Experimental Strength Model and Optimization of Solid Sandcrete Block with 4% Mound Soil Inclusion

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ABSTRACT

The paper looks into the model development and optimization of the compressive strength of solid sandcrete block with mound soil inclusion. The study applies the Scheffe's optimization approach to obtain a mathematical model of the form $f(x_{i1},x_{i2},x_{i3,},x_{i4})$, where x_i are proportions of the concrete components, viz: cement, mound soil, sand and water. Scheffe's experimental design techniques are followed to mould various solid block samples measuring 450mm x 225mm x 150mm and tested for 28 days strength. The task involved experimentation and design, applying the second order polynomial characterization process of the simplex lattice method. The model adequacy is checked using the control factors. Finally a software is prepared to handle the design computation process to take the desired property of the mix, and generate the optimal mix ratios.

Keywords: Sandcrete, Pseudo-component, Simplex-lattice, optimization, Ternary mixtures, mound. soil.

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1. INTRODUCTION

The construction of structures is a regular operation which heavily involves solid sandcrete blocks for load bearing or non-load bearing walls. The cost/stability of this material has been a major issue in the world of construction where cost is a major index.

This means that the locality and usability of the available materials directly impact on the achievable development of any area as well as the attainable level of technology in that area.

As it is, concrete is the main material of construction, and the ease or cost of its production accounts for the level of success in the area of environmental upgrading involving the construction of new roads, buildings, dams, water structures and the renovation of such structures [1]. To produce the concrete several primary components such as cement, sand, gravel and some admixtures are to be present in varying quantities and qualities. Unfortunately, the occurrence and availability of these components vary very randomly with location and hence the attendant problems of either excessive or scarce quantities of the different materials occurring in different areas. Where the scarcity of one component prevails exceedingly, the cost of the concrete production increases geometrically. Such problems obviate the need to seek alternative materials for partial or full replacement of the scarce component when it is possible to do so without losing the quality of the concrete.

1.1 Optimization

In order to maximize gains or outputs it is often necessary to keep inputs or investments at a minimum at the production level. The process involved in this planning activity of minimization and maximization is referred to as optimization, [2]. In the science of optimization, the desired property or quantity to be optimized is referred to as the objective function. The raw materials or quantities whose amount of combinations will produce this objective function are referred to as variables.

The variations of these variables produce different combinations and have different outputs. Often the space of variability of the variables is not universal as some conditions limit them. These conditions are called constraints. For example, money is a factor of production and is known to be limited in supply. The constraint at any time is the amount of money available to the entrepreneur at the time of investment.

Hence or otherwise, an optimization process is one that seeks for the maximum or minimum value and at the same time satisfying a number of other imposed requirements [3]. The function is called the objective function and the specified requirements are known as the constraints of the problem.

Everybody can make concrete but not everybody can make structural concrete. Structural concrete are made with specified materials for specified strength. Concrete is heterogeneous as it comprises sub-materials. Concrete is made up of fine aggregates, coarse aggregates, cement, water, and sometimes admixtures. [4] report that modern research in concrete seeks to provide greater understanding of its constituent materials and possibilities of improving its qualities. For instance, Portland cement has been partially replaced with ground granulated blast furnace slag (GGBS), a by–product of the steel industry that has valuable cementatious properties [5].

1.2 Concrete Mix optimization

The task of concrete mix optimization implies selecting the most suitable concrete aggregates from the data base [6]. Several methods have been applied. Examples are by [7], [8], and [9]. [10] proposed an approach which adopts the equilibrium mineral assemblage concept of geochemical thermodynamics as a basis for establishing mix proportions. [11] report that optimization of mix designs require detailed knowledge of concrete properties. Low water-cement ratios lead to increased strength but will negatively lead to an accelerated and higher shrinkage. Apart from the larger deformations, the acceleration of dehydration and strength gain will cause cracking at early ages.

1.3 Compressive Strength Modeling

Modeling means setting up some physical array of parts of a system, or a mathematical formulations governing the operation or functioning of some systems. Many factors of different effects occur simultaneously dependently or independently in systems. When they interplay they inter-affect one another at equal, direct, combined or partially combined rates, to generate varied natural constants in the form of coefficients and/or exponents. The challenging problem is to understand and asses these distinctive constants by which the interplaying factors underscore some unique natural phenomenon towards which their natures tend, in a single, double or multi phase systems.

For such assessment a model could be constructed for a proper observation of response from the interaction of the factors through controlled experimentation followed by schematic design where such simplex lattice approach of the type of Henry Scheffe [12] optimization theory could be employed. Also entirely different physical systems may correspond to the same mathematical model so that they can be solved by the same methods. This is an impressive demonstration of the unifying power of mathematics [13].

2. LITERATURE REVIEW

In the past ardent researchers have done works in the behavior of concrete under the influence of its components. With given proportions of aggregates the compressive strength of concrete depends primarily upon age, cement content, and the cement-water ratio [14]. Of all the desirable properties of hardened concrete such as the tensile, compressive, flexural, bond, shear strengths, etc., the compressive strength is the most convenient to measure and is used as the criterion for the overall quality of the hardened concrete [3].

Macrofaunal activities in soil are known to affect the nutrient and organic matter dynamics and structure of the soil. Such changes in soil properties have profound influences on the productivity of the ecosystem. Termites are the dominant macrofaunal group found in the tropical soils. Termites process considerable quantities of soil materials in their mound building activities. Such activities might have potential effects on carbon sequestration, nutrient cycling, and soil texture [15].

The result of a study on some characteristics of laterite-cement mix containing termite mound soil (50% by weight of laterite) as replacement of laterite are presented by [16. The study showed that laterite-mound soil mix stabilized with 6% cement could serve as a base course for roads for agricultural trafficking in rural areas where mound soils are abundant.

The inclusion of mound soil in mortar matrix resulted in a compressive strength value of up to 40.08N/mm2, and the addition of 5% of mound soil to a concrete mix of 1:2:4:0.56 (cement: sand: coarse aggregate: water) resulted in an increase of up to 20.35% in compressive strength [17].

Simplex is a structural representation (shape) of lines or planes joining assumed positions or points of the constituent materials (atoms) of a mixture, and they are equidistant from each other [18]. When studying the properties of a q-component mixture, which are dependent on the component ratio only the factor space is a regular (q-1)–simplex [19]. Simplex lattice designs are saturated, that is, the proportions used for each factor have m + 1 equally spaced levels from 0 to 1 (x_i = 0, 1/m, 2/m, … 1), and all possible combinations are derived from such values of the component concentrations, that is, all possible mixtures, with these proportions are used [19].

Sandcrete blocks are masonry units used in all types of masonry constructions such as interior and exterior load bearing walls, fire walls party walls, curtain walls, panel walls, partition, backings for other masonry, facing materials, fire proofing over structured steel members, piers, pilasters columns, retaining walls, chimneys, fireplaces, concrete floors, patio paving units, curbs and fences [20]. The block is defined by ASIM as hollow block when the cavity area exceeds 25% of the gross cross-sectional area, otherwise it belongs to the solid category [20]. [21] stated that methods of compaction during moulding has a marked effect on the strength of sandcrete blocks. Hence, it was found that blocks from factories achieving compaction by using wooden rammers had higher strength than those compacted by mechanical vibration, except when the vibration is carried out with additional surcharge.

3. BACKGROUND THEORY

This is a theory where a polynomial expression of any degrees, is used to characterize a simplex lattice mixture components. In the theory only a single phase mixture is covered. The theory lends path to a unifying equation model capable of taking varying mix component v(ariables to fix equal mixture properties. The optimization that follows selects the optimal ratio from the component ratios list that is automatedly generated. This theory is the adaptation to this work of formulation of response function for compressive strength of sandcrete block.

3.1 Simplex Lattice

Simplex is a structural representation (shape) of lines or planes joining assumed positions or points of the constituent materials (atoms) of a mixture [18], and they are equidistant from each other. Mathematically, a simplex lattice is a space of constituent variables of X_1, X_2, X_3, … X_i which obey these laws:

$$\left.\begin{array}{l} X_i \neq \text{negative} \\ 0 \leq x_i \leq 1 \\ \sum_{i=1} x_i = 1 \end{array}\right\} \quad \text{……………………………………………………………………} \quad (1)$$

That is, a lattice is an abstract space.

To achieve the desired strength of concrete, one of the essential factors lies on the adequate proportioning of ingredients needed to make the concrete. [12] developed a model whereby if the compressive strength desired is specified, possible combinations of needed ingredients to achieve the compressive strength can easily be predicted by the aid of computer, and if proportions are specified the compressive strength can easily be predicted.

3.2 Simplex Lattice Method

In designing experiment to attack mixture problems involving component property diagrams the property studied is assumed to be a continuous function of certain arguments and with a sufficient accuracy it can be approximated with a polynomial [19]. When investigating multi-components systems the use of experimental design methodologies substantially reduces the volume of an experimental effort. Further, this obviates the need for a special representation of complex surface, as the wanted properties can be derived from equations while the possibility to graphically interpret the result is retained.

As a rule the response surfaces in multi-component systems are very intricate. To describe such surfaces adequately, high degree polynomials are required, and hence a great many experimental trials. A polynomial of degree n in q variable has C^{n}_{q+n} coefficients. If a mixture has a total of q components and x_1 be the proportion of the i^{th} component in the mixture such that,

$x_i >= 0$ (i=1,2, ….q), ... (2)

then the sum of the component proportion is a whole unity i.e.

$X_1 + x_2 + x_3 + x_4 = 1$ or $\sum x_i - 1 = 0$ …. .. .. .. (3)

where i = 1, 2, …., q… Thus the factor space is a regular (q-1) dimensional simplex. In (q-1) dimensional simplex if q = 2, we have 2 points of connectivity. This gives a straight line simplex lattice. If q=3, we have a triangular simplex lattice and for q = 4, it is a tetrahedron simplex lattice, etc. Taking a whole factor space in the design we have a (q,m) simplex lattice whose properties are defined as follows:

i. The factor space has uniformly distributed points,
ii. Simplex lattice designs are saturated [19]. That is, the proportions used for each factor have m + 1 equally spaced levels from 0 to 1 (x_i = 0, 1/m, 2/m, … 1), and all possible combinations are derived from such values of the component concentrations, that is, all possible mixtures, with these proportions are used.

Hence, for the quadratic lattice (q,2), approximating the response surface with the second degree polynomials (m=2), the following levels of every factor must be used 0, ½ and 1; for the fourth order (m=4) polynomials, the levels are 0, 1/4, 2/4, 3/4 and 1, etc; [12], showed that the number of points in a (q,m) lattice is given by

$C_{q+m-1} = q(q+1) \ldots (q+m-1)/m!$ …………….. .. ..
(4)

3.2.1The (4,2) Lattice Model

The properties studied in the assumed polynomial are real-valued functions on the simplex and are termed responses. The mixture properties were described using polynomials assuming a polynomial function of degree m in the q-variable x_1, x_2 ……, x_q, subject to equation 3.1, and will be called a (q,m) polynomial having a general form:

$$\hat{Y} = b_0 + \sum_{i\leq 1\leq q} b_i X_i + \sum_{i\leq 1<j\leq q} b_{ij} X_i X_{ij} + \ldots + \sum_{i\leq 1<j<k\leq q} b_{ijk} + \sum b_{i1i2\ldots in} X_{i1} X_{i2} \ldots X_{in} \quad \ldots\ldots \quad .. \quad ..$$
(5)

$$\hat{Y} = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{24}X_2X_4 + b_{23}X_2X_3 + b_{34}X_3X_4$$

$$b_{11}X^2_{1} + b_{22}X^2_{2} + b_{33}X^2_{3} + b_{44}X^2_{4} \quad \ldots \quad \ldots \quad (6)$$

where b is a constant coefficient.

The relationship obtainable from Eqn 6) is subjected to the normalization condition of Eqn. (3) for a sum of independent variables. For a ternary mixture, the reduced second degree polynomial can be obtained as follows:
From Eqn. (3)

$X_1+X_2+X_3+X_4=1$ ……………………………………. (7)

i.e

$b_0 X_2 + b_0X_2 + b_0 X_3 + b_0X_4 = b_0$ …………………………….. (8)

Multiplying Eqn. (3.7) by X_1, X_2, x_3, x_4, in succession gives

$$X_1^2 = X_1 - X_1X_2 - X_1X_3 - X_1X_4$$
$$X_2^2 = X_2 - X_1X_2 - X_2X_3 - X_2X_4 \quad \ldots\ldots\ldots \quad (9)$$
$$X_3^2 = X_3 - X_1X_3 - X_2X_3 - X_3X_4$$
$$X_4^2 = X_4 - X_1X_4 - X_2X_4 - X_3X_4$$

Substituting Eqn. (8) into Eqn. (9), we obtain after necessary transformation that

$$\hat{Y} = (b_0 + b_1 + b_{11})X_1 + (b_0 + b_2 + b_{22})X_2 + (b_0 + b_3 + b_{33})X_3 + (b_0 + b_4 + b_{44})X_4 + (b_{12} - b_{11} - b_{22})X_1X_2 + (b_{13} - b_{11} - b_{33})X_1X_3 + (b_{14} - b_{11} - b_{44})X_1X_4 + (b_{23} - b_{22} - b_{33})X_2X_3 + (b_{24} - b_{22} - b_{44})X_2X_4 + (b_{34} - b_{33} - b_{44})X_3X_4 \quad \ldots \;..\; ...$$

(10)

If we denote

$\beta_i = b_0 + b_i + b_{ii}$

and $\beta_{ij} = b_{ij} - b_{ii} - b_{jj}$,

then we arrive at the reduced second degree polynomial in 6 variables:

$$\hat{Y} = \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_{12}X_1X_2 + \beta_{13}X_1X_3 + \beta_{14}X_1X_4 + \beta_{23}X_2X_{23} + \beta_{24}X_2X_4 + \beta_{34}X_3X_4 \quad . \quad . \quad (11)$$

Thus, the number of coefficients has reduced from 15 in Eqn 6 to 10 in Eqn (11). That is, the reduced second degree polynomial in q variables is

$$\hat{Y} = \sum \beta_iX_i + \sum\beta_{ij}X_i \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (12)$$

3.2.2 Construction of Experimental/Design Matrix

From the coordinates of points in the simplex lattice, we can obtain the design matrix. We recall that the principal coordinates of the lattice, only a component is 1 (Table 1) zero.

Table 1 Design matrix for (4,2) Lattice

N	X_1	X_2	X_3	X_4	Y_{exp}
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	½	1/2	0	0	Y_{12}
6	½	0	1/2	0	Y_{13}
7	1//2	0	0	1/2	Y_{14}
8	0	1/2	1/2	0	Y_{23}
9	0	1/2	0	1/2	Y_{24}
10	0	0	1/2	1/2	Y_{34}

Hence if we substitute in Eqn. (11), the coordinates of the first point (X_1=1, X_2=0, X_3=0,and X_4=0, Fig (1), we get that $Y_1 = \beta_1$.

And doing so in succession for the other three points in the tetrahedron, we obtain

$$Y_2= \beta_2,\ Y_3= \beta_3,\ Y_4= \beta_4 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (13)$$

The substitution of the coordinates of the fifth point yields

$$Y_{12} = ½\, X_1 + ½X_2 + ½X_1.{}^1/_2X_2$$
$$= ½\, \beta_1 + ½\, \beta_2 + {}^1/_4\, \beta_{12}$$

But as $\beta_i = Y_i$ then

$$Y_{12} = ½\, \beta_1 - ½\, \beta_2 - {}^1/_4\, \beta_{12}$$

Thus

$$\beta_{12} = 4\, Y_{12} - 2Y_1 - 2Y_2 \quad . \quad . \quad . \quad . \quad . \qquad (14)$$

And similarly,

$$\beta_{13} = 4\, Y_{13} - 2Y_1 - 2Y_2$$
$$\beta_{23} = 4\, Y_{23} - 2Y_2 - 2Y_3$$

etc.

Or generalizing,

$$\beta_i = Y_i \text{and } \beta_{ij} = 4\, Y_{ij} - 2Y_i - 2Y_j \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (15)$$

which are the coefficients of the reduced second degree polynomial for a q-component mixture, since the four points defining the coefficients β_{ij} lie on the edge. The subscripts of the mixture property symbols indicate the relative content of each component X_i alone and the property of the mixture is denoted by Y_i.

3.2.3 Actual and Pseudo Components

The requirements of the simplex that

$$\sum_{X=1} Xi = 1$$

makes it impossible to use the normal mix ratios such as 1:3, 1:5, etc, at a given water/cement ratio. Hence a transformation of the actual components (ingredient proportions) to meet the above criterion is unavoidable. Such transformed ratios say $X_1^{(i)}$, $X_2^{(i)}$, and $X_3^{(i)}$ and $X_4^{(i)}$ for the ith experimental points are called pseudo components. Since X_1, X_2 and X_3 are subject to $\sum Xi = 1$, the transformation of cement:mound soil:sand:water at say 0.30 water/cement ratio cannot easily be computed because X_1, X_2, X_3 and X_4 are in pseudo expressions $X_1^{(i)}$, $X_2^{(i)}$, $X_3^{(i)}$ and X_4. For the ith experimental point, the transformation computations are to be done.

The arbitrary vertices chosen on the triangle are A_1(1:0.77:17.18:0.57), A_2(1:0.72:16.27:0.55) A_3(1:0.69:15.31:0.48), and A_4(1:0.75:16.75:0.58), based on experience and earlier research reports.

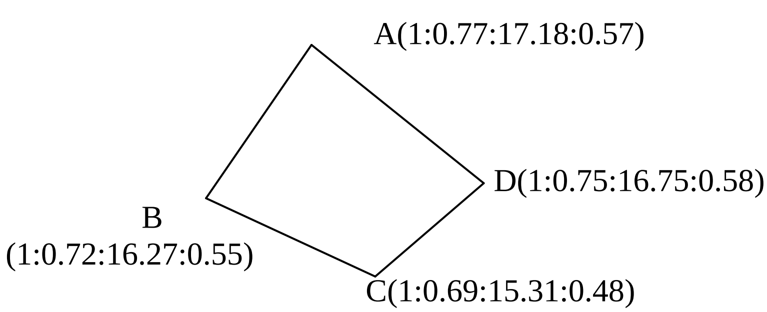

Fig 1 Tetrahedral Simplex

3.2.4 Transformation Matrix

If Z denotes the actual matrix of the i^{th} experimental points, observing from Table 2 (points 1 to 3),

$$BZ = X = 1 \qquad (16)$$

where B is the transformed matrix.

Therefore, $B = I.Z^{-1}$

Or $B = Z^{-1}$ . . . . (17)

For instance, for the chosen ratios A_1, A_2 and A_3 (fig. 1),

$$Z = \begin{pmatrix} 1 & 0.77 & 17.18 & 0.57 \\ 1 & 0.72 & 16.27 & 0.55 \\ 1 & 0.69 & 15.31 & 0.48 \\ 1 & 0.75 & 16.75 & 0.58 \end{pmatrix} \qquad (18)$$

From Eqn 3.17,

$$B = Z^{-1}$$

$$Z^{-1} = \begin{pmatrix} -14.45 & 2.20 & 6.59 & 6.66 \\ -8.51 & 101.77 & 31.38 & 78.90 \\ 2.13 & 4.61 & -1.60 & -5.14 \\ -25.53 & 5.32 & -5.85 & 36.70 \end{pmatrix}$$

Hence,

$$B\,Z^{-1} = Z.\,Z^{-1}$$

$$= \begin{pmatrix} 1 & 0.77 & 17.18 & 0.57 \\ 1 & 0.72 & 16.27 & 0.55 \\ 1 & 0.69 & 15.31 & 0.48 \\ 1 & 0.75 & 16.75 & 0.58 \end{pmatrix} \begin{pmatrix} -14.45 & 2.20 & 6.59 & 6.66 \\ -8.51 & 101.77 & 31.38 & 78.90 \\ 2.13 & 4.61 & -1.60 & -5.14 \\ -25.53 & 5.32 & -5.85 & 36.70 \end{pmatrix}$$

$$= \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Thus, for actual component Z, the pseudo component X is given by

$$X\begin{pmatrix} X_1^{(i)} \\ X_2^{(i)} \\ X_3^{(i)} \\ X_4^{(i)} \end{pmatrix} = B\begin{pmatrix} -14.45 & 2.20 & 6.59 & 6.66 \\ -8.51 & 101.77 & 31.38 & 78.90 \\ 2.13 & 4.61 & -1.60 & -5.14 \\ -25.53 & 5.32 & -5.85 & 36.70 \end{pmatrix} Z\begin{pmatrix} Z_1^{(i)} \\ Z_2^{(i)} \\ Z_3^{(i)} \\ Z_4^{(i)} \end{pmatrix}$$

which gives the X_i(i=1,2,3) values in Table 3.2.

The inverse transformation from pseudo component to actual component is expressed as

$$AX = Z \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (19)$$

where A = inverse matrix

$$A = Z X^{-1}.$$

From Eqn 3.16, X = BZ, therefore,

$$A = Z.(BZ)^{-1}$$
$$A = Z.Z^{-1}B^{-1}$$
$$A = IB^{-1}$$
$$= B^{-1}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (20)$$

This implies that for any pseudo component X, the actual component is given by

$$Z\begin{pmatrix} Z_1^{(i)} \\ Z_2^{(i)} \\ Z_3^{(i)} \\ Z_4^{(i)} \end{pmatrix} = B\begin{pmatrix} 1 & 0.77 & 17.18 & 0.57 \\ 1 & 0.72 & 16.27 & 0.55 \\ 1 & 0.69 & 15.31 & 0.48 \\ 1 & 0.75 & 16.75 & 0.58 \end{pmatrix} X\begin{pmatrix} X_1^{(i)} \\ X_2^{(i)} \\ X_3^{(i)} \\ X_4^{(i)} \end{pmatrix} \quad . \quad . \quad . \quad . \quad . \qquad (21)$$

Eqn (21) is used to determine the actual components from points 5 to 10 , and the control values from points 11 to 13 (Table 2).

Table 2 Values for Experiment

N	X_1	X_2	X_3	X_4	RESPONSE	Z_1	Z_2	Z_3	Z_4
1	1	0	0	0	Y_1	**1.00**	0.77	17.18	0.57
2	0	1	0	0	Y_2	1.00	0.72	16.27	0.55
3	0	0	1	0	Y_3	1.00	0.69	15.31	0.48
4	0	0	0	1	Y_4	1.00	0.75	16.75	0.58
5	½	1/2	0	0	Y_{12}	1.00	0.75	16.73	0.56
6	½	0	1/2	0	Y_{13}	1.00	0.73	15.75	0.53
7	1//2	0	0	1/2	Y_{14}	1.00	0.76	16.72	0.58
8	0	1/2	1/2	0	Y_{23}	1.00	0.71	14.92	0.52
9	0	1/2	0	1/2	Y_{24}	1.00	0.74	15.89	0.57
10	0	0	1/2	1/2	Y_{34}	1.00	0.72	15.86	0.53
Control points									
11	0.25	0.25	0.25	0.25	Y_{1234}	1.00	0.73	15.82	0.55
12	0.5	0.25	0.25	0	Y_{1123}	1.00	0.74	15.76	0.54
13	0.25	0.5	0	0.25	Y_{1224}	1.00	0.74	15.83	0.56

3.2.5 Use of Values in Experiment

During the laboratory experiment, the actual components ratios were used to measure out the appropriate proportions of the ingredients: cement, mound soil, sand and water for casting the samples. The values obtained are presented in Tables in section 5.

3.3 Adequacy of Tests

This is carried out by testing the fit of a second degree polynomial [19] After the coefficients of the regression equation has been derived, the statistical analysis is considered necessary, that is, the equation should be tested for goodness of fit, and the equation and surface values bound into the confidence intervals. In experimentation following simplex-lattice designs there are no degrees of freedom to test the equation for adequacy, so, the experiments are run at additional so-called control points.

The number of control points and their coordinates are conditioned by the problem formulation and experiment nature. Besides, the control points are sought so as to improve the model in case of inadequacy. The accuracy of response prediction is dissimilar at different points of the simplex. The variance of the predicted response, S_Y^2, is obtained from the error accumulation law. To illustrate this by the second degree polynomial for a ternary mixture, the following points are assumed:

X_i can be observed without errors [19].

The replication variance, S_Y^2, is similar at all design points, and

Response values are the average of n_i and n_{ij} replicate observations at appropriate points of the simplex

Then the variance $S_{\hat{Y}i}$ and $S_{\hat{Y}ij}$ will be

$$(S_{\hat{Y}}^2)_i = S_Y^2/n_i \quad (22)$$

$$(S_{\hat{Y}}^2)_{ij} = S_Y^2/n_{ij} \quad (23)$$

In the reduced polynomial,

$$\hat{Y} = \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_{12}X_1X_2 + \beta_{13}X_1X_3 + \beta_{14}X_1X_4 + \beta_{23}X_2X_{23} + \beta_{24}X_2X_4 + \beta_{34}X_3X_4 \quad (24)$$

If we replace coefficients by their expressions in terms of responses,

$\beta_i = Y_i$ and $\beta_{ij} = 4Y_{ij} - 2Y_i - 2Y_j$

$$\hat{Y} = Y_1X_1 + Y_2X_2 + Y_3X_3 ++ Y_4X_4 + (4Y_{12} - 2Y_1 - 2Y_2)X_1X_2 + (4Y_{13} - 2Y_1 - 2Y_3)X_1X_3 + (4Y_{14} - 2Y_1 - 2Y_4)X_1X_4 + (4Y_{23} - 2Y_2 - 2Y_3)X_2X_3 + (4Y_{24} - 2Y_2 - 2Y_4)X_2X_4 + (4Y_{34} - 2Y_3 - 2Y_4)X_3X_4$$

$$= Y_1(X_1 - 2X_1X_2 - 2X_1X_3 - 2X_1X_4) + Y_2(X_2 - 2X_1X_2 - 2X_2X_3 - 2X_2X_4) + Y_3(X_3 - 2X_1X_3 + 2X_2X_3 + 2X_3X_4) + Y_4(X_4 - 2X_1X_4 + 2X_2X_4 + 2X_3X_4) + 4Y_{12}X_1X_2 + 4Y_{13}X_1X_3 + 4Y_{14}X_1X_4 +$$

$4Y_{23}X_2X_3 + 4Y_{24}X_2X_4 + 4Y_{34}X_3X_4$ . . . . (25)

Using the condition $X_1+X_2+X_3+X_4=1$, we transform the coefficients at Y_i

$$X_1 - 2X_1X_2 - 2X_1X_3 - 2X_1X_4 = X_1 - 2X_1(X_2 + X_3 + X_4)$$

$$= X_1 - 2X_1(1 - X_1) = X_1(2X_1 - 1) \text{ and so on.} \quad (26)$$

Thus

$$\hat{Y} = X_1(2X_1 - 1)Y_1 + X_2(2X_2 - 1)Y_2 + X_3(2X_3 - 1)Y_3 + X_4(2X_4 - 1)Y_4 + 4Y_{12}X_1X_2 + 4Y_{13}X_1X_3 + 4Y_{14}X_1X_4 + 4Y_{23}X_2X_3 + 4Y_{24}X_2X_4 + 4Y_{34}X_3X_4 \quad (27)$$

Introducing the designation

$$a_i = X_i(2X_1 - 1) \text{ and } a_{ij} = 4X_iX_j \quad (27)$$

and using Eqns (3.22) and (3.230) give the expression for the variance S_Y^2.

$$S_{\hat{Y}}^2 = S_Y^2 \left(\sum_{1\le i\le q} a_{ii}/n_i + \sum_{1\le i<j\le q} a_{jj}/n_{ij}\right) \quad (28)$$

If the number of replicate observations at all the points of the design are equal, i.e. $n_i=n_{ij}= n$, then all the relations for $S_{\hat{Y}}^2$ will take the form

$$S_{\hat{Y}}^2 = S_Y^2\xi/n \quad (29)$$

where, for the second degree polynomial,

$$\xi = \sum_{1\le i\le q} a_i^2 + \sum_{1\le i<j\le q} a_{ij}^2 \quad (30)$$

As in Eqn (30), ξ is only dependent on the mixture composition. Given the replication Variance and the number of parallel observations n, the error for the predicted values of the response is readily calculated at any point of the composition-property diagram using an appropriate value of ξ taken from the curve.

Adequacy is tested at each control point, for which purpose the statistic is built:

$$t = \Delta_Y/(S_{\hat{Y}}^2 + S_Y^2) = \Delta_Y n^{1/2} /(S_Y(1 + \xi)^{1/2} \quad (31)$$

where $\Delta_Y = Y_{exp} - Y_{theory}$ . . . . (32)

and n = number of parallel observations at every point.

The t-statistic has the student distribution, and it is compared with the tabulated value of $t_{\alpha/L}(V)$ at a level of significance α, where L = the number of control points, and V = the number for the degrees of freedom for the replication variance.

The null hypothesis is that the equation is adequate is accepted if $t_{cal} < t_{Table}$ for all the control points.

The confidence interval for the response value is

$$\hat{Y} - \Delta \leq Y \leq \hat{Y} + \Delta \qquad (33)$$

$$\Delta = t_{\alpha/L,k} S_{\hat{Y}} \qquad (34)$$

where k is the number of polynomial coefficients determined.

Using Eqn (29) in Eqn (34)

$$\Delta = t_{\alpha/L,k} S_Y(\xi/n)^{1/2} \qquad (35)$$

METHODOLOGY

4. Introduction

To be a good structural material, the material should be homogeneous and isotropic. The Portland cement, sandcrete or concrete are none of these, nevertheless they are popular construction materials [22].The necessary materials required in the manufacture of the sandcrete in the study are cement, mound soil, sand and water.

4.1 Materials

The sand material were collected at the Iyioku River sand basin in Enugu State and conformed to BS 882and belongs to zone 2 of of the ASHTO classification. The mound soil were collected at Adjoining bushes around Enugu State.

The water for use is pure drinking water which is free from any contamination i.e. nil Chloride content, pH =6.9, and Dissolved Solids < 2000ppm. Ordinary Portland cement is the hydraulic binder used in this project and sourced from the Dangote Cement Factory, and assumed to comply with the Standard Institute of Nigeria (NIS) 1974, and kept in an air-tight bag.

4.2 Preparation of Samples

The sourced materials for the experiment were transferred to the laboratory. The pseudo components of the mixes were designed following the background theory from where the actual variables were developed. The component materials were mixed at ambient temperature according to the specified proportions of the actual components generated in Table 3.2. In all, two solid blocks of 450mm x225 x150mm for each of ten experimental points and three control points were cast for the compressive strength test, cured for 28 days after setting and hardening.

4.3 Strength Test

After 28 day of curing, the blocks were crushed to determine the sandcrete block strength, using the compressive testing machine to the requirements of [23].

5 RESULT AND ANALYSIS

5.1 Determination of Replication Error and Variance of Response

To raise the experimental design equation models by the lattice theory approach, two replicate experimental observations were conducted for each of the design and control points.

Hence we have below, the table of the results (Tables 3) which contain the results of two repetitions each of the 10 design points plus the three Control Points of the (4,2) simplex lattice, and show the mean and variance values per test of the observed response, using the following mean and variance equations below:

$$\ddot{Y} = \sum_i (Y_r)/r \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (36)$$

where Ÿ is the mean of the response values and r =1,2.

$$S_Y^2 = \sum_i^n [(Y_i - \ddot{Y}_i)^2]/(n-1) \quad . \quad . \quad . \quad . \quad . \quad . \qquad (37)$$

where n = 13.

Table 3 Result of the Replication Variance of the Compressive Strength Response for **450x225x150 mm Block**

Experiment No (n)	**Repetition**	**Response Y (N/mm²)**	**Response Symbol**	$\sum Y_r$	$\ddot{Y}_r$	$\sum(Y_r - \ddot{Y}_r)^2$	S_i^2
1	1A 1B	3.03 2.50	Y_1	5.53	2.77	0.14	0.01
2	2A 2B	2.01 4.20	Y_2	6.21	3.11	2.40	0.20
3	3A 3B	3.01 3.20	Y_3	6.21	3.11	0.02	0.00
4	4A 4B	3.10 3.40	Y_4	6.50	3.25	0.40	0.00
5	5A 5B	3.21 3.85	Y_{12}	7.06	3.53	0.20	0.02
6	6A 6B	2.72 2.80	Y_{13}	5.52	2.76	0.00	0.00
7	7A 7B	2.22 2.45	Y_{14}	4.67	2.84	0.30	0.02
8	8A 8B	2.66 2.57	Y_{23}	5.23	2.62	0.00	0.00

9	9A 9B	3.45 3.34	Y_{24}	5.79	2.90	0.62	0.05
10	10A 10B	3.61 2.92	Y_{34}				
Control Points							
11	11A 11B	3.92 3.15	C_1	6.47	3.24	0.01	0.00
12	11A 11B	3.02 3.50	C_2	6.52	3.26	0.127	0.01
13	13A 13B	2.88 3.21	C_3	6.09	3.05	0.24	0.02
							∑0.35

Replication Variance

$S_{Yc}^2 = (\sum S_i^2)/(n-1) = 0.35$

Replication Error

$S_{Yc} = (S_{Yc}^2)^{1/2} = 0.35^{1/2} = 0.59$

5.1.2.4 Determination of Regression Equation for the Compressive Strength

From Eqns (15) and Table 3 the coefficients of the reduced second degree polynomial is determined as follows:

$\beta_1 = 2.77$

$\beta_2 = 3.11$

$\beta_3 = 3.10$

$\beta_4 = 3.25$

$\beta_{12} = 4(3.53) - 2(2.77) - 2(3.33) = 2.38$

$\beta_{13} = 4(2.76) - 2(2.77) - 2(3.11) = -0.70$

$\beta_{14} = 4(2.84) - 2(2.77) - 2(3.25) = -0.69$

$\beta_{23} = 4(2.62) - 2(3.11) - 2(3.11) = -1.93$

$\beta_{24} = 4(2.90) - 2(3.11) - 2(3.11) = -1.96$

$\beta_{12} = 4(3.27) - 2(3.11) - 2(3.25) = 0.35$

Thus, from Eqn (11),

$$\hat{Y} = 2.77X_1 + 3.11X_2 + 3.10X_3 + 3.25X_4 + 2.38X_1X_2 - 0.70X_1X_3 - 0.69X_1X_4 - 1.96X_2X_3 - 1.13X_2X_4 + 0.35X_3X_4 \quad (38)$$

Eqn (38) is the mathematical model of the compressive strength of the hollow sandcrete block based on the 28-day strength.

5.1.2.5 Test of Adequacy of the Compressive strength Model

Eqn (38), the equation model, will be tested for adequacy against the controlled experimental results.

We recall our statistical hypothesis as follows:

1. Null Hypothesis (H_0): There is no significant difference between the experimental values and the theoretical expected results of the compressive strength.
2. Alternative Hypothesis (H_1): There is a significant difference between the experimental values and the theoretical expected results of the compressive strength.

5.1.2.6 t-Test for the Compressive strength Model

If we substitute for X_i in Eqn (38) from Table 1, the theoretical predictions of the response ($\hat{Y}$) can be obtained. These values can be compared with the experimental results (Table 3). For the t-test (Table 4), a, ξ, t and Δ_y are evaluated using Eqns (27), (30), (31) and (32) respectively.

Table 4 t-Test for the Test Control Points

N	CN	I	J	a_i	a_{ij}	a_i^2	a_{ij}^2	ξ	$\ddot{Y}$	$\hat{Y}_a$	Δ_y	t
1	C_1	1	2	-0.125	0.250	0.016	0.063	0.469	3.24	2.95	0.95	0.57
		1	3	-0.125	0.250	0.016	0.063					
		1	4	-0.125	0.250	0.016	0.063					
		2	3	-	0.250	0.016	0.063					

				0.125								
		2	4	-0.125	0.250	0.016	0.063					
		3	4	-0.125	0.250	0.016	0.063					
						0.094	0.375					
2	C_2	1	2	0.000	0.500	0.000	0.250					
		1	3	0.000	0.500	0.000	0.250					
		1	4	0.000	0.000	0.000	0.000					
		2	3	0.000	0.250	0.000	0.063		3.26	3.02	0.24	0.46
		2	4	0.000	0.000	0.000	0.000					
		3	4	0.000	0.000	0.000	0.000					
						0.000	0.563	0.563				
3	C_3	1	2	-0.125	0.500	0.016	0.250					
		1	3	-0.125	0.000	0.016	0.000					
		1	4	-0.125	0.250	0.016	0.063					
		2	3	-0.125	0.000	0.016	0.000		3.05	3.17	-0.12.	-0.23
		2	4	-0.125	0.500	0.016	0.250					
		3	4	-0.125	0.000	0.016	0.000					
						0.094	0.563	0.656				

Significance level $\alpha = 0.05$,

i.e. $t_{\alpha/L}(V_c) = t_{0.05/3}(13)$, where L=number of control point.

From the Student's-T Table, the tabulated value of $t_{0.05/3}(13)$ is found to be 3.01 which is greater than any of the calculated t-values in Table 4. Hence we can accept the Null Hypothesis.

From Eqn 3.35, with k= 3 and $t_{\alpha/k,v} = t_{0.05/k}(13) = 3.01$,

Δ = 2.14 for C_{1234}, 2.21 for $C_{1124\ =0.26}$, and 2.28 for C_{1224},

which satisfies the confidence interval equation of

Eqn (33) when viewed against the response values in Table 4.

5.2 Computer Program

The computer program is developed for the model). In the program any desired Compressive Strength can be specified as an input and the computer processes and prints out possible combinations of mixes that match the property, to the following tolerance:

Compressive Strength - 0.00005 N/mm^2,

Interestingly, should there be no matching combination, the computer informs the user of this. It also checks the maximum value obtainable with the model.

5.2.1 Choosing a Combination

It can be observed that the strength of 3.20 N/sq mm yielded 5 combinations. To accept any particular proportions depends on the factors such as workability, cost and honeycombing of the resultant lateritic concrete.

6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Henry Scheffe’s simplex design was applied successfully to prove that the modulus of of lateritic concrete is a function of the proportion of the ingredients (cement, mound oil, and and water), but not the quantities of the materials.

The maximum compressive strength obtainable with the compressive strength model is 2.99 N/sq mm. See the computer run outs which show all the possible lateritic concrete mix options for the desired modulus property, and the choice of any of the mixes is the user’s.

One can also draw the conclusion that the maximum values achievable, within the limits of experimental errors, is above that obtainable using only sand. This is due to the added pure quality effect of mound soil.

It can be observed that the task of selecting a particular mix proportion out of many options is not easy, if workability and other demands of the resulting lateritic concrete have to be satisfied. This is an important area for further research work.

The project work is a great advancement in the search for the applicability of mound soil in concrete mortar production in regions where mound soil is ubiquitous.

6.2 Recommendations

From the foregoing study, the following could be recommended:
i) The model can be used for the optimization of the strength of concrete made from cement, mound oil, sand and water.
ii) Mound soil admixture can be used to improve the strength sandcrete block.
iii) More research work need to be done in order to match the computer recommended mixes with the workability of the resulting concrete.
iii) The accuracy of the model can be improved by taking higher order polynomials of the simplex.

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APPENDIX

```
    'QBASIC BASIC PROGRAM THAT OPTIMIZES THE
PROPORTIONS OF SANDCRETE MIXES
    'USING THE SCHEFFE'S MODEL FOR CONCRETE
COMPRESSIVE STRENGTH
    CLS
    C1$ = "(ONUAMAH.HP) RESULT OUTPUT ": C2$ =
"A COMPUTER PROGRAM "
    C3$ = "ON THE OPTIMIZATION OF A 4-
COMPONENT SANDCRETE MIX"
    PRINT C2$ + C1$ + C3$
    PRINT
    'VARIABLES USED ARE
    'X1, X2, X3,X4, Z1, Z2, Z3,Z4, Z$,YT, YTMAX, DS

    'INPUT "ARE MIX RATIOS KNOWN AND THE
ATTAINABLE STRENGTH NEEDED?,CHOOSE Y=
YES OR N=NO"; OPTION$
    IF OPTION$ = "Y" THEN
      INPUT "X1="; X1
      INPUT "X2="; X2
      INPUT "X3="; X3
      INPUT "X4="; X4
      X = X1 + X2 + X3 + X4
      X1 = X1 / X: X2 = X2 / X: X3 = X3 / X: X4 = X4 / X
      GOTO 25
    ELSE
      GOTO 20
    END IF

    'INITIALISE I AND YTMAX

20 I = 0: YTMAX = 0


     FOR MX1 = 0 TO 1 STEP .01
       FOR MX2 = 0 TO 1 - MX1 STEP .01
         FOR MX3 = 0 TO 1 - MX1 - MX2 STEP .01
           MX4 = 1 - MX1 - MX2 - MX3
           YTM = 2.77 * MX1 + 3.11 * MX2 + 3.1 * MX3 +
3.25 * MX4 + 2.38 * MX1 * MX2 - .7 * MX1 * MX3 - .69
* MX1 * MX4 - 1.96 * MX2 * MX3 - 1.13 * MX2 * MX4
+ .35 * MX3 * MX4
```

```
          IF YTM >= YTMAX THEN YTMAX = YTM
        NEXT MX3
      NEXT MX2
    NEXT MX1
   INPUT "ENTER DESIRED STRENGTH, DS = "; DS

   'PRINT OUTPUT HEADING
   PRINT
25  PRINT TAB(1); "No"; TAB(10); "X1"; TAB(18);
"X2"; TAB(26); "X3"; TAB(34); "X4"; TAB(40);
"YTHEORY"; TAB(50); "Z1"; TAB(58); "Z2"; TAB(66);
"Z3"; TAB(74); "Z4"
   IF OPTION$ = "Y" THEN 30
   PRINT
   'COMPUTE THEORETICAL STRENGTH, YT
    FOR X1 = 0 TO 1 STEP .01
      FOR X2 = 0 TO 1 - X1 STEP .01
        FOR X3 = 0 TO 1 - X1 - X2 STEP .01
          X4 = 1 - X1 - X2 - X3
30        YT = 2.77 * X1 + 3.11 * X2 + 3.1 * X3 + 3.25 * X4
- 2.38 * X1 * X2 - .7 * X1 * X3 - .69 * X1 * X4 - 1.96 * X2
* X3 - 1.13 * X2 * X4 + .35 * X3 * X4

          IF OPTION$ = "Y" THEN 40
          IF ABS(YT - DS) <= .00005 THEN
          'PRINT MIX PROPORTION RESULTS
          Z1 = X1 + X2 + X3 + X4: Z2 = .77 * X1 + .72 * X2
+ .69 * X3 + .75 * X4: Z3 = 17.18 * X1 + 16.27 * X2 +
15.31 * X3 + 16.75 * X4: Z4 = .57 * X1 + .55 * X2 + .48 *
X3 + .58 * X4
40        I = I + 1
          PRINT TAB(1); I; USING "##.###"; TAB(7); X1;
TAB(15); X2; TAB(23); X3; TAB(32); X4; TAB(40); YT;
TAB(48); Z1; TAB(56); Z2; TAB(64); Z3; TAB(72); Z4
          PRINT
          PRINT
          IF OPTION$ = "Y" THEN 540
          IF (X1 = 1) THEN 550
        ELSE
          IF (X1 < 1) THEN GOTO 150
        END IF


150       NEXT X3
      NEXT X2
    NEXT X1
```

```
   IF I > 0 THEN 550
   PRINT
   PRINT "SORRY, THE DESIRED STRENGTH IS OUT
OF RANGE OF MODEL"
   GOTO 600
540 PRINT TAB(5); "THE ATTAINABLE STRENGTH IS
"; YT; "N/mm2"
   GOTO 600
550 PRINT TAB(5); "THE MAXIMUM VALUE
PREDICTABLE BY THE MODEL IS "; YTMAX; "N / Sq
mm "
600 END
```

```
  A COMPUTER PROGRAM
  (ONUAMAH.HP) RESULT OUTPUT
  ON THE OPTIMIZATION OF A 4-
  COMPONE
  NT SANDCRETE MIX

  ENTER DESIRED STRENGTH, DS = ?
  3.2

  No      X1      X2      X3      X4
  YTHEORY   Z1      Z2      Z3      Z4

   1    0.150   0.750   0.060    0.040
  3.200   1.000   0.727  16.368   0.550


   2    0.230   0.570   0.020    0.180
  3.200   1.000   0.736  16.547   0.559


   3    0.380   0.390   0.010    0.220
  3.200   1.000   0.745  16.712   0.563


   4    0.460   0.360   0.100    0.080
  3.200   1.000   0.742  16.631   0.555


   5    0.730   0.220   0.040    0.010
  3.200   1.000   0.756  16.901   0.562

    THE MAXIMUM VALUE
  PREDICTABLE BY THE MODEL IS
```

3.547137 N / Sq mm

Press any key to continue
A COMPUTER PROGRAM
(ONUAMAH.HP) RESULT OUTPUT
ON THE OPTIMIZATION OF A 4-
COMPONE
NT SANDCRETE MIX

ENTER DESIRED STRENGTH, DS = ?
3.6

No X1 X2 X3 X4
YTHEORY Z1 Z2 Z3 Z4

SORRY, THE DESIRED STRENGTH
IS OUT OF RANGE OF MODEL

Press any key to continue
A COMPUTER PROGRAM
(ONUAMAH.HP) RESULT OUTPUT
ON THE OPTIMIZATION OF A 4-
COMPONE
NT SANDCRETE MIX

ARE MIX RATIOS KNOWN AND
THE ATTAINABLE STRENGTH
NEEDED?,CHOOSE Y= YES OR
N=NO?
Y
X1=? 1
X2=? .77
X3=? 17.18
X4=? .57
No X1 X2 X3 X4
YTHEORY Z1 Z2 Z3 Z4
1 0.051 0.039 0.880 0.029
3.000 0.000 0.000 0.000 0.000

THE ATTAINABLE STRENGTH IS
2.999731 N/mm2

Press any key to continue