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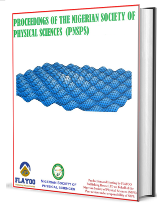

Assessment of physicochemical properties of Lafarge cement towards achieving a sustainable society

Abiodun Oluwatosin Adeoye*, Rukayat Oluwatobiloba Quadri, Olayide Samuel Lawal

Department of Chemistry, Federal University Oye-Ekiti, Ekiti State, Nigeria

ABSTRACT

Conducive shelter is one of the basic needs of life, and in this modern society, large numbers of livable structures are made of cement. The number of cases of collapsed structures/buildings in Nigeria has been on the increase in recent times, reported in cities like Lagos, Ibadan, Abuja, Port Harcourt, etc. There is an urgent need to find lasting solutions to tackle structural/building challenges arising from the use of cement. The manufacturing of cement is a continuous process, necessitating ongoing monitoring of the quality of Ordinary Portland Cement, as recommended by the Standard Organisation of Nigeria (SON). The study assessed the physicochemical and mechanical properties of four brands of Lafarge cement named Elephant Classic Supaset, Powermax, and Standard grade using standard procedures. The cement analysis reveals that the SiO_2 content increases with the grade of cement, with the highest value of 20.46% in 52.5-grade cement. Similarly, higher grades of cement demonstrate greater values in Al_2O_3, Fe_2O_3, and MgO, indicating enhanced material composition for higher strength applications. Most of the parameters analyzed (%SiO_2, %SO_3, 28-Day strength, and % oxides of metal) align with the standards of SON and ASTM. It can be concluded that building failure due to the use of these cements could be linked to the use of nonprofessional builders, other fake materials, and corruption by contractors.

Keywords: Physicochemical properties, Cement grades, Portland cement, Lafarge cement.

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1. INTRODUCTION

The housing system in Nigeria has expanded significantly due to the widespread availability of cement, a crucial component of concrete that is essential for modern society. Therefore, it may be inferred that comfortable lifestyle in this present era cannot be achieved without cement, since it is the fundamental component of concrete utilized in the construction of contemporary buildings and structures [1]. Cement is a major material used in concrete production, serving as a binding agent when combined with water. Concrete is suitable to build a definite structural and non-structural applications. The quality of any concrete is mostly contingent upon the grade of cement. The primary attribute of structural concrete is its compressive strength, which depends on the strength of the cement paste. The utilization of standard and high-quality cement yields economical concrete production.

Numerous brands of Ordinary Portland Cement (OPC) are sold in various building market in Nigeria. Many of these brands exhibit clear differences in physical qualities attributable to dif-

*Corresponding Author Tel. No.: +234-805-6478-597.
e-mail: bioken2017@gmail.com (Abiodun Oluwatosin Adeoye)

ferences in the proportion of chemical materials components. Portland cement primarily comprises lime, silica, alumina, and iron oxide as its principal basic components. Aside from a little residue of unreacted lime during the heating of the raw materials in kiln (calcination), these materials react at molten state to yield complex products, achieving a condition of chemical equilibrium. The heating process in the kiln (calcination) causes volume contraction, whereas hydration results in expansion. Calcination and hydration are the two possible reactions state:

Calcination:

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g),$$

Hydration:

$$CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s).$$

Properties of Portland cement largely depends on ratio combination of lime, silica, alumina, iron oxide and other additives. Portland cement contains four major phases; Alite: tricalcium silicate (C_3S), belite: dicalcium silicate(C_2S); aluminate: tricalcium aluminate (C_3A) which is detrimental and Tetracalcium alumino-ferrate (C_4AF) which has little on cement property [2]. The hydration of alite (C_3S), and belite (C_2S) contributes to the early and late strength respectively resulting into amorphous calcium silicate hydrate (C-S-H gel) which works as the major binding phase in hardened paste of Portland cement and portlandite $Ca(OH)_2$ [3].

There is urgent need to find lasting solutions to tackle structural/building challenges arising from the use of cement, this research seeks to examine the quality of a major cement manufacture being used in Nigeria for concrete making to know if it of standard quality because use of substandard cement in construction of edifice, structural works and non-structural work may lead to loss of income, lives and properties. Building collapsed cases are now a common trend in major cities in Nigeria such as Lagos Island, Ibadan, Abuja, Port Harcourt etc. [4, 5]. The number of building collapse instances in Nigeria from 1974 to 2010 was 47 in Lagos, 17 in Southwest Nigeria, 8 in Abuja, 6 in South Nigeria, 5 in Southeastern Nigeria, 4 in North West Nigeria, 4 in North Central Nigeria, and 0 in North Eastern Nigeria, according to Windapo & Rotimi [6]. Between 2010 and 2019, 415 people died in collapse instances in Lagos, Abuja, Enugu, Gombe, Jos, Benin, Abeokuta, Ilorin, Imo, Anambra, and Porthacourt, according to Awoyera *et al.* [7].

Building collapses in Nigeria are often caused by poor structural design, low-quality materials, a failure to adhere to authorised plans, craftsmanship, and an absence of competent construction experts, according to studies [4, 5]. Those involved in the construction industry, including manufacturers, consultants, governments, developers, landlords, and residents, faced a grave danger from these building collapse incidents.

Assessment of physicochemical and mechanical properties of cement is very important since these parameters are the determinants of cement quality which include its strength, durability and workability respectively. The Standard Organization of Nigeria is the regulatory body that determines the quality of cement based on listed physicochemical and mechanical properties ranges. Several studies have worked on physicochemical analysis of cement to ascertain conformity with Standard Organisation of Nigeria (SON) [8]. Muibat [9], analysed indigenous Portland cement brands (Burham, Dangote, Ashaka and Elephant) and found out that they conform in their chemical composition with the set of standards. However, the study revealed Ashaka and Elephant physico-mechanical properties show considerable deviation from [10, 11]. The study described Ashaka and Elephant brand to be fit for structures involved with low loading. The Burham cement matched well both in its chemical and physicomechanical properties and thus can be used for structures involved with loading. Omoniyi and Okunola, [12] selected four cement brands randomly and confirmed that they are comparable and also demonstrated high quality via the analysis of their physicochemical and mechanical properties. Research by Soltani *et al.* [13] evaluated the quality of three different brands of Portland cement. Two of the three brands were found to efficiently meet the European (EN197-1) standard specification, according to the results. Two locally produced brands of Portland cement in Nigeria were analysed using standard procedures, and the results show that their chemical composition is in line with global standards.

In addition, structures that are subjected to low loading are likely not to have failure issue if constructed by majority of Portland cement marketed in Nigeria [14]. The major important factors in cement chemical content control are; lime saturation factor (LSF), silica ratio (SR) and aluminum ratio (AR) [15, 16]. An evaluation of various brands of Portland cement sourced from the Umuahia industrial market indicated that the specific gravity of several brands fell below the minimum standard value of 3.1 [17]. Abdulmumeen [18], studied the physico- mechanical properties of three brands of cement use in Kwara state. The selected brands were Dangote cement, Elephant supaset cement and Elephant Lafarge cement. The properties investigated were cement fineness, consistency, setting time, soundness and compressive strength. All samples' brands analyzed falls within the requirements of the appropriate BS standards but Elephant superset cement on the other hand performed better than others by attaining a strength of 26.0 N/mm^2 at 28 days which means that it is suitable structural concrete works.

Since production of cement is a continuous process a need for continuous monitoring of the quality of Ordinary Portland Cement (OPC) is inevitable has recommended by Standard Organization of Nigeria (SON). This study seeks to perform detailed analysis of physicochemical properties (metal oxides, anions, loss on ignition, insoluble residues, surface area, cement quality and mineralogy and mechanical properties (compressive strength)) of different cement grades of a major cement manufacturer (Lafarge Cement) and also to compare the quality of the different grades of cement. Metal oxide determination and SO_3 will be done using X-ray fluorescence, which provides accurate readings as compared to common wet chemical analysis reported in Abdulmumeen [18]. It is expected that these grades of cement satisfy SON [8] and ASTM C150-04 [19] criteria in order to function effectively in building or structural works. These properties are indicators which give users the confidence that in most cases that concrete from such cement will give satisfactory performance as stated by the company that Supaset is formulated for block making, PowerMax for construction work and homeowner buildings and Elephant classic for productive concrete and mortar.

2. MATERIALS AND METHODS

2.1. CHEMICALS

The chemicals utilized were of analytical grade, including concentrated hydrochloric acid, sodium hydroxide solution, glycol, dilute nitric acid, methyl red, and deionized water.

2.2. COLLECTION AND SAMPLE PREPARATION

Four elephant cement grades Standard (52.5 grade), Elephant classic (32.5 grade), Supaset (42.5 grade), PowerMax (52.5 grade) coded as (G1, G2, G3 and G4) were used in this study. The cement brands were obtained from prominent dealers in the market and were carefully stored and covered with plastic sheets in the laboratory. Regular monitoring is conducted to prevent the formation of lumps.

2.3. PHYSICAL PARAMETERS ANALYSES

2.3.1. Analysis of fineness

This study employed a Blaine air permeability apparatus, characterized by precise measurement, standardization, correlation with strength, broad acceptance, simplicity, and cost-effectiveness, to assess the fineness of cement samples (G1, G2, G3, and G4) utilizing the standard air permeability method (ASTM C204-11) [20]. To find the fineness of cement, the air permeability technique uses its specific surface area, which is the sum of the surface areas of all the particles in 1 g of cement. Fineness average value was obtained by using three samples of each cement grade. A 45 µm sieve was used to determine the fineness of the samples (G1, G2, G3 and G4) analysed.

2.3.2. Analysis of insoluble residue (IR)

After measuring and transferring 1.0 g of each sample (G1, G2, G3, and G4) into 250 ml beakers, exactly 5 ml of concentrated HCl was added to dissolve the samples. The mixture was then diluted to 100 ml with warm deionised H_2O. Uniform sample dispersion was attained with a magnetic stirrer prior to bringing the fluid to a boil on a hot plate. Filtering was done using high grade Whatman No. 41 filter paper after heating. The obtained filtrate was rinsed many times (four times) with hot distilled water in a beaker. The residue obtained on the filter paper was transferred to a beaker, to which 100 ml of 0.10 M NaOH solution was added, followed by the addition of 3 to 5 drops of methyl red indicator. Four to five drops of concentrated HCl were added to the liquid while boiling until the color changed to pink. The mixture was re-filtered through filter paper, followed by washing the filter paper with 0.20 M NH4Cl solution about four times. The removal of precipitates from the filter paper was accomplished using rubber scrapers [10]. The mass of an empty crucible was documented as W_1 following its ignition at 950 °C for 5 minutes in a furnace, subsequently cooled to room temperature in a desiccator. The filter paper along with its residue was then placed in the crucible and ignited in the furnace at a temperature of 950 °C for a duration of 30 minutes. The crucible and its contents were withdrawn, cooled to ambient room temperature in a desiccator, and then weighed as W2. The Insoluble Residue (IR) proportion was calculated using:

$$\%IR = (W_2 - W_1) \times 100. \tag{1}$$

2.3.3. Analysis of loss on ignition (LOI)

A mass of 3.0 g of each sample (G1, G2, G3, and G4) was weighed and transferred into pre-weighed dried platinum crucibles. Subsequently, the crucibles containing the samples were ignited in a furnace at temperatures exceeding 900 °C for approximately 30 minutes. Subsequently, the crucibles were extracted, allowed to cool, and then weighed [10]. LOI was computed using:

$$LOI = \frac{(W_3 + W_2 + W_1) \times 100}{W_2}, \tag{2}$$

where W_1 is the weight of empty crucible, W_2 is the weight of sample and crucible, W_3 is the weight of crucible and sample after ignition

2.3.4. Consistency of standard cement paste

Samples G1, G2, G3, and G4, each weighing 400 g, were distributed on steel plates for approximately 30 minutes to equilibrate to the mixing room temperature of 27 ± 2°C. Samples were mixed for 90 seconds following the addition of 200 ml of water to the mixer bowl. To scrape and transfer any paste that stuck to the bowl outside the mixer zone, the mixing was stopped every 15 seconds. Within a short period, mould was promptly removed using a trowel. The Vicat apparatus's plunger component had its mortar placed on top of the mould and paste. After then, the plunger was lowered until it touched the paste's surface. The substance was quickly discharged and allowed to soak into the paste. At the end of the minute, the Vicat apparatus reading was recorded. A water-cement ratio is seen to be indicative of consistency if the plunger reaches a depth of 5 to 7 mm above the mould bottom [11]. The percentage consistency of each cement sample was calculated using:

$$Percentage\ Consistency = \frac{Water\ Consumed}{Weight\ of\ the\ cement\ sample} \times 100. \tag{3}$$

2.3.5. Analysis of strength

Four samples, designated G1, G2, G3, and G4, each with a mass of 450 g, were added to a bowl. Following this, 225 g of water was added, and standard sand was placed into the hopper at the top of the mixer. After the 90 seconds of mixing, the machine was stopped for another fifteen seconds so that a rubber scraper could be used to move the mortar from the bowl to the bottom. After another 60 seconds of mixing, the mortar bowl was transferred to the jolting apparatus [11]. A single scoop, or around 300 g, of the mixture was distributed throughout the mold's layers. Careful disassembly of the jolting machine and the mould was required to remove the hopper. The mold's top was covered by a plate with identification markings. After demoulding, samples older than one day were kept in a controlled water container; the prisms were subsequently separated inside the water. After 15 minutes, before the strength test, the prisms were removed from the water. At 2 days and 28 days of age, the strength test was carried out.

In the compressive strength machine, the prism was placed in the middle, sandwiched between two plates. The mass loading in gram was increased at a steady rate of 2.4 kNS^{-1}. The test was conducted again with all prism halves; the compressive strength (Cs) in MPa was determined using:

$$Cs = \left[\frac{Fc}{1.6 \times 10^3}\right], \tag{4}$$

where Fc denotes maximum load at fracture in evaluated in kilonewton (kN).

2.4. CHEMICAL PARAMETERS ANALYSES

2.4.1. Quality and mineralogy of cement

The mineralogy composition of cement determines its quality usually calculated from the oxide concentrations of the cement [13, 21]. Tricalcium potassium (C_3S), tricalcium aluminate (C_3A), dicalcium sulphate (C_2S), and tetracalcium aluminoferate (C_4AF) were calculated using the following equations:

$$\frac{\left[(4.0713CaO)-(7.6929SiO_2)-(6.1155Al_2O_3)-(1.4578Fe_2O_3)-(2.8529MgO)\right]}{2.8598}, \tag{5}$$

$$C_3A = \left[(2.650Al_2O_3)-(1.682Fe_2O_3)\right], \tag{6}$$

$$C_2S = \left[(2.87SiO_2) - (0.7544C_3S)\right], \tag{7}$$

$$C_4AF = \left[(3.043Fe_2O_3)\right], \tag{8}$$

$$LSF = \left[\left(\frac{CaO}{2.8SiO_2} + 1.2Al_2O_3\right) + (0.65Fe_2O_3)\right], \tag{9}$$

$$Aluminum\ ratio\ (AR) = \left[\left(\frac{Al_2O_3}{Fe_2O_3}\right)\right], \tag{10}$$

and

$$Silica\ ratio\ (SR) = \left[\left(\frac{SiO_2}{Fe_2O_3 + Al_2O_3}\right)\right]. \tag{11}$$

Equations (5) - (11) are solutions of simultaneous equations which is valid for $A/F \geq 0.64$. In the equations, C is calcium oxide (%), S is silica oxide (%), A is aluminum oxide (%), F is ferric oxide (%), and S is sulfur trioxide (%), and F = 0.2344.

2.4.2. Determination of free-lime (CaO)

In a 500 ml volumetric flask, 100 g of each sample (G1–G4) was added, followed by 2 g of dry sand and 40 ml of glycol. Upon sealing with a stopper, the solution was shaken vigorously. The mixture was placed in a gravity convection oven for set at 70 °C for 30 mins, with extra shaking every 5 minutes. After then, the solution was filtered via suction pump through a dry filter paper. Then, three drops of bromophenol blue indicator were added to the filtrate and the colour change was observed after titration with 0.10 M HCl [11]. The Free CaO was determined using the mathematical expression:

$$\%FL = V(HCl) \times F. \tag{12}$$

2.4.3. Determination of Cl^-

In order to facilitate decomposition and eliminate sulphides, boiling diluted HNO_3 was applied to all four samples (G1, G2, G3, and G4). A specific amount of a commercially available silver nitrate solution was used to precipitate the dissolved chloride. Back titration procedures were used to assess the chloride concentration.

3. RESULTS AND DISCUSSION

3.1. PHYSICOCHEMICAL AND MECHANICAL PROPERTIES OF THE DIFFERENT GRADES

As shown in Table 1, the percentage compositions of SiO_2 in cement samples G1, G2, G3, and G4 are 19.80, 15.90, 17.76, and 20.46%, respectively. Samples G1 and G4 fall within the range of 19.00 - 23.00% for general purpose cement, as shown in Table 3, but samples G2 and G3 are do not conform with this standard. The grades (G1, G3 & G4) conform to the SON standard of SiO_2 > 17% presented in Table 2. The range obtained in this study is similar to study [12]. The G4 grade has the highest silica content (SiO_2) (20.46%), which in turn increases strength development because SiO_2 facilitates the formation of the strong C-S-H (Calcium—Silicate—Hydrate) gel responsible for strength. Its high value in G3 and G4 contributes to clinker formation and improving early strength.

According to Table 1, the percentage compositions of calcium oxide in cement samples G1, G2, G3, and G4 are 63.22%, 61.74%, 61.55%, and 61.42%, respectively. The results show that the calcium oxide content of G1-G4 cement falls between 61% and 67%, meeting the requirements of ASTM C 150 and BSI (1978). Studies [13, 14] showed average values of 65.33 ± 0.41% and 57.54 ± 1.48%, which is consistent with the favourable outcome of our study. Calcium oxide is essential for the hydration process, and the study indicated a constant acceptable range of levels across grades, roughly 61-63%. The proportion of SiO_2 and CaO in G4 enhances long-term strength [22].

Table 1 indicates that the percentage proportion of magnesium oxide in G1, G2, G3, and G4 cement is 0.74%, 1.58%, 1.74%, and 1.86%, respectively. These values fall within the 2.00% maximum threshold established by SON standards. The MgO concentration complies with the SON standard and BSI as indicated in Table 2. The outcome aligns with findings of studies [14, 21]. An MgO content above 1.5% can cause expansion in hardened cement, and as G2, G3, and G4 all surpass this threshold, caution may be needed about durability.

The aluminum oxide percentages in cement samples G1, G2, G3, and G4 are 3.22%, 4.41%, 4.96%, and 5.67%, respectively, as shown in Table 1. All of these values are in line with what is required for general-purpose cement based on ASTM C 150, which specifies an aluminium oxide content of 2.5 to 6.0% (BSI, 1978). This confirms previous study reported [14].

The iron oxide percentages in the cement samples G1, G2, G3, and G4 are 4.74%, 2.87%, 3.05%, and 3.18%, respectively (Table 1). The result obtained does not surpass the maximum allowable iron oxide level of 6.0% in standard cement, as stipulated by ASTM C 150. Omoniyi and Okunola, [12] reported a similar finding of mean Fe_2O_3 concentration between 3.0 - 5.2%.

G1, G2, G3, and G4 cement samples have the following percentages of free lime (CaO) composition: 2.18, 0.59, 0.77, and

Table 1. Chemical composition analysis.

	G1	G2	G3	G4
SiO_2	19.80	15.90	17.76	20.46
Al_2O_3	3.22	4.41	4.96	5.67
Fe_2O_3	4.74	2.87	3.05	3.18
CaO	63.22	61.74	61.55	61.42
MgO	0.74	1.58	1.74	1.86
SO_3	2.80	1.94	1.78	1.88
Na_2O	0.13	0.02	0.03	0.03
K_2O	0.68	0.23	0.27	0.29
P_2O_5	0.44	0.26	0.28	0.3
Cl^-	0.051	0.0128	0.0143	0.013
Free lime (CaO)	2.18	0.59	0.77	1.35

Table 2. SON standards.

SON Requirement (NIS 444:2018)	Lafarge Cement Compliance
$SiO_2 > 17\%$	Passed for grades (G1, G3 & G4)
$SO_3 < 4\%$	Passed for all grades (G1, G2, G3 & G4)
Loss on ignition < 5% (except for 32.5)	G2 grade exceeds limit
MgO < 2%	All grades are close to the limit, but acceptable
28-Day Strength	Passed for all grades (G1, G2, G3 & G4)

1.35%, respectively, according to Table 1. In comparison with the standard, G1 and G4 values are higher than the ASTM C150 limits of 1.00% for type I cement and 1.30% for type III cement. But G2 and G3 fall within the range. In contrast, a greater free CaO mean value of 65% was reported in cements by Soltani *et al*. [13] using EDXRF, respectively.

The SO_3 has values in providing proper sulfate resistivity. All grades (G1, G2, G3 and G4) are within safe limits of SON Requirement (NIS 444:2018) on Table 2 and ASTM C 150 on Table 3.

IR of cement samples reveals the percentage of unburned raw materials and gypsum additives. The compressive strength of cement is affected by a considerable amount of residual material in early ages. Table 4 shows that the four cement samples analyzed, samples G1, G2, G3, and G4 had 1.32%, 0.75%, 1.8%, and 0.2 % of insoluble residue (IR), respectively. G2 and G4 fall within the range allowed by ASTM C 150 for all-purpose cement, whereas G1 and G3 are outside of the range.

As stated in the SON Standard, cement should have a low LOI (<5%) and a maximum of 3.0 as stated in ASTM C 150 for durability; the value of G2 of LOI (12.77%) exceeds this, raising concerns. G2 has the highest loss on ignition (LOI) (12.77%), i.e., higher unburnt carbon or moisture, which affects durability. LOI < 5% is required for high-grade cement when using SON. Parameters to include an increase in kiln temperature, an increase in residence time in the kiln, the use of fuel with higher calorific value, and moisture reduction during the grinding process can help reduce LOI in the G2 brand.

The G2 grade has higher cement fineness (4926 cm^2/g), which enhances early reactivity, but too fine will lead to rapid hydration. The lower residue in G4 of (1.98%) is due to finer grinding and is responsible for higher strength.

Table 5 presents the mechanical properties of the different grades. The 2-day strength attained by G4 is 29.19 MPa, which is high strength and a suitable application for precast. Early strength (15.55 MPa) for G2 is the lowest among the three grades and can be used for the general purpose. All grades comply with 28-day strength. As stated in ACI (American Concrete Institute) 318, it recommends that G1, G3, and G4 be used for structural applications, aligning with the high strength of these Lafarge grades.

Table 3. ASTM standards.

Oxide/parameters (%)	ASTM requirement
SiO_2	17-25
Fe_2O_3	0.5-0.6
CaO	60-67
Al_2O_3	3-8
MgO	Max. 6.0
SO_3	Max. 3.0
Loss on ignition	Max. 3.0
Insoluble residue	Max. 0.75

Table 4. Physical property analysis.

Physical property	G1	G2	G3	G4
Loss on ignition	4.20	12.77	7.24	1.31
Residue (45 µm sieve) %	8.10	8.20	8.01	1.98
Insoluble residue (%)	1.32	0.75	1.84	0.20
Surface area (cm^2g^{-1})	4438	4926	4218	3760

Table 5. Mechanical properties analysis.

Strength (MPa)	G1	G2	G3	G4
2- DAY	32.10	15.55	20.88	29.19
28-DAY	57.80	39	56.50	64.55

Table 6. Mineral composition of different grades of Lafarge cement.

Cement sample	Percentage Composition			
	C_2S	C_3S	C_3A	C_4AF
G1	40.11	77.73	70.07	14.42
G2	6.77	96.32	6.86	8.73
G3	30.34	77.45	8.01	9.28
G4	63.51	51.50	9.68	9.68
ASTM C150-07 & BS12:1991 Standards				
	45-65	7-32	8.0-12	10-11

3.2. QUALITY ASSESSMENT OF THE DIFFERENT GRADES OF LAFARGE

Quality of these brands were assessed via determination of C_3S, C_2S, C_3A and C_4AF respectively according to studies [3, 13].

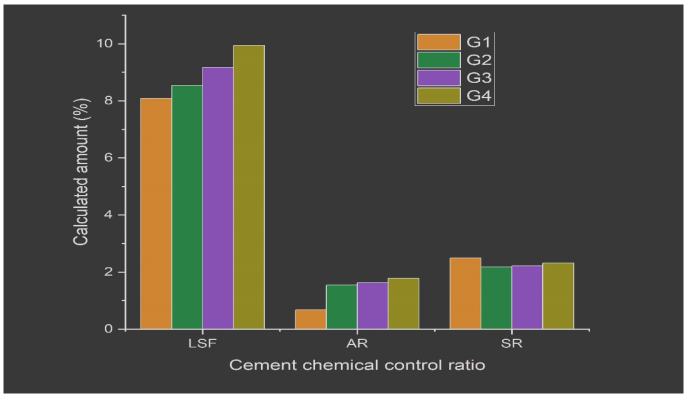

Figure 1. Cement chemical control ratio.

3.2.1. Composition of tricalcium sodium oxide (C_3S)

The percentage composition of tricalcium sodium oxide in the cement samples G1, G2, G3, and G4 is 77.73%, 96.32%, 77.45%, and 51.50%, respectively, as shown in Table 6. Cements G1, G2, and G3 do not meet the C_3S value requirement of 45.0 – 65.0% as outlined by ASTM C 150 for general purpose cement, whereas G4 complies with this specification. The reported percentage of C_3S is consistent with Yahaya's findings [14], which range from 20.58% to 33.33%. The hydration of C_3S provides cement pastes with a significant portion of their strength, especially in the early stages.

3.2.2. Composition of dicalcium silicate (C_2S)

The study revealed that the percentages of dicalcium silicate (C_2S) in the cement samples G1, G2, G3, and G4 are 40.11%, 6.77%, 30.34%, and 63.51%, respectively, as shown in Table 5. G2 and G3 cements exhibit C_2S values ranging from 7.0% to 32.0%, conforming to the ASTM C 150 standards for general-purpose cement. In contrast, G1 and G4 do not meet these specifications. Yahaya [14] reported a C_2S range of 26.47% to 46.41% for the Nigerian cement analyzed. C_2S exhibits a stable crystal structure and is entirely unreactive in water; an excess of this compound leads to impurities in cement, as noted in study [23].

3.2.3. Composition of tricalcium aluminate (C_3A)

The cement brands G1, G2, G3, and G4 exhibit tricalcium aluminate percentages of 70.07%, 6.86%, 8.01%, and 9.68%, respectively, as shown in Table 6. G1 does not conform to ASTM C 150; however, the cement samples G2, G3, and G4 contain C_3A within the specified limit of 8.0 – 12.0% for Type I general-purpose cement and Type III. The findings are consistent with those reported by Yahaya [14] and Sam *et al.* [13] for Nigerian and Ghanaian cements, respectively. The presence of sulphate ions can adversely affect concrete by causing C3A and its products to engage in expansive reactions, resulting in stress and cracking [23].

3.2.4. Composition of tetracalcium aluminoferrite (C_4AF)

The aluminum oxide percentages in cement samples G1, G2, G3, and G4 are 14.42%, 8.73%, 9.28%, and 9.68%, respectively, as shown in Table 6. The C4AF content in G2, G3, and G4 cement ranges from 8.0% to 12.0%, adhering to the ASTM C 150 limit for general-purpose cement, and complies with the 12.0% specification for Type IV cement, which is characterized by low heat of hydration and reduced levels of C_3S and C_3A, making it suitable for massive structures. G1 cement brands contain C_4AF, characteristic of Type V cement, which exhibits high sulphate resistance [24].

3.2.5. Lime saturation factor (LSF), silica ratio (SR) and aluminum ratio (AR)

The cement grades G1–G4 were shown in Figure 1 with the following LSF, SR, and AR ratios. The four cement brands' LSF ranges of 8.09-9.94 were above the 0.9 - 1.1 reported in Sam *et al.* [13] for specific Portland cements sold in Ghana. A LSF value exceeding 1.0 suggests the probable presence of free lime in the clinker. At an LSF of 1.0, it is expected that all free lime would react with belite to produce alite. If the LSF value exceeds 1.0, the excess free lime lacks a reactive counterpart and will persist as free lime [25]. The cement brands analyzed exhibit LSF values significantly exceeding 1. The LSF influences setting time; a high LSF can increase setting, whilst a low LSF may prolong it. A high LSF can also lead to increased expansion, which adversely affects concrete durability. A suitable LSF range is essential for guaranteeing durability. The silica ratio can be improved by using biomass materials rich in silica, such as biochar made from oil palm fruit fibre with 84.37% SiO_2 according to Adeoye *et al.* [26].

4. CONCLUSION AND RECOMMENDATIONS

The study performed a critical assessment of chemical, physical and mechanical properties of Lafarge cement brands sold in Nigeria market. To a significant level, the results obtained well to ASTM international and SON standards.

The use of G2 (Elephant Classic) is suitable for non-structural applications, however, this has high LOI and may have an effect or durability over a longer term. The G3 (Supaset) is suitable for general construction and precast concrete with moderate early strength. The application of G4 (Powermax) is ideally suitable to high strength application meeting SON standard for structural works.

The study recommends improvement on LOI on (Elephant Classic) to meet SON standards. Parameters to include an increase in kiln temperature, an increase in residence time in the kiln, the use of fuel with higher calorific value, and moisture reduction during the grinding process can help reduce LOI in the G2 brand. The improvement of finess control in G3 (Supaset), G1 (standard grade) and G4 (PowerMax) is needed for better hydration efficiency. It also recommends strict monitoring of G1, G3 and G4 to prevent long-term expansion problems.

DATA AVAILABILITY

All data were obtained from experimental analysis.

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