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Comparative-study of Compressive-strengths and Densities of Concrete Produced with Different Brands of Ordinary Portland Cement in Nigeria

Osagie Ibhadode*, Taofiq Bello, A. E. Asuquo, F. W. Idris, F. A. Okougha, I. I. Umanah, M. C. Ugonna, D. N. Nwaigwe

Abstract— In this research paper, each of six (6) commonly-used brands ['Dangote', 'Eagle', 'Ibeto', 'Lafarge', 'Purechem' and 'Unicem'] of Ordinary Portland Cement in Nigeria; were used to produce eighteen (18) cylindrical test-samples of 'grade M10 normal-weight Concrete' and another eighteen (18) cylindrical test-samples of 'grade M15 normal-weight Concrete' in accordance with ASTM C 192/C 192M Standard—which amounted to the casting and consequent testing of a total number of two hundred and sixteen (216) cylindrical concrete test-samples in all, i.e. thirty six (36) concrete test-samples per cement-brand. Then, for both strength-grades 'M10' and "M15' respectively, each of three (3) Concrete-samples produced with each Cement-brand were tested in accordance with ASTM C 39 Standard, using a Universal Testing Machine, to obtain the Characteristic Compressive-strength ' f_{ck} ' (N/mm^2) and Average Compressive-strength per curing-age ' $\bar{f}_{ck}$ ' (N/mm^2) at various curing-ages of 1 day, 3 days, 7days, 14 days, 21 days and 28 days respectively. This was actually preceded by measurements of the weights of these 216 hardened Concrete-samples using a digital Weighing-scale, so as to empirically compute the Dry density ' ρ ' (Kg/m^3) and Average Dry density per curing-age ' $\bar{\rho}$ ' (Kg/m^3) of the hardened Concrete-samples at all six (6) curing-ages. Amongst other things, the experimental results obtained revealed that: All six (6) commonly-used brands of Ordinary Portland Cement in Nigeria are of good quality, since they produced Concrete-samples that exhibited 28 day Compressive-strengths which were higher than the minimum values of $10N/mm^2$ [for grade M10 Concrete] and $15N/mm^2$ [for grade M15 Concrete], as recommended by the ASTM and BSI; while the 28 day Dry densities were also higher than values within the recommended range of 2240 – 2400 Kg/m^3 for normal-weight Concrete.

Index Terms— ASTM, BSI, Compressive-strength, Concrete, Concrete test-samples, Dry density, Ordinary Portland Cement (OPC)

1 INTRODUCTION

The global construction industry will forever remain indebted to the British engineer 'John Smeaton' and the English scientist 'John Aspdin', for their novel inventions of the 'Concrete' in 1756, and the 'Portland Cement' in 1824 respectively. While Portland Cement has become an indispensable ingredient for the production of Concrete—being the binder of all other ingredients in the presence of water, Concrete is unarguably reputed to be the second most used (applied) substance (material) worldwide—lagging behind Water only.

- Osagie Ibhadode is a Research & Development (R&D) Engineer in the Nigerian Building and Road Research Institute (NBRRI), Nigeria. E-mail: osagie.ibhadode@gmail.com
- Taofiq Bello is a Research Officer in the Nigerian Building and Road Research Institute (NBRRI), Nigeria. E-mail: taofiqbello4@gmail.com
- A. E. Asuquo is a Research Officer in the Nigerian Building and Road Research Institute (NBRRI), Nigeria. E-mail: asuquoa77@gmail.com
- F. W. Idris is a Research Officer in Nigerian Building and Road Research Institute (NBRRI), Nigeria. E-mail: farida_idris6@hotmail.com
- F. A. Okougha is a Research Scientist in Nigerian Building and Road Research Institute (NBRRI). E-mail: ferdinandokougha@gmail.com
- I. I. Umanah is a Technical Officer in Nigerian Building and Road Research Institute (NBRRI), Nigeria. E-mail: iko1life@gmail.com
- M. C. Ugonna is a Research Officer in the Nigerian Building and Road Research Institute (NBRRI). E-mail: ugonnamatthias@yahoo.com
- D. N. Nwaigwe is a Research Officer in Nigerian Building and Road Research Institute (NBRRI), Nigeria. E-mail: dantechnig@yahoo.com

By the year 2012, a conservatively estimated ten (10) billion metric tons of Concrete were being produced annually in America; and the concrete industry in America, when it was isolated from other industries that made-up the Construction sector of the American economy, had a net worth that exceeded US$37 billion; and provided gainful employment for well over two (2) million persons in the USA [1]. Also, the European Ready-Mix Concrete Organization (ERMCO) in its June 2016 publication, of the "Year 2015 Ready-Mix Concrete Industry Statistics", revealed that: In the year 2015 alone, the Total/Average Ready-Mix Concrete production in sixteen (16) EU countries stood at 214.8 metric tons, while that of twenty (20) registered member-nations of the ERMCO was 353.0 metric tons, followed by 40.5 metric tons, 99.0 metric tons and 260.0 metric tons for Russia, Japan and USA respectively [2].

Simply put, Concrete is a manmade composite construction material, composed by mixing batched quantities of fillers (Fine aggregates + Coarse aggregates) embedded in a binder-paste (Cement + Water + Air); under certain conditions that make it easy to move/transport, place, cure, compact/set and harden to become a strong, durable and compression-resistant product. Concrete, basically exists in any of these three states—Plastic (fresh) state, Setting state & Hardened state; and as an engineering material, it is technically evaluated on the basis of five main determining characteristics, which are Strength, Workability, Durability, Cohesiveness and Stiffness.

When carrying-out the design of any proposed Concrete structure, and making considerations for its Quality Control (QC), the [compressive] strength of the concrete is generally the specified property. This arises from the fact that, in comparison with other properties of concrete, the testing of concrete [compressive] strength is easier. In addition, some other properties of concrete such as Weathering resistance, impermeability and modulus of elasticity have a direct relationship with the [compressive] strength of concrete, and thus, are deducible from the values of concrete [compressive] strength [3].

Of the three commonly tested strengths of hardened concrete, which are: 'Compressive strength', 'Tensile strength' and 'Flexural strength'; its Compressive strength is generally regarded as its most important engineering property. The Compressive strength of a material or structure, is the capacity of that material or structure to overcome (resist) loads which tend to reduce its size. It is usually determined using a Universal Testing Machine (UTM), and reported with respect to a specified technical standard [4]. According to the Indian Standard (IS), "The 'Strength of Concrete' oftentimes referring to its Compressive strength is expressed in terms of the Characteristic Compressive strength of 150mm size Concrete-cubes tested at 28 days; while the Characteristic strength of Concrete is simply defined as the strength of Concrete, below which not more than 5% of the test results are expected to fall"[5]

Nemati, K. M. (2015), noted that there are three broad determining factors that primarily affect the compressive strength of concrete, which are:

- Effect of constituent-materials (ingredients) and the mix proportions (Water/Cement ratio, Air-entrainment, Cement-type, Maximum aggregate size & mixing water etc.),
- Curing conditions (Time/Age, Temperature & Relative Humidity), and
- Testing parameters. [3]

According to Abram's law,

$$f_c = \frac{K_1}{K_2^{(w/c)}} \qquad - \qquad - \qquad (1)\ [3]$$

Where:

'f_c' is Compressive-strength of the concrete

'K_1' and 'K_2' are empirical constants, and

'w/c' is the water/cement ratio [3]

The 'Workability of fresh (plastic) Concrete' which simply refers to the ease with which a concrete-mix is placed, handled, compacted and finished; prior to hardening, is usually obtained, by conducting a 'Slump test', using a 'Slump test Apparatus'.

The 'Durability of any Concrete structure' greatly influences the overall financial cost [inclusive of maintenance/repair cost and material & labour cost] that will be incurred during its entire life time, and is essentially related to its permeability. Thus, the higher the permeability of concrete, the lower the durability and vice versa. Menon, D. and Sengupta, A. K. (2008), defined the durability of concrete, as the ability of concrete to withstand weathering/environmental action, abrasion, chemical attack or other processes that could result in deterioration. They went further to list the most commonly observed durability-problems suffered by concrete structures [particularly under harsh environmental conditions], as the following:

- Corrosion of steel bars and/or tendons,
- Sulphate and/or other chemical attacks,
- Freezing and thawing damage in cold regions, and
- Alkali-aggregate reaction [6].

The 'Cohesiveness of Concrete' which is influenced by the water content and aggregate-grading, is simply a measure of the extent to which the Concrete itself holds together, in its plastic (fresh) state. The 'Stiffness of Concrete' is factor which is usually required or determined, in order to estimate the deflection of structural members composed of it, in its hardened (solid) state.

Generally, cement which comprises of several chemical compounds including the 'Aluminates of Calcium' and the 'Silicates of Calcium'; is essentially referred to as a hydraulic binder, which in the presence of the adequate amounts of water and air, will undergo an exothermic chemical reaction, to produce a hardened, tough mass of matter; whose solubility is very low. Presently, all Cements which are generally categorized as being "hydraulic in action", are basically classified into four (4) broad groups i.e. High alumina-cement, Portland cement, Blended Portland cement and Additives-added Portland cement.

Specifically, Portland Cement, is simply a finely ground adhesive and cohesive powdery substance, which in the presence of the adequate amounts of water and air, undergoes a chemical reaction called 'Hydration', in order to gradually bind the fragments of fillers—[fine aggregates and coarse aggregates] together, thereby producing a compression-resistant, fire-proof, hard, durable and chemically-inert composite construction material known as 'Concrete'.

Basically, the different types of Portland Cement that find application in the Construction industry/sector are listed as: Ordinary Portland Cement(OPC), Sulphate resisting Portland Cement(SRPC), Portland Pozzolana Cement(PPC), Low Heat Portland Cement(LHPC), Blast Furnace Portland Cement(BFPC), Modified Portland Slag Cement(MPC) and Rapid Hardening Portland Cement(RHPC), etc. [7]. Taylor (1997) showed that, approximately 5.0-10.0% of Portland cement consists of Na_2SO_4, K_2SO_4, MgO, unreacted CaO and trace amounts of other compounds, which remain after the stages of clinkering and grinding. However, the larger bulk [i.e. approximately 90.0-95.0%] of Portland cement consists of four major cementitious components shown in Table 1—each which distinctly contributes to the hydration process, and thereby chemically transforms cement from being a fine dry powder to a hard binding paste [8], [9]. Although, the main oxides present in ordinary Portland cement are lime, alumina, iron oxide and silica, it may also be important to see the tabulated result of its chemical composition analysis, as shown in Table 2.

TABLE 1
CHEMICAL COMPOSITIONS, PERCENTAGE CONTENTS AND ABBREVIATIONS OF THE FOUR MAJOR CHEMICAL COMPOUNDS PRESENT IN PORTLAND CEMENT

S/No.	Compound	Chemical Composition	Common Abbreviation	Percentage Content (%)
1.	Tricalcium Silicate	$3CaO.SiO_2$	C_3S	51
2.	Dicalcium Silicate	$2CaO.SiO_2$	C_2S	23
3.	Tricalcium aluminate	$3CaO.Al_2O_3$	C_3A	8
4.	Tetracalcium aluminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF	9

SOURCE: "Cements", http://www.civil.emu.edu.tr/courses/civl284/3Cements.pdf., 2017 [10]

TABLE 2
APPROXIMATE AND ANALYTICALLY DETERMINED PERCENTAGE CONTENTS AND ABBREVIATIONS OF ALL CHEMICAL COMPOUNDS PRESENT IN PORTLAND CEMENT

Common Name	Compound/ Parameter	Common Abbreviation	Approximate Chemical Composition Limit (%)	Analytically determined Chemical Composition/ Value (%)
Lime		C	60 - 66	63.6
Silica	SiO_2	S	19 – 25	20.7
Alumina	Al_2O_3	A	3 – 8	6.0
Iron Oxide	Fe_2O_3	F	1 – 5	2.4
Magnesia	MgO	M	0 – 5	2.4
Soda	Na_2O	N	0.5 – 1	0.1
Potassa	K_2O	K	0.5 – 1	0.7
Sulphur trioxide	SO_3	$\overline{S}$	1 – 3	1.4
Loss on Ignition		LOI		1.2
Insoluble Residue				0.3
Free CaO				1.1
TOTAL				100.0

SOURCE: "Cements", http://www.civil.emu.edu.tr/courses/civl284/3Cements.pdf., 2017 [10]

The basic chemical reactions of the four (4) major minerals that are present in Portland Cement, which occur during the 'Setting' of Concrete, are illustrated by the chemical equations below:

- Hydration of Tricalcium silicate (C_3S) mineral:

$$C_3S + (1.3 + x)H \rightarrow C_{1.7}SH_x + 1.3CH \quad \text{- (2) [11]}$$

- Hydration of Dicalcium silicate (C_2S) mineral:

$$C_2S + (0.3 + x)H \rightarrow C_{1.7}SH_x + 0.3CH \quad \text{- (3) [11]}$$

- Hydration of Tricalcium aluminate (C_3A) mineral:

$$C_3A + 3C\overline{S}H_2 + 26H \rightarrow C_6A\overline{S}_3H_{32} \quad \text{- (4) [11]}$$

$$2C_3A + C_6A\overline{S}_3H_{32} + 4H \rightarrow 3C_4A\overline{S}H_{12} \quad \text{- (5) [11]}$$

- Hydration of Tetracalcium aluminoferrate (C_4AF) mineral:

$$C_4AF + 3C\overline{S}H_2 + 21H \rightarrow C_6(A,F)\overline{S}_3H_{32} + (F,A)H_3 \quad \text{- (6) [11]}$$

$$C_4AF + C_6(A,F)\overline{S}_3H_{32} + 7H \rightarrow 3C_4(A,F)\overline{S}H_{12} + (F,A)H_3 \quad \text{-- (7) [11]}$$

Actually, cement is a major ingredient used in concrete production. It is that chemically active ingredient, whose characteristic properties, greatly influence the critical properties of the resulting concrete-sample produced from it and other ingredients [fine aggregate, coarse aggregate, water and air). Thus, by implication, a high quality concrete, is obviously the product of a high quality cement.

As was mentioned earlier, the major determining factor for the compressive strength of Concrete, is the effect of the constituent-materials (ingredients) and the mix proportion adopted. Now, as was observed in certain field trips [i.e. during visits to construction sites], where all other variables were kept constant—i.e. same water/cement ratio, same air entrainment, same maximum aggregate size, same mix proportion, same curing age/time, same curing temperature, same relative humidity of air during curing, and same testing parameters were all adopted]; there were still variations in the compressive strengths of the concrete-samples produced, even when the very same samples (stock) of fine aggregates and coarse aggregates were used, and the same quantity and class, [but different brands] of ordinary Portland cement were used for the concrete production.

These unexpected [but interesting] observations in a number of undocumented cases, and several preliminary random investigations identified during the desk-study, drew the attention of the inquisitive authors, and gradually motivated them to state a research hypothesis as follows: "When all other determining variables [i.e. water/cement ratio, air entrainment, maximum aggregate size, mix proportion, curing age/time, curing temperature, relative humidity of air during curing, and testing parameters] are kept constant, the brands[i.e. characteristic properties] of the Cements used [even when of the same class and quantity] can result in the production of Concrete-samples of varying compressive strengths".

Thus, the aim of this research work, is to determine if different brands of [commonly used] ordinary Portland cements [of the same class], will result in the production of Concrete-samples of the same strength-grade, but with different compressive-strengths; when all other [influencing] conditions are kept constant.

2 Materials and Method

2.1 Collection of Materials

The experimental materials used to produce the Concrete test-samples during this research work, included Ordinary Portland Cement [as binder], Natural River Sand [as fine aggregate], Granite chippings [as coarse aggregate] and water.

- Cement:

Six (6) commonly-used brands ['Dangote', 'Eagle', 'Ibeto', 'Lafarge', 'Purechem' and 'Unicem'] of ASTM type 1 Ordinary Portland Cements, available in Nigeria, were obtained.

- Fine Aggregate:

Locally available natural river sand was obtained to be used as fine aggregate/filler. Care was taken to ensure that, there were no organic impurities, salty compounds and clay/clayey-matter etc., present in the sand. Most importantly, it was subjected to sieve analysis testing to ensure that it passed through the 4.75mm BSI test sieve, under sun-dried condition.

- Coarse Aggregate

Quarried angular-shaped granite chippings of average nominal size ranging from 19 – 20mm, obtained from a nearby source, was used for the experiments, only after it was carefully ensured that it was sun-dried; and free of any organic materials, clay/clayey matter, dust and other impurities that could chemically interfere with the hydration reactions that result in the setting of Concrete.

- Water

Potable (drinkable) water, tested to be free from the presence of chemical substances which could be deleterious to Concrete; was used for the experiments.

2.2 Preparation of Concrete test-samples (Concrete-samples)

The experimental procedures that comprise the preparation [Mixing, Casting and Curing] of the Concrete test-samples were performed as described in the ASTM C 192/C 192M Standard—being one of the globally recognized and recommended Standard Practices, which provides standardized requirements for the preparation of ingredients (materials), Mixing, Casting and Curing of Concrete test-samples under ideal laboratory conditions. However, it should be noted that, the ingredients (materials) were batched by weight to obtain two (2) different strength-grades of ordinary (normal-weight) Concrete, i.e. 'M10' [with a mix ratio of 1:3:6] and 'M15' [with a mix ratio of 1:2:4], with both having a constant w/c (water/cement ratio) of 0.5. Standard cylindrical Moulds of dimensions Ø (100mm) * h (200mm) [Ø (4ft) * h (8ft)] were used, as specified in ASTM C31 Standard. Finally, using each of the six (6) commonly-used brands of Ordinary Portland Cement, as was earlier mentioned; three (3) Cylindrical Concrete test-samples were produced for the two (2) Strength-grades 'M10' and 'M15', at Six (6) different Curing-ages of 1, 3, 7, 14, 21 and 28 days respectively. Thus, for this experimentation, a total of two hundred and sixteen (216) Concrete test-samples were produced and tested in all—[i.e. 2 Strength-grades * 6 Curing-ages * 3 Concrete test-samples * 6 Cement-brands].

2.3 Dry Density (Unit Weight) Determination of Hardened Concrete test-samples (Concrete-samples)

The Dry Densities (Unit Weights) of the two hundred and sixteen (216) hardened Concrete test-samples produced using each of the six (6) Cement brands—['Dangote', 'Eagle', 'Ibeto', 'Lafarge', 'Purechem' and 'Unicem'], were respectively obtained in sets of eighteen (18)—i.e. three (3) Samples per Curing age [i.e. 1, 3, 7, 14, 21 and 28 days] per Strength-grade [i.e. Grade M10 and Grade M15]. This was done by measuring the Weight of each Sample using the SF-400 4 digital Weighing Scale; and computing the 'Mass' and 'solid Volume'; and then, combining a number of simple mathematical equations, to determine its dry density, [based on the assumption the Concrete test-sample was a solid composite cylinder with minimal air voids] as shown below:

Recall from basic knowledge of Physics, that:

$$W_{Cyl.Con.Samp.} = m_{Cyl.Con.Samp.} * g \quad - \quad - \quad (8)$$

Where:

'$W_{Cyl.Con.Samp.}$' is the Weight (N) of the test-sample measured using the SF-400 4 digital Weighing Scale

'$m_{Cyl.Con.Samp.}$' is the unknown Mass (Kg) of the Concrete test-sample, and

'g' is the acceleration due to gravity = 9.78 m/s^2

$$m_{Cyl.Con.Samp.} = \frac{W_{Cyl.Con.Samp.}}{g} \quad - \quad - \quad (9)$$

Also,

$$\rho_{Con.Samp.} = \frac{m_{Cyl.Con.Samp.}}{V_{cyl}} \quad - \quad - \quad (10)$$

Where:

'$\rho_{Con.Samp.}$' is the unknown Density (Kg/m^3) of the Concrete test-sample to be determined, and

'V_{cyl}' is the unknown cylindrical solid Volume (m^3) of the Concrete test-sample

However,

$$V_{cyl} = \pi * r^2_{Cyl.Con.Samp.} * h_{Cyl.Con.Samp.} \quad - \quad - \quad (11)$$

Thus, substituting '$\pi * r^2_{Cyl.Con.Samp.} * h_{Cyl.Con.Samp.}$' from (11), for '$V_{cyl}$' into (10)

$$\rho_{Con.Samp.} = \frac{m_{Cyl.Con.Samp.}}{\pi * r^2_{Cyl.Con.Samp.} * h_{Cyl.Con.Samp.}} \quad - \quad (12)$$

Now, we may recall that, the dimensions of the cylindrical Concrete test-sample were as follows:

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Vertical Height of cylindrical concrete Mould (h) = 200mm [i.e. 0.2m] = $h_{Cyl.Con.Samp.}$

And,

Diameter of cylindrical concrete Mould ($\varnothing$) = 100mm [i.e. 0.1m]

But,

Radius of cylindrical concrete Mould (r) =

$$\frac{Diameter(\varnothing)}{2} = \frac{100}{2} = 50\text{mm [i.e. 0.05mm]} = r_{Cyl.Con.Samp.}$$

Therefore, substituting '0.2m' for ' $h_{Cyl.Con.Samp.}$ ', and '0.05' for ' $r_{Cyl.Con.Samp.}$ ' into (11) above, gives:

$$V_{cyl} = 3.124 * (0.05)^2 * 0.2 = 0.001571 m^3$$

Consequently, substituting '0.00157' for ' V_{cyl} ' into (12) above, paraphrases it to become:

$$\rho_{Con.Samp.} = \left(\frac{m_{Cyl.Con.Samp.}}{0.001571} \right) \text{ expressed in '} Kg/m^3 \text{' - - (13)}$$

2.4 Compressive-strength Testing of Hardened Concrete test-samples (Concrete-samples)

For both strength grades—M10 and M15, the Characteristic Compressive strength (f_{ck}) of each of the one hundred and eighteen (118) hardened cylindrical Concrete test-samples, produced in sets (groups) of three (3) samples per Cement brand—['Dangote', 'Eagle', 'Ibeto', 'Lafarge', 'Purechem' and 'Unicem'], per Curing age—[1, 3, 7, 14, 21 and 28 days]; were tested with a Universal Testing Machine (UTM) at the Materials Testing Laboratory of 'Bough Resources Nigeria Limited, Port-Harcourt, Nigeria'; in accordance with the test procedures specified in ASTM C 39 Standard.

2.5 Comparative Analyses of Experimental and Computed data

The values of 'Characteristic Compressive-strengths (f_{ck})' in N/mm² and 'Dry Densities (ρ)' in Kg/m³, so obtained, at various Curing ages—[1, 3, 7, 14, 21 and 28 days], for both Strength-grades, were then tabulated in Six (6) tables and graphically illustrated with six (6) graphs; starting with the Concrete test-samples produced using Dangote Cement brand, followed by Eagle Cement brand, and then, Ibeto, Lafarge, Purechem, and Unicem Cement brands respectively.

Also, for both Strength-grades, the values of the 'Average Characteristic Compressive Strength ($\overline{f_{ck}}$)' in N/mm², and the 'Average Dry Density ($\overline{\rho}$)' in Kg/m³ were computed from the obtained experimental data and tabulated and graphically illustrated. While the ranges of the 'Standard expected Percentage of 28 day Compressive Strength per Curing-age' in '%' were obtained based on the recommended ranges stated by Umange Ranasinghe [12]; and the 'Actual Experimental Percentages of 28 day Compressive Strength' also expressed in '%' were calculated, tabulated and graphically illustrated.

Then, at each Curing-age, the values of 'Actual Experimental Percentages of 28 day Compressive Strength' (%) were then directly compared with the values of the 'Standard expected Percentage of 28 day Compressive Strength per Curing-age' (%), so as to determine if the 'rate of Strength-gain per Curing-age' fell below the 'standard recommended range of values' for grades M10 and M15 Concrete test-samples, produced using each of the six (6) commonly used brands of Ordinary Portland Cement in Nigeria.

Likewise, for both Strength-grades, the increase/decrease in the Dry Densities of the Hardened Concrete test-samples [produced using all six (6) Cement brands], from one curing age to another was carefully observed and summarily discussed.

Finally, for both Strength-grades—i.e. M10 and M15, a comparison of the values of 'Average Characteristic Compressive Strength ($\overline{f_{ck}}$)' and 'Average Dry Density ($\overline{\rho}$)' of the Concrete Samples produced using the six (6) different Cement brands—['Dangote', 'Eagle', 'Ibeto', 'Lafarge', 'Purechem' and 'Unicem'], at all six (6) Curing-ages—[1, 3, 7, 14, 21 and 28 days], was conclusively discussed; so as to determine the Cement brands that produced the strongest and most dense Concrete samples, and vice versa.

3 RESULTS AND DISCUSSION

3.1 Dangote-Cement Concrete Samples

From Table 3 and Fig. 1, it could be seen that, for grade M10 (1:3:6) of Dangote-cement Concrete Samples [$DCS1_{M10(1day)}$ to $DCS3_{M10(28days)}$], that there is a steady increase in the average compressive strength as the curing-age increases. Thus, average Compressive strength increased from 1.97 N/mm² at a curing-age of 1 day to 14.60 N/mm² at a curing-age of 28 days. Similarly, based on the experimental observations for grade M15 (1:2:4) of Dangote-cement Concrete Samples [$DCS1_{M15(1day)}$ to $DCS3_{M15(28days)}$], it was noted that, the average Compressive strength increased from 4.15 N/mm² at a curing-age of 1 day to 35.83 N/mm² at a curing-age of 28 days.

Also, about half [50.9% (7.52 N/mm²) ' $DCS1_{M10(7days)}$ ', 50.1% (7.16 N/mm²) ' $DCS2_{M10(7days)}$ ' and 50.4% (7.44N/mm²) ' $DCS3_{M10(7days)}$ '] of the maximum (28 day) Compressive Strengths of 14.77 N/mm² [$DCS1_{M10(28days)}$], 14.28 N/mm² [$DCS2_{M10(28days)}$] and 14.75 N/mm² [$DCS3_{M10(28days)}$] for grade M10 (1:3:6) Dangote-cement Concrete Samples was attained, after curing for 7 days. A very similar behaviour was observed with the grade M15 (1:2:4) of Dangote-cement Concrete Samples, in which strength-values which were slightly above half [55.3% (20.44 N/mm²) ' $DCS1_{M15(7days)}$ ', 55.5% (17.76 N/mm²) ' $DCS2_{M15(7days)}$ ' and 55.5% (21.36 N/mm²) ' $DCS3_{M15(7days)}$ '] of the maximum (28 day) Compressive Strengths of 36.99 N/mm² [$DCS1_{M15(28days)}$], 32.02 N/mm² [$DCS2_{M15(28days)}$] and 38.48 N/mm² [$DCS3_{M15(28days)}$]; were attained, after curing for 7 days.

Furthermore, It is important to mention that, slight differences were observed between the Compressive-strength values of each of the three (3) Concrete-samples, at all the Curing-ages [1, 3, 7, 14, 21 and 28 days], for both Strength-grades M10 (1:3:6) and M15 (1:2:4).

TABLE 3
COMPRESSIVE-STRENGTHS AND DENSITIES OF GRADES M10 AND M15 CONCRETE-SAMPLES PRODUCED WITH 'DANGOTE' BRAND OF ORDINARY PORTLAND CEMENT AT VARIOUS CURING-AGES.

S/No	Dangote-Cement Concrete Sample Designation	Curing-Age of Concrete Sample (Days)	Characteristic Compressive Strength f_{ck} (N/mm^2)	Average Characteristic Compressive Strength $\overline{f}_{ck}$ (N/mm^2)	Standard expected Percentage of 28 day Compressive Strength per Curing-age (%)	Actual Experimental Percentage of 28 day Compressive Strength (%)	Density ρ (Kg/m^3)	Average Density $\overline{\rho}$ (Kg/m^3)
Concrete Grade: M10 (1:3:6), w/c = 0.5								
1	$DCS1_{M10(1day)}$	1	1.96	1.97	≥ 16	13.3	2364.0	2361.1
2	$DCS2_{M10(1day)}$		1.94			13.6	2361.1	
3	$DCS3_{M10(1day)}$		2.02			13.7	2358.2	
4	$DCS1_{M10(3days)}$	3	7.52	7.37	≥ 40	50.9	2421.3	2420.7
5	$DCS2_{M10(3days)}$		7.16			50.1	2419.3	
6	$DCS3_{M10(3days)}$		7.44			50.4	2421.6	
7	$DCS1_{M10(7days)}$	7	9.88	9.69	≥ 65	66.9	2519.6	2519.8
8	$DCS2_{M10(7days)}$		9.47			66.3	2519.5	
9	$DCS3_{M10(7days)}$		9.79			66.4	2520.4	
10	$DCS1_{M10(14days)}$	14	11.75	11.65	≥ 90	79.6	2523.8	2522.5
11	$DCS2_{M10(14days)}$		11.40			79.8	2522.3	
12	$DCS3_{M10(14days)}$		11.80			80.0	2521.5	
13	$DCS1_{M10(21days)}$	21	14.07	13.92	≥ 95	95.3	2470.8	2470.3
14	$DCS2_{M10(21days)}$		13.67			95.7	2469.4	
15	$DCS3_{M10(21days)}$		14.01			95.0	2470.6	
16	$DCS1_{M10(28days)}$	28	14.77	14.60	≥ 99	100.0	2570.2	2569.1
17	$DCS2_{M10(28days)}$		14.28			100.0	2567.8	
18	$DCS3_{M10(28days)}$		14.75			100.0	2569.2	
Concrete Grade: M15 (1:2:4), w/c = 0.5								
19	$DCS1_{M15(1day)}$	1	4.42	4.15	≥ 16	11.9	2309.2	2328.5
20	$DCS2_{M15(1day)}$		3.71			11.6	2314.3	
21	$DCS3_{M15(1day)}$		4.33			11.3	2362.2	
22	$DCS1_{M15(3days)}$	3	20.44	19.85	≥ 40	55.3	2437.7	2428.8
23	$DCS2_{M15(3days)}$		17.76			55.5	2391.3	
24	$DCS3_{M15(3days)}$		21.36			55.5	2457.2	
25	$DCS1_{M15(7days)}$	7	25.40	25.33	≥ 65	68.7	2462.7	2495.8
26	$DCS2_{M15(7days)}$		21.88			68.3	2457.0	
27	$DCS3_{M15(7days)}$		28.71			74.6	2567.7	
28	$DCS1_{M15(14days)}$	14	32.43	30.98	≥ 90	87.7	2543.5	2529.5
29	$DCS2_{M15(14days)}$		26.86			83.9	2472.2	
30	$DCS3_{M15(14days)}$		33.66			87.5	2572.9	
31	$DCS1_{M15(21days)}$	21	35.42	34.23	≥ 95	95.8	2552.9	2558.2
32	$DCS2_{M15(21days)}$		30.54			95.4	2534.4	
33	$DCS3_{M10(21days)}$		36.72			95.4	2587.3	
34	$DCS1_{M10(28days)}$	28	36.99	35.83	≥ 99	100.0	2596.6	2600.3
35	$DCS2_{M10(28days)}$		32.02			100.0	2599.9	
36	$DCS3_{M10(28days)}$		38.48			100.0	2604.4	

NOTE: The 'Standard expected Percentage of 28 day Compressive Strength per Curing-age' expressed in '%' were obtained from [12]

Moreover, the average Densities of the Concrete-samples increased steadily from 2361.09 Kg/m³ at a Curing-age of 1 day to 2569.06 Kg/m³ at a Curing-age of 28 days for grade M10 (1:3:6); and from 2328.54 Kg/m³ at a Curing-age of 1 day to 2600.30 Kg/m³ at a Curing-age of 28 days for grade M15 (1:2:4).

3.2 Eagle-Cement Concrete Samples

A careful look at the results of 'grade M10 (1:3:6) Eagle-cement Concrete Samples' [$ECS1_{M10(1day)}$ to $ECS3_{M10(28days)}$] presented in Table 4 and Fig. 2, shows that, at a Curing-age of 1 day, the three (3) Concrete-samples [$ECS1_{M10(1day)}$, $ECS2_{M10(1day)}$ and $ECS3_{M10(1day)}$] attained over one-tenth [11.1% (1.14 N/mm²), 11.0% (1.12 N/mm²) and 11.7% (1.23 N/mm²)] respectively of their various 28 day Compressive-strengths of 10.26 N/mm² ($ECS1_{M10(28days)}$), 10.17 N/mm² ($ECS2_{M10(28days)}$) and 10.54 N/mm² ($ECS3_{M10(28days)}$). At 7 days of curing, the three (3) Concrete-samples [$ECS1_{M10(7days)}$, $ECS2_{M10(7days)}$ and $ECS3_{M10(7days)}$] attained Compressive-strength values that respectively exceeded two-thirds [70.4% (7.22 N/mm²) 70.7% (7.19 N/mm²) and 70.9% (7.47 N/mm²)] of their various 28 days compressive-strengths of 10.26 N/mm² ($ECS1_{M10(28days)}$), 10.17 N/mm² ($ECS2_{M10(28days)}$) and 10.54 N/mm² ($ECS3_{M10(28days)}$).

It was interesting to note that, similar results were obtained with 'grade M15 (1:2:4) Eagle-cement Concrete Samples' [$ECS1_{M15(1day)}$ to $ECS3_{M15(28days)}$] at various Curing-ages of 1, 3, 7, 14, 21 and 28 days. This is because strength values that exceeded one-tenth [16.8% (6.29 N/mm²) ' $ECS1_{M15(1day)}$ ', 16.5% (6.05 N/mm²) ' $ECS2_{M15(1day)}$ ' and 17.2% (6.10 N/mm²) ' $ECS3_{M15(1day)}$ '] of the 28 day Compressive-strengths were attained after curing for 1 day. While about 70% [70.7% (26.50 N/mm²) ' $ECS1_{M15(7days)}$ ', 70.3% (25.80 N/mm²) ' $ECS2_{M15(7days)}$ ' and 70.6% (25.38 N/mm²) ' $ECS3_{M15(7days)}$ '] were attained after curing for 7 days. However, after curing for 21 days, Compressive-strength values which were approximately 96% [i.e. 96.5% (36.15 N/mm²), 96.4% (35.39 N/mm²) and 96.5% (34.67 N/mm²)] of the 28 day Compressive-strengths [37.45 N/mm², 36.70 N/mm² and 35.94 N/mm²] were attained by Samples ' $ECS1_{M15(21days)}$ ', ' $ECS2_{M15(21days)}$ ' and ' $ECS3_{M15(21days)}$ ' respectively.

3.3 Ibeto-Cement Concrete Samples

Table 5 displays and Fig. 3 illustrates the test results obtained after subjecting three (3) Concrete-samples of both strength-grades ['M10' and 'M15'] of Concretes produced with Ibeto-cement, at six (6) Curing-ages of 1, 3, 7, 14, 21 and 28 days.

For all the three (3) 'grade M10 (1:3:6) Ibeto-cement Concrete-samples' [generally represented by $ICS1_{M10}$, $ICS2_{M10}$ and $ICS1_{M10}$], it was noticed that, with each passing day, there were increases in the characteristic Compressive-strengths from minimum to maximum values of: 1.16 - 1.27 N/mm² ($ICS1_{M10(1day)}$ - $ICS3_{M10(1day)}$), with an average of 1.22 N/mm² [at a Curing-age of 1 day]; 6.82 - 7.13 N/mm² ($ICS1_{M10(3days)}$ - $ICS3_{M10(3days)}$), with an average of 7.00 N/mm² [at a Curing-age of 3 days]; and 7.54 – 7.97 N/mm² ($ICS1_{M10(7days)}$ - $ICS3_{M10(7days)}$), with an average of 7.81 N/mm² [at a Curing-age of 7 days]. While for Curing-ages of 14, 21 and 28 days, the Characteristic Compressive-strengths of the Concrete- samples ranged from 8.71 - 9.17N/mm² ($ICS3_{M10(14days)} - ICS1_{M10(14days)}$), 10.62 – 11.08 N/mm² ($ICS1_{M10(21days)} - ICS3_{M10(21days)}$) and 11.19 – 11.73 N/mm² ($ICS1_{M10(28days)} - ICS3_{M10(28days)}$); and averaged at 8.97 N/mm², 10.91 N/mm² and 11.55 N/mm² respectively.

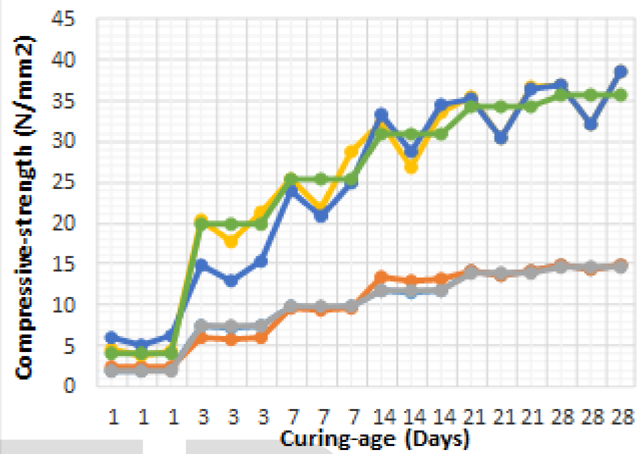

Fig. 1. Graphs of Characteristic and Average Compressive-strenghs of Grades M10 and M15 Concrete-samples Produced with DANGOTE Brand of Ordinary Portland Cement

Likewise, for all the three (3) 'grade M15 (1:2:4) Ibeto-cement Concrete-samples' [generally represented by $ICS1_{M15}$, $ICS2_{M15}$ and $ICS3_{M15}$], it was clearly observed that, the daily increments in Curing-age, consequently resulted in increments in the strengths of the Samples. Thus, the Characteristic Compressive-strengths of the Samples increased from minimum to maximum values of: 4.44 – 4.48 N/mm² ($ICS1_{M15(1day)}$ - $ICS3_{M15(1day)}$), with an average of 4.46 N/mm² [at a Curing-age of 1 day]; 18.84 – 19.54 N/mm² ($ICS1_{M15(3days)} - ICS3_{M15(3days)}$), with an average of 17.43 N/mm² [at a Curing-age of 3 days]; and 22.85 – 26.83 N/mm² ($ICS1_{M15(7days)} - ICS3_{M15(7days)}$), with an average of 24.25 N/mm² [at a Curing-age of 7 days]. While for Curing-ages of 14, 21 and 28 days, the Characteristic Compressive-strengths of the Concrete- samples ranged from 30.67 – 31.17 N/mm²

TABLE 4
COMPRESSIVE-STRENGTHS AND DENSITIES OF GRADES M10 AND M15 CONCRETE-SAMPLES PRODUCED WITH 'EAGLE' BRAND OF ORDINARY PORTLAND CEMENT AT VARIOUS CURING-AGES.

S/No	Eagle-Cement Concrete Sample Designation	Curing-Age of Concrete Sample (Days)	Characteristic Compressive Strength f_{ck} (N/mm^2)	Average Characteristic Compressive Strength $\overline{f}_{ck}$ (N/mm^2)	Standard expected Percentage of 28 day Compressive Strength per Curing-age (%)	Actual Experimental Percentage of 28 day Compressive Strength (%)	Density ρ (Kg/m^3)	Average Density $\overline{\rho}$ (Kg/m^3)
Concrete Grade: M10 (1:3:6), w/c = 0.5								
1	$ECS1_{M10(1day)}$	1	1.14	1.16	≥ 16	11.1	2413.7	2415.5
2	$ECS2_{M10(1day)}$		1.12			11.0	2416.9	
3	$ECS3_{M10(1day)}$		1.23			11.7	2415.9	
4	$ECS1_{M10(3days)}$	3	3.66	3.65	≥ 40	35.7	2518.2	2517.9
5	$ECS2_{M10(3days)}$		3.59			35.3	2517.5	
6	$ECS3_{M10(3days)}$		3.70			35.1	2518.1	
7	$ECS1_{M10(7days)}$	7	7.22	7.29	≥ 65	70.4	2567.3	2552.4
8	$ECS2_{M10(7days)}$		7.19			70.7	2568.0	
9	$ECS3_{M10(7days)}$		7.47			70.9	2565.9	
10	$ECS1_{M10(14days)}$	14	7.86	7.89	≥ 90	76.6	2521.6	2521.3
11	$ECS2_{M10(14days)}$		7.81			76.8	2520.5	
12	$ECS3_{M10(14days)}$		8.06			76.5	2521.7	
13	$ECS1_{M10(21days)}$	21	9.56	9.64	≥ 95	93.2	2565.6	2567.9
14	$ECS2_{M10(21days)}$		9.48			93.2	2569.8	
15	$ECS3_{M10(21days)}$		9.88			93.7	2568.3	
16	$ECS1_{M10(28days)}$	28	10.26	10.44	≥ 99	100.0	2568.3	2568.8
17	$ECS2_{M10(28days)}$		10.17			100.0	2568.9	
18	$ECS3_{M10(28days)}$		10.54			100.0	2569.3	
Concrete Grade: M15 (1:2:4), w/c = 0.5								
19	$ECS1_{M15(1day)}$	1	6.29	6.15	≥ 16	16.8	2365.0	2348.0
20	$ECS2_{M15(1day)}$		6.05			16.5	2348.3	
21	$ECS3_{M15(1day)}$		6.10			17.2	2330.7	
22	$ECS1_{M15(3days)}$	3	19.19	18.89	≥ 40	51.2	2462.5	2444.2
23	$ECS2_{M15(3days)}$		18.87			51.4	2451.5	
24	$ECS3_{M15(3days)}$		18.62			52.5	2418.5	
25	$ECS1_{M15(7days)}$	7	26.50	25.89	≥ 65	70.7	2511.1	2491.4
26	$ECS2_{M15(7days)}$		25.80			70.3	2492.7	
27	$ECS3_{M15(7days)}$		25.38			70.6	2470.3	
28	$ECS1_{M15(14days)}$	14	30.26	30.70	≥ 90	80.8	2528.9	2550.6
29	$ECS2_{M15(14days)}$		32.83			89.5	2572.1	
30	$ECS3_{M15(14days)}$		29.01			80.7	2550.9	
31	$ECS1_{M15(21days)}$	21	36.15	35.50	≥ 95	96.5	2605.1	2598.7
32	$ECS2_{M15(21days)}$		35.39			96.4	2605.5	
33	$ECS3_{M10(21days)}$		34.67			96.5	2585.6	
34	$ECS1_{M10(28days)}$	28	37.45	36.70	≥ 99	100.0	2637.8	2635.5
35	$ECS2_{M10(28days)}$		36.70			100.0	2639.3	
36	$ECS3_{M10(28days)}$		35.49			100.0	2629.5	

NOTE: The 'Standard expected Percentage of 28 day Compressive Strength per Curing-age' expressed in '%' were obtained from [12]

$(ICS1_{M15(14days)} - ICS3_{M15(14days)})$, 34.30 – 35.43 N/mm² $(ICS1_{M15(21days)} - ICS3_{M15(21days)})$ and 35.17 – 36.27 N/mm² $(ICS1_{M15(28days)} - ICS3_{M15(28days)})$; and averaged at 30.95 N/mm², 34.88 N/mm² and 35.74 N/mm² respectively. Very similar results of an increase in Average density per curing-age [2433.45 – 2519.73 Kg/m³ and 2301.18 – 2591.94 Kg/m³], as Curing-age increased, was observed for both strength-grades 'M10' and 'M15' respectively, as is seen in Table 5 and Fig. 3.

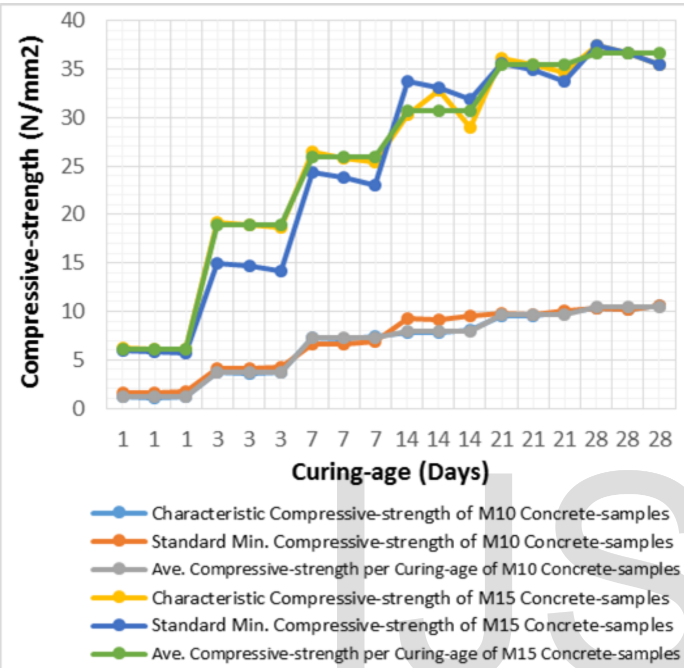

Fig. 2. Graphs of Characteristic and Average Compressive-strenghs of Grades M10 and M15 Concrete-samples Produced with EAGLE Brand of Ordinary Portland Cement

1.4 Lafarge-Cement Concrete Samples

From Table 6 and Fig. 4, it could be seen that, for grade M10 (1:3:6) of Lafarge-cement Concrete Samples [$LCS1_{M10(1day)}$ to $LCS3_{M10(28days)}$], that there is a steady increase in the average compressive strength as the curing-age increases. Thus, average Compressive strength increased from 1.80 N/mm² at a curing-age of 1 day to 14.34 N/mm² at a curing-age of 28 days. Similarly, based on the experimental observations for grade M15 (1:2:4) of Lafarge-cement Concrete Samples [$LCS1_{M15(1day)}$ to $LCS3_{M15(28days)}$], it was noted that, the average Compressive strength increased from 5.20 N/mm² at a curing-age of 1 day to 37.86 N/mm² at a curing-age of 28 days.

Also, over two-third [68.0% (10.13 N/mm²) '$LCS1_{M10(7days)}$', 68.2% (9.63 N/mm²) '$LCS2_{M10(7days)}$' and 68.1% (9.53 N/mm²) '$LCS3_{M10(7days)}$'] of the maximum (28 day) Compressive Strengths of 14.89 N/mm² [$LCS1_{M10(28days)}$], 14.13 N/mm² [$LCS2_{M10(28days)}$] and 14.00 N/mm² [$LCS3_{M10(28days)}$] for grade M10 (1:3:6) Lafarge-cement Concrete Samples was attained, after curing for 7 days. A very similar behaviour was observed with the grade M15 (1:2:4) of Lafarge-cement Concrete Samples, in which strength-values which were above two-third [69.8% (26.36 N/mm²) '$LCS1_{M15(7days)}$', 69.9% (26.71 N/mm²) '$LCS2_{M15(7days)}$' and 75.8% (28.49 N/mm²) '$LCS3_{M15(7days)}$'] of the maximum (28 day) Compressive Strengths of 37.78 N/mm² [$LCS1_{M15(28days)}$], 38.22 N/mm² [$LCS2_{M15(28days)}$] and 37.58 N/mm² [$LCS3_{M15(28days)}$]; were attained, after curing for 7 days.

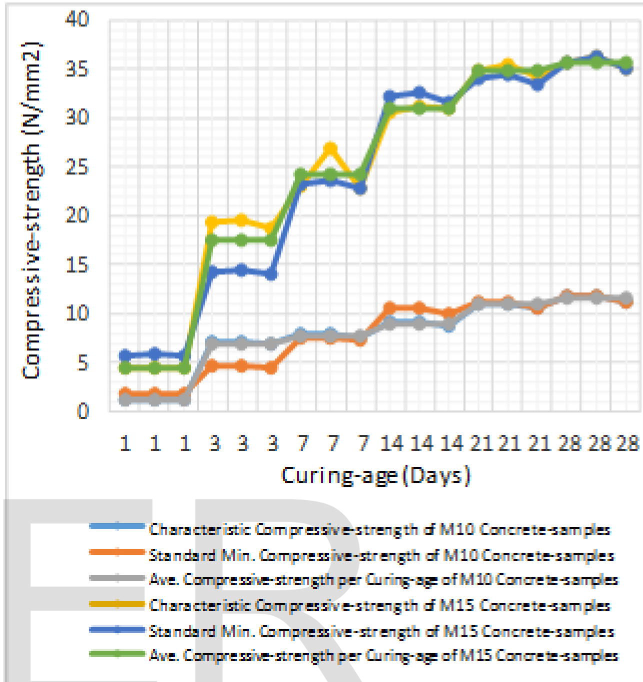

Fig. 3. Graphs of Characteristic and Average Compressive-strenghs of Grades M10 and M15 Concrete-samples Produced with IBETO Brand of Ordinary Portland Cement

Furthermore, It is important to mention that, slight differences were observed between the Compressive-strength values of each of the three (3) Concrete-samples, at all the Curing-ages [1, 3, 7, 14, 21 and 28 days], for both Strength-grades M10 (1:3:6) and M15 (1:2:4). Moreover, the average Densities of the Concrete-samples increased steadily from 2374.26 Kg/m³ at a Curing-age of 1 day to 2570.17 Kg/m³ at a Curing-age of 28 days for grade M10 (1:3:6); and from 2329.50 Kg/m³ at a Curing-age of 1 day to 2645.46 Kg/m³ at a Curing-age of 28 days for grade M15 (1:2:4).

1.5 Purechem-Cement Concrete Samples

A careful look at the results of 'grade M10 (1:3:6) Purechem-cement Concrete Samples' [$PCS1_{M10(1day)}$ to $PCS3_{M10(28days)}$] presented in Table 7 and illustrated in Fig. 5, shows that, at a Curing-age of 1 day, the three (3) Concrete-samples[$PCS1_{M10(1day)}$, $PCS2_{M10(1day)}$ and $PCS3_{M10(1day)}$] attained less than one-tenth [9.8% (1.02 N/mm²), 9.9% (1.06 N/mm²) and 9.5% (1.03 N/mm²)] respectively of their various

TABLE 5
COMPRESSIVE-STRENGTHS AND DENSITIES OF GRADES M10 AND M15 CONCRETE-SAMPLES PRODUCED WITH 'IBETO' BRAND OF ORDINARY PORTLAND CEMENT AT VARIOUS CURING-AGES.

S/No	Ibeto-Cement Concrete Sample Designation	Curing-Age of Concrete Sample (Days)	Characteristic Compressive Strength f_{ck} (N/mm²)	Average Characteristic Compressive Strength $\overline{f}_{ck}$ (N/mm²)	Standard expected Percentage of 28 day Compressive Strength per Curing-age (%)	Actual Experimental Percentage of 28 day Compressive Strength (%)	Density ρ (Kg/m³)	Average Density $\overline{\rho}$ (Kg/m³)
Concrete Grade: M10 (1:3:6), w/c = 0.5								
1	$ICS1_{M10(1day)}$	1	1.24	1.22	≥ 16	10.6	2434.1	2433.5
2	$ICS2_{M10(1day)}$		1.27			10.8	2434.5	
3	$ICS3_{M10(1day)}$		1.16			10.4	2431.7	
4	$ICS1_{M10(3days)}$	3	7.13	7.00	≥ 40	60.8	2468.3	2468.4
5	$ICS2_{M10(3days)}$		7.06			60.2	2469.6	
6	$ICS3_{M10(3days)}$		6.82			60.9	2467.3	
7	$ICS1_{M10(7days)}$	7	7.92	7.81	≥ 65	67.5	2517.7	2518.6
8	$ICS2_{M10(7days)}$		7.97			67.9	2517.4	
9	$ICS3_{M10(7days)}$		7.54			67.4	2520.8	
10	$ICS1_{M10(14days)}$	14	9.17	8.97	≥ 90	77.9	2519.4	2518.6
11	$ICS2_{M10(14days)}$		9.06			77.2	2518.3	
12	$ICS3_{M10(14days)}$		8.71			77.8	2518.1	
13	$ICS1_{M10(21days)}$	21	11.08	10.91	≥ 95	94.5	2570.9	2570.5
14	$ICS2_{M10(21days)}$		11.04			94.1	2571.6	
15	$ICS3_{M10(21days)}$		10.62			94.9	2568.9	
16	$ICS1_{M10(28days)}$	28	11.73	11.55	≥ 99	100.0	2520.3	2519.7
17	$ICS2_{M10(28days)}$		11.73			100.0	2521.5	
18	$ICS3_{M10(28days)}$		11.19			100.0	2517.3	
Concrete Grade: M15 (1:2:4), w/c = 0.5								
19	$ICS1_{M15(1day)}$	1	4.47	4.46	≥ 16	12.5	2286.7	2301.2
20	$ICS2_{M15(1day)}$		4.48			12.4	2305.8	
21	$ICS3_{M15(1day)}$		4.44			12.6	2311.1	
22	$ICS1_{M15(3days)}$	3	19.30	17.43	≥ 40	53.9	2426.9	2423.4
23	$ICS2_{M15(3days)}$		19.54			53.9	2407.8	
24	$ICS3_{M15(3days)}$		18.84			53.6	2435.3	
25	$ICS1_{M15(7days)}$	7	23.08	24.25	≥ 65	64.5	2477.0	2501.1
26	$ICS2_{M15(7days)}$		26.83			74.0	2555.6	
27	$ICS3_{M15(7days)}$		22.85			65.0	2470.7	
28	$ICS1_{M15(14days)}$	14	30.67	30.95	≥ 90	85.7	2583.3	2564.8
29	$ICS2_{M15(14days)}$		31.17			85.9	2561.4	
30	$ICS3_{M15(14days)}$		31.02			88.2	2549.8	
31	$ICS1_{M15(21days)}$	21	34.92	34.83	≥ 95	97.6	2570.2	2592.5
32	$ICS2_{M15(21days)}$		35.43			97.7	2588.5	
33	$ICS3_{M10(21days)}$		34.30			97.5	2618.9	
34	$ICS1_{M10(28days)}$	28	35.78	35.74	≥ 99	100.0	2554.4	2591.9
35	$ICS2_{M10(28days)}$		36.27			100.0	2596.2	
36	$ICS3_{M10(28days)}$		35.17			100.0	2625.2	

NOTE: The 'Standard expected Percentage of 28 day Compressive Strength per Curing-age' expressed in '%' were obtained from [12]

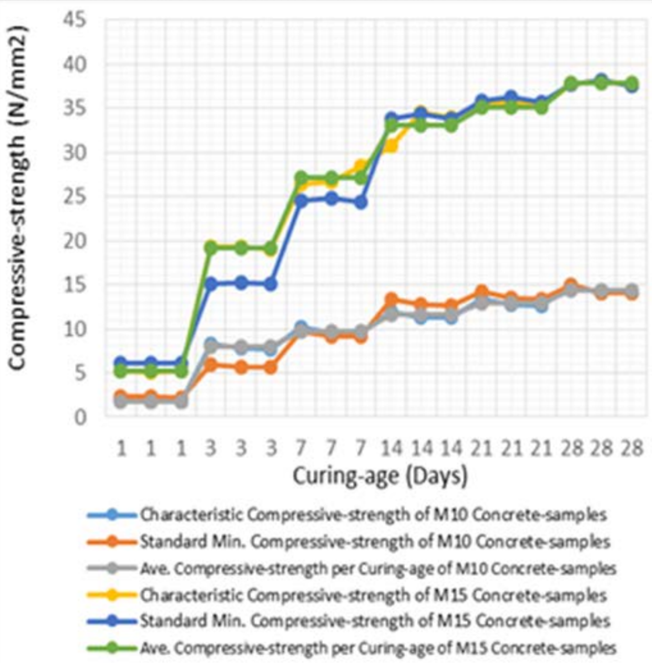

Fig. 4. Graphs of Characteristic and Average Compressive-strenghs of Grades M10 and M15 Concrete-samples Produced with LAFARGE Brand of Ordinary Portland Cement

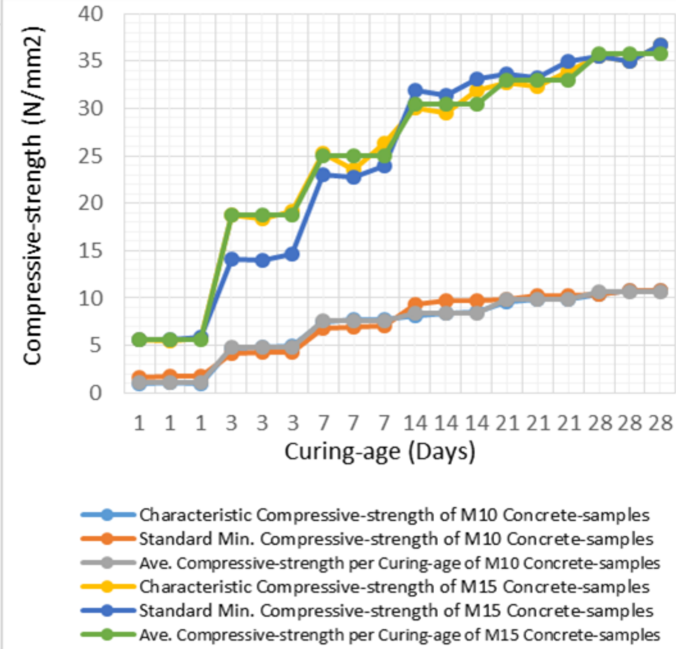

Fig. 5. Graphs of Characteristic and Average Compressive-strenghs of Grades M10 and M15 Concrete-samples Produced with PURECHEM Brand of Ordinary Portland Cement

28 day Compressive-strengths of 10.41 N/mm² ($PCS1_{M10(28days)}$), 10.74 N/mm² ($PCS2_{M10(28days)}$) and 10.85 N/mm² ($PCS3_{M10(28days)}$). At 7 days of curing, the three (3) Concrete-samples [$PCS1_{M10(7days)}$, $PCS2_{M10(7days)}$ and $PCS3_{M10(7days)}$] attained Compressive-strength values that exceeded two-third [71.6% (7.45 N/mm²) 71.9% (7.72 N/mm²) and 71.4% (7.75 N/mm²)] respectively of their various 28 days compressive-strengths of 10.41 N/mm² ($PCS1_{M10(28days)}$), 10.74 N/mm² ($PCS2_{M10(28days)}$) and 10.85 N/mm² ($PCS3_{M10(28days)}$).

It is interesting to note that, similar results were obtained with 'grade M15 (1:2:4) Purechem-cement Concrete Samples' [$PCS1_{M15(1day)}$ to $PCS3_{M15(28days)}$] at various Curing-ages of 1, 3, 7, 14, 21 and 28 days. This is because strength values that exceeded one-tenth [15.8% (5.61 N/mm²) ' $PCS1_{M15(1day)}$ ', 15.5% (5.43 N/mm²) ' $PCS2_{M15(1day)}$ ' and 15.7% (5.75 N/mm²) ' $PCS3_{M15(28days)}$ '] of the 28 day Compressive-strengths were attained after curing for 1 day. While about 52% [52.8% (18.71 N/mm²) ' $PCS1_{M15(7days)}$ ', 52.6% (18.37 N/mm²) ' $PCS2_{M15(7days)}$ ' and 52.3% (19.22 N/mm²) ' $PCS3_{M15(7days)}$ '] were attained after curing for 3 days. However, after curing for 21 days, Compressive-strength values which were approximately 92% [i.e. 92.4% (32.74 N/mm²), 92.4% (32.28 N/mm²) and 92.2% (33.89 N/mm²)] of the 28 day Compressive-strengths [35.45 N/mm², 34.94N/mm² and 36.74 N/mm²] were attained by Samples ' $PCS1_{M15(21days)}$ ', ' $PCS2_{M15(21days)}$ ' and ' $PCS3_{M15(21days)}$ ' respectively.

1.6 Unicem-Cement Concrete Samples

Table 8 displays and Fig. 6 illustrates the test results obtained after subjecting three (3) Concrete-samples of both strength-grades ['M10' and 'M15'] of Concretes produced with Unicem-cement, at six (6) Curing-ages of 1, 3, 7, 14, 21 and 28 days.

For all the three (3) 'grade M10 (1:3:6) Unicem-cement Concrete-samples' [generally represented by $UCS1_{M10}$, $UCS2_{M10}$ and $UCS3_{M10}$], it was noticed that, with each passing day, there were increases in the characteristic Compressive-strengths from minimum to maximum values of: 1.75 - 1.95 N/mm² ($UCS1_{M10(1day)} - UCS3_{M10(1day)}$), with an average of 1.86 N/mm² [at a Curing-age of 1 day]; 4.97 – 5.41 N/mm² ($UCS1_{M10(3days)} - UCS3_{M10(3days)}$), with an average of 5.17 N/mm² [at a Curing-age of 3 days]; and 8.48 – 9.26 N/mm² ($UCS1_{M10(7days)} - UCS3_{M10(7days)}$), with an average of 8.80 N/mm² [at a Curing-age of 7 days] . While for Curing-ages of 14, 21 and 28 days, the Characteristic Compressive-strengths of the Concrete-samples ranged from 9.30 – 9.93 N/mm² ($UCS1_{M10(14days)} - UCS3_{M10(14days)}$), 11.37 – 12.25 N/mm² ($UCS1_{M10(21days)} - UCS3_{M10(21days)}$) and 12.24 – 13.24 N/mm² ($UCS1_{M10(28days)} - UCS3_{M10(28days)}$); and averaged at 9.54 N/mm², 11.73 N/mm² and 12.67 N/mm² respectively.

Likewise, for all the three (3) 'grade M15 (1:2:4) Unicem-cement Concrete-samples' [generally represented by $UCS1_{M15}$, $UCS2_{M15}$ and $UCS3_{M15}$], it was observed that, the daily increments in Curing-age, consequently resulted in increments in the strength of the Samples. Thus, the Characteristic Compressive-strengths of the Samples increased

TABLE 6

COMPRESSIVE-STRENGTHS AND DENSITIES OF GRADES M10 AND M15 CONCRETE-SAMPLES PRODUCED WITH 'LAFARGE' BRAND OF ORDINARY PORTLAND CEMENT AT VARIOUS CURING-AGES.

S/No	Lafarge-Cement Concrete Sample Designation	Curing-Age of Concrete Sample (Days)	Characteristic Compressive Strength f_{ck} (N/mm^2)	Average Characteristic Compressive Strength $\overline{f}_{ck}$ (N/mm^2)	Standard expected Percentage of 28 day Compressive Strength per Curing-age (%)	Actual Experimental Percentage of 28 day Compressive Strength (%)	Density ρ (Kg/m^3)	Average Density $\overline{\rho}$ (Kg/m^3)
Concrete Grade: M10 (1:3:6), w/c = 0.5								
1	$LCS1_{M10(1day)}$	1	1.86	1.80	≥ 16	12.5	2362.8	2374.3
2	$LCS2_{M10(1day)}$		1.76			12.5	2364.2	
3	$LCS3_{M10(1day)}$		1.78			12.7	2361.7	
4	$LCS1_{M10(3days)}$	3	8.33	7.95	≥ 40	55.9	2570.4	2569.3
5	$LCS2_{M10(3days)}$		7.78			55.1	2567.6	
6	$LCS3_{M10(3days)}$		7.74			55.3	2569.9	
7	$LCS1_{M10(7days)}$	7	10.13	9.76	≥ 65	68.0	2519.9	2519.7
8	$LCS2_{M10(7days)}$		9.63			68.2	2521.2	
9	$LCS3_{M10(7days)}$		9.53			68.1	2518.1	
10	$LCS1_{M10(14days)}$	14	11.96	11.54	≥ 90	80.3	2520.5	2521.6
11	$LCS2_{M10(14days)}$		11.37			80.5	2522.7	
12	$LCS3_{M10(14days)}$		11.28			80.6	2521.7	
13	$LCS1_{M10(21days)}$	21	13.41	12.92	≥ 95	90.1	2524.4	2524.4
14	$LCS2_{M10(21days)}$		12.73			90.1	2524.7	
15	$LCS3_{M10(21days)}$		12.65			90.4	2524.0	
16	$LCS1_{M10(28days)}$	28	14.89	14.34	≥ 99	100.0	2569.0	2570.2
17	$LCS2_{M10(28days)}$		14.13			100.0	2570.8	
18	$LCS3_{M10(28days)}$		14.00			100.0	2570.7	
Concrete Grade: M15 (1:2:4), w/c = 0.5								
19	$LCS1_{M15(1day)}$	1	5.25	5.20	≥ 16	13.9	2332.8	2329.5
20	$LCS2_{M15(1day)}$		5.09			13.3	2330.8	
21	$LCS3_{M15(1day)}$		5.21			13.9	2324.9	
22	$LCS1_{M15(3days)}$	3	19.23	19.17	≥ 40	50.9	2453.3	2451.0
23	$LCS2_{M15(3days)}$		19.28			50.4	2447.7	
24	$LCS3_{M15(3days)}$		19.01			50.6	2451.9	
25	$LCS1_{M15(7days)}$	7	26.36	27.19	≥ 65	69.8	2511.5	2519.1
26	$LCS2_{M15(7days)}$		26.71			69.9	2514.2	
27	$LCS3_{M15(7days)}$		28.49			75.8	2531.7	
28	$LCS1_{M15(14days)}$	14	30.78	33.06	≥ 90	81.5	2561.9	2722.4
29	$LCS2_{M15(14days)}$		34.49			90.2	2579.6	
30	$LCS3_{M15(14days)}$		34.01			90.5	2580.9	
31	$LCS1_{M15(21days)}$	21	35.45	35.07	≥ 95	93.8	2602.3	2600.6
32	$LCS2_{M15(21days)}$		35.75			93.5	2596.5	
33	$LCS3_{M10(21days)}$		35.20			93.7	2603.1	
34	$LCS1_{M10(28days)}$	28	37.78	37.86	≥ 99	100.0	2641.6	2645.5
35	$LCS2_{M10(28days)}$		38.22			100.0	2649.3	
36	$LCS3_{M10(28days)}$		37.58			100.0	2645.5	

NOTE: The 'Standard expected Percentage of 28 day Compressive Strength per Curing-age' expressed in '%' were obtained from [12]

from minimum to maximum values of: 5.18 – 5.38 N/mm² ($UCS1_{M15(1day)}$ - $UCS3_{M15(1day)}$), with an average of 5.27 N/mm² [at a Curing-age of 1 day]; 19.75 – 19.83 N/mm² ($UCS1_{M15(3days)}$ - $UCS3_{M15(3days)}$), with an average of 19.80 N/mm² [at a Curing-age of 3 days]; and 23.92 – 26.31 N/mm² ($UCS1_{M15(7days)}$ - $UCS3_{M15(7days)}$), with an average of 25.51 N/mm² [at a Curing-age of 7 days]. While for Curing-ages of 14, 21 and 28 days, the Characteristic Compressive-strengths of the Concrete-samples ranged from 29.91 – 33.48 N/mm² ($UCS1_{M15(14days)}$ - $UCS3_{M15(14days)}$), 34.00 – 34.64 N/mm² ($UCS1_{M15(21days)}$ - $UCS3_{M15(21days)}$) and 36.08 – 36.49 N/mm² ($UCS1_{M15(28days)}$ - $UCS3_{M15(28days)}$); and averaged at 32.29 N/mm², 34.33 N/mm² and 36.26 N/mm² respectively.

Very similar results of an increase in Average density per curing-age [2431.94 – 2568.79 Kg/m³ and 2331.19 – 2631.76 Kg/m³], as Curing-age increased, was observed for both strength-grades 'M10' and 'M15' respectively, as could be seen in Table 8 and Fig. 6.

4 CONCLUSION

As was generally observed in this experimental-study, all six (6) commonly used brands of Cement in Nigeria, conformed to the standard code requirements for grade 32.5 Ordinary Portland Cement, as specified by the ASTM and BSI. This is because all six (6) cement-brands produced grade M10 normal-weight Concrete-samples with values of 28 day average Compressive-strengths that exceeded 10N/mm², and grade M15 concrete-samples with values of 28 day average compressive-strengths that far exceeded 15N/mm². This therefore implies that, if the current level of Quality Assurance/Quality Control (QA/QC) in the production plants (factories) of these cement-brands are sustainable, every single one of them will perform credibly (optimally), when professionally used for construction, within the validity period of the shelf-life.

The Dry densities of majority of the hardened cylindrical concrete-samples [produced with all six (6) cement-brands] generally varied slightly, and increased with curing-age, and also conformed to the ASTM and BSI code requirements for the recommended density-values (ranges) at the various curing-ages; except in a few isolated cases. Also, the most dense grade M10 concrete-samples were produced using Lafarge cement, followed by Dangote cement, and then Eagle, Unicem, Purechem and Ibeto cements respectively. Likewise, the most dense grade M15 concrete-samples were produced using Lafarge cement, followed by Eagle cement, and then, Unicem, Purechem, Dangote and Ibeto cements respectively.

Furthermore, the Compressive-strengths of the concrete-samples increased with curing-age, for concrete-samples produced using all six (6) commonly used brands of ordinary Portland cement (OPC), as is evident from the correspondingly rising crushing loads [exerted on the Universal Testing Machine] per curing-age. In addition, the highest early compressive-strengths were observed with grade M10 Concrete-samples produced using Dangote brand of OPC; while for grade M15 Concrete, the highest early compressive-strengths were noticed with Concrete-samples produced using Eagle brand of OPC. Finally, of all six (6) commonly-used cement-brands in Nigeria, Dangote Ordinary Portland Cement produced the grade M10 normal-weight Concrete-samples with the highest average 28 day Compressive-strength, followed by Lafarge Ordinary Portland Cement, and then, Unicem, Ibeto, Purechem and Eagle Ordinary Portland Cements respectively.

However, for the grade M15 normal-weight Concrete-samples, the highest average Compressive-strength was achieved with Lafarge Ordinary Portland Cement, followed by Eagle Ordinary Portland Cement, and then, Unicem, Dangote, Ibeto and Purechem Eagle Ordinary Portland Cements respectively.

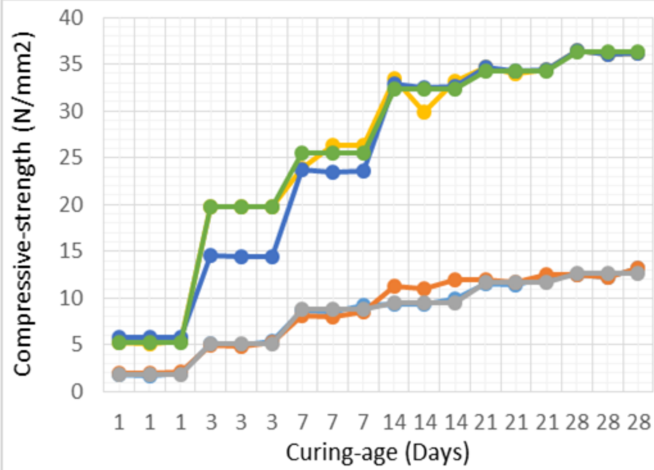

Fig. 6. Graphs of Characteristic and Average Compressive-strenghs of Grades M10 and M15 Concrete-samples Produced with UNICEM Brand of Ordinary Portland Cement

5 RECOMMENDATIONS

- The current level of Quality Assurance/Quality Control (QA/QC) in the production plants (factories) of these six (6) commonly used cement-brands in Nigeria should be sustained/maintained, and possibly improved upon.
- The use/application of these cement-brands in concrete-production, after the validity/expiration of the shelf-life should be prohibited, if the expected [design] compressive-strengths are to be achieved.
- Even when any of these cement-brands are used/applied for concrete production within the validity period of the shelf-life, it should strictly be under professional supervision.

TABLE 7

COMPRESSIVE-STRENGTHS AND DENSITIES OF GRADES M10 AND M15 CONCRETE-SAMPLES PRODUCED WITH 'PURECHEM' BRAND OF ORDINARY PORTLAND CEMENT AT VARIOUS CURING-AGES.

S/No	Purechem-Cement Concrete Sample Designa-tion	Curing-Age of Concrete Sample (Days)	Characteristic Compressive Strength f_{ck} (N/mm^2)	Average Cha-racteristic Compressive Strength $\overline{f}_{ck}$ (N/mm^2)	Standard expected Percentage of 28 day Compressive Strength per Curing-age (%)	Actual Experimental Percentage of 28 day Compressive Strength (%)	Density ρ (Kg/m^3)	Average Density $\overline{\rho}$ (Kg/m^3)
Concrete Grade: M10 (1:3:6), w/c = 0.5								
1	$PCS1_{M10(1day)}$		1.02			9.8	2466.4	
2	$PCS2_{M10(1day)}$	1	1.06	1.04	≥ 16	9.9	2464.4	2463.8
3	$PCS3_{M10(1day)}$		1.03			9.5	2460.8	
4	$PCS1_{M10(3days)}$		4.71			45.2	2517.3	
5	$PCS2_{M10(3days)}$	3	4.87	4.84	≥ 40	45.3	2516.6	2517.7
6	$PCS3_{M10(3days)}$		4.94			45.5	2519.2	
7	$PCS1_{M10(7days)}$		7.45			71.6	2518.5	
8	$PCS2_{M10(7days)}$	7	7.72	7.64	≥ 65	71.9	2516.8	2517.6
9	$PCS3_{M10(7days)}$		7.75			71.4	2517.1	
10	$PCS1_{M10(14days)}$		8.18			78.6	2520.5	
11	$PCS2_{M10(14days)}$	14	8.41	8.39	≥ 90	78.3	2520.3	2530.0
12	$PCS3_{M10(14days)}$		8.57			79.0	2519.2	
13	$PCS1_{M10(21days)}$		9.57			91.9	2523.5	
14	$PCS2_{M10(21days)}$	21	9.86	9.81	≥ 95	91.8	2522.9	2523.0
15	$PCS3_{M10(21days)}$		9.87			91.0	2522.7	
16	$PCS1_{M10(28days)}$		10.41			100.0	2523.6	
17	$PCS2_{M10(28days)}$	28	10.74	10.67	≥ 99	100.0	2523.3	2524.9
18	$PCS3_{M10(28days)}$		10.85			100.0	2527.8	
Concrete Grade: M15 (1:2:4), w/c = 0.5								
19	$PCS1_{M15(1day)}$		5.61			15.8	2295.5	
20	$PCS2_{M15(1day)}$	1	5.43	5.60	≥ 16	15.5	2316.1	2310.9
21	$PCS3_{M15(1day)}$		5.75			15.7	2321.0	
22	$PCS1_{M15(3days)}$		18.71			52.8	2441.4	
23	$PCS2_{M15(3days)}$	3	18.37	18.77	≥ 40	52.6	2449.1	2443.3
24	$PCS3_{M15(3days)}$		19.22			52.3	2439.5	
25	$PCS1_{M15(7days)}$		25.23			71.2	2496.9	
26	$PCS2_{M15(7days)}$	7	23.56	25.02	≥ 65	67.4	2501.8	2500.6
27	$PCS3_{M15(7days)}$		26.28			71.5	2503.1	
28	$PCS1_{M15(14days)}$		30.08			84.6	2557.5	
29	$PCS2_{M15(14days)}$	14	29.48	30.48	≥ 90	84.4	2540.2	2544.2
30	$PCS3_{M15(14days)}$		31.87			86.7	2535.0	
31	$PCS1_{M15(21days)}$		32.74			92.4	2578.4	
32	$PCS2_{M15(21days)}$	21	32.28	32.97	≥ 95	92.4	2574.9	2578.8
33	$PCS3_{M10(21days)}$		33.89			92.2	2583.0	
34	$PCS1_{M10(28days)}$		35.45			100.0	2602.3	
35	$PCS2_{M10(28days)}$	28	34.94	35.71	≥ 99	100.0	2592.3	2604.4
36	$PCS3_{M10(28days)}$		36.74			100.0	2618.7	

NOTE: The 'Standard expected Percentage of 28 day Compressive Strength per Curing-age' expressed in '%' were obtained from [12]

TABLE 8

COMPRESSIVE-STRENGTHS AND DENSITIES OF GRADES M10 AND M15 CONCRETE-SAMPLES PRODUCED WITH 'UNICEM' BRAND OF ORDINARY PORTLAND CEMENT AT VARIOUS CURING-AGES.

S/No	Unicem-Cement Concrete Sample Designation	Curing-Age of Concrete Sample (Days)	Characteristic Compressive Strength f_{ck} (N/mm²)	Average Characteristic Compressive Strength $\overline{f}_{ck}$ (N/mm²)	Standard expected Percentage of 28 day Compressive Strength per Curing-age (%)	Actual Experimental Percentage of 28 day Compressive Strength (%)	Density ρ (Kg/m³)	Average Density $\overline{\rho}$ (Kg/m³)
Concrete Grade: M10 (1:3:6), w/c = 0.5								
1	$UCS1_{M10(1day)}$		1.87			14.9	2433.3	
2	$UCS2_{M10(1day)}$	1	1.75	1.86	≥ 16	14.3	2433.8	2431.9
3	$UCS3_{M10(1day)}$		1.95			14.7	2428.9	
4	$UCS1_{M10(3days)}$		5.13			40.9	2519.4	
5	$UCS2_{M10(3days)}$	3	4.97	5.17	≥ 40	40.6	2515.3	2517.7
6	$UCS3_{M10(3days)}$		5.41			40.9	2518.3	
7	$UCS1_{M10(7days)}$		8.67			69.2	2568.6	
8	$UCS2_{M10(7days)}$	7	8.48	8.80	≥ 65	69.3	2566.6	2568.3
9	$UCS3_{M10(7days)}$		9.26			69.9	2569.7	
10	$UCS1_{M10(14days)}$		9.40			75.0	2520.8	
11	$UCS2_{M10(14days)}$	14	9.30	9.54	≥ 90	76.0	2520.9	2520.7
12	$UCS3_{M10(14days)}$		9.93			75.0	2520.2	
13	$UCS1_{M10(21days)}$		11.57			92.3	2569.3	
14	$UCS2_{M10(21days)}$	21	11.37	11.73	≥ 95	92.9	2568.7	2568.2
15	$UCS3_{M10(21days)}$		12.25			92.5	2566.6	
16	$UCS1_{M10(28days)}$		12.53			100.0	2570.5	
17	$UCS2_{M10(28days)}$	28	12.24	12.67	≥ 99	100.0	2567.3	2568.8
18	$UCS3_{M10(28days)}$		13.24			100.0	2568.6	
Concrete Grade: M15 (1:2:4), w/c = 0.5								
19	$UCS1_{M15(1day)}$		5.24			14.4	2334.6	
20	$UCS2_{M15(1day)}$	1	5.18	5.27	≥ 16	14.4	2329.9	2331.2
21	$UCS3_{M15(1day)}$		5.38			14.9	2328.7	
22	$UCS1_{M15(3days)}$		19.83			54.3	2456.5	
23	$UCS2_{M15(3days)}$	3	19.82	19.80	≥ 40	54.9	2455.4	2456.6
24	$UCS3_{M15(3days)}$		19.75			54.6	2457.8	
25	$UCS1_{M15(7days)}$		23.92			65.6	2493.1	
26	$UCS2_{M15(7days)}$	7	26.29	25.51	≥ 65	72.9	2507.3	2505.3
27	$UCS3_{M15(7days)}$		26.31			72.7	2515.6	
28	$UCS1_{M15(14days)}$		33.48			91.8	2585.8	
29	$UCS2_{M15(14days)}$	14	29.91	32.29	≥ 90	82.9	2541.1	2567.7
30	$UCS3_{M15(14days)}$		33.17			91.6	2576.5	
31	$UCS1_{M15(21days)}$		34.64			94.9	2592.4	
32	$UCS2_{M15(21days)}$	21	34.00	34.33	≥ 95	94.2	2584.2	2590.1
33	$UCS3_{M10(21days)}$		34.34			94.9	2593.7	
34	$UCS1_{M10(28days)}$		36.49			100.0	2632.3	
35	$UCS2_{M10(28days)}$	28	36.08	36.26	≥ 99	100.0	2631.2	2631.8
36	$UCS3_{M10(28days)}$		36.20			100.0	2631.8	

NOTE: The 'Standard expected Percentage of 28 day Compressive Strength per Curing-age' expressed in '%' were obtained from [12]

- For construction projects requiring high early strength concrete applications such as: the construction of emergency concrete structures and the production of pre-stressed and precast concrete etc., the use of 'Dangote' and 'Eagle' brands of Ordinary Portland Cement is preferably recommended.
- The Nigerian government should fund and encourage further research in this area/subject-matter, since it will go a long way to benefit professional and other stakeholders in the Nigeria's construction industry.

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