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Flexural Strength Models for Normal Laterised and High Strength Laterised Concretes at Optimum Mix Proportions

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ABSTRACT: This study develops mathematical models for obtaining optimum flexural strengths of normal laterised(NLC) and high strength laterised concretes (HSLC). The models can be expressly used to evaluate the indirect tensile strengths of both types of concretes without going through the traditional methods of mix design. Optimum mixing ratios and optimum flexural strengths predicted are also supplied by the models. The three point load method was adopted for testing for the flexural strengths. Laterite, has been widely used to partially or wholly replace sand in concrete with resultant low strengths. The production of HSLC using superplasticiser was achieved in this study. Scheffe's simplex theory based on (5, 2) simplex lattice (for NLC) and (6, 2) simplex lattice (for HSLC) was used to optimize the mix proportions for the flexural strengths of each respective laterised concrete. Conplast SP 430 superplasticiser (a sulphonated naphthalene formaldehyde admixture) was used to obtain the high strength laterised concrete. Mathematical models were developed for the mix proportioning of the laterised concretes and all strengths predicted by the models agreed with their corresponding experimentally observed values. Using the model, the optimum flexural strength and the corresponding mix proportions for the targeted strength of laterised concrete could be easily evaluated with the help of the written Q-BASIC computer programme.

KEYWORDS: Laterised concrete, simplex lattice, Flexural strength, Optimisation, Superplasticise, Q-Basic.

1.0 INTRODUCTION

Laterised concrete has found immense use of recent for the construction of low-cost buildings. The use of this material is known to reduce the cost of structures due its abundance within the tropics and sub tropics (Udoeyo et al, 2006). Studies on laterite usage as concrete aggregate have shown very encouraging results (Orangun 1981). Although used, its usage has hitherto been limited to structures of lower strengths. Moreover, the traditional mix design methods with its cumbersome nature are still utilized in achieving its strengths. The need to produce laterised concretes of higher strengths and also eliminate the errors and cumbersome nature of the traditional mix design methods informed the will to embark on this study in order to develop mathematical optimization models for accurate proportioning to achieve optimum flexural strengths. The flexural strength of concrete is a function of the proportions of the ingredients that make up the concrete. The task of accurate proportioning still remains a problem to concreters and eliminating this problem is the focus of this study.

The flexural strength (f_s), which tests the ability of unreinforced concrete beam or slab to withstand failure, is optimized in this study. It is evaluated using:

2.0 LITERATURE REVIEW

2.1 Concrete Strength Prediction Models: Researchers have attempted to provide optimization models for various types of concretes and most of the models concentrate on optimizing the strengths of the conventional sand concretes.

Ortiz, *et al* (2006) provided optimization models for ready-mix concrete for hot weather climates with a view to developing industrial applications that will optimize the manufacture of ready-mix concrete in adverse weather. Their project aimed at identifying the influence that each component had on the resulting effect of temperature on the workability and compressive strength of concrete. They simulated variable thermal cycles (temperature and relative humidity) as a function of time in order to ascertain and quantify the influence of temperature on the concrete's compressive strength.

Maruyama, *et al* (1992) also presented a method of optimizing concrete mixture proportions and stated that since various qualities are required of concrete, proportioning problem should be categorized as multi-criteria optimization problem. They dealt with the notion of Pareto optimality to derive the optimum solution and applied it to a genetic algorithm. Two proportioning problems were solved by the genetic algorithm: a request of delayed setting time and high flow ability in hot weather and the other of accelerated setting and high flow ability in cold weather. They finally provided a Genetic algorithm system integrating the concept of Pareto optimality, which is named MixGA for solving the multi-criteria optimization problem in concrete mix proportioning.

Shilstone (1990) also produced concrete mixture optimization models. According to him concrete mix proportions for a given need can be optimized using coarseness factor, mortar factor and aggregate particle distribution. The coarseness factor chart was developed during an investigation conducted under contract with the United States Army Corps of Engineers, Mediterranean Division, for Construction of the Saudi Arabian National Guard Headquarters, Riyadh, Saudi Arabia. The Mortar Factor is an extension of the Coarseness Factor Chart. Both charts are adapted for optimizing concrete mixtures.

3.0 MATERIALS AND METHODS

3.1 Materials: The experiments in this research utilized laterite fine aggregate to partially replace sand in concrete. Other ingredients were coarse granite aggregates and Portland limestone cement. The high strength laterised concrete incorporated Conplast SP 430 superplasticiser.

Cement: The cement used for all the experiment was UNICEM Brand of Portland limestone cement conforming to Type 1- cement specified in BS 12: 1991. It is manufactured in Cross River State of Nigeria.

Water: Water used was portable, clean and free from deleterious substances. It was obtained from the Civil Engineering laboratory of the University of Uyo, Nigeria and conformed to the requirements of BS 3148: 1959.

Fine Aggregate (sand): Sand was obtained from Ikpa River in Uyo, Nigeria. The sand was prepared to comply with the requirements of BS 882: 1992 and BS 812: 1975.

Fine Aggregate (**Laterite**): Laterite was collected from a burrow pit located in Uyo, Nigeria. It was collected in bags and transported to the laboratory where it was sieved to exclude the clay contents as well as the coarse aggregate contents of lateritic soils.

Coarse Aggregates: The coarse aggregate was crushed granite with size range between 10 and 22mm. The aggregates conformed to the requirements of BS 882: 1992.

All the aggregates were spread and air-dried in the laboratory for a week to ensure that they were in a saturated surface-dry condition before use. They were all sieved and analysed respectively. The specific gravity, average impact value and average crushing value of the coarse aggregates were also determined.

Superplasticizer

The high performance Conplast SP430 superplasticizing admixture belonging to the sulphonated naphthalene formaldehyde (SNF) class was used for this work. It is marketed by Al Gurg Fosroc LLC International Limited, Dubai and has a specific gravity of 1.18 at a temperature of 22^0C + 2^0C with alkali content typically less than 55g.Na_2O equivalent/litre of the admixture. It is a brown solution that is chloride free, water based and non-flammable. Conplast SP430 does not fall into the hazard classifications of current regulations. It disperses the fine particles in the concrete mix, enabling the water content of the concrete to perform more effectively. The very high level of water reduction possible allows major increases in strength to be obtained. It conforms to the requirements of BSEN 934 – 2, BS 5075 Part 3 and ASTM C494 as type A and type F, depending on dosage used.

3.2 Methods

The base mix proportions were selected based on trial mixes and the following mix proportions were chosen for the five points A_1 (0.55:1:2:0:5), A_2 (0.60:1:1.5:0.5:4), A_3 (0.55:1:1:1:3), A_4 (0.5:1:0:1:1.5) and A_5 (0.65:1:1:2:6) for normal laterised concrete; the proportions representing water/cement ratio, cement, sand, laterite and coarse aggregate.

Similarly for the high strength laterised concrete the following points were chosen: A_1 (0.36:1:0.5:0.5:2.5:0.035), A_2 (0.38:1:1:0.5:3:0.03), A_3 (0.4:1:1.2:0.8:4:0.025), A_4 (0.42:1:0.5:1:3.5:0.02), A_5 (0.45:1:0.5:1:3:0.015) and A6 (0.35:1:1.2:0.6:3.6:0.04). The last proportion represents the superplasticizer content.

3.3 Preparations and Testing of Concrete Specimens

Batching and Mixing of Specimens

The ordinary laterised concrete was obtained from the pre-determined mix proportions of water – cement ratio, cement, sand, laterite and coarse aggregate shown in Table 1 while the high strength laterised concrete was obtained from the predetermined mix proportions of water-cement ratio, cement, sand, laterite, coarse aggregate and superplasticizer shown in Table 2. Batching of the constituents was done by weight and mixing was manually executed using a shovel and trowel. For the high strength laterised concrete, the predetermined quantity of superplasticizer was added to the mix while the mixture was about ready for use and the mix was stirred to a homogeneous state before moulding.

Tests on Fresh Concretes: Slump tests were performed on all fresh concretes to determine their workabilities. The tests were performed in conformity to BS 1881: Part 102:1983.

Preparation and Curing of Flexural Strength Test Beams

Flexural test beams were prepared in conformity with BS 1881: Part 108:1983 and BS1881: Part3: 1970 requirements. The mould used was 150 x 150 x 500mm beam size. After oiling the inside of the mould lightly with mineral oil, it was filled with the mixed concrete in three layers. Each layer was evenly rammed 150 strokes with a steel bar 380mm long weighing 1.8kg and having a ramming face 25mm square. The surface of the concrete was then towelled as smooth as practicable levelled with the top of the mould. Each beam was identified and kept in a damp environment for 24 hours before demoulding. After 24 hours the beams were removed from the mould and cured in a water bath for 28 days before testing. The flexural beam specimens are shown in Fig. 1.

3.4 Testing of flexural beams

Testing of flexural beams was carried out using CONTROLS testing machine in accordance to the requirements of BS1881: part118: 1983. The symmetrical two-point loading (at third points of the span) was adopted as shown in Fig.2 and Fig. 3. The beams were tested on their side in relation to the as-cast position. The load was applied without shock at a rate of increase in stress in the bottom fibre of about 12N/mm^2 per minute. In all the specimens, fracture occurred within the middle one-third of the beam. The flexural strength (or modulus of rupture) was therefore calculated on the basis of ordinary elastic theory using eqn. 1 and recorded to the nearest 0.1N/mm^2.

Fig. 1. Flexural Specimen Samples

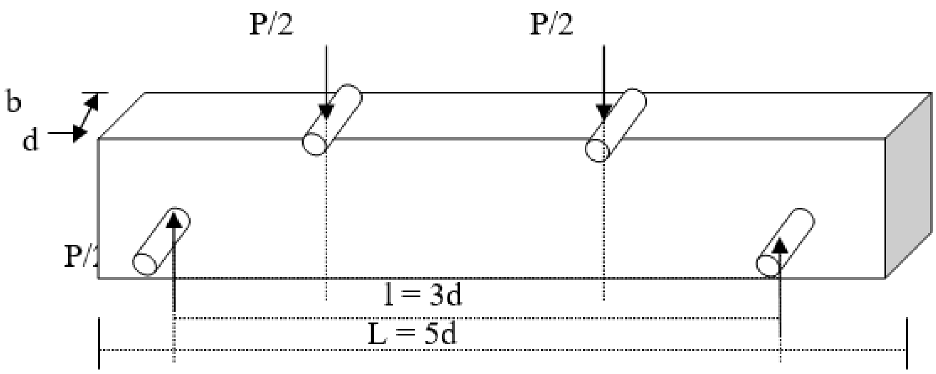

Fig. 2. Loading arrangement for flexural specimen testing.

Fig. 3. Testing of Concrete Beams in Flexure.

$$\mathbf{fs} = \frac{\boldsymbol{PL}}{\boldsymbol{bd2}} \ldots\ldots\ldots\ldots\ldots \quad [1]$$

Where

fs is the flexural strength (N/mm^2)
P is the maximum load at failure (N)
L is the span of the beam specimen (mm)
b is the breadth of the beam (mm)
d is the depth of the beam (mm)

3.5 Development of the Model Equations

The Simplex optimization theory developed by Scheffe (1958) was used in developing the model equations. According to Jackson (1983), simplex is the structural representation (shape) of the lines or planes joining the assumed positions of the constituent materials (atoms) of the mixture.

In adopting the simplex method, Scheffe (1958) considered experiments with mixtures of which the properties studied depend on the proportions of the components present and not on the quantity of the mixture (Akhanzarova and Kafarov, 1982). An example of such studies is a study of the relationship between the strengths (compressive, flexural, or split-tensile) of concrete and the proportions of concrete constituents such as water-cement ratio, cement, sand, coarse aggregate, superplasticiser, etc.

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) dimensional simplex, and for the mixture, the relationship in equation [2] holds.

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

That is:

$$\sum_{i=1}^{q} X_i = 1, \quad \text{Or} \quad X_1 + X_2 + X_3 + \text{----} X_q = \ldots\ldots\ldots\ldots\ldots\ldots \quad [2]$$

Simplex Lattices

In a (q - 1) - dimensional simplex, for binary system, (q = 2) the simplex is a straight-line segment having only two points of connectivity and for q = 3, the regular 2-simplex is an equilateral triangle with its interior. Each point in the triangle corresponds to a certain composition of the mixture system, and conversely each composition is represented by one distinct point. For a four-component (q = 4) mixture, the regular simplex is a tetrahedron where each vertex represents a binary system. In all, the composition might be expressed as molar, weight or volume fraction, or percentage.

Scheffe's simplex-lattice designs provide a uniform scatter of points over the (q - 1) simplex. The points form a (q, n) - lattice on the simplex where q is the number of mixture components, n is the degree of polynomial. Simplex-lattice designs are saturated. For each component there exist

(n + 1) similar levels from 0 to 1; i.e. $X_i = 0, 1/n, 2/n, ---, 1$ and all possible combinations are derived with such values of component concentrations.

Scheffe (1958) also showed that the property studied (e.g. flexural strength of concrete) is assumed to be a continuous function of certain arguments and with a sufficient accuracy it can be approximated by a polynomial. 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], the number of points can be reduced to $C^n_{q+n-1.}$

This implies that the number of points for a (5, 2) and (6, 2) experiments which this study experiments are based are as follows:

(i) For a (5, 2) lattice, equals:

$$C^n_{q+n-1} = \frac{q(q+1)--(q+n-1)}{n!}$$

$= \frac{5(5+1)}{2*1} = 15$ And (ii) for a (6, 2) lattice, equals: $= \frac{6(6+1)}{2*1} = 21$

Simplex Canonical Polynomials

Scheffe (1958) described mixture properties by reduced polynomials obtained subject to the condition in equation [2]. The properties studied in the assumed polynomial are real-valued functions on the simplex referred to as "RESPONSES". In this study, either the targeted flexural strength of the concrete or the proportions of the concrete ingredients (variables) would be the response depending on which one is being sought at a time. It is also shown that a polynomial function of degree n in q variables x_1, x_2, $x_{3,}$. …x_q subject to equation [2] will be called a (q, n) polynomial. Accordingly if the response ($\hat{y}$) is a function of the components (or variables) $x_1, x_2, x_3, x_4, \ldots x_q$, then the polynomial is of the form;

$$\hat{y} = b_0 + \sum_{1 \le i \le q} b_i X_i + \sum_{1 \le i \le j \le q} b_{ij} X_i X_j + \sum_{1 \le i \le j \le k \le q} b_{ijk} X_i X_j X_k + \sum bi_1 i_2 ---i_n Xi_1 Xi_2 Xi_n \quad [3]$$

Where all *b*s are constant coefficients. The number of coefficients in eqn [3] is given by C^n_{q+n} corresponding to the number of points (or experiments). These coefficients can be reduced to C^n_{q+n-1} when the condition in eqn. [2] is applied. For example if from eqn. [2], we let

$$X_q = 1 - \sum_{i=1}^{q} X_i \quad \ldots\ldots\ldots\ldots [4]$$

Then substituting the value of X_q into eqn [3], the number of coefficient b_i will reduce to C^n_{q+n-1} implying that the number of the coefficients equals to a (q, n) lattice. Another implication is that the values of a (q, n) polynomial can be assigned arbitrarily on a (q, n) lattice and its values on the simplex [2] are then uniquely determined.

In order to have a manageable number of coefficients, Scheffe (1958) avoided high-degree polynomials and also showed that the general low-degree polynomial of degree n and q variables subject to eqn. [2] may be written as:

1. if n = 1; $\hat{y} = \sum_{1 \le i \le q} b_i X_i \quad \ldots\ldots\ldots\ldots [5]$

2. if n = 2; $\hat{y} = \sum_{1 \le i \le q} b_i X_i + \sum_{1 \le i \le j \le q} b_{ij} X_i X_j \quad \ldots\ldots\ldots\ldots [6]$

Equations [5] and [6] are known as Scheffe canonical forms of the polynomials of degree 1 and 2 respectively. Other forms of the polynomial exist depending on the degree. This study is based on a (5, 2) and (6, 2) simplex lattice hence the usable form of the equations was developed as follows:

The response ($\hat{y}$), for example the flexural strength of laterised concrete, is a function of the five variables X_1, X_2, X_3, X_4, and X_5 representing the proportion of water/ cement ratio, cement, sand, laterite and coarse aggregate respectively, for normal laterised concrete. That is:

$$\hat{y} = f(X_1, X_2, X_3, X_4, X_5)$$

$$\hat{y} = \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_{12}X_1X_2 + \beta_{13}X_1X_3 + \beta_{14}X_1X_4 + \beta_{15}X_1X_5 + \beta_{23}X_2X_3 + \beta_{24}X_2X_4 + \beta_{25}X_2X_5 + \beta_{34}X_3X_4 + \beta_{35}X_3X_5 + \beta_{45}X_4X_5 \ldots\ldots [7]$$

Written in compact form [7]

$$\hat{y} = \sum_{1\le i\le q} \beta_i X_i + \sum_{1\le i\le j\le q} \beta_{ij} X_i X_j \ldots\ldots \quad [8]$$

It can be observed that [8] is synonymous with [3]. The coefficients in [3] have been reduced to fifteen (15) in [7] thereby requiring fifteen (15) experimental points. Eqn [7] is the polynomial equation for the 5-component normal laterised concrete.

Similarly for the 6-component high strength laterised concrete containing cement, sand, laterite, coarse aggregate, superplasticizer and water-cement ratio, the model equation is as shown in [9]:

$$\hat{y} = \alpha_1X_1 + \alpha_2X_2 + \alpha_3X_3 + \alpha_4X_4 + \alpha_5X_5 + \alpha_6X_6 + \alpha_{12}X_1X_2 + \alpha_{13}X_1X_3 + \alpha_{14}X_1X_4 + \alpha_{15}X_1X_5 + \alpha_{16}X_1X_6 + \alpha_{23}X_2X_3 + \alpha_{24}X_2X_4 + \alpha_{25}X_2X_5 + \alpha_{26}X_2X_6 + \alpha_{34}X_3X_4 + \alpha_{35}X_3X_5 + \alpha_{36}X_3X_6 + \alpha_{45}X_4X_5 + \alpha_{46}X_4X_6 + \alpha_{56}X_5X_6 \ldots\ldots [9]$$

The Coefficients of a (5, 2) and a (6, 2) Polynomial

Let the response function be denoted by $\hat{y}$, and let it take the form of [8]. The coefficient β_i (i = 1,2,3,4,5) or α_i (i = 1,2,3,4,5,6) can be interpreted in terms of the response to pure component i. β_{ij} or α_{ij} may also be interpreted in terms of the response to binary mixture of component i and j.

If the response to the pure component is denoted by y_i and the response to a 1:1 binary mixture of components i and j by y_{ij}, then:

From [5] if $X_i = 1$ ($\ge X_j = 0$ for $j \ne i$) therefore $\beta_i = y_i$ ………………………. [10]

Similarly, for the six component mixture; $\alpha_i = y_i$

This implies that the coefficients βi are the responses to the pure components. From [6] it can easily be seen that:

$$\sum_{i=1}^{5} \beta_i X_i = \sum_{i=1}^{5} y_i X_i \quad \ldots\ldots [11]$$

And $$\sum_{i=1}^{6} \alpha_i X_i = \sum_{i=1}^{6} y_i X_i$$

The excess of the response y over this linear mixing or blending is termed SYNERGISM. To evaluate β_{ij}; let $X_i = X_j = ½$ (because $\Sigma X_i + \Sigma X_j = 1$) and let $y = y_{ij}$ and from [11] we obtain that $y_{ij} = ½ \beta_i + ½ \beta_j + ¼ \beta_{ij}$, but from [10], $\beta_i = y_i$ and similarly $\beta_j = y_j$.

Therefore

$$y_{ij} = ½y_i + ½ y_j + ¼ \beta_{ij}$$

Hence

$$\beta_{ij} = 4y_{ij} - 2y_i - 2y_j \ldots\ldots [12]$$

Similarly, $\alpha_{ij} = 4y_{ij} - 2y_i - 2y_j$

Testing the Fit of the Quadratic Polynomial

For testing the agreement or otherwise of the assumed quadratic polynomial model and the actual experimental observations would be tested using the student's t-test. For a t-test statistic, adequacy is tested at each control point. The equation as given by Akhnazarova and Kafarov (1982) is

$$t = \frac{\Delta y}{\sqrt{S_y^2 + S_y^2}} = \frac{\Delta y \sqrt{n}}{S_y^2 \sqrt{1+\varepsilon}} \quad \ldots\ldots [13]$$

Where

$$^{\Delta}y = [y_{\text{ experiment}} - y_{\text{ theoretical}}] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad [14]$$

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)

Where

$^{\alpha}$ = Significant level (taken as 0.05)

L = number of control points

V_e = number of degrees of freedom for the replication variance.

Actual and Pseudo–Components for the (5, 2) Concrete

The requirement of simplex lattice designs that $\sum_{i=1}^{q} X_i = 1$ makes it impossible to use the conventional mix ratios such as 1: 2: 4, 1: $1^1/_2$: 3, 1:1:2, etc at a given water/cement ratio. This necessitates the transformation of the actual components (ingredients) proportions to meet the above criterion. Such transformed ratios, say $X_1^{(i)}$, $X_2^{(i)}$, $X_3^{(i)}$, $X_4^{(i)}$, $X_5^{(i)}$ for the i-th experimental points are called "pseudo – components" (or coded components). The following arbitrary prescribed mix proportions were chosen for the five points of the normal laterised concrete, A_1 (0.55:1:2:0:5), A_2 (0.60:1:1.5:0.5:4), A_3 (0.55:1:1:1:3), A_4 (0.5:1:0:1:1.5) and A_5 (0.65:1:1:2:6). The proportions represent water/cement ratio, cement, sand, laterite and coarse aggregate respectively. In order to satisfy the requirement that $\sum x_i = 1$, the design matrix with actual and pseudo components for a (5, 2) lattice is as presented in Table 2.

Table 2. Pseudo and Actual components for points 1-21 of the (5, 2) mixture

No	Pseudo Components					Response y	Actual Component				
	X_1	X_2	X_3	X_4	X_5		Z_1	Z_2	Z_3	Z_4	Z_5
1	1	0	0	0	0	y_1	0.55	1	2	0	5
2	0	1	0	0	0	y_2	0.60	1	1.5	0.5	4
3	0	0	1	0	0	y_3	0.55	1	1	1	3
4	0	0	0	1	0	y_4	0.50	1	0	1	1.5
5	0	0	0	0	1	y_5	0.65	1	1	2	6
6	0.5	0.	0	0	0	y_{12}	0.575	1	1.75	0.25	4.5
7	0.5	0	0.5	0	0	y_{13}	0.55	1	1.5	0.5	4
8	0.5	0	0	0.5	0	y_{14}	0.525	1	1	0.5	3.25
9	0.5	0	0	0	0.5	y_{15}	0.60	1	1.5	1	5.5
10	0	0.5	0.5	0	0	y_{23}	0.575	1	1.25	0.75	3.5
11	0	0.5	0	0.5	0	y_{24}	0.55	1	0.75	0.75	2.75
12	0	0.5	0	0	0	Y	0.625	1	1.25	1.25	5.0
13	0	0	0.5	0.5	0	y_{34}	0.525	1	0.5	1	2.25
4		0	0.5	0	05	y_{35}	0.60	1	1	1.5	4.5
15	0	0	0	0.5	05	y_{45}	0.575	1	0.50	1.5	3.75
CONTOL POINTS											
16	0.2	0.2	0.2	0.2	0.2	C_1	0.57	1	1.1	0.7	3.9
17	0.25	0.25	0.25	0.25	0	C_2	0.55	1	1.13	0.63	3.38
18	0.2	0.2	0.6	0	0	C	0.56	1	1.3	0.7	3.6
19	0.4	0.4	0.2	0	0	C_4	0.57	1	1.6	0.4	4.2
20	0.2	0	0	0.4	0.4	C_5	0.57	1	0.8	1.2	4
21	0.25	0	0.25	0.5	0	C_6	0.525	1	0.75	0.75	2.75

$$C^{n}_{q+n-1} = \frac{5(5+1)}{2*1} = \frac{5 \text{ x } 6}{2} = 15$$

-

3.10.9 Actual and Pseudo–Components for the (6, 2) Concrete

In order to satisfy the requirement that $\sum x_i = 1$, the design matrix with pseudo and actual components for the (6, 2) lattice is presented in Table 3.

Table 3. Pseudo and Actual components for points 1-30 (6, 2) mixture

S/No.	Pseudo Components						Res.	Actual Components					
	X_1	X_2	X_3	X_4	X_5	X_6	y	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6
1.	1	0	0	0	0	0	Y_1	0.36	1	0.5	0.5	2.5	0.035
2.	0	1	0	0	0	0	Y_2	0.38	1	1	0.5	3	0.03
3.	0	0	1	0	0	0	Y_3	0.4	1	1.2	0.8	4	0.025
4.	0	0	0	1	0	0	Y_4	0.42	1	0.5	1	3.5	0.02
5.	0	0	0	0	1	0	Y_5	0.45	1	0.5	1	3	0.015
6.	0	0	0	0	0	1	Y_6	0.35	1	1.2	0.6	3.6	0.04
7.	0.5	0.5	0	0	0	0	Y_{12}	0.3	1	0.7	0.5	2.5	0.0325
8.	0.5	0	0.5	0	0	0	Y_1	08	1	0.85	0.65	3.25	0.03
9.	0.5	0	0	0.5	0	0	Y_{14}	0.39	1	0.5	0.75	3	0.0275
10.	0.5	0	0	0	0.5	0	Y_{15}	0.405	1	0.5	0.75	2.75	0.025
11.	0.5	0	0	0	0	0.5	Y_{16}	0.355	1	0.85	0.55	3.05	0.0375
12.	0	0	0	0	0	0	Y_2	0.39	1	1.1	0.65	3.5	0.0275
13.	0	0.5	0	0.5	0	0	Y_{24}	0.4	1	0.75	0.75	3.25	0.025
14.	0	0.5	0	0	0.5	0	Y_{25}	0.415	1	0.75	0.75	3	0.0225
15.	0	0.5	0	0	0	0.5	Y_{26}	0.365	1	1.1	0.55	3.3	0.035
16.	0	0	0.5	0.5	0	0	Y_{34}	0.41	1	0.85	0.9	3.75	0.0225
17.	0	0	0.5	0	0.5	0	Y_{35}	0.425	1	0.85	0.9	3.5	0.02
18.	0	0	0.5	0	0	0.5	Y_{36}	0.375	1	1.2	0.7	3.8	0.0325
19.	0	0	0	0.5	0.5	0	Y_{45}	0.435	1	0.5	1	3.25	0.0175
20.	0	0	0	0.5	0	0.5	Y_{46}	0.385	1	0.85	0.8	3.55	0.03
21.	0	0	0	0	0.5	0.5	Y_{56}	0.4	1	0.85	0.8	3.3	0.0275
Control Points													
22.	0.2	0.2	0.2	0.1	0.2	0.1	C_{11}	0.395	1	0.81	0.72	3.21	0.027
23.	0	0.3	0.2	0.3	0	0.2	C_{22}	0.39	1	0.93	0.73	.47	0.028
24.	0.1	0.1	0.1	0.4	0.2	0.1	C_{33}	0.4	1	0.69	0.84	.31	0.024
25.	0.3	0.3	0.3	0	0.1	0	C_{44}	0.387	1	0.86	0.64	3.15	0.0285
26.	0	0	0	0.3	0.3	0.4	c_{55}	0401	1	0.78	0.84	3.39	0.0265
27.	0.2	0.4	0	0	0.2	0.2	C_{66}	0.84	1	0.84	0.62	3.02	0.03
28.	0.2	0	0.2	0.3	0.1	0.2	C_{77}	0.393	1	0.78	0.78	3.37	0.0275
29.	0.1	0.1	0.5	0.1	0.1	0.1	C_{88}	0.396	1	0.97	0.76	3.56	0.0265
30.	0.2	0.2	0.2	0.2	0	0.2	C_{99}	0.382	1	0.88	0.64	3.32	0.03

4.0 RESULTS AND ANALYSIS

Physical Properties of Materials used

Table 4.1 presents a summary of the physical properties of the materials used for this study. The laterite was reddish – brown in colour and had a specific gravity of 2.62, particle sizes range of between 63µm and 2.36mm in diameter with a fineness modulus of 2.33, and a coefficients of uniformity of 2.4. The laterite was suitable as fine aggregates according to ASTM C 33 – 93 which stipulates that a fine aggregate should have a fineness modulus of between 2.3 and 3.1. With reference to BS 882 – 103.1:1985 grading, the laterite fell in zone 3 grouping.

The sand had a specific gravity of 2.65, a fineness modulus of 2.37 and a coefficient of uniformity of 2.83. Its grain sizes ranged between 63µm and 5mm. The sand could be described as being well graded. With reference to BS882 – 103.1:1985 grading, the sand fell into zone 2 grading.

Flexural Strength Models for Normal Laterised and High Strength Laterised Concretes at Optimum Mix Proportions

The coarse aggregate was coarse granite having a specific gravity of 2.71, impact value of 13.15% and a crushing value of 21.43 with particle sizes ranging between 5 and 22mm.

Workability of the Laterised Concretes

The slump of the normal laterised concretes ranged between 15mm and 175mm. The mean slump for all the mixes stood at 62mm. On the whole, it was generally observed that concretes containing a greater amount of laterite had the workability reduced which implied that more water was needed to make the concrete more workable. This agreed with the works of Adepegba (1976). All high strength laterised concretes were flowing concretes.

Table 4. Physical Properties of Materials Used

Material	Property	Value
Laterite	Specific gravity Fineness Modulus Coefficient of uniformity	2.62 2.33 2.40
Sand	Specific gravity Fineness Modulus Coefficient of uniformity	2.65 2.37 2.83
Coarse aggregate	Specific gravity Average Impact Value Average Crushing Value	2.71 13.15% 21.43
Cement	Specific Gravity Initial Setting Time Final Setting Time Soundness	3.15 53 minutes 90 minutes 0.50 mm
Concrete	Workability Density Water absorption	15 – 175mm 2280 – 2430kg/m3 0.63 – 1.89%

Flexural Strength of Normal Laterised Concrete (f_b)

Table 5 presents the results of two replications of each of the fifteen (15) design points and the six (6) control points of the (5, 2) simplex lattice for the flexural strengths of NLC as determined using eqn. [1].

Considering Table 5, the replication variance and replication error for NLC were determined as follows:

Replication variance, $S_y^2 = 1/V_e\,[\Sigma S_i^2]$ = 1.526/21 = 0.073 and Replication error, $S_y = \sqrt{S_y^2} = \sqrt{0.073} = 0.270$

Regression Equation of NLC - Flexural

Using equations [11] and [12] and Table 5, the coefficients of the second degree polynomial for the flexural strength of normal laterised concrete were determined as follows:

$\beta_1 = y_1 = 3.23$, $\beta_2 = y_2 = 3.18$, $\beta_3 = y_3 = 3.35$, $\beta_4 = y_4 = 3.56$ and $\beta_5 = y_5 = 2.39$

$\beta_{12} = 4(3.26) - 2(3.23) - 2(3.18) = 0.22$

$\beta_{13} = 4(3.18) - 2(3.23) - 2(3.35) = -0.44$

$\beta_{14} = 4(2.95) - 2(3.23) - 2(3.56) = -1.78$

$\beta_{15} = 4(3.82) - 2(3.23) - 2(2.39) = 4.04$

$\beta_{23} = 4(3.80) - 2(3.18) - 2(3.35) = 2.14$

$\beta_{24} = 4(3.30) - 2(3.18) - 2(3.56) = -0.28$

$\beta_{25} = 4(3.31) - 2(3.18) - 2(2.39) = 2.10$

$\beta_{34} = 4(3.02) - 2(3.35) - 2(3.56) = -1.74$

$\beta_{35} = 4(2.65) - 2(3.35) - 2(2.39) = -0.88$

$\beta_{45} = 4(3.96) - 2(3.56) - 2(2.39) = 3.94$

Table 5. Analysis of Flexural Strength of NLC

Exp. No.	Max. Load (kN)	Response y_r (N/mm^2)	y_r^2	Σy_r	$\bar{y}$ (N/mm^2)	Response symbol	Σy_r^2	S^2
1A	32.9	3.22	10.35	6.46	3.23	Y_1	20.89	0.000
1B	33.2	3.25	10.54					
2A	31.6	3.09	9.55	6.36	3.18	Y_2	20.21	0.015
2B	33.4	3.27	10.67					
3A	33.7	3.30	10.86	6.71	3.35	Y_3	22.50	0.007
3B	34.9	3.41	11.64					
4A	43.4	4.24	18.01	7.12	3.56	Y_4	26.27	0.937
4B	29.4	2.87	8.26					
5A	24.3	2.38	5.65	4.78	2.39	Y_5	11.43	0.000
5B	24.6	2.41	5.79					
6A	33.4	3.27	10.67	6.51	3.26	Y_{12}	21.20	0.000
6B	33.2	3.25	10.54					
7A	33.5	3.28	10.73	6.37	3.18	Y_{13}	20.28	0.017
7B	31.6	3.09	9.55					
8A	31.2	3.05	9.31	5.90	2.95	Y_{14}	17.40	0.021
8B	29.1	2.85	8.10					
9A	38.9	3.80	14.47	7.64	3.82	Y_{15}	29.16	0.000
9B	39.2	3.83	14.69					
10A	38.7	3.78	14.32	7.61	3.80	Y_{23}	28.93	0.001
10B	39.1	3.82	14.62					
11A	34.3	3.35	11.25	6.59	3.30	Y_{24}	21.72	0.007
11B	33.1	3.24	10.47					
12A	32.5	3.18	10.10	6.62	3.31	Y_{25}	21.94	0.035
12B	35.2	3.44	11.85					
13A	33.0	3.23	10.41	6.04	3.02	Y_{34}	18.34	0.084
13B	28.8	2.82	7.93					
14A	26.9	2.63	6.92	5.30	2.65	Y_{35}	14.04	0.001
14B	27.3	2.67	7.13					
15A	41.0	4.01	16.07	7.93	3.96	Y_{45}	31.44	0.004
15B	40.1	3.92	15.37					
16A	37.1	3.63	13.16	6.83	3.42	C_1	23.44	0.088
16B	32.8	3.21	10.29					
17A	33.6	3.29	10.79	6.38	3.19	C_2	20.34	0.019
17B	31.6	3.09	9.55					
18A	33.4	3.27	10.67	7.11	3.55	C_3	25.43	0.166
18B	39.3	3.84	14.77					
19A	32.9	3.22	10.35	6.76	3.38	C_4	22.88	0.052
19B	36.2	3.54	12.53					
20A	39.2	3.83	14.69	7.67	3.83	C_5	29.38	0.000
20B	39.2	3.83	14.69					
21A	29.2	2.86	8.15	6.08	3.04	C_6	18.56	0.069
21B	33.0	3.23	10.41					
	Σ							1.526

Thus from eqn [7]

$$y_{fa} = 3.23x_1 + 3.18x_2 + 3.35x_3 + 3.56x_4 + 2.39x_5 + 0.22x_1x_2 - 0.44x_1x_3 - 1.78x_1x_4 + 4.04x_1x_5 + 2.14x_2x_3 - 0.28x_2x_4 + 2.1x_2x_5 - 1.74x_3x_4 - 0.88x_3x_5 + 3.94x_4x_5 \quad [18]$$

Flexural Strength Models for Normal Laterised and High Strength Laterised Concretes at Optimum Mix Proportions

Equation [18] is the mathematical model for the flexural strength of NLC based on the 28^{th} - day strength.

Test of the Adequacy of the flexural Strength Models using t-statistic (NLC)

Using the six control points' experimental results the flexural strength model equation was tested for adequacy using the t-statistic distribution. By substituting the values of x_i from Table 5 in the equations the theoretical predictions of the flexural strength response ($\hat{y}_i$) were obtained. These theoretical predictions were compared with the experimental results. At the Significance level, α = 0.05, that is: $t_{\alpha/L}$ (V_e) = $t_{0.05/6}$ (21) = $t_{0.008}$ (21) the tabulated value of $t_{0.008}$ (21) is 2.95. This is greater than all the t-values calculated in Table 15; hence the model equation is adequate.

Table 15. t – Statistics for NLC

S/No.	Control point	X_1	X_2	X_3	X_4	X_5	$y_{exp.}$	$\hat{y}_{theory}$	ΔY	t
1.	C_{11}	0.2	0.2	0.2	0.2	0.2	3.42	3.43	-0.01	-0.27
2.	C_{22}	0.25	0.25	0.25	0.25	0	3.19	3.21	-0.02	-0.59
3.	C_{33}	0.2	0.2	0.6	0	0	3.55	3.50	0.05	1.57
4.	C_{44}	0.4	0.4	0.2	0	0	3.38	3.41	-0.03	-0.98
5.	C_{55}	0.2	0	0	0.4	0.4	3.83	3.84	-0.01	-0.33
6.	C_{66}	0.25	0	0.25	0.5	0	3.04	2.96	0.08	2.57

Flexural Strength of HSLC Data Analysis

Table 6 presents the results of two replications of each of the twenty-one design points and the nine control points of the (6, 2) simplex lattice for the flexural strengths of the high strength laterised concrete. Considering Table 6, the replication variance and replication error for HSLC were:

Replication variance, $S_y^2 = 1/V_e\,[\Sigma S_i^2]$ = 1.2980/30 = 0.043 and Replication error, $S_y = \sqrt{S_y^2}$ = √0.043 = 0.208

Table 6. Analysis of Flexural Strength of HSLC

Exp. No.	Max. Load (kN)	Response y_r (N/mm²)	y_r^2	Σy_r	$\bar{y}$ (N/mm²)	Response symbol	Σy_r^2	S_i^2
1A	46.6	4.14	17.16	8.85	4.43	y_1	39.35	0.1618
1B	53.0	4.71	22.19					
2A	48.6	4.32	18.66	8.87	4.44	y_2	39.38	0.0267
2B	51.2	4.55	20.71					
3A	45.2	4.02	16.14	8.44	4.22	y_3	35.74	0.0836
3B	49.8	4.43	19.60					
4A	46.0	4.09	16.72	8.26	4.13	y_4	34.10	0.0032
4B	46.9	4.17	17.38					
5A	43.8	3.89	15.16	7.96	3.98	y_5	31.73	0.0158
5B	45.8	4.07	16.57					
6A	47.0	4.18	17.45	8.55	4.28	y_6	36.58	0.0191
6B	49.2	4.37	19.13					
7A	52.4	4.66	21.69	8.95	4.48	y_{12}	40.13	0.0664
7B	48.3	4.29	18.43					
8A	48.7	4.33	18.74	8.76	4.38	y_{13}	38.41	0.0057
8B	49.9	4.44	19.67					
9A	49.5	4.40	19.36	8.57	4.28	y_{14}	36.74	0.0267
9B	46.9	4.17	17.38					
10A	49.5	4.40	19.36	8.66	4.33	y_{15}	37.49	0.0101
10B	47.9	4.26	18.13					
11A	46.8	4.16	17.31	8.75	4.37	y_{16}	38.34	0.0910
11B	51.6	4.59	21.04					
12A	47.4	4.21	17.75	8.44	4.22	y_{23}	35.58	0.0000
12B	47.5	4.22	17.83					

13A	44.7	3.97	15.79	8.51	4.25	y_{24}	36.34	0.1568
13B	51.0	4.53	20.55					
14A	44.9	3.99	15.93	8.14	4.07	y_{25}	33.16	0.0128
14B	46.7	4.15	17.23					
15A	50.6	4.50	20.23	8.63	4.32	y_{26}	37.31	0.0664
15B	46.5	4.13	17.08					
16A	46.9	4.17	17.38	8.23	4.12	y_{34}	33.88	0.0057
16B	45.7	4.06	16.50					
17A	44.0	3.91	15.30	8.20	4.10	y_{35}	33.65	0.0697
17B	48.2	4.28	18.36					
18A	47.8	4.25	18.05	8.55	4.28	y_{36}	36.56	0.0014
18B	48.4	4.30	18.51					
19A	46.2	4.11	16.86	7.92	3.96	y_{45}	31.41	0.0430
19B	42.9	3.81	14.54					
20A	49.3	4.38	19.20	8.37	4.19	y_{46}	35.13	0.0765
20B	44.9	3.99	15.93					
21A	46.5	4.13	17.08	8.46	4.23	y_{56}	35.82	0.0191
21B	48.7	4.33	18.74					
22A	44.3	3.94	15.51	8.42	4.21	C_{11}	35.58	0.1470
22B	50.4	4.48	20.07					
23A	46.8	4.16	17.31	8.38	4.19	C_{22}	35.13	0.0019
23B	47.5	4.22	17.83					
24A	48.7	4.33	18.74	8.35	4.17	C_{33}	34.88	0.0484
24B	45.2	4.02	16.14					
25A	47.4	4.21	17.75	8.70	4.35	C_{44}	37.90	0.0380
25B	50.5	4.49	20.15					
26A	44.8	3.98	15.86	8.6	4.18	C_{55}	35.06	0.0800
26B	49.3	4.38	19.20					
27A	49.0	4.36	18.97	8.60	4.30	C_{66}	37.02	0.0057
27B	47.8	4.25	18.05					
28A	47.5	4.22	17.83	8.50	4.25	C_{77}	36.11	0.0014
28B	48.1	4.28	18.28					
29A	46.9	4.17	17.38	8.49	4.24	C_{88}	36.04	0.0114
29B	48.6	4.32	18.66					
30A	47.6	4.23	17.90	8.53	4.27	C_{99}	36.41	0.0025
30B	48.4	4.30	18.51					
Σ							1.2980	

Determination of the Regression Equation of HSLC - Flexural

Using equations [11] and [12] and Table 6, the coefficients of the second degree polynomial for flexural strength of high strength laterised concrete were determined as follows:

$\alpha_1 = y_1 = 4.43$, $\alpha_2 = y_2 = 4.44$, $\alpha_3 = y_3 = 4.22$, $\alpha_4 = y_4 = 4.13$, $\alpha_5 = y_5 = 3.98$ and $\alpha_6 = y_6 = 4.28$.

$\alpha_{12} = 4(4.48) - 2(4.43) - 2(4.44) = 0.18$

$\alpha_{13} = 4(4.38) - 2(4.43) - 2(4.22) = 0.22$

$\alpha_{14} = 4(4.28) - 2(4.43) - 2(4.13) = 0.00$

$\alpha_{15} = 4(4.33) - 2(4.43) - 2(3.98) = 0.50$

$\alpha_{16} = 4(4.37) - 2(4.43) - 2(4.28) = 0.06$

$\alpha_{23} = 4(4.22) - 2(4.44) - 2(4.22) = -0.44$

$\alpha_{24} = 4(4.25) - 2(4.44) - 2(4.13) = -0.14$

$\alpha_{25} = 4(4.07) - 2(4.44) - 2(3.98) = -0.56$

$\alpha_{26} = 4(4.32) - 2(4.44) - 2(4.28) = -0.16$

$\alpha_{34} = 4(4.12) - 2(4.22) - 2(4.13) = -0.22$

$\alpha_{35} = 4(4.10) - 2(4.22) - 2(3.98) = 0.00$

$\alpha_{36} = 4(4.28) - 2(4.22) - 2(4.28) = 0.12$

$\alpha_{45} = 4(3.96) - 2(4.13) - 2(3.98) = -0.38$

$\alpha_{46} = 4(4.19) - 2(4.13) - 2(4.28) = -0.06$

$\alpha_{56} = 4(4.23) - 2(3.98) - 2(4.28) = 0.40$

Thus from equation (3.21c)

$$y_{fsa} = 4.43x_1 + 4.44x_2 + 4.22x_3 + 4.13x_4 + 3.98x_5 + 4.28x_6 + 0.18x_1x_2 + 0.22x_1x_3 + 0.0x_1x_4 + 0.5x_1x_5 + 0.06x_1x_6 - 0.44x_2x_3 - 0.14x_2x_4 - 0.56x_2x_5 - 0.16x_2x_6 - 0.22x_3x_4 + 0.0x_3x_5 + 0.12x_3x_6 - 0.38x_4x_5 - 0.06x_4x_6 + 0.4x_5x_6 \quad \ldots\ldots\ldots\ldots [19]$$

Equation [19] is the mathematical model for optimizing the flexural strength of high strength laterised concrete based on the 28-day strength.

Test of the Adequacy of the HSLC Flexural Strength Model using t-statistic

Using the nine control points experimental results the model equation, was tested for adequacy using the t-statistic distribution. At the Significance level, $\alpha = 0.05$, that is: $t_{\alpha/L}$ (V_e) = $t_{0.05/9}$ (30) = $t_{0.006}$ (30), the tabulated value of $t_{0.006}$ (30) is 2.97. This is greater than any of the t-values calculated in Table 16; hence the equation is satisfied.

Table 16. t – Statistics for HSLC

S/No.	Control point	X_1	X_2	X_3	X_4	X_5	X_6	$Y_{experiment}$	$\hat{Y}$	ΔY	t
1.	C_{11}	0.2	0.2	0.2	0.1	0.2	0.1	4.21	4.24	-0.03	-1.39
2.	C_{22}	0	0.3	0.2	0.3	0	0.2	4.19	4.21	-0.02	-1.00
3.	C_{33}	0.1	0.1	0.1	0.4	0.2	0.1	4.17	4.14	0.03	1.33
4.	C_{44}	0.3	0.3	0.3	0	0.1	0	4.35	4.32	0.03	1.59
5.	C_{55}	0	0	0	0.3	0.3	0.4	4.18	4.15	0.03	1.61
6.	C_{66}	0.2	0.4	0	0	0.2	0.2	4.30	4.31	-0.01	-0.49
7.	C_{77}	0.2	0	0.2	0.3	0.1	0.2	4.25	4.23	0.02	0.94
8.	C_{88}	0.1	0.1	0.5	0.1	0.1	0.1	4,24	4.22	0.02	0.85
9.	C_{99}	0.2	0.2	0.2	0.2	0	0.2	4.27	4.28	-0.01	-0.48

Computer Programme and Test Results

Programme 1: A-Q-Basic programme that optimises the flexural strength of NLC.

```
100 REM A Q - BASIC PROGRAMME THAT OPTIMISES LATERIZED CONCRETE MIX
    PROPORTIONS
110 REM VARIABLES USED ARE
120 REM X1, X2, X3, X4, X5, Z1, Z2, Z3, Z4, Z5, ymax, yout, yin
130 REM MODEL USED: FLEXURAL STRENGTH MODEL, EQN (4.11)
140 REM
150 REM MAIN PROGRAMME BEGINS
160 LET COUNT = 0
170 CLS
180 GOSUB 210
190 END
200 REM END OF MAIN PROGRAMME
210 REM PROCEDURE BEGINS
220 LET ymax = 0
230 PRINT
240 REM
250 PRINT "A COMPUTER MODEL FOR COMPUTING LATERIZED CONCRETE MIX PROPORTIONS"
260 PRINT "CORRESPONDING TO A REQUIRED FLEXURAL STRENGTH"
270 REM
280 REM
290 PRINT
```

```
300 INPUT "ENTER DESIRED FLEXURAL STRENGTH"; yin
310 GOSUB 550
320 FOR X1 = 0 TO 1 STEP .01
330 FOR X2 = 0 TO 1 - X1 STEP .01
340 FOR X3 = 0 TO 1 - X1 - X2 STEP .01
350 FOR X4 = 0 TO 1 - X1 - X2 - X3 STEP .01
360 LET X5 = 1 - X1 - X2 - X3 - X4
370 LET yout = 3.22 * X1 + 3.18 * X2 + 3.28 * X3 + 3.52 * X4 + 2.41 * X5 + .25 * X1
        * X2 - .17 * X1 * X3 - .52 * X1 * X4 + 3.12 * X1 * X5 + 2.01 * X2 * X3 -.45
        * X2 * X4 + 1.78 * X2 * X5 - 1.6 * X3 * X4 - .36 * X3 * X5 + 3.8 * X4 * X5
380 GOSUB 600
390 IF (ABS (yin - yout) <= .001) THEN 400 ELSE 420
400 LET COUNT = COUNT + 1
410 GOSUB 630
420 NEXT X4
430 NEXT X3
440 NEXT X2
450 NEXT X1
460 PRINT
470 IF (COUNT > 0) THEN GOTO 480 ELSE GOTO 520
480 PRINT "THE MAXIMUM FLEXURAL STRENGTH PREDICTABLE"
490 PRINT "BY THIS MODEL IS"; ymax; "N/SQ.MM."
500 SLEEP (2)
510 GOTO 540
520 PRINT "SORRY! DESIRED STRENGTH OUT OF RANGE OF MODEL"
530 SLEEP 2
540 RETURN
550 REM PROCEDURE PRINT HEADING
560 REM
570 PRINT "COUNT X1 X2 X3 X4 X5 Y Z1 Z2 Z3 Z4 Z5"
580 REM
590 RETURN
600 REM PROCEDURE CHECK MAX
610 IF ymax < yout THEN ymax = yout ELSE ymax = ymax
620 RETURN
630 REM PROCEDURE OUT RESULTS
640 LET Z1 = .55 * X1 + .6 * X2 + .55 * X3 + .5 * X4 + .65 * X5
650 LET Z2 = X1 + X2 + X3 + X4 + X5
660 LET Z3 = 2 * X1 + 1.5 * X2 + X3 + X5
670 LET Z4 = .5 * X2 + X3 + X4 + 2 * X5
680 LET Z5 = 5 * X1 + 4 * X2 + 3 * X3 + 1.5 * X4 + 6 * X5
690 PRINT TAB(1); COUNT; USING "###.##"; X1; X2; X3; X4; X5; yout; Z1; Z2; Z3; Z4; Z5
700 RETURN
```

Programme 2: A-Q-Basic programme that optimizes the flexural strength of High Strength Laterised Concrete.

```
100 REM A Q - BASIC PROGRAMME THAT OPTIMISES SPLC MIX PROPORTIONS
110 REM VARIABLES USED ARE
120 REM X1, X2, X3, X4, X5, X6, Z1, Z2, Z3, Z4, Z5, Z6, ymax, yout, yin
130 REM MODEL USED: SPLC FLEXURAL STRENGTH MODEL, EQN (4.23)
140 REM
150 REM MAIN PROGRAMME BEGINS
160 LET COUNT = 1
170 CLS
180 GOSUB 210
190 END
200 REM END OF MAIN PROGRAMME
```

```
210 REM PROCEDURE BEGINS
220 LET ymax = 0
230 PRINT
240 REM
250 PRINT "A COMPUTER MODEL FOR COMPUTING SPLC MIX PROPORTIONS"
260 PRINT "CORRESPONDING TO A REQUIRED FLEXURAL STRENGTH"
270 REM
280 REM
290 PRINT
300 INPUT "ENTER DESIRED STRENGTH"; yin
310 GOSUB 570
320 FOR X1 = 0 TO 1 STEP .02
330 FOR X2 = 0 TO 1 - X1 STEP .02
340 FOR X3 = 0 TO 1 - X1 - X2 STEP .02
350 FOR X4 = 0 TO 1 - X1 - X2 - X3 STEP .02
360 FOR X5 = 0 TO 1 - X1 - X2 - X3 - X4 STEP .02
370 LET X6 = 1 - X1 - X2 - X3 - X4 - X5
380 LET yout = 4.42 * X1 + 4.38 * X2 + 4.19 * X3 + 4.16 * X4 + 4.01 * X5 + 4.28 * X6 +
    .15 * X1 * X2 + .31 * X1 * X3 + 0 * X1 * X4 + .46 * X1 * X5 + .05 * X1 * X6 - .44 *
     X2 * X3 - .15 * X2 * X4 - .49 * X2 * X5 - .15 * X2 * X6 - .23 * X3 * X4 + .02 * X3
     *X5 + .19 * X3 * X6 - .34 * X4 * X5 - .08 * X4 * X6 + .38 * X5 * X6
390 GOSUB 620
400 IF (ABS(yin - yout) <= .001) THEN 410 ELSE 430
410 LET COUNT = COUNT + 1
420 GOSUB 650
430 NEXT X5
440 NEXT X4
450 NEXT X3
460 NEXT X2470 NEXT X1
480 PRINT
490 IF (COUNT > 0) THEN GOTO 500 ELSE GOTO 540
500 PRINT "THE MAXIMUM FLEXURAL STRENGTH PREDICTABLE"
510 PRINT "BY THIS MODEL IS"; ymax; "N/SQ.MM."
520 SLEEP (2)
530 GOTO 560
540 PRINT "SORRY! DESIRED STRENGTH OUT OF RANGE OF MODEL"
550 SLEEP 2
560 RETURN
570 REM PROCEDURE PRINT HEADING
580 REM
590 PRINT "COUNT X1 X2 X3 X4 X5 X6 Y Z1 Z2 Z3 Z4 Z5 Z6"
600 REM
610 RETURN
620 REM PROCEDURE CHECK MAX
630 IF ymax < yout THEN ymax = yout ELSE ymax = ymax
640 RETURN
650 REM PROCEDURE OUT RESULTS
660 LET Z1 = .36 * X1 + .38 * X2 + .4 * X3 + .42 * X4 + .45 * X5 + .35 * X6
670 LET Z2 = X1 + X2 + X3 + X4 + X5 + X6
680 LET Z3 = .5 * X1 + 1 * X2 + 1.2 * X3 + .5 * X4 + .5 * X5 + 1.2 * X6
690 LET Z4 = .5 * X1 + .5 * X2 + .8 * X3 + X4 + X5 + .6 * X6
700 LET Z5 = 2.5 * X1 + 3 * X2 + 4 * X3 + 3.5 * X4 + 3 * X5 + 3.6 * X6
710 LET Z6 = .035 * X1 + .03 * X2 + .025 * X3 + .02 * X4 + .015 * X5 + .04 * X6
720 PRINT TAB(1); COUNT; USING "###.##"; X1; X2; X3; X4; X5; X6; yout; Z1; Z2; Z3; Z4;
    Z5; Z6
730 RETURN
```

OUTPUT RESULT 1: A COMPUTER PROGRAMME FOR COMPUTING NLC MIX PROPORTIONS CORRESPONDING TO A TARGET FLEXURAL STRENGTH

COUNT	X1	X2	X3	X4	X5	Y	Z1	Z2	Z3	Z4	Z5
1	0.00	0.00	0.00	0.73	0.27	3.97	0.54	1.00	0.27	1.27	2.72
2	0.00	0.01	0.00	0.58	0.41	3.97	0.56	1.00	0.43	1.41	3.37
3	0.00	0.02	0.00	0.63	0.35	3.97	0.55	1.00	0.38	1.34	3.13
4	0.00	0.02	0.00	0.64	0.34	3.97	0.55	1.00	0.37	1.33	3.08
5	0.01	0.00	0.00	0.57	0.42	3.97	0.56	1.00	0.44	1.41	3.43
6	0.01	0.01	0.00	0.66	0.32	3.97	0.55	1.00	0.36	1.31	3.00
7	0.02	0.00	0.00	0.58	0.40	3.97	0.56	1.00	0.44	1.38	3.37
8	0.03	0.00	0.00	0.60	0.37	3.97	0.56	1.00	0.43	1.34	3.27
9	0.03	0.00	0.00	0.61	0.36	3.97	0.56	1.00	0.42	1.33	3.23
10	0.03	0.00	0.00	0.62	0.35	3.97	0.55	1.00	0.41	1.32	3.18
11	0.03	0.00	0.00	0.63	0.34	3.97	0.55	1.00	0.40	1.31	3.14

THE MAXIMUM FLEXURAL STRENGTH PREDICTABLE BY THIS MODEL IS 3.996 N/SQ.MM.

OUTPUT RESULT 2: A COMPUTER PROGRAMME FOR COMPUTING HSLC MIX PROPORTIONS CORRESPONDING TO A REQUIRED FLEXURAL STRENGTH

COUNT	X1	X2	X3	X4	X5	X6	Y	Z1	Z2	Z3	Z4	Z5	Z6
2	0.38	0.62	0.00	0.00	0.00	0.00	4.43	0.37	1.00	0.81	0.50	2.81	0.03
3	0.44	0.54	0.00	0.00	0.00	0.02	4.43	0.37	1.00	0.78	0.50	2.79	0.03
4	0.52	0.44	0.00	0.00	0.00	0.04	4.43	0.37	1.00	0.75	0.50	2.76	0.03
5	0.54	0.42	0.00	0.00	0.00	0.04	4.43	0.37	1.00	0.74	0.50	2.75	0.03
6	0.56	0.40	0.00	0.00	0.00	0.04	4.43	0.37	1.00	0.73	0.50	2.74	0.03
7	0.56	0.40	0.02	0.00	0.00	0.02	4.43	0.37	1.00	0.73	0.51	2.75	0.03
8	0.58	0.38	0.02	0.00	0.00	0.02	4.43	0.37	1.00	0.72	0.51	2.74	0.03
9	0.60	0.36	0.02	0.00	0.00	0.02	4.43	0.37	1.00	0.71	0.51	2.73	0.03
10	0.60	0.36	0.04	0.00	0.00	0.00	4.43	0.37	1.00	0.71	0.51	2.74	0.03
11	0.62	0.34	0.00	0.00	0.02	0.02	4.43	0.37	1.00	0.68	0.51	2.70	0.03
12	0.62	0.34	0.04	0.00	0.00	0.00	4.43	0.37	1.00	0.70	0.51	2.73	0.03
13	0.64	0.32	0.00	0.00	0.02	0.02	4.43	0.37	1.00	0.67	0.51	2.69	0.03
14	0.64	0.32	0.02	0.00	0.02	0.00	4.43	0.37	1.00	0.67	0.52	2.70	0.03
15	0.66	0.30	0.00	0.00	0.02	0.02	4.43	0.37	1.00	0.66	0.51	2.68	0.03
16	0.66	0.30	0.02	0.00	0.02	0.00	4.43	0.37	1.00	0.66	0.52	2.69	0.03
17	0.68	0.28	0.00	0.00	0.02	0.02	4.43	0.37	1.00	0.65	0.51	2.67	0.03
18	0.68	0.28	0.02	0.00	0.02	0.00	4.43	0.37	1.00	0.65	0.52	2.68	0.03
19	0.70	0.26	0.00	0.00	0.02	0.02	4.43	0.37	1.00	0.64	0.51	2.66	0.03
20	0.70	0.26	0.02	0.00	0.02	0.00	4.43	0.37	1.00	0.64	0.52	2.67	0.03
21	0.72	0.24	0.00	0.00	0.00	0.04	4.43	0.36	1.00	0.65	0.50	2.66	0.03
22	0.72	0.24	0.00	0.00	0.02	0.02	4.43	0.37	1.00	0.63	0.51	2.65	0.03
23	0.72	0.24	0.02	0.00	0.02	0.00	4.43	0.37	1.00	0.63	0.52	2.66	0.03
24	0.74	0.22	0.00	0.00	0.00	0.04	4.43	0.36	1.00	0.64	0.50	2.65	0.03
25	0.74	0.22	0.00	0.00	0.02	0.02	4.43	0.37	1.00	0.62	0.51	2.64	0.03
26	0.74	0.22	0.02	0.00	0.02	0.00	4.43	0.37	1.00	0.62	0.52	2.65	0.03
27	0.76	0.20	0.00	0.00	0.00	0.04	4.43	0.36	1.00	0.63	0.50	2.64	0.03
28	0.76	0.20	0.00	0.00	0.02	0.02	4.43	0.37	1.00	0.61	0.51	2.63	0.03
29	0.76	0.20	0.02	0.00	0.00	0.02	4.43	0.36	1.00	0.63	0.51	2.65	0.03
30	0.76	0.20	0.02	0.00	0.02	0.00	4.43	0.37	1.00	0.61	0.52	2.64	0.03
31	0.76	0.22	0.00	0.02	0.00	0.00	4.43	0.37	1.00	0.61	0.51	2.63	0.03
32	0.78	0.18	0.02	0.00	0.00	0.02	4.43	0.36	1.00	0.62	0.51	2.64	0.03
33	0.78	0.18	0.02	0.00	0.02	0.00	4.43	0.37	1.00	0.60	0.52	2.63	0.03
34	0.78	0.20	0.00	0.02	0.00	0.00	4.43	0.37	1.00	0.60	0.51	2.62	0.03

35	0.80	0.16	0.02	0.00	0.00	0.02	4.43	0.36	1.00	0.61	0.51	2.63	0.03
36	0.80	0.16	0.02	0.00	0.02	0.00	4.43	0.37	1.00	0.59	0.52	2.62	0.03
37	0.80	0.16	0.04	0.00	0.00	0.00	4.43	0.36	1.00	0.61	0.51	2.64	0.03
38	0.82	0.14	0.04	0.00	0.00	0.00	4.43	0.36	1.00	0.60	0.51	2.63	0.03
39	0.82	0.16	0.00	0.00	0.00	0.02	4.43	0.36	1.00	0.59	0.50	2.60	0.03
40	0.84	0.12	0.04	0.00	0.00	0.00	4.43	0.36	1.00	0.59	0.51	2.62	0.03
41	0.84	0.14	0.00	0.00	0.00	0.02	4.43	0.36	1.00	0.58	0.50	2.59	0.03
42	0.84	0.14	0.00	0.00	0.02	0.00	4.43	0.36	1.00	0.57	0.51	2.58	0.03
43	0.86	0.12	0.00	0.00	0.02	0.00	4.43	0.36	1.00	0.56	0.51	2.57	0.03
44	0.86	0.12	0.02	0.00	0.00	0.00	4.43	0.36	1.00	0.57	0.51	2.59	0.03
45	0.88	0.10	0.02	0.00	0.00	0.00	4.43	0.36	1.00	0.56	0.51	2.58	0.03
46	0.90	0.10	0.00	0.00	0.00	0.00	4.43	0.36	1.00	0.55	0.50	2.55	0.03

THE MAXIMUM FLEXURAL STRENGTH PREDICTABLE BY THIS MODEL IS 4.44016 N/SQ.MM.

5.0 CONCLUSIONS

The following conclusions have been established based on this study:-

The flexural strength of laterised concrete depends on the proportioning of the ingredients (water, cement, sand, laterite and coarse aggregate with or without superplasticizer).

The flexural strength model for NLC predicted a maximum flexural strength of 3.996 N/mm^2 while the flexural strength model for HSLC predicted a maximum flexural strength of 4.446 N/mm^2. These strengths are quite comparable to those of normal sand concretes.

The problem of having to go through a rigorous mix-design procedure for a target strength has been reduced by utilizing the models.

HSLC show enormous increases in slump without any significant segregation and the concretes are flowing. This suggests that high-strength concretes can be placed in heavily reinforced and inaccessible areas without mechanical compaction.

The trial and error method of mix proportioning is overcome by using the written programme.

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