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Effect of Sawdust Ash on the Properties of Concrete Produced with Portland Limestone Cement Grades 32.5N and 42.5R

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ABSTRACT

The search for sustainable and resource-efficient construction materials has increased interest in waste-derived materials as partial cement substitutes. This study investigated the effects of sawdust ash (SDA) on concrete produced with Portland limestone cement grades 32.5N and 42.5R. SDA replaced cement at 0%, 5%, 10%, 15%, and 20% by mass using a 1:2:4 mix ratio and water-to-cementitious-material ratio of 0.58. For each cement type, 50 cubes and 50 cylindrical specimens were produced and cured for 28 and 56 days. A two-way ANOVA assessed the effects of SDA level and cement type on 56-day compressive strength using 10 treatment combinations with five independent replicates each. The specific gravities of river sand, crushed granite, and SDA were 2.53, 2.54, and 2.05, respectively. Slump decreased from 53 to 20 mm for 32.5N concrete and from 48 to 22 mm for 42.5R concrete as SDA increased from 0% to 20%. Density similarly decreased, while water absorption increased. At 56 days, compressive strength of 32.5N concrete increased from 25.60 N/mm² at 0% SDA to 26.80 N/mm² at 5%, while 42.5R concrete increased from 26.90 to 31.90 N/mm². Further SDA addition reduced strength. The highest 56-day split tensile strengths were 2.90 N/mm² for 32.5N and 3.80 N/mm² for 42.5R at 5% SDA. Two-way ANOVA showed that SDA content, cement type, and their interaction significantly affected compressive strength ($p < 0.001$). The study concluded that, within the investigated replacement levels, 5% SDA replacement provided optimum strength performance, particularly with 42.5R cement, and shows potential as a partial cement replacement.

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INTRODUCTION

Concrete is one of the most widely used construction materials in the world because of its availability, versatility, durability and relatively high compressive strength (Alexander et al., 2017). It is commonly produced by combining cement, fine aggregate, coarse aggregate and water in appropriate proportions (Tunio et al., 2019). The performance of concrete depends on the properties and proportions of its constituent materials, the water-cement ratio, method of mixing and compaction, curing conditions, age and the characteristics of the cement used (Surahyo et al. 2019). Portland limestone cement has become increasingly common in construction because of its availability and potential environmental advantages compared with conventional Portland cement (Akerele et al., 2025; Gupta et al., 2020).

Cement is the principal binding material in conventional concrete (Soomro et al., 2022). However, the manufacture of cement requires substantial quantities of raw materials and energy and is associated with significant carbon dioxide emissions (Mohamad et al., 2022; Naqi & Jang, 2019). The increasing demand for cement resulting from rapid urbanisation, population growth and infrastructure development has consequently generated interest in alternative supplementary cementitious materials that can partially replace cement without compromising the required engineering properties of concrete (Wasiu et al., 2026; Ahmed, 2024). Agricultural and industrial wastes have received considerable attention as potential supplementary cementitious materials (Thomas et al., 2021). Their use in concrete provides an opportunity to reduce waste disposal problems, conserve natural resources and decrease dependence on cement (Naik, 2020; Vishwakarma & Ramachandran, 2018). One such waste material is sawdust, which is generated in large quantities from sawmills, furniture workshops and wood-processing activities. Sawdust is often disposed of by open burning or uncontrolled dumping, practices that can contribute to environmental pollution and other health concerns (Udokpoh & Nnaji, 2023; Nnaji & Udokpoh, 2022; Oguntoke et al., 2019). When sawdust is subjected to control burning and the resulting residue is properly processed, it produces sawdust ash (SDA) (Mbaraga, 2021). Sawdust ash contains appreciable quantities of silica and other oxides that may contribute to pozzolanic reactions when used in cementitious systems (Onyango et al., 2026a; Onyango et al., 2026b; Kola-Aderoju & Ibrahim, 2026) The pozzolanic activity of SDA depends on factors such as the type of wood, combustion temperature, duration of burning, fineness, chemical composition and method of processing (Onyango et al., 2026b). When incorporated into concrete as a partial replacement for cement, SDA can alter the fresh and hardened properties of the resulting concrete (Fahad et al., 2025; Ayuba et al., 2022ab). The use of SDA in concrete may influence properties such as workability, slump, density, water absorption, compressive strength and tensile strength (Fapohunda et al., 2018). Because SDA particles can be porous and possess relatively high surface area, increasing SDA content also increase water demand and consequently affect workability (Harriet et al., 2021). At suitable replacement levels, however, the silica-rich components of SDA may react with calcium hydroxide produced during cement hydration to form additional calcium silicate hydrate

(C-S-H) (Adagba, 2026), which is one of the principal binding products responsible for strength development in concrete. The performance of SDA also depends on the type and strength class of cement with which it is combined. Dangote 3X PLC 42.5R and Dangote Falcon PLC 32.5N are Portland limestone cements with different strength classifications and performance characteristics (Danchuwa et al. 2022). Grade 42.5R is classified as a higher-strength rapid-hardening cement, while Grade 32.5N is a lower strength-class cement with normal early-strength development (Fapohunda et al., 2020; Joel & Mbapuun, 2016). Differences in cement composition, fineness, hydration characteristics and strength development may therefore affect the manner in which SDA interacts with each cement. Comparing SDA concrete produced with these two cement types is important because the same percentage replacement of cement by SDA may not produce identical results in both systems. A replacement level that performs satisfactorily with one cement may produce a different response with another. Existing studies (Iro et al., 2022; Meko, & Ighalo, 2021; Gwarah et al., 2019; Raheem & Ige, 2019; Raheem et al., 2012; Udoeyo and Dashibil, 2002) have established that SDA can act as a supplementary cementitious material and have generally examined its effect on concrete produced with a single cement type or strength class. However, it remains unclear whether the same SDA replacement level produces comparable fresh, physical and mechanical performance when combined with cements of different strength classes, since differences in clinker composition, fineness and hydration behaviour between PLC 32.5N and PLC 42.5R may alter the response of concrete to SDA incorporation. This comparative behaviour has not been adequately established in the literature and constitutes the specific gap addressed by this study. Therefore, this study comparatively evaluates the fresh, physical and mechanical properties of SDA-modified concrete produced with PLC 32.5N and PLC 42.5R at replacement levels of 0-20%.

MATERIALS AND METHODS

Materials

Cement

Dangote Portland limestone cement (PLC) of strength classes 42.5R and 32.5N was used as the principal cementitious material. The two cement types were obtained from a Dangote Cement depot at North Bank Market, Makurdi, Benue State, Nigeria.

Sawdust Ash

Sawdust obtained from sawmill at Wurukum Makurdi Benue State, Nigeria.

Fine Aggregate

Natural river sand obtained from the River Benue, Benue State, Nigeria, was used as the fine aggregate.

Coarse Aggregate

Crushed granite with a maximum nominal particle size of 20 mm was used as the coarse aggregate. The granite was obtained from Court 5, North Bank, Makurdi, Benue State, Nigeria.

Water

Potable water obtained from Joseph Sarwuan Tarka University (JOSTUM), Makurdi, was used for both concrete mixing and curing. The water was clean and free from visible contaminants and was considered suitable for concrete production.

Methods

Preparation of Sawdust Ash

Sawdust obtained from sawmill at Wurukum Makurdi Benue State, Nigeria was used for the production of sawdust ash (SDA). The collected sawdust was manually sorted to remove visible impurities such as stones, soil, plastics, metallic materials and other foreign matter. It was subsequently spread on a clean surface and air-dried to reduce its moisture content. The dried sawdust was placed in a clean metallic container and subjected to controlled combustion of 650 ^{0}C for 1 hour using a muffle furnace (Electric SXL- 1030 Series Muffle Furnace) at the Mechanical Engineering Laboratory, Joseph Sarwuan Tarka University Makurdi Benue State until it was substantially converted to ash. The resulting ash was allowed to cool to room temperature before further processing. The cooled ash was pulverised using a mechanical grinder to break down lumps and agglomerated particles. The pulverised material was then passed through a 75-µm sieve to obtain a relatively fine and uniform sawdust ash. The fraction passing through the sieve was collected and stored in clean, dry and airtight containers to prevent moisture absorption and contamination before use.

Concrete Production

Concrete mixtures were prepared using a nominal mix proportion of 1:2:4 for cementitious material, fine aggregate, and coarse aggregate, respectively, with a constant water-to-cementitious-material ratio of 0.58, as presented in Table 1. This nominal proportion is a conventional volumetric/mass ratio widely used for normal-grade structural concrete in the study area and was adopted to provide a common baseline mix against which the comparative effect of SDA replacement and cement strength class could be isolated, rather than to target a specific design strength class. Dangote 3X PLC 42.5R and Dangote Falcon 32.5N cements were investigated separately.

Table 1: Mix Proportions of SDA-Modified Concrete

SDA replacement (%)	Cement (kg)	SDA (kg)	Sand (kg)	Granite (kg)	Water (kg)
0	327.23	0.00	654.45	1,308.90	189.79
5	310.86	16.36	654.45	1,308.90	189.79
10	294.50	32.72	654.45	1,308.90	189.79
15	278.14	49.08	654.45	1,308.90	189.79
20	261.78	65.45	654.45	1,308.90	189.79

For each cement type, sawdust ash (SDA) was incorporated as a partial replacement for cement at 0%, 5%, 10%, 15%, and 20% by mass. The 0% SDA mixture served as the control, while the other replacement levels constituted the SDA-modified concrete mixtures. A total of 50 cube specimens and 50 cylindrical specimens were produced for each cement type, giving 100 specimens per cement type and 200 specimens for the two cement types combined. This corresponds to five cube specimens and five cylindrical specimens for each combination of SDA replacement level (0, 5, 10, 15 and 20%) and curing age (28 and 56 days), for each cement type. For each cube-specimen set, non-destructive density and water absorption measurements were first taken. The required quantities of cement, SDA, fine aggregate, coarse aggregate, and water were measured according to the specified mix proportion. The cement and SDA were first blended thoroughly to obtain a relatively uniform cementitious material before the fine and coarse aggregates were added. The constituents were mixed thoroughly, after which the measured quantity of water was gradually introduced and mixing continued until a homogeneous concrete mixture with uniform distribution of the constituent materials was obtained. Prior to casting, the internal surfaces of the moulds were cleaned and lightly coated with oil to facilitate easy removal of the hardened specimens. The fresh concrete was placed into 150 × 150 × 150 mm cube moulds and 150 × 300 mm cylindrical moulds in three equal layers. Each layer was adequately compacted to remove entrapped air. The moulds were filled and the specimen's surface were smoothened. After casting, the specimens were left undisturbed in the moulds for approximately 24 hours before demoulding. The specimens were cured for the specified periods of 28 and 56 days respectively. The specimens were removed and prepared for the relevant concrete property tests. These procedures were conducted in accordance with the applicable provisions of BS EN 12390-2:(2019).

Experimental Method

Chemical Analysis

Samples of the Dangote 3X PLC 42.5R cement, Dangote Falcon 32.5N cement and sawdust ash were collected and prepared for chemical analysis. The chemical constituents of the materials were determined at the laboratory of the Department of Chemical Engineering, Ahmadu Bello University (ABU) Zaria Kaduna, using X-ray fluorescence (XRF) analysis (Shimadzu EDX-702HS), which was used to determine the major oxide constituents (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, SO_3, Na_2O, K_2O, MnO and P_2O_5), while Atomic Absorption Spectrophotometry (AAS) (Shimadzu AA-7000) was used to cross-check selected elemental concentrations. Samples were oven-dried, pulverised and homogenised prior to analysis in accordance with the standard operating procedures of the laboratory.

Setting Time and Soundness

The setting time and soundness of the cement samples were determined in accordance with BS EN 196-3:(2016). The tests were conducted to establish the initial and final setting characteristics of the cement used.

Sieve Analysis

Sieve analysis was conducted on the fine and coarse aggregates to determine their particle-size distribution and grading characteristics. A series of standard sieves was used to separate the aggregate particles according to size. The procedure was conducted in accordance with BS 812-103 :(1990).

Specific Gravity Test

The specific gravity of the aggregates was determined to establish the ratio of the density of the aggregate particles to the density of an equivalent volume of water. The specific gravity test was carried out in accordance with the method described in BS EN 1097-6:(2022). The specific gravity was calculated using equation (1).

$$Gs = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)} \quad (1)$$

Where, Gs = specific gravity, M_1 = weight of empty flask, (g), M_2 = weight of empty flask + weight of the sample, (g), M_3= weight of empty flask + weight of the sample + water, (g), M_4 = weight of empty flask + water, (g)

Slump Test

The slump test was conducted to determine the consistency and workability of the fresh concrete. The test was carried out immediately after mixing, before significant loss of moisture or commencement of setting. The procedure was conducted in accordance with BS EN 12350-2 :(2019). The measured slump values were used to assess the effect of increasing SDA replacement on the workability of the fresh concrete.

Water Absorption Test

The water absorption test was conducted to determine the amount of water absorbed by the hardened concrete cube specimens. The test was carried out in accordance with BS 1881-122 :(1983). Water absorption was calculated using equation (2):

$$W_a = \frac{W_2 - W_1}{W_1} \times 100 \quad (2)$$

W_a = Water absorption (%), W_1 = weight of oven dried cube (kg), W_2 = weight of wet cube (kg)

Density of Concrete Test

The concrete density was determined by dividing the mass of each cube by its volume as specified by BS EN 12350-6 :(2019). The volume of each specimen was calculated using equation (3).

$$\text{Density } (\rho \text{ in kg}/m^3) = \frac{\text{mass of cube (kg)}}{\text{volume of cube } (m^3)} \quad (3)$$

Compressive Strength Test

The compressive strength test was conducted to determine the load-bearing capacity of the hardened concrete. The cured 150 × 150 × 150 mm cube specimens were tested using a compression testing machine at the specified curing ages. The test was conducted in accordance with BS EN 12390-3 :(2019). The compressive strength was calculated using equation (4).

$$\text{Compresive Strength } (\sigma \text{ in N/mm}^2) = \frac{\text{crushing load of cube (N)}}{\text{Area of cubes (mm}^2)} \quad (4)$$

Splitting Tensile Strength

The splitting tensile strength test was conducted in accordance with the provision of BS EN 12390-6:(2023) using universal testing machine with accuracy of ± 1% of test force. In order to obtain the splitting tensile strength (Ts), the expression in equation (5) was used.

$$Ts = \frac{2P}{\pi l d} \quad (5)$$

Where: Ts is the splitting tensile strength (N/mm^2), P is the maximum applied load (in Newtons) by the testing machine, l is the length of the specimen (mm), and d is the diameter of the specimen (mm).

Statistical Analysis

The experimental results were subjected to statistical analysis to determine whether the observed differences in concrete properties were statistically significant. A two-way analysis of variance (ANOVA) was employed to examine the effects of sawdust ash replacement level (five levels: 0, 5, 10, 15 and 20%) and cement type (two levels: PLC 32.5N and PLC 42.5R) on the 56-day compressive strength, giving ten cells with five independent replicate specimens per cell. The replicate specimens within each cell were tested independently and treated as independent observations for the analysis. The analysis also examined the interaction effect between sawdust ash replacement level and cement type. Curing age was analysed separately by direct comparison of the 28- and 56-day means for each mix, rather than being incorporated as a third factor in the reported factorial model, because the primary objective of the ANOVA was to isolate the effects of SDA content and cement type at the design strength age. Prior to the analysis, the normality of the residuals and the homogeneity of variance across cells were checked and found to be reasonably satisfied, supporting the validity of the ANOVA assumptions. Where a significant overall effect was found, simple-effects comparisons were used to examine differences between SDA replacement levels within each cement type. Statistical significance was evaluated at the 5% probability level ($\alpha = 0.05$). Where the calculated *p*-value was less than 0.05, the corresponding effect was considered statistically significant.

RESULTS AND DISCUSSION

Oxide Composition Tests

Table 2 presents the oxide composition of sawdust ash (SDA), Dangote PLC 42.5R and Dangote Falcon 32.5N cement. The SDA recorded a high SiO_2 content of 67.20%, compared with 22.74% and 28.79% for Dangote PLC 42.5R and Dangote Falcon 32.5N, respectively. In contrast, the CaO content of SDA was relatively low (9.98%) compared with 58.58% for Dangote PLC 42.5R and 54.17% for Dangote Falcon 32.5N. The high silica content indicates the potential of SDA to exhibit pozzolanic activity when used as a partial cement replacement, as reported in previous studies on sawdust ash (Elinwa & Mahmood, 2002; Udoeyo & Dashibil, 2002). The combined content of the major pozzolanic oxides in SDA was 73.55% (SiO_2 + Al_2O_3 + Fe_2O_3). This is consistent with Elinwa & Mahmood (2002) and Raheem & Ige (2019), who reported high combined contents of these oxides in sawdust ash and identified its potential as a supplementary cementitious material. The SDA contained 4.09% Al_2O_3 and 2.26% Fe_2O_3, which contributed to its total pozzolanic oxide content. However, the LOI of SDA was 11.94%, considerably higher than those of Dangote PLC 42.5R (3.25%) and Dangote Falcon 32.5N (3.31%). The relatively high LOI may indicate the presence of unburnt carbon and volatile materials, which can influence the water demand and workability of concrete. Udoeyo & Dashibil (2002) and Raheem & Ige (2019) have noted that the chemical properties of sawdust ash depend strongly on the source of the wood and the conditions under which the ash is produced. Comparatively, Dangote PLC 42.5R contained higher CaO (58.58%), while Dangote Falcon 32.5N contained higher SiO_2 (28.79%). These differences in oxide composition may contribute to variations in strength development and the response of the two cement types to SDA incorporation. However, the results indicate that the SDA is rich in silica and possesses appreciable pozzolanic potential, supporting its use as a partial cement replacement. This agrees with previous studies which reported that moderate sawdust ash replacement can produce satisfactory concrete properties, whereas excessive replacement may reduce strength due to dilution of the cementitious material (Elinwa & Mahmood, 2002; Udoeyo & Dashibil, 2002).

Table 2: Chemical Composition of Sawdust Ash and Portland Limestone Cements

Compound Name	Chemical Formula	Sawdust Ash (%)	Dangote 3X PLC 42.5 (%)	Dangote Falcon 32.5N Cement (%)
Calcium Oxide	CaO	9.98	58.58	54.17
Silicon Dioxide (Silica)	SiO_2	67.20	22.74	28.79
Aluminium Oxide (Alumina)	Al_2O_3	4.09	6.08	6.78
Iron(III) Oxide (Ferric Oxide)	Fe_2O_3	2.26	2.00	1.81
Sulfur Trioxide	SO_3	0.45	4.69	6.34
Magnesium Oxide	MgO	5.80	5.28	4.07
Sodium Oxide	Na_2O	0.08	0.33	0.00
Potassium Oxide	K_2O	0.11	1.91	2.69
Manganese(II) Oxide	MnO	0.01	0.10	0.04
Phosphorus Pentoxide	P_2O_5	0.48	0.26	0.15
Loss on Ignition	LOI	11.94	3.25	3.31

Particle-Size Distribution

Figures 1 and 2 show the particle-size distribution curve for the river sand and granite. For the river sand, Cu was 2.51 and Cc was 1.20. Since Cu is less than 4, the sand is classified as poorly graded. Similarly, the granite recorded a Cu of 1.60 and Cc of 1.10, indicating a poorly graded aggregate. These results shows that both materials contain a relatively narrow range of particle sizes, which may affect particle packing and the void structure of the concrete. The findings are consistent with Neville (2011), who noted that poorly graded aggregates contain particles concentrated within a limited size range and generally produce greater voids than well-graded aggregates. Kebede (2020) also reported that aggregate grading significantly influences workability, density and strength of concrete because of its effect on particle packing and paste requirement.

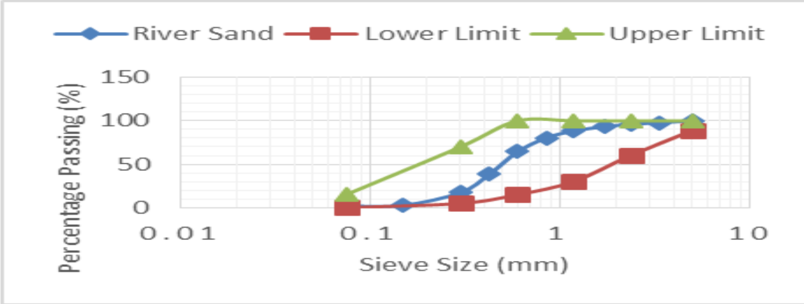

Figure 1: Grading Curve for River Sand

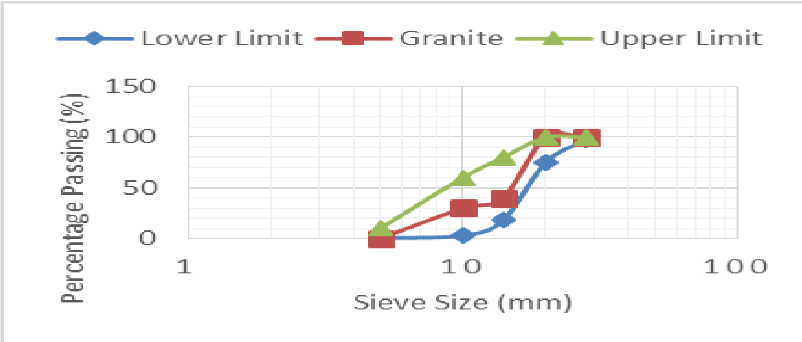

Figure 2: Grading Curve for Crushed Granite

Specific Gravity of Constituent Materials

Table 3 shows the average specific gravity of the constituent materials. River sand and crushed granite recorded specific gravities of 2.53 and 2.54, respectively, while sawdust ash recorded the lowest value of 2.05. The relatively higher specific gravities of the aggregates indicate that they possess greater particle density than sawdust ash, whereas the lower value for sawdust ash shows its lightweight and porous nature. This result is similar with Elinwa & Iro (2014) reported sawdust ash specific gravities of 2.29 and 2.25, compared with higher values for fine and coarse aggregates (Babafemi & Akinola, 2021). The lower specific gravity of sawdust ash implies that a greater volume of ash would occupy the same mass of material compared with cement or natural aggregates. Consequently, increasing sawdust ash content may influence the density and packing characteristics of the resulting concrete.

Table 3: Specific Gravity of the Constituent Materials

Parameter	River sand		Sawdust Ash		Crushed Granite	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Mass of pycnometer, W_1 (g)	37.11	39.50	39.2	38.7	38.81	39.40
Mass of pycnometer and dry soil, W_2 (g)	586.95	343.47	629.3	531.7	592.72	586.55
Mass of pycnometer, dry soil and water, W_3 (g)	1025.65	885.85	1004.55	954.81	1034.70	1029.83
Mass of pycnometer and water, W_4 (g)	698.79	698.79	702.3	702.3	698.79	698.79
$W_2 - W_1$ (g)	549.84	303.97	590.1	493.0	553.91	547.15
$W_4 - W_1$ (g)	661.68	659.29	663.1	663.6	659.98	659.39
$W_3 - W_2$ (g)	438.70	542.38	375.25	423.11	441.98	443.28
$(W_4 - W_1) - (W_3 - W_2)$ (g)	222.98	116.91	287.85	240.49	218.00	216.11
$G_s = \frac{W2 - W1}{(W4 - W1) - (W3 - W2)}$	2.466	2.600	2.050	2.050	2.541	2.532
Average specific gravity	2.53		2.05		2.54	

Consistency Test

Figure 3 shows consistency test result for Dangote Falcon PLC 32.5N and Dangote 3X PLC 42.5R.

The results show that Dangote Falcon PLC 32.5N and Dangote 3X PLC 42.5R recorded standard consistency values of 30.0% and 33.0%, respectively. The higher water requirement of the 42.5R cement indicates a slightly greater demand for water to achieve standard consistency. Similar variations in cement consistency have been reported by Ogunbiyi et al. (2017), where Dangote Falcon PLC 32.5N and 42.5N recorded consistency values of 28.8% and 37.4%, respectively.

Setting Times of Cement

Figure 4 shows the setting times of cement grades. The initial setting times were 168 minutes for Dangote Falcon PLC 32.5N and 105 minutes for Dangote 3X PLC 42.5R, while the final setting times were 487 and 369 minutes, respectively. Thus, the Dangote 3X PLC 42.5R cement exhibited faster setting than the Dangote Falcon PLC 32.5N cement. This behaviour agrees with the characteristics of Dangote 3X PLC 42.5R cement, which is classified for rapid early-strength development.

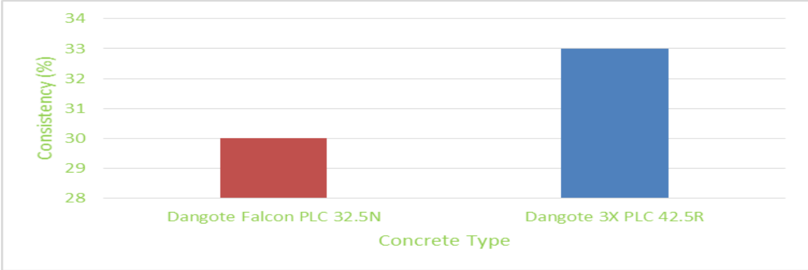

Figure 3: Consistency Test Result for Cement Grades.

The result is also consistent with Joshua et al. (2019) in which Dangote 3X PLC 42.5R cement generally exhibited shorter setting times than lower-strength cement classes. However, the results indicate that both cements possess appreciable setting characteristics, although Dangote 3X PLC 42.5R is more suitable where faster setting and early strength development are desirable.

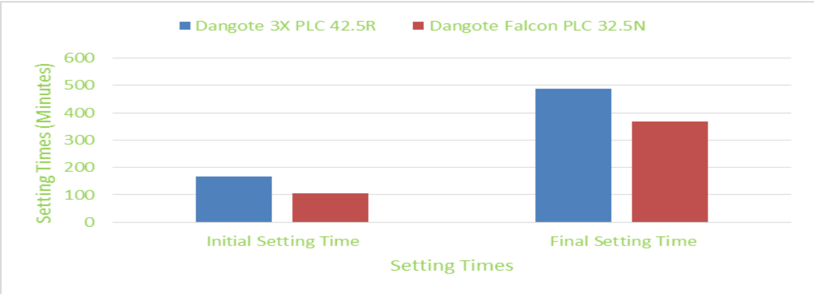

Figure 4: Setting Times of Cement Grades.

Slump Test

Figure 5 shows slump test results of concrete produced. The result shows that the slump generally decreased with increasing sawdust ash (SDA) replacement for both cement grades. For Dangote Falcon PLC 32.5N, the slump decreased from 53 mm at 0% SDA to 20 mm at 20% SDA, while for Dangote 3X PLC 42.5R it decreased from 48 mm to 22 mm over the same replacement range. The decrease in slump indicates a reduction in workability as SDA content increased. This can be attributed to the relatively fine and porous nature of SDA, which increases its surface area and water demand, thereby reducing the free water available to lubricate the cement and aggregate particles.

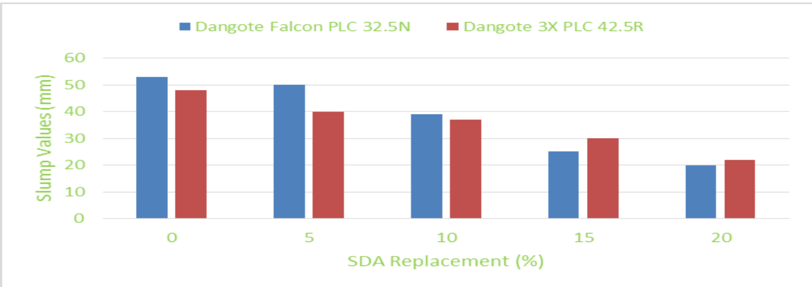

Figure 5: Slump Test Results of Concrete Produced

Consequently, higher SDA replacement levels require additional water or chemical admixtures to maintain the desired workability. The findings are similar with Raheem et al. (2012), who reported that slump and compacting factor decreased progressively with increasing SDA replacement from 5% to 25%, indicating that SDA concrete becomes less workable at higher replacement levels. Similarly, Gwarah et al. (2019) found that slump decreased as SDA content increased from 0% to 30%, and concluded that approximately 5–10% replacement could still provide satisfactory concrete performance. Elinwa and Mahmood (2002) also reported an adverse effect of SDA replacement on concrete workability and identified 10% SDA as giving a desirable balance between workability and strength. The result is further supported by Meko & Ighalo (2021) who reported that concrete workability decreased as SDA replacement increased from 0% to 20%. Therefore, the reduction in slump shows that increasing SDA replacement reduces the workability of fresh concrete, irrespective of whether Dangote Falcon PLC 32.5N or Dangote 3X PLC 42.5R cement is used.

Density of Concrete

Figure 6 shows density of concrete for the cement grade. The result shows that the density of concrete decreased progressively with increasing sawdust ash (SDA) replacement for both cement grades. For Dangote Falcon PLC 32.5N, the density decreased from 2370.4 kg/m³ at 0% SDA to 2084.0 kg/m³ at 20% SDA. Similarly, concrete produced with Dangote 3X PLC 42.5R decreased from 2429.8 kg/m³ to 2103.7 kg/m³. At all replacement levels, the Dangote 3X PLC 42.5R concrete recorded a slightly higher density than the Dangote Falcon PLC 32.5N concrete.

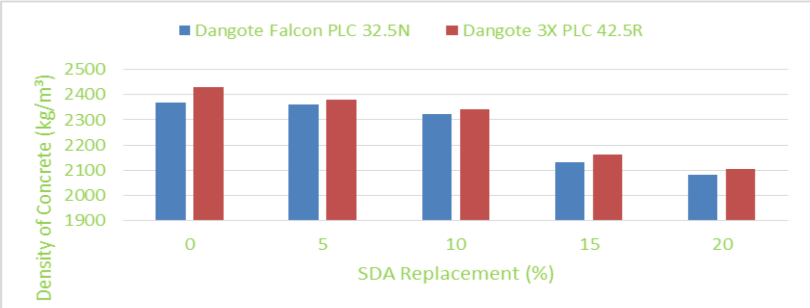

Figure 6: Density of Concrete for the Cement Grades

The reduction in density with increasing SDA content can be attributed primarily to the lower specific gravity of SDA compared with cement and conventional aggregates. In this study, SDA had a specific gravity of 2.05, compared with 2.53 for river sand and 2.54 for crushed granite. Consequently, replacing part of the cement with the lighter SDA reduces the mass of solid material within a given concrete volume, resulting in lower concrete density. The greater reduction observed at 15–20% replacement suggests that the influence of the lightweight ash becomes more pronounced as its proportion increases. The finding agrees with Elinwa and Mahmood (2002), who investigated sawdust ash as a cement replacement and reported that increasing SDA replacement affected the physical properties of concrete, with SDA exhibiting pozzolanic characteristics. Chowdhury et al. (2015) also reported that bulk density decreases as the proportion of wood ash increases, attributing the reduction to the lower specific gravity of wood ash compared with Portland cement. However, Onyechere (2022) reported that both the workability and density of concrete decreased as SDA content increased. Similarly, Ibeabuchi (2025) found that increasing SDA reduced the density of the resulting concrete, confirming the lightweight effect of the ash. However, the results indicate that SDA can be used to produce relatively lighter concrete, with the reduction in density becoming more substantial at higher replacement levels. Among the cement grades, Dangote 3X PLC 42.5R produced denser concrete than Dangote Falcon PLC 32.5N at all SDA replacement levels, although both followed the same general decreasing trend.

Water Absorption Test

Figure 7 shows that water absorption of concrete cement grades containing sawdust. For Dangote Falcon 32.5N, water absorption increased from 2.6% at 0% SDA to 3.8% at 20% SDA. Similarly, concrete produced with Dangote 3X 42.5R increased from 2.0% to 2.9%. At every replacement level, the Dangote Falcon PLC 32.5N concrete recorded higher water absorption than the Dangote 3X PLC 42.5R concrete. The progressive increase in water absorption implies that incorporating SDA increased the porosity and moisture uptake of the concrete matrix. This may be associated with the relatively porous nature and high surface area of SDA, which can increase water demand and create additional pathways for water penetration when the ash content becomes excessive.

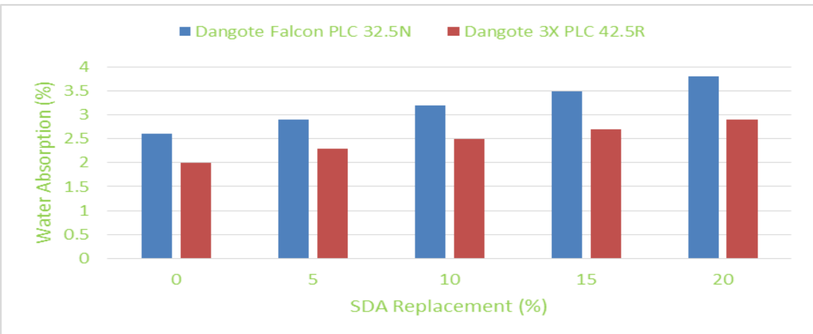

Figure 7: Water Absorption of Concrete Produced from Cement Grades

The lower absorption recorded by the Dangote 3X PLC 42.5R concrete indicates comparatively lower water penetration than the Dangote Falcon PLC 32.5N concrete under the conditions of this study. The finding agrees with Udoeyo et al. (2006), who investigated wood waste ash in concrete at replacement levels of 0–30%. They reported that water absorption increased with increasing ash content, with the highest absorption occurring at the highest ash replacement level. Similarly, Chowdhury et al. (2015) reported that water absorption increased as wood ash replacement increased, attributing the trend to the characteristics of the ash and its influence on the concrete pore structure. The result is also consistent with the findings of Meko & Ighalo (2021) who observed a slight increase in water absorption as SDA content increased and reported that SDA-containing concrete generally had higher absorption than the control concrete. The studies associated the increased absorption with the porous nature of SDA. Alabduljabbar et al. (2020) likewise reported increased water absorption with increasing sawdust-based material content because of increased water demand and structural porosity.

Compressive Strength Test

Figure 8 show compressive strength results of concrete produced from cement grades at 28 and 56 days. For the Dangote Falcon PLC 32.5N concrete, the control mix containing 0% SDA recorded compressive strengths of 25.10 N/mm² and 25.60 N/mm² at 28 and 56 days, respectively.

With the addition of 5% SDA, the strength increased slightly to 25.50 N/mm² at 28 days and 26.80 N/mm² at 56 days. However, further increases in SDA replacement resulted in a progressive reduction in strength. At 10%, 15% and 20% SDA, the 28-day strengths decreased to 23.20, 22.70 and 20.00 N/mm², respectively, while the corresponding 56-day strengths were 24.20, 23.40 and 21.90 N/mm².

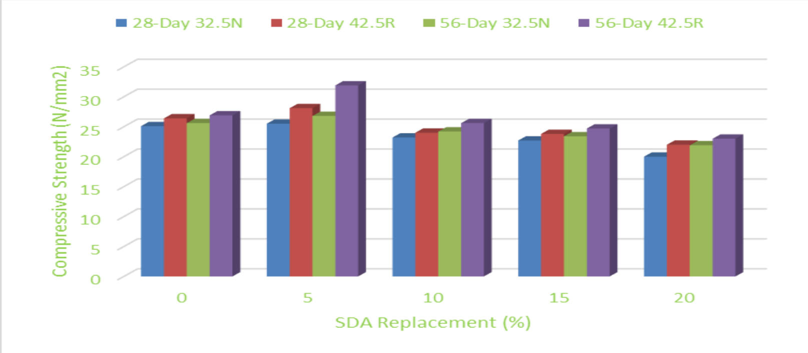

Figure 8: Compressive Strength Result of Concrete Produced from Cement Grades at 28 days

This indicates that 5% SDA was the most favourable replacement level for the 32.5N cement under the conditions of the study. A similar trend was observed for the Dangote 3X PLC 42.5R concrete, although the strength values were generally higher than those obtained with the 32.5N cement. The control concrete recorded 26.40 N/mm² at 28 days and 26.90 N/mm² at 56 days. At 5% SDA replacement, the compressive strength increased considerably to 28.10 N/mm² at 28 days and 31.90 N/mm² at 56 days, representing the highest strengths recorded in the study. Beyond 5% SDA, compressive strength declined to 24.00 and 25.60 N/mm² at 10%, 23.80 and 24.70 N/mm² at 15%, and 22.00 and 23.00 N/mm² at 20% SDA for 28 and 56 days, respectively. The pronounced improvement at 5% SDA may be attributed to the filler and pozzolanic effects of the ash, which can improve particle packing and provide additional reactive silica for the formation of secondary calcium silicate hydrate (C-S-H) gel. The reduction in compressive strength at higher SDA replacement levels may be associated with the dilution of cementitious material. Although SDA contains a substantial amount of silica and other pozzolanic oxides, excessive replacement reduces the quantity of clinker available for hydration. The relatively porous and fine nature of SDA can also increase water demand and produce less efficient particle packing when used at high replacement levels, thereby increasing porosity and reducing the load-bearing capacity of the hardened concrete. Similar reductions in compressive strength with increasing sawdust ash content have been reported by Udoeyo and Dashibil (2002), Raheem et al. (2012), and Gwarah et al. (2019). The findings are also consistent with Meko & Ighalo (2021) who reported that compressive strength generally decreased as the proportion of ash increased, with low replacement levels providing better performance. Comparison between the two cement grades shows that the concrete produced with Dangote 3X PLC 42.5R consistently developed higher compressive strength than the corresponding concrete produced with Dangote Falcon PLC 32.5N at all SDA replacement levels and curing ages. The difference was particularly pronounced at 5% SDA, where the 42.5R concrete attained 28.10 N/mm² at 28 days and 31.90 N/mm² at 56 days, compared with 25.50 N/mm² and 26.80 N/mm², respectively, for the Dangote Falcon PLC 32.5N concrete. This superior performance can be associated with the higher strength class and more rapid early-strength development of the Dangote 3X PLC 42.5R cement. The result agrees with Joel and Mbapuun (2016), who reported higher concrete strength for the Dangote 3X PLC 42.5R cement compared with Dangote Falcon PLC 32.5N cement under comparable concrete production conditions. The increase in compressive strength between 28 and 56 days observed in most of the mixes indicates continued hydration and strength development with increasing curing age. The most pronounced improvement was recorded for the concrete produced with Dangote 3X PLC 42.5R cement containing 5% SDA, where the strength increased from 28.10 N/mm² at 28 days to 31.90 N/mm² at 56 days. This later-age strength development may be attributed to the continued hydration of cement and the pozzolanic reaction of the reactive constituents of SDA, which can contribute to the formation of additional cementitious products within the concrete matrix. Furthermore, COREN (2017) reported that a specified grade of concrete can be produced using any appropriate strength class of cement, provided that the mix design procedure is properly followed and the relevant standards and codes are adhered to during production. The results of this study therefore indicate that 5% SDA represents the optimum replacement level within the investigated range, particularly when used with Dangote 3X PLC 42.5R cement, while replacement levels above 5% tend to result in a reduction in compressive strength.

Split Tensile Strength

Figure 9 show split tensile strength results of Concrete Produced from Cement Grades at 28 and 56 days. The split tensile strength results indicate that the incorporation of sawdust ash (SDA) influenced the tensile strength of concrete produced with Dangote Falcon PLC 32.5N and Dangote 3X PLC 42.5R cements. For the Dangote Falcon PLC 32.5N concrete, the control mix containing 0% SDA recorded split tensile strengths of 2.60 N/mm² and 2.70 N/mm² at 28 and 56 days, respectively. The addition of 5% SDA increased the strength to 2.80 N/mm² at 28 days and 2.90 N/mm² at 56 days, representing the highest values obtained with the 32.5N cement. However, further increases in SDA replacement resulted in a progressive reduction in strength. At 10%, 15% and 20% SDA, the 28-day strengths were 2.50, 2.30 and 2.00 N/mm², respectively, while the corresponding 56-day values were 2.60, 2.40 and 2.10 N/mm². A similar trend was observed for the Dangote 3X PLC 42.5R concrete. The control mix recorded split tensile strengths of 3.20 N/mm² at 28 days and 3.40 N/mm² at 56 days.

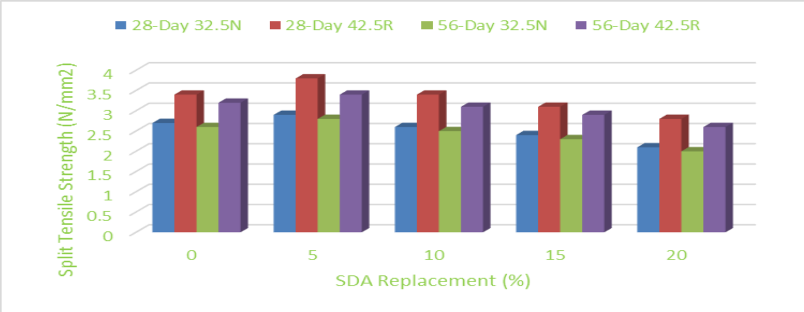

Figure 9: Split Tensile Strength Result of Concrete Produced from Cement Grades at 28 and 56 days

At 5% SDA replacement, the strength increased to 3.40 N/mm² and 3.80 N/mm² at 28 and 56 days, respectively, representing the highest tensile strength obtained in the study. Thereafter, the strength decreased to 3.10, 2.90 and 2.60 N/mm² at 28 days for 10%, 15% and 20% SDA, respectively. The corresponding 56-day strengths were 3.40, 3.10 and 2.80 N/mm². The improvement at 5% SDA may be associated with the filler and pozzolanic effects of the ash, which can improve particle packing and promote the formation of additional cementitious products within the concrete matrix. The findings are similar with Udoeyo and Dashibil (2002), who reported that split tensile strength decreased as the SDA replacement level increased. They also observed that SDA concrete developed strength at later curing ages, indicating the contribution of pozzolanic reactions. The slight improvement obtained at 5% SDA in this study is also supported by Ayuba and Uche (2022), who reported that the strength properties, including splitting tensile strength, generally decreased with increasing SDA content beyond 5% SDA. The reduction in split tensile strength beyond 5% SDA may be attributed to the increasing replacement of cement with a material having lower cementitious activity than Portland cement, together with the relatively porous nature and high surface area of SDA. At excessive replacement levels, these effects may increase water demand and porosity while reducing the quantity of cement available for hydration, thereby weakening the bond between the cement paste and aggregate. Previous research has similarly associated reductions in tensile strength of wood-ash concrete with increased porosity and weaker bonding within the concrete matrix. Comparison of the two cement grades shows that the Dangote 3X PLC 42.5R concrete consistently recorded higher split tensile strengths than the corresponding Dangote Falcon PLC 32.5N concrete at all SDA replacement levels and curing ages. At 5% SDA, the Dangote 3X PLC 42.5R concrete recorded 3.40 N/mm² at 28 days and 3.80 N/mm² at 56 days, compared with 2.80 N/mm² and 2.90 N/mm², respectively, for the Dangote Falcon PLC 32.5N concrete. This indicates better tensile strength development for the Dangote 3X PLC 42.5R cement under the conditions of the investigation. The increase in split tensile strength between 28 and 56 days observed in most of the mixes indicates continued hydration and strength development with curing age. The most notable increase occurred in the Dangote 3X PLC 42.5R 42.5R concrete containing 5% SDA, which increased from 3.40 N/mm² at 28 days to 3.80 N/mm² at 56 days. This observation is consistent with Udoeyo and Dashibil (2002), who reported continued later-age strength development in SDA concrete and attributed it partly to the pozzolanic activity of the ash. This submission is in line with the work of Naik (2002) who studied the effect of SDA at early ages up to 28 days curing on the splitting tensile strength of concrete and revealed the strength decreases with increasing content of SDA. However, the results indicate that 5% SDA represents the optimum replacement level within the investigated range for split tensile strength, particularly when used with Dangote 3X PLC 42.5R cement, while replacement levels above 5% generally result in reduced tensile strength.

Statistical Treatment using Two-Way Analysis of Variance

Tables 4 and 5 shows the mean compressive strength of concrete containing different levels of sawdust ash. The compressive strength results showed variation across sawdust ash replacement levels and cement types. For Dangote 3X PLC 42.5R, the mean strength increased from 26.33 ± 0.58 N/mm² at 0% sawdust ash to 32.00 ± 0.00 N/mm² at 5%, after which it declined to 26.00 ± 0.00 N/mm², 25.00 ± 0.00 N/mm², and 23.00 ± 0.00 N/mm² at 10%, 15%, and 20% replacement, respectively. Similarly, concrete produced with Dangote Falcon PLC 32.5N recorded 25.33 ± 0.58 N/mm² at 0% replacement, increased to 26.67 ± 0.58 N/mm² at 5%, and subsequently declined to 24.00 ± 0.00 N/mm², 23.67 ± 0.58 N/mm², and 21.33 ± 0.58 N/mm² at 10%, 15%, and 20%, respectively. Thus, the highest observed mean strength occurred at 5% sawdust ash replacement with Dangote 3X PLC 42.5R (32.00 ± 0.00 N/mm²), while the lowest occurred at 20% replacement with Dangote Falcon PLC 32.5N (21.33 ± 0.58 N/mm²).

Table 4: Mean Compressive Strength of Concrete Containing Different Levels of Sawdust Ash

Sawdust ash (%)	Cement type	Mean ± SD (N/mm²)	n
0	Dangote 3X PLC 42.5R	26.33 ± 0.58	5
0	Dangote Falcon PLC 32.5N	25.33 ± 0.58	5
5	Dangote 3X PLC 42.5R	32.00 ± 0.00	5
5	Dangote Falcon PLC 32.5N	26.67 ± 0.58	5
10	Dangote 3X PLC 42.5R	26.00 ± 0.00	5
10	Dangote Falcon PLC 32.5N	24.00 ± 0.00	5
15	Dangote 3X PLC 42.5R	25.00 ± 0.00	5
15	Dangote Falcon PLC 32.5N	23.67 ± 0.58	5

Sawdust ash (%)	Cement type	Mean ± SD (N/mm²)	n
20	Dangote 3X PLC 42.5R	23.00 ± 0.00	5
20	Dangote Falcon PLC 32.5N	21.33 ± 0.58	5

Table 5: Overall Mean compressive strength of concrete

Cement type	Overall mean ± SD (N/mm²)	n
Dangote 3X PLC 42.5R	26.47 ± 3.11	25
Dangote Falcon PLC 32.5N	24.20 ± 1.90	25
Overall	25.33 ± 2.78	50

Table 6 shows statistical treatment using two-way analysis of variance. The two-way analysis of variance (ANOVA) established that sawdust ash percentage and cement type significantly influenced concrete strength. A significant interaction between the two factors was also observed, indicating that the effect of sawdust ash replacement depended on the type of cement used. The overall model was statistically significant, $F(9, 20) = 147.56$, $p < .001$, with an R^2 of 0.985 and adjusted R^2 of 0.978. Thus, 98.5% of the variation in concrete strength was explained by sawdust ash percentage, cement type, and their interaction, showing strong explanatory capacity of the model.

Table 6: Two-Way ANOVA for Compressive Strength

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	221.333[a]	9	24.593	147.556	0.001	.985
Intercept	19253.333	1	19253.333	115520.000	0.001	1.000
Sawdust Ash	164.333	4	41.083	246.500	0.001	.980
Cement type	38.533	1	38.533	231.200	0.001	.920
Sawdust Ash * Cement type	18.467	4	4.617	27.700	0.001	.847
Error	3.333	20	.167			
Total	19478.000	30				
Corrected Total	224.667	29				

a. R Squared = .985 (Adjusted R Squared = .978)

Sawdust ash percentage had a significant and very large effect on concrete strength, $F(4, 20) = 246.50$, $p < .001$, $\eta^2p = 0.980$. Strength increased to an optimum at 5% sawdust ash replacement and subsequently declined at higher replacement levels. This implies that a limited quantity of sawdust ash contributed positively to strength improvement, whereas excessive replacement becomes detrimental. The improvement at 5% may be associated with the physical and potential pozzolanic contributions of the ash. Table 2 shows that the sawdust ash contained 67.20 % of SiO_2, considerably higher than the 22.74% and 28.79% recorded for Dangote 3X PLC 42.5R and Dangote Falcon 32.5N cements, respectively. The high silica content provides potential for pozzolanic activity where the silica is present in reactive form. Raheem et al. (2012) reported a combined SiO_2, Al_2O_3 and Fe_2O_3 content of 73.07% in sawdust ash and identified the material as having pozzolanic potential. The fine ash particles may also improve particle packing and fill voids within the cementitious matrix, resulting in a denser structure. The reduction in strength beyond 5% replacement may be attributed mainly to cement dilution. Although the sawdust ash contained substantial SiO_2, its CaO content was only 9.98%, compared with 58.58% for Dangote 3X PLC 42.5R and 54.17% for Dangote Falcon 32.5N. Increasing the ash content therefore progressively reduced the proportion of calcium-rich cementitious material available for hydration. At higher replacement levels, the potential contribution of the ash may have become insufficient to compensate for the reduction in cement content, resulting in lower strength. This interpretation agrees with Elinwa et al. (2018) who reported that compressive strength generally decreased as sawdust ash replacement increased, with 5% producing the highest reported strength in their investigation. In addition, the sawdust ash recorded a relatively high LOI of 11.94%, compared with 3.25% and 3.31% for the two cements.

Cement type also exerted a significant effect on concrete strength, $F(1, 20) = 231.20$, $p < .001$, $\eta^2p = 0.920$. The effect indicates that cement type was a major determinant of strength performance. Concrete produced with Dangote 3X PLC 42.5R generally achieved higher strength than that produced with Dangote Falcon 32.5N. This difference may partly be associated with the higher strength classification and chemical composition of the 42.5R cement. Its CaO content of 58.58% was higher than the 54.17% recorded for Falcon 32.5N. The greater availability of calcium-bearing phases may favour hydration and strength development. Nevertheless, the difference in strength cannot be attributed to CaO alone, since cement performance is also influenced by clinker mineralogy, fineness and hydration characteristics. The interaction between sawdust ash percentage and cement type was significant, $F(4, 20) = 27.70$, $p < .001$, $\eta^2p = 0.847$. This indicates that the effect of sawdust ash on strength varied according to the cement used. The simple-effects analysis showed that 5% replacement was the optimum for both cement types, although the strength achieved differed substantially. At 5% replacement, Dangote 3X PLC 42.5R concrete attained 31.83 N/mm^2, compared with 26.53 N/mm^2 for Falcon 32.5N. The higher strength obtained with 42.5R implies that sawdust ash performed more favourably within this cement system under the experimental conditions. At 5% SDA and 56 days, compressive strength increased from 25.60 to 26.80 N/mm² (4.7%) for 32.5N concrete, while 42.5R concrete increased from 26.90 to 31.90 N/mm² (18.6%). Thus, although 5% SDA improved the strength of both cement types, the improvement was substantially greater with 42.5R, indicating a stronger later-age response of the higher-strength-class cement to SDA incorporation.

CONCLUSION

The study established that sawdust ash (SDA) significantly influences the fresh and hardened properties of concrete produced with Dangote Falcon Portland limestone cement 32.5N and Dangote 3X Portland limestone cement 42.5R. The incorporation of SDA resulted in a progressive reduction in workability and density, while water absorption generally increased with increasing SDA replacement. These changes indicate that higher SDA contents affect the fresh concrete characteristics and increase the porous nature of the hardened concrete. In terms of strength development, 5% SDA replacement produced the optimum performance within the investigated replacement range for both cement types. The 56-day compressive strength increased from 25.60 N/mm^2 for the 32.5N control concrete to 26.80 N/mm² at 5% SDA, while the 42.5R concrete increased from 26.90 N/mm^2 to 31.90 N/mm^2. Similarly, the highest 56-day split tensile strengths were 2.90 N/mm^2 and 3.80 N/mm^2 for 32.5N and 42.5R concretes, respectively, at 5% SDA replacement. Beyond 5% replacement, both compressive and split tensile strengths declined progressively. The two-way ANOVA confirmed that SDA content, cement type, and their interaction had statistically significant effects on compressive strength ($p < 0.001$). Within the tested levels, 5% SDA is supported as the best-performing replacement for the measured properties, particularly with Dangote 3X PLC 42.5R cement, although additional durability and field-scale investigations would be desirable before broader construction recommendations are made. Concrete containing SDA should be cured beyond 28 days to support the later-age strength development observed in this study. Within the investigated conditions, 5% SDA replacement provided the most favourable balance of mechanical performance for both cement strength classes, with a more pronounced improvement for PLC 42.5R. Higher SDA replacement levels reduced workability and strength and increased water absorption. Further studies incorporating standardised pozzolanic-reactivity tests and long-term durability evaluation are required before wider structural application is recommended.

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