JOURNAL OF ENGINEERING AND APPLIED SCIENCES

JEAS **Journal of Engineering and Applied Sciences 10 (2016-2017)**

Optimization of the Compressive strength of Concrete made with Sedimentary Rock Aggregates of 12-mm maximum size, from Neyi-Aguleri Gravel Quarry

[1*]Adinna B. O, [2]Aginam C. H, [3]Nwaiwu C. M. O.

[1]Department of Civil Engineering, Nnamdi Azikiwe University, Awka
[2]Department of Civil Engineering, Nnamdi Azikiwe University, Awka
[3] Department of Civil Engineering, Nnamdi Azikiwe University, Awka
[*]Corresponding Author's E-mail: adinnaboniface@yahoo.com

Abstract

Sedimentary rocks have mechanical properties that vary from one rock outcrop to the other. It is not always easy to predict the strength of concrete made with sedimentary rock aggregate, because of this variability, making it a poor substitute for granite in major constructions. This report is centered on 12-mm aggregate from Neyi-Aguleri gravel pit that has extra problem of silt contaminations which causes greater uncertainty about the strength characteristics of its concrete. This report produced a mathematical model for the strength of concrete made with 12-mm aggregate from Neyi-Aguleri as a means of characterizing this aggregate in terms of quality and limitations of application. The model gave an optimum strength of 11.110 N/mm^2 for mix proportions of 1: 1.6: 3.1, and water-cement ratio of 0.551.This strength was found to be very low when compared with recommendable values from code of practice. It was therefore, recommended that the aggregate be avoided in structural concrete for bridges, culverts, columns of building above three storeys and any other structural element where stress can be above the calculated *optimum value. It was recommended for short lintel beams of all buildings, when used at the obtained optimum mix proportion*

Keywords: sedimentary rock, aggregate contaminations, concrete strength, model.

1.1 Introduction

Aggregate constitutes 70 to 80 percent of the volume of concrete. The influence of aggregates property on concrete strength cannot be overlooked (Shetty,2005 ;Mosley and Bungey,1990)). There are two main types of aggregates used in Nigeria granite and sedimentary rock aggregate. Sedimentary rock covers over 50% percent of surface area of Nigeria landmass with outcrops in almost every state and regions Nwajide (2013). They are locally used for concrete making as cheap substitute for granite, but not in mainstream constructions. The major setback in the use of sedimentary rock aggregate is that its mechanical properties vary significantly from one outcrop to the other and from one quarry site to the next, due to variation in the geological processes that formed the parent rocks (Kogbe, 1989) and differences in the method of production of the aggregate from one quarry site to the other. These aggregates if properly harnessed can be an acceptable substitute for granite in many cases and this will go a long way to reduce the cost of building materials in general. This report intends only to optimize the strength of concrete produced from sedimentary rock aggregate of 12-mm size from Neyi-Aguleri to show the range of strength of concrete obtainable from the aggregate and the maximum possible value within the range of mix proportions considered using Scheffe's simplex method of optimization. It is not intended to suggest an alternative mix proportion procedure for sedimentary rock aggregate.

Furthermore, Neyi-Aguleri is one of the sites or quarry in which sedimentary rock aggregate are produced for use in the south-eastern part of Nigeria. The aggregate produced there are granular rocks with grains often weakly cemented. The 12mm size aggregate have extra problem of silt contamination, up to 10%, causing more doubts as to the quality of its concrete. It then becomes necessary to optimize the strength of concrete from this aggregate size to guide engineers in making safe use of these aggregate; that is, to avoid structural failures.

Scheffe's Simplex Method

A simplex can be defined as a geometrical figure formed by intersecting planes and which has $(k + 1)$ vertices, where k is the number of planes intersecting. If the number of planes is one, the simplex is a straight line, and is regarded as a one-dimensional simplex; and is formed by one edge of the plane. If the number of planes are two, it is a two dimensional simplex, and it is a triangle with the intersection of the planes and the remaining two edges forming the three vertices (Akchnazarova,and Kafarove 1952). If the sides of the simplex are of equal length, it is called a regular simplex. Simplex can be used to represent or relate data information graphically. Scheffe (1958) used a regular $(q-1)$ simplex to represent the factor space for mixtures needed to form a response surface for a desired property of a mixture. Here q represents the number of components in the mixture or the number of elements that are mixed; if the number of component is q=2, then the simplex has a dimension of one, and is a straight line. If q=3, the simplex has a dimension of two and is an equilateral triangle. For number of components q=4, like most concrete, the simplex has a dimension of three. A three dimensional simplex has 4 vertices and it is a tetrahedron. The property of the mixture studied is regarded as dependent on the component ratios only. For multi-component systems the response surface takes the form of a high degree polynomial of the types in Eq(1.0), having number of coefficients given by C_{q+n}^{n}, where n is the degree of the chosen polynomial and q is the number components in the mixture:

$$\hat{Y} = b_0 + \sum_{1 \le i \le q} b_i x_i + \sum_{1 \le i < j \le q} b_{io} x_i x_j + \sum_{1 \le i < j < k \le q} b_{ijk} x_i x_j x_k + \sum b_{i_1, i_2, \ldots i_n} x_{i_1} x_{i_2} \ldots x_{i_n} \tag{1}$$

Knowing that Equation (2) also holds for mixtures

$$\sum_{i=1}^{q} x_i = 1 \tag{2}$$

(where $X_i \ge 0$ represents the component concentrations in the mixture) Scheffe (1958) was able to derive a new polynomial with fewer number of coefficients, given by C_{q+n-1}^{n}, thereby reducing the bulk of experimental work required to evaluate the coefficients. From Scheffe's derivations, the second degree polynomial $(n = 2)$ for 4 component mixtures $(q = 4)$ needed for this report is given by:

$$\hat{Y} = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{14} x_1 x_4 + \beta_{23} x_2 x_3 + \beta_{24} x_2 x_4 + \beta_{34} x_3 x_4 \tag{3}$$

Where $\beta_i = \bar{Y}_i$, $\beta_{ij} = 4\bar{Y}_{ij} - 2\bar{Y}_i - 2\bar{Y}_j$ in which $\bar{Y}_i$ and $\bar{Y}_{ij}$ are responses from the various experimental trials. Eq (3.0) has 10 coefficients instead of 15 coefficients obtainable from Eq (1.0) alone.

Evaluation of the coefficients in Eq (3.0), requires 10 different mixtures ($C^{n}_{q+n-i} = 10$) to be used in laboratory experiment in search of responses required for the evaluation of the coefficients in Eq (3.0). These 10 mixtures are shown with their co-ordinates on the simplex, and in so doing the boundary space of the mixtures required and the relative proportions of the component in each mixture is properly described in the simplex in
Fig(1.0)

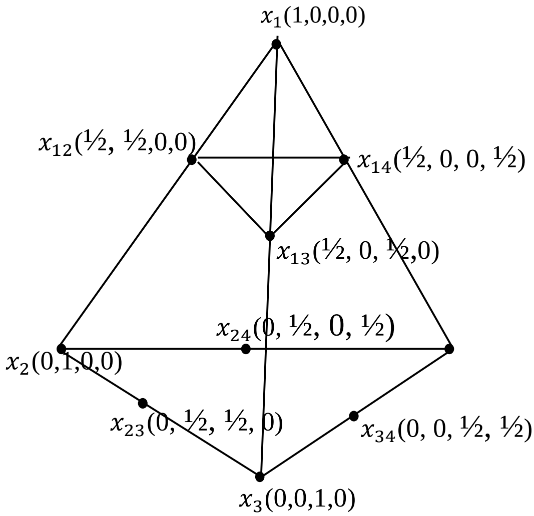


Fig 1.0: Factor Notations on the Simplex

These mixtures are further presented in tabular format alongside with the corresponding responses obtained from the experiments (see let side of Table 1.0).

Data given in Fig(1.0) and Table(1.0) cannot be used for concrete; they must be converted to corresponding concrete ratios. This can be done by selecting four concrete ratios, e.g. $x_1(0.6: 1.0: 1.5: 4.0)$; $x_2(0.5: 1.0: 1.0: 1.5)$; $x_3(0.55: 1.0: 1.5: 3)$; and $x_4(0.555: 1.0 : 1.5 : 4)$ that shows the range of water-cement ratio, fine aggregate and course aggregate ratios to be use in the research and position them variously at the vertices of Fig(1.0) to replace x_1 x_2, x_3 and x_4, respectively; to represent the range of concrete ratios that the model will be based. The remaining co-ordinates x_{12} x_{13} x_{14} x_{23} x_{24} and x_{34} in the factor space can be obtained by linear interpolation, normally done using the matrix in equation Eq (4.0)

$$Z^T = \begin{bmatrix} 0.6 & 1.0 & 1.5 & 4 \\ 0.5 & 1.0 & 1.0 & 1\frac{1}{2} \\ 0.55 & 1.0 & 1\frac{1}{2} & 3 \\ 0.555 & 1.0 & 1\frac{1}{2} & 4 \end{bmatrix}^T \quad (4)$$

Table 1.0: Matrix table for Scheffe's second degree polynomial

	Pseudo-Components				Response	Real-components			
S/N	x_1	x_2	x_3	x_4		z_1	z_2	z_3	z_4
1	1	0	0	0	y_1	0.6	1.0	1.5	4
2	0	1	0	0	y_2	0.5	1.0	1.0	1 ½
3	0	0	1	0	y_3	0.55	1.0	1 ½	3
4	0	0	0	1	y_4	0.555	1.0	1 ½	4
5	½	½	0	0	y_{12}	0.55	1.0	1.25	2.75
6	½	0	½	0	y_{13}	0.575	1.0	1.5	3.5
7	½	0	0	½	y_{14}	0.578	1.0	2.0	4.0
8	0	½	½	0	y_{23}	0525	1.0	1.25	2.25
9	0	½	0	½	y_{24}	0528	1.0	1.75	2.75
10	0	0	½	½	y_{34}	0.553	1.0	2.0	3 ½

Corresponding points x_{12} x_{13} x_{14} x_{23} x_{24} and x_{34} can be obtained by following the procedure for x_{12} in Eq (5.0)

$$\begin{bmatrix} 0.6 & 0.5 & 0.55 & 0.555 \\ 1.0 & 1.0 & 1.0 & 1.0 \\ 1.5 & 1.0 & 1\frac{1}{2} & 1\frac{1}{2} \\ 4 & 1\frac{1}{2} & 3 & 4 \end{bmatrix} \begin{bmatrix} 1/2 \\ 1/2 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 0.55 \\ 1.0 \\ 1.25 \\ 2.75 \end{bmatrix} \quad (5)$$

These new co-ordinates so obtained are recorded on the right side of Table(1.0) as real components for the laboratory experiments alongside their corresponding pseudo-components. This new factor space can be displayed on a simplex like the former and it replaces the former simplex because it is suitable for concrete. It is this new factor space of real component that will be used in this research, see right side of Table (1.0)

2.0 Material and methods

2.1 Materials

Materials used for the research include sample of unwashed coarse aggregate (12-mm size) from Neyi-Aguleri gravel pit. The sample was stored in-doors so that there will be minimal moisture variation in the sample. River sand from Onitsha was also obtained and stored in the same way. Laboratory equipment needed include, universal crushing machine, 150 x 150 x 150- mm cube mould, mould-oil, weighing balance, trowel and curing tank.

2.2 Method

(i) Experiments

Using the weighing balance, water, cement, fine aggregate and coarse aggregates, were weighed out in the proportion shown in Table (1.0), respectively, for each mixture and in such a quantity that the materials weighed out served for three cubes. The materials were thoroughly mixed together inside a non-absorbent container, before water was added and final mixing was done. Three cubes were cast for each of the mix proportions making 60 cubes on the whole. The fresh concrete was filled into the mould in three layers, with each layer tamped 25 times. The top was scraped off with the trowel and the concrete cubes cured in water for 28 days. The cubes were crushed in a universal crushing machine. The compressive cubes strength results and the averages for each test point were tabulated

(ii) Development of the Model

From the general form of Scheffe's second degree polynomial in 4 component mixture given in Eq(3.0); and from tabulated values of compressive strengths, and making use of the expressions for β_i and β_{ii} of Eq(3.0) the coefficients of the model were calculated and built from Eq(3.0)

(iii) Validation of the Model

Adequacy of the model was tested through fisher's variance ratio, whereby the calculated values of fisher's ratio F was compared with the tabulated value in the quantiles for the F distribution at .95 percentile (Greer,1988)

$$F = S_g^2/S_e^2 \text{ --} \qquad (6)$$

Where sum of squares related to goodness of fit

$$s_g^2 = \frac{m}{n-l} \sum_1^n (\bar{y}_i - \hat{y}_i)^2 \text{--} \qquad (7)$$

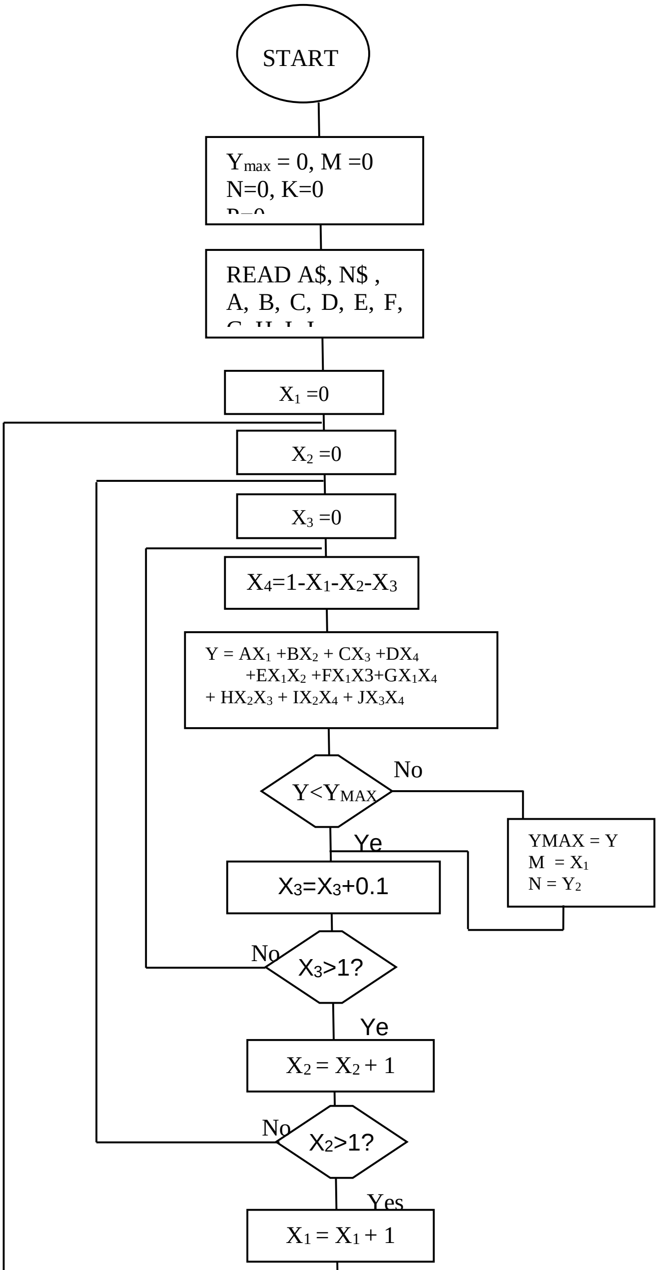
and sum of squares related to error mean square

$$s_e^2 = \frac{1}{n(m-l)} \sum_{i=1}^{n} \sum_{u=1}^{m} (y_{iu} - \hat{y}_i)^2 \qquad (8)$$

In the above equations, n is the number of experimental points (trials), m is the number of replication for each point, ι is the number of coefficients in the model, $\hat{y}_i$ is the average response for the ith experimental point, $\hat{y}$ in the predicted value from the model for the ith test point, y_{iu} is the replicate response value for the test point. If F is less than the tabulated value, then the model is adequate.

(iv) Optimization of the model

The optimization of the model was done through a computer quick-basic program whose flowchart is given in Fig (2.0)



KEY
A$ = Quarry Site
N$ = Strength type
A, B, C, D, E, F, G, H, I and J
Are the Coefficients of the Model.
Y_{max}, Z_1, Z_2, Z_3 and Z_4 are maximum strength, **maximum w/c, cement, fine aggregate and coarse aggregate respectively**

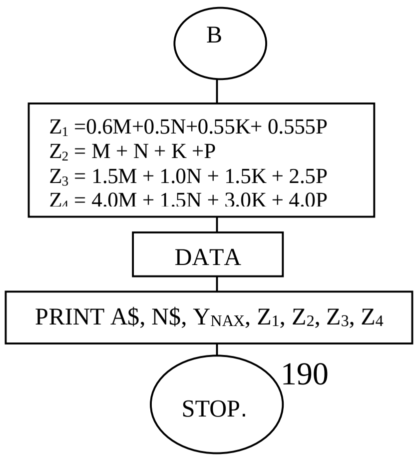


Fig 2.0: Optimization flow Chart for QuickBasic algorithm

3.0 Results and Discussions

(i) Results

In Table (2.0) the results of the concrete cube strengths are recorded; columns 7,8and 9 contain replicate results of the three cubes from each mix proportion, while 10 contains the average and 11 contains the corresponding predictions from model.

Table 2.0: Response from experiment and predictions from mode

N)	Pseudo-Component (2)	(3)	(4)	(5)	Response Symbol (6)	Replicate Response (N/mm^2) (7)	(8)	(9)	Average Response (10)	Predictions (11)	Real Components (12)	(13)	(14)	(
	x_1	x_2	x_3	x_4		1	2	3	$\bar{Y}$ (N/mm^2)	$\hat{Y}$ (N/mm^2)	Concrete mix ratios			
1	1	0	0	0	y_1	7.11	5.33	11.78	8.07	8.07	0.6	1	1½	4
2	0	1	0	0	y_2	7.78	11.78	11.11	10.22	10.22	05	1	1	1
3	0	0	1	0	y_3	9.11	14.44	11.78	11.78	11.78	0.55	1	1½	3
4	0	0	0	1	y_4	9.87	8.44	8.00	8.77	8.77	0.555	1	2½	4
5	½	½	0	0	y_{12}	10.22	8.89	10.31	9.81	9.81	0.55	1	2¼	2
6	½	0	½	0	y_{13}	7.78	5.33	7.11	6.74	6.74	0.575	1	1½	3
7	½	0	0	½	y_{14}	7.56	7.64	9.56	8.25	8.25	0.578	1	2	4
8	0	½	½	0	y_{23}	12.22	8.44	10.76	10.47	10.47	0.525	1	1¼	2
9	0	½	0	½	y_{24}	9.33	9.42	8.00	8.92	8.92	0.528	1	1¾	1
0	0	0	½	½	y_{34}	8.67	7.96	11.11	9.25	9.25	0.533	1	2	3
							Control							
1	½	0	¼	¼	C_1	8.89	6.67	12.0	9.19	7.24	0.576	1	2¾	3
2	¼	0	½	¼	C_2	8.13	10.89	10.89	9.97	7.24	0.576	1	1¾	3
3	¼	¼	¼	¼	C_3	8.22	8.89	10.22	9.11	8.51	0.551	1	1.625	3.1

4	2/3	0	0	1/3	C_4	10.00	7.56	6.44	8.00	8.15	0.585	1	1.833	4
5	¼	¼	½	0	C_5	10.00	6.22	8.89	8.37	8.77	0.55	1	1.375	2.8
6	¼	½	0	¼	C_6	12.44	9.78	12.00	11.41	9.32	0.539	1	1½	3
7	¼	0	¼	½	C_7	8.00	8.66	8.44	8.37	7.92	0.535	1	2	3
8	½	¼	0	¼	C_8	10.49	8.22	8.22	8.98	8.89	0.564	1	1.625	3.3
9	¼	½	1/8	1/8	C_9	10.00	7.56	8.89	8.82	9.26	0.538	1	1.375	2.6
0	1/3	1/3	0	1/3	C_{10}	8.22	9.33	4.89	7.48	8.98	0.552	1	1.667	3.1

From the general form of Scheffe's second degree polynomial given in Eq(3.0); and from Table (2.0), column 10, and making use of the expressions for β_i and β_{ii} of Eq(3.0) the model(Eq 9.0) for compressive strength of concrete for Neyi-Aguleri gravel quarry for 12-mm maximum size aggregates was developed.

$$\begin{aligned} \hat{Y} = {} & 8.07x_1 + 10.22x_2 + 11.78x_3 + 8.77x_4 \\ & + 2.66x_1x_2 - 12.74x_1x_3 - 0.68x_1x_4 \\ & -2.12x_2x_3 - 2.3x_2x_4 - 4.1x_3x_4 \end{aligned} \qquad (9.0)$$

The predictions from the model is given in column 11 of Table (2.0). The model was validated using Fisher's ratio which gave calculated F as 1.51. The critical F_{cr} from table was 2.8: the model was adequate.

The model was also optimized, and the optimum value obtained by the computer within the given factor space, was 11.110 N/mm^2, 0.551: 1:1.6:3.1; for compressive strength; water, cement, fine aggregate and coarse aggregate ratios, respectively.

(ii) Discussion

The results of the compressive strengths recorded in Table (2.0) columns 7, 8, 9, 10, 11 and the optimum strength are too low compared with similar mix ratios of concrete made with granite. Mix ratio of 1:2:4, for instance, is generally regarded as Grade 20 ,that means a compressive strength of 20N/mm^2 as given in code of practice(B.S 8110, 1975) but for the aggregate sample studied the result obtained was 8.25 N/mm^2 . The optimum value of strength is 11.110 N/mm^2 for a mix ratio of 1:1.6:3.1 and water cement ratio of 0.551. This is the richest practicable mix within the factor space, yet it is less than 20N/mm^2 commonly prescribed for reinforced concrete structures.

4.0 Conclusion

From the results of the experiments and the predictions of the model, it is very clear that the strength of concrete produced from 12-mm aggregate from Neyi-Aguleri is poor and cannot be used for general purposes

5.0 Recommendation

It is, therefore, recommended that the aggregate be avoided in structural concrete like bridges, culverts, and column of building above three storeys and any other structural element where stresses are calculated to be above the obtained optimum value. The most recommended places of application are in short lintels of all type of building and columns of one or two storey buildings.

REFERENCES

Akhnazarova S and Kafarov V (1952) Experiment Optimization in Chemistry and Chemical Engineering, Mir Publisher, Moscow

Akhnazarova. S and kafarov. V (1972) Statistical Method of Design and Processing of Experiment "MKHTT" Press, Moscow

B.S 8110**:**Part1(1985) Stuctural use of Concrete,Gaylard and sons ltd, England

Greer A (1988) Statistics for Engineers, Stanley Thornes Ltd, Cheltenhan, England.

Kogbe C. A (1989) Geology of Nigeria, Rock View Nigeria Ltd, Jos Nigeria

Mosley W.H and Bungey J.H (1990): Reinforced concrete Design, Macmillan Press Ltd, Hong kong

Nwajide C.S. (2013) Geology of Nigeria's Sedimentary Basins, CSS Bookshop Ltd Lagos, Nigeria.

Onwuka D. O,Okere C.E,Arimanwa J.I and,Onwuka S.U (2011) Prediction of concrete mix ratios using modified regression theory Journal of Computational Method in Civil Engineering 2 pp 95-107

Scheffe.H(1958) Experiments with mixtures ,Journal of Royal Statistics Society, Ser B, 25, No**, 2**