INVESTIGATION INTO THE SUITABILITY OF GRAVEL AGGREGATES (8 TO 16mm SIZE) FROM UMUNYA GRAVEL SITES FOR STRUCTURAL CONCRETE PRODUCTION

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Abstract
Like many towns in Nigeria, Umunya is blessed with rock outcrops of sedimentary rock formations. Some of these rocks are, unfortunately, characterized with alternating layers of shale and sedimentary rock, especially those near the expressway leading to Onitsha. Production of concrete aggregates of size 8mm -16mm, from these rocks results in aggregates with heavy contamination of shale with the shale camouflaging perfectly as rock when the aggregate is dry. In this report a mathematical model based on Scheffe's Simplex Method was developed for the compressive strengths of concretes produced with the aggregate, for a given range of water/cement and aggregate/cement ratios. Optimum values of strength and water/cement ratio obtained were 4.63N/mm2 and 0.538, respectively, for an optimum mix proportion of 1: 1:375 : 2.625, representing cement, sand and gravels, respectively. When compared with the strength of a similar mix proportion using granite aggregate, estimated at an average of 25N/mm2 to 35N/mm2, it was suggested that 8-16mm size of aggregate from such rocks be disused for the production of structural concrete to avoid structural failure and unnecessary waste of materials.

***Keywords:** Sedimentary Rocks, Aggregate contaminations, concrete strength, model.*

Introduction

Umunya, a town in Nigeria has a landscape dotted with outcrops of sedimentary rock formations. The problem with these rocks is that some of the outcrops are characterized with alternating layers of shale and rock. Aggregates obtained from these rocks, of sizes between 8mm-16mm, are mixed up with pieces of shale. When the aggregate is dry the shale camouflage as rocks, when the aggregate is wetted, shale soften and the high level of contamination becomes apparent. Because of its cheapness people frequently make use of these aggregates for purpose of structural concrete.

This paper wishes to assess the quality of these aggregates by developing a mathematical model for the strength of concrete made from them for a given range of water/cement, fine and coarse aggregate ratios. The optimum values of strength, water/cement ratio and mix proportion can then be compared with that of granite aggregate to enable appropriate recommendations to be made.

The method of optimization to be used in the Scheffe's Simplex Lattice Method for mixtures, where the property studied depends on the component ratios only. Firstly, a simplex is defined as a convex polyhedron with (k+1) vertices produced by K intersecting hyperplanes in K dimensional space (Akhnazarova, 1982). Any co-ordinate system above 3 dimensions is referred to as hyper plane, such planes are not orthogonal. A 2 dimensional regular simplex is, therefore, an equilateral triangle, while a 3 dimensional regular simplex is a regular tetrahedron.

Scheffe (1958) used a regular (q-1) simplex to represent the factor space needed to describe a response surface for mixtures consisting of several components. If the number of components is denoted by q, then for binary system (q=2) the required simplex is a straight line; for q=3, the required simplex is an equilateral triangle; and for q=4, the simplex is a regular tetrahydron. The response surface for such a multi component system is normally described using a high degree polynominal, of the type in Eq1.0, having number of coefficients given by where n is the degree of the polynomial (Alhnazarova etal, 1982).

$$\hat{Y} = bo + \sum_{1\le i\le q}' b_i X_i + \sum_{1\le i<j\le q}' b_{ij} X_i X_j + \sum_{1\le i<j<k\le q}' b_{ij}\,k\, X_i X_j X_k + \sum' b_{i1in} - i_n X_{i1} X_{i2} X_{in} - - - (1.0)$$

Knowing that Eq (2.0)also holds for mixtures

$$\sum_{i=1}^{q} x_i = 1 - - - - 2.0$$

where $X_i = 0$ represents the component concentration in the mixture, seheffe (1958) was able to reduce the number of coefficients in Eq(1.0) to arrive at a new polynominal whose number of coefficients is given by C^n_{q+n-1} thereby reducing the number of experimental trials required to evaluate the coefficients. Scheffe's reduced polynomial is commonly used. Demonstrating this reduction for a four-component mixture we have:

From Eq (1.0) and Eq (2.0)

$$\begin{gathered} Y = bo + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_{12} X_1 X_2 \\ + b_{13} X_1 X_3 + b_{14} X_1 X_4 + b_{23} X_2 X_3 + b_{24} X_2 X_4 \\ + b_{34} X_3 X_4 + b_{11} X_1^2 + b_{22} X_2^2 + b_{33} X_3^2 + b_{44} X_4^2 - - - ?3.0? \\ \text{and } X_1 + X_2 + X_3 + X_4 = - - - - (4.0) \end{gathered}$$

Multiplying Eq (4.0)by bo, X_1, X_2, X_3 and X_4, separately, and rearranging the variables the following equations are obtained.

$$b_o = b_o X_1 + b_o X_2 + b_o X_3 + b_o X_4 - - - (5.0)$$
$$X_1^2 = X_1 - X_1 X_2 + X_1 X_3 + X_1 X_4 - - - (6.0)$$
$$X_2^2 = X_2 - X_1 X_2 + X_2 X_3 + X_2 X_4 - - - (7.0)$$
$$X_3^2 = X_3 - X_1 X_3 + X_2 X_3 + X_3 X_4 - - - (8.0)$$
$$X_4^2 = X_4 - X_1 X_4 + X_2 X_4 + X_3 X_4 - - - (9.0)$$

Substituting Eqs 5.0, 6.0, 7.0, 8.0 and 0.9 into Eq 3.0 and rearranging, yields

$$\begin{gathered} \bar{Y} = B_1 X_1 + B_2 X_2 + B_3 X_3 + B_4 X_4 + B_{12} X_1 X_2 + B_{13} X_1 X_3 \\ + B_{12} X_1 X_4 + B_{23} X_2 X_3 + B_{24} X_2 X_4 + B_{34} X_3 X_4 - - - - - (10) \end{gathered}$$

Eq (10) is the scheffe's reduced second degree polynomial for 4 –component mixtures. It has only 10 coefficients instead of 15, reducing the number of experimental trials by 5.

Factor Notation on a Simplex Lattice

Each component to be used in a mixture is divided into (n+1) similar levels (parts), where n is the degree of the polynomial to be used in the model. The component compositions and their respective concentrations in each mixture are shown by the use of these levels as subscripts. For example, a mixture X_{ij} could contain only one component with its full concentration denoted as X_1, X_2, X_3, or X_4; another mixture could contain two components of equal concentration demoted as $X_{12}, X_{13}, X_{14}, X_{23}$ X_{24}, or X_{34}

A mixture having two components with different concentrations is denoted as X_{112}, X_{113}, or X_{224} - the number of times each component appears in the subscript shows the number of levels of concentration it has above or below the other in the mixture.

These mixtures are placed on the simplex to form a lattice, or a uniform scatter that could he joined by crossing straight lines parallel to the edges of the simplex. For tetrahydron, starting from the vertex with straight component mixtures X_1, X_2, X_3 followed by the edges with binary component mixtures X_{12}, X_{13}, X_{24} etc; then the faces with three -component mixtures X_{124}, X_{234}, etc; and finally the interior with 4 component mixtures, this sequence is followed until all the experimental trials required are depicted on the simplex. Fig (1.0) shows the positions of all the factors (mixtures) on a regular tetrahydron for second degree polynomial for 4-component mixtures a (4,2) lattice

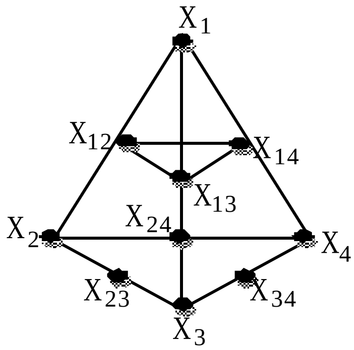

Fig 1.0: factor notations for a (4,2) lattice

Matrix table is normally used to display these factors (see left side of table 1.1) each row displaying a mixture with its components and concentrations

Table 1.0: Matrix table for Schettes (4,2) lattice polynomial

Pseudo-Component					Response	Real CC 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	
3	0	0	1	0	Y_3	0.55	1.0	1 ½	3.0
4	0	0	0	1	Y_4	0.555	1.0	2 ½	4.0
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}	0.525	1.0	1.25	2.25
9	0	½	0	½	Y_{24}	0.528	1.0	1.75	2.75
10	0	0	½	½	Y_{34}	0.553	1.0	2.0	

For the fact that concrete mixtures must contain four components, all the time and the sum of the mixture ratios defers from unity, a congruent simplex must be produced for concrete such that the mix ratios at the vertices show the range of w/c ratio, cement, fine aggregate and coarse aggregate ratios, respectively, the require polynomial model well cover. (see fig 2.0)

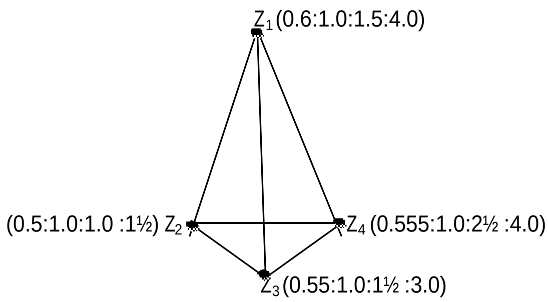

Fig 2.0 Real Component simplex (only vertices are shown)

The former simplex fig 1.0, is called Pseudo component simplex and the later, fig 2.0, real component simplex. From the later (real components) a Z-matrix is formed whose transpose becomes the conversion factor from pseudo to real component; i.e from fig 2.0

$$Z = \begin{pmatrix} 0.6 & 1.0 & 1.5 & 4.0 \\ 0.5 & 1.0 & 1.0 & 1\tfrac{1}{2} \\ 0.55 & 1.0 & 1\tfrac{1}{2} & 3.0 \\ 0.555 & 1.0 & 2\tfrac{1}{2} & 4.0 \end{pmatrix}$$

$$Z^T = \begin{pmatrix} 0.6 & 0.5 & 0.55 & 0.555 \\ 1.0 & 1.0 & 1.0 & 1.0 \\ 1.5 & 1.0 & 1\tfrac{1}{2} & 2\tfrac{1}{2} \\ 4.0 & 1\tfrac{1}{2} & 3.0 & 4.0 \end{pmatrix} \underline{\hspace{3cm}} 11.0$$

To demonstrate the use of Eq (II) in table 1.0, the 5th row in the real component side is obtained by multiplying [Z]T matrix by the corresponding row in the pseado-componnent side of table 1.0 i.e

$$\begin{pmatrix} 0.6 & 0.5 & 0.55 & 0.555 \\ 1.0 & 1.0 & 1.0 & 1.0 \\ 1.5 & 1.0 & 1\tfrac{1}{2} & 2\tfrac{1}{2} \\ 4.0 & 1\tfrac{1}{2} & 3.0 & 4.0 \end{pmatrix} \begin{bmatrix} \tfrac{1}{2} \\ \tfrac{1}{2} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 0.55 \\ 1.0 \\ 1.25 \\ 2.75 \end{bmatrix}$$

In this way all corresponding rows in the real component side are obtained producing a congruent table and simplex suitable for concrete.

Material and method

i. Materials

Materials needed for the research include sample of unwashed coarse aggregate (gravels) from Umunya gravel pith. The specimens were stored in sacks indoor, so that moisture variations in the samples were minimal. The laboratory equipments needed include, universal crushing machine, 150 X 150 X 150mm cube moulds, mould oil, weighing balance, trowel and curing tank

ii. Method

Using the weighing balance water, cement, fine aggregate and coarse aggregate, were weighed out, respectively, and in the proportions shown in table 1.0 in such a way that the materials weighed out served for three cubes. The materials are mixed thoroughly together inside a non-absorbent container or bowel before water was added, and final mixing was done three cubes were cast for each of the mix proportions making 60 cubes in the whole. The fresh concrete was filled into the moulds in three layers, each layer tamped not less than 25 times. The top was scraped off with the trowel

	Pseudo Component				Response Symbol	Replicate Response (N/mm²)			Average Response	Prediction	Real Component			
S/N	X_1	X_2	X_3	X_4		1	2	3	YN/mm²	YN/mm²	(concrete Mix ratios)			
1	1	0	0	0	Y_1	2.22	2.67	2.89	2.59	2.59	0.6	1	1 ¼	4
2	0	1	0	0	Y_2	6.22	8.89	5.78	6.96	6.96	0.5	1	1	1 ½
3	0	0	1	0	Y_3	5.11	6.67	4.44	5.41	5.41	0.55	1	1 ½	3
4	0	0	0	1	Y_4	3.56	3.78	4.22	3.85	3.85	0.555	1	2 ½	4
5	½	½	0	0	Y_{12}	4.53	5.33	3.56	4.47	4.47	0.55	1	1 ¼	2 ¾
6	½	0	½	0	Y_{13}	3.78	4.22	4.22	4.07	4.07	0.575	1	1 ½	3 ½
7	½	0	0	½	Y_{14}	4.0	2.67	3.11	3.26	3.26	0.578	1	2	4
8	0	½	½	0	Y_{23}	5.11	4.89	4.22	4.74	4.74	0.525	1	1 ¼	2 ¼
9	0	½	0	½	Y_{24}	4.78	4.22	5.11	4.37	4.37	0.528	1	1 ¾	1 ¾
10	0	0	½	½	Y_{34}	4.22	4.00	3.33	3.85	3.85	0.533	1	2	3 ½
Control Points														
11	½	0	¼	¼	C_1	3.56	4.44	3.11	3.70	3.47	0.576	1	2 ¾	3 ¾
12	¼	0	½	¼	C_2	4.22	4.44	4.00	4.22	3. 97	0.564	1	1 ¾	3 ½
13	¼	¼	¼	¼	C_3	4.22	5.33	4.22	4.59	3.83	0.551	1	1.625	3.125
14	2/3	0	0	1/3	C_4	3.00	4.44	4.34	3.93	3.05	0.585	1	1.833	4.0
15	¼	¼	½	0	C_5	4.89	3.78	4.44	4.37	4.33	0.55	1	1.375	2.875
16	¼	½	0	¼	C_6	5.78	5.0	4.00	4.93	4.43	0.539	1	1 ½	2 ¾
17	¼	0	¼	½	C_7	3.01	2.56	5.14	3.57	4.27	0.535	1	2	3 ¾
18	½	¼	0	¼	C_8	3.20	4.21	3.42	3.61	3.81	0.564	1	1.625	3.375
19	¼	½	1/8	1/8	C_9	3.41	5.45	5.03	4.63	4.53	0.538	1	1.375	2.625
20	1/3	1/3	0	1/3	C_{10}	3.40	4.10	4.14	3.88	3.42	0.552	1	1.667	3.167

The concrete was allowed to harden for 24 hours, after which the mould was removed and the cubes cured in water for 28 day in the curing tank. At the end of 28 days the cubes were crushed in the universal crushing machine. The results and averages for each test point are tabulated in columns 7 to 10 table 2.0. Extra ten test points were provided for validation of the model. The number of extra text point depends on choice.

TABLE 2.0 Responses From Experiment And Predictions From Model\Development of the Model

The general form of seheffe's (4,2) – lattice polynomial is given by

$$\hat{Y} = \sum_{1 \le i \le 4} \beta_i X_i + \sum_{1 \le i < j \le 4} \beta_{ij} X_i X_j \; ----12$$

Where $\beta_i = y_i, \beta_{ij} = \beta_{ij} = 4y_{ij} - 2y_i - 2y_j$
From table 2.0, Column 10:

$$\beta_1 = 2.59, \beta_2 = 6.96, \beta_3 = 5.41, \beta_4 = 3.85$$
$$\beta_{12} = 4 \times 4.47 - 2 \times 2.59 - 2 \times 6.96 = -1.22$$
$$\beta_{13} = 4 \times 4.07 - 2 \times 2.59 - 2 \times 5.41 = -0.28$$
$$\beta_{14} = 4 \times 3.26 - 2 \times 2.59 - 2 \times 3.85 = -0.16$$
$$\beta_{23} = 4 \times 4.74 - 2 \times 6.96 - 2 \times 5.41 = -5.78$$
$$\beta_{24} = 4 \times 4.37 - 2 \times 6.96 - 2 \times 3.85 = -4.14$$
$$\beta_{34} = 4 \times 3.85 - 2 \times 5.41 - 2 \times 3.85 = -3.12$$

The model for compressive strength for Umunya sample becomes

$$\widehat{y} = 2.59X_1 + 6.96X_2 + 5.41X_3 + 3.85X_4 - 1.22 \times_1 \times_2$$
$$+ 0.28X_1X_3 + 0.16X_1X_4 - 5.78X_2X_3 - 4.14X_2X_3 - 3.12 X_2X_3 - - - - - 13$$

The prediction from Eq 13 is given in table 2.0 column 11
2.2 Validation of the Model (test for adequacy) Adequacy of the model (Eq 13) can be tested through Fisher's variance Ratio, whereby the calculated value of Fisher's ratio F is compared with the tabulated value in the Quintile of the F-Distribution:

$$F = {}^{Sg^2}/_{Se^2} - - - - - -14$$

$$\text{Where } Sg^2 = \frac{m}{n-1}\sum_{i=1}^{n}(y_i - \widehat{Y}_i)^2 - - - - -15$$

$$\text{and } Se^2 - \frac{1}{n(m-1)}\sum_{i=1}^{n}\sum_{i=1}^{m}(y_{iu} - \bar{y}_i)^2 - 16$$

In the above equations n is the number of experimental points (trails), m is the number of replication for each point, I is the number of coefficients in the model, $\widehat{y}_i$ is the average response for jth experimental point, $\widehat{y}_i$ is the predicted value from model for j^{th} test point $\widehat{y}_i$ is the uth replicate response value for j^{th} test point.

If F is greater than the tabulated value then the model is adequate, i.e

$$Sg^2 = {}^3/_{10} \times 2.4706$$

$$Se^2 = \frac{24.6377}{40}$$

$$F = \frac{Sy^2}{Se^2} = \frac{({}^3/_{10}) \times 2.4706 \times 40}{24.6377} = 1.2 < 2.1\ Okay$$

Where 2.1 is the limiting value of F obtainable from any table of Quartiles of F – Distribution.

Optimization of the Model

The model (Eq13) was optimized through a Quick-Basic computer programme, whose flowchart is given in fig 3.0. The maximum value given by the computer for strength water cement, fine aggregate and coarse aggregate ratios are 15.066, 0.501, 1, 0.2499, 0.8499, respectively. The result falls outside the range of fine aggregate and coarse aggregate ratio limits of the investigation and, therefore, not reliable. The maximum predicted value in table 2.0 is taken as the optimum values (4.53N/mm2 0.538, 1, 1.375, 2.625) for strength, water cement, fine aggregate and coarse aggregate, respectively.

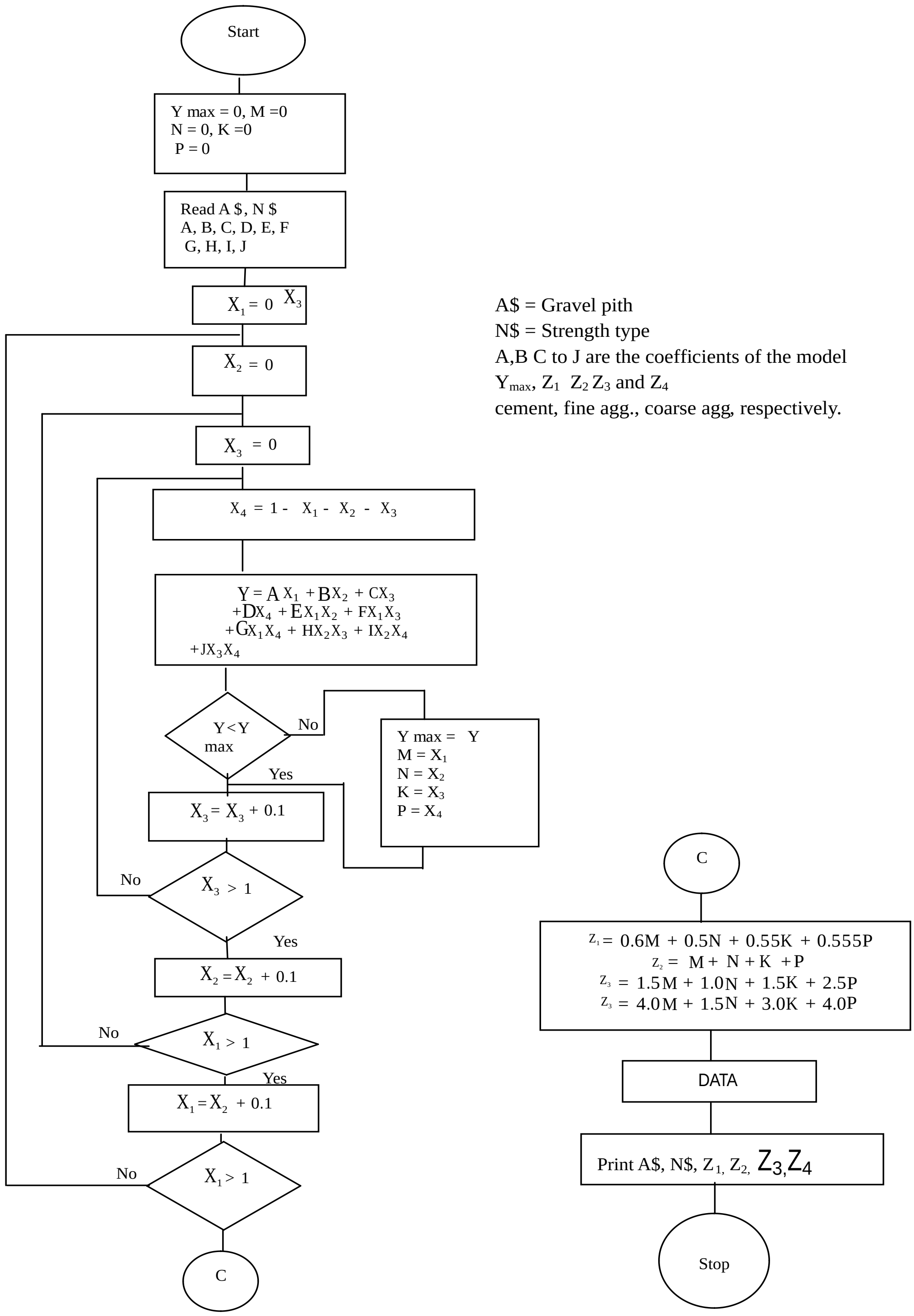

Fig 3.0 Computer Programme Optimization Flowchart

Discussion of results

Looking at the results and the predictions from the model in table 2.0 (columns 7, 8, 9, 10 and 11) it is easy to see that the compressive cube strengths for the various mix proportions are far below the expected values. Considering the 17th row of table 2.0, showing the result and predictions for the mix proportion of , w/c = 0.535, which can be approximated to a grade 20 concrete, if gravel aggregate is used instead, has 4.27/mm2 as the predicted average compressive strength. This is much lower than the average of 25N/mm2, or above, commonly obtained for such mixes in practice when granite aggregates are used.

In addition, production of structural concrete with characteristic strength of 18 N/mm2, 20 N/mm2 and 25N/mm2 which are normally recommended for floors, oversite concretes, columns and suspended floors of building are not possible with this aggregate. This is understood from the optimum values given by the computer programme, which is strength of 15.066N/mm2, mix ratio of 1: 0.25: 0.85 and w/c ratio of 0.501. This computer result shows that this mixture will be too dry to mix and the quantity of cement and aggregate must be equal, before strength of 15N/mm2 can be obtained from these aggregates.

Recommendation and conclusion

From the above discussion it is clear that it is not only dangerous to use these aggregates for structural concrete, it is also uneconomical to use them. It is therefore recommended that these aggregates (sizes 8 16mm from Umunya having the problems so described) be disused for structural concrete.

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