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Influence of Cement Brand on the Fresh, Mechanical, and Durability Properties of Concrete

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ABSTRACT
This study evaluated the influence of three commercially available Portland cement brands in Nigeria (Dangote, Lafarge, and BUA) on the fresh, mechanical, and durability properties of 1:2:4 (cement: fine aggregate: coarse aggregate) concrete mix at a constant water-cement ratio of 0.5. Concrete cubes (150 × 150 × 150 mm) were cast and cured for 3, 7, 14, and 28 days, after which slump, setting time, compressive strength, and water absorption were determined. Two-way analysis of variance (ANOVA) showed that both cement brand ($F(2, 24) = 15.73$, $p < 0.001$) and curing age ($F(3, 24) = 28.70$, $p < 0.001$) significantly influenced compressive strength, whereas their interaction was not significant ($p = 0.13$). One-way ANOVA revealed significant differences among brands at 3 and 7 days ($p < 0.01$), but not at 14 or 28 days ($p > 0.05$). Although BUA recorded the highest mean 28-day compressive strength (28.22 ± 2.14 N/mm²), followed by Lafarge (26.44 ± 3.74 N/mm²) and Dangote (23.78 ± 0.22 N/mm²), however, Tukey's HSD test found no significant pairwise differences. The cement brand did not significantly affect water absorption ($p = 0.08$), whereas curing age did ($p = 0.04$). Lafarge produced the highest slump (45 mm) and shortest setting time (5-6 hours), while BUA produced the lowest slump (25 mm) and longest setting time (8-9 hours). These findings indicate that the cement brand primarily influences fresh properties and early-age strength, supporting project-specific testing when selecting cement.

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INTRODUCTION

Concrete is the most widely used construction material worldwide, and Portland cement is the principal binder governing its fresh and hardened performance. Even where mix proportions, aggregates, and curing regimes are held constant, cements produced by different manufacturers can differ in clinker mineralogy, fineness, and gypsum content, and these differences can translate into measurable differences in Workability, setting behaviour, strength development, and durability indices (Neville, 2011; Mehta & Monteiro, 2014). In Nigeria, Dangote, Lafarge, and BUA are the three dominant commercial Portland cement brands, and contractors routinely substitute between them based on price and availability rather than verified performance data.

The differences among commercial cements are rooted in the four principal clinker phases identified by Bogue: tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A), and tetracalcium aluminoferrite (C_4AF) (Neville, 2011; Mehta & Monteiro, 2014). C_3S hydrates rapidly and dominates strength development during the first week, whereas C_2S hydrates more slowly and governs long-term strength gain beyond 28 days; C_3A governs early setting behaviour and heat evolution, while C_4AF contributes comparatively little to strength but influences colour and grindability (Hewlett & Liska, 2019). Because the relative proportions of these phases, together with clinker fineness and the gypsum content used to regulate set, are governed by each manufacturer's raw-material sourcing and kiln operation, cements nominally conforming to the same strength class can differ measurably in early hydration kinetics even when their 28-day mortar-prism strengths are similar (Hewlett & Liska, 2019). This chemical and physical variability is the underlying mechanism through which brand substitution can influence the fresh- and early-age behaviour of concrete, and it motivates treating brand as an explicit statistical factor rather than an incidental one.

Dangote, Lafarge, and BUA together supply the substantial majority of Portland cement consumed in Nigeria, each operating an integrated plant that converts locally sourced limestone into clinker, which is then ground with gypsum and other additives into finished cement, which is then bagged for the retail market. Because kiln conditions, raw-mix chemistry, and grinding fineness are set independently by each producer, nominally equivalent grades (such as 32.5N or 42.5N cements) leaving different plants are not guaranteed to be chemically or physically identical, even though all are required to satisfy the same NIS, BS EN 197-1, or ASTM C150 specification limits. Several laboratory studies have directly compared the physical and mechanical properties of these Nigerian brands, generally finding that all satisfy the relevant standard while differing in fineness, setting time, and short-term strength (Gana et al., 2020).

Beyond immediate structural performance, verifying which brand-related differences in concrete behaviour are real and which are statistical noise also has implications for sustainability. Cement production remains one of the most carbon-intensive stages of the construction-material supply chain, and inefficient or overly conservative mix design, driven by unverified assumptions about brand performance, can unnecessarily increase cement consumption and the associated embodied carbon of concrete (Barbhuiya et al., 2024). This concern is particularly acute in rapidly urbanising economies such as Nigeria, where cement demand is projected to keep rising for decades to come (Cheng et al., 2023). Parallel efforts to reduce clinker demand through partial cement replacement, such as using cow bone ash and bentonite to enhance the strength, durability, and microstructure of concrete, reflect the same underlying motivation: achieving adequate performance without unnecessary cement consumption (Awoyemi et al., 2023). Statistically defensible brand comparisons, of the kind undertaken here, therefore support more rational specification and reduce the risk of both under-design, which threatens durability, and over-design, which wastes cement unnecessarily.

Several Nigerian studies have compared these brands (Bamigboye et al., 2015; Olonade et al., 2020; Falade et al., 2018), generally reporting comparable 28-day strengths across brands with more pronounced differences at early ages, and evidence that fineness and gypsum content drive differences in slump and setting time. However, many comparative studies, including earlier, purely descriptive analyses of the dataset re-examined here, report brand rankings based on triplicate means without formal hypothesis testing, leaving it unclear whether observed differences reflect genuine brand effects or ordinary specimen-to-specimen scatter. This is an important gap: with only three specimens per cell, the coefficient of variation for some properties (particularly water absorption; see Section 4) can exceed 100%, rendering a simple ranking of means misleading. The problem is not unique to Nigeria: comparable branded-cement studies elsewhere, for example, an eight-brand comparison of fineness, consistency, and compressive strength in Pakistan, likewise report brand differences as simple mean rankings without formal significance testing (Sultan et al., 2023), suggesting that the gap this study addresses is a general feature of the comparative cement literature rather than a peculiarity of the Nigerian market.

This study re-examines triplicate laboratory data for concrete produced with Dangote, Lafarge, and BUA cement at a fixed 1:2:4 mix ratio and 0.5 water-cement ratio, applying one-way and two-way analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) post-hoc test to determine which brand-related differences in Workability, setting time, water absorption, and compressive strength are statistically defensible, and which are not.

MATERIALS AND METHODS

Materials

Despite the widespread brand substitution in Nigerian concrete practice, existing comparative studies of Dangote, Lafarge, and BUA cement have relied on triplicate means and simple rankings without formal hypothesis testing. With only three specimens per test cell, such rankings risk mistaking ordinary specimen-to-specimen scatter for genuine brand effects, particularly for properties like water absorption, where variability can be substantial. Engineers and contractors may therefore be selecting cement brands based on differences that are not statistically defensible, risking either unsafe under-design or wasteful over-design. To address this gap, the study adopted a controlled experimental design that compared three dominant Nigerian cement brands under standardised mix and curing conditions and applied ANOVA and Tukey's HSD post hoc test to determine which brand-related differences were statistically significant.

Dangote, Lafarge, and BUA were selected on the basis of their dominant market share in Nigeria, where they together account for the substantial majority of cement consumed nationally, and because contractors and site engineers routinely switch among them based on price and availability. For each brand, a single batch of bags was procured from certified suppliers in Yenagoa, with bags randomly selected from retail stock to represent typical open-market procurement conditions. All bags were checked for manufacturer date and intact packaging prior to use, and cement was tested within 7 days of purchase to minimise storage-related hydration or moisture uptake.

Fine aggregate consisted of cleaned, sieved river sand, and coarse aggregate of graded crushed granite, both sourced from a single supply batch to eliminate aggregate-related variability as a confounding factor. Clean potable water was used throughout to ensure consistency of the mix.

Mix Proportioning

A nominal mix ratio of 1:2:4 (cement: sand: granite) by weight and a constant water-cement ratio of 0.5 were adopted for all three brands, so that any differences observed between brands could be attributed to the cement rather than to the mixed design. Quantities were computed from the volume of a single 150 mm cube:

$$V = l^3 \qquad (1)$$

Where V is the volume of the cube (m³) and l is the cube edge length (0.15 m), giving V = 0.003375 m³.

$$Mt_{total} = V \times \rho \qquad (2)$$

Where M_{total} is the total mass of concrete per cube (kg), and ρ is the assumed fresh concrete density (2500 kg/m³), giving 8.4375 kg per cube.

$$M_i = \left(\frac{r_i}{\Sigma r}\right) \times M_{total} \qquad (3)$$

Where M_i is the mass of constituent i (cement, sand, or granite), r_i is its ratio component (1, 2, or 4, respectively), and Σr is the sum of ratio parts (7).

$$M_{water} = (w/c) \times M_{cement} \qquad (4)$$

With w/c = 0.5. Applying Equations (1)-(4) to twelve cubes per brand gave 14.52 kg cement, 29.04 kg sand, 58.08 kg granite, and 7.26 kg water.

Specimen Preparation, Casting, and Curing

Materials were batched by weight. The dry constituents were thoroughly mixed before water was added, and the fresh concrete was placed into 150 mm × 150 mm × 150 mm steel cube moulds in three layers, with each layer compacted by manual tamping using a standard rod to minimise entrapped air. After 24 hours, the cubes were demoulded and cured in water for 3, 7, 14, and 28 days before testing. Three cubes were prepared for each cement brand at each curing age (n = 3), giving 36 cubes per brand and 108 cubes in total.

Test Methods

Workability

The slump test was used to assess the Workability of the fresh concrete for each brand immediately after mixing, following the standard slump-cone procedure.

Setting Time

Initial setting time was assessed for each cement brand's paste fraction in accordance with the general principles of ASTM C191/BS EN 196-3 (Vicat needle penetration), which define initial set as the time at which the needle penetration reaches a specified depth from the base of the mould.

Water Absorption

Cubes were weighed immediately upon removal from the curing tank (wet weight) and again after oven-drying to constant mass (dry weight), following the general procedure of ASTM C642. Water absorption was expressed both as a percentage of dry mass and per unit volume:

$$WA\ (\%) = \frac{W_{wet} - W_{dry}}{W_{dry}} \times 100 \quad (5)$$

$$WA\ (kg/m^3) = \frac{W_{wet} - W_{dry}}{V} \quad (6)$$

Water absorption for each cement brand and curing age was calculated for each cube, and the three values were then averaged. This approach replaces an earlier descriptive analysis in which average wet and dry weights were first calculated before determining a single water absorption value for each group. Because the two methods can yield different results when specimen weights vary, the present approach is statistically preferable because it preserves the variability among individual specimens required for valid ANOVA.

Compressive Strength

Cubes were crushed to failure in a compression testing machine at each curing age, and compressive strength was calculated as:

$$f_c = \frac{P}{A} \quad (7)$$

Where fc is the compressive strength (N/mm²), P is the failure load (N), and A is the loaded face area (22 500 mm² for a 150 mm cube).

Statistical Analysis

For every brand–age combination (n = 3), the sample mean ($\bar{x}$) and sample standard deviation (s) were computed, and the coefficient of variation was calculated as:

$$CoV\ (\%) = \frac{s}{\bar{x}} \times 100 \quad (8)$$

Differences in compressive strength and water absorption between the three cement brands were tested using: (i) one-way ANOVA comparing the three brands separately at each curing age; and (ii) a two-way factorial ANOVA with cement brand and curing age (and their interaction) as fixed factors, fitted as:

$$y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk} \quad (9)$$

Where y_{ijk} is the response (compressive strength or water absorption) for the k-th cube of brand i at age j, μ is the grand mean, α_i is the brand effect, β_j is the age effect, $(\alpha\beta)_{ij}$ is the brand×age interaction, and ε_{ijk} is the random error. When the overall ANOVA F-test was significant, Tukey's HSD post hoc test was used for pairwise comparisons. A significance level of $\alpha = 0.05$ was adopted throughout.

RESULTS AND DISCUSSION

Fresh Properties: Workability and Setting Time

Table 1 presents the slump and initial setting time recorded for each cement brand.

Table 1: Workability (slump) and initial setting time by cement brand

Cement Brand	Slump (mm)	Initial Setting Time (hours)
Dangote	30	7-8
Lafarge	45	5-6
BUA	25	8-9

Compressive Strength

Table 2 presents the mean compressive strength, standard deviation (SD), and coefficient of variation (CoV) for each brand at each curing age (n = 3 per cell).

Table 2: Compressive strength (N/mm²): mean ± SD and CoV (n = 3)

Age (days)	Dangote	Lafarge	BUA
3	14.07 ± 0.68 (4.8%)	15.41 ± 2.96 (19.2%)	22.67 ± 2.78 (12.3%)
7	17.48 ± 0.51 (2.9%)	18.37 ± 0.68 (3.7%)	21.33 ± 1.60 (7.5%)
14	18.67 ± 2.69 (14.4%)	20.96 ± 0.90 (4.3%)	21.11 ± 2.78 (13.2%)
28	23.78 ± 0.22 (0.9%)	26.44 ± 3.74 (14.1%)	28.22 ± 2.14 (7.6%)

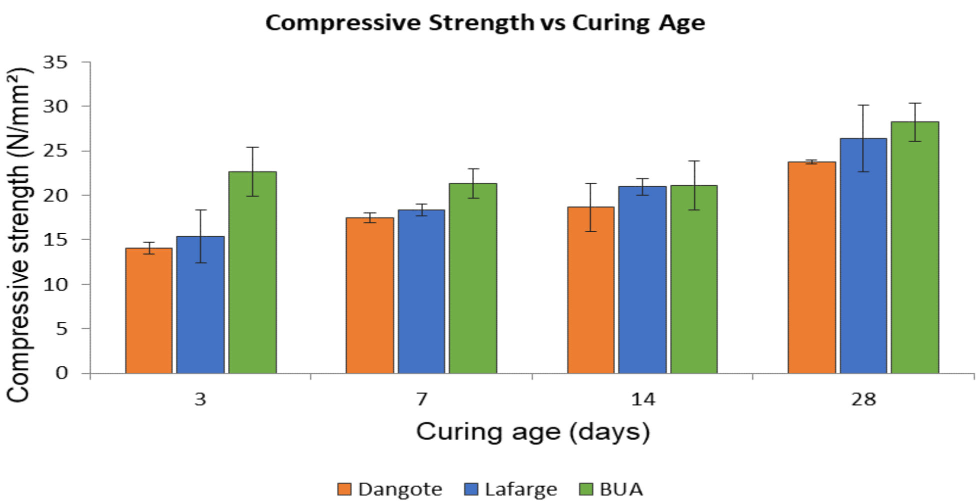

Figure 1: Mean compressive strength versus curing age for the three cement brands (error bars = ±1 SD, n = 3)

Table 3 summarises the one-way ANOVA comparing the three brands at each curing age.

Table 3: One-Way ANOVA Effect of Cement Brand on Compressive Strength at Each Curing Age

Age (days)	F(2,6)	p-value	Significant at α = 0.05?
3	11.37	0.009	Yes
7	11.12	0.010	Yes
14	1.07	0.401	No
28	2.42	0.170	No

Table 4 gives the two-way (brand × age) ANOVA across the full dataset.

Table 4: Two-way ANOVA Compressive Strength (Brand × Curing Age)

Source	df	F	p-value
Brand	2	15.73	< 0.001
Age	3	28.70	< 0.001
Brand × Age	6	1.86	0.130
Residual	24	–	–

Because the overall brand effect was significant, Tukey's HSD post hoc test was conducted on the 28-day data, as 28-day strength is the value most used for design and specification purposes. The results are given in Table 5.

Table 5: Tukey HSD Post-Hoc Comparison, 28-day Compressive Strength

Comparison	Mean Difference (N/mm^2)	Adjusted p	Significant?
BUA vs Dangote	4.44	0.153	No
BUA vs Lafarge	1.78	0.675	No
Dangote vs Lafarge	−2.67	0.440	No

No pairwise comparison reached significance at 28 days, despite an overall significant brand main effect across all four ages combined; this reflects the fact that brand differences are concentrated at early ages (3 and 7 days; Table 3) and narrow considerably by 28 days.

Water Absorption

Table 6 presents the mean, SD, and CoV for water absorption (%) at each brand–age combination, computed per specimen (Section 2.4.3).

Table 6: Water absorption (%): mean ± SD and CoV (n = 3)

Age (days)	Dangote	Lafarge	BUA
3	8.96 ± 6.35 (70.9%)	0.96 ± 0.32 (33.6%)	4.59 ± 6.91 (150.6%)
7	1.16 ± 0.57 (49.6%)	0.76 ± 0.33 (43.9%)	0.59 ± 0.01 (1.8%)
14	4.04 ± 5.61 (138.9%)	0.58 ± 0.02 (3.4%)	0.59 ± 0.02 (2.8%)
28	0.79 ± 0.37 (47.5%)	0.77 ± 0.35 (45.8%)	0.59 ± 0.01 (1.7%)

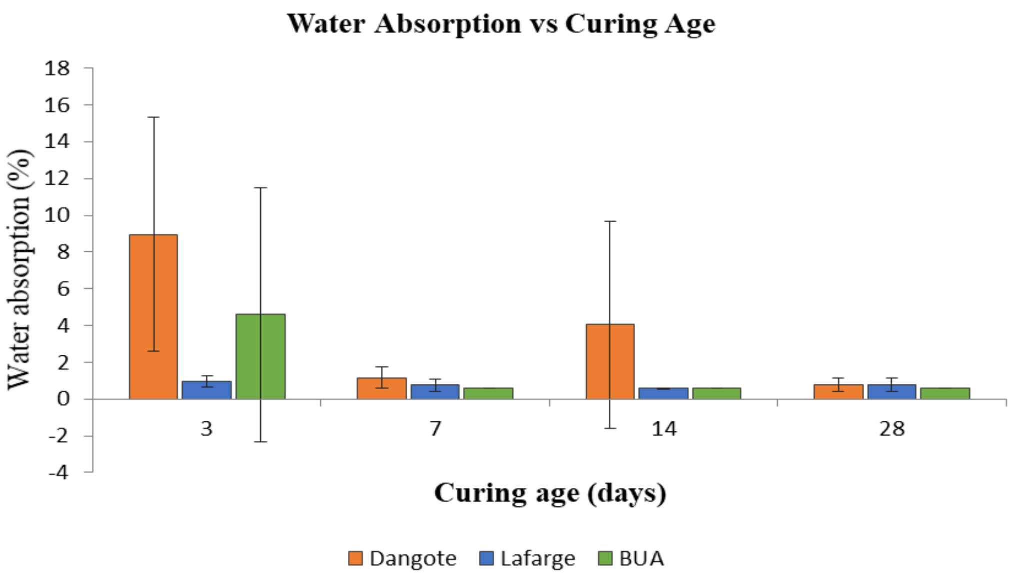

Figure 2: Mean water absorption versus curing age for the three cement brands (error bars = ±1 SD, n = 3)

The two-way ANOVA for water absorption (Table 7) shows that curing age had a significant effect, but cement brand did not, at the conventional α = 0.05 threshold.

Table 7: Two-Way ANOVA Water Absorption

Source	df	F	p-value
Brand	2	2.81	0.080
Age	3	3.32	0.037
Brand × Age	6	1.07	0.408
Residual	24	–	–

The very high CoV values in Table 6 (up to 150.6% for BUA at 3 days and 138.9% for Dangote at 14 days) indicate that individual cube-to-cube variability, rather than a systematic brand effect, is the dominant source of the scatter in early-age absorption results.

Discussion

Workability

Lafarge cement produced the most workable mix (45 mm slump), followed by Dangote (30 mm), with BUA the stiffest (25 mm). Workability is a critical fresh-state property that governs the ease of mixing, transporting, placing, and compacting concrete without segregation or bleeding (Neville & Brooks, 2010). The higher slump obtained with Lafarge cement is consistent with differences in fineness and water demand between brands (Mehta & Monteiro, 2014); however, with only a single slump value recorded per brand (no replication of the fresh-state test itself), this result should be treated as indicative rather than statistically confirmed, and repeat slump trials are recommended in any follow-up study. This pattern is consistent with fineness-related findings from other national cement markets, where finer, higher-surface-area cements generally increase water demand for a given consistency and correspondingly reduce slump at a fixed water-cement ratio (Sultan et al., 2023).

Setting Time

Lafarge cement achieved the shortest setting time (5-6 hours), Dangote an intermediate time (7-8 hours), and BUA the longest (8-9 hours). Setting time governs the available working time for placing and finishing, as well as the onset of early strength development (Neville, 2011), and the observed differences are broadly consistent with variation in C_3A and gypsum content between clinkers (Hewlett & Liska, 2019). All three brands fell within the setting-time ranges expected for ordinary Portland cements under BS EN 196-3 and ASTM C191, confirming their general suitability for structural applications; however, as with the slump test, only a single determination was made per brand.

Compressive Strength

Across all four curing ages combined, cement brand had a statistically significant effect on compressive strength (two-way ANOVA, $p < 0.001$), and BUA recorded the numerically highest mean strength at every age except 14 days, where Lafarge marginally exceeded it. At 3 and 7 days specifically, the one-way ANOVA confirms that brand differences were statistically significant ($p = 0.009$ and $p = 0.010$ respectively), supporting the interpretation that BUA and, to a lesser extent, Lafarge cement promote faster early strength gain than Dangote at this mix ratio plausibly reflecting a higher proportion of tricalcium silicate (C_3S) or finer grinding (Hewlett & Liska, 2019).

This early-age divergence followed by later-age convergence is a well-documented pattern in cement science rather than a peculiarity of this dataset. Mindess, Young and Darwin (2003) and Mehta and Monteiro (2014) both note that C_3S dominates the first-week strength gain of Portland cement while C_2S, which hydrates far more slowly, becomes the principal contributor to strength beyond about 28 days; because most commercial Portland cements are formulated to reach a broadly similar total silicate content by the time hydration is largely complete, brand-related differences that are pronounced at 3 and 7 days are expected, on chemical grounds, to narrow substantially by 28 days. The present results are consistent with this expectation and with comparable field evidence: a four-brand comparison of Nigerian Portland cements in pervious concrete similarly found brand-related strength differences that did not scale proportionally with stated grade classification (Gana et al., 2020), and an eight-brand comparison of Pakistani cements found that finer, faster-hydrating brands gave a pronounced early-strength advantage that narrowed by 28 days (Sultan et al., 2023). Taken together with the present dataset, this cross-national consistency strengthens the case that the observed early-age brand effect reflects a genuine, chemically grounded phenomenon rather than a dataset-specific artefact, even though the present study's small sample size means the statistical evidence for the effect's persistence to 28 days remains weak. From a specification standpoint, the mix-design procedures underlying ACI 211.1 implicitly assume that once a target 28-day strength is achieved, the cement source used to reach it is largely immaterial to structural design; the present results support that assumption for the three Nigerian brands and mix ratio examined, but not for early-age requirements such as formwork-removal or early-loading criteria, where brand-related differences remain significant and merit separate consideration (ACI Committee 211, 2009).

By contrast, at 14 and 28 days, the one-way ANOVA was not significant ($p = 0.401$ and $p = 0.170$). Tukey's HSD post hoc comparison at 28 days found no statistically significant pairwise differences between any two brands (Table 5), even though BUA's mean (28.22 N/mm²) was numerically 4.4 N/mm² higher than Dangote's (23.78 N/mm²). This is an important correction to an earlier, purely descriptive reading of the same data, which concluded that "BUA cement consistently outperformed the other brands" at 28 days: the descriptive ranking of the means is accurate, but the strength of that claim is not supported once ordinary specimen variability (SD up to 3.74 N/mm² on a mean of 26-28 N/mm²) is taken into account. With only three cubes per cell, the study is statistically underpowered to detect brand differences of this size at later ages, and the appropriately cautious conclusion is that 28-day strength differences between these three brands, while numerically present, have not been demonstrated beyond a reasonable statistical doubt in this dataset.

It is also worth correcting a conceptual point from the earlier analysis: BS EN 197-1 and ASTM C150 strength classes (e.g., 42.5N) are determined from standard mortar prisms tested under BS EN 196-1, not from 1:2:4 concrete cubes with coarse aggregate. Comparing the concrete strengths obtained here (23.8-28.2 N/mm² at 28 days) with the mortar-grade cement requirement of 42.5 N/mm² is therefore not a like-for-like comparison. The strengths obtained are, in fact, consistent with what would ordinarily be expected of a 1:2:4 nominal-mix concrete at a water-cement ratio of 0.5, and should not be read as evidence that the cements underperformed their stated grade.

Water Absorption and Implications for Durability

Water absorption is often used as a proxy for concrete porosity and, by extension, permeability and durability (Neville & Brooks, 2010). In the present dataset, absorption fell sharply for all three brands between 3 and 28 days, consistent with the progressive refinement of the pore structure as hydration proceeds (Mehta & Monteiro, 2014). However, unlike compressive strength, the two-way ANOVA found no statistically significant brand effect on water absorption ($p = 0.080$); only curing age was significant ($p = 0.037$). The very high coefficients of variation recorded 150.6% for BUA at 3 days and 138.9% for Dangote at 14 days show that individual cube-to-cube variability was often larger than the mean value itself at early ages. This substantially revises an earlier interpretation of an "anomalous" rise in Dangote absorption at 14 days as a genuine brand-related durability signal: given a CoV of 138.9% at that age, the apparent spike is fully consistent with ordinary specimen scatter (most plausibly from minor differences in oven-drying consistency or entrapped-air distribution between individual cubes) rather than a real microstructural reversal specific to Dangote cement.

By 28 days, all three brands recorded absorption below 1% (Dangote 0.79%, Lafarge 0.77%, BUA 0.59%), comfortably within the ASTM C642 / BS EN 480-5 threshold generally associated with durable, low-permeability concrete. Given the lack of statistical significance for brand at this stage, the most defensible conclusion is that all three cements produced comparably durable concrete by 28 days under these test conditions, rather than that any one brand offers a demonstrated long-term durability advantage over the others. This finding also has a practical sustainability dimension: because all three brands produced comparably low-absorption, durable concrete at 28 days, specifying additional cement content or a stricter mix solely as a hedge against brand variability is not supported by this dataset, reinforcing broader calls to avoid unnecessary over-specification of cementitious content, and the associated embodied carbon, in ordinary structural concrete (Barbhuiya et al., 2024).

CONCLUSION

This study statistically examined the effect of three Nigerian cement brands (Dangote, Lafarge, and BUA) on the properties of 1:2:4 concrete. The data support the following conclusions:

i. Lafarge cement produced the most workable mix and the shortest setting time; BUA produced the stiffest mix and the longest setting time; Dangote was intermediate on both measures.
ii. Cement brand had a statistically significant effect on compressive strength overall ($p < 0.001$), driven mainly by significant differences at 3 and 7 days ($p < 0.01$); brand differences at 14 and 28 days were not statistically significant, and no pairwise comparison at 28 days reached significance under Tukey's HSD test.
iii. The cement brand did not have a statistically significant effect on water absorption ($p = 0.080$); only curing age did ($p = 0.037$). Very high coefficients of variation at early ages indicate that specimen-level scatter, not brand, is the dominant source of variability in the absorption data.
iv. All three brands produced structurally adequate, comparably durable concrete by 28 days under the test conditions used.

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