DESIGN OF COMPUTER MODEL FOR OPTIMIZING THE COMPRESSIVE STRENGTH OF CONCRETE MADE OF GRANITE AGGREGATES.

BY

ENGR. ADAMU ABDULLAHI AYNI

SNR. LECTURER, DEPARTMENT OF CIVIL ENGINEERING,

ADINO OJONE ERNEST

TECHNOLOGIST, DEPARTMENT OF CIVIL ENGINEERING,

KOGI STATE POLYTECHNIC, LOKOJA.

JULY, 2020.

ABSTRACT

The traditional methods of mix design employ empirical formulae and are very cumbersome, time wasteful and energy consuming. Therefore, the search for alternative means of producing concrete without extremely affecting the properties of the concrete is a task on researchers, technologists, engineers, and scientists.

This research was aimed at overcoming these limitations by optimizing the strength of concrete made from granite aggregates in Nsukka, Nigeria. Model for compressive strength based on Henry Scheffe's simplex theory using a quadratic polynomial and a (4, 2) simplex lattice was developed. A QBASIC computer optimization program was equally developed for the model. Using the model, once the user specifies the required strength, the computer provides all the possible mix ratios that can yield such strength. The students' t-test statistic confirmed the adequacy of the model.

The maximum compressive strength attainable with the model using granite is 48.06N/mm^2.

1.0 INTRODUCTION

Concrete is such a composite materials in construction industries whose use and application cuts through the sphere of civil engineering structures.

There are many types of aggregates used for concrete work in this country, most of these fall into the igneous rock type, lateritic crust and stones on their part are the iron-rich gravels formed as a result of the decomposition of the igneous and other rocks due to intense tropical heat, high humidity and heavy rainfall and yet are of uncertain performance.

The abundance of the natural deposit of local aggregates in this country, its ever increasing use by builders and the ever-increasing cost of construction materials prompted research into local and cheap construction materials. Granite, the common coarse aggregate in normal concrete is equally affected. Therefore, the search for alternative low-cost materials that can be used as aggregate in concrete without extremely affecting the properties of the concrete is a task on researchers, technologists, engineers and scientists.

Aggregate constitute about 70 to 75% of the total volume of concrete and the quality of the aggregate plays a very important part in the strength and durability of the concrete, thus concrete failure have often been tied to the use of aggregate.

For government, multinational, and some private projects, mini or large, with regards to economy and adequate design where ‘very high’ concrete strength is the over-riding design consideration, granite chippings are always specified.

1.1 CONCRETE MIX DESIGN

Concrete mix design is the process of selecting ingredients of concrete and determining their relative quantities with the purpose of producing an economical concrete which has certain minimum properties notably workability, strength and durability. The objective of concrete mix design is therefore to find the most economical way of producing concrete of certain quality from readily available materials at a particular working condition. In concrete mix design, the properties of fresh and hardened concrete are equally important, the strength, durability and appearance of the hardened concrete can be realized if the workability and cohesiveness of the fresh concrete are suitable for the particular working condition. (Neville, A. M., 1996).

Of all the desirable properties of hardened concrete i.e. compressive, tensile, flexural, bond, and split-tensile strengths, the compressive strength is the most convenient to measure and is usually used as a criterion of the over all quality of the hardened concrete. Thus in concrete mix design, compressive strength of the hardened concrete is often considered. Majid, K. I. (1974).

Several empirical methods have been developed in order to achieve the objectives of mix design. All these procedures try to find the appropriate ratios of cement, sand and coarse aggregate at a particular water/cement ratio (w/c). Typical ratios often used are 1: 1½ : 3, 1 : 2 : 4, 1 : 3 : 6, etc at 0.55, 0.56, 0.58, etc. w/c. These proportions can either be determined by weight or by volume.

some of the current methods used in concrete mix design include the American Concrete Institute (ACI) approach, the Department of Environment (DOE) method, the

Road Note 4 (Road Research Laboratory, 1950) method, the Arithmetic (or Hughes, 1971) method, the BS 817 (1975) method, etc. Almost all these methods have limitations. Most often, there is the need to perform some trial mixes in the laboratory to ascertain the efficiency of a chosen procedure. Moreover, the method so adopted may not be cost effective. Again, the time and energy required in order to set the appropriate mix proportions may be enormous. Neville, A. M. (1996).

1.2 AIM AND OBJECTIVES OF THE RESEARCH

The objective of the research specifically include;-

⇒ To carry out test and measure the strength of concrete manufactured using granite chippings.

⇒ To formulate a mathematical model, which with the aid of a computer program prescribe mix proportion that will produce the required strength using granite chippings.

⇒ To reduce the experimental efforts used in the traditional system of mix design.

⇒ To minimize the cost of producing concrete since the traditional mix design methods which require experience and many trial mixes which are tedious and require much time and energy.

1.3 JUSTIFICATION FOR THE RESEARCH

The traditional methods of mix design employ empirical formulae and are very cumbersome, time wasteful and energy consuming. Therefore, the search for alternative means of producing concrete without extremely affecting the properties of the concrete is a task on researchers, technologists, engineers, and scientists.

In this regard, this experimental research seeks to provide a design model for the strength of concrete made from granite chippings, the results of which will have a beneficial effect on the quality control of concrete. It will also provide design data for concretors and help to reduce the cost of producing such concrete.

1.4 HYPOTHESES

This study is based on the hypotheses, that the interaction between mixtures is a factor space matrix. (Akhnazarova and Kafarov,1982). The Null and Alternative hypotheses stated in order to test the adequacy or otherwise of Scheffe's model are as follows:-

(a) Null Hypothesis (H_0): there is no significant difference between the experimental strength values and the theoretically expected results.

(b) Alternative Hypothesis (H_1): there is a significant difference between the experimental strength results and the theoretically expected results (see section5.3).

1.5 LIMITATIONS OF THE PROJECT

Constraints in terms of finance, time, testing equipment errors and personal mistakes could be other inhibiting factors. The workability of each of the mix was not considered. However, a careful selection of the mix provided a workable concrete.

2.0 OPTIMISATION

It is a process of finding the maximum or minimum value for a function of several variables while at the same time not violating certain imposed requirements. The function is called an objective or target function and the imposed requirements are known as the constraints of the problem. In order to minimize some of the limitations in the traditional method of mix design, an optimization procedure has been proposed. (Majid, 1974)

For this study, an optimization theory proposed by H. Scheffe will be used to derive optimization models for concrete made from granite aggregates because of the numerous advantages that it offers.

2.1 SCHEFFE'S OPTIMISATION THEORY

One of the essential factors for achieving the desired strength of concrete is the adequate proportioning of the ingredients needed to produce the concrete. Henry Scheffe developed a model whereby if the desired strength is specified, then the possible combinations of the needed ingredients to achieve the strength can easily be predicted by the aid a computer and vice versa (i.e. if the proportions are specified, the strength can easily be predicted). (Aknazarova, S and Kafaro, V. (1982)

2.1.1 ADVANTAGES OF SCHEFFE'S THEORY

The advantages of Scheffe's optimization theory include the following:

i. Computer can easily be used for the mix design calculations

ISSN 2229-5518

ii. Optimum quantity or quantities (Strength vs ingredient proportions) can easily be calculated.

iii. With the model, computer can prepare more than one combination of ingredients for a particular strength required. This enables the user to choose the least costly combination that satisfies his aim.

iv. The method reduces labour and saves time as compared to the other empirical methods of mix design.

2.2 THE SIMPLEX

Simplex is the structural representation (shape) of the lines or planes joining the assumed positions of the constituent materials (atoms) of the mixture. (Jackson, 1983)

According to Scheffe (1958), when studying the properties of a q-component mixture, the studied properties depending on the component ratio only, the factor space is a regular (q - 1) simplex, and for the mixture, the relationship in equation 3.1 holds.

$$\sum_{i=1}^{q} P_i = 1 \quad \text{Or} \quad P_1 + P_2 + P_3 + \text{----} + P_q = 1 \qquad - \quad - \quad - \quad \text{-eqn (2.1)}$$

If P_i is the proportion of the i-th component in the mixture such that P_i / 0 (i =1, 2, 3, …, q) then assuming the mixture to be a unit quantity, the proportions of the components must sum up to unity.

2.2.1 SIMPLEX LATTICES

In a (q-n) dimensional simplex, (1) if q = 2, we have 2 points of connectivity, giving a straight line simplex lattice. (2) if q = 3, we have a triangular simplex lattice and (3) if q = 4, we have a tetrahedron simplex lattice. e.t.c.

Moreover, he proved that a polynomial of degree n in q variables has C^n_{q+n} points on the lattice but by using the relationship in eqn. 2.1, the number of points can be reduced to C^n_{q+n-1}.

This implies that the number of points

(i) for a (3, 2) lattice, equals:

$$C^n_{q+n-1} = \frac{q(q+1)---(q+n-1)}{n!} \qquad - \quad - \quad - \quad - \qquad \text{eqn. (2.2)}$$

$$= \frac{3(3+1)}{2*1} = 6 \text{ (See fig 2.1 a)}$$

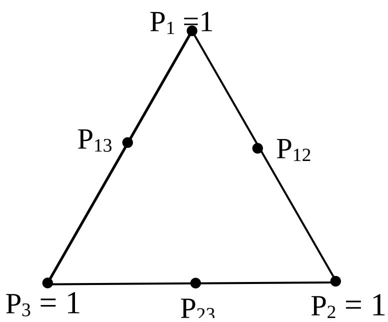
ISSN 2229-5518

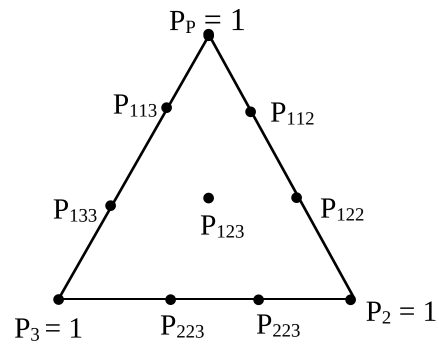
(ii) for a (3, 3) lattice, equals: $\frac{3(3+1)(3+2)}{3*2*1} = 10$ (See fig 2.1 b)

(iii) for a (4, 2) lattice, equals 10 (see fig 2.1 c) ;

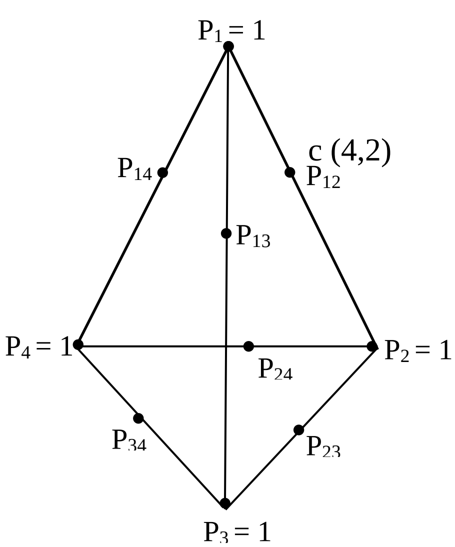
(iv) for a (4, 3) lattice, equals 20 (see fig 2.1 d) and

(v) for a (5, 2) lattice, equals 15





a (3,2) b. (3,3)



c (4,2)

d. (4,3)

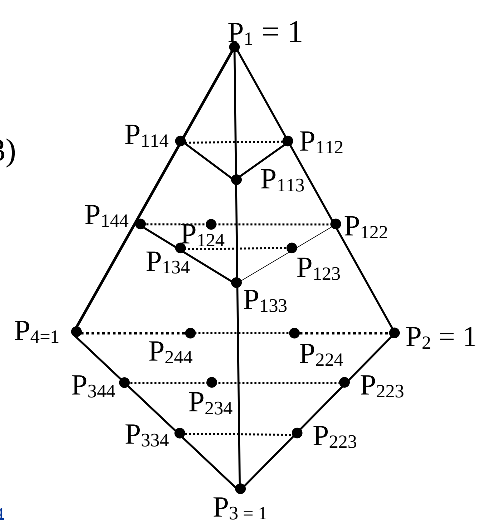


Fig. 2.1 (a-d).The (q, n) simplex lattices

2.2.2 THE SIMPLEX CANONICAL POLYNOMIALS

Scheffe also showed that a polynomial function of degree n in q variables P_1, P_2, P_3, …P_q subject to equation 2.1 will be called a (q , n) polynomial. Accordingly if the response (y) is a function of the components (or variables) P_1, P_2, P_3, P_4, …P_q, then the polynomial is of the form;

$$\hat{y} = b_0 + \sum_{1\le i\le q} b_i P_i + \sum_{1\le i\le j\le q} b_{ij} P_i P_j + \sum_{1\le i\le j\le k\le q} b_{ijk} P_i P_j P_k + \sum bi_1 i_2 ---i_n Pi_1 Pi_2 Pi_n \quad \text{.eqn. (2.3)}$$

Where all bs are constant coefficients.

In order to have a manageable number of coefficients, scheffe avoided high-degree polynomials. the general low-degree polynomial of degree n and q variables subject to eqn. (2.1) may be written as:

1. if n = 1; $\hat{y} = \sum_{1\le i\le q} b_i P_i$ - - - - - - enq. (2.4)

2. if n = 2; $\hat{y} = \sum_{1\le i\le q} b_i P_i + \sum_{1\le i\le j\le q} b_{ij} P_i P_j$ - - - - enq. (2.5)

Equations (2.4) and (2.5) are known as Scheffe canonical forms of the polynomials of degree 1 and 2 respectively. This study is based on a (4,2) simplex lattice hence the usable form of equation (2.3) will be developed as follows:

The response (ŷ), is a function of the four variables P_1, P_2, P_3, and P_4, representing the proportion of water/cement ratio, cement, sand, and coarse aggregate respectively, that is: $\hat{y} = f(P_1, P_2, P_3, P_4)$ - - - - - eqn(2.6)

The reduced form of the equation is given by Scheffe (1958) as:

$\hat{y} = b_0 + b_1P_1 + b_2P_2 + b_3P_3 + b_4P_4 + b_{12}P_1P_2 + b_{13}P_1P_3 + b_{14}P_1P_4 + b_{23}P_2P_3 + b_{24}P_2P_4 + b_{34}P_3P_4 + b_{11}P^2{}_1 + b_{22}P^2{}_2 + b_{33}P^2{}_3 + b_{44}P^2{}_4$ - - eqn. (2.7)

from eqn(2.1), $P_1 + P_2 + P_3 + P_4 = 1$ eqn (2.8)

Multiplying eqn (2.7) by b_0 we have:

$b_0P_1 + b_0P_2 + b_0P_3 + b_0P_4 = b_0$ - - - - eqn (2.9)

Again multiplying eqn (2.8) by P_1, P_2, P_3, and P_4 and making P_1, P_2, P_3, and P_4 respectively the subject of the formula yield;

ISSN 2229-5518

$$\left.\begin{aligned} P^2{}_1 &= P_1 - P_1P_2 - P_1P_3 - P_1P_4 \\ P^2{}_2 &= P_2 - P_1P_2 - P_2P_3 - P_2P_4 \\ P^2{}_3 &= P_3 - P_1P_3 - P_2P_3 - P_3P_4 \\ P^2{}_4 &= P_4 - P_1P_4 - P_2P_4 - P_3P_4 \end{aligned}\right\} \quad - \quad - \quad \text{eqn(2.10)}$$

Substituting eqn(2.9) and eqn(2.10) into eqn (2.7) and factorizing we obtain

$$\hat{y} = (b_0 + b_1 + b_{11})P_1 + (b_0 + b_2 + b_{22})P_2 + (b_0 + b_3 + b_{33})P_3 + (b_0 + b_4 + b_{44})P_4 + (b_{12} - b_{11} - b_{22})P_1P_2 + (b_{13} - b_{11} - b_{33})P_1P_3 + (b_{14} - b_{11} - b_{44})P_1P_4 + (b_{23} - b_{22} - b_{33})P_2P_3 + (b_{24} - b_{22} - b_{44})P_2P_4 + (b_{34} - b_{33} - b_{44})P_3P_4 \quad - \quad - \quad - \quad \text{eqn(2.11)}$$

If we denote; $\beta_i = b_0 + b_i + b_{ii}$ and $\beta_{ij} = b_{ij} - b_{ii} - b_{jj}$ - - eqn.(2.12)

Equation (2.11) reduces to,

$$\hat{\mathbf{y}} = \beta_1P_1 + \beta_2P_2 + \beta_3P_3 + \beta_4P_4 + \beta_{12}P_1P_2 + \beta_{13}P_1P_3 + \beta_{14}P_1P_4 + \beta_{23}P_2P_3 + \beta_{24}P_2P_4 + \beta_{34}P_3P_4 \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad \text{eqn.(2.13a)}$$

Equation (2.13a) is the governing equation for a (4,2) simplex lattice

Written in compact form eqn (2.13a) becomes

$$\hat{y} = \sum_{1 \le i \le q} \beta_i P_i + \sum_{1 \le i \le j \le q} \beta_{ij} PiP_j \quad - \quad - \quad - \quad - \quad - \quad - \quad \text{eqn. (2.13b)}$$

2.2.3 THE COEFFICIENTS OF A (4, 2) POLYNOMIAL

If the response to the pure component is denoted by y_i and the response to a binary mixture of components i and j by y_{ij}., then

from eqn (2.13b) if $P_i = 1$ ($\geq P_j = 0$ for $j \neq i$) therefore $\beta_i = y_i$ - -eqn (2.14).

This implies that, from eqn (2.13b) it can easily be seen that

$$\sum_{i=1}^{4} \beta_i P_i = \sum_{i=1}^{4} y_i P_i \quad - \quad - \quad - \quad - \quad - \quad - \quad \text{eqn. (2.15)}$$

Hence, the coefficient as given by Scheffe(26) are,

$\beta_i = y_i$ and $\beta_{ij} = 4y_{ij} - 2y_i - 2y_j$ - - - - - eqn(2.16)

2.2.4 ADOPTION OF THE POLYNOMIAL REGRESSION FUNCTION

There are generally two process of designing experiments to fit the polynomial regression function. These are;

i. a (4, 2) lattice with more than one observation per point.

ii. a (4, m) lattice (m>2) and one observation per point.

Experience has shown that process (i) is simpler to use. The reason is that, the least square estimates of the regression coefficients are easily calculated from the means of the observations at the points of the lattice, by replacing β and y by β and ŷ in eqn. (2.16). The second process is rather tedious as the regression is fitted by least square on smaller distantly spaced points of the lattice as can be observed from fig. 2.1 c and d respectively. Scheffe. (1958)

2.3 TESTING THE FIT OF THE QUADRATIC POLYNOMIAL

The hypotheses formulated in section 1.3 will be tested using the “Student” t-distribution.

2.3.1 THE “STUDENT” T-DISTRIBUTION

This is a statistical test for small samples. The unbiased estimate of the unknown variance σ^2 is given by Cramer (1946) and Adamu (1974) as:

$$S_y^2 = \frac{1}{n-1}\sum\left(y_i - \bar{y}\right)^2 \quad - \quad - \quad - \quad - \quad - \quad - \qquad \text{eqn (2.17)}$$

Where, y_i = the responses, y = the mean of the responses for each control points

n = control points, n-1 = degree of freedom

And the estimated standard deviation or the error, $\varepsilon = \sqrt{S_y^2}$ - eqn (2.18)

For a t-test statistic, adequacy is tested at each control point. The equation as given by Paradine and Rivett (1970) and Akhnazarova and Kafarov (1982) is

$$t = \frac{\Delta y}{\sqrt{S_y^2 + S_y^2}} = \frac{\Delta y\sqrt{n}}{S_y^2\sqrt{1+\varepsilon}} \quad - \quad - \quad - \quad - \quad - \quad - \qquad \text{eqn(2.19a)}$$

Where, $\Delta y = [\, y_{\text{experiment}} - y_{\text{theoretical}} \,]$ - - - eqn (2.19b)

n = number of parallel observations at every point.

The t – statistics has the student distribution and is compared with the tabulated value of $t_{\alpha/L}$ (V_e)

The Null Hypothesis that the equation is adequate is accepted if the value of t obtained from the table is greater than $t_{\text{experiment}}$ for all control points.

2.4 ACTUAL AND PSEUDO – COMPONENTS

The requirement of simplex lattice designs that $\sum_{i=1}^{q} P_i = 1$ makes it impossible to use the normal mix ratios such as 0.60:1: 2: 4, Thus, the transformation of the actual components (ingredients) proportions to meet the above criterion is necessary. Such transformed ratios, say $P_1^{(i)}$, $P_2^{(i)}$, $P_3^{(i)}$, $P_4^{(i)}$ for the i-th experimental points are called "pseudo – components" (or coded components).

Based on experience, the following arbitrary prescribed mix proportions were chosen for the four points R_1(0.50:1:2:4), R_2(0.55:1:1.5:3), R_3(0.60:1:2:5), and R_4 (0.65:1:4:8). The proportions represent water/cement ratio, cement, sand, and coarse aggregate respectively.

In order to satisfy the requirement that $\sum_{i=1}^{q} p_i = 1$

The design matrix with pseudo components for a (4, 2) lattice obtainable from fig.2.2 is as presented in table 2.2

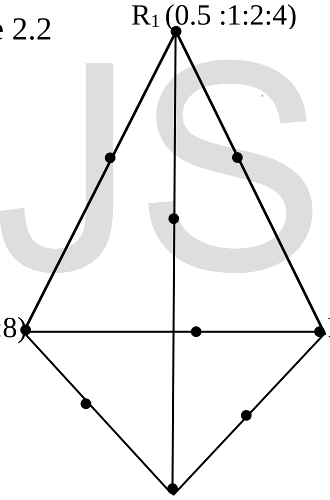


Fig. 2.2 Tetrahedron vertices of a (4, 2) lattice

Table 2.1 Matrix for a (4, 2) lattice

S/N	P_1	P_2	P_3	P_4	y_{0bs}
1	1	0	0	0	y_1
2	0	1	0	0	y_2
3	0	0	1	0	y_3
4	0	0	0	1	y_4
5	0.5	0.5	0	0	y_{12}

6	0.5	0	0.5	0	y_{13}
7	0.5	0	0	0.5	y_{14}
8	0	0.5	0.5	0	y_{23}
9	0	0.5	0	0.5	y_{24}
10	0	0	0.5	0.5	y_{34}

y_{0bs} = the observed values of the "strength" being studied termed the RESPONSES.

The inverse transformation from pseudo components to actual componentsis expressed as;

Let $NP = A$ - - - - - - eqn. (2.20a)

Where, N = Inverse Matrix

$$N = AP^{-1}$$

Therefore, $N = A(B\ A)^{-1} = AA^{-1}B^{-1} = I\ B^{-1}$

$$N = B^{-1} \quad - \quad - \quad - \quad - \quad - \quad - \qquad \text{eqn.(2.20b)}$$

This implies that for any pseudo-component P_i, the actual component A_i is given by:

$$\begin{Bmatrix} A_1^{(i)} \\ A_2^{(i)} \\ A_3^{(i)} \\ A_4^{(i)} \end{Bmatrix} = \begin{Bmatrix} 0.50 & 0.55 & 0.60 & 0.65 \\ 1 & 1 & 1 & 1 \\ 2 & 1.50 & 2 & 4 \\ 4 & 3 & 5 & 8 \end{Bmatrix} P \begin{Bmatrix} P_1^{(i)}A \\ P_2^{(i)} \\ P_3^{(i)} \\ P_4^{(i)} \end{Bmatrix}$$

Or $A = [T_1]\ [P]$ - - - - - - eqn (2.21)

Equation 2.21 is used for determining the actual components from point 5 to 10 and from point 11 to 16 (the control points); that is: shown in table 2.2

Table 2.2: Pseudo and Actual components for points 1-16

	Pseudo Components					Actual Components			
No	P_1	P_2	P_3	P_4	Response	A_1	A_2	A_3	A_4
1	1.00	0.00	0.00	0.00	y_1	0.500	1.0	2.00	4.0
2	0.00	1.00	0.00	0.00	y_2	0.550	1.0	1.50	3.0
3	0.00	0.00	1.00	0.00	y_3	0.600	1.0	2.00	5.0
4	0.00	0.00	0.00	1.00	y_4	0.650	1.0	4.00	8.0
5	0.50	0.50	0.00	0.00	y_{12}	0.525	1.0	1.75	3.5
6	0.50	0.00	0.50	0.00	y_{13}	0.550	1.0	2.00	4.5
7	0.50	0.00	0.00	0.50	y_{14}	0.575	1.0	3.00	6.0
8	0.00	0.50	0.50	0.00	Y_{23}	0.575	1.0	1.75	4.0

9	0.00	0.50	000	0.50	y_{24}	0.600	1.0	2.75	5.5
10	0.00	0.00	0.50	0.50	y_{34}	0.625	1.0	3.00	6.5
CONTROL POINTS									
11	0.25	0.25	0.25	0.25	C_1	0.575	1.0	2.375	5.0
12	0.30	0.20	0.30	0.20	C_2	0.570	1.0	5.00	4.9
13	0.40	0.20	0.20	0.20	C_3	0.560	1.0	2.30	4.8
14	0.20	0.30	0.40	0.10	C_4	0.570	1.0	2.05	4.5
15	0.10	0.60	0.10	0.20	C_5	0.570	1.0	5.50	4.3
16	0.30	0.10	0.30	0.30	C_6	0.580	1.0	2.55	5.4

2.5 EXPERIMENTAL VALUE

The actual components as transformed (eqn. 3.21) and shown in table 2.2 were used for measuring out the quantities: water (A_1), cement (A_2), sand (A_3), and coarse aggregate (A_4) in their respective ratios for the compressive strength test.

3.0 MATERIALS AND METHODOLOGY

The granite chippings is a dark grey diorite sample which falls in the Gabbro group.

Plate 1: samples of Granite chippings

3.1 PRELIMINARY LABORATORY TESTS

These include aggregate grading (coarse), average crushing value (ACV), specific gravity, and percentage water absorption of the coarse aggregate.

Results of some of the test carried out are tabulated below.

Properties	Granite chippings	Notes
Elongation index	6.90	
Flakiness index	8.30	
Angularity No	8.15	

Specific gravity (%)	2.75	
Water absorption (%)	7.20	
Bulk density (kg/m^3)	1748	
Percentage voids (%)	33.00	
Aggregate crushing value (%)	22.00	15cm diameter cylinder
Los Angeles abrasion test (%)	33.20	
Workability and strength of concrete (N/mm^2)	29.00	w/c=0.65, 28 days
PH- value	5.10	

Table 3.1: properties of granite chippings

3.2 PREPARATION OF SAMPLES

The cement was Ordinary Portland cement (Dangote brand) conforming to type 1-cement. (BS 12: 1991). Clean water free from deleterious substances was drawn from the university of Nigeria Nsukka boreholes and conformed to BS 3148: 1959. Sand was from Opi River in Enugu state and prepared to BS 882: 1992 and BS 812: 1975.

The granite chippings was obtained from a construction site in the University Of Nigeria, Nsukka, and of size 3/4”

Material	Property	Value
Sand	Specific gravity (%) Percentage water absorption (%)	2.65 0.11
Granite aggregate	Specific gravity (%) Percentage water absorption (%) Average Crushing Value (%)	2.62 2.41% 20.92
Cement	Specific Gravity (%) Initial Setting Time Final Setting Time Soundness	3.15+ 53 minutes 90 minutes 0.50 mm

Table 3.2: Physical Properties of Materials Used

ISSN 2229-5518

3.3 PREPARATION AND TESTING OF SPECIMENS

From the pre-determined mix proportions of water – cement ratio, cement, sand, and coarse aggregate, batching of the constituents was by weight. Mixing of the constituents was done manually using a hand trowel. Water was added gradually and the mixture turned until a homogeneous mix was obtained.

3.4 CRUSHING STRENGTH TEST CUBES

The moulds were 100mm size. Each cube was prepared to conform to BS 1881: parts 108: 1983. demoulded after 24 hours, transferred immediately to the curing tank and cured at room temperature for 28 days, The cubes were then tested for compressive strength using DENNISON compression testing machine in accordance with BS 1881: part 115: 1986 and part 116: 1983.

4.0 CRUSHING STRENGTH

The crushing strength (f_c) was obtained as follows:

$$f_c = \frac{\text{Maximum Load}}{\text{Cross-Sectional Area}} \quad (\text{N/mm}^2) \quad - \quad - \quad - \quad \text{eqn (3.1)}$$

4.1 DETERMINATION OF REPLICATION ERROR AND VARIANCE OF RESPONSES: LATERIZED SANDSTONES

Table 4.1 gives the results of two repetitions each of the ten (10) design points and the six (6) control points of the (4, 2) simplex lattice for the crushing strength for the laterized sandstones aggregate.

Note that, $y = \left[\sum_{r=1}^{m_i} y_r\right] / m_i, \quad S_i^2 = \frac{1}{m_{i-1}}\left[\sum_{r=1}^{m_i} y_r^2 - \frac{1}{m_i}\left(\sum_{r=1}^{m_i} y_r\right)^2\right]$

$$V_e = \sum_{i=1}^{16} V_i = \sum_{i=1}^{16}(m_i - 1) = 16$$

Table 4.1: Crushing Strength Test Results and Replication Variance of the Responses for the granite chippings..

Exp. No	Repetition	Response y_r	Response Symbol	$\sum_{r=1}^{m_i} y_r$	$\bar{y}$	$\sum_{r=1}^{m_i} y_r^2$	S_i^2
N		(N/mm^2)					
1	1A 1B	34.00 33.00	y_1	67.00	33.50	2245.00	0.500
2	2A 2B	46.00 44.50	y_2	90.50	45.25	4096.25	1.125

ISSN 2229-5518

3	3A 3B	36.00 34.00	y_3	70.00	35.00	2452.00	2.000
4	4A 4B	19.50 18.50	y_4	38.00	19.00	722.50	0.500
5	5A 5B	40.00 41.00	y_{12}	81.00	40.50	3281.00	0.500
6	6A 6B	34.00 32.50	y_{13}	66.50	33.25	2212.25	1.125
7	7A 7B	26.00 25.50	y_{14}	51.50	25.75	1326.25	0.125
8	8A 8B	36.00 34.50	y_{23}	70.50	35.25	2486.25	1.125
9	9A 9B	38.00 38.00	y_{24}	76.00	38.00	2888.00	0.000
10	10A 10B	28.00 26.00	y_{34}	54.00	27.00	1460.00	2.000
11	11A 11B	38.00 37.00	C_1	75.00	37.50	2813.00	0.500
12	12A 12B	30.50 29.00	C_2	59.50	29.75	1771.25	1.125
13	13A 13B	34.50 36.00	C_3	70.50	35.25	2486.25	1.125
14	14A 14B	36.00 34.00	C_4	70.00	35.00	2452.00	2.000
15	15A 15B	32.00 34.00	C_5	66.00	33.00	2180.00	2.000
16	16A 16B	32.00 31.00	C_6	63.00	31.50	1985.00	0.500
						$\sum =$	**16.25**

Replication Variance: $S_y^2 = \frac{1}{V_e}\sum_{i=1}^{16} S_i^2 = \frac{16.25}{16} = 1.0156$

Replication Error:

$S_y = \sqrt{S_y^2} = \sqrt{1.0156} = 1.008$ - - - - - eqn (4.2)

4.2 DETERMINATION OF THE REGRESSION EQUATION

Using equation (2.16) and table 4.1, the coefficients of the second-degree polynomial are determined as follows:

$\beta_1 = y_1 = 33.5$, $\beta_2 = y_2 = 45.25$, $\beta_3 = y_3 = 35.0$, $\beta_4 = y_4 = 38.0$, $\beta_{12} = 4.5$, $\beta_{13} = -4.0$

$\beta_{14} = -2.0$, $\beta_{23} = -31.5$, $\beta_{24} = 23.5$, $\beta_{34} = 0.0$

Thus from equation (2.13a)

$y_c = 32.25P_1 + 43.5P_2 + 33.25P_3 + 21.25P_4 - 21.5P_1P_2 + 13P_1P_3 - 10P_1P_4 - 12.5P_2P_3 + 15.5P_2P_4 - 1.0P_3P_4$ - - - - - eqn (4.3)

Equation (4.3) is the Scheffe's Mathematical model for the Crushing strength of concrete made from granite aggregate, based on the 28-day strength.

4.3 THE STUDENTS' T-STATISTIC TEST

For the t-statistic, the results are presented in table 4.2.

Table 4.2: t-Statistic for the Crushing Strength Test (Control) Points for the laterized sandstones

N	Control points	Error, ε	$\bar{y}_{obser}$	Y_{exper}	Y △	T
1	C_1	**0.4842**	31.00	31.53	0.53	0.59
2	C_2	**0.4864**	32.00	31.69	-0.31	0.34
3	C_3	**0.4864**	31.50	31.10	-0.60	0.67
4	C_4	**0.5216**	34.00	34.40	0.60	0.66
5	C_5	**0.4288**	36.00	36.63	0.63	0.71
6	C_6	**0.5168**	30.50	30.00	-0.50	0.55

The Significance level, $\alpha = 0.05$

That is: $t_{\alpha/L}(V_e) = t_{0.05/6}(16) = t_{0.01}(16)$

The tabulated value of $t_{0.01}(16)$ is 2.92. This is greater than any of the t-values calculated in table 4.2, hence the Null Hypothesis is accepted.

4.4 THE COMPUTER PROGRAMME FOR THE MODEL

The computer programs developed for the model in equation (4.3) is attached in appendix A. Once the desired strength is fed, the computer prints out all the possible combinations of the mixes that match the strength, to a tolerance of ± 0.01 N/mm^2. It notifies the user if there is no matching combination. It also checks and prints out the maximum strength obtainable with the model.

4.4.1 CHOOSING A COMBINATION

From the executed program compressive strength of 35.00N/mm^2 predicted 36 Possible mix for granite. Accepting any particular mix depends on factors such as type of construction, workability, cost, honeycombing of the resultant concrete, etc. The crushing strength (f_c) was obtained as follows:

4.5 CRUSHING STRENGTH

Let P = crushing load from compressive machine (tons)

A = cross sectional area.

f_c = compressive strength of cubes = P/A

P = 1000Pkgf in S.I unit = 100039.81P (N)

A = 1003100 (Nominal Cross-Sectional Area (mm^2))

$$f_c = \frac{100039.81P(N)}{\text{Nominal Cross-Sectional Area (mm}^2)} \quad - \quad - \quad - \quad \text{eqn (4.4)}$$

4.5 CHARACTERISTIC STRENGTH

The characteristic strength is that strength below which not more than a stated proportion of the test results should fall. Given by;

$$f_{cu} = f_m - k\sigma \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad \text{eqn. (4.5)}$$

Where

f_{cu} = minimum compressive strength of concrete (or characteristic strength in N/mm^2).

f_m = mean compressive strength of concrete in N/mm^2

k = a probability factor. Its value is obtained from statistical tables for Gaussian distribution curves.

σ = standard deviation of the strength of concrete samples.

When k = 1.88, the percentage of results falling below the minimum strength is 3% and the value of the minimum strength is called the characteristic strength.

Considering eqns. (4.4) and (4.5), the characteristic strength obtainable from the model is 43.5 – (1.88 X 1.05) = 41.5 N/mm^2

5.0 CONCLUSION

Based on the analysis of the results of this study, it has been deemed necessary to make the following conclusions.

(1) Henry Scheffe's simplex design model applied in this study proved successful, this means that the strength of concrete is a function of the proportion of the ingredients (i. e. water, cement, sand and coarse aggregate) of the concrete but not on the quantities of the materials.

(2) The maximum strength obtainable with the model is 43.5N/mm^2. This strength is quite comparable to that of normal concrete.

(3) The computer printout in chapter four (4) shows all possible mix proportions for the desired strength. The choice of any of the mixes rest on the user.

(4) The maximum strength achievable within the limit of experimental using crushed granite aggregate is 48.06N/mm^2.

(5) The student t-test used in testing the adequacy of the formulated hypothesis agreed to the acceptance of the simplex model.

(6) The characteristic strength of concrete made from granite chippings can easily be computed using the model.

(7) Though the model aimed to predict the mix proportions of the ingredients made from granite chippings corresponding to a desired strength, this model can also be easily modified to predict same for other concrete ingredients if the appropriate laboratory test procedures and model equation can be adequately formulated.

(8)The problem of having to go through a rigorous mix design procedure for a desired strength has been reduced using the model.

(9) The task of selecting a particular mix proportions out of many options is not easy, if workability and other demands of the resulting concrete have to be satisfied.

5.2 RECOMMENDATIONS

Based on the results of this research project, the following recommendations are made for maximum efficiency and best results.

(1) More research work is needed in order to match the computer recommended mixes with workability of the resulting concrete.

(2) The adequacy of the model can be improved by taking higher polynomial of this simplex.

(3) There is the need for more experimental work on creep, shrinkage, and durability properties of the concrete made from granite chippings.

(4) Due to great variability of the properties of granite chippings with geographical distribution and composition, it is necessary that every source be investigated before it is approved for use in structural concrete.

REFERENCES

1 Adamu, S. O. and Johnson, T .L. (1974),” Statistics for Beginners”, 1st Edition, Onibonoje Press & Book Industries (Nig.) Ltd. Ibadan, Nigeria, PP. 117 – 160.

2 Akhnazarova, S and Kafaro, V. (1982), “Experiment Optimization in Chemistry and Chemical Engineering, First Translated Edition, MIR Publishers, Moscow, PP. 1 – 75 and 240 – 301.

3 Becker, N.G. (1968), “Model for the Response of a Mixture”, Journal of the Royal Statistical Society; Ser. B30, PP. 349 – 358.

4 British Standards Institution, BS12 (1991), “Specifications for Portland Cements”, London.

5 British Standards Institution, BS812 (1975), “Methods of Testing Aggregates”, London.

6 British Standards Institution, BS1881: Part 108 (1983), "Method for Making Test Cubes from Fresh Concrete, London.

7 British Standards Institution, BS1881: Part 116 (1983), "Method for Determination of Compressive Strength of Concrete Cubes", London.

8 British Standards Institution, BS3148 (1980), "Test for Water for Making Concrete (including Notes on the Suitability of the Water)", London.

9 British Standards Institution, BS882 (1992), "Specifications for Aggregates from Natural Sources for Concrete", London.

10 British Standards Institution, BS1881: Part 115 (1983), "Specifications for Compression Testing Machines for Concretes", London.

11 Cramer, H.(1946), "Mathematical Methods, of Statistics", Princeton University Press, U.S.A.

12 Gottfried, B.S. (1991), "Programming with Basic", 3rd Edition, Tata McGraw – Hill Publishing Company Ltd, New Delhi, India.

13 Lydon, F.D. (1972) "Concrete Mix Design ", Applied Science Publishers Ltd; England, PP.1 – 134

14 Lea, F. M. (1970), "The chemistry of cement and concrete" Arnold 3rd Edition London, pp. 557- 591.

15 Majid, K.I. (1974), "Optimum Design of Structures", Butterworth & Co. Ltd, London, PP. 16.

16 MOT (1969), "Ministry of Transport – Specification for Road and Bridge Works", London, HMSO, PP.195.

17 Neville, A.M. (1996), "Properties of Concrete", 4th Edition, ELBS/Longman, Malaysia.

18 Obam, S. O. and Osadebe, N. N. (2005) "Optimisation of Strength of Light Weight Aggregate Concrete: A Case Study of Palm Kernel Shell". Journal of Science and Technology Research Nigeria, Vol. 4, pp. 29-32

19 Obam, S. O. and Osadebe, N. N. (2006) ," Optimisation of compressive strength of Rice Husk Ash Pozzolan Concrete". Journal of Scientific and Industrial Studies, Vol.1. No. 2, PP. 51-57.

20 Osadebe, N. N. and Obam, S. O. (2006). “ improvement in the properties of concrete by partial substitution of Ordinary Portland cement Rice Husk Ash” Proceedings of Annual Conference of IRDI Science and Technology Forum, University of Nigeria Nsukka, Nov. 22-23, Vol. 2, No. 2, PP. 87-91

21 Ndububa, E. E. and Osadebe N. N. (2007). “ An Optimisation of the flexural Strength of Fibre Cement Mixture Using Scheffe’s Simplex Lattice. NSE Technical Transaction, Vol. 42. No.1. PP. 1-17.

22 Osadebe, N. N. and Nwakonobi, T. U. (2007). “ Structural Characteristics of Laterized Concrete at Optimum Mix Proportion” Nigerian Journal of Technology, Vol. 26, No. 1, PP. 12-17.

23 Osadebe, N. N., Mbajiorgu, C. C. and Nwkonobi, T. U. (2007).” An Optimsation Model for Laterized Concrete Mix Proportioning in Building Constructions. Nigerian Journal of technology, Vol. 26, No. 1, PP. 37-46.

24 Okediya, P. R. (1988), “ performance of some Nigerian aggregates” Unpublished B.Eng. Thesis, University Of Nigeria, Nsukka.

25 Paradine, C. G. and Rivett, B. H. (1970), “ Statistical Methods for Technologists”, University Press limited, London, pp78.

26 Scheffe, H. (1958), “ Experiments with Mixtures”, Royal Statistical Society Journal, Ser. B, V.20, pp.344-360.

APPENDIX B

```
10 REM A QBASIC PROGRAM FOR THE COMPUTATION OF CONCRETE MIX
PROPORTIONS CORRESPONDING TO A DESIRED STRENGTH USING GRANITE
CHIPPINGS
20 REM VARIABLE USED:
30 REM A1,A2,A3,A4,P1,P2,P3,P4,Ymax,Yout,Yin
40 REM BEGIN MAIN PROGRAM
41 OPEN "GRANITE.las" FOR APPEND AS #1

50 LET COUNT = 0
60 CLS
70 GOSUB 100
71 CLOSE #1
80 END
90 REM END OF MAIN PROGRAM

100 REM PROCEDURE BEGIN
110 LET Ymax = 0
```

```
120 PRINT #1,
130 PRINT #1,
140 PRINT #1, " A COMPUTER MODEL FOR THE COMPUTATION OF CONCRETE MIX PROPORTIONS"
160 PRINT #1, " CORRESPONDING TO A DESIRED STRENGTH USING GRANITE CHIPPINGS"
170 PRINT #1,
180 INPUT " ENTER DESIRED STRENGTH"; Yin
185 PRINT #1, "ENTER DESIRED STRENGTH"; Yin "N/sq.mm"
186 PRINT #1,
187 PRINT #1,
190 GOSUB 400
200 FOR P1 = 0 TO 1 STEP .01
210 FOR P2 = 0 TO 1 - P1 STEP .01
220 FOR P3 = 0 TO 1 - P1 - P2 STEP .01
230 LET P4 = 1 - P1 - P2 - P3
240 LET Yout = 33.5 * P1 + 45.25 * P2 + 35 * P3 + 38 * P4 + 4.5 * P1 * P2 - 4 * P1 * P3 - 2 * P1 * P4 - 31.5 * P2 * P3 + 23.5 * P2 * P4 + 0 * P3 * P4
250 GOSUB 500

260 IF (ABS(Yin - Yout) <= .001) THEN 270 ELSE 290
270 LET COUNT = COUNT + 1
280 GOSUB 600
290 NEXT P3
291 NEXT P2
292 NEXT P1

295 PRINT #1,
300 IF (COUNT > 0) THEN GOTO 310 ELSE GOTO 340
310 PRINT #1, "THE  MAXIMUM VALUE OF STRENGTHPREDICTABLE BY THIS MODEL IS "; Ymax; "N / sq.mm."; ""
320 SLEEP (2)
330 GOTO 360
340 PRINT #1, "SORRY! DESIRED STRENGTH OUT OF RANGE OF MODEL."
350 SLEEP 2
360 RETURN
400 REM PROCEDURE PRINT HEADING
410 PRINT #1,
420 PRINT #1, TAB(1); "COUNT"; TAB(7); "P1"; TAB(13); "P2"; TAB(20); "P3"; TAB(29); "P4"; TAB(35); "Y"; TAB(41); "A1"; TAB(47); "A2"; TAB(54); "A3"; TAB(62); "A4"
430 PRINT #1,
440 RETURN

500 REM PROCEDURE CHECKMax
510 IF Ymax < Yout THEN Ymax = Yout ELSE Ymax = Ymax
520 RETURN

600 REM PROCEDURE OUTRESULTS
610 LET A1 = .5 * P1 + .55 * P2 + .6 * P3 + .65 * P4
620 LET A2 = P1 + P2 + P3 + P4
630 LET A3 = 2 * P1 + 1.5 * P2 + 2 * P3 + 4 * P4
```

ISSN 2229-5518

```
640 LET A4 = 4 * P1 + 3 * P2 + 5 * P3 + 8 * P4
650 PRINT #1, TAB(1); COUNT; USING "###.###"; P1; P2; P3; P4; Yout; A1; A2; A3; A4
660 RETURN
```

APPENDIX B1

A COMPUTER MODEL FOR THE COMPUTATION OF CONCRETE MIX PROPORTIONS CORRESPONDING TO A DESIRED STRENGTH USING GRANITE CHIPPINGS

ENTER DESIRED STRENGTH 35

COUNT	P1	P2	P3	P4	Y	A1	A2	A3	A4
1	0.000	0.000	1.000	0.000	35.000	0.600	1.000	2.000	5.000
2	0.000	0.540	0.390	0.070	34.999	0.577	1.000	1.870	4.130
3	0.010	0.240	0.550	0.200	35.000	0.597	1.000	2.280	5.110
4	0.040	0.540	0.370	0.050	35.000	0.572	1.000	1.830	4.030
5	0.050	0.330	0.470	0.150	35.000	0.586	1.000	2.135	4.740
6	0.070	0.020	0.740	0.170	34.999	0.601	1.000	2.330	5.400
7	0.080	0.090	0.610	0.220	35.000	0.599	1.000	2.395	5.400
8	0.080	0.100	0.600	0.220	35.001	0.598	1.000	2.390	5.380
9	0.150	0.420	0.370	0.060	35.001	0.567	1.000	1.910	4.190
10	0.190	0.280	0.410	0.120	35.001	0.573	1.000	2.100	4.610
11	0.210	0.050	0.490	0.250	35.000	0.589	1.000	2.475	5.440
12	0.230	0.110	0.450	0.210	34.999	0.582	1.000	2.365	5.180
13	0.260	0.430	0.310	0.000	34.999	0.553	1.000	1.785	3.880
14	0.280	0.060	0.410	0.250	34.999	0.581	1.000	2.470	5.350
15	0.310	0.130	0.380	0.180	35.000	0.572	1.000	2.295	4.970
16	0.310	0.180	0.370	0.140	35.000	0.567	1.000	2.190	4.750
17	0.330	0.030	0.340	0.300	35.000	0.581	1.000	2.585	5.510
18	0.340	0.010	0.300	0.350	35.000	0.583	1.000	2.695	5.690
19	0.350	0.130	0.350	0.170	34.999	0.567	1.000	2.275	4.900
20	0.360	0.350	0.290	0.000	35.000	0.547	1.000	1.825	3.940
21	0.370	0.060	0.320	0.250	34.999	0.572	1.000	2.470	5.260
22	0.380	0.080	0.320	0.220	35.000	0.569	1.000	2.400	5.120
23	0.400	0.010	0.220	0.370	35.000	0.578	1.000	2.735	5.690
24	0.400	0.030	0.260	0.310	35.000	0.574	1.000	2.605	5.470
25	0.410	0.300	0.280	0.010	35.001	0.545	1.000	1.870	4.020
26	0.420	0.170	0.300	0.110	35.000	0.555	1.000	2.135	4.570
27	0.460	0.090	0.260	0.190	35.000	0.559	1.000	2.335	4.930
28	0.480	0.100	0.250	0.170	35.000	0.556	1.000	2.290	4.830
29	0.520	0.000	0.040	0.440	34.999	0.570	1.000	2.880	5.800
30	0.520	0.030	0.140	0.310	35.000	0.562	1.000	2.605	5.350
31	0.530	0.110	0.220	0.140	35.000	0.549	1.000	2.225	4.670
32	0.540	0.050	0.160	0.250	35.000	0.556	1.000	2.475	5.110
33	0.650	0.090	0.130	0.130	35.000	0.537	1.000	2.215	4.560
34	0.680	0.030	0.010	0.280	34.999	0.545	1.000	2.545	5.100
35	0.680	0.160	0.150	0.010	35.000	0.525	1.000	1.940	4.030
36	0.770	0.060	0.020	0.150	34.999	0.528	1.000	2.270	4.560