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PREDICTION OF THE FLEXURAL STRENGTHS OF LIGHTWEIGHT PERIWINKLE SHELL-RIVER GRAVEL CONCRETE

O. M Ibearugbulem, C. A Ajoku
[*]Department of civil engineeriing, federal university of technology owerri, NIGERIA

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ABSTRACT
This research work puts into application the regression equation derived by Ibearugbulem for a four component mixture of concrete to develop a model for the easy forecast of 28th day flexural strengths. To ensure an accurate forecast, the mix ratios to be predicted must fall within the boundaries defined for a four component simplex latex structure. The materials used in the laboratory experiment include; water, Ordinary Portland Cement, river sand, river gravel, and periwinkle shells. River gravel and periwinkle shells were combined at a volumetric mix ratio of 1:1 thereby reducing the number of material components from five to four. Manual mixing operation was adopted while all concrete ingredients except for the coarse aggregates were batched by weight. A total of 30 mix ratios were utilised in the concreting operation. While the first 15 mix ratios were used in the formulation of the model, the last 15 mix ratios were used in the validation of the formulated model using fisher's statistical test. Three concrete beams were cast for each mix ratio of which a total of 90 prototype beams measuring 150x150x600mm were produced and cured for 28 days in an open curing tank filled with potable water. From the statistical analysis, the calculated f-value 1.05 was less than the allowable f-value of 2.48 obtained from statistical table at 95% confidence level. This shows that the difference between the laboratory and model flexural strength results is not significant. Therefore, the formulated model is adequate and reliable for predicting the 28th day flexural strengths of periwinkle shell-river gravel concrete when given mix ratios.

KEYWORDS: Flexural strength, Periwinkle shell-river gravel concrete, Mix ratio, Regression model

INTRODUCTION
Concrete is one of the major building materials in civil engineering practice and construction works in Nigeria. Its basic constituents are cement, fine aggregates, coarse aggregate and water. Therefore, the overall cost of concrete production depends on the availability of these constituent materials. The conventional normal weight coarse aggregates needed for construction purposes are expensive hence the need to source for suitable and more readily available alternative construction materials.

Periwinkle shell obtained from periwinkle, which is an available proteinous food to people living in riverine and coastal communities in Nigeria, has been investigated by several researchers as a coarse aggregate for lightweight concrete production. Adewuyi and Adegoke (2009), Amaziah et al. (2013), Awe et al. (2014), Elijah et al. (2009), Ettu et al. (2013), Falade et al. (2010), Njoku et al. (2011), Ohimain et al. (2009), and Osarenwinda and Awaro (2009) have all carried out series of investigations on the prospects of using periwinkle shells, which were regarded as pollutants due to their unsightly appearance in open-dump sites as partial replacement for the unavailable and expensive conventional normal weight coarse aggregates in lightweight concrete production. These researchers having combined periwinkle shells at different partial replacements with the conventional normal weight coarse aggregate proved it to be adequate for lightweight concrete production.

Another factor which could increase the cost of production of concrete is the enormous time and effort invested in carrying-out trial mixes for desired fresh or hardened concrete properties. To overcome this short coming,

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Ibearugbulem et al. (2013), Osadebe (2003) and Scheffe(1950) have all developed optimisation equations for the prediction of compressive and flexural strengths of concretes and sandcrete/lateritic blocks.

This research work therefore seeks to apply the regression equation developed by Ibearugbulem for a four component mixture to formulate a new model for the prediction of the 28^{th} day flexural strengths of periwinkle shell-river gravel concrete. The objective of this research if realised will help equip civil engineers working in concrete or construction industries with easy to use mathematical tool for predicting flexural strengths of lightweight concrete, thereby saving the enormous time and effort invested in carrying out trial mixes. It will also help manage the enormous pollution generated by periwinkle shell through their use as a construction material for lightweight concrete production.

IBEARUGBULEM'S REGRESSION MODEL

Ibearugbulem et al. (2013) derived a regression equation for a four component mixture of concrete of degree four given in Equation 1. This equation forms the basis of the regression model developed in this research for the prediction of flexural strength of lightweight concrete having equal volume of periwinkle shells and river gravel.

$$F(z) = \alpha_1 z_1 + \alpha_2 z_2 + \alpha_3 z_3 + \alpha_4 z_4 + \alpha_{12} z_1 z_2 + \alpha_{13} z_1 z_3 + \alpha_{14} z_1 z_4 + \alpha_{23} z_2 z_3 + \alpha_{24} z_2 z_4 + \alpha_{34} z_3 z_4 + \alpha_{123} z_1 z_2 z_3 + \alpha_{124} z_1 z_2 z_4 + \alpha_{134} z_1 z_3 z_4 + \alpha_{234} z_2 z_3 z_4 + \alpha_{1234} z_1 z_2 z_3 z_4 \quad (1)$$

Where, $F(z)$ is the response function (i.e the property of concrete that is of interest).

α is the coefficient of the regression equation obtained from Equation 4.

Z is the pseudo variable obtained from Equations 2 and 3.

PSEUDO AND ACTUAL VARIABLES

The relationship between the pseudo variable, z_i and actual variable, s_i is as given below.

$$Z_i = s_i/S \quad (2)$$

$$S = \sum s_i \quad (3)$$

COEFFICIENT OF THE REGRESSION FUNCTION

The matrix expression below given by Ibearugbulem is used to obtain the coefficient of the regression function.

$$\begin{vmatrix} \sum_r Z_1.F(z) \\ \sum_r Z_2.F(z) \\ \sum_r Z_3.F(z) \\ \vdots \\ \cdots \\ \sum_r Z_1 Z_2 Z_3 \ldots .F(z) \end{vmatrix} = \begin{vmatrix} \sum_r \sum z_1 z_1 & \sum_r \sum z_2 z_1 & \sum_r \sum z_3 z_1 & \cdots & \cdots \\ \sum_r \sum z_1 z_2 & \sum_r \sum z_2 z_2 & \sum_r \sum z_3 z_2 & \cdots & \cdots \\ \sum_r \sum z_1 z_3 & \sum_r \sum z_2 z_3 & \sum_r \sum z_3 z_3 & \cdots & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \cdots & \cdots & \cdots & \vdots & \vdots \\ \sum_r \sum z_1 z_1 z_2 & \cdots & \sum_r \sum z_2 z_1 z_2 & \cdots & \cdots \end{vmatrix} \begin{vmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \vdots \\ \vdots \\ \alpha_{123\ldots\ldots} \end{vmatrix} \quad (4)$$

Equation 4 can be written in a short form as shown in Equation 5.

$$[F(z).Z] = [CC][\alpha] \quad (5)$$

Where, CC is always a symmetric matrix. For a mixture of four components, CC is a 15x15 matrix shown in Table 2. Making $[\alpha]$ the subject of the gives Equation 6.

$$[\propto] = [F(z).Z].[CC]^{-1} \quad (6)$$

MATERIALS AND METHODS

MATERIALS

Five constituent materials were used in the laboratory to produce the prototype concrete beams measuring 150x150x600mm. These materials include Ordinary Portland cement, river sand, river gravel, periwinkle shell and water.

(i) The Ordinary Portland cement with properties conforming to BS EN 197-1:2000 was used in the laboratory experiment.

(ii) The river sand used was obtained from Otamiri River located in federal university of technology owerri. It has physical properties of 1670kg/m^3, 0.36, 2.608 and 2.52 corresponding to its values of un-compacted bulk density, void ratio, specific gravity and fineness modulus respectively. The river sand is uniformly graded because it has coefficient of uniformity and coefficient of curvature values of 2.32 and 0.87 respectively obtained from Figure 1.

(iii) The river gravel used in the experiment has a maximum size of 20mm and rounded in shape. It has an un-compacted bulk density, water absorption, void ratio, specific gravity, fineness modulus, impact value and abrasion value of 1588kg/m^3, 0.8%, 0.42, 2.718, 8.02, 21.49% and 41.58% respectively. The river gravel is poorly graded because of its values of coefficient of uniformity and curvature which are 1.39 and 1.14 respectively obtained from Figure 2.

(iv) The periwinkle shells which have a maximum size of 19mm were obtained from Rumuagholu market in River state. It has physical and mechanical properties of 520kg/m^3, 2.4%, 0.55, 1.16, 3.72, 33.50% and 55.04% which corresponds to the un-compacted bulk density, water absorption, void ratio, specific gravity, fineness modulus, impact value and abrasion value respectively. Its coefficient of uniformity and curvature values of 1.18 and 1.12 obtained from Figure 3 indicate a poorly graded particle.

(v) Potable water was used for the experiment during mixing and curing operation.

METHODS

CONCRETE MATERIALS BATCHING, MIXING, PLACING AND CURING OPERATIONS

Batching in this experiment was done with a weighing balance of 50kg capacity using the mix ratios given in Table 1. These mix ratios were chosen arbitrarily from Scheffe's simplex latex structure for a four component mixture. The batching for the different constituent materials was by mass except for the coarse aggregates (i.e river gravel and periwinkle shells) which were volumetrically combined at a mix ratio of 1:1.

TABLE 1: ACTUAL MIX RATIOS

S/N	OBSERVATION POINTS	WATER,s_1	CEMENT,s_2	SAND,s_3	COARSE AGGREGATE,s_4
1	N1	0.6	1	2	4
2	N2	0.55	1	2	3
3	N3	0.5	1	1.5	2
4	N4	0.45	1	1	1.5
5	N12	0.575	1	2	3.5
6	N13	0.55	1	1.75	3
7	N14	0.525	1	1.5	2.75
8	N23	0.525	1	1.75	2.5
9	N24	0.5	1	1.5	2.25
10	N34	0.475	1	1.25	1.75
11	N123	0.55	1	1.8333	3
12	N124	0.533333	1	1.6667	2.8333
13	N134	0.516667	1	1.5	2.5
14	N234	0.5	1	1.5	2.1667
15	N1234	0.525	1	1.675	2.625
16	C1	0.5175	1	1.575	2.475
17	C2	0.5275	1	1.675	2.65
18	C3	0.5375	1	1.7	2.85
19	C4	0.5175	1	1.55	2.525
20	C5	0.521	1	1.575	2.565
21	C6	0.4985	1	1.485	2.16

22	C7	0.5215	1	1.54	2.565
23	C8	0.5285	1	1.65	2.745
24	C9	0.5515	1	1.825	3.03
25	C10	0.5045	1	1.545	2.21
26	C11	0.585	1	2	3.7
27	C12	0.535	1	1.85	2.7
28	C13	0.485	1	1.35	1.85
29	C14	0.495	1	1.3	2.25
30	C15	0.5325	1	1.6625	2.65
30	C15	0.5325	1	1.6625	2.65

Manual mixing was adopted with the aid of spade. The constituent materials were mixed thoroughly until homogeneity was attained. After mixing, the concrete was cast into steel moulds measuring 150x150x600mm.
Three representative samples were cast for each mix ratio, making a total of 90 prototype concrete beams produced. They were cured for 28 days in an open curing tank filled with potable water. 100kN capacity hand operated flexural testing machined designed for third point loading was used to crush the cured concrete beams. Constant rate of loading was applied on the concrete beams until failure occurred. The laboratory modulus of rupture or flexural strength of each beam was determined using Equation 7. The results obtained are given on Table 3.

$$\text{Flexural strength} = \frac{load\ on\ beam\ X\ span}{6\ x\ elastic\ modulus\ of\ beam} \qquad (7)$$

GOODNESS OF FIT

Fisher's test is used to test the adequacy of the model by comparing the properties (flexural strengths) of the "control samples" of the experiment with that of the model. The values obtained from the model is said to be adequate if $\frac{1}{f_\propto(v_1,v_2)} < \frac{S_1^2}{S_2^2} < f_\propto(v_1, v_2)$.

Where,

$\frac{S_1^2}{S_2^2}$= fisher value obtained from statistical analysis

S_1^2 = greater of S_E^2 and S_m^2

S_m^2 = variance from the model

S_E^2 = variance from the experiment

$f_\alpha\ (v_1, v_2)$ = fisher value obtained from F- distribution table.

α = significant level = 5% = 0.05

$V_1 = V_2$ = N-1 = degree of freedom.

TABLE 2:CC Matrix of a Mix of Four Components

∑∑Z1Z1	∑∑Z1Z2	∑∑Z1Z3	∑∑Z1Z4	∑∑Z1Z1Z2	∑∑Z1Z1Z3	∑∑Z1Z1Z4	∑∑Z1Z2Z3	∑∑Z1Z2Z4	∑∑Z1Z3Z4	∑∑Z1Z1Z2Z3	∑∑Z1Z1Z2Z4	∑∑Z1Z1Z3Z4	∑∑Z1Z2Z3Z4	∑∑Z1Z1Z2Z3Z4
∑∑Z1Z2	∑∑Z2Z2	∑∑Z2Z3	∑∑Z2Z4	∑∑Z1Z2Z2	∑∑Z1Z2Z3	∑∑Z1Z2Z4	∑∑Z2Z2Z3	∑∑Z2Z2Z4	∑∑Z2Z3Z4	∑∑Z1Z2Z2Z3	∑∑Z1Z2Z2Z4	∑∑Z1Z2Z3Z4	∑∑Z2Z2Z3Z4	∑∑Z1Z2Z2Z3Z4
∑∑Z1Z3	∑∑Z2Z3	∑∑Z3Z3	∑∑Z3Z4	∑∑Z1Z2Z3	∑∑Z1Z3Z3	∑∑Z1Z3Z4	∑∑Z2Z3Z3	∑∑Z2Z3Z4	∑∑Z3Z3Z4	∑∑Z1Z2Z3Z3	∑∑Z1Z2Z3Z4	∑∑Z1Z3Z3Z4	∑∑Z2Z3Z3Z4	∑∑Z1Z2Z3Z3Z4
∑∑Z1Z4	∑∑Z2Z4	∑∑Z3Z4	∑∑Z4Z4	∑∑Z1Z2Z4	∑∑Z1Z3Z4	∑∑Z1Z4Z4	∑∑Z2Z3Z4	∑∑Z2Z4Z4	∑∑Z3Z4Z4	∑∑Z1Z2Z3Z4	∑∑Z1Z2Z4Z4	∑∑Z1Z3Z4Z4	∑∑Z2Z3Z4Z4	∑∑Z1Z2Z3Z4Z4
∑∑Z1Z1Z2	∑∑Z1Z2Z2	∑∑Z1Z2Z3	∑∑Z1Z2Z4	∑∑Z1Z1Z2Z2	∑∑Z1Z1Z2Z3	∑∑Z1Z1Z2Z4	∑∑Z1Z2Z2Z3	∑∑Z1Z2Z2Z4	∑∑Z1Z2Z3Z4	∑∑Z1Z1Z2Z2Z3	∑∑Z1Z1Z2Z2Z4	∑∑Z1Z1Z2Z3Z4	∑∑Z1Z2Z2Z3Z4	∑∑Z1Z1Z2Z2Z3Z4
∑∑Z1Z1Z3	∑∑Z1Z2Z3	∑∑Z1Z3Z3	∑∑Z1Z3Z4	∑∑Z1Z1Z2Z3	∑∑Z1Z1Z3Z3	∑∑Z1Z1Z3Z4	∑∑Z1Z2Z3Z3	∑∑Z1Z2Z3Z4	∑∑Z1Z3Z3Z4	∑∑Z1Z1Z2Z3Z3	∑∑Z1Z1Z2Z3Z4	∑∑Z1Z1Z3Z3Z4	∑∑Z1Z2Z3Z3Z4	∑∑Z1Z1Z2Z3Z3Z4

∑∑Z1 Z1Z4	∑∑Z1 Z2Z4	∑∑Z1 Z3Z4	∑∑Z1 Z4Z4	∑∑Z1 Z1Z2 Z4	∑∑Z1 Z1Z3 Z4	∑∑Z1 Z1Z4 Z4	∑∑Z1 Z2Z3 Z4	∑∑Z1Z2 Z4Z4	∑∑Z1 Z3Z4 Z4	∑∑Z1 Z1Z2 Z3Z4	∑∑Z1Z1 Z2Z4Z4	∑∑Z1Z1 Z3Z4Z4	∑∑Z1Z2 Z3Z4Z4	∑∑Z1Z1 Z2Z3Z4 Z4
∑∑Z1 Z2Z3	∑∑Z2 Z2Z3	∑∑Z2 Z3Z3	∑∑Z2 Z3Z4	∑∑Z1 Z2Z2 Z3	∑∑Z1 Z2Z3 Z3	∑∑Z1 Z2Z3 Z4	∑∑Z2 Z2Z3 Z3	∑∑Z2Z2 Z3Z4	∑∑Z2 Z3Z3 Z4	∑∑Z1 Z2Z2 Z3Z3	∑∑Z1Z2 Z2Z3Z4	∑∑Z1Z2 Z3Z3Z4	∑∑Z2Z2 Z3Z3Z4	∑∑Z1Z2 Z2Z3Z3 Z4
∑∑Z1 Z2Z4	∑∑Z2 Z2Z4	∑∑Z2 Z3Z4	∑∑Z2 Z4Z4	∑∑Z1 Z2Z2 Z4	∑∑Z1 Z2Z3 Z4	∑∑Z1 Z2Z4 Z4	∑∑Z2 Z2Z3 Z4	∑∑Z2Z2 Z4Z4	∑∑Z2 Z3Z4 Z4	∑∑Z1 Z2Z2 Z3Z4	∑∑Z1Z2 Z2Z4Z4	∑∑Z1Z2 Z3Z4Z4	∑∑Z2Z2 Z3Z4Z4	∑∑Z1Z2 Z2Z3Z4 Z4
∑∑Z1 Z3Z4	∑∑Z2 Z3Z4	∑∑Z3 Z3Z4	∑∑Z3 Z4Z4	∑∑Z1 Z2Z3 Z4	∑∑Z1 Z3Z3 Z4	∑∑Z1 Z3Z4 Z4	∑∑Z2 Z3Z3 Z4	∑∑Z2Z3 Z4Z4	∑∑Z3 Z3Z4 Z4	∑∑Z1 Z2Z3 Z3Z4	∑∑Z1Z2 Z3Z4Z4	∑∑Z1Z3 Z3Z4Z4	∑∑Z2Z3 Z3Z4Z4	∑∑Z1Z2 Z3Z3Z4 Z4
∑∑Z1 Z1Z2 Z3	∑∑Z1 Z2Z2 Z3	∑∑Z1 Z2Z3 Z3	∑∑Z1 Z2Z3 Z4	∑∑Z1 Z1Z2 Z2Z3	∑∑Z1 Z1Z2 Z3Z3	∑∑Z1 Z1Z2 Z3Z4	∑∑Z1 Z2Z2 Z3Z3	∑∑Z1Z2 Z2Z3Z4	∑∑Z1 Z2Z3 Z3Z4	∑∑Z1 Z1Z2 Z2Z3 Z3	∑∑Z1Z1 Z2Z2Z3 Z4	∑∑Z1Z1 Z2Z3Z3 Z4	∑∑Z1Z2 Z2Z3Z3 Z4	∑∑Z1Z1 Z2Z2Z3 Z3Z4
∑∑Z1 Z1Z2 Z4	∑∑Z1 Z2Z2 Z4	∑∑Z1 Z2Z3 Z4	∑∑Z1 Z2Z4 Z4	∑∑Z1 Z1Z2 Z2Z4	∑∑Z1 Z1Z2 Z3Z4	∑∑Z1 Z1Z2 Z4Z4	∑∑Z1 Z2Z2 Z3Z4	∑∑Z1Z2 Z2Z4Z4	∑∑Z1 Z2Z3 Z4Z4	∑∑Z1 Z1Z2 Z2Z3 Z4	∑∑Z1Z1 Z2Z2Z4 Z4	∑∑Z1Z1 Z2Z3Z4 Z4	∑∑Z1Z2 Z2Z3Z4 Z4	∑∑Z1Z1 Z2Z2Z3 Z4Z4
∑∑Z1 Z1Z3 Z4	∑∑Z1 Z2Z3 Z4	∑∑Z1 Z3Z3 Z4	∑∑Z1 Z3Z4 Z4	∑∑Z1 Z1Z2 Z3Z4	∑∑Z1 Z1Z3 Z3Z4	∑∑Z1 Z1Z3 Z4Z4	∑∑Z1 Z2Z3 Z3Z4	∑∑Z1Z2 Z3Z4Z4	∑∑Z1 Z3Z3 Z4Z4	∑∑Z1 Z1Z2 Z3Z3 Z4	∑∑Z1Z1 Z2Z3Z4 Z4	∑∑Z1Z1 Z3Z3Z4 Z4	∑∑Z1Z2 Z3Z3Z4 Z4	∑∑Z1Z1 Z2Z3Z3 Z4Z4
∑∑Z1 Z2Z3 Z4	∑∑Z2 Z2Z3 Z4	∑∑Z2 Z3Z3 Z4	∑∑Z2 Z3Z4 Z4	∑∑Z1 Z2Z2 Z3Z4	∑∑Z1 Z2Z3 Z3Z4	∑∑Z1 Z2Z3 Z4Z4	∑∑Z2 Z2Z3 Z3Z4	∑∑Z2Z2 Z3Z3Z4	∑∑Z2 Z3Z3 Z4Z4	∑∑Z1 Z2Z2 Z3Z3 Z4	∑∑Z1Z2 Z2Z3Z4 Z4	∑∑Z1Z2 Z3Z3Z4 Z4	∑∑Z2Z2 Z3Z3Z4 Z4	∑∑Z1Z2 Z2Z3Z3 Z4Z4
∑∑Z1 Z1Z2 Z3Z4	∑∑Z1 Z2Z2 Z3Z4	∑∑Z1 Z2Z3 Z3Z4	∑∑Z1 Z2Z3 Z4Z4	∑∑Z1 Z1Z2 Z2Z3 Z4	∑∑Z1 Z1Z2 Z3Z3 Z4	∑∑Z1 Z1Z2 Z3Z4 Z4	∑∑Z1 Z2Z2 Z3Z3 Z4	∑∑Z1Z2 Z2Z3Z3 Z4	∑∑Z1 Z2Z3 Z3Z4 Z4	∑∑Z1 Z1Z2 Z2Z3 Z3Z4	∑∑Z1Z1 Z2Z2Z3 Z4Z4	∑∑Z1Z1 Z2Z3Z3 Z4Z4	∑∑Z1Z2 Z2Z3Z3 Z4Z4	∑∑Z1Z1 Z2Z2Z3 Z3Z4Z4

RESULTS AND DISCUSSION

GRAIN SIZE DISTRIBUTION OF RIVER SAND, RIVER GRAVEL AND PERIWINKLE SHELLS

Figures 1, 2 and 3 represent the grain size distribution of river sand, river gravel and periwinkle shells used in the laboratory experiment.

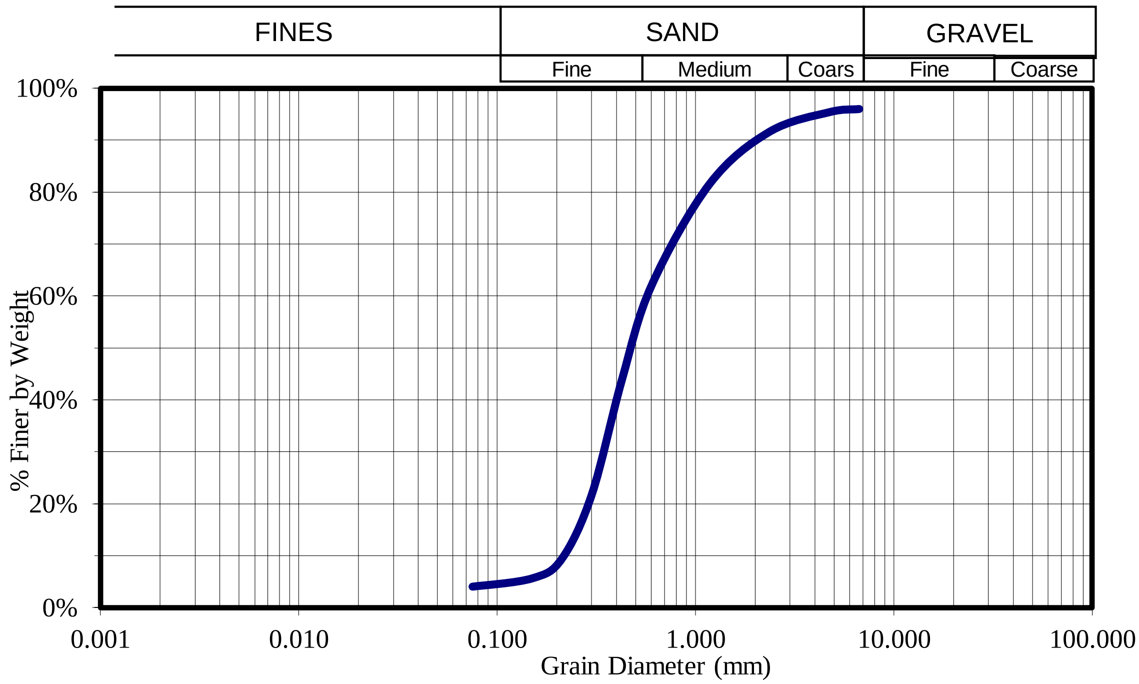

Figure 1: Grain size distribution analysis for river sand

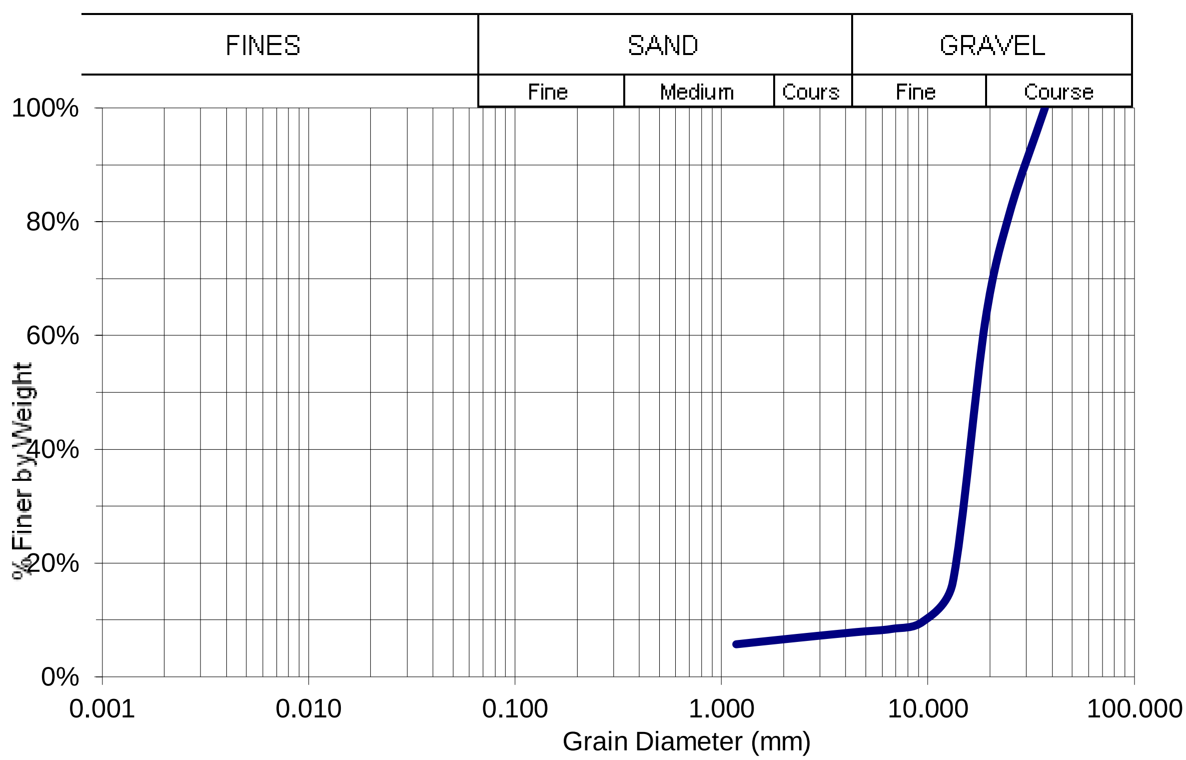

Figure 2: Grain size distribution analysis for a river gravel

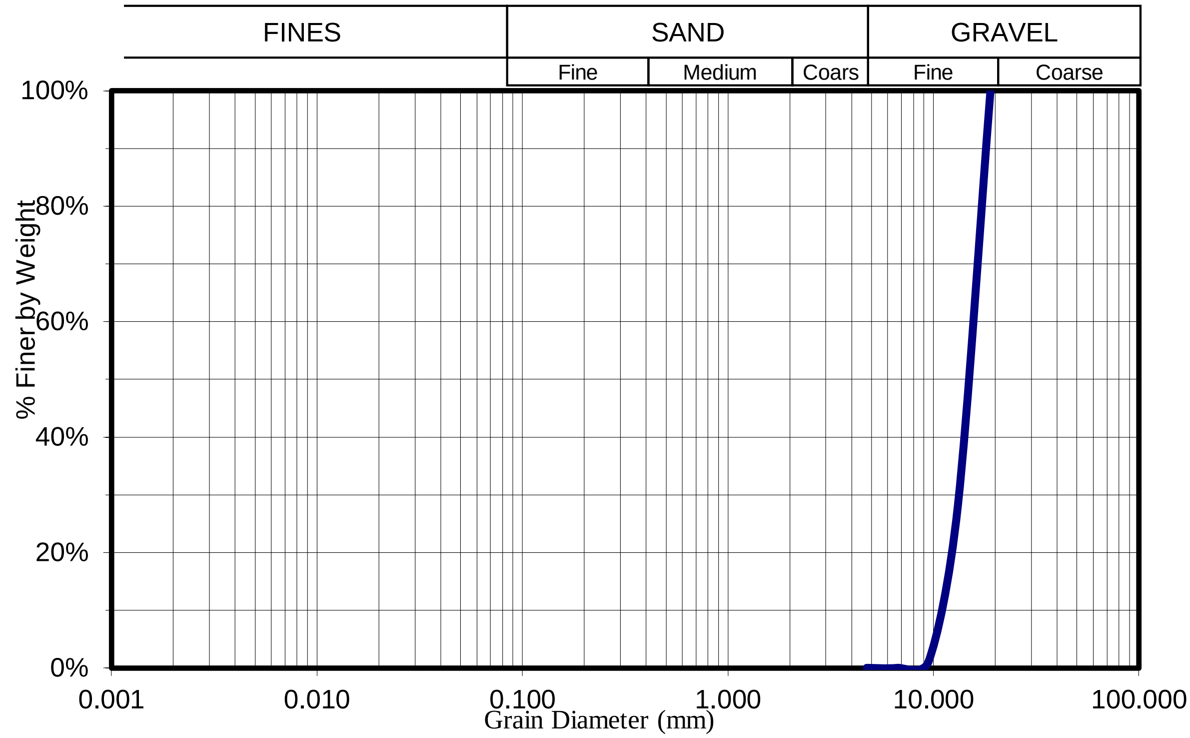

Figure 3: Grain size distribution of periwinkle shells

LABORATORY FLEXURAL STRENGTHS

Table 3: Laboratory Flexural Strengths of Periwinkle shell-River gravel concrete

ACTUAL MIX RATIOS															
MIX NO	N1	N2	N3	N4	N12	N13	N14	N23	N24	N34	N123	N124	N134	N234	N1234
AVERAGE FLEXURAL STRENGTH (N/mm^2)	3.5	3.32	3.54	3.72	2.8	2.69	2.65	2.17	3.04	3.27	2.69	2.5	2.78	2.52	2.6
CONTROL MIX RATIOS															
MIX NO	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
AVERAGE FLEXURAL STRENGTH (N/mm^2)	2.77	2.47	2.24	2.75	2.9	2.65	3.07	3.04	3.29	2.77	3.12	3.02	3.13	3.09	3.15

FLEXURAL STRENGTH FROM FORMULATED REGRESSION MODEL

PSEUDO VARIABLES, Z_i

The pseudo variable values given in Table 4 are obtained using Table 1 and Equations 2 and 3.

TABLE 4: PSEUDO VARIABLES (Z_i)

Z1	Z2	Z3	Z4	Z1Z2	Z1Z3	Z1Z4	Z2Z3	Z2Z4	Z3Z4	Z1Z2 Z3	Z1Z2 Z4	Z1Z3 Z4	Z2Z3 Z4	Z1Z2 Z3Z4
0.079	0.132	0.263	0.526	0.010	0.021	0.042	0.035	0.069	0.139	0.003	0.005	0.011	0.018	0.001
0.0	0.1	0.30	0.45	0.01	0.02	0.03	0.04	0.07	0.14	0.00	0.00	0.01	0.02	0.00

84	53	5	8	3	6	8	7	0	0	4	6	2	1	2
0.100	0.200	0.300	0.400	0.020	0.030	0.040	0.060	0.080	0.120	0.006	0.008	0.012	0.024	0.002
0.114	0.253	0.253	0.380	0.029	0.029	0.043	0.064	0.096	0.096	0.007	0.011	0.011	0.024	0.003
0.081	0.141	0.283	0.495	0.011	0.023	0.040	0.040	0.070	0.140	0.003	0.006	0.011	0.020	0.002
0.087	0.159	0.278	0.476	0.014	0.024	0.042	0.044	0.076	0.132	0.004	0.007	0.012	0.021	0.002
0.091	0.173	0.260	0.476	0.016	0.024	0.043	0.045	0.082	0.124	0.004	0.008	0.011	0.021	0.002
0.091	0.173	0.303	0.433	0.016	0.028	0.039	0.052	0.075	0.131	0.005	0.007	0.012	0.023	0.002
0.095	0.190	0.286	0.429	0.018	0.027	0.041	0.054	0.082	0.122	0.005	0.008	0.012	0.023	0.002
0.106	0.223	0.279	0.391	0.024	0.030	0.042	0.062	0.087	0.109	0.007	0.009	0.012	0.024	0.003
0.086	0.157	0.287	0.470	0.013	0.025	0.040	0.045	0.074	0.135	0.004	0.006	0.012	0.021	0.002
0.088	0.166	0.276	0.470	0.015	0.024	0.042	0.046	0.078	0.130	0.004	0.007	0.011	0.022	0.002
0.094	0.181	0.272	0.453	0.017	0.025	0.042	0.049	0.082	0.123	0.005	0.008	0.012	0.022	0.002
0.097	0.194	0.290	0.419	0.019	0.028	0.041	0.056	0.081	0.122	0.005	0.008	0.012	0.024	0.002
0.091	0.173	0.281	0.455	0.016	0.026	0.041	0.049	0.079	0.128	0.004	0.007	0.012	0.022	0.002
0.093	0.180	0.283	0.445	0.017	0.026	0.041	0.051	0.080	0.126	0.005	0.007	0.012	0.023	0.002
0.090	0.171	0.286	0.453	0.015	0.026	0.041	0.049	0.077	0.130	0.004	0.007	0.012	0.022	0.002
0.088	0.164	0.279	0.468	0.015	0.025	0.041	0.046	0.077	0.131	0.004	0.007	0.012	0.021	0.002
0.093	0.179	0.277	0.452	0.017	0.026	0.042	0.050	0.081	0.125	0.005	0.007	0.012	0.022	0.002
0.092	0.177	0.278	0.453	0.016	0.026	0.042	0.049	0.080	0.126	0.005	0.007	0.012	0.022	0.002
0.097	0.194	0.289	0.420	0.019	0.028	0.041	0.056	0.082	0.121	0.005	0.008	0.012	0.024	0.002
0.093	0.178	0.274	0.456	0.016	0.025	0.042	0.049	0.081	0.125	0.005	0.008	0.012	0.022	0.002
0.089	0.169	0.279	0.463	0.015	0.025	0.041	0.047	0.078	0.129	0.004	0.007	0.012	0.022	0.002
0.086	0.156	0.285	0.473	0.013	0.025	0.041	0.044	0.074	0.135	0.004	0.006	0.012	0.021	0.002
0.096	0.190	0.294	0.420	0.018	0.028	0.040	0.056	0.080	0.123	0.005	0.008	0.012	0.023	0.002
0.080	0.137	0.275	0.508	0.011	0.022	0.041	0.038	0.070	0.139	0.003	0.006	0.011	0.019	0.002
0.088	0.164	0.304	0.444	0.014	0.027	0.039	0.050	0.073	0.135	0.004	0.006	0.012	0.022	0.002
0.104	0.213	0.288	0.395	0.022	0.030	0.041	0.062	0.084	0.114	0.006	0.009	0.012	0.024	0.003
0.098	0.198	0.258	0.446	0.019	0.025	0.044	0.051	0.088	0.115	0.005	0.009	0.011	0.023	0.002
0.091	0.171	0.284	0.453	0.016	0.026	0.041	0.049	0.078	0.129	0.004	0.007	0.012	0.022	0.002

CC MATRIX

Substituting the values of Table 4 into Table 2, the numeric values of CC matrix is obtained as given in Table 5. The inverse of it is given in Table 6.

Table 5: CC MATRIX

0.129	0.250	0.389	0.616	0.024	0.036	0.057	0.070	0.110	0.173	0.007	0.010	0.016	0.031	0.003
0.129	0.488	0.749	1.181	0.047	0.070	0.110	0.137	0.213	0.331	0.013	0.020	0.031	0.060	0.006
0.389	0.749	1.189	1.891	0.070	0.109	0.173	0.211	0.331	0.533	0.020	0.031	0.049	0.093	0.009
0.616	1.181	1.891	3.042	0.110	0.173	0.277	0.331	0.527	0.854	0.031	0.049	0.078	0.148	0.014
0.024	0.047	0.070	0.110	0.004	0.007	0.010	0.013	0.020	0.031	0.001	0.002	0.003	0.006	0.001
0.036	0.070	0.110	0.173	0.007	0.010	0.016	0.020	0.031	0.049	0.002	0.003	0.004	0.009	0.001
0.057	0.110	0.173	0.277	0.010	0.016	0.025	0.031	0.049	0.078	0.003	0.005	0.007	0.014	0.001
0.070	0.137	0.211	0.331	0.013	0.020	0.031	0.038	0.060	0.093	0.004	0.006	0.009	0.017	0.002
0.110	0.213	0.331	0.527	0.020	0.031	0.049	0.060	0.094	0.148	0.006	0.009	0.014	0.026	0.002
0.173	0.331	0.533	0.854	0.031	0.049	0.078	0.093	0.148	0.240	0.009	0.014	0.022	0.042	0.004
0.007	0.013	0.020	0.031	0.001	0.002	0.003	0.004	0.006	0.009	0.000	0.001	0.001	0.002	0.000
0.010	0.020	0.031	0.049	0.002	0.003	0.005	0.006	0.009	0.014	0.001	0.001	0.001	0.002	0.000
0.016	0.031	0.049	0.078	0.003	0.004	0.007	0.009	0.014	0.022	0.001	0.001	0.002	0.004	0.000
0.031	0.060	0.093	0.148	0.006	0.009	0.014	0.017	0.026	0.042	0.002	0.002	0.004	0.007	0.001
0.003	0.006	0.009	0.014	0.001	0.001	0.001	0.002	0.002	0.004	0.000	0.000	0.000	0.001	0.000

Table 6: INVERSE OF CC MATRIX

89.58244	-8.23989	19.0674	-13.9619	-69.8066	-498.213	209.9039	111.5498	-43.8296	6.033514	117.3796	-267.688	-157.164	-12.6437	88.14253
5844471	68.56985	1087359	-1178226	-6150015	-3.40E+07	17337558	9204905	-2986336	1124862	1911533	-2.50E+07	-1.20E+07	-5402420	6118754
-1527327	-22.7285	-375557	470242.1	1673259	11953464	-7291901	-3628974	900465	-527846	-1361864	9873048	3862733	3066123	-1946844
5928941	79.00822	1456552	-1416526	-6065459	-4.10E+07	22828587	10525356	-4133513	1142219	5740519	-2.90E+07	-1.50E+07	-4622520	7820639
53767678	1329.34	-4186093	34800770	-1.30E	4.46E+08	-6.20E	-3.09E	10807450	-6.70E	4.13E+08	8.65E+08	2.14E+08	4.23E+08	-1.00

	9			+08		+08	+08		+07					E+08
3.21E+08	4827.16	43022542	-425610	-4.20E+08	-7.60E+08	-1.40E+08	-9.5E+07	-1.08E+08	-5.10E+07	7.52E+08	56700490	-3.40E+08	4.48E+08	2.17E+08
-4.50E+07	1056.329	-2.50E+07	80775691	-3.60E+07	1.36E+09	-1.30E+09	-6.86E+08	60000075	-1.40E+08	5.97E+08	1.85E+09	6.43E+08	8.46E+08	-2.40E+08
-2.10E+08	-3747.97	-2.00E+07	-2.80E+07	3.00E+08	48211406	5.60E+08	3.09E+08	57984921	83903944	-7.40E+08	-7.00E+08	7598047	-6.30E+08	-6.10E+07
-1.30E+07	-1533.1	3036311	-4.50E+07	6.60E+07	-5.80E+08	7.16E+08	3.92E+08	2574008	92788837	-4.90E+08	-1.10E+09	-3.40E+08	-5.80E+08	93212128
-5658244	-191.912	-1828362	-1968985	1.00E+07	2211466	27550727	18229502	5818900	6885361	-4.50E+07	-5.90E+07	-1.50E+07	-4.00E+07	5812754
2.29E+08	8982.95	-3833674	2.07E+08	-4.70E+08	2.52E+09	-3.40E+09	-1.91E+09	-1.7E+07	-4.40E+08	2.53E+09	4.67E+09	1.21E+09	2.90E+09	-3.50E+08
-1.70E+08	1805.592	11748036	64757954	2.30E+08	7.98E+08	-7.30E+08	-5.55E+08	-7.4E+07	-1.70E+08	7.01E+08	1.53E+09	7.35E+08	9.56E+08	-7.70E+07
-6.90E+08	-15055.6	-3.40E+07	-2.20E+08	1.10E+09	-1.90E+09	4.02E+09	2.14E+09	1.06E+08	5.10E+08	-3.50E+09	-5.20E+09	-8.80E+08	-3.50E+09	27564092
4.21E+08	13540.23	15163498	2.68E+08	-8.60E+08	2.86E+09	-4.50E+09	-2.46E+09	-8.2E+07	-5.90E+08	3.63E+09	6.42E+09	1.62E+09	3.84E+09	-4.10E+08
1.27E+08	-38912.6	1.10E+08	-1.40E+09	1.30E+09	-1.90E+10	2.16E+10	1.19E+10	-1.61E+08	2.85E+09	-1.40E+10	-3.20E+10	-1.10E+10	-1.70E+10	3.73E+09

RZ VECTOR

RZ vector is defined as the matrix product of the response function ® on Table 3 and the pseudo variables (z) on Table 4. The result is as presented below.

Σ(Z1.F(z))	4.063473
Σ(Z2.F(z))	7.862
Σ(Z3.F(z))	12.287505
Σ(Z4.F(z))	19.577023
Σ(Z1Z2.F(z))	0.743303
Σ(Z1Z3.F(z))	1.138644
Σ(Z1Z4.F(z))	1.800394
Σ(Z2Z3.F(z))	2.20069
Σ(Z2Z4.F(z))	3.459767
Σ(Z3Z4.F(z))	5.490081
Σ(Z1Z2Z3.F(z))	0.207623
Σ(Z1Z2Z4.F(z))	0.324026
Σ(Z1Z3Z4.F(z))	0.50437
Σ(Z2Z3Z4.F(z))	0.968467
Σ(Z1Z2Z3Z4.F(z))	0.0905437

COEFFICIENTS OF THE REEGRESSION EQUATION

The coefficients of the regression equation given in Equation 1 can be obtained using Equation 6. That is, the coefficients of the regression equation are the matrix product of the RZ vector and the inverse of the CC matrix given on Table 6. The result is as given in Table 7.

Table 7: Coefficients of the Regression Equation

α1	α2	α3	α4	α12	α13	α14	α23	α24	α34	α123	α124	α134	α234	α1234
0	-146.41	55.2	-172.6	7441.25	4582.69	13283.4	-6905.69	-7183.75	-405.19	36047.5	4272.23	-46729.42	48935.93	-232975.54

Substituting the coefficients in Table 7 into Equation 1 will give the regression model for the prediction of 28th day flexural strengths of periwinkle shell-river gravel concrete given in Equation 8.

$$F(z) = -464.49z_2 + 55.20z_3 - 172.60z_4 + 7441.25z_1z_2 + 4582.69z_1z_3 + 13283.40z_1z_4 - 6905.69z_2z_3 - 7183.75z_2z_4 - 405.19z_3z_4 + 36047.50z_1z_2z_3 + 4272.23z_1z_2z_4 - 46729.42z_1z_3z_4 + 48935.93z_2z_3z_4 - 232975.54z_1z_2z_3z_4 \quad (8)$$

The flexural strengths from the formulated model given in Table 8 are obtained through substitution of the pseudo variables in Table 4 into Equation 8. The flexural strengths from the model are placed side by side with that from the laboratory experiment for easy comparison and statistical analysis as represented on Table 9.

Table 8: Laboratory and Model Flexural Strengths of Periwinkle shell-River gravel concrete

ACTUAL MIX RATIOS																
MIX NO		N1	N2	N3	N4	N12	N13	N14	N23	N24	N34	N123	N124	N134	N234	N1234
AVERAGE FLEXURAL STRENGTH (N/mm²)	YMODEL	3.56	2.74	3.13	3.79	2.57	2.92	2.45	2.95	2.75	3.31	2.79	3.06	2.19	2.82	2.77
	YEXP	3.50	3.32	3.54	3.72	2.80	2.69	2.65	2.17	3.04	3.27	2.69	2.50	2.78	2.52	2.60
CONTROL MIX RATIOS																
MIX NO		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
AVERAGE FLEXURAL STRENGTH (N/mm²)	YMODEL	2.58	2.90	2.99	2.51	2.58	2.76	2.39	3.00	2.82	2.91	2.83	2.98	3.31	3.44	2.53
	YEXP	2.77	2.47	2.24	2.75	2.90	2.65	3.07	3.04	3.29	2.77	3.12	3.02	3.13	3.09	3.15

FISHER TEST FOR ADEQUACY OF MODEL

LEGEND

Y_E = response from experiment

Y_M = response from model

$\tilde{Y}_E$ = mean response from experiment = $\sum Y_E/N$

$\tilde{Y}_M$ = mean response from model = $\sum Y_M/N$

N = total points of observation (for controls) = 15

$S_E^2 = \sum(Y_E - \tilde{Y}_E)^2/(N-1)$

$S_M^2 = \sum(Y_M - \tilde{Y}_M)^2/(N-1)$

(N-1) = degree of freedom = 15-1 = 14

S_E^2 = variance from the experiment

S_M^2 = variance from the model

Table 9: Periwinkle Shell-River Gravel Concrete

MIX NO	Y_E	Y_M	$Y_E - \tilde{Y}_E$	$Y_M - \tilde{Y}_M$	$(Y_E - \tilde{Y}_E)^2$	$(Y_M - \tilde{Y}_M)^2$
C1	2.77	2.58	-0.13	-0.26	0.0169	0.0676
C2	2.47	2.90	-0.43	0.06	0.1849	0.0036

C3	2.24	2.99	-0.66	0.15	0.4356	0.0225
C4	2.75	2.51	-0.15	-0.33	0.0225	0.1089
C5	2.90	2.58	0.00	-0.26	0.0000	0.0676
C6	2.65	2.76	-0.25	-0.08	0.0625	0.0064
C7	3.07	2.39	0.17	-0.45	0.0289	0.2025
C8	3.04	3.00	0.14	0.16	0.0196	0.0256
C9	3.29	2.82	0.39	-0.02	0.1521	0.0004
C10	2.77	2.91	-0.13	0.07	0.0169	0.0049
C11	3.12	2.83	0.22	-0.01	0.0484	0.0001
C12	3.02	2.98	0.12	0.14	0.0144	0.0196
C13	3.13	3.31	0.23	0.47	0.0529	0.2209
C14	3.09	3.44	0.19	0.60	0.0361	0.3600
C15	3.15	2.53	0.25	-0.31	0.0625	0.0961
	$\sum Y_E = 43.46$	$\sum Y_M = 42.53$			$\sum(Y_E - \tilde{Y}_E)^2 = 1.1541$	$\sum(Y_M - \tilde{Y}_M)^2 = 1.2067$

$\tilde{Y}_E = \sum Y_E/N = 43.46/15 = 2.90$
$\tilde{Y}_M = \sum Y_M/N = 42.53/15 = 2.84$
$S_E^2 = \sum(Y_E - \tilde{Y}_E)^2/(N-1) = 1.1541/14 = 0.0824$
$S_M^2 = \sum(Y_M - \tilde{Y}_M)^2/(N-1) = 1.2067/14 = 0.0862$
Therefore, $S_1^2 = 0.0862$ and $S_2^2 = 0.0824$
$F_{calculated} = S_1^2/ S_2^2 = 0.0862/0.0824 = 1.05$
$F_{table} = F_{0.05}(14,14)$
From statistical table for F-distribution values, $F_{0.05}(14,14) = 2.48$
$1/F_{table} = 0.403$
Therefore, $0.403 < 1.05 < 2.48$
Thus, the condition $1/F < S_1^2/ S_2^2 < F$ has been satisfied. Null hypothesis will be accepted.

CONCLUSION

From the statistical analysis carried out on the generated regression model for the prediction of flexural strengths of concrete made with periwinkle shells and river gravel, blended as a single component at a volumetric mix ratio of 1:1, the calculated f-value of 1.05 was less than the allowable f-value of 2.48 from the statistical table at 5% significance level. This means that the flexural strengths results from the experiment and those from the model compare favourably with each other. It can therefore be concluded that the regression model proved adequate for the prediction of 28th-day flexural strengths of concrete made from equal volume of river gravel and periwinkle shells at 95% confidence level or 5% significance level. This model is recommended for use in concrete industry or construction industry for easy forecast of flexural strengths of lightweight concretes whose mix ratios are within the boundaries provided in this research work.

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AUTHOR BIBLIOGRAPHY

	**ENGR.DR. IBEARUGBULEM MATHIAS OWUS** Engr. Dr. Ibearugbulem M.O is a senior lecturer in department of civil engineering, federal university of technology owerri. He is a Ph.D holder in structural engineering, obtained from federal university of technology owerri, imo state, Nigeria. His research area is in dry/analytical structures and concrete production. He is a corporate member of council for the regulation of engineering in Nigeria.
	**AJOKU, CHINEDU AZUBUIKE** MrAjokuC.A is a lecturer in the department of civil engineering, federal university of technology owerri. He obtained his M.Eng and B.Eng in structural engineering from federal university of technology owerri, Nigeria. His research interest is in the use of waste materials in concrete production.