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Effect of Chemical Composition of Ordinary Portland cement on the Compressive Strength of Concrete

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Abstract:-This research work assessed the effect of chemical composition of ordinary Portland cement (OPC) on the compressive strength of concrete. Scheffe's simplex technique was used to develop models for the assessment of the compressive strength of concrete produced from five different brands of OPC available for construction works in South Eastern Nigeria. Five (5) models were formulated, which were used for the prediction of compressive strength of concrete if mix proportions are known and vice versa. The result of this research work was intended to eliminate the difficulty encountered by engineers in making appropriate choices of concrete mix proportions through the traditional method. It provided a simple way of obtaining information about the compressive strength of concrete made from different brands of OPC. The models were tested for adequacy and the results from laboratory experiments were compared with the responses of the model functions. Three hundred (300) sample cubes measuring 150 x 150 x 150 mm were produced for compressive strength tests. The result of the work showed that all the cement samples investigated substantially complied with the requirements of the relevant British Standard Specifications. The results also showed that the chemical composition of cement as well as the mix proportions of the combining elements influenced the value of the compressive strength of the resulting concrete. Cement Sample B produced concrete with the highest 28th day compressive strength value of 27.96 N/mm^2. The work concluded that cement with identical chemical characteristics will produce concrete with similar compressive strength values. It recommended Cement Sample B as the best choice among those investigated, when resistance to compression and rate of strength development are of the essence.

Keywords:-adequacy of models, brands of OPC, chemical composition, compressive strength, response functions

I. INTRODUCTION

Ordinary Portland cement (OPC) is the brand of cement used for most building construction jobs in South Eastern part of Nigeria. It provides the binding medium for aggregates in concrete and mortar. According to Duggal [1], cement finds extensive use in all types of construction works – in structures where high strength is required and in structures exposed to the action of water. Cement used in construction is required to satisfy a range of properties specified by BS 12 [2]. Cement manufacturing companies in Nigeria produce brands of OPC, which satisfy the general requirements specified by British Standards Institution shown in part in Table 4. However, due to the peculiarities of each manufacturing company, the different brands of OPC have different chemical compositions. The knowledge of the properties of concrete manufactured from specified brands of OPC is essential to help the engineer make informed decisions about which brand to use in specific circumstances. For example, if early striking of formwork is an advantage on a particular site, the cement brand, which produces a fast setting and initial high rate of strength development, will be an intelligent choice. In addition, if flexural resistance or compressive strength is critical, the corresponding cement brand, which produces the highest flexural or compressive strength, should be chosen.

This work is based on Scheffe's simplex technique [3], which utilizes the combination or mixture of different components to optimize or predict any desired outcome [4]. Many researchers have used this technique to optimize or predict compressive strength [5], [6], modulus of rupture [7] and other required characteristics [8] of concrete/sandcrete materials and mortar [9]. It has also been used for product improvement [10]. The purpose of this paper is to develop mathematical models, which will be used to readily predict and compare the compressive strengths of concrete made from some brands of OPC available for construction works in South Eastern Nigeria. The brands of OPC used for this research are DANGOTE, IBETO, UNICEM, LAFARGE and ELEPHANT. The cement brands shall hereafter be referred to as cement samples A, B, C, D and E but not in any particular order.

II. MATERIALS AND METHODS

The materials used for this work, the experiments performed and the methods employed are described here.

2.1 Materials

The materials used for this work are five different brands of ordinary Portland cement namely DANGOTE, IBETO, UNICEM, LAFARGE and ELEPHANT (referred to as cement samples A, B, C, D and E but not in any particular order), fine aggregates from Otamiri River in Owerri West Local Government Area in Imo State, Nigeria, granite chippings from Okigwe in Imo State, Nigeria and potable water. The cement brands conformed to the chemical requirements of BS 12 [2] while the aggregates were free of silt, clay, organic matter or any other material that could inhibit concrete setting and hardening processes. The maximum grain size of fine aggregates was 5mm while for coarse aggregates the maximum size was 20mm. The aggregate impact value for the coarse aggregates was determined. The water for the work was potable and was obtained from piped municipal water supply. In order to establish a valid basis for comparing the different cement brands, samples of the various brands of OPC were obtained from their distributors the same day they took delivery of the products from their respective factories. The laboratory tests were performed within one week of the purchase of the products in an environment with approximately the same range of ambient temperature.

2.2 Method

The following experiments and procedures were performed in the course of this work.

(a) Chemical analysis of the different brands of OPC used for the work. Results are shown in Table 3 where the concentrations of the chemical compositions obtained for cement samples A, B, C, D and E are compared.

(b) The level of compliance of the different cement brands to British Standards requirements in terms of chemical composition is compared in Table 4.

(c) Grain size distribution analyses of the aggregates used for the work.

(d) Aggregate Impact value test for coarse aggregates.

(e) Compressive strength tests for concrete cubes made from the different brands of OPC. A total of three hundred (300) sample concrete cubes measuring 150 x 150 x 150mm were produced for compressive strength tests. Results are shown in Tables 5.

(f) Formulation of mathematical models using Scheffe's simplex technique for the prediction of the compressive strength of concrete determined experimentally or derived from formulae.

(g) Tests for the adequacy of the formulated models using standard statistical tools.

(h) Demonstration/validation of the formulated models.

2.3 Tests on Materials

2.3.1 Chemical Analysis of Cement

The chemical analysis of the different brands of OPC used for this work was performed.

2.3.2 Grain Size Distribution Analysis of Sand

Grain size distribution analysis on a representative sample of the sand for the research was carried out to obtain the proportions by weight of the different sizes of sand particles present according to BS 812-103 [11] and BS 882 [12]. The proportions were expressed as percentages by weight passing various sieve sizes conforming to BS 410 [13]. When compared with the grading limits of fine aggregates specified in Clause 4.3 of Indian Standard [14]the sand for this work belongs to Grading Zone 2.

2.3.3 Grain Size Distribution Analysis of Coarse Aggregates

Grain size distribution analysis on a representative sample of the granite chippings for the work was carried out to obtain the proportions by weight of the different sizes of coarse aggregates present. The maximum aggregate size was 20mm.

2.3.4 Impact Value Test for Coarse Aggregates

This test was performed to characterize the coarse aggregates used for the work. The specific gravity of the coarse aggregates was determined as 2.71 while the aggregate impact value (AIV) was 10.18.

2.3.5 Production of Concrete Specimens for Tests

2.3.5.1 Mix Proportioning of Materials

Proportioning of materials for this work was by weight because it is more accurate and produces results that are more reliable. The weighing was done using an electronic top loading balance readable to 0.5g accuracy. The aggregates were air/sun dried and were considered dry for all practical purposes. No allowance was, therefore, made for moisture in them. Twenty different concrete mix proportions named Mix-01 to Mix-20 were used. These were obtained from Scheffe's simplex theory (4, 2 polynomial). Ten mix proportions were the actual components while the next ten mix proportions represented the mix proportions at the control points. Three (3) concrete cubes measuring 150 x 150 x 150mm were produced for each mix proportion and for the five brands of OPC giving three hundred (300) cubes. The mix proportions (actual components) required to produce test specimens for compressive tests are given in Table 2.

2.3.5.2 Mixing of Constituent Materials

Manual or hand mixingwas employed for this work. The mixing was done on hard, clean and impermeable surface. Dry sharp river sand was first deposited on the impermeable surface before cement was added. Both materials were mixed thoroughly before the addition of granite chippings. The process of quartering was used in the mixing process to ensure that the materials were mixed properly. Water was added last and the whole batch thoroughly mixed. Immediately after preparing the concrete cube specimens, they were stored in a place free from vibration and in conditions, which did not permit rapid loss of moisture. The specimens were removed from their moulds after 24 hours and cured for twenty-seven days in line with the specifications of BS 1881-111 [15].

2.3.5.3 Concrete Cube Specimens

The specimens for compressive strength tests were concrete cubes cast in steel moulds with internal dimensions 150 x 150 x 150mm in accordance with the specifications of BS 1881-108 [16]. Measures were taken to ensure that leakage of water or mortar from the moulds did not occur. A thin layer of engine oil was applied to the inside surfaces of the moulds to forestall the development of bond between the concrete and the surface of the moulds. Sixty (60) concrete cubes were prepared for each brand of OPC. The moulds were filled with concrete in three equal layers as specified by BS 1881-108 [16]. Each layer was compacted using 35 strokes from a 25-mm^2 steel punner spread uniformly across the surface of the concrete. The top of the concrete cube was finally finished using a trowel and the cubes stored undisturbed for 24 hours. After 24 hours of production, the concrete cubes were demoulded and the cubes immersed in water in an open curing tank for 27 days making a total of 28 days from date of production.

2.3.5.4. Compressive Strength Tests

Specifications for compressive strength test are given in BS 1881-116 [17]. Concrete cubes brought out of the curing tank at the end of the curing period were allowed to dry, weighed and placed within the platens of the compression machine. The position of the concrete cubes when tested in the compression machine was at right angles to that as cast. The loads causing failure of the concrete cubes were recorded and the compressive/crushing strength reported to the nearest 0.5MPa. Three concrete cubes for each of the twenty mix proportions for each of the five brands of OPC were loaded to the point of failure in a 1500kN compression machine (Universal Testing Machine) after 28 days of curing. The crushing loads were noted and the average compressive strength results obtained from the tests are presented in Table 5.

2.4 Initial Mix Ratios

For this work, concrete is considered a quaternary system (that is, a four-component mixture) - a mixture of water, cement, sand and granite chippings. The implication of this is that the factor space has four vertices (A_1, A_2, A_3, A_4) resulting in a tetrahedron. The starting set of mixture proportions arbitrarily selected for the vertices of the tetrahedron and their corresponding water-cement ratios are $1{:}1^1/_2{:}3$, 1:2:3, 1:2:4, 1:3:6 and 0.6, 0.5, 0.65 and 0.55 respectively. Intermediate points between the vertices were established to completely describe the factor space.The nominal mix ratios of were taken to occupy the vertices of the tetrahedron forming the factor space in Scheffe's simplex technique.

2.5 Scheffe'sSimplex Optimization Technique

Attaining any required characteristic of concrete depends largely on the ability of personnel to correctly proportion the components of the mix. This is why the traditional method uses many trial mixes. This work is based on Scheffe'ssimplex technique. The method was used to developoptimizationequationsfor the determination of compressive strength of concrete. The equations were then used to predict the quantitative value of compressive strength of concrete if a mix ratio within the factor space is specified and vice versa. In order to optimize desired properties Scheffe [3] considered in his experiments with mixtures that the desired property depended on the proportions of the components present rather than on the quantity of mixture (Okere, [7].As an illustration, let a mixture have a total of q components and X_i be the proportions of the different constituents of the i^{th} component in the mixture as shown in (1):

$$X_i \geq 0 \quad (i = 1, 2, \ldots q) \qquad (1)$$

If the mixture is a unit quantity, then the sum of all the proportions must be unity. This is shown in (2):

$\sum Xi = 1$ (2)

The factor space therefore, is defined using a regular (q -1) dimensional simplex lattice.

2.6 Scheffe's Simplex Lattice Design

Simplex lattice can be analogously described as a structural representation of lines joining the atoms of a mixture. This lattice can be used as a mathematical space for modeling experiments involving mixtures by considering the constituent components of the mixture as atoms interacting and combining within the mathematical or factor space. In a {q – 1} dimensional simplex lattice, for a binary system {that is, if q = 2}, there are two points of connectivity which gives a straight line simplex lattice {one dimension} with two principal coordinates. For a ternary system {that is, if q = 3}, a triangular simplex lattice {two dimensions} results. This has three principal coordinates. For a quaternary system {that is, where q = 4}, a tetrahedron simplex lattice {three dimensions} is achieved with four principal coordinates. The tetrahedron simplex lattice was used in this work since we have four interacting components namely water, cement, fine and coarse aggregates. The tetrahedron simplex lattice is shown in Fig. 1.

The mathematical or factor space consists of three regions, the vertices {where pure components exist}, borderlines {where binary components exist} and inside the body of the space. Every borderline joins two vertices. The pure components are the reacting ingredients and are represented by the proportions of actual components making up the mixture. Inside the body of an n-dimensional space, n+ 1 components exist.

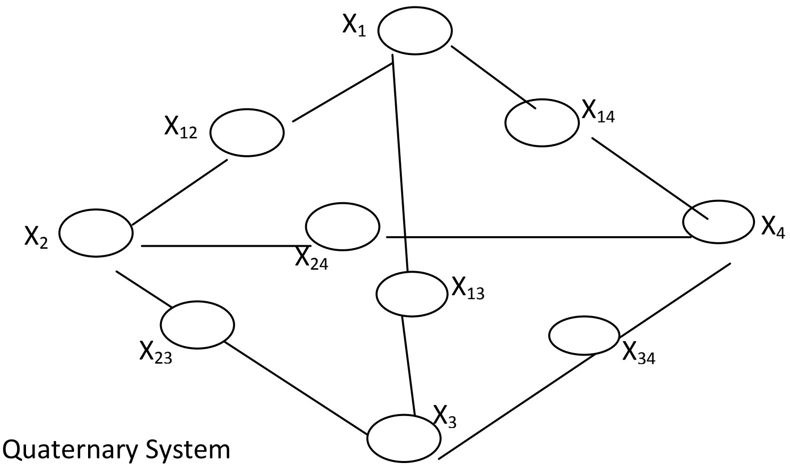

Fig 1: Quaternary System

2.7 Number of Coefficients in a (4, 2) Lattice

The number of coefficients of a Scheffe model equation depends on the number of combining elements and the degree of the polynomial function. For a Scheffe (q,m) simplex lattice, the number of coefficients is given by (3):

$N_c = (q + m - 1)! / ([q - 1]! * m!)$ (3)

Where q = number of combining elements in the mixture and m = the degree or power of the polynomial function.

The total number of points or coefficients N_c in a {4, 2} simplex lattice is, therefore, ten. This means that ten different mix proportions are required for the experiment and another ten for validation. The factor space for the analysis in this work is a q-1 dimensional factor space {that is a 3-dimensional factor space}.

2.8 Pseudo and Actual Components

As stated in (2), the sum of all the proportions of the components making up a q- component mixture must be equal to unity. To satisfy the requirement in (2), Scheffeintroduced the pseudo components. The pseudo components represent the proportions of the i^{th}component in the concrete mixture. At any point in the factor space, the summation of the pseudo components must be equal to one. No pseudo component is more than one or less than zero. That is:

$0 \leq X_i \leq 1$

Table 1 shows the proportions of both the pseudo $\{X_i\}$ and actual $\{Z_i\}$ proportions in the same system at the vertices of the tetrahedron {that is, at A_1, A_2, A_3 and A_4}. These proportions are taken as starting proportions before the derivation of other proportions. The intermediate mix proportions were determined and shown in the remaining part of the Table 1.

Table 1: Pseudo $\{X_i\}$ and Actual $\{Z_i\}$ Components for Scheffe's {4, 2} Simplex Lattice[18]**

Pseudo Components					Response Function $\{Y_i\}$	Actual Components			
N	X_1	X_2	X_3	X_4		Z_1	Z_2	Z_3	Z_4
1	1	0	0	0	Y_1	0.65	1.0	2.0	4.0
2	0	1	0	0	Y_2	0.60	1.0	1.5	3.0
3	0	0	1	0	Y_3	0.55	1.0	3.0	6.0
4	0	0	0	1	Y_4	0.50	1.0	2.0	3.0
12	$^1/_2$	$^1/_2$	0	0	Y_{12}	0.625	1.0	1.75	3.5
13	$^1/_2$	0	$^1/_2$	0	Y_{13}	0.60	1.0	2.5	5.0
14	$^1/_2$	0	0	$^1/_2$	Y_{14}	0.575	1.0	2.0	3.5
23	0	$^1/_2$	$^1/_2$	0	Y_{23}	0.575	1.0	2.25	4.5
24	0	$^1/_2$	0	$^1/_2$	Y_{24}	0.55	1.0	1.75	3.0
34	0	0	$^1/_2$	$^1/_2$	Y_{34}	0.525	1.0	2.5	4.5
CONTROL POINTS									
1	0.25	0.25	0	0.50	C_1	0.5625	1.0	1.875	3.25
2	0.25	0.50	0	0.25	C_2	0.5875	1.0	1.75	3.25
3	0.25	0.25	0.25	0.25	C_3	0.575	1.0	2.125	4.0
4	0.20	0.40	0.20	0.20	C_4	0.58	1.0	2.0	3.8
5	0.20	0.20	0.30	0.30	C_5	0.565	1.0	2.2	4.1
6	0.30	0.25	0.25	0.20	C_6	0.5825	1.0	2.125	4.05
7	0.10	0.50	0.20	0.20	C_7	0.575	1.0	1.95	3.7
8	0.15	0.15	0.30	0.40	C_8	0.5525	1.0	2.225	4.05
9	0.20	0.20	0.60	0.0	C_9	0.58	1.0	2.5	5.0
10	0.45	0.15	0	0.40	C_{10}	0.5825	1.0	1.925	3.45

Where Y is the response or outcome of the equation at the point of consideration or observation.
N is any observation point of interest within the factor space. C_n is the response at control point n.
X_i are the pseudo components of water, cement, fine aggregate and coarse aggregate
Z_i are the actual components of water, cement, fine aggregate and coarse aggregate

2.9 Relationship Between Pseudo and Actual Components

Scheffe [4] established a relationship between pseudo $\{X_i\}$ and actual $\{Z_i\}$ components as shown in (4):

$$\{Z\} = \{A\}\{X\} \quad (4)$$

Where {A} is the matrix of coefficients with elements a_{ij}.
The actual components {Z} of a quaternary system are obtained by carrying out the multiplying operation of (4). Twenty different mix proportions as derived from Scheffe'soptimizationtechniquewere used for this work. Ten mix proportions were the actual components and the other ten mix proportions were mix proportions at control points. The ten control mixture proportions were required to validate the models. Table 1 shows the complete design matrix for the observation points for Scheffe's {4, 2}simplex lattice obtained by expanding and solving (4).

2.10 Responses

A response, as used in this work, is a measurable outcome of a property of concrete whether in the plastic or hardened state, Simon [19]. We can also define it as the model equations when all the coefficients are substituted. For this work, the response, outcome or dependent variable Y_i, is compressive strength. The response of the model equation is presented using a polynomial function of the pseudo components of the mixture.Scheffe [3] and Simon [19] derived the general equation of response as shown in (5):

$$Y = b_o + \sum b_iX_i + \sum b_{ij}X_iX_j + \sum b_{ijk}X_iX_jX_k + \ldots + \sum b_{i1}, b_{i2}, b_{i3} \ldots b_{in} X_{i1}X_{12} X_{13} \ldots X_{in} + e \quad (5)$$

Where b_i, b_{ij} and b_{ijk} are constants
X_i, $X_j$and X_k are pseudo components

e is the random error term, which represents the combined effects of all variables not included in the model
The equation of response for four component mixture can be given as (6):

$$Y = b_o + \sum b_i X_i + \sum b_{ij} X_i X_j + e \quad (6)$$

Where $0 \leq i \leq j \leq 4$
i and j represent any points on the factor space.

Carrying out appropriate arithmetic operations on (6) yields (7):

$$Y = X_1(2X_1 - 1)y_1 + X_2(2X_2 - 1)y_2 + X_3(2X_3 - 1)y_3 + X_4(2X_4 - 1)y_4 + 4y_{12} X_1 X_2 + 4y_{13} X_1 X_3 + 4y_{14} X_1 X_4 + 4y_{23} X_2 X_3 + 4y_{24} X_2 X_4 + 4y_{34} X_3 X_4 + e \quad (7)$$

(7) is the mixture design function for the optimization or prediction of a concrete mixture consisting of four components obtained by applying the principles of Scheffe's technique. In this work, the terms y_i and y_{ij} are responses corresponding to the compressive strength of concrete at the points i and ij. These responses were obtained by carrying out laboratory tests. Substituting the laboratory results of Table 5 into (7) yields (8) to (12):

Models for Compressive Strength of Concrete Cubes.
With Cement Sample A

$$Y = 7.04 X_1(2X_1-1) + 20.91 X_2(2X_2-1) + 15.74 X_3(2X_3-1) + 17.99 X_4(2X_4-1) + 59 X_1X_2 + 54.96 X_1X_3 + 65.04 X_1X_4 + 57.72 X_2X_3 + 65.28 X_2X_4 + 44.6 X_3X_4 + e \quad (8)$$

With Cement Sample B

$$Y = 15.01 X_1(2X_1-1) + 20.77 X_2(2X_2-1) + 18.49 X_3(2X_3-1) + 25.51 X_4(2X_4-1) + 78.40 X_1X_2 + 75.84 X_1X_3 + 111.84 X_1X_4 + 105.64 X_2X_3 + 84.72 X_2X_4 + 51.94 X_3X_4 + e \quad (9)$$

With Cement Sample C

$$Y = 13.77 X_1(2X_1-1) + 16.56 X_2(2X_2-1) + 13.42 X_3(2X_3-1) + 15.30 X_4(2X_4-1) + 52 X_1X_2 + 80.04 X_1X_3 + 58.80 X_1X_4 + 66 X_2X_3 + 77.72 X_2X_4 + 49.8 X_3X_4 + e \quad (10)$$

With Cement Sample D

$$Y = 12.14 X_1(2X_1-1) + 12.42 X_2(2X_2-1) + 14.73 X_3(2X_3-1) + 13X_4(2X_4-1) + 72.7 X_1X_2 + 51.69X_1X_3 + 66.39 X_1X_4 + 46.2 X_2X_3 + 73.92 X_2X_4 + 57.08 X_3X_4 + e \quad (11)$$

With Cement Sample E

$$Y = 11.38 X_1(2X_1-1) + 15.18 X_2(2X_2-1) + 7.46 X_3(2X_3-1) + 16.38 X_4(2X_4-1) + 52 X_1X_2 + 28.84X_1X_3 + 29 X_1X_4 + 46.16 X_2X_3 + 51.76 X_2X_4 + 52.56 X_3X_4 + e \quad (12)$$

(8) to (12) are the specific models for the determination of compressive strength of concrete made from the previously identified ordinary Portland cement brands. These models were used to determine compressive strengths of concrete for known mix ratios and vice versa.

2.11 Quantitative Proportions of Concrete Constituents

The quantities of the constituent materials required for producing three samples of concrete cubes measuring 150 x 150 x 150mm at the required observation points and their mix proportions are shown in Table 2.

3.1 Presentation of Results

The results obtained from the various tests performed in this work are presented in this section. Table 3 shows the main chemical constituents of cement samples A, B, C, D and E. Table 4 shows the extent of compliance of the cement brands to British Standards requirements. Sharp river sand used for this work belongs to Zone 2 of the grading table while the coarse aggregate has an aggregate impact value of 10.18. The compressive strength test results for concrete cubes produced from all cement samples are presented in Table 5 while Table 7 shows the comparison between compressive strength values obtained from experimental tests and Scheffe's model equations.

Table 2: Quantitative proportions of constituents of concrete for compressive strength test**

Observation Points	Z_1	Z_2	Z_3	Z_4	Water (kg)	Cement (kg)	Sand (kg)	Granite Chippings (kg)
N_1	0.65	1	2	4	2.37	3.65	7.30	14.6
N_2	0.60	1	1.5	3	2.78	4.64	6.96	13.92
N_3	0.55	1	3	6	1.40	2.55	7.65	15.3
N_4	0.50	1	2	3	2.125	4.25	8.5	12.75
N_{12}	0.625	1	1.75	3.5	2.55	4.08	7.14	14.28
N_{13}	0.60	1	2.5	5	1.80	3.00	7.50	15.0

N_{14}	0.575	1	2	3.5	2.25	3.92	7.84	13.72
N_{23}	0.575	1	2.25	4.5	1.89	3.29	7.40	14.80
N_{24}	0.55	1	1.75	3	2.44	4.44	7.77	13.32
N_{34}	0.525	1	2.5	4.5	1.67	3.19	7.98	14.36
CONTROL POINTS								
C_1	0.5625	1	1.875	3.25	2.34	4.16	7.8	13.52
C_2	0.5875	1	1.75	3.25	2.50	4.25	7.44	13.81
C_3	0.575	1	2.125	4	2.06	3.58	7.61	14.32
C_4	0.58	1	2	3.8	2.18	3.75	7.5	14.25
C_5	0.565	1	2.2	4.1	1.98	3.50	7.70	14.35
C_6	0.5825	1	2.125	4.05	2.07	3.56	7.57	14.42
C_7	0.575	1	1.95	3.7	2.21	3.84	7.49	14.21
C_8	0.5525	1	2.225	4.05	1.94	3.51	7.81	14.22
C_9	0.58	1	2.5	5	1.74	3.00	7.50	15.0
C_{10}	0.5825	1	1.925	3.45	2.33	4.00	7.70	13.8

**Arimanwa [18]

Table 3: Chemical constituents of different cement samples[18]**

	Sample A (g)	Sample B (g)	Sample C (g)	Sample D (g)	Sample E (g)
Sodium Oxide (Na_2O)	4770 ± 220	3115 ± 40	5500 ± 200	4910 ± 230	5700 ± 250
Magnesium Oxide (MgO)	10480 ± 80	26370 ± 210	14790 ± 80	22440 ± 100	15850 ± 120
Aluminium Oxide (Al_2O_3)	29400 ± 60	41650 ± 90	23820 ± 50	33030 ± 60	34150 ± 60
Silicon Dioxide (SiO_2)	133800 ± 100	170900 ± 100	101800 ± 100	158700 ± 100	160800 ± 100
Phosphorus Oxide (P_2O_5)	1320 ± 9	2066 ± 11	1790 ± 7	1462 ± 9	1520 ± 10
Sulphur Trioxide (SO_3)	29940 ± 20	44960 ± 40	29630 ± 20	40370 ± 30	41200 ± 40
Chlorine (Cl)	58.1 ± 0.4	188.2 ± 0.8	65.7 ± 0.4	564.2 ± 1.4	410 ± 1.2
Potassium Oxide (K_2O)	3760 ± 25	5095 ± 28	6508 ± 27	8302 ± 30	7300 ± 35
Lime (CaO)	615400 ± 400	636300 ± 400	542500 ± 300	610900 ± 400	520500 ± 400
Iron Oxide (Fe_2O_3)	27110 ± 40	29290 ± 40	17270 ± 30	34870 ± 40	30520 ± 40
Total Mass Concentration	856,038.1 ± 954.4	959,934.2 ± 959.8	743,673.7 ± 814.4	915,548.2 ± 969	817,950 ± 1056.2
Total Percent Concentration (%)	85.6 ± 0.1	96.0 ± 0.1	74.4 ± 0.08	91.6 ± 0.1	81.8 ± 0.1
LOI	0.04%	0.20%	0.16%	0.30%	0.28%

Table 4: Compliance of cement brands to British Standards Requirements++

S/No	BS Requirements**	Sample A	Sample B	Sample C	Sample D	Sample E
1.	$CaO + SiO_2 \geq 50\%$	74.92%	80.72%	64.43%	76.96%	68.13%
2.	$CaO/SiO_2 \geq 2$	4.6	3.72	5.33	3.85	3.24
3.	MgO Content ≤ 5%	1.05%	2.64%	1.48%	2.24%	1.59%
4.	SO_3 Content ≤ 3.5(+0.1)%	2.99%	4.5%	2.96%	4.04%	4.12%
5.	Chloride Content ≤ 0.4%	0.01%	0.02%	0.01%	0.06%	0.04%
6.	$Na_2O + P_2O_5 + K_2O < 5\%$	0.99%	1.03%	1.38%	1.47%	1.45%
7.	Loss on Ignition ≤ 3.0 (+0.1)%	0.04%	0.20%	0.16%	0.30%	0.28%
8.	Initial Setting Time ≥ 60(-15) Minutes	42	40	48	52	55

**** BS 12 [2], BS 5328 -1 [20], ++Arimanwa [18]**

3.2 Discussion of Results

3.2.1 Properties of aggregates and water

The sand was found to be in Zone 2 of the sand grading table. The sand was free of silt, clay and any other deleterious material and had a maximum aggregate size of 5 mm. This was achieved using a British standards sieve with 5 mm maximum aperture. The AIV was 10.18 with amaximum aggregate size of 20 mm. Both the fine and coarse aggregates were suitable for concrete production. The water used for the work was potable municipal water supply.

3.2.2 Chemical Composition of Cement Samples

Table 3 shows the chemical composition of the different cement samples used in this research. The cement samples substantially complied with British Standards requirements for ordinary Portland cement as enunciated in British Standards and shown in Table 4. The total percent concentration for the investigated cement samples were 85.6, 96.0, 74.4, 91.6 and 81.8% for samples A, B, C, D and E respectively. This indicates that cement sample B was the purest of all with impurities accounting for 4% of the analyzed material while cement sample C had the highest amount of non-chemical impurities.

Table 5: Compressive strength test results for concrete cubes for all cement samples **

Observation Point	Mean Compressive Strength (N/mm^2) Sample A	Mean Compressive Strength (N/mm^2) Sample B	Mean Compressive Strength (N/mm^2) Sample C	Mean Compressive Strength (N/mm^2) Sample D	Mean Compressive Strength (N/mm^2) Sample E
N_1A	7.04	15.01	13.77	12.14	11.38
N_2A	20.91	20.77	16.56	12.42	15.18
N_3A	15.74	18.49	13.42	14.73	7.46
N_4A	17.99	25.51	15.30	13.00	16.38
N_{12}A	14.75	19.60	13.00	18.18	13.0
N_{13}A	13.74	18.69	20.01	12.92	9.92
N_{14}A	16.26	27.96	14.70	16.60	8.63
N_{23}A	14.43	26.41	16.50	11.55	11.54
N_{24}A	16.32	21.18	19.44	18.48	12.94
N_{34}A	11.15	12.99	12.45	14.27	13.14
CONTROL POINTS					
C_1 A	17.83	22.73	15.96	18.93	10.46
C_2 A	17.13	21.42	16.63	19.26	10.36
C_3 A	12.75	20.88	16.03	15.65	11.56
C_4 A	13.61	26.36	17.25	16.35	12.73
C_5 A	14.03	22.66	14.86	17.07	11.81
C_6 A	15.20	20.08	16.67	17.56	9.50
C_7 A	15.74	22.74	18.67	14.85	11.23
C_8 A	12.71	21.67	15.52	15.22	12.44
C_9 A	14.82	22.38	16.27	14.96	9.21
C_{10} A	14.68	27.85	14.63	18.83	9.22

**Arimanwa [18]

Table 6: Maximum values of compressive strength obtainable using the computer programs**

Concrete Property	Sample A	Sample B	Sample C	Sample D	Sample E
Compressive Strength	20.91 N/mm^2	27.96 N/mm^2	20.01 N/mm^2	21.47 N/mm^2	16.38 N/mm^2

**Arimanwa [18]

3.2.3 Effect of CaO + SiO_2

BS 12 [2] specifies that the sum of lime (CaO) and silicon dioxide (SiO_2) obtained in the chemical analysis of ordinary Portland cement should not be less than 50%. All cement samples used for this work satisfied this requirement. Table 4 indicates that cement sample B has a CaO + SiO_2 value of 80.72%. Table 6 shows that the same cement sample B produced concrete with the highest compressive strength of 27.96 N/mm^2. This result was closely followed by cement sample D with CaO + SiO_2 value of 76.96% and concrete compressive strength of 21.47 N/mm^2. The next was cement sample A with CaO + SiO_2 value of 74.92% and a compressive strength of 20.91 N/mm^2. Cement sample C with CaO + SiO_2 value of 68.13% and concrete compressive strength of 20.01 N/mm^2 placed fourth in compressive strength ranking while cement sample E with CaO + SiO_2 value of 64.43% and compressive strength of 16.38 N/mm^2 ranked fifth among the cement samples investigated. The results indicate that the higher the CaO + SiO_2 content the higher the compressive strength, which can be produced with the cement under the same conditions. This is consistent with the known fact that both CaO and SiO_2 give strength to concrete though SiO_2 has to be limited relative to CaO in order not to negatively affect setting time.

3.2.4 Effect of CaO/SiO_2

British standards require that the ratio of lime (CaO) to silicon dioxide (SiO_2) contents in ordinary Portland cement should not be less than 2. All the cement samples investigated satisfied this requirement. The lime-silicon dioxide ratio for cement samples A, B, C, D and E were 4.6, 3.72, 3.24, 3.85 and 5.33 respectively. The results also indicated that the higher the sum of (CaO + SiO_2) and (CaO/SiO_2) of a cement sample the higher the compressive strength of concrete which can be produced from it. The values of the sum of (CaO + SiO_2) and (CaO/SiO_2) for the different cement samples are 79.52, 84.44, 71.37, 80.81 and 69.76 for cement samples A, B, C, D and E respectively. The restriction on the ratio of lime to silicon dioxide by BS 12 [2] is to ensure that the quantity of silicon dioxide is considerably lower than that of lime so that the setting of concrete is not inhibited.

3.2.5 Effect of MgO

BS 12 [2] recommends that the quantity of magnesium oxide (MgO) in ordinary Portland cement should not exceed 5%. All the cement samples satisfied this requirement with 1.05%, 2.64%, 1.48%, 2.24% and 1.59% for cement samples A, B C, D and E respectively. Magnesium oxide contributes to colour of cement and hardness of the resulting concrete or mortar. Cement sample B with the highest MgO content of 2.64% was expected to produce concrete with the highest compressive strength since MgO contributes to hardness of concrete. However, if the quantity of MgO is in excess of 5 percent, unsightly cracks will appear in both mortar and concrete and may even lead to unsoundness.

3.2.6 Effect of SO_3

The British standards requirement for sulphur trioxide (SO_3) content in ordinary Portland cement is that it should be less than 3.5 (+0.1)%. Only two of the investigated cement samples satisfied this requirement namely cement samples A and C with SO_3 contents of 2.99 and 2.96% respectively. Cement samples B, D and E did not satisfy this requirement with their respective SO_3 contents as 4.5, 4.04 and 4.12%. Sulphur trioxide is known to accelerate the setting time of cement paste and contributing to soundness. Cement sample B showed the fastest setting time of 40 minutes for the cement paste as shown in Table 4 obviously because of its highest SO_3 content.

3.2.7 Effect of Chloride Content

British standards limit the chloride content in ordinary Portland cement to not more than 0.4%. All the cement samples in this work satisfied this requirement with 0.01, 0.02, 0.01, 0.06 and 0.04% for cement samples A, B, C, D and E respectively

Table 7: Comparison between compressive strength values obtained from experimental tests and Scheffe's model equations**

OP	Sample A (N/mm^2)			Sample B (N/mm^2)			Sample C (N/mm^2)			Sample D (N/mm^2)			Sample E (N/mm^2)		
	ER	SR	DIFF	ER	SR	DIFF	ER	SR	DIFF	ER	SR	DIFF	ER	SR	DIFF
N_1	7.04	7.04	0	15.01	15.01	0	13.77	13.77	0	12.14	12.14	0	11.38	11.38	0
N_2	20.91	20.91	0	20.77	20.77	0	16.56	16.56	0	12.42	12.42	0	15.18	15.18	0
N_3	15.74	15.74	0	18.49	18.49	0	13.42	13.42	0	14.73	14.73	0	7.46	7.46	0
N_4	17.99	17.99	0	25.51	25.51	0	15.30	15.30	0	13.00	13.00	0	16.38	16.38	0
N_{12}	14.75	14.75	0	19.60	19.60	0	13.00	13.00	0	18.18	18.18	0	13.0	13.0	0
N_{13}	13.74	13.74	0	18.69	18.69	0	20.01	20.01	0	12.92	12.92	0	9.92	9.92	0
N_{14}	16.26	16.26	0	27.96	27.96	0	14.70	14.70	0	16.60	16.60	0	8.63	8.63	0
N_{23}	14.43	14.43	0	26.41	26.41	0	16.50	16.50	0	11.55	11.55	0	11.54	11.54	0
N_{24}	16.32	16.32	0	21.18	21.18	0	19.44	19.44	0	18.48	18.48	0	12.94	12.94	0
N_{34}	11.15	11.15	0	12.99	12.99	0	12.45	12.45	0	14.27	14.27	0	13.14	13.14	0
					CONTROL POINTS										
C_1	17.83	16.484	7.55	22.73	24.998	-9.98	15.96	16.524	-3.53	18.93	19.012	-0.43	10.46	10.05	3.92
C_2	17.13	16.471	3.85	21.42	22.315	-4.18	16.63	16.256	2.25	19.26	19.335	-0.39	10.36	11.338	9.44
C_3	12.75	13.953	-9.44	20.88	21.801	-4.41	16.03	16.641	-3.81	15.65	16.508	-5.48	11.56	10.61	8.22
C_4	13.61	14.579	-7.12	26.36	25.51	3.22	17.25	16.78	2.75	16.35	16.683	-2.04	12.73	11.587	8.98
C_5	14.03	13.52	3.41	22.66	20.919	7.68	14.86	16.43	-10.57	17.07	16.128	5.52	11.81	10.722	9.21
C_6	15.20	13.966	8.12	20.08	21.944	-9.28	16.67	16.696	-0.16	17.56	16.376	6.74	9.50	10.38	9.26
C_7	15.74	14.823	5.83	22.74	22.306	1.91	18.67	17.193	7.91	14.85	16.022	-7.89	11.23	12.502	-11.33
C_8	12.71	13.304	-4.67	21.67	19.941	7.98	15.52	15.89	-2.84	15.22	16.009	-5.18	12.44	11.318	9.02
C_9	14.82	14.416	2.73	22.38	22.839	-4.59	16.27	17.576	-8.02	14.96	13.475	9.93	9.21	8.186	11.12
C_{10}	14.68	15.655	-6.69	27.85	25.609	8.05	14.63	15.175	-3.73	18.83	18.403	2.27	9.22	8.431	8.56

**Arimanwa [18]

OP = Observation Point
ER = Experimental Results
SR = Scheffe'sModel Results
DIFF = % Difference between Experimental and Scheffe's Model Resul

3.2.8 Effect of Al_2O_3

Aluminium oxide (Al_2O_3) aids the quick setting of cement paste. Cement sample B contained the highest quantity of 4.17% of Al_2O_3 resulting in the fastest initial set of the cement paste

3.2.9 Effect of Fe_2O_3

Iron oxide (Fe_2O_3) contributes to cement colour and helps in the fusion of the different ingredients. The Fe_2O_3 contents for the different cement samples are 2.71, 2.93, 1.73, 3.49 and 3.05% for cement samples A, B, C, D and E respectively as shown in Table 4.

3.2.10 Effect of Residues

British standards consider Na_2O, K_2O, TiO_2 and P_2O_5 in ordinary Portland cement as residues and limit the sum of all of them to 5%. All the cement samples investigated satisfied this requirement with cement samples A, B, C, D and E having total residue contents of 0.99, 1.03, 1.38, 1.47 and 1.45% respectively. If in excess of 5% efflorescence and unsightly cracking will occur.

3.2.11 Properties of concrete within the factor space

Both the responses from the model equations and laboratory experimental results indicate that compressive strength of concrete was influenced by the mix ratios of the combining elements (water, cement, sharp river sand and granite chippings) in the factor space. The results are shown in Table 5. Cement sample A produced a range of concrete compressive strengths from 7.04 to 20.91 N/mm^2 from laboratory test results depending on the mix ratio of the combining elements. For cement sample B the range was 12.99 to 27.85 N/mm^2 while for cement sample C the range was 12.45 to 20.01 N/mm^2. Cement samples D and E had their own ranges of compressive strengths as 11.55 to 19.26 N/mm^2 and 7.46 to 16.38 N/mm^2 respectively. The derived models could be applied to any concrete produced with cement of identical chemical characteristics as those investigated in this work.

3.2.12 Comparison between values of compressive strength obtained from experimental tests and model equations

It has been established that all the cement brands used in this study significantly complied with the requirements of the relevant British Standard Specifications. Table 7 shows the comparison between values of the compressive strengths of concrete produced in the laboratory using the ordinary Portland cement brands A, B, C, D, E and those obtained by model equations.The adequacy of the response functions was tested using the t-statistic and f-statistic tools. The values indicate that the differences between the experimental results and those from model equations were not significant. The models, therefore, can be reliably used to predict mix ratios and values of compressive strength of concrete made with the above cement brands or other brands with similar chemical characteristics. Table 6 compares the maximum values of the compressive strength properties obtainable using the models. The results show that cement sample B produced the highest value of compressive strength while Cement Sample E produced the least value.

IV. CONCLUSION

The following conclusions have been reached from the outcome of this work:

i) The higher the lime (CaO) and silicon dioxide (SiO_2) content in cement, the higher the compressive strength of concrete that can be produced with it. Cement sample B produced concrete with the highest compressive strength because it has the highest CaO + SiO_2 content.

ii) The higher the aluminium oxide (Al_2O_3) and sulphur trioxide (SO_3) contents of cement the faster the setting time. Cement sample B produced the fastest initial set because it has the highest Al_2O_3 + SO_3 content.

iii) The five model functions formulated for this work from Scheffe's simplex technique yielded satisfactory results as shown by the test for adequacy/fit using the f-statistic and t-statistic tools.

iv) The laboratory experimental results yielded compatible results when compared with the outcome of the model equations.s

v) The order of preference for resisting compression is Cement Sample B (27.96 N/mm^2), Sample D (21.47 N/mm^2), Sample A (20.91 N/mm^2), Sample C (20.01 N/mm^2) and Sample E (16.38 N/mm^2).

4.2 Recommendations

The following recommendations are derived from the outcome and conclusions of this research:

i) The chemical analysis of cement should always be done and the results compared with available standards before choosing any brand for major construction works.

ii) The Council for the Regulation of Engineering Practice in Nigeria COREN should sponsor a bill requiring the National Assembly to make a law making it mandatory for all cement-manufacturing firms in Nigeria to clearly print the chemical composition of their product on the bag. The law should make it a serious and punishable offence if wrong information is given.

iii) If compressive strength and early striking of forms are of the essence then Cement Sample B with CaO + SiO_2content equal to 80.72% is the most preferred option among those investigated.

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