Nigerian Journal of Technology (NIJOTECH)
Vol. 36, No. 1, January 2017, pp. **32 – 38**

Print ISSN: 0331-8443, Electronic ISSN: 2467-8821
www.nijotech.com
http://dx.doi.org/10.4314/njt.v36i1.5

OPTIMISATION OF COMPRESSIVE STRENGTH OF PERIWINKLE SHELL AGGREGATE CONCRETE

S. Egamana[1] and S. Sule[2,*]
[1] THE SHELL PETROLEUM DEVELOPMENT COMPANY LIMITED, EPG – PESI, PORT HARCOURT, RIVERS STATE. NIGERIA
[2] CIVIL AND ENVIRONMENTAL ENGINEERING, UNIVERSITY OF PORT HARCOURT, P.M.B. 5323, RIVERS STATE. NIGERIA
E-mail addresses: [1] *samuel.egamana@yahoo.com,* [2] *samvictoryahead@yahoo.com*

ABSTRACT
In this paper, a regression model is developed to predict and optimise the compressive strength of periwinkle shell aggregate concrete using Scheffe's regression theory. The results obtained from the derived regression model agreed favourably with the experimental data. The model was tested for adequacy using a student t-test at 95% confidence level and was found to be adequate. A computer programme coded in basic language was used to select the mix ratios that optimized the compressive strength of periwinkle shell aggregate concrete. The optimum compressive strength was found to be 19.50N/mm²corresponding to a mix ratio of 1:3:6 (cement, sand and periwinkle shell) at a water-cement ratio of 0.65. With the formulated model, the mix ratios corresponding to a desired strength value can be predicted with reasonable accuracy and without waste of time.

Keywords: *Compressive strength, desired strength, mix ratios, periwinkle shell aggregate concrete, regression model, optimise*

1. INTRODUCTION

Coarse aggregate usually constitutes about 55% and 60% of the total concrete volume and is one of the major cost components of concrete and is rated second after cement in terms of high cost. The high cost of granite has made it difficult for most citizens of Nigeria to afford their own accommodation. As a result, alternative materials to granite as coarse aggregates in concrete production would help reduce the cost of concrete production in Nigeria. Any material that can replace granite in concrete production and is much cheaper will reduce the cost of concrete production. Efforts are therefore, being directed towards using materials that can partly or wholly replace granite in concrete production without adversely affecting the structural properties of concrete. Identification of cheaper coarse aggregate substitute materials has therefore, become a task of paramount importance to both civil and structural engineers. Recently, periwinkle shells have been introduced as one of the substitute materials for coarse aggregates in concrete production [1–6]. Periwinkle shells are abundant in the swampy mud and river banks of the Niger Delta area of Nigeria. The strength property of concrete is a function of the proportions of the various component materials [7-11].

This paper demonstrates the applicability of Scheffe's regression theory to determine the mix ratios that optimise the compressive strength of periwinkle shell aggregate concrete.

2. FORMULATION OF OPTIMISATION MODEL

According to [5], the regression equation for a 4-component mixture based on a (4, 2) factor space is given by:

$$\hat{Y} = \alpha_1 X_1 + \alpha_2 X_3 + \alpha_3 X_3 + \alpha_3 X_4 + \alpha_{12} X_1 X_2 + \alpha_{13} X_1 X_3 + \alpha_{14} X_1 X_4 + \alpha_{23} X_2 X_3 + \alpha_{24} X_2 X_4 + \alpha_{34} X_3 X_4 \quad (1)$$

$$\alpha_i = b_0 + b_i + b_{ii}; \alpha_{ij} = b_{ii} - b_{ij} \quad (2)$$

Scheffe gave the solution of equation (1) for the polynomial coefficients as follows:

$$\alpha_i = Y_i \text{ and } \alpha_{ij} = 4Y_i - 2Y_{ij} - 2Y_j \quad (3)$$

Where:

$$\alpha_i = \alpha_1, \alpha_3, \dots, \alpha_4$$
$$\alpha_{ij} = \alpha_{12}, \alpha_{13}, \alpha_{14}, \dots, \alpha_{23}$$

According to Scheffe, the objective function to be optimized is subject to equation (1) [12].

$$\sum_{i-1}^{q} X_i - 1 = 0 \quad (4)$$

Where: $X_i \geq 0$ is the component proportion, q is the number of components in the mixture.

*** Corresponding author, tel: +234-806-673-2115**

In (4), X_1 is the pseudo proportion of water, X_2 is the pseudo proportion of cement, X_3 is the pseudo proportion of sand, X_4 is the pseudo proportion of periwinkle shell.

According to Scheffe, the number required for the mixture experiment (q, n) is given by:

$$N = \frac{(q+n-1)}{n!\,(q-1)!} \quad (5)$$

Where: n is the degree of the polynomial. From equation (5), the number of experimental points is: $\frac{(4+2-1)!}{2!(4-1)!} = 10$

Let the actual and pseudo components be denoted by S_i and X_i. The relationship between S_i and X_i is given by:

$$X = BS \quad (6)$$

Where: B is the inverse of matrix

Similarly, the inverse transformation from pseudo to actual components according to [5] is given by:

$$S = AX \quad (7)$$

A is the transpose of the real mix ratios, S is the real mix ratio, X is the coded mix ratio

3. MATERIALS AND METHOD

3.1 Materials

The periwinkle shells used for this study were obtained from heaps at Okrika waterside, by Hospital Road, Port Harcourt, Rivers State, Nigeria. The length varied from 31.8mm to 63.96mm and diameter of about 16.9mm near one end and tapering to a point at the other end. The periwinkle shell aggregates were thoroughly washed to remove dirt and later air dried for use in concrete production.

The sand used was collected from Opi River, Nsukka-Enugu State, Nigeria. It was prepared to [13] requirements. The grading was carried out to [14] requirements. The sand belongs to grading zone 2 judging from the grading limits for fine aggregates [15]. The cement used was ordinary portland cement obtained from Nsukka market. The water was portable and free of organic materials.

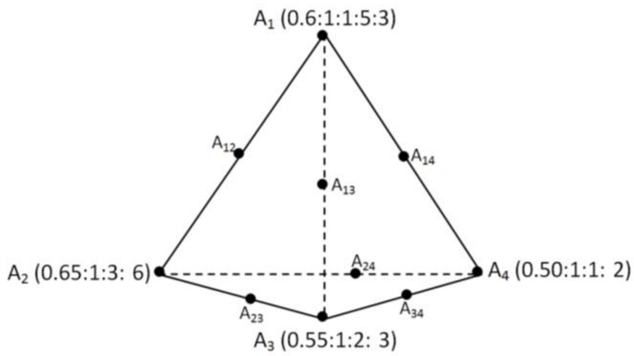

Fig 1: A simplex lattice for a (4, 2) factor space

Using equation (7), the actual mix ratios are given by:

$$\begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{bmatrix} = \begin{bmatrix} 0.6 & 0.5 & 0.55 & 0.65 \\ 1.0 & 1.0 & 1.0 & 1.0 \\ 1.5 & 1.0 & 2.0 & 3.0 \\ 3.0 & 2.0 & 6.0 & 6.0 \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \end{bmatrix} \quad (8)$$

Using equation (8), the actual components for all trial and control mixes were obtained (Fig. 1).

3.2 Method

3.1 Compressive Strength Test

Cube specimens of size 150mm x 150mm x 150mm were made and tested for compressive strength at 28 days. The cube specimens were prepared by filling each moulds in three layers and compacted in accordance with the requirements of [16]. The cubes were removed from moulds after 24hours of casting and later transferred to a curing tank and allowed to cure for 28days.

Table 1: Pseudo and actual mix ratios for trial points based on (4, 2) factor space

S/N	X_1	X_2	X_3	X_4	Response	S_1	S_2	S_3	S_4
1	1	0	0	0	y_1	0.6	1	1.50	3.0
2	0	1	0	0	y_2	0.5	1	1	2.0
3	0	0	1	0	y_3	0.55	1	2.0	3.0
4	0	0	0	1	y_4	0.65	1	3.0	6.0
5	0.5	0.5	0	0	y_{12}	0.55	1	1.25	2.5
6	0.5	0	0.5	0	y_{13}	0.575	1	1.750	3.0
7	0.5	0	0	0.5	y_{14}	0.625	1	2.250	4.5
8	0	0	0.5	0.5	y_{23}	0.525	1	1.5	2.5
9	0	0.5	0	0.5	y_{24}	0.575	1	2.0	4.0
10	0	0	0.5	0.5	y_{34}	0.60	1	2.5	5.4

Table 2: Pseudo and Actual mix ratios for control points based on (4, 2) factor space

S/N	X_1	X_2	X_3	X_4	Response	Z_1	Z_2	Z_3	Z_4
1	0.25	0.25	0.25	0.25	C_1	0.576	1.00	1.875	3.750
2	0.25	0.50	0.25	0.00	C_2	0.538	1.00	1.375	2.5
3	0.25	0.50	0.00	0.25	C_3	0.563	1.00	1.625	3.25
4	0.50	0.25	0.25	0.00	C_4	0.563	1.00	1.50	2.75
5	0.50	0.25	0.00	0.25	C_5	0.588	1.00	1.75	3.50
6	0.25	0.25	0.50	0.00	C_6	0.55	1.00	1.625	2.75

Table 3: Compressive Strength Results based on 28 days Test (N/mm²)

No. of Expt	Replicates	Response (N/mm²)	Symbol of response	$\sum_{i-1}^{n} y_i$	$\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n}$
1	A B	18.4 19.2	Y_1	37.6	18.8
2	A B	14.4 15.4	Y_2	29.8	14.9
3	A B	14.5 13.0	Y_3	27.5	13.75
4	A B	18.5 20.5	Y_4	39.0	19.5
5	A B	15.0 15.0	Y_{12}	30.0	15
6	A B	17.0 18.0	Y_{13}	35.0	17.5
7	A B	15.0 15.0	Y_{14}	30.5	15.25
8	A B	17.5 16.0	Y_{23}	33.5	16.75
9	A B	13.5 13.0	Y_{24}	26.5	13.25
10	A B	17.0 16.0	Y_{34}	33.0	16.5
11	A B	15.5 13.5	C_1	29	14.5
12	A B	18.5 17.0	C_2	35.5	17.75
13	A B	15.0 15.5	C_3	30.5	15.25
14	A B	16.0 17.0	C_4	33.0	16.5
15	A B	14.0 13.5	C_5	27.5	13.75
16	A B	16.5 14.5	C_6	31.0	15.50

The cubes were then weighed and tested in compression using the Avery Denison Compression Machine with load capacity of 200KN at constant rate of 15kN/s. The maximum load at failure was recorded. Two replicates where produced from each mix ratio, giving a total of 32 cubes. The compressive strength, (f_c) of periwinkle shell aggregate concrete was determined using the formula:

$$f_c = \frac{Maximum\ load\ at\ gailure}{Cross - sectional\ area\ of\ cube} M/mm^2 \qquad (9)$$

4. RESULTS AND DISCUSSION

The results of the compressive strength obtained from both the trial and control mixes are as given in Table 3. The compressive strength of each cube was determined using equation (9). From equation (3) and Table 3, the coefficients of equation (2) are obtained as follows:

$$\alpha_1 = 18.80, \quad \alpha_2 = 14.90, \quad \alpha_3 = 13.75 \quad \alpha_4 = 19.50$$
$$\alpha_{12} = 7.40, \quad \alpha_{13} = 4.90 \quad \alpha_{14} = 15.60,$$
$$\alpha_{23} = 9.80 \quad \alpha_{24} = 15.80 \quad \alpha_{34} = -0.50$$

Substitution of the obtained values of coefficients into equation (1) gives:

$$Y = 18.8X_1 + 14.9X_2 + 13.8X_3\ 19.5X_4 - 7.4X_1X_2 + 4.9X_1X_3 - 15.6\,X_1X_4 + 9.8X_2X_3 - 15.8X_2X_4 - 0.50X_3X_4 \qquad (10)$$

Equation (10) is the mathematical model for the prediction and optimisation of compressive strength of periwinkle shell aggregate concrete based on 28days strength.

Table 4: Particle Size Distribution of Fine Aggregate

Sieve size (mm)	Mass of sample retained (g)	Percentage Retained (%)	Cumulative Percentage Retained (%)	Percentage Passing (%)
10	0	0	0	100.00
4.75	16	3.20	3.20	96.80
2.36	34	6.80	10.00	90.00
1.18	86	17.20	27.20	72.80
0.60	78	15.60	42.80	57.20
0.300	214	42.80	85.60	14.40
0.15	70	14.00	99.60	0.400
Pan	2	0.400	100	

Table 5: Grading Limits for Fine aggregate [15]

BS Sieve (mm)	Sieve	Percentage	By Mass	Passing	Passing
		Grading Zone 1	Grading Zone 2	Percentage Grading Zone 3	Percentage Grading Zone 4
10	3/8in	100	100	100	100
5	3/16in	90 – 100	90 – 100	90 - 100	95 - 100
2.36	No. 7	60 – 95	85 – 100	85 - 100	95 - 100
1.18	No. 14	30 – 70	75 – 100	75 - 100	90 - 100
600 μm	No. 25	15 – 34	60 – 79	60 - 79	80 - 100
300 μm	No. 52	5 – 20	12- 40	12- 40	15- 50
15 μm	No. 100	0 – 10	0 – 10	0 - 10	0 - 15

Table 6: Student t-Test for Six Control Points

S/N	Control points	Y_O	Y_P	Δy	T
1	C_1	14.50	14.94	-0.44	-0.66
2	C_2	17.75	17.30	0.45	0.64
3	C_3	15.25	14.90	0.35	0.53
4	C_4	16.50	18.00	-1.50	-2.12
5	C_5	13.75	16.00	-2.25	-2.18
6	C_6	15.50	16.00	-0.50	-0.71

Legend: Y_O , Y_P = experimental and predicted values of compressive strength respectively

4.1 Testing the Adequacy of the formulated Mathematical Model

The formulated optimisation model was tested for adequacy using a student t-test at 5% level of significance. The tabulated t value (2.92) was found to be greater than any of the calculated t values for all the six control points as shown in Table6.The results of the computer programmes coded in basic language are shown in the appendix. The computer programmes select the best mix proportions corresponding to a desired strength value with accuracy and without waste of time.

5. CONCLUSION

The strength of concrete is dependent on the proportion of the component materials (water, cement, sand and periwinkle shell). The maximum strength predictable by the model is 19.50N/mm^{2}and the corresponding mix ratio is 1:3.0:6.0 at a water-cement ratio of 0.65. The Student t-test showed that the optimisation model is adequate.

The model can be used to predict and optimize other structural properties of concrete such as flexural strength, shear strength, split tensile strength, etc. With the written computer programmes, the best mix ratios corresponding to particular desired strength are selected with accuracy and without waste of time.

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7. APPENDIX

```
10 REM A QBasic program that optimises the proportion of concrete mixes
for perinwinkle shell aggregates
20 REM VARIABLE Used:
30 REM zi, z2,z3, z4, xl, x2, x3, x4, yzuax, yout, yin
40 REM Begin Main Program
45 OPEN "WINKLE.SAM" FOR APPEND AS #1
50 LET Count = 0
60 CLS
70 GOSUB 100
75 CLOSE #1
80 END
90 REM End of Main Program
100 REM Procedure Begin
110 LET ymax = 0
120 PRINT #1,
130 PRINT 11,
140 PRINT #1, "A Computer Model for the Computation of Concrete Mix
Proportions"
160 PRINT *1, "Corresponding to a Desired Strength using periwinkle
shell aggregates"
170 PRINT #1,
180 INPUT "Enter Desired Strength"; yin
185 PRINT #1, "Enter Desired Strength"; yin; "N/sq.mm"
190 GOSUB 400
200 FOR xl = 0 TO 1 STEP .01
210 FOR x2 0 TO 1 - xl STEP .01
220 FOR x3 = 0 TO 1 xl - x2 STEP .01
230 IETx4 =1 - xl -x2 - x3
240 LET yout = 18.8 * xl + 14.9 * x2 + 13.8 * x3 + 19.5 * x4 7.4 * xl
* x2 + 4.9 * xl * x3 15.6 * xl * x4 + 9.8 * x2 * x3 — 15.8 * x2 * x4
```

```
— 5*x3*x4
250 GOSUB 500

260 IF (ABS(yin - yout) <= .001) THEN 270 ELSE 290
270 LET Count = Count + 1
280 GOSUB 600
290 NEXT x3
291 NEXT x2
292 NEXT xl
295 PRINT #1,
300 IF (Count > 0> THEN GOTO 310
310 PRINT #1, "The maximum value of strength predictable by this model
is "; ymax; "N/sq.mm"
320 SLEEP (2)
330 GOTO 360
340 PRINT #1, "Sorry! Desired Strength out of range of model"
350 SLEEP 2
360 RETURN

400 REM Procedure Print Heading
410 PRINT #1,
420 PRINT #1, TAB(1); "COUNT"; TAB(7); " xl"; TAB(13); " x2"; T2B(20); x3" TAB(29) " x4" TAB(35) " y"- TJ.B(4l) " zl"
TAB(47) "
TAB(54); z3"; TAB(62); " z4"
430 PRINT #1,
440 RETURN
500 REM Procedure CheckMax
510 IF ymax < yout THEN ymax = yout ELSE ymax = ymax
520 RETURN
600 REM Procedure Out Results
610 LET z1 .6*xl+ .5 + .55 * x3 + 65 * x4
620 LET z2 = xl + x2 + x3 + x4
630 LET z3=1.5 *x1+ 1 *x2 + 2 * x3 + 3 * x4
640 LET z4 3 *xl+2 *x2 + 3 * x3 + 6 * x4
650 PRINT #1, TAB(1); Count; USING "###.###"; xl; x2; x3; x4; yout; zl;
z2; z3; z4;
660 RETURN
```

A Computer Model for the Computation of Concrete Mix Proportions
Corresponding to a Desired Strength using periwinkle shell aggregates
Enter Desired Strength 13 N/sq.mm

1	0.040	0.600	0.010	0.350	13.000	0.557	1.000	1.730	3.450
2	0.040	0.610	0.010	0.340	12.999	0.556	1.000	1.710	3.410
3	0.070	0.570	0.010	0.350	13.000	0.560	1.000	1.745	3.480
4	0.070	0.600	0.010	0.320	13.001	0.556	1.000	1.685	3.360
5	0.080	0.570	0.010	0.340	12.999	0.560	1.000	1.730	3.450
6	0.100	0.490	0.000	0.410	l3O0O	0.572	1.000	1.870	3.740
7	0.120	0.480	0.000	0.400	12.999	0.572	1.000	1.860	3.720
8	0.150	0.470	0.000	0.380	13.000	0.572	1.000	1.835	3.670
9	0.170	0.470	0.000	0.360	13.000	0.571	1.000	1.805	3.610

The maximum value of strength predictable by this model is 19.50N/sq.mm

A Computer Model for the Computation of Concrete Mix Proportions
Corresponding to a Desired Strength using periwinkle shell aggregates
Enter Desired Strength 13 N/sq.mm

COUNT	x1	x2	x3	x4	y	z1	z2	z3	z4
1	0.050	0.060	0.180	0.710	17.000	0.620	1.000	2.625	5.070
2	0.060	0.090	0.000	0.850	17.000	0.633	1.000	2.730	5.460
3	0.080	0.010	0.270	0.640	16.999	0.618	1.000	2.590	4.910
4	0.080	0.070	0.030	0.820	16.999	0.632	1.000	2.710	5.390
5	0.100	0.050	0.060	0.790	17.000	0.632	1.000	2.690	5.320
6	0.120	0.030	0.090	0.760	17.001	0.631	1.000	2.670	5.250
7	0.140	0.020	0.070	0.770	17.000	0.633	1.000	2.680	5.290
8	0.150	0.020	0.030	0.800	17.001	0.637	1.000	2.705	5.380
9	0.160	0.010	0.050	0.780	17.000	0.636	1.000	2.690	5.330
10	0.180	0.000	0.030	0.790	16.999	0.638	1.000	2.700	5.370
11	0.380	0.090	0.530	0.000	17.000	0.565	1.000	1.720	2.910
12	0.440	0.050	0.460	0.050	17.000	0.575	1.000	1.780	3.100
13	0.440	0.090	0.430	0.040	17.000	0.572	1.000	1.730	3.030
14	0.450	0.000	0.480	0.070	16.999	0.580	1.000	1.845	3.210
15	0.460	0.000	0.460	0.080	17.000	0.581	1.000	1.850	3.240
16	0.460	0.030	0.440	0.070	17.000	0.579	1.000	1.810	3.180
17	0.480	0.080	0.380	0.060	17.001	0.576	1.000	1.740	3.100
18	0.490	0.200	0.300	0.010	17.001	0.566	1.000	1.565	2.830
19	0.510	0.060	0.350	0.080	17.000	0.581	1.000	1.765	3.180
20	0.510	0.180	0.290	0.020	17.000	0.569	1.000	1.585	2.880
21	0.520	0.140	0.300	0.040	17.000	0.573	1.000	1.640	2.980
22	0.560	0.020	0.300	0.120	17.001	0.589	1.000	1.820	3.340
23	0.570	0.080	0.270	0.080	16.999	0.583	1.000	1.715	3.160
24	0.590	0.130	0.230	0.050	17.000	0.578	1.000	1.625	3.020
25	0.590	0.200	0.200	0.010	16.999	0.571	1.000	1.515	2.830
26	0.630	0.010	0.220	0.140	17.000	0.595	1.000	1.815	3.410
27	0.630	0.100	0.200	0.070	17.001	0.584	1.000	1.655	3.110
28	0.640	0.000	0.210	0.150	17.000	0.597	1.000	1.830	3.450
29	0.640	0.130	0.180	0.050	17.000	0.581	1.000	1.600	3.020
30	0.650	0.100	0.180	0.070	17.001	0.585	1.000	1.645	3.110
31	0.660	0.100	0.170	0.070	17.000	0.585	1.000	1.640	3.110
32	0.770	0.000	0.080	0.150	16.999	0.604	1.000	1.765	3.450

The maximum value of strength predictable by this model is 19.50N/sq. mm