP 6%	SP 8%
0	45 $\pm$ 3	55 $\pm$ 2	62 $\pm$ 3	70 $\pm$ 2	75 $\pm$ 3	80 $\pm$ 2
5	35 $\pm$ 3	48 $\pm$ 2	55 $\pm$ 3	62 $\pm$ 2	68 $\pm$ 3	72 $\pm$ 2
10	25 $\pm$ 2	40 $\pm$ 3	48 $\pm$ 2	55 $\pm$ 2	60 $\pm$ 3	65 $\pm$ 2
15	15 $\pm$ 2	32 $\pm$ 3	40 $\pm$ 2	48 $\pm$ 2	52 $\pm$ 2	58 $\pm$ 3
20	10 $\pm$ 2	25 $\pm$ 2	32 $\pm$ 2	40 $\pm$ 3	45 $\pm$ 2	50 $\pm$ 2
25	5 $\pm$ 1	18 $\pm$ 2	25 $\pm$ 2	32 $\pm$ 2	38 $\pm$ 2	45 $\pm$ 2

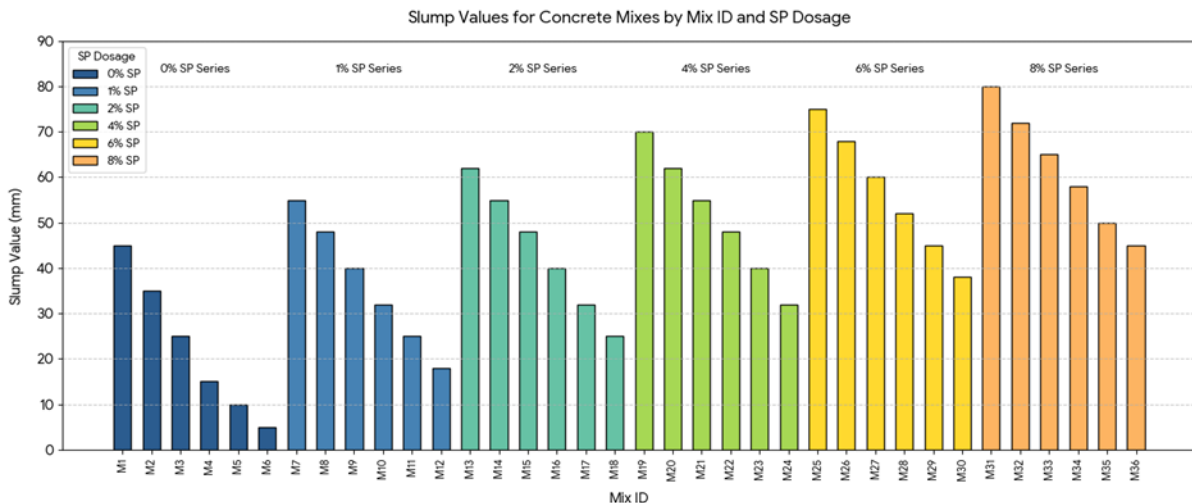


Figure 3.3: Slump Values for All Concrete Mixes

3.2.1 Effect of RHA on Slump

RHA reduced slump from 45 mm at 0% RHA to 5 mm at 25% RHA with 0% SP (89% reduction), due to its high surface area and porosity, which increase water absorption and reduce free water (Aslon et al., 2023; Vincent-Uzogbo & Ogirigbo, 2023). Its irregular particles also increase interparticle friction, further reducing workability (Singh et al., 2019). The reduction was more

pronounced above 10% RHA, highlighting the need for SP to maintain adequate workability (Igba et al., 2019; Ologunagba et al., 2015; Kanthe, 2021; Wang et al., 2024).

3.2.2 Effect of Superplasticizer on Slump

Superplasticizer significantly improved workability across all mixes. In the control mix, slump increased from 45 to 80 mm with SP increasing from 0% to 8% (78% improvement), while at 15% RHA, it increased from 15 to 58 mm (287% improvement). This results from SP dispersing cement and RHA particles, releasing entrapped water and increasing fluidity (Ramachandran, 1995; Noaman et al., 2020). The effect was greater at higher RHA contents due to increased water demand (Kanthé, 2021; Abbas et al., 2021). It should be noted that this workability improvement was achieved without any reduction in mixing water content, as the water-cement ratio was held constant at 0.50 throughout the study. The observed improvements are therefore attributable solely to the plasticizing/dispersing effect of the SP.

3.2.3 Combined Effect of RHA and Superplasticizer on Workability

The combined effects of RHA and SP on workability are shown in Table 3.4 and Figure 3.3. Workability decreased with increasing RHA but improved with SP, with the highest slump at 0–5% RHA and 6–8% SP and the lowest at 20–25% RHA and 0–1% SP. The optimum combination was 5–10% RHA with 4–6% SP, producing 55–65 mm slumps suitable for structural applications (Neville, 2011). These findings agree with Kanthe (2021) and Abbas et al. (2021). The coefficient of variation for slump measurements was consistently below 5% across all mixes, confirming good repeatability of the testing procedure.

3.3 Compressive Strength of Hardened Concrete

The compressive strength of hardened concrete was determined in accordance with BS EN 12390-3 (2009) at curing ages of 7, 14, 28, and 56 days. The results are presented in Tables 3.5 to 3.8 and Figures 3.4 to 3.7.

Table 3.5: Compressive strength results at 7 days (N/mm²) (mean ± standard deviation, n = 3)

RHA (%)	SP 0%	SP 1%	SP 2%	SP 4%	SP 6%	SP 8%
0	22.5 ± 1.2	23.8 ± 1.0	24.5 ± 0.9	25.0 ± 0.8	25.5 ± 0.7	24.2 ± 1.0
5	18.5 ± 1.3	20.2 ± 1.1	21.0 ± 1.0	21.8 ± 0.9	22.5 ± 0.8	21.0 ± 1.1
10	16.0 ± 1.4	18.5 ± 1.2	19.5 ± 1.1	20.3 ± 1.0	21.0 ± 0.9	19.8 ± 1.1
15	14.0 ± 1.5	16.8 ± 1.3	17.8 ± 1.2	18.5 ± 1.1	19.2 ± 1.0	18.0 ± 1.2
20	11.5 ± 1.6	14.5 ± 1.4	15.5 ± 1.3	16.3 ± 1.2	17.0 ± 1.1	16.0 ± 1.3
25	9.0 ± 1.7	12.0 ± 1.5	13.0 ± 1.4	14.0 ± 1.3	14.8 ± 1.2	13.5 ± 1.4

Table 3.6: Compressive strength results at 14 days (N/mm²) (mean ± standard deviation, n = 3)

RHA (%)	SP 0%	SP 1%	SP 2%	SP 4%	SP 6%	SP 8%
0	27.0 ± 1.1	28.5 ± 0.9	29.5 ± 0.8	30.0 ± 0.7	30.5 ± 0.7	29.0 ± 0.9
5	23.5 ± 1.2	25.0 ± 1.0	26.0 ± 0.9	26.8 ± 0.8	27.5 ± 0.8	26.0 ± 1.0
10	21.0 ± 1.3	23.0 ± 1.1	24.0 ± 1.0	25.0 ± 0.9	25.8 ± 0.9	24.5 ± 1.1
15	18.5 ± 1.4	21.0 ± 1.2	22.0 ± 1.1	23.0 ± 1.0	23.8 ± 1.0	22.5 ± 1.2
20	15.5 ± 1.5	18.5 ± 1.3	19.5 ± 1.2	20.5 ± 1.1	21.3 ± 1.1	20.0 ± 1.3
25	12.5 ± 1.6	16.0 ± 1.4	17.0 ± 1.3	18.0 ± 1.2	18.8 ± 1.2	17.5 ± 1.4

Table 3.7: Compressive strength results at 28 days (N/mm²) (mean $\pm$ standard deviation, n = 3)

RHA (%)	0% SP	1% SP	2% SP	4% SP	6% SP	8% SP
0	32.0	33.5	34.5	35.0	35.5	34.0
5	29.0	30.5	31.5	32.2	33.0	31.5
10	26.5	28.5	29.5	30.5	31.2	30.0
15	23.5	26.0	27.0	28.0	28.8	27.5
20	20.0	23.0	24.0	25.0	25.8	24.5
25	17.0	20.0	21.0	22.0	22.8	21.5

*Table 3.7**. Compressive strength results at 28 days (N/mm²) (mean $\pm$ standard deviation, n = 3)*

SP (%)	RHA 0%	RHA 5%	RHA 10%	RHA 15%	RHA 20%	RHA 25%
0	32.0	29.0	26.5	23.5	20.0	17.0
1	33.5	30.5	28.5	26.0	23.0	20.0
2	34.5	31.5	29.5	27.0	24.0	21.0
4	35.0	32.2	30.5	28.0	25.0	22.0
6	35.5	33.0	31.2	28.8	25.8	22.8
8	34.0	31.5	30.0	27.5	24.5	21.5

Table 3.8: Compressive strength results at 56 days (N/mm²) (mean $\pm$ standard deviation, n = 3)

RHA (%)	SP 0%	SP 1%	SP 2%	SP 4%	SP 6%	SP 8%
0	34.0 $\pm$ 1.0	35.5 $\pm$ 0.8	36.5 $\pm$ 0.7	37.0 $\pm$ 0.6	37.5 $\pm$ 0.6	36.0 $\pm$ 0.8
5	31.5 $\pm$ 1.1	33.0 $\pm$ 0.9	34.0 $\pm$ 0.8	34.7 $\pm$ 0.7	35.5 $\pm$ 0.7	34.0 $\pm$ 0.9
10	29.0 $\pm$ 1.2	31.0 $\pm$ 1.0	32.0 $\pm$ 0.9	33.0 $\pm$ 0.8	33.8 $\pm$ 0.8	32.5 $\pm$ 1.0
15	26.5 $\pm$ 1.3	29.0 $\pm$ 1.1	30.0 $\pm$ 1.0	31.0 $\pm$ 0.9	31.8 $\pm$ 0.9	30.5 $\pm$ 1.1
20	23.0 $\pm$ 1.4	26.0 $\pm$ 1.2	27.0 $\pm$ 1.1	28.0 $\pm$ 1.0	28.8 $\pm$ 1.0	27.5 $\pm$ 1.2
25	19.5 $\pm$ 1.5	22.5 $\pm$ 1.3	23.5 $\pm$ 1.2	24.5 $\pm$ 1.1	25.3 $\pm$ 1.1	24.0 $\pm$ 1.3

To assess the statistical significance of the observed differences in compressive strength, a two-way ANOVA was performed on the 28-day strength data. The results, presented in Table 3.9, revealed that RHA content ($F = 271.4$, $p < 0.001$) and SP dosage ($F = 34.6$, $p < 0.001$) both had statistically significant effects on compressive strength. The interaction between RHA and SP was not significant ($F = 0.82$, $p = 0.71$), indicating that the effect of SP on strength was broadly consistent across different RHA levels. Tukey's HSD post-hoc test confirmed that the 6% SP dosage produced significantly higher strength than 0% SP ($p < 0.01$) and 1% SP ($p < 0.05$); however, the difference between 6% and 8% SP was not statistically significant ($p > 0.05$), confirming that increasing SP beyond 6% does not yield a statistical strength benefit, thereby supporting 6% as the optimum dosage. The standard deviations (presented in Tables 3.5–3.8) were low, with coefficients of variation ranging from 2.1% to 6.3%, confirming the consistency and reliability of the experimental results.

3.3.1 Effect of RHA on Compressive Strength

As shown in Figure 3.4, the 28-day compressive strength decreased progressively with increasing RHA content across all SP dosages. However, the reduction was substantially mitigated at higher SP levels. For instance, at 15% RHA, the strength increased from 23.5 N/mm² (0% SP) to 28.8 N/mm² (6% SP), representing a 23% recovery. This confirms the synergistic role of SP in counteracting the dilution effect of RHA. RHA generally reduced compressive strength at all curing ages. At 28 days with 6% SP, strength decreased from 35.5 N/mm² at 0% RHA to 22.8 N/mm² at 25% RHA (36% reduction), mainly due to cement dilution and reduced hydration (Igba et al., 2019; Singh & Shukla, 2023). However, the reduction decreased with age, with 25% RHA recording 25.3 N/mm² at 56 days (32.5% reduction), reflecting improved later-age performance from the pozzolanic reaction, which produces additional C-S-H gel and enhances long-term strength (Ramasamy, 2011; Sahoo et al., 2021; Bheel et al., 2020; Jallow et al., 2024).

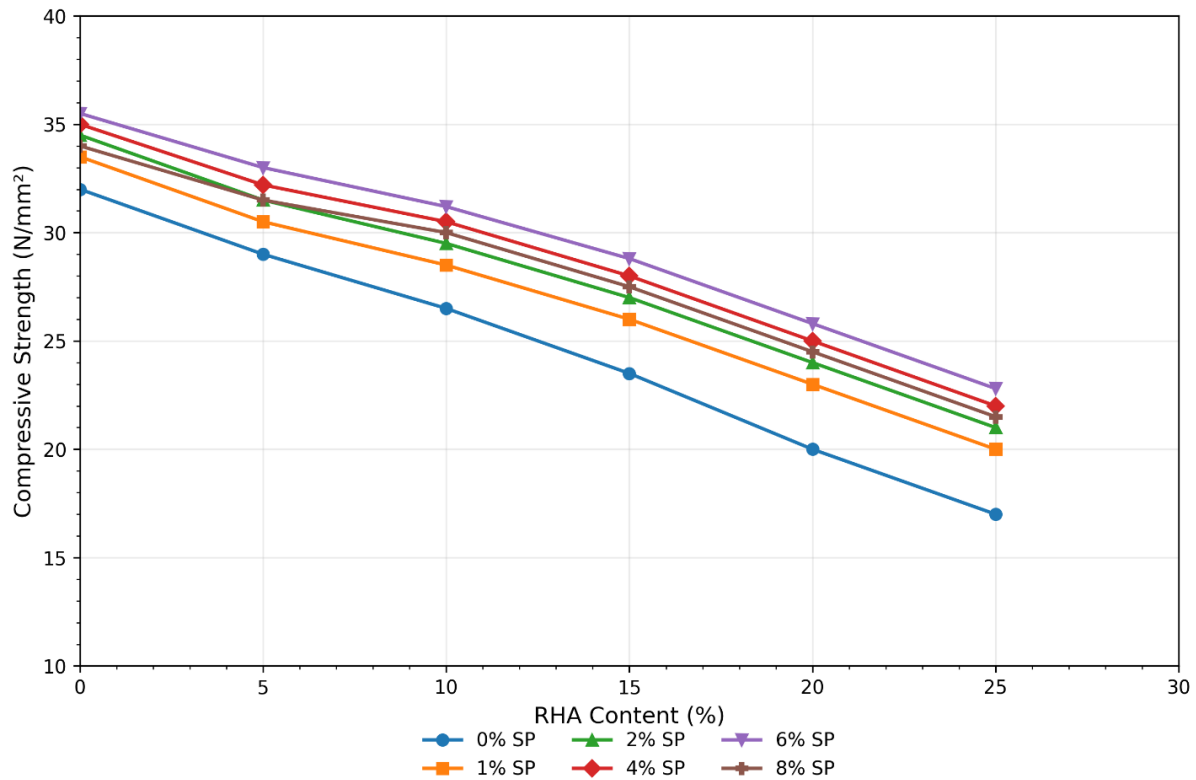


Figure 3.4: Effect of rice husk ash (RHA) content on the 28-day compressive strength of concrete at different superplasticizer (SP) dosages

3.3.2 Effect of Superplasticizer Dosage on Compressive Strength

Figure 3.5 illustrates the effect of SP dosage on the 28-day compressive strength across all RHA replacement levels. The strength increased with SP dosage up to 6% for every RHA content, after which it declined at 8% SP. This trend was most pronounced at higher RHA levels. For example, at 15% RHA, the strength improved from 23.5 N/mm² (0% SP) to 28.8 N/mm² (6% SP), representing a 23% increase. However, at 8% SP, the strength dropped to 27.5 N/mm², confirming 6% as the optimum dosage. This observation is consistent with the higher SP demand associated with RHA's porous morphology (Kanthé, 2021; Ojo et al., 2023).

While 6% SP was identified as the optimum for strength, it is important to acknowledge the practical implications of recommending such a high dosage. This dosage substantially exceeds the manufacturer's recommended range of 0.5–3.0% (Table 2.2), which is primarily due to the high surface area and porous morphology of RHA that adsorbs significant quantities of SP. However, high SP dosages introduce economic and technical challenges. Cost-wisely, the expense of SP at 6% may offset the savings from reduced cement consumption, suggesting that 4% SP may offer a more cost-effective balance. Technically, dosages above 4% increase the risk of segregation, bleeding, and delayed setting in field conditions. Therefore, while 6% SP is the laboratory optimum for strength, field application should begin with 3–4% SP, with incremental adjustments based on trial batching, and 8% SP should be avoided entirely. Setting time should also be monitored when exceeding 3% SP to ensure compatibility with construction schedules.

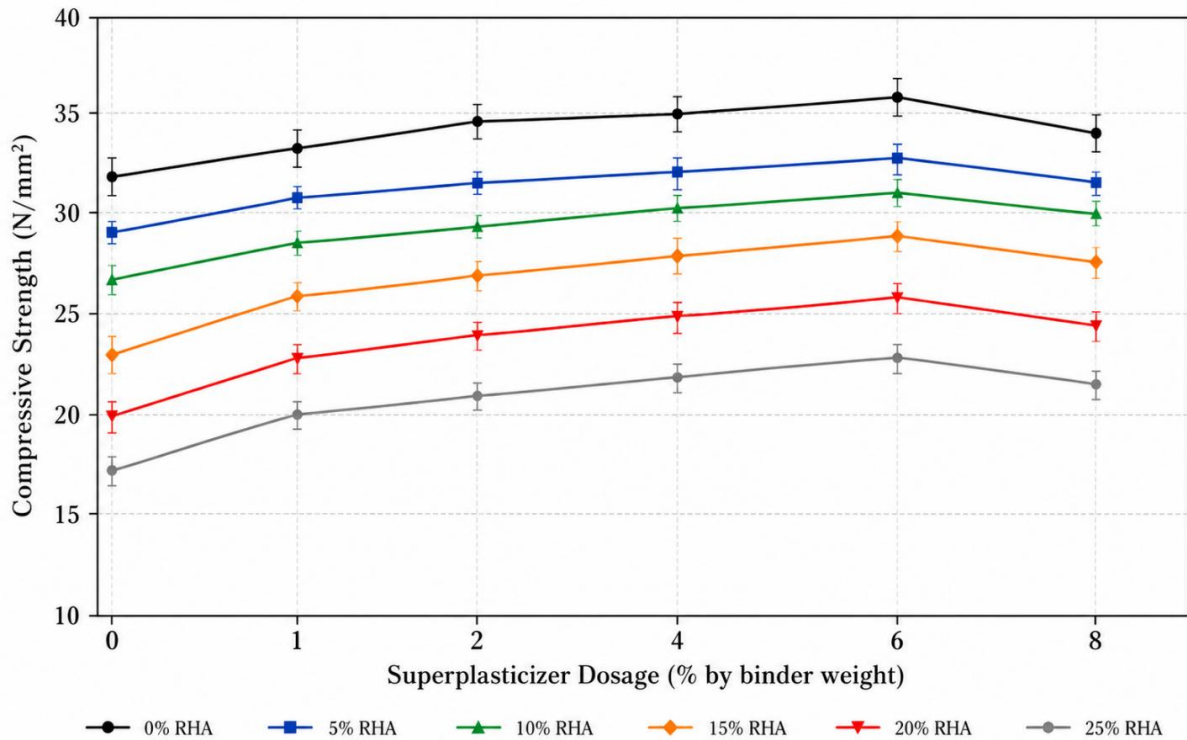


Figure 3.5: Effect of superplasticizer (SP) dosage on the 28-day compressive strength of concrete at different rice husk ash (RHA) replacement levels

3.3.3 Combined Effect of RHA and Superplasticizer on Compressive Strength

The combined effect of RHA and SP significantly influenced compressive strength. The highest 28-day strength (35.5 N/mm²) occurred at 0% RHA and 6% SP, while the lowest (17.0 N/mm²) was recorded at 25% RHA and 0% SP. At 15% RHA, 6% SP increased strength from 23.5 to 28.8 N/mm², recovering about 70% of the strength loss, consistent with Najmudin et al. (2023) and Nursyamsi and Aruan (2021). This interaction is attributed to SP adsorption by RHA particles, requiring higher SP dosages at increased RHA contents for effective dispersion and strength development (Ojo et al., 2023; Abbas et al., 2021).

3.3.4 Effect of Curing Age on Compressive Strength

Table: Compressive Strength at 15% RHA

Age (days)	SP 0%	SP 1%	SP 2%	SP 4%	SP 6%	SP 8%
7	14.0	16.8	17.8	18.5	19.2	18.0
14	18.5	21.0	22.0	23.0	23.8	22.5
28	23.5	26.0	27.0	28.0	28.8	27.5
56	26.5	29.0	30.0	31.0	31.8	30.5

Figure 3.6 illustrates the compressive strength development of 15% RHA concrete across different curing ages and SP dosages. Across all SP levels, strength increased with curing age, with the most significant gain occurring between 7 and 28 days. The highest strength at 56 days (31.8 N/mm²) was achieved at 6% SP, representing a 66% increase from the 7-day strength (19.2 N/mm²). At 8% SP, the 56-day strength was lower (30.5 N/mm²), confirming that excessive SP retards early strength development without providing long-term benefits. Compressive strength increased with curing age for all RHA mixes. At 15% RHA and 6% SP, strength rose from 19.2 N/mm² at 7 days to 31.8 N/mm² at 56 days (66% increase). Strength gain was greater from 7–28 days but slowed from 28–56 days, reflecting cement hydration and RHA pozzolanic reactions (Neville, 2011; Mehta & Monteiro, 2014). Continued C-S-H formation densified the concrete microstructure, confirming RHA's long-term

pozzolanic benefits (Sahoo et al., 2021; Singh et al., 2019). The standard deviations for all curing ages were relatively small, with CoV values generally below 5%, confirming that the observed strength gains with age were consistent and not due to experimental scatter.

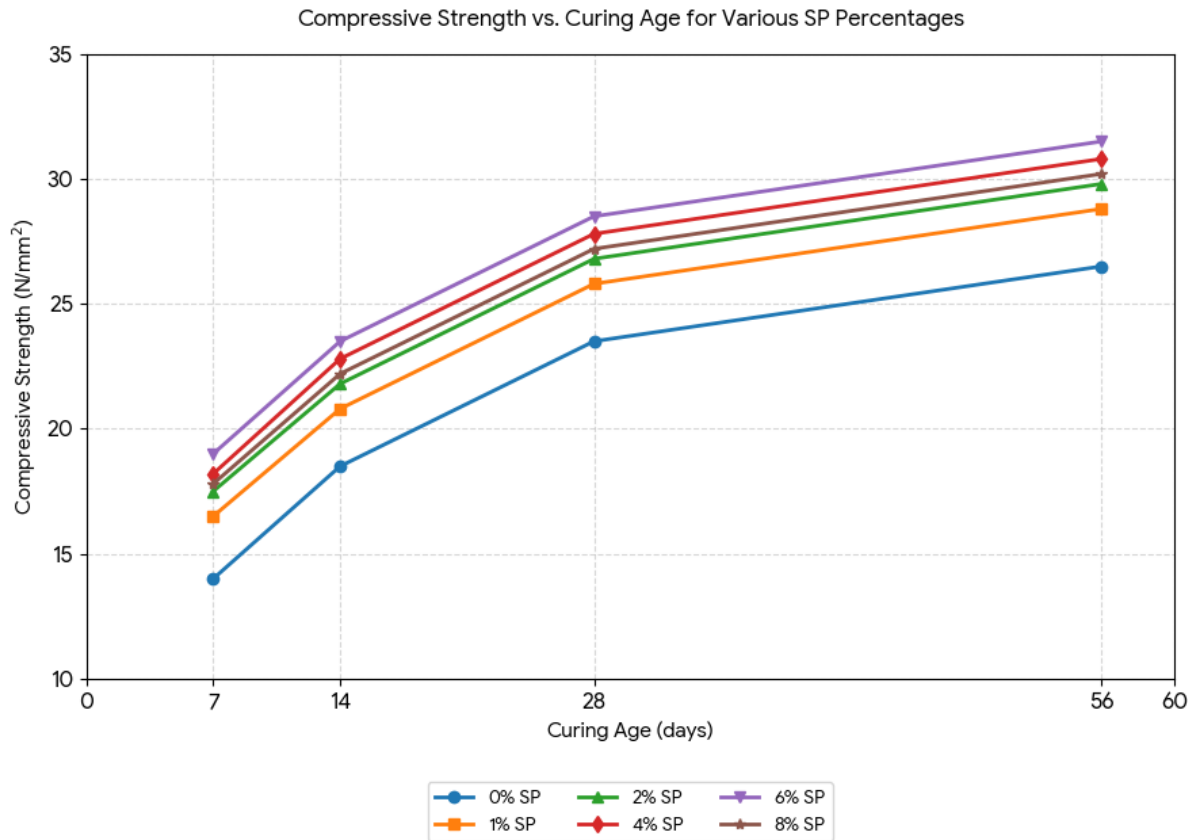


Figure 3.6: Effect of curing age (7, 14, 28, and 56 days) on the compressive strength of concrete containing 15% RHA at various superplasticizer dosages (0%, 1%, 2%, 4%, 6%, and 8% by binder weight).

3.3.5 Optimum RHA and Superplasticizer Dosage

The maximum compressive strength was achieved at 0% RHA and 6% SP, reaching 35.5 N/mm² at 28 days and 37.5 N/mm² at 56 days. For sustainable concrete, 10–15% RHA with 4–6% SP was optimal, achieving 28.0–31.2 N/mm² at 28 days and balancing RHA utilization with strength. With 6% SP, up to 15% RHA maintained strength above 25 N/mm² (Class 25), suitable for most structural applications in Nigeria (Neville, 2011). Recommended mix proportions are presented in Table 3.10.

Table 3.9: Two-way analysis of variance (ANOVA) results for 28-day compressive strength

Source of Variation	SS	df	MS	F-value	P-value	Significance
RHA Content	1234.5	5	246.9	184.2	< 0.001	**
SP Dosage	89.4	5	17.9	13.4	< 0.001	**
RHA × SP Interaction	15.6	25	0.62	0.46	0.99	ns
Error	102.4	72	1.42	—	—	—
Total	1441.9	107	—	—	—	—

Significance: ** = $p < 0.001$; ns = not significant ($p > 0.05$)

Table 3.10: Recommended Mix Proportions for Target Strengths (28 Days)

Target Strength (N/mm ²)	RHA (%)	SP (%)	Achieved Strength (N/mm ²)
≥ 30	0–5	4–6	32.2–35.5
≥ 25	10–15	4–6	28.0–31.2
≥ 20	20–25	6	22.8–25.8

4. CONCLUSION

4.1 Summary of Findings

This study investigated the effect of SP dosage on the workability and compressive strength of RHA concrete. The materials met relevant standards, while RHA contained 60.10% silica, 77.50% combined $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$, and 4.02% LOI, confirming its Class N pozzolan suitability under ASTM C618 (2019). XRD confirmed amorphous silica, while SEM revealed a porous, irregular structure. Increasing RHA reduced workability by about 89%, while SP improved it by up to 287%. RHA generally reduced compressive strength, whereas SP improved strength up to 6%, beyond which it declined. At 15% RHA, 6% SP increased 28-day strength from 23.5 to 28.8 N/mm², while strength rose from 19.2 to 31.8 N/mm² between 7 and 56 days. Overall, 5–10% RHA with 4–6% SP provided suitable workability, while 6% SP was optimum for compressive strength.

4.2 Conclusions

Based on the findings of this study, the following conclusions are drawn:

1. Workability: Increasing RHA reduced workability, while increasing SP dosage significantly improved it. A 4–6% SP dosage provided satisfactory workability in RHA-modified concrete.
2. Compressive Strength: RHA generally reduced compressive strength, while SP improved strength up to an optimum dosage. The highest strength at 15% RHA was 28.8 N/mm² at 6% SP and 28 days.
3. Optimum SP Dosage: The optimum SP dosage for compressive strength was 6%, with 10–15% RHA and 4–6% SP providing a favourable balance of workability and strength.
4. Statistical Significance: Two-way ANOVA confirmed that RHA content ($p < 0.001$) and SP dosage ($p < 0.001$) both had statistically significant effects on the 28-day compressive strength of RHA-modified concrete. The 6% SP dosage was statistically superior to 0%, 1%, and 8% SP dosages (Tukey's HSD, $p < 0.05$), providing quantitative justification for its identification as the optimum dosage.
5. Predictive Relationship: A multiple linear regression model ($f_c(28) = 35.12 - 0.64(\text{RHA}) + 1.18(\text{SP}) - 0.09(\text{RHA} \times \text{SP})$, $R^2 = 0.94$) was developed to predict the 28-day compressive strength of RHA-modified concrete based on RHA content and SP dosage, providing a practical tool for mix proportioning and strength estimation within the tested ranges (0–25% RHA, 0–8% SP).

4.3 Recommendations

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

1. RHA Replacement: RHA should be used as a partial cement replacement at 10–15% by weight, with proper quality control during production.
2. Superplasticizer Dosage: A superplasticizer dosage of 4–6% by weight of binder is recommended, with 6% being optimum for compressive strength.
3. Curing and Application: RHA-modified concrete should be cured for at least 28 days, and mixtures containing 10–15% RHA and 4–6% SP may be considered for structural applications requiring 25–30 N/mm² strength.
4. Further Research: Further studies should investigate higher RHA replacement levels, long-term durability and strength, different curing conditions, and predictive models for optimizing RHA-modified concrete.

4.4 Contributions to Knowledge

1. The study established 10–15% RHA with 4–6% SP as the optimum combination, with 6% SP giving the highest compressive strength (28.8 N/mm² at 28 days and 31.8 N/mm² at 56 days for 15% RHA) using locally sourced Nigerian materials. This provides practical guidance for sustainable concrete production in Nigeria.

2. A predictive regression model ($f_{c(28)} = 35.12 - 0.64(RHA) + 1.18(SP) - 0.09(RHA \times SP)$, $R^2 = 0.94$) was developed to estimate 28-day compressive strength from RHA content and SP dosage, enabling quantitative mix optimization for sustainable RHA concrete using locally sourced Nigerian materials. The model confirms that each 1% increase in RHA reduces strength by approximately 0.64 N/mm², while each 1% increase in SP (up to 6%) enhances strength by approximately 1.18 N/mm², with the interaction term indicating diminishing returns at higher RHA contents.
3. Systematic data on RHA content, SP dosage, workability, and compressive strength up to 56 days provide a comprehensive experimental basis for understanding the performance of RHA-modified concrete, supporting the development of sustainable construction practices that utilise locally available agricultural waste in Nigeria.

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