



Physiochemical and Mechanical Performance of Portland Cement Grades Marketed in Nigeria

*¹Patrick Ushie Adah, ²Samuel Shamaye Silas, ²Gloria Irepiaatabuchi Oli, ²Raymond Ana, ¹Stanley Nwoziri and ²Osha Ade Odey

¹Department of Mechanical Engineering, Faculty of Engineering and Technology, University of Calabar, Cross-River State, Nigeria.

²Department of Chemical Engineering, Faculty of Engineering and Technology, University of Calabar, Cross-River State, Nigeria.

*Corresponding authors' email: patadah1976@gmail.com

ABSTRACT

This study presents a comparative assessment and analysis of the hydration properties of Portland cement grades 32.5 and 42.5 marketed in Calabar, Cross River State, Nigeria. The research was motivated by concerns over inconsistent cement quality and its impact on structural performance. Five (5) cement samples (A, B, C, D and E) were analyzed for chemical composition (XRF), physical properties (Blaine fineness, residue, consistency, expansion, and setting times), and mechanical properties (compressive and flexural strength at 2, 7, and 28 days). Results from Blaine values ranged from 3940 to 4480 cm²/g, showed sample D (32.5R) exhibiting the highest fineness. Setting times (initial: 133 to 155 min; final: 205 to 216 min) and expansion values (0.5 to 1.0 mm) were within permissible limits. Strength development increased with curing age, with 42.5R achieving the highest 28-day flexural strength (5.8 MPa), outperforming 32.5R (4.7 to 5.0 MPa). The findings confirm that while both cement grades meet national and international standards, 42.5 grade cements offer superior hydration performance and strength, making them more suitable for high-strength structural applications, whereas 32.5 grade cements are better suited for light construction and finishing works. The research result showed analyses that falls within the acceptable range of the National and International Standards, and the coefficient of variation indicate the robustness and reliability of the result. And objectives of the assessment were fully achieved, with empirical data guide in cement selection, improving production quality, and support regulatory enforcement in Nigeria's construction industry.

Received: 17 Aug. 2026

Accepted: 05 Oct. 2026

Published: 08 Oct. 2026

Keywords:

Hydration, Setting time, Durability, Lime stone, Kiln, Cement, Blain finest, Mechanical properties

INTRODUCTION

Portland Cement (PC) is a fine powder, produced by heating limestone and clay minerals in a kiln and forming a clinker, grinded to fine powder with small additives [Taylor, 2020]. Construction industries rely on various brands of Portland like Dangote, Lafarge (Elephant), BUA, Purechem, and UNICEM, among others in Nigeria [Onyelowe *et al.*, 2021]. Performance of cement involves exothermic chemical reactions with significant influence on strength, setting time, and durability of structures [Taylor, 2020]. Grades of Portland cement such as 32.5 and 42.5, are produced with various chemical compositions and performance characteristics [Adesina and Awoyera, 2022; Barbuiya *et al.*, 2023], and hydration property influenced by factors such as water-cement ratio, curing conditions, fineness, and chemical composition for optimizing concrete mix designs, ensuring structural integrity, and enhancing the sustainability of construction projects [Saillio *et al.*, 2015; Onyelowe *et al.*, 2021; ; Briki *et al.*, 2024; Mohammed *et al.*, 2025]. Despite the daily usage of cement in Nigeria, there are concerns geared to inconsistencies in quality, and adherence to international standards (NIS 444-1:2014 and ASTM C150) [Adesina and Awoyera, 2022; Ettu *et al.*, 2019; Adeleke *et al.*, 2023; Joshua *et al.*, 2021; Abdullahi *et al.*, 2023] and studies have suggested that certain cement brands in Nigeria do not meet the declared strength grades [Montgomery, 2020; Wang *et al.*, 2021; Briki *et al.*, 2021] due to the alteration in the

hydration processes caused by environmental factors such as high temperature and humidity [Taylor, 2020; Alababan *et al.*, 2020].

Cement in Nigeria consists of Calcium Silicates (C₃S and C₂S), Aluminates (C₃A), and Ferrites (C₄AF) forming strength-giving compounds [Adeleke *et al.*, 2023; Abdullahi *et al.*, 2023; Scrivener *et al.*, 2019; Juenger *et al.*, 2019; Snelling, 2022]. They are classified into grades based on 28-days compressive strength, 32.5 grade for general purpose and 42.5 grade for structural [Onyelowe *et al.*, 2022; Dangote, 2023]. Portland cement is made from Limestone (CaO), combined with Silica (SiO₂) and alumina (Al₂O₃) [Abdullahi *et al.*, 2023; Lea, 2025] and cement raw materials are typically obtained through quarrying. Consequently, this study aims to bridge the gap of inconsistency by evaluating the physiochemical properties of different cement grades, providing insights in quality, and performance of cement [Onyelowe *et al.*, 2022; Adeniran *et al.*, 2021].

MATERIALS AND METHODS

Materials

Portland cement production involves four critical stages the crushing and grinding of raw materials, with about 4 % gypsum to control the setting time. And techniques for grinding raw materials are divided into wet, dry and semi dry [Scrivener *et al.*, 2015; Harris *et al.*, 2021; IEA, 2020; Montgomery, 2020; Scrivener *et al.*, 2023; Gartner, 2020]. To

ensure homogeneity, a mechanical stirring is employed [Gartner, 2020] and slurry introduced to reduce water content to 20 % or 30 %, while improving fuel efficiency during the burning process [Harris *et al.*, 2021]. Kiln is heated to temperatures between 1,350 °C, and 1,550 °C, with either pulverized coal, oil, or natural gas [Gartner, 2020], with a heat exchanger to enhance energy efficiency [Muller *et al.*, 2019]. And finally cooling the clinker, directly ground to cement or stored for future processing [IEA, 2020]. However, recent studies have emphasized the importance of reducing emissions by adopting energy-efficient technologies, using alternative fuels, like by-products fly ash or slag to replace part of the clinker [Scrivener *et al.*, 2019; Harris *et al.*, 2021]. And, modern plants are equipped with advanced dust collection systems, such as cyclone arrestors, bag filters, or electrostatic precipitators, to reduce environmental defects [TechFlow, 2020].

Experimental Method

Cement grades of 32.5 and 42.5 sample were collected from Calabar-South market, Cross River State. The Brand collected were Dangote Cement, Lafarge Cement and BUA Cement and these brands are chosen based on their widespread usage and availability in the Nigerian construction industry, especially in Calabar, Cross River State. Portable water conforming to ASTM C1602 standards for all mixing was utilized. Samples of 10 g were weighed, and four tablets of ethylene glycol were added and then weighed. After which, the mixture was grinded using an automated milling machine. The mixtures were pelletized with a ring put into the X-ray Fluorescence (XRF) (Model ARL-990) for analysis. 1.0 g portion of the cement sample was accurately weighed into a 250 mL beaker where 100 mL of distilled water and 10 mL of concentrated hydrochloric acid (HCl) were added respectively. Table 1, below shows the simple Sample arrangement according to the Brand selected.

Table 1: Samples and Identification

S/N	Sample ID	Sample Grade	Sample Source
1	A	42.5R	Lanfarge
2	B	42.5R	Dangote
3	C	42.5R	BUA
4	D	32.5R	Lafarge
5	E	32.5R	Dangote

Consequently, the mixture was thoroughly stirred to ensure complete dispersion of the sample and then heated gently on a hot plate for 3 – 4 minutes, taking care to avoid boiling. The mmixture was filtered through a Whatman No. 40 filter paper into a clean beaker and the original beaker, and the filter paper were washed thoroughly with hot distilled water to ensure complete transfer of all soluble components. A 40 mL of 0.5 M sodium carbonate (Na₂CO₃) solution was then added with distilled water and the solution was again heated for 3 – 4 minutes and filtered. The beaker was then rinsed with approximately 30 mL of hot dilute hydrochloric acid (1:10 v/v), and the rinsing were transferred to the filter paper. The washing was continued with hot distilled water until the total volume of the filtrate reached approximately 250 mL – 300 mL. A clean porcelain or platinum crucible was dried to constant weight, cooled in a desiccator, and weighed (recorded as W₁). The residue from the filter paper was then quantitatively transferred into the crucible and dried on a hot plate for 40 minutes to an hour (105 °C – 110 °C), then cooled in a desiccator and reweighed (recorded as W₂). The percentage of insoluble residue (IR) was calculated using the following formula:

$$IR = \frac{W_2 - W_1}{W} \times 100 \quad (1)$$

Where:

W₁ = The crucible mass

W₂ = The crucible plus dried residue

W = Weight of sample.

Consequently, with a clean platinum crucible in a muffle furnace at 1000 ± 50 °C for 30 minutes, cooled in a desiccator, and weighed to constant mass (W₁), approximately, 1.0 ± 0.05 g of cement was weighed into the crucible, and the combined mass was recorded as W₂. The crucible containing the sample was placed in a furnace maintained at 1000 ± 50 °C and ignited for about 15 minutes with the lid slightly raised to allow gases to escape. After ignition, the crucible was cooled in a desiccator and weighed (W₃). Heating, cooling, and weighing were repeated until the weight difference between two successive measurements were less than or equal to 1 mg,

confirming a stable mass. The percentage Loss on Ignition (LOI) were then calculated using the formula:

$$LOI = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \quad (2)$$

Where; W₁ = Weight of the empty crucible, W₂ = Weight of the crucible plus cement sample before ignition and W₃ = Weight of the crucible plus cement sample after ignition. Also, with the aid of Vicat apparatus having different penetrating attachments setting Time was being determined. Initial setting time, a round needle with a diameter of 1.13 ± 0.05 mm was used. When the paste stiffens sufficiently for the needle to penetrate only to a point 5 ± 1 mm from the bottom, initial set is said to have taken place. Initial set is expressed as the time elapsed since the mixing water was added to the cement. A minimum time of initial set of 45 minutes was prescribed by ASTM C150. Final set was determined by a similar needle fitted with a metal attachment hollowed out so as to leave a circular cutting edge 5mm in diameter and set 0.5 mm behind the tip of the needle. The final setting time is considered from the moment when mixing water is added to the cement, and is required by the relevant both NIS and ASTM C191

standard to be not more than 10 hours.

Mechanical, Physical, and Chemical Test

- X-ray Fluorescence (XRF) Analysis: Employed in accordance with the standard, was used for chemical parameters determination for CaO, Al₂O₃, SiO₂, Fe₂O₃, SO₃, Insoluble Residue (IR) and Loss on Ignition (LOI) present in a cement
- Flexural Test: With the mortar proportions set at 6:1 ratio of sand to cement (1350 g sand + 225 g cement), water addition was used at a water cement ratio of 0.99, for all mixes by weight (222 g water), and Mortar, 160 mm cubes were made on jotting table with time allowance of 120 seconds. The cubes were demolded after 24 hours and cured in water under humidity of ≥ 90 %, temperature 20 ± 1 °C until tested in wet-surface conditions to obtain strength of 99.8 % after 28 days. Flexural strength, after 28 days, was measured to

determine actual width and depth. Each prism positioned horizontally on the flexural testing machine, with the span length of 100 mm. And Load was applied steadily and continuously without shock and failed within approximately 60 to 90 seconds, maximum load recorded. The flexural strength (Modulus of rupture) was calculated using equation (3) below:

$$\text{Flexural Strength } (\alpha) = \frac{3PL}{2bd^2} \quad (3)$$

Where, P is the maximum load (N), L is the span length (mm), b is the specimen width (mm), and d is the depth (mm) measured at the fracture section.

- iii. Determination of Blaine Test: A cement sample of 2.46 g was accurately weighed and placed into the Blaine chamber. The assembly consisted of a perforated dish, filter paper, the cement sample, and another filter paper on top. The sample was compressed using a piston to ensure uniform packing and placed into the Blaine apparatus, which contains a U-shaped manometer filled with a suitable solution. With stopwatch, the time taken for the solution level to fall from the upper limit to the lower limit was recorded, including the measured time. Blaine fineness was calculated using equation (4):

$$B = 356.35 \times \sqrt{t} \quad (4)$$

Where; B is the Blaine fineness (cm²/g) and t is the measured time in second (s).

- iv. Determination of Residue Test (Wet Method): A 10 g cement sample was carefully weighed, placed on a 45 µm mesh sieve and the sieve, positioned under a running tap, and controlled to prevent splashing while

ensuring adequate washing. The sample was continuously washed for about 10 minutes to allow finer particles to pass through the sieve, leaving behind the residue. Retained material were transferred into a pre-weighed container and oven-dried for approximately 5 - 7 minutes to removing moisture. And the dried residue weighed, and the result obtained and multiplied by 10 in order to determine the percentage residue of the cement sample.

- v. (v) Determination of Expansion Test: With a Le-Chatelier mould, positioned between two glass slides and cement sample placed in the mould, filled without voids and covered with the second glass plate and labeled. And the assembled mould was then stored in a humidity between 90 % – 100 % relative humidity for 24 hours. After this period, the initial distance between the indicator arms of the mould was measured using a caliper. Then the mould and hardened cement paste were immersed in water, boiled gradually and maintained for 3 hours. After cooling to room temperature, the final distance between the indicator arms was recorded and expansion value of the cement was calculated using difference between the initial and final measurements, expressed in millimeters.

RESULTS AND DISCUSSION

X-ray Fluorescence (XRF) Analysis

XRF was carried out in accordance with the standard and results are presented in table 1, including Insoluble Residue (IR) and Loss on Ignition (LOI):

Table 2: Chemical Properties of Cement Grades

Sample ID	A	B	C	D	E
Cement Grades	42.5R	42.5R	42.5N	32.5R	32.5R
Coefficient of Variation	1 %	1 %	1 %	0 %	2 %
Al ₂ O ₃	4.63	5.36	4.75	4.56	5.74
Coefficient of Variation	5 %	4 %	3 %	4 %	1 %
Fe ₂ O ₃	3.36	3.95	4.03	3.14	3.87
Coefficient of Variation	3 %	3 %	2 %	2 %	1 %
CaO	65.07	64.42	64.79	65.30	64.35
Coefficient of Variation	0 %	0 %	0 %	0 %	0 %
SO ₃	1.81	1.95	1.59	1.89	1.89
Coefficient of Variation	5 %	2 %	10 %	4 %	7 %
Loss on Ignition (LOI)	10.96	8.20	7.84	12.96	11.76
Coefficient of Variation	1 %	2 %	2 %	5 %	4 %
Insoluble Residue (IR)	2.10	1.61	1.74	2.04	2.13
Coefficient of Variation	4 %	5 %	3 %	1 %	2 %

Table 2 above, shows XRF chemical analysis of cement grades 42.5R, 42.5N, and 32.5R, with corresponding coefficients of variation from quintuplicate analysis. And provide conformity with international standards such as ASTM C150, EN 197-1, and NIS 439. The silica (SiO₂) content across the samples varied from 14.14 % in sample D to 16.47 % in sample E. Compared with the typical standard range for Portland cement, which lies between 19 to 23 % according to [Scrivener *et al.*, 2015], the cements samples analyzed here appear slightly lower in silica, which reflects the high-lime and relatively low-silica nature of raw materials commonly used in local production. Sample E, with the highest SiO₂, lower early strength development but greater strength at later curing time, while sample D, with the lowest silica, showed improved reactivity. The very low coefficient of variation (0 % to 2 %) associated with SiO₂, demonstrated high reliability of the measurements. Consequently, alumina

(Al₂O₃) ranged from 4.56 % (D) to 5.74 % (E), falling within the standard range of 2% to 8 % as stipulated by ASTM C150, has strong influence in early strength gain as well as sulfate resistance and accelerate early setting reactions but also heightens the risk of sulfate attack in aggressive environments. Ferric oxide (Fe₂O₃) concentrations were observed between 3.14 % (D) and 4.03 % (C), fell within the acceptable range for Portland cement between 0.5 % and 6 %. Calcium oxide (CaO), dominant component, was found to be consistently high across the samples, 64.35 % (E) to 65.30 % (D) and the values are close in agreement with the typical Portland cement range of 60 % to 67 %. And Sulphur trioxide (SO₃) content was observed between 1.59 % in (C) and 1.95 % (B) and below maximum permissible limit of 3.5 % for CEM II (EN 197-1). SO₃ originated from gypsum added during cement grinding and regulates setting by controlling the hydration rate of C₃A. Also, prevent flash setting, but

excess SO₃ may lead to expansion and durability issues. However, Loss on ignition (LOI) ranged from 7.84 % (C) to 12.96 % (D). LOI reflects the presence of volatile components such as moisture, carbon dioxide from carbonates compounds. Standards LOI values is less than 5 % for pure clinker, and tolerate up to 10 %. The higher LOI were observed in samples D and E, exceeding 11 %, and indicates poor storage conditions, partial carbonation, or excessive blending materials. And this, adversely affect durability, reduce strength, and lead to potential volume instability. Sample C, with the lowest LOI of 7.84 %, is more stable and less likely to be compromised by carbonation effects. Finally, Insoluble Residue (IR) content ranged between 1.61 % (B) and 2.13 % (E), all comfortably within the EN 197-1 limit of 5 %. Insoluble residue represents non-reactive impurities such as unburnt carbon, quartz, or other inert materials.

Lower IR values are desirable as they indicate a higher proportion of hydraulically active material. Comparatively, 42.5R cements (samples A and B) showed balanced oxide compositions with good CaO levels, moderate silica, and controlled alumina.

Setting Time of Cement Grades

Affected by cement fineness, water to cement ratio, and sulfite content. ASTM specifies ≥ 45 minutes for initial setting time and ≤ 375 minutes for final setting time using a Vicat apparatus. Table 3, shows the setting time results using NIS 444-1:2018 specifies initial setting time of ≥ 75 minutes for 32.5R and ≥ 60 minutes for 42.5N and 42.4R classes respectively. The initial and final setting time each cement grade samples are in Table 2:

Table 3: Setting Times of Cement Grades

Sample	Cement Grade	Initial Setting Time	Coefficient Variation	of NIS-444-1: 2018	Final Setting Time	Coefficient of variation
A	42.5R	136	1.04	≥ 60	216	0.98
B	42.5R	133	0.98	≥ 60	208	0.79
C	42.5N	155	1.58	≥ 60	216	0.21
D	32.5R	136	1.40	≥ 75	205	1.16
E	32.5R	142	1.11	≥ 75	212	1.07

From the above table 3, initial setting time values for the cement samples analyzed are within the range of initial 133 to 155 minutes and final setting time are within the range 205

to 216 minutes, satisfying NIS 444-1:2018 and ASTM standard and the data from table 2 deduced the bar chat as shown in figure 1.

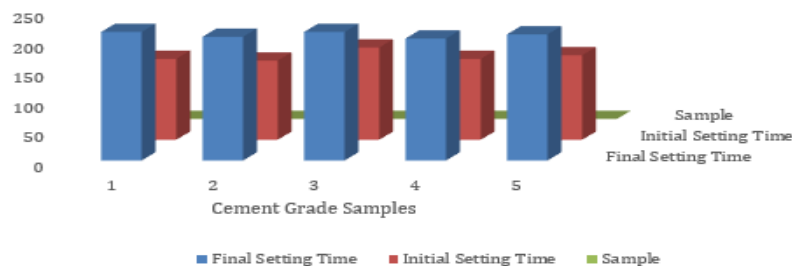


Figure 1: Setting Times of Cement Grades

Flexural Test Result and Analysis

Cement paste strength is typically defined in three ways: compressive, tensile and flexural. These strengths are affected by water and cement ratio, cement fineness, aggregate ratio,

mixing and compaction, curing conditions, size and shape of specimen, loading conditions and curing age. Table 4 below gives a breakdown of the results obtained from Flexural Test.

Table 4: Flexural Strength (MPa) of the Cement Grades at different Curing Ages

Sample	Cement Grades	2 Days	C.V	7 Days	C.V	28 Days	C.V
A	42.5R	3.6	2.78	4.6	3.3	5.8	1.72
B	42.5R	3.9	1.5	5.0	1.1	5.4	0.91
C	42.5N	3.6	4.8	5.0	1.2	5.4	2.94
D	32.5R	2.8	0.0	4.1	5.1	5.0	2.0
E	32.5R	3.8	4.0	4.7	1.2	5.4	2.85

The Flexural Strength in Table 4 above, at 2 days, the 42.5R samples (A and B) achieved the highest strengths (3.6 MPa - 3.9 MPa), reflecting hardening characteristic while the 32.5R samples (D and E) showed the lowest values (2.8-3.8 MPa). By seven (7) days all grade recorded significant improvement with 42.5 (sample C) and 42.5R grade reaching 5.0 MPa, outperforming the 32.5R grades, and matches with some

researchers view that higher clinker content and finer particles, accelerate hydration and promote higher strengths compared to 32.5R cements [Aniweteli, 2023; Odewale, *et al.*, 2020]. And at 28-days, the 42.5R cement again demonstrated superior strength up to 5.8 MPa, while 42.5N achieved comparable performance (5.4 MPa), surpassing the 32.5R grades (4.7 MPa - 5.0 MPa).

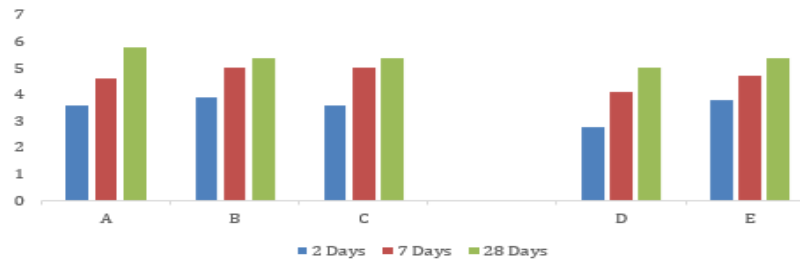


Figure 2: Flexural Strength (MPa) of the Cement Grades at different Curing Ages.

Compressive Strength (MPa) of the Cement Grades at different Curing Time

Compressive strength in cement is the measure of its ability to bind to the solid particles with which it is mixed. The NIS

for cement clearly specifies three classes of cement, namely, 32.5N/32.5R, 42.5N/42.5R, and 52.5N/52.5R (where N denotes the class with ordinary early strength and R signifies class with higher early strength).

Table 5: Compressive Strength (MPa) of the Cement Grades at different Curing Ages

Sample	Cement Grades	2 Days	NIS	C.V	7 Days	NIS	C.V	28 Days	NIS	C.V
A	42.5R	20.1	≥20	1.66	31.3	≥16	2.6	43.2	≥42.5	0.71
B	42.5R	23.5	≥20	0.6	34.8	≥16	2.2	44.8	≥42.5	0.43
C	42.5N	20.8	≥10	1.6	33.1	≥16	1.9	43.7	≥42.5	0.59
D	32.5R	15.1	≥10	2.0	24.7	≥16	2.2	33.52	≥32.5	1.01
E	32.5R	20.4	≥10	1.4	31.8	≥16	1.9	37.6	≥32.5	0.52

The compressive strengths for all samples of the cements studied were determined at 2-days, 7-days and 28-days after mixing, Table 5. The results indicated that about 70% of the 28-day strength was attained at early age of 7-days for all the cement grade samples, which is within the specification limits as shown in Figure 3, but after 28 days the development of strength increased in the cement samples studied namely: A, B, C, D and E where the values ranged from 33.52 MPa to 44.8 MPa, all within the specification limits compared to other researchers work. High lime content is associated with early strength whereas a slightly lower content of lime favors the ultimate strength, which develops gradually over a longer

period of time, and note that higher cement production temperatures are required to burn the high lime mixtures. The two (2) days compressive strengths test analysis, showed sample D having the least compressive strength and sample B attaining the highest 2 days. Low strength of sample D could be due to its higher high-grade limestone as indicated by its highest LOI. Results also are in conformance with work by. The 7 days compressive strength are in the order, with sample D showing lowest strength and samples B highest strength. The 28 days compressive strength showed similar behaviour of sample D being lower while B showing highest strength.

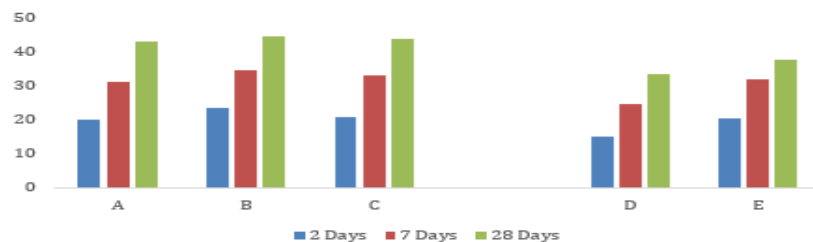


Figure 3: Compressive Strength and Curing Age of Cement Grade Samples.

NIS specifies 32.5 MPa for 32.5R and 42.5 Nmm² 42.5N and 42.5R classes of cement. All cement samples satisfy NIS 444-1:2018 specification for compressive strength. The coefficient of variation in all cases is below 10% indicating an excellent reliability and reproducibility of the results.

Blaine of the Cement Grade

Base on principle that the rate of flow of air through a layer of compressed particles is proportional to the fineness of the particles, the test estimates the flow rate of air through a bed of cement particles. Table 6, below shows the result obtained from the Blaine of Cements.

Table 6: Blaine of Cement Grades

Sample	Cement Grade	Blaine (cm ² /g)	Coefficient of Variation	EN 197-1 (cm ² /g)
A	42.5R	4100	0.30	≥ 3,200-4,500
B	42.5R	4040	0.18	≥ 3,200-4,500
C	42.5 N	3940	0.09	≥ 3,200-4,500
D	32.5R	4480	0.16	≥ 3,200-4,500
E	32.5R	4010	0.09	≥ 3,200-4,500

Particle size distribution plays a vital role in determining the hydration rate and strength gain of cement: the smaller the particle size, the greater the surface area-to-volume ratio, which enhances the possibility for the water-cement reaction to occur effectively [Kindi *et al.*, 2024]. Sample D recorded the highest Blaine values, indicating fineness of the surface

Area which enhances the potential for effective hydration reactions, and followed by sample A, B, E and C, with sample C having the lowest Blaine value. All five samples exhibited Blaine values in EN 197-1 specification of $\geq 3,200$ -4,500, and figure 4 below gives clarity of Blaine test across the five cement samples.

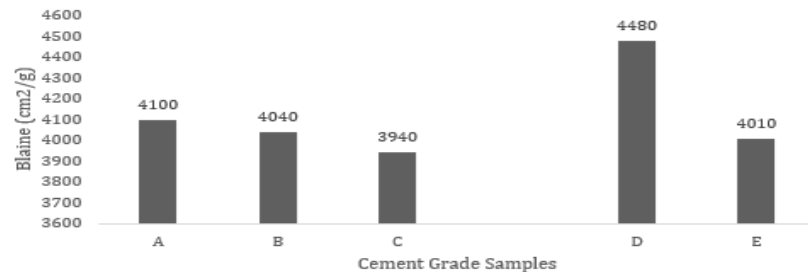


Figure 4: Blaine of Cement Grades

Residue of Cement Grades

Sharma *et al.*, 2021, stated that cement grade with low residue value exhibit higher rates of strength gain at early curing time. From Table 7 below, sample A, B, C, D and E exhibited residue on 45µm are within the range of 9.2 to 12.3 %. While D exhibited the lowest residue passing through the 45 µm sieves but indicates a finer particle size distribution. Such fineness is expected to enhance early hydration kinetics, thereby contributing to higher early-age strength development. This trend is followed by samples A, B, E and C, with sample C presenting the highest residue content, signifying comparatively coarser particles. The effects of

greater fineness on strength are generally seen during the first seven days. NIS 448:2018 recommended that the percentage by mass of fines retained on 45 µm should not exceed 10 %, making sample D the sample that meets recommended specification.

Furthermore, the coefficient of variation (CV) obtained from quintuplicate determinations for all samples was ≤ 10 % confirming excellent reproducibility and reliability of the experimental results. When correlated with Blaine specific surface area, the results reveal an inverse relationship with samples with higher Blaine values exhibiting lower residue percentage. This is shown in Figure 5 below.

Table 7: Residue of Cement Grades

Sample	Cement Grade	Residue 45µm	Coefficient of Variation
A	42.5R	10.1	0.77
B	42.5R	10.5	1.15
C	42.5N	12.3	0.70
D	32.5R	9.2	1.3
E	32.5R	10.5	0.95

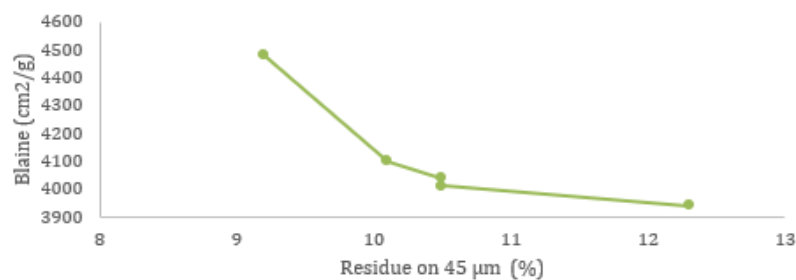


Figure 5: Graph of Blaine vs Residue on 45 µm

Expansion LC of Cement Grades

Le Chatelier's (LC), a measure of the extent to which a hardened cement pastes retain its volume after setting without delayed destructive expansion, caused by hydration of excessive amounts of free lime. Expansion in the cement

samples analyzed within 0.5 -1.0 mm range, with NIS 444-1:2018 specifies ≤ 10 mm for destructive expansion. Low LC expansion values, indicate low free lime content in the cement samples and indicate the cement sample being sound. Table 8 below shows the LC result.

Table 8: Le Chatelier's Expansion of Cement Grades

Sample	Cement Grade	Expansion LC (mm)	Coefficient of Variation	NIS 444-1:2018
A	42.5R	0.5	1.80	≤ 10
B	42.5R	0.5	7.61	≤ 10
C	42.5N	1.0	4.44	≤ 10
D	32.5R	1.0	1.01	≤ 10
E	32.5R	0.5	1.80	≤ 10

CONCLUSION

The research was motivated by concerns over variations in cement quality, structural failures, and the lack of empirical data on hydration kinetics of Nigerian cements. This research effectively identified the characteristics and involved methodological laboratory tests to determine the chemical composition (XRF), setting times (Vicat apparatus), fineness (Blaine and residue tests), consistency, soundness (Le Chatelier's expansion), and mechanical strength development (compressive and flexural strength at 2, 7, and 28-days curing). Results obtained were benchmarked against Nigerian Industrial Standard (NIS 444-1:2018) and selected international standards (ASTM and EN).

Consequently, it was observed that all cement samples exhibited Blaine fineness within EN 197-1 limits (3,200 to 4,500 cm²/g), with 32.5R (sample D) showing the highest fineness (4480 cm²/g) and lowest residue, indicating superior early hydration potential. A normal consistency of all samples falling within 25 % to 28 %, satisfying NIS standards, except for sample B which slightly exceeded the range. The expansion values were very low (0.5 to 1.0 mm), indicating that all samples were sound with negligible free lime content and Setting times (initial: 133min to 155 min, final: 205 to 216 min) satisfied both NIS and ASTM standards, with coefficients of variation ≤ 10 %, confirming reliability.

On the mechanical test and analysis, Flexural strength test showed that 42.5R cements have highest early strength (3.6 MPa to 3.9 MPa at 2 days; 5.8 MPa at 28 days), outperforming 32.5R cements (2.8 MPa to 3.8 MPa at 2 days; 4.7 to 5.0 MPa at 28 days). All samples conformed with NIS/ASTM standards, but higher grade (42.5) cement consistently outperformed grade 32.5, particularly in early and long-term strength development.

The study confirmed significant differences in hydration properties between the two cement grades, aligning with their intended structural applications. Based on the results and in line with the objectives of the study, the following conclusions are drawn. The Chemical Composition, XRF analysis revealed that the oxide compositions of all cement samples were within acceptable limits, with minor variations in silica, alumina, and lime contents. These differences accounted for observed variations in hydration kinetics and strength development. The Setting Time, Compressive Strength, and Other Physical Properties (Objective 2): All samples met NIS and ASTM requirements for setting time and expansion. However, compressive and flexural strength analysis demonstrated that 42.5-grade cements (R & N) consistently achieved higher strengths than 32.5R across all curing time.

Finally, comparing results with National and International Standards, all tested samples complied with the minimum requirements of NIS 444-1:2018, ASTM C150, and EN 197-1, demonstrating acceptable quality. However, 42.5R cement provided superior performance, making it more suitable for high-strength structural applications, while 32.5R is better suited for non-load-bearing or plastering applications. The determination of hydration kinetics using indirect methods were fully achieved, and the study provides empirical evidence for optimal cement selection in Nigerian construction practice

REFERENCES

Abdullahi M. E., Samuel S. S., Enumah A., & Yakubu S. (2023). A Review of the Operational Challenges in the Cement Industry in Nigeria. *Journal of Environmental Planning and Sustainable*, 8(2), 32–52.

Adeleke, B. O., Olutoge, F. A., & Amusan, L. M. (2023). Evaluation of the quality of selected Portland cement brands in Nigeria. *Journal of Building Pathology and Rehabilitation*, 8(1), 12-24.

Adeniran, A. A., Olutoge, F. A., & Aderonmu, P. A. (2021). Comparative analysis of the strength characteristics of Nigerian Portland cement brands. *Construction and Building Materials*, 287, 123045.

Adesina, A., & Awoyera, P. (2022). Durability performance of concrete made with different grades of Nigerian Portland cement. *Case Studies in Construction Materials*, 16, e00921.

Alabadan, B. A., Olutoge, F. A., & Fapohunda, C. A. (2020). Hydration and strength characteristics of Portland cement in tropical climatic conditions. *Nigerian Journal of Technology*, 39(2), 345-354.

Aniweteli, J. N. (2023). Effects of Selected Brands of Portland Cement on Compressive Strength of Concrete. *NAU Department of Civil Engineering Final Year Project & Postgraduate Portal*, 2(1).

Barbhuiya, S., Nepal, J., & Das, B. B. (2023). Properties, compatibility, environmental benefits and future directions of limestone calcined clay cement (LC3) concrete. *A review Journal of Building Engineering*, 79, Article 107794, <https://doi.org/10.1016/j.jobee.2023.107794>

Briki, Y., Zajac, M., Ben Haha, M., & Scrivener, K. (2021). Impact of limestone fineness on cement hydration at early age. *Cem. Concr. Res.*, 147, Article 106515, <https://doi.org/10.1016/J.CEMCONRES.2021.106515>

Dangote Industries. (2023). *Nigeria Cement Market Report*.

Ettu, L. O., Ajoku, C. A., & Nwachukwu, K. C. (2019). Quality assessment of some commercially available Portland cement brands in Nigeria. *Journal of Civil Engineering and Construction Technology*, 10(3), 45-53.

Gartner, E. (2020). Eco-efficient cements: Potential economically viable solutions for a low-CO₂ cement-based materials industry. *Cement and Concrete Research*, 114, 2–26.

Harris, B., Matthews, H. S., & Grant, J. A. (2021). The environmental impact of cement production: A global assessment. *Environmental Science & Technology*, 45(22), 9079-9085.

International Energy Agency (IEA). (2020). *Cement technology roadmap: Carbon emissions reductions in the cement sector*.

Joshua, O., Olusola, K. O., & Ogunde, A. O. (2021). Comparative evaluation of the mechanical properties of Nigerian Portland cement brands. *International Journal of Civil Engineering and Technology*, 12(4), 112-125.

Juenger, M.C.G., Snellings, R., & Bernal, S.A. (2019). Supplementary cementitious materials. New sources, characterization, and performance insights. *Cement and Concrete Research*, 122. pp. 257-273.

- Kindi, H.A., Abdel-Gawwad, H.A., Meddah, M. S., Jabri, K. A., & Mohamedzein, Y. (2024). An overview of the critical influential parameters on the performance of limestone calcined clay cement paste, mortar, and concrete. *Constr. Build. Mater.*, 444, Article 137615.
- Lea, M. F., & Mason, O. T. (2025, April 7). Cement - Definition, Composition, Manufacture, History and Facts. *Encyclopedia Britannica*.
- Mohammed, S., Jimoh, A., Evuti, A. M., Giwa, A., & Ibrahim, A. A. (2025). Pretreatment and Characterization of Selected Precursors for Chitin/Chitosan Production[†]: *FUDMA Journal of Engineering and Technology*, vol. 1, no.2, Pp. 885-897.
- Montgomery, D. C. (2020). Design and analysis of experiments (10th ed.). Wiley.
- Müller, D., Clift, R., & Chen, G. (2019). Sustainable development in cement production: Assessing environmental impacts and future strategies. *Journal of Cleaner Production*, 220, 484-494.
- Odewale, S. A., Oladunni, A. A., & Oyewale, B. O. (2020). Chemical Characterization of Nine Locally Made Cement Products for Quality Assurance in Nigeria Cement Industry. *European Journal of Engineering and Technology Research*, 5(6), 1-7.
- Onyelowe, K. C., Onyia, M. E., & Onukwugha, E. (2021). Hydration kinetics and compressive strength development of Nigerian cement blends. *Journal of Materials in Civil Engineering*, 33(7), 04021145.
- Onyelowe, K. C., Kontoni, D. N., Ebid, A. M., Dabbaghi, F., Soleymani, A., Jahangir, H., & Nehdi, M. L. (2022, July 7). Multi-objective optimization of sustainable concrete containing fly ash based on environmental and mechanical considerations. *Journal Buildings*, Vol. 12, Issue 7, Pp 948, Pub. MDPI.
- Saillio, M., Baroghel-Bouny, V., & Pradelle, S. (2015). Various durability aspects of calcined kaolin-blended Portland cement pastes and concretes. *RILEM Bookse*, 10 (2015), pp. 491-499.
- Scrivener, K. L., Juilland, P., & Monteiro, P. J. M. (2015, December). Advances in understanding hydration of Portland cement. *Cement and Concrete Research*. Vol. 78, Part A, Pp 38-56.
- Scrivener, K., Ben-Haha, M., Juilland, P., & Levy, C. (2023). Research Needs for Cementitious Building Materials with Focus on Europe. *RILEM Tech Lett* 2023, 7, 220-252.
- Sharma, M., Bishnoi, S., Martirena, F., & Scrivener, K. (2021). Limestone calcined clay cement and concrete: a state-of-the-art review *Cem. Concr. Res.*, 149, Article 106564, <https://doi.org/10.1016/j.cemconres.2021.106564>
- Snellings, R. (2022). *Cement and Concrete Research*, 152, 106682.
- Taylor, H. F. W. (1997). *Cement chemistry* (2nd ed.). Pearson Education Limited.
- Taylor, H. F. W. (2020). *Cement chemistry* (3rd ed.). Thomas Telford Publishing.
- Techflow, (2020). *Clearing the Air: Dust Collection & Emission Control Technologies for Global Cement Industry*.
- Wang, L., Ur-Rehman, N., Curosu, I., Zhu, Z., Beigh, M.A.B., Liebscher, M., & Mechtcherine, V. (2021). On the use of limestone calcined clay cement (LC3) in high-strength strain-hardening cement-based composites (HS-SHCC). *Cem. Concr. Res.*, Article 106421, <https://doi.org/10.1016/j.cemconres.2021.106421>

