ISSN: 2277-9655
Impact Factor: 1.852

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

A New Regression Model for Optimizing Concrete Mixes

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Abstract

Scheffe's and Osadebe's models are the statistical methods of concrete mix design most frequently used in civil engineering. Although these methods are quite suitable for concrete mix optimization, they are greatly limited in that a predetermined number of experiments must be carried out in order to formulate them and they can only be applied for mix ratios that fall within the predetermined observation points. Ibearugbulem's regression model has been formulated as a new model to take care of these inherent problems in Scheffe's and Osadebe's. The formulation started with the Osadebe's procedure and Scheffe's and Osadebe's constraints were imposed on it. Some modifications were made to obtain the new model. This new model has been satisfactorily tested through laboratory experiments on concrete. 150mm x 150mm x 150mm concrete cubes were prepared using each of 21 mix ratios, cured for 28 days, and crushed to determine their compressive strengths. The Fisher f-test revealed that the values of compressive cube strength predicted by the new regression model are very close to those from the experiment, with f-value of 1.510 at 95% confidence level. Thus, within 95% confidence level, the compressive cube strength of concrete made with water, cement, sand, and granite can be predicted using this new model. Therefore, the new Ibearugbulem's Regression Model is suitable for concrete mix optimization. It is therefore, recommended as a new regression model for use in concrete mix design, with merits over the existing Scheffe's simplex and Osadebe's alternative regression models.

Keywords: Concrete mix design, Optimization, Regression, Response function, Scheffe's model,Osadebe's model.

Introduction

Scheffe's and Osadebe's models are the statistical methods of concrete mix design most frequently used in civil engineering, as illustrated by Scheffe (1958, 1963), Obam (1998, 2006), Ibearugbulem (2006), and Osadebe and Ibearugbulem (2008, 2009). Simon et al. (1997) has also used a close method to Scheffe's in concrete mix design. Although these methods have been found suitable for concrete mix optimizations, they still have some inherent problems. Both methods have predetermined number of experiments to be carried out in order to formulate them. These predetermined observation points determine the mix ratios that can be used in them. Hence, they cannot be used to optimize an already conducted series of laboratory tests. This great limitation has led some scholars to search for an alternative optimization method capable of being applied for various laboratory test results. This work presents Ibearugbulems's new regression model as a satisfactory option.

Basic Polynomial Response Function

Osadebe (2003) gives the response function F(z) as shown in equation (1).

$$F(z) = \sum F^m(z_0) \,.\, (z_i - z_0)^m / m! \text{ --------------- } (1)$$
$$0 \le m \le \infty$$

Since $F^m(z_0)$ is the derivative of the function $F(z_0)$ to m degree, equation (1) can be rewritten as in equation (2).

$$F(z) = \sum \frac{d^m F(z_0)}{d Z_0^m} \,.\, \frac{(z_i - z_0)^m}{m!} \text{ -------- } (2)$$
$$0 \le m \le \infty \,,\, 2 \le m \le \infty$$

The number of terms in equation (2) is dependent on the degree of the polynomial, m, and the number of independent variables, i. Taking m equal to 1, equation (2) can be written as in equation (3).

$$F(z) = \sum \frac{d^0 F(z_0)}{d Z_0^0} \,.\, \frac{(z_i - z_0)^0}{0!} + \sum \frac{d F(z_0)}{d Z_0} \,.\, \frac{(z_i - z_0)}{1!} \text{ --------- } (3)$$
$$0 \le m \le \infty \,,\, 2 \le m \le \infty$$

If m is equal to 2, the equation will be as shown in equation (4).

 ISSN: 2277-9655
Impact Factor: 1.852

$$F(z) = \sum \frac{d^0 F(z_0)}{d Z_0^0} \cdot \frac{(z_i - z_0)^0}{0!} + \sum \frac{d F(z_0)}{d Z_0} \cdot \frac{(z_i - z_0)}{1!} + \sum \frac{d^2 F(z_0)}{d Z_0^2} \cdot \frac{(z_i - z_0)^2}{2!} + \sum \frac{d^2 F(z_0)}{d Z_0^2} \cdot \frac{(z_i - z_0)(z_j - z_j)}{2!} \text{----} \quad (4)$$

$0 \le m \le \infty$, $2 \le m \le \infty$

It isassumed that the origin is z_0, which is equal to zero. Since the products and quotients of constants are themselves constants, this equation can be written simply as shown in equation (5).

$F(z) = \sum b_m \cdot z_i^m$ -------------------------- (5)

$0 \le m \le \infty$, $2 \le m \le \infty$

It can be seen from equation (5) that:

For m = 0, $b_m = b$ ------------ (6)

For m = 1, $b_m = b_i$ -------------- (7)

For m = 2, $b_m = b_{ii}$ (for z_i^2 term) ----------- (8)

$b_m = b_{ij}$ (for z_iz_j term) ----------- (9)

For m = 3, $b_m = b_{iii}$ (for z_i^3 term) ---------- (10)

$b_m = b_{ijk}$ (for $z_iz_jz_k$ term) ---------- (11)

$b_m = b_{iij}$ (for $z_i^2z_j$ term) ---------- (12)

$b_m = b_{ijj}$ (for $z_i z_j^2$ term) ---------- (13)

$b_m = b_{iik}$ (for $z_i^2z_k$ term) ---------- (14)

$b_m = b_{ikk}$ (for $z_i z_k^2$ term) ---------- (15)

$b_m = b_{jjk}$ (for $z_j^2z_k$ term) ---------- (16)

$b_m = b_{jkk}$ (for $z_j z_k^2$ term) ---------- (17)

Equation (5) can also be written as in equation (18).

$F(z) = bo + \sum b_m \cdot z_i^m$ ----------------------- (18)

$1 \le m \le \infty$, $2 \le m \le \infty$

For i = n, $1 \le m \le n$ ----------------------- (19)

The implication of equation (19) is that the maximum degree of polynomial that can be used is equal to the number of independent variables, i.

Boundary Conditions

Both Scheffe (1958) and Osadebe and Ibearugbulem (2008) restricted the summation of the independent variables to unity, as expressed in equation (20).

$\sum z_i = 1$ ---------------------------- (20)

Scheffe (1958) also restricted the value of each arbitrary independent variable to between zero and one, as expressed in equation (21).

$0 \le m \le 1$ -------------------------------- (21)

Ibearugbulem's Regression Model

Multiplying equation (20) by b_0 gives equation (22).

$b_0 = \sum b_0z_i$--------------------------------(22)

Multiplying equation (20) by z_i and rearranging gives equation (23).

$Z_i^2 = z_i - z_1z_i - z_2z_i - \ldots - z_iz_n$------------(23)

Multiplying equation (20) by z_i^r and rearranging gives equation (24).

$Z_i^{r+1} = z_i^r - z_1z_i^r - z_2z_i^r - \ldots - z_i^rz_n$-------(24)

Taking the highest degree of the polynomial and substituting equations (22) and (24) into equation(18) and factorizing, making sure that every term has no independent variable of more than one degree will yield equation (25), which is the new Ibearugbulem's regression model.

$F(z) = \sum\propto_i z_i + \sum\propto_{ij} z_i z_j + \sum\propto_{ijk} z_i z_j z_k + \ldots + \sum\propto_{ijk\ldots\infty} z_i z_j z_k \ldots z_\infty$ ------- (25)

$1 \le i \le \infty,\ 1 \le i \le j \le \infty,\ 1 \le i \le j \le k \le \infty,\ \ldots,\ 1 \le i \le j \le k \le \ldots \le \infty$

For i = 2, equation (25) can be expressed as in equation (26).

$F(z) = \propto_1 z_1 + \propto_2 z_2 + \propto_{12} z_1 z_2$ --------- (26)

For i = 3, equation (25) can be expressed as in equation (27).

$F(z) = \propto_1 z_1 + \propto_2 z_2 + \propto_3 z_3 + \propto_{12} z_1 z_2 + \propto_{13} z_1 z_3 + \propto_{23} z_2 z_3 + \propto_{123} z_1 z_2 z_3$ ---- (27)

For i = 4, equation (25) can be expressed as in equation (28).

$F(z) = \propto_1 z_1 + \propto_2 z_2 + \propto_3 z_3 + \propto_4 z_4 + \propto_{12} z_1 z_2 + \propto_{13} z_1 z_3 + \propto_{14} z_1 z_4 + \propto_{23} z_2 z_3 + \propto_{24} z_2 z_4 + \propto_{34} z_3 z_4 + \propto_{123} z_1 z_2 z_3 + \propto_{124} z_1 z_2 z_4 + \propto_{134} z_1 z_3 z_4 + \propto_{234} z_2 z_3 z_4 + \propto_{1234} z_1 z_2 z_3 z_4$ ------ (28)

Pseudo and Actual Variables

The independent variables used in the regression function (equation25) are pseudo variables. They are not the actual variables. However, a relationship exists between the pseudo variables, z_i and the actual variables, s_i.

$Z_i = s_i / S$ -------------------- (29)

$S = \sum s_i$ ------------------- (30)

COEFFICIENTS OF THE REGRESSION FUNCTION

Summing equation (25) for n observation points gives equation (31).

$$\sum_r F(z) = \sum_r \sum \alpha i\, zi + \sum_r \sum \alpha ij\, zi\, zj + \ldots \quad ------(31)$$

$1 \le r \le n$

Multiplying equation (31) by z_w gives equation (32).

$$\sum_r z_w . F(z) = \sum_r \sum \alpha i\, zi . z_w + \sum_r \sum \alpha ij\, zi\, zj . z_w + \ldots \quad ------(32)$$

Multiplying equation (31) by $z_q z_s z_t \ldots$ gives equation (33).

$$\sum_r z_q . z_s z_t\, F(z) = \sum_r \sum \alpha i\, zi . z_q . z_s z_t + \sum_r \sum \alpha ij\, zi\, zj . z_q . z_s z_t + \ldots \quad ------(33)$$

Adding equations (32) and (33) will give n simultaneous equations with n unknowns, represented in matrix form as shown in equation (34).

$$\begin{bmatrix} \sum_r z_1 . F(z) \\ \sum_r z_2 . F(z) \\ \sum_r z_3 . F(z) \\ \vdots \\ \sum_r z_1 z_2 z_3 \ldots F(z) \end{bmatrix} = \begin{bmatrix} \sum_r\sum z_1 . z_1 & \sum_r\sum z_2 . z_1 & \sum_r\sum z_3 . z_1 & \ldots & \ldots & \ldots & \ldots \\ \sum_r\sum z_1 . z_2 & \sum_r\sum z_2 . z_2 & \sum_r\sum z_3 . z_2 & \ldots & \ldots & \ldots & \ldots \\ \sum_r\sum z_1 . z_3 & \sum_r\sum z_2 . z_3 & \sum_r\sum z_3 . z_3 & \ldots & \ldots & \ldots & \ldots \\ \vdots & \vdots & \ldots & \ldots & \ldots & \ldots & \ldots \\ \sum_r\sum z_1 . z_1 . z_2 & \ldots & \sum_r\sum z_2 . z_1 . z_2 & . & . & . & . \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \vdots \\ \alpha_{123\ldots} \end{bmatrix} — (34)$$

Solving the simultaneous equation expressed in equation (34) gives the values of the coefficients of regression function in equation (25). Equation (34) can be written in a short form as shown in equation (34b).

$[F(z).Z] = [CC]\ [\alpha]$--------------- (34b).

Where CC is always a symmetric matrix. For a mixture of three components, CC is a 7 x 7 matrix as shown in table 1.

Table 1: Matrix showing elements of CC matrix of a mix of three components

ΣΣZ1Z1	ΣΣZ1Z2	ΣΣZ1Z3	ΣΣZ1Z1Z2	ΣΣZ1Z1Z3	ΣΣZ1Z2Z3	ΣΣZ1Z1Z2Z3
ΣΣZ1Z2	ΣΣZ2Z2	ΣΣZ2Z3	ΣΣZ1Z2Z2	ΣΣZ1Z3Z2	ΣΣZ2Z2Z3	ΣΣZ1Z2Z3Z2
ΣΣZ1Z3	ΣΣZ2Z3	ΣΣZ3Z3	ΣΣZ1Z2Z3	ΣΣZ1Z3Z3	ΣΣZ2Z3Z3	ΣΣZ1Z2Z3Z3
ΣΣZ1Z1Z2	ΣΣZ1Z2Z2	ΣΣZ1Z2Z3	ΣΣZ1Z1Z2Z2	ΣΣZ1Z1Z2Z3	ΣΣZ1Z2Z2Z3	ΣΣZ1Z1Z2Z3Z2
ΣΣZ1Z1Z3	ΣΣZ1Z3Z2	ΣΣZ1Z3Z3	ΣΣZ1Z1Z2Z3	ΣΣZ1Z1Z3Z3	ΣΣZ1Z2Z3Z3	ΣΣZ1Z1Z2Z3Z3
ΣΣZ1Z2Z3	ΣΣZ2Z2Z3	ΣΣZ2Z3Z3	ΣΣZ1Z2Z2Z3	ΣΣZ1Z2Z3Z3	ΣΣZ2Z2Z3Z3	ΣΣZ1Z1Z2Z3Z3
ΣΣZ1Z1Z2Z3	ΣΣZ1Z2Z3Z2	ΣΣZ1Z2Z3Z3	ΣΣZ1Z1Z2Z3Z2	ΣΣZ1Z1Z2Z3Z3	ΣΣZ1Z1Z2Z3Z3	ΣΣZ1Z1Z2Z2Z3Z3

Illustrative Application of the New Regression Model

The new Ibearugbulem's regression model has been satisfactorily tested through laboratory experiments on concrete. The concrete was made using potable water; Ibeto brand of Ordinary Portland Cement that conforms to BS 12 (1978); river sand with compacted and non-compacted bulk densities both equal to 1675 Kg/m^3, free from deleterious matters, and well graded in the size range of 0.15mm $\leq x \leq$ 4.75mm as shown in figure 1; and granite free from deleterious matters, with compacted and non-compacted bulk densities of 1603 Kg/m^3 and 1368 Kg/m^3 respectively, in conformity with BS 882 (1992), and particle size range of 4.75 mm $\leq x \leq$ 19 mm as shown in figure 2.

The test was carried out in accordance with BS 1881 (1983). Batching of the materials was by mass. A total of 21 mix ratios were used, as shown in table 2. The first 12 mix ratios designated with Ni were used to formulate the model. The remaining 9 mix ratios designated with Ci were used as control to test the adequacy of the model. 150mm x 150mm x 150mm concrete cubes were prepared using each of these 21 mix ratios, cured for 28 days, and crushed to determine their compressive strengths, which were calculated using equation 35. (See values in table 5).

$$compressive\ cube\ strength = \frac{failure\ load\ (N)}{cross\ section\ area\ (mm^2)} --------- 35$$

Table 2: Concrete mix ratios used in this work

Mixes used in formulating the model

S/N	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12
WATER	0.45	0.55	0.65	0.7	0.45	0.55	0.65	0.7	0.45	0.55	0.65	0.7
CEMENT	1	1	1	1	1	1	1	1	1	1	1	1
RIVER SAND	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2	2	2	2
GRANITE	1.7	1.7	1.7	1.7	2	2	2	2	2.5	2.5	2.5	2.5

Mixes for control

S/N	C1	C2	C3	C4	C5	C6	C7	C8	C9
WATER	0.575	0.5	0.6	0.575	0.5	0.6	0.575	0.5	0.6
CEMENT	1	1	1	1	1	1	1	1	1
RIVER SAND	1.5	1.5	1.5	1.5	1.5	1.5	2	2	2
GRANITE	1.7	1.7	1.7	2	2	2	2.5	2.5	2.5

Four materials were used, namely water, cement, sand, and gravel; but the components of the mix are three, namely water/cement ratio (S1), sand/cement ratio (S2), and granite/cement ratio (S3). It should be noted from equations (29) and (30) that S = S1 + S2 + S3 and Zi = Si / S. This transformation enables the model to reduce the size of CC matrix from 14 X 14 to 7 X 7. Although the actual number of elements in the concrete mix is 4, this new regression model has kept cement constant, thereby reducing the components to 3. This is another improvement of the present regression model over Scheffe's and Osadebe's regression models. Table 3 shows values of S and Z, while table 4 shows the Z-matrix for the concrete mixes.

Table 3: Values of S and Z

S/N	S1	S2	S3	S	Z1	Z2	Z3	Z1Z2	Z1Z3	Z2Z3	Z1Z2Z3
N1	0.45	1.5	1.7	3.65	0.123288	0.410959	0.465753	0.050666	0.057422	0.191406	0.023598
N2	0.55	1.5	1.7	3.75	0.146667	0.4	0.453333	0.058667	0.066489	0.181333	0.026596
N3	0.65	1.5	1.7	3.85	0.168831	0.38961	0.441558	0.065778	0.074549	0.172036	0.029045
N4	0.7	1.5	1.7	3.9	0.179487	0.384615	0.435897	0.069034	0.078238	0.167653	0.030092
N5	0.45	1.5	2	3.95	0.113924	0.379747	0.506329	0.043262	0.057683	0.192277	0.021905
N6	0.55	1.5	2	4.05	0.135802	0.37037	0.493827	0.050297	0.067063	0.182899	0.024838
N7	0.65	1.5	2	4.15	0.156627	0.361446	0.481928	0.056612	0.075483	0.174191	0.027283
N8	0.7	1.5	2	4.2	0.166667	0.357143	0.47619	0.059524	0.079365	0.170068	0.028345
N9	0.45	2	2.5	4.95	0.090909	0.40404	0.505051	0.036731	0.045914	0.204061	0.018551
N10	0.55	2	2.5	5.05	0.108911	0.39604	0.49505	0.043133	0.053916	0.196059	0.021353
N11	0.65	2	2.5	5.15	0.126214	0.38835	0.485437	0.049015	0.061269	0.188519	0.023794
N12	0.7	2	2.5	5.2	0.134615	0.384615	0.480769	0.051775	0.064719	0.184911	0.024892
C1	0.575	1.5	1.7	3.775	0.152318	0.397351	0.450331	0.060524	0.068593	0.17894	0.027256
C2	0.5	1.5	1.7	3.7	0.135135	0.405405	0.459459	0.054785	0.062089	0.186267	0.025171
C3	0.6	1.5	1.7	3.8	0.157895	0.394737	0.447368	0.062327	0.070637	0.176593	0.027883
C4	0.575	1.5	2	4.075	0.141104	0.368098	0.490798	0.05194	0.069254	0.180662	0.025492
C5	0.5	1.5	2	4	0.125	0.375	0.5	0.046875	0.0625	0.1875	0.023438
C6	0.6	1.5	2	4.1	0.146341	0.365854	0.487805	0.05354	0.071386	0.178465	0.026117
C7	0.575	2	2.5	5.075	0.1133	0.394089	0.492611	0.04465	0.055813	0.194132	0.021995
C8	0.5	2	2.5	5	0.1	0.4	0.5	0.04	0.05	0.2	0.02
C9	0.6	2	2.5	5.1	0.117647	0.392157	0.490196	0.046136	0.05767	0.192234	0.022616

Table 4: Z-matrix for the concrete mixes

S/N	Z1	Z2	Z3	Z1Z2	Z1Z3	Z2Z3	Z1Z2Z3
N1	0.123288	0.410959	0.465753	0.050666	0.057422	0.191406	0.023598
N2	0.146667	0.4	0.453333	0.058667	0.066489	0.181333	0.026596
N3	0.168831	0.38961	0.441558	0.065778	0.074549	0.172036	0.029045
N4	0.179487	0.384615	0.435897	0.069034	0.078238	0.167653	0.030092
N5	0.113924	0.379747	0.506329	0.043262	0.057683	0.192277	0.021905
N6	0.135802	0.37037	0.493827	0.050297	0.067063	0.182899	0.024838
N7	0.156627	0.361446	0.481928	0.056612	0.075483	0.174191	0.027283
N8	0.166667	0.357143	0.47619	0.059524	0.079365	0.170068	0.028345
N9	0.090909	0.40404	0.505051	0.036731	0.045914	0.204061	0.018551

N10	0.108911	0.39604	0.49505	0.043133	0.053916	0.196059	0.021353
N11	0.126214	0.38835	0.485437	0.049015	0.061269	0.188519	0.023794
N12	0.134615	0.384615	0.480769	0.051775	0.064719	0.184911	0.024892

Substituting the values from Z matrix into the CC matrix of table 1 gives the CC matrix with its inverse as follows:

CC MATRIX

0.23533843	0.63449416	0.78210875	0.09008663	0.11068002	0.30029023	0.04234662
0.634494156	1.787028771	2.205412504	0.2441173	0.300290228	0.851584964	0.115493981
0.782108751	2.205412504	2.733601975	0.300290228	0.371138501	1.053537312	0.142449623
0.090086629	0.2441173	0.300290228	0.034543454	0.042346623	0.115493981	0.016229859
0.110680022	0.300290228	0.371138501	0.042346623	0.052175383	0.142449623	0.019952943
0.300290228	0.851584964	1.053537312	0.115493981	0.142449623	0.406721281	0.054769116
0.042346623	0.115493981	0.142449623	0.016229859	0.019952943	0.054769116	0.00764367

CC INVERSE

-73559048.5	-16926229.03	-11490356.85	217125188.3	174752656.1	57228644.19	-449843017.9
-16822924.54	-3213812.688	-2204745.839	48990836.42	39601483.85	10959052.47	-103073903.7
-11410062.8	-2202406.631	-1493936.761	33290084.94	26790789.29	7468757.982	-69803211.94
216858850.9	49234476.3	33485486.43	-639132974.3	-514881232.2	-166635148.5	1325720992
174485761.8	39785488.68	26939851.67	-514726169.1	-413800752.8	-134366565.4	1066003052
56845502.85	10951260.6	7471377.491	-165711434.8	-133663987.4	-37238507.59	347957039.6
-448892744.6	-103486990.3	-70145803.87	1324544818	1065377673	349560793.4	-2740342267

Using the values of Zi from table 3 and the laboratory compressive cube strength shown in table 5, $[F(z).Z] = \sum_{r} z_q . z_s z_t F(z)$ was obtained as:

∑(Z1.F(Z)) = 44.89459
∑(Z2.F(Z)) = 128.6564
∑(Z3.F(Z)) = 159.219
∑(Z1Z2.F(Z)) = 17.28834
∑(Z1Z3.F(Z)) = 21.32949
∑(Z2Z3.F(Z)) = 61.54378
∑(Z1Z2Z3.F(Z)) = 8.210941

Substituting $[F(z).Z]$ and inverse of CC matrix into equation 34 gave the coefficients, $[\alpha]$ of the regression model as shown in table 4.

Table 4: Values of the coefficients of the model

α1	α2	α3	α12	α13	α23	α123
-2425.34	4164.749	2805.652	3004.033	2516.641	-13542.6	-16616

Using the coefficient, αi of table 4, the mix ratios of table 2, and equations (29), (30) and (34), the compressive cube strengths predicted by the model were obtained as shown in table 5, together with their laboratory equivalents.

ISSN: 2277-9655
Impact Factor: 1.852

Table 5: Compressive cube strength (Y) from laboratory and Model

Mixes used in formulating the model

S/N	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12
Y_{Lab} (N/mm^2)	31.85	27.85	24.51	23.70	32.59	29.62	25.11	23.55	33.11	30.22	26.51	24.15
Y_{Model} (N/mm^2)	31.76	28.02	24.81	23.31	33.06	28.88	25.29	23.63	33.38	29.51	26.28	24.84

Mixes for control

S/N	C1	C2	C3	C4	C5	C6	C7	C8	C9
Y_{Lab} (N/mm^2)	25.77	29.92	25.70	26.96	30.22	26.37	27.18	31.63	27.03
Y_{Model} (N/mm^2)	27.18	29.80	26.37	27.94	30.88	27.03	28.65	31.35	27.83

Fisher f- test was carried out to determine whether there is significant difference between values of compressive strengths from the laboratory and those from the model. The result is shown in table 6.

Table 6: Fisher F- test on the compressive strength from the model using the nine control mixes

RESPONSE SYMBOL	Y_P	Y_M	Y_P - $ÿ_P$	Y_M - $ÿ_M$	$(Y_P - Ÿ_p)^2$	$(Y_M - ÿ_M)^2$
C1	25.77	27.18	-2.094	-1.379	4.387	1.901
C2	29.92	29.8	2.056	1.241	4.225	1.540
C3	25.7	26.37	-2.164	-2.189	4.685	4.791
C4	26.96	27.94	-0.904	-0.619	0.818	0.383
C5	30.22	30.88	2.356	2.321	5.549	5.388
C6	26.37	27.03	-1.494	-1.529	2.233	2.338
C7	27.18	28.65	-0.684	0.091	0.468	0.008
C8	31.63	31.35	3.766	2.791	14.179	7.790
C9	27.03	27.83	-0.834	-0.729	0.696	0.531
Total	250.78	257.03			37.241	24.671
Mean	27.86	28.56				

Legend: $ÿ_P$ = Y_P / N, $ÿ_M$ = Y_M /N, N = 9

$S_p^2 = (Y_p - ÿ_p)^2 / (N – 1) = 37.241 / (9 -1) = 4.655$

$S_M^2 = (Y_M - ÿ_M)^2 / (N – 1) = 24.671/(9 - 1) = 3.084$

Therefore, $S_1^2 = 4.655$ and $S_2^2 = 3.084$.

$f_{calculated} = S_1^2 / S_2^2 = 4.655 / 3.084 = 1.510$

From statistic tables, $f_{.0.05}$ (8,8) = 3.44 and 1/f = 0.662.

Thus, the condition 1/F S_1^2 / S_2^2 F has been satisfied.Therefore, the difference between lab result and model result is not significant

Discussion and Conclusion

The Fisher f-test revealed that the values of compressive cube strength predicted by the new regression model are very close to those from the experiment. The calculated f (f = 1.510) is less than the allowable f from statistic table (f = 3.44) at 95% confidence level. Laboratory conditions and some human errors during the conduct of the laboratory experiment might be attributed to any difference between laboratory compressive cube strength and compressive cube predicted by the model. Thus, within 95% confidence level, the compressive cube strength of concrete made with water, cement (OPC), river sand, and granite can be predicted by using this new model. Therefore, this new Ibearugbulem's Regression Model can be used to optimize mixes at 95% confidence level by Fisher f-test. It is therefore, recommended as a new regression model for use in concrete mix design, with merits over the existing Scheffe's simplex and Osadebe's alternative regression models.

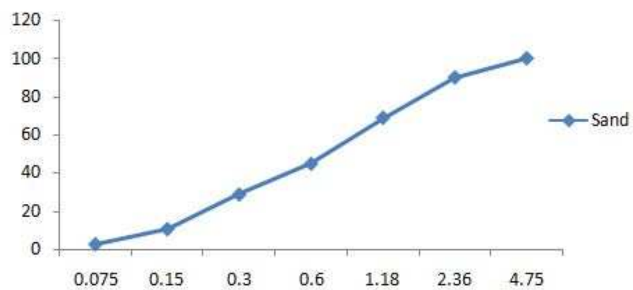

Figure 1: Grain size distribution of the sand used

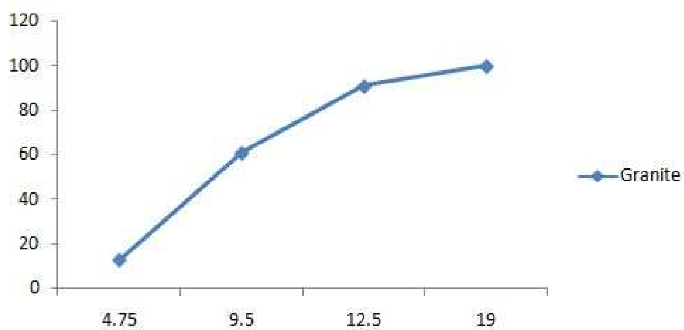

Figure 2: Grain size distribution of the granite used

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