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Investigating the Physical, Chemical, and Mechanical Properties of Concrete from Different Cement Brands

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ABSTRACT
This study investigates the physical, chemical, and mechanical properties of selected brands of cement in Nigeria to ascertain their conformity to specified standards. Eight brands of cement: A(32.5R),B(42.5R),C(32.5R),D(42.5N), E(42.5N),F(42.5R),G(42.5R), andH(42.5R) were sourced from different locations within the Nigeria market. Tests conducted include Fineness, Consistency, Soundness, Setting Time, Compressive strength, X-ray Diffraction (XRD), and X-ray Fluorescence (XRF). Tests specimens for the study were prepared from design mixes of (1:3) and cubes size 50mm x 50mm x 50mmformortar. Also, concrete grades 20, 25, and 30of cubes size 150 x 150 x 150 mm were cast and cured for a period of 3,7, and 28 days. Results obtained show that the percentage fineness modulus is within the NIS standard of 10mm maximum, the consistency of types of cement A, E, and Ffall within the recommended values of 26-33% as specified by Nigeria Industrial Standard (NIS): 445-1:2003. Also, the soundness and setting time of cement brandsare within the NIS: 446:2003. In concrete grades, cement brands D, F, and H satisfied the recommended compressive strength while brands B in grade 25, E, and G in grade 30 also satisfied the compressive strength as recommended in BS 8110 part 1 1997. The chemical test revealed oxide composition:silica, alumina, and calcium oxide in cement brands D, E, and H to be withinthe optimal percentage. It can be concluded that in all the samples collected, only sample H satisfied the requirements while others are lacking in one way or the other.

KEYWORD: Cement, Mortar, Concrete, Oxide Composition, Compressive Strength.
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I. INTRODUCTION

In recent times, Nigeria has witnessed an ever-growing population which becomes a major concern in addressing the issue of housing deficit and infrastructural development. According to research conducted by Head of Energy Research, Ecobank Plc, Dolapo Oni stated that Nigeria would need at least $30 billion (N9.47 trillion) annual investment to bridge the infrastructure gap in the country (Punch Newspaper, 2017).With this huge amount, the implication is that more buildings, more bridges, more dams, more culverts, and drainage systems, and more road networks need to be constructed to achieve that. Moreover,the aforementioned infrastructures are all strength dependent and they consume a huge amount of cementfor them to achieve their optimal binding capacity.(Claisse P. A, 2016) However, cement as stated by (Gagg C. R, 2014) is the main component in the construction and production of infrastructures which form the basis of concrete

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production andis also, the second most consumed commodity apart from water.The raw materials used for the manufacturing of cement consist mainly of lime, silica, alumina, and iron oxides. And thus, the quality cement is important to the development and sustainability of the construction industry as well as the economic growth of any nation; therefore, its properties most conformed to the international required specification. Nigeria is a developing country with an annually increased build up a stock of infrastructures (buildings, roads, rail networks, bridges, etc) that requires the harvest of quality construction materials. (Bert-okonkwo et al., 2020) As estimated in 2015, out of 174 million people, Nigeria recorded about 17 million units' national housing deficits and with a population growth rate of 2.8 percent, Nigeria needs to build about 700,000 housing units yearly to bridge the housing deficit gap (Olugbenga et al., 2017). Hence, the increase in demand for construction materials which cement has been the pivotal material has estimated expansion consumption in Nigeria over nine years by 2.1 % (consumption per annual growth rate-CAGR) to about 20.7mmt in 2018. The wide infrastructural deficit has pointed out the potential of increased cement consumption which presently stands at the tune of 150kg per capita as against the global consumption of 561 per capita.This huge gapin infrastructural deficit creates more opportunities for private investors to expand and open more industries in the area of building material. Moreover, this necessitatesthe Nigerian government to engage professional and regulatory bodiesto focus attention and ascertain the quality of such materials more especially cement.

As the argument continues, Nigerian Building and Road Research Institute (NBRRI) Technical Reports (No 22 and 23; 2011) attached significant importance to the use of quality materials on sites, observing that poor application and the use of inferior materials especially concrete that has cement as a binder has been a major factor for infrastructural failure in Nigeria. However, as the country record a significant improvement in the number of indigenous manufacturing industry, the researchers and other regulatory organization emphasis is on the quality of the main binding materials (cement). A study by (Faleye et al., 2009) stressed the independent analysis of the properties of cement to ensure its conformity with the relevant standard. Nigerian Industrial Standard (NIS; 466; 2003) states that the properties of cement brands in Nigeria must maintain a uniform consistency in quality.Given that, some researchers kick-start work on cement and concrete such as; (Bert-okonkwo et al., 2020) who make a comparative analysis of concrete strength through mechanical testing of four (4) selected brands of cement available in Anambra state Nigeria and concluded that all brands satisfied the minimum compressive strength of 21N/mm2 within 7 days of production. In a different approach using the physical and mechanical testto appraised five different brands of Portland cement(Dangote, Elephant, Ibeto, Unicem, and Atlas) sampled in Umuahia Industrial market Nigeria of which the result stated that all samples fail to meet international standards specification for ordinary Portland cement (Nduka & Osinachi, 2014).However, a study carried out by (Bedioko and Amankwah, 2015) investigated five different brands of Portland cement through chemical analysis and found out each brand varies in chemical composition and the variation, in turn, affects the strength.

Due to the outcry of stakeholders in the cement sector, evidence concludes there is a significant level of inconsistency in the properties of cement, which is an indication that cement in Nigeria requires regular checking. Mean while, after perusal through works of literature, it has indicated that many researchers approach findings for cement properties either using physical, chemical, or mechanical testing.

Therefore, this research is aimed at periodically investigating the quality of different brands of cement in Nigeria according totheir physical, chemical, and mechanical properties combined using Nigerian Industrial Standard (NIS) and European Standard.

II. LITERATURE REVIEW

2.1 Concrete Properties

Concrete is a composite construction material composed of cement and aggregates made of gravel or crushed rocks such as limestone, or granite plus a fine aggregate such as sand, water, and chemical admixture (Arbuckle, 2007). Different schools of thought defined concrete as a mixture of aggregates (fine and coarse) with cement and water to form a solid mass (S.B.Hegde, 2020). However, concretes are considered as two-phase materials, the paste phase and the aggregate phase, while understanding the paste phase is more important as it influences the behavior of concrete to a much greater extend. Moreover, the permeability, durability, drying shrinkage, elastic properties, and creep as well as volume change properties of concrete are greatly influenced by the paste structure. Concrete is the most versatile material of great strength and durability, providing good control measures throughout all stages of construction (Arbuckle, 2007). The cement acts as the binder that bonds the aggregates together after undergoing a chemical reaction with water. Concrete is weak in tension but strong in compression. The inclusion of steel into the concrete provides the tensile strength missing in concrete as steel has the high tensile strength to form a composite known as reinforced concrete (Mccormac et al., 2006). for; water-cement ratio, aggregate type, aggregates surface texture, cement type/brand, chemical compositions, concrete age, cement fineness, and the extent of hydration as the factors that affect concrete strength. (Ghambhir, 2009) By and large concrete strength increases with a decrease in water-cement ratio and increases with the age of concrete (Jackson, Neil; Dhir, 1996). More also, if a particular concrete mix has been selected, it is essential to maintain the ratio throughout the series of operations, otherwise, the change might affect the quality of the structural members.

2.2 Properties Cement

Portland cement is defined as the cement that hardens by reacting with water to form a water-resistant product produced by pulverizing clinker consisting of one or more of the forms of calcium silicates, usually containing one or more of the calcium sulfates. The low cost and widespread availability of limestone, shale, and other naturally occurring materials make Portland cement one of the lowest cost materials widely used over the last century all over the world (Adam M. Neville, 1987). For cement to be viable to be used in major and important works it is incumbent on the part of the users to test the cement in the laboratory to confirm the requirements specifications concerning its physical and chemical properties. No doubt, such confirmations will have been done at the factory laboratory before the product comes out but the cement may be tempered during transportation and storage before its use in work (Ghambhir, 2009).

(a) Physical Properties

Samples of Portland cement are to be tested for the following physical properties: fineness, soundness, standard consistency, compressive strength, and setting time. Each of these properties influences the performance of cement in concrete (Maruyama et al., 2014), and BS 8110-1; 1997).

(i) Fineness of Cement

The fineness of cement is the measure of cement particle size, which can be expressed in terms of the specific surface area of cement particles. However, there are different methods to cement fineness testing, which are; Blaine Air Permeability Test Method, Wagner's Turbidimeter Test, Particle Size Distribution Method, and Lea & Nurses Permeability Method (www.cilvilquery.com). Fineness is an important property of cement that influences the rate of reaction with water (hydration), acceleration of initial strength gaining, increased shrinkage and cracking, and increase exothermic reaction (Ali Mardani et al, 2017). Finer cement is of great importance because the rate of reaction is high, more rapid, and greater strength development, bleeding rate of concrete isalso reduced significantly due to cement fineness as well as improved the workability of the concrete. See (Neville; et al., 2002). Additionally,(Ghambhir, 2009) also concur that the finer the cement particles, the greater the surface area for hydration and rapid development of initial strength but ultimate strength remains constant. According to a study by Mardani (Mardani etal, 2017) who relates the behavior of cement and found out that as cement fineness increases, the C_3A compound behaves more reactively and forms larger amounts of ettringite. However, fineness impacts positively on the workability of fresh concrete, but not quite so on-air entrained concrete (Higginson E.C, 1970). But it is disadvantageous for finer cement as it is more prone to damage than coarser cement in terms of durability (Mehta P.K, 1997).

(ii) Standard Consistency Test

Standard consistency is the amount of water required to attain standard consistency or normal consistency of cement or measures the ability of cement paste to flow and is expressed as the percentage by weight of water content of the paste to dry cement.It can also be expressed in an experimental term as standard consistency of a cement pastewhich permits the Vicat plunger to penetrate a cement paste to a point 5 ± 2 mm from the bottom of the Vicat mold(Ghambhir, 2009). The water content of the standard paste is expressed as a percentage of the dry cement and generally, the percentage varies from 26-33% for optimal production of a homogenous concrete mix (Ghambhir, 2009). Moreover, it is pertinent to determine the standard amount of water for each case of initial setting time, final setting time, soundness, and compressive strength of cement (Shui Z. etal, 2009).

(iii) Soundness Test

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The soundness of cement refers to the ability of a hardened cement paste to retain its volume after setting and it can be tested through Le Chatelier Apparatus Test or Autoclave Method. However, a study stated that an appreciable change in volume of cement after setting or expansioncan causes disruption of the set and hardened mass thereby affecting the durability of the structure (Mehta & Monteiro, 2001).The soundness test is an important parameter for cement testing, it is crucial that after setting cement shall not undergo any appreciable change in volume, but certain types of cement are observed to have shown some degree of expansion after setting, causing disruption of the set and hardened mass thereby affecting the durability of the structure (Ghambhir, 2009). However, unsoundness in cementoccurs due to factors such as excess lime combined with acidic oxide at the kiln, insufficient fineness, high proportion of magnesium content, or calcium sulfate contents in the cement (Claisse P. A 2016).However, a recent study pointed out that unsoundness occurs due to water storage in concrete for a long period at high temperatures and also with the addition of admixtures such as magnesium oxide (Kabir and Hooton, 2020).

(iv) Setting Time

The setting of cement is determined in two different means; initial and final setting times. The initial setting is the time elapsed from the moment water is added to the cement to the time that the paste starts losing its plasticity while the final setting time is the moment between when water is added to the cement and when the cement pastes completely lost its plasticity and has attained sufficient firmness to resist certain definite pressure (Ghambhir, 2009).

(v) Compressive Strength

The strength of cement can be defined as the ability to resist force and when applied for structural purposes can be described as the unit force required to cause a rupture and also, they are indirectly found on cement sand mortar in specific proportions (Ghambhir, 2009; Mc carter W. J, 2017). The compressive strength of hardened cement is an important property of cement. This test is not made on neat cement paste because of difficulties of excessive shrinkage and subsequent cracking. The strength is indirectly found on cement sand mortar in specific proportions (1:3) using standard sand (Ghambhir, 2009).However, compressive strength varies depending on the cement design grade, for example, the compressive strength for cement grade 32.5 and 42.5 Portland cement cured for 3, 7, and 28day are found to be 16, 22, 33N/mm^{2,} and 23, 33, and 43Nmm^2 respectively, which indicates higher grades gives higher strength and confirmsBS EN 197-1:2016, NIS 446-3:2003 standard.(Ghambhir, 2009).

(b) Chemical Composition

ASTM classified Portland cement as type I for use in general concrete construction (Ghambhir, 2009). Cement is made of fine powdered grinding clinker of more than 90 percent and limited calcium sulfate (10-5 %) that controls the setting time. Clinker is a hydraulic material that consists of at least two-thirds by mass of calcium silicates (3CaO.SiO2 and 2CaO.SiO2). However, understanding the clinker activities and the calcium silicates hydrates (CSH) reaction requires the cement oxide composition.The oxides composition of cementcan be detected with the aid of X-ray fluorescence spectroscopy (XRF) andsuch oxides are found to be major key players in determining the quality, reactivity, and general chemistry involves in cement usage. They are composed of both major and minor oxides(Punmatharith et al., 2010). The predominant oxides are CaO, SiO_2, Al_2O_3, and Fe_2O_3 while MgO, SO_3, and some alkali oxides (K_2O and Na_2O) are the minor oxides and sometimes other traces of compounds such as P_2O_5, Cl, TiO_2, MnO_3, etc.(Bediako & Amankwah, 2015).Each of the oxides performsa distinct functionduring the cement hydration process and as such, eachof the oxides must be within a proportionate limit from the raw material to the finished product for the cement to performoptimally(Huntzinger & Eatmon, 2009).

Moreover, the compositions of the oxide are instrumental to the computation of Silica Ratio (SR) (1.4-4.2) which slow reaction if SR is high, Alumina Ratio (AR) (0.6-4.2) that controls melt temperature, Lime Saturation Factor (LSF) (90-101) as reported by (bested and Barnes, 2002). However, the discovery of Bogue's Equations gives more insight into cement chemistrywith the extraction of four major key players of C_3S, C_2S, C_3A, and C_4AF in the activation of calcium silicate hydrate (C-S-H)(Punmatharith et al., 2010). Furthermore,(Neville; et al., 2002)expressed thefour major compounds formed in the cementwith their chemical formula and approximate weight percentage as presented in table 1. The cement hydration CaO in conjunction with SiO_2, Al_2O_3, and Fe_2O_3 leads to hardening of Portland cement due to the formation of calcium aluminosilicates and aluminoferrite hydrate which in a nutshell refer tocalcium silicate hydrate (C-S-H)(Bullard et al., 2011); (Karen L Scrivener et al.,

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2015).As reported by (K. L. Scrivener et al., 2004)the amount of C-S-H formed was estimated from the amounts of anhydrous silicate phases consumed according to the stoichiometric equations: $C_3S+5.3H \rightarrow C_{1.7}SH_4+1.3CH$; $C_2S+4.3H \rightarrow C_{1.7}SH_4+0.3CH$.

Likewise, other mineralogical compounds present in the cement crystalline phase are detected and quantifiedby X-ray diffraction spectroscopy (XRD) and such compounds are quartz, calcite, portlandite, hemihydrate, anhydrite,periclase,etc(K. L. Scrivener et al., 2004).

Table 1: Major compounds that plays role in the (C-S-H) of cement. Adopted from (Neville; et al., 2002)

Name	Formular	Shorthand	Approx. Weight %
Tricalcium silicate (Alite)	$(3CaO.SiO_2)$	C_3S	55-60
Dicalcium silicate (Belite)	(2CaO.SiO 2)	C_2S	15-20
Tricalcium aluminate	$(3CaO.\ Al_2O_3)$	C_3A	5-10
Tetracalciumaluminoferrite	$(4CaO.Al_2O_3.Fe_2O_3)$	C_4AF	5-8
Gypsum	$CaSO_4.\ 2H_2O$	CSH_2	2-6

2.2 CONCRETE MATERIALS

Fresh concrete is a plastic mass, which can be molded into any desired shape. This is its main advantage as a construction material (Gupta, 2004). Aggregate (coarse and fine) combined to form about 70% space in a given mass of concrete and the rest 30% space is filled by water, cement, and air voids. Concrete is described as a mixture of Portland cement, fine and coarse aggregate, air, and water (Bert-okonkwo et al., 2020). On the other hand, a different view by (Brown & Taylor, 2001) describedconcreteas a heterogeneous mix consisting of materials such as Cement, fine and coarse aggregates, water, and admixtures (if required).However, the concrete can be obtained in various forms by varying the mixture of cement, sand, and aggregate used in a concrete blend which also enables it wide range of applications. (Colin R.G, 2014)

Cement is seen generally as binding material or a substance made of burned lime and clay which is capable of binding other materials to form a hardened structure after mixing with water. The study of (Biernacki et al., 2017)summarizes cement as a cementitious material with adhesive and cohesive properties capable of binding inert aggregates into a solid mass of adequate strength and durability. Furthermore, cement acts as a constituent of concrete which reacts chemically with water to form a hardened mass on hydratingor can be described as a finely pulverized product resulting from calculations of natural argillaceous limestone at a temperature below the fusion(Huntzinger & Eatmon, 2009). Besides, cement containsa mixture of compounds, consisting mainly of silicates and aluminates of calcium, formed out of calcium oxide, silica, aluminium oxide, and iron oxide(Oliveira et al., 2010). Also, (Herfort et al., 2010) assess Portland cement as a product manufactured by firing a controlled mixture of chalk or limestone ($CaCo_3$) and substances containing silica and alumina such as shale in a kiln at 1500°c temperature. They are heated to clinker and grounded to a fine powder with a small proportion of gypsum (calcium sulfate) which regulates the rate of setting when the cement is mixed with water.

However, to fabricate hardened concrete, mixing of aggregate with cement is imperative and the term aggregate includes the natural sand, gravels, and crushed stone used in making concrete. In other words, aggregates are described as inert materials like gravel, crushed stones, broken bottles that are mixed with cement and water to make concrete (Bert-okonkwo et al., 2020). Furthermore, concrete usually occupied about 60-75 % (fine and coarse) aggregate (Suchorski, 2007). The aggregates have to be graded so the whole mass of concrete acts as a relatively solid, homogeneous, dense combination with the smallest particles acting as an inert filler for the voids that exist between the larger particles (S.B.Hegde, 2020). Aggregates provide better strength, stability, and durability to the structure made out of cement concrete than cement paste alone (Anosike, 2011). Aggregate is not truly inert because its physical, thermal, and chemical properties influence the performance of concrete. While selecting aggregate for a particular concrete, the economy of the mixture, the strength of the hardened mass, and durability of the structure must first be considered (Gupta, 2004).

To activate the chemical process in making concrete or to kick start the cementitious process, a universal solvent must be added to the mixture, which is water. Water to cement ratio (w/c) as the weight of water divided by the weight of cement; Eg: w/c = Water/ Cement where 1litre = Ikg(Jackson, Neil; Dhir, 1996). BS8110: Part 1, 1997, states that the amount of water required in a concrete mix is the minimum for complete hydration of cement and if such concrete is completely compacted without segregation, it would develop the maximum attainable strength at a given age. It further suggested that the water-cement ratio of approximately 0.25 weights is requisite for the full hydration of cement. Water used for concrete mixing is required to be fit for drinking or to be taken from an approved source (Arbuckle, 2007). (Bert-okonkwo et al., 2020) hint that to achieve the required workability and strength of concrete in both fresh and hardened state, the water used for mixing and curing needs to be of fitting quality, that is, free from impurities such as suspended solids, organic matter, and salts which may adversely affect the setting, hardening, strength, and durability of the concrete.

III. MATERIALS AND METHODS

3.1 MATERIALS

3.1.1 Cement

The research work was carried out in the Nigerian Building Road Research Institute (NBRRI) laboratory in Abuja, Nigeria. The available cement brands under investigation are; Unicem, Elephant, Ashaka, DangoteBlockmaster, Dangote Falcons, BUA, Dangote 3X, and Sokoto Cements and they are all of the different types according to their production-grade. The research team has identified four major source points of cement samples in Nigeria, which are, the manufacture, dealer, sub-dealer, andend-user. But the research team decides to source the samples from a sub-dealer since it is the point that relateswith the end-user and the dealer. Meanwhile, any sample that will be tested from the manufacturer will not give results base on the effect of storage condition, duration of stay, and transportation condition and also an idea of how the cement behaves after it left the manufacturer's point. The sub-dealer point of source in this research will form a basis to which can give an idea of the kind and condition of cement the major population in Nigeria are using in terms of building and construction. This research hopes to continue with investigating all other source points of cement from themanufacturer, dealer, and the end-user, to combine all the results in other to have a broader understanding of the cement behaviors across the supply chain network. All the eight cement brands are sourced from different sub-dealers inBauchi, FCT, Imo, and Minna. The samples were carefully stored and covered in the NBRRI science laboratory and are inspected regularly to ensure that their quality is not compromised because of lump formation throughout the research. The cement samples according to their brand, grade, and location, are given representation in alphabetical order as shown in table 2.

Table 2: Cement samples and their grade

Samples	A	B	C	D	E	F	G	H
Grade	32.5R	42.5N	32.5N	42.5R	32.5R	42.5N	42.5N	32.5R

3.1.2 Aggregate

The coarse aggregates are sourced from Venus Mining Company at Bwari Area Council, Abuja, while the fine aggregate is river sand sourced from Jere LGA, Kaduna. The coarse aggregate is a normal weight crushed stoneof 20mm size used in the concrete mix for this research work. Both aggregates (coarse and fine) used for the research work were characterized as specified by BS standard 8110; 1985 as supported by (Mc carter W. J, 2017)

3.1.3 Water

The water is clear, colorless, and impurity-free tab water that is fit for drinkingsourced from the NBRRI laboratory reservoir and was used in the mixing and curing throughout the research work.

3.2 METHODS

The following physical, chemical, and mechanical and chemical laboratory testing wereconducted; (a) Setting time test (b) Soundness test, (c) Consistency test, (d) Fineness test, (e) Strength test, (f) Chemical analysis.

3.2.4 Setting Time Test

EN 196-3:2008 and NIS 447:2003 described the procedure for setting the time of cement.

3.2.1 Fineness Test

The research procedure for the fineness testwas conducted according to BS EN 196-6:2008 and NIS 448:2003.

3.2.2 Soundness Test

The procedure for soundness test was described by EN 196-3:2008 and NIS 447:2003

3.2.3 Standard Consistency Test

The procedures are in accordance with the European standard EN 196-3:2008 and NIS 446:2003 for testing cement consistency.

3.2.5 Strength Test

The test procedure for cement and concrete strength was conducted according to NIS 446:2003, NIS ISO-4:2005

3.2.6 Chemical analysis (XRF and XRD)

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The eight cement samples werecharacterized for oxide composition using X-ray Fluorescence (XRF) machine. Samples for X-ray fluorescence analysis were prepared by pressing powdered cement samples into cellulose before analyzing on a PanAnalytical XRF spectrometer using calibration software. The test was conducted at the Nigerian Geological Survey Agency, Kaduna, and according to NIS 368:1990 and NIS 445:2003

IV. RESULTS AND DISCUSSION

4.1 Physical Test

4.1.1 Setting Time of Cement

Setting times are required in Portland cement for the normal development of engineering projects. As stated by the NIS standard the initial setting time for 32.5R and 32.5N should be greater or equal to 7.5min, for 42.5R and 42.5N should be 60min or above. However, as shown in table 3, all the eight different brands of cement made the initial setting time requirement and the final setting time of not more than 600min. The result of sample C has the least interval of initial and final setting time which can be attributed dueto high reactivity due to fineness, while sample D has the highest interval due to which can be as a result of poor surface area. (Ma et al, 2019)

Table 3: Setting Time of Cement

CEMENT BRAND	SETTING TIME (minutes)		
	Initial	Final	Interval
A	97	182	85
B	125	184	59
C	118	170	52
D	125	240	115
E	129	224	95
F	139	234	95
G	114	233	119
H	187	276	89

4.1.2 Fineness

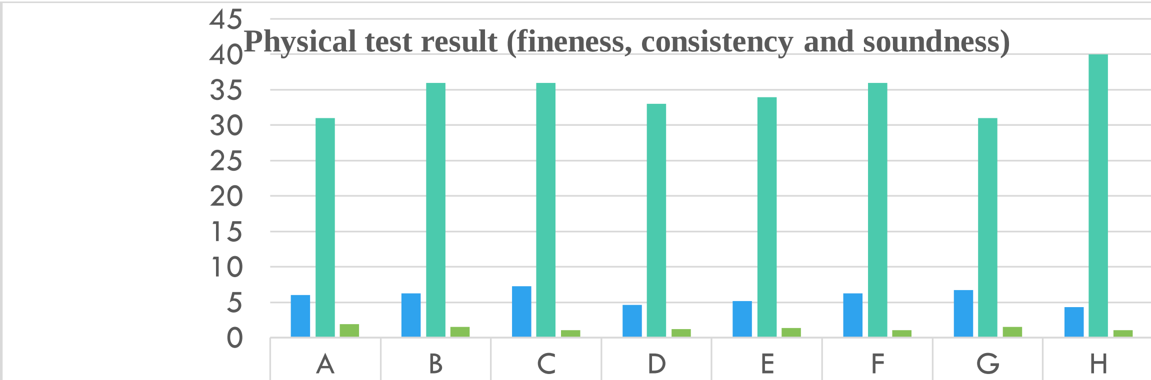
More the finer the cement particles are, the more reactive they should be and this was confirmed by the result of setting time which shows sample Chas been most reactive among the samples because of its fineness. However, as stipulated by NIS: 446:2003 specification, the requirement for Portland cement shouldn't be more than 10%, which figure 1 has indicated that all the eight cement brands samples have satisfied that requirement.But sample C which is thefinest with 4.26% have the higher surface area andis most likely to be more reactive, hencethe rate of gain of strength and rate of heat evolution,while samples D is the least fine with 7% which correspond to lower surface area and least reactive at the early stage.

4.1.3 Standard Consistency

Standard consistency is the consistency range of water content that should allow the settlement of the Vicat plunger to a point 5mm to 7mm of the cement paste. The range was given as 26-33 by ASTM, BS, and EN and also by NIS: 446:2003. Results from Fig.1. shows that sample A,D, and G with values 31,33, and 31 falls within the required values, while sample B,C,E,F, and H did not meet the NIS required consistency values.

4.1.4 Soundness

Table 5 shows the soundness results of eight different brands of cement available in the Nigerian market. The results values which are 1.88, 0.50, 1, 1.13, 1.35, 1.01, 1.44, and 1 for samples A, B, C, D, E, G, and H are within the NIS requirement of 10mm maximum. Standard has stipulated that the expansion should not be more than 10mm.



	A	B	C	D	E	F	G	H
Fineness (%)	5.95	6.2	7.26	4.56	5.1	6.2	6.7	4.3
Consistency (%)	31	36	36	33	34	36	31	40
Soundness (mm)	1.88	1.51	1	1.13	1.35	1.01	1.44	1

Fig. 1. Fineness, Standard Consistency, and Soundness result chart for all the eight cement brands.

4.2.0 Chemical Analysis

The chemical analysis results for the eight (8) cement brand samples are shown below in table 4, which presents for each cement brand the oxide composition of the Fe_2O_3, MgO, Al_2O_3, SiO_2, SO_3, K_2O, and CaO, and the LOI. The approximate oxide composition and the LOI of cement as shown in the second column of Table 4, which the recommended values are given by NIS 446:2003 for Portland cement. Most significant among the oxide composition that plays role in the cement hydration process and the formation of strength are the Al_2O_3,SiO_2, and CaOand the result shows that only samples D, F, and H have values that are within the approximate optimal limit. However, unlike samples H and D that proper distribution of SiO_2 and CaO, sample F has an uneven proportion of SiO_2 which is low compared to the high value of CaO and this will affect the development of early and late strength of the cement during the hydration process. Consequently, as indicated by the result of other samples;A lacks in SiO_2, B and C lacks in CaO, while E and G lack in both SiO_2 and CaO. The lack of optimal proportion of SiO_2 and CaO in samples A, B, C, E, and G will affect negatively the strength result of the respective sample. Moreover, all sampleshave met up with the appropriate limit of Al_2O_3 but none meet up for Fe_2O_3.

Going forward, NIS recommend 5% as the maximum limit of L.O.I, and going by the result obtained, samples C, F, and H are within the recommended approximate limits, while samples A, B, D, E, and G are above the NIS recommended values of 5.0 %. This implies that samples with higher values are prone to pre-hydration and carbonation which is an indication that such cementsare improperly or prolongedstorage or adulterated.

Furthermore, the oxide composition of the cement samples is also used in the computation of the cement phase composition with the employment of Bogue's Equations. Two of these phases are alite and belite, which are impure forms of tricalcium silicate (C_3S) and dicalcium silicate (C_2S), respectively and they account for 70% to 80% of the cement early and final strength. Table 5, show the computed phase composition of the eight cement brands, and from the results obtained only cement sample D and H has fullalite(C_3S), belite(C_2S), celite(C_3A), and felite(C_4AF) data. Other cement brands; A that has no data for alite and belite is likely to lack in both early and late, brand (B&C) has only belite that contribute only to late strength, while brand (E,F&G) is alite positive that has impact for only early strength. This is an indication that these cement brands are having deficiencies in their oxide composition that prevented the full formation of phase composition and the hydrate products which are amorphous calcium silicate hydrate (C-S-H gel) and portlandite (Ca(OH)2).

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Table 4: Chemical composition of the eight (8)cement brands in Nigeria

Comp	Approx. oxide comp. limits %	Percentage present in cement samples							
		A	B	C	D	E	F	G	H
Fe_2O_3	0.5-0.6	1.15	1.65	1.70	1.36	1.13	1.14	1.29	1.83
MgO	0.1-4.0	2.47	1.81	1.88	0.98	1.34	1.321	1.51	3.07
Al_2O_3	3.0-8.0	4.11	6.79	7.61	3.00	3.58	3.130	3.13	5.42
SiO_2	17-25	11.23	23.86	24.62	21.07	16.19	18.19	16.61	21.37
SO_3	1.3-3.0	1.62	1.35	1.74	1.23	1.85	1.35	1.72	1.11
K_2O	0.4-1.3	1.38	1.58	1.57	0.72	0.65	0.75	0.40	0.38
CaO	60-67	63.03	55.78	55.29	61.42	59.76	65.28	60.94	62.10
LOI	Max 5.0	14.60	5.80	4.00	6.60	11.10	4.2	9.60	4.60

Table 5: Phase composition for the eight cement brands Bogue's Equation

(%)	A	B	C	D	E	F	G	H
C_3S	-	-	-	64.4	89	99	94	48
C_2S	-	69	82	10	-	-	-	23
C_3A				6				11
C_4AF				4				6

4.3.0 Compressive Strength Test Results

4.3.1 Concrete Compressive Strength Test Results

The compressive strength results show increased compressive strength with increase curing days for all brands of cement for each of the concrete grades. For concrete grade 20, samples A, B, C, E, and F fail to meet the minimum compressive strength of 20N/mm^2 at 28 days of curing. However, brands D, F, and H satisfied the minimum required strength according to BS 8110(1997) with brand H having the highest compressive strength of 27.37N/mm^2 at 28days.

Also, for grade 25 only brands B, D, F, and H satisfied the minimum required strength at 28days as specified in BS 8110(1997) with brand H recording the highest compressive value of 35.09 N/mm^2.

The compressive strength values for grade 30 show brands D, E, F,G, and H satisfied the minimum required strength at 28days as specified in BS 8110(1997).

Furthermore, observing the strength development of the concrete from Figures 2, 3 & 4, confirms that only samples D, F & H satisfied the standard for concrete grade 20, 25 & 30 which shows a similar trend to previous discussions of cement mortar strength and chemical composition.

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Table 6: Compressive strength for concrete grade 20, 25 & 30

Cement brands	Compressive strength of concrete (N/mm^2)								
	Grade 20			Grade 25			Grade 30		
9DAYS	3	7	28	3	7	28	3	7	28
A	4.03	7.12	16.14	11.08	18.58	22.08	15.07	19.81	22.23
B	6.92	10.68	16.85	18.70	21.90	27.85	15.37	20.28	25.84
C	6.51	9.70	16.02	11.12	18.72	20.61	15.39	20.77	27.13
D	11.46	15.47	23.32	16.03	20.01	25.14	22.80	29.17	38.41
E	7.80	8.94	13.24	10.64	15.35	18.20	13.13	25.28	33.90
F	9.63	15.54	20.55	17.52	21.50	27.18	20.63	28.60	31.92
G	9.43	11.33	17.65	11.78	16.30	22.24	12.43	23.78	35.27
H	9.70	16.54	27.37	14.37	26.35	35.09	18.81	31.96	38.96

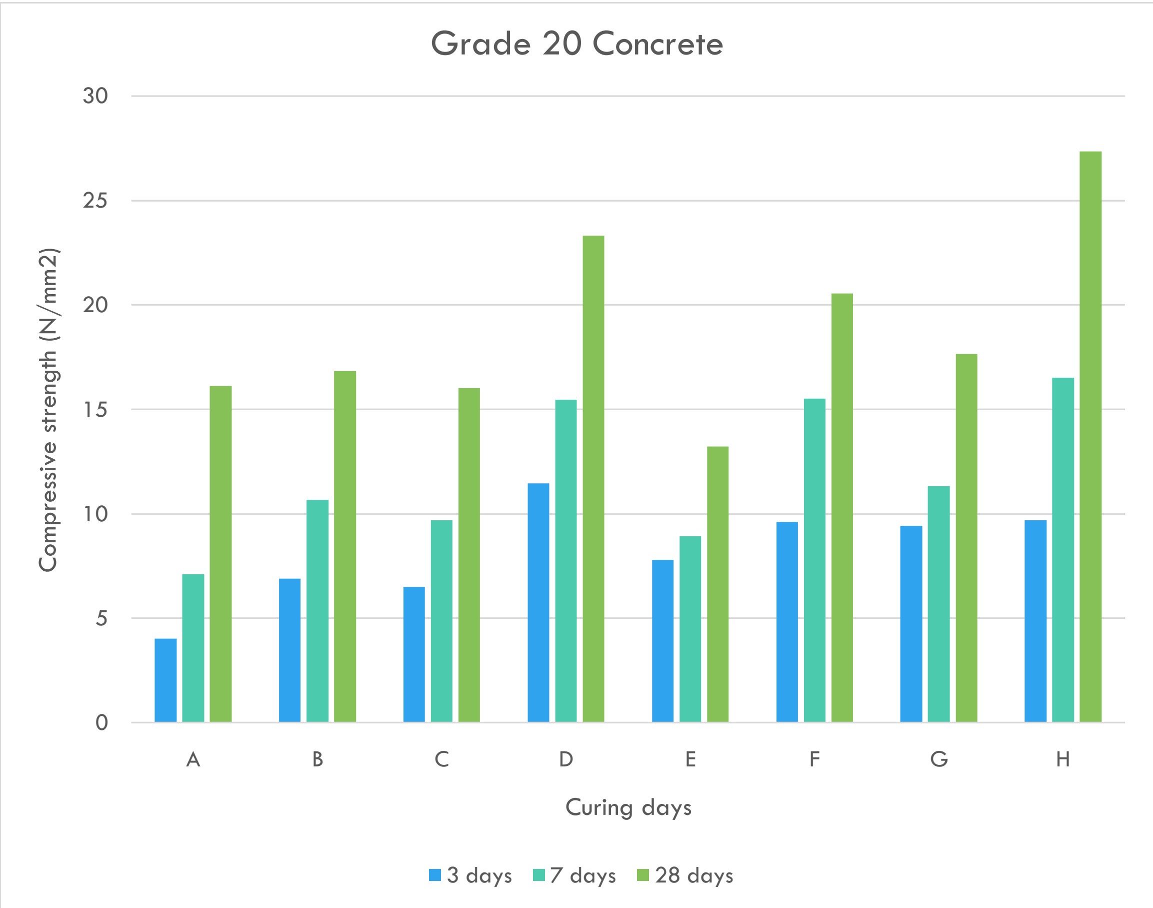

Fig. 2. Compressive strength results for concrete grade 20

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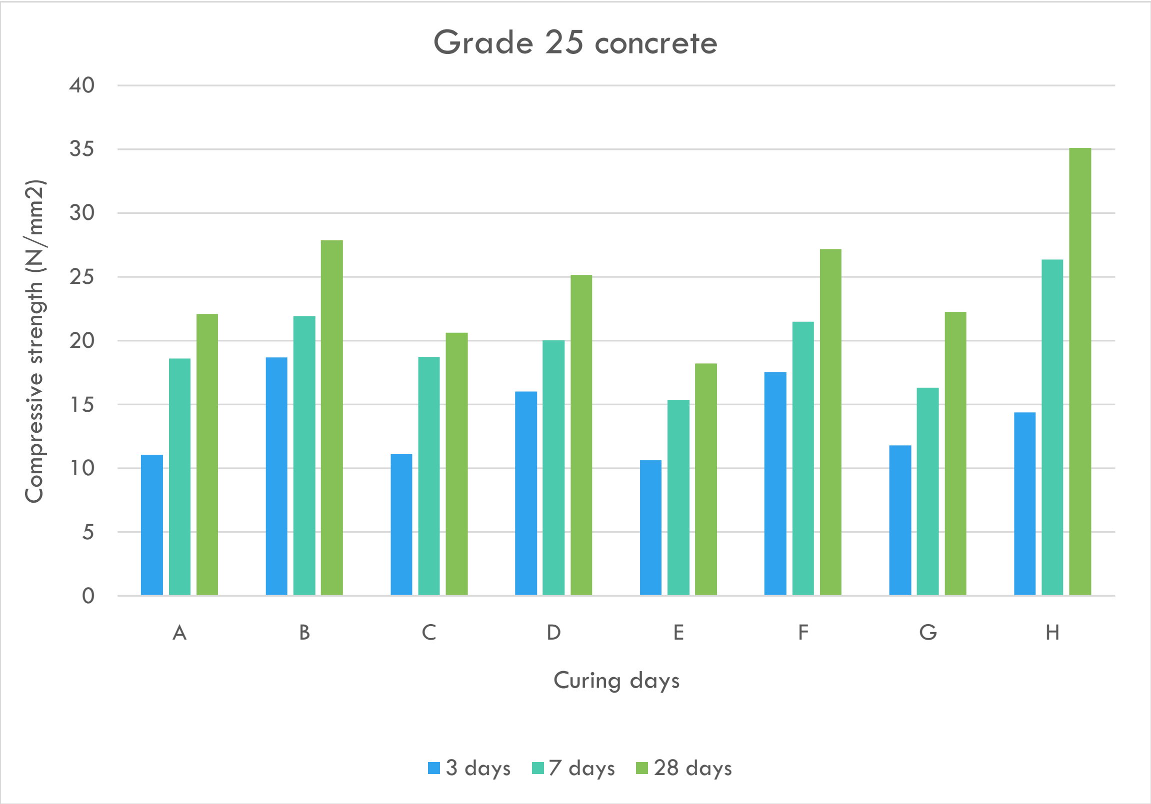

Fig. 3. Compressive strength for concrete grade 25

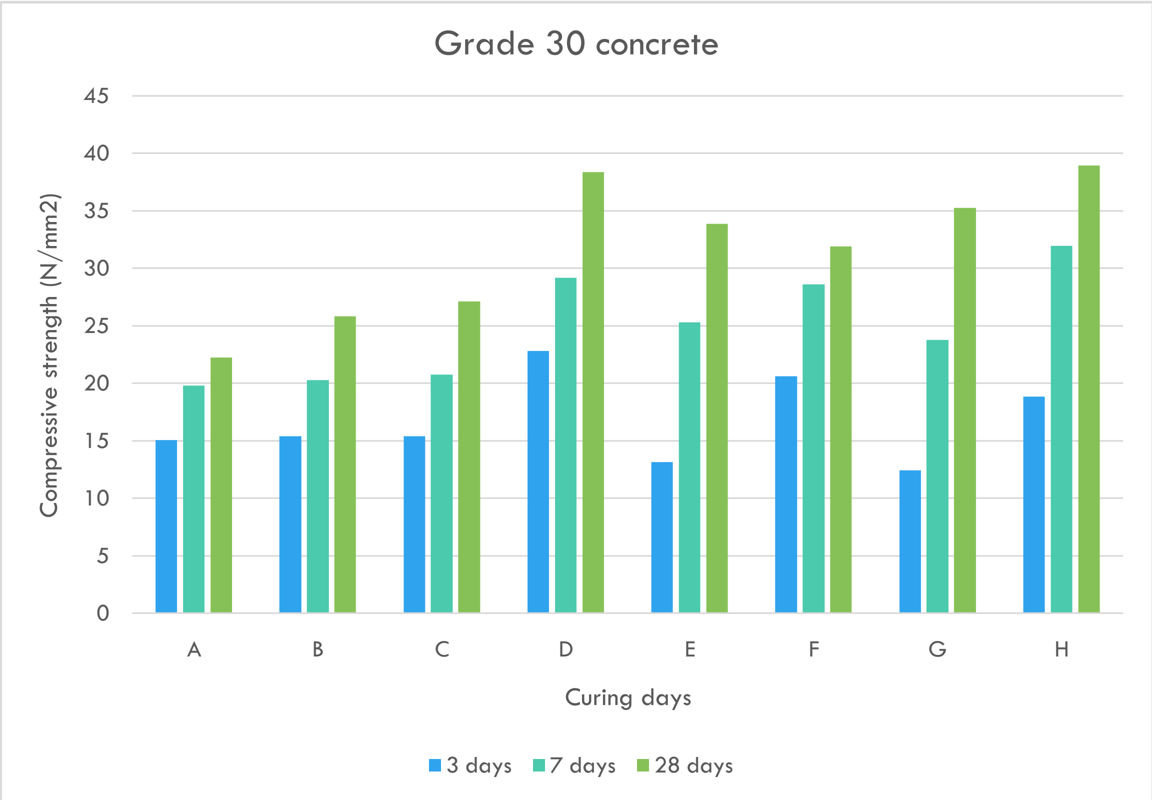

Fig. 4. Compressive strength for concrete grade 30

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V. CONCLUSION AND RECOMMENDATION

From the study conducted, the following conclusions were deduced.

- Cement brands A, E, and F satisfied NIS: 445 1- 2003, and NIS: 446 1- 2003
- The composition of silica, alumina, and calcium oxide in cement brands D and H are within the optimal percentage.
- In cement mortar, all brands conformed with NIS standards at 3 and 7 days while at 28days only E and H met the requirement for compressive strength.
- In concrete, for all grades, cement brands D, F, and H satisfied the compressive strength as recommended in BS 8110 Part 1 1997. However, for grade 25 only cement brand B satisfied the requirement, while cement brands E and G met the requirement only in grade 30.
- Therefore, in all the cement brands, only brand H met the requirements for physical, chemical, and mechanical properties.

Moreover, the research was able to ascertain the quality of different cement brandssourcedfrom the sub-dealer point through a combined approach of a physical, chemical, and mechanical test. The results obtained through different test methods for all the cement brands were analyzed and compare and found out that only brand H among all the brands certified

6.1 RECOMMENDATION

- It is recommended that further research should be conducted and cement samples under investigationare sourced from manufacturers, dealers, sub-dealers, and end-users.
- This study should be continuous work and hence be carried out periodicallyto ascertain the quality of cement used in the built environment.

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