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Optimization of Class C25/30 Interlocking Concrete Tiles Produced by Partial Replacement of Quarry Chippings with Pit Gravel in Enugu Nigeria

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Abstract

The utilization of Pit Gravel in concrete construction is on the increase. This local stone is available in large quantity in Enugu and its environs. This local stone in its natural form is mixed with laterite or other deleterious material which may reduce the performance of this gravel in concrete and other concrete products. To enhance its performance, the pit gravel is thoroughly washed to remove the dirt and some organic compositions.In this study, the effectiveness of local pit gravel was established as an alternative material to replace granite chippings. This research discusses the strength properties and workability behavior of Ugwuaji pit gravel concrete in different replacement level and also compares with control mixture. To achieve this, several laboratory tests were carried out, such as sieve analysis and specific gravity, the result of which was employed to perform a mix design using the Scheffe's experimental design theory. Concrete specimens containing 0%, 10%, 20% ,30 % and 40% Pit gravel were made at a water-cement ratio of 0.57.Using this mix proportion, a transformation matrix was applied to transform a total of 23 pseudo components of the experimental point into the actual mix proportions.

***Key Words*: **Local gravel, Optimization, Laterite, transformation Matrix, Mix Design.

INTRODUCTION

BACKGROUND OF STUDY

Generally interlocking concrete tiles are unreinforced precast units with fixed thickness but they are used for very different purposes ranging from tithing residential compounds and private parks to pedestrian walk-ways in public spaces and to roads for vehicular traffic.

It has been extensively used in a number of countries for quite some time as a specialized problem – solving technique for providing pavement in areas where conventional types of construction are less durable due to many operational and environmental constructs.

Concrete paver blocks were first introduced in Holland in the fifties as replacement of paver bricks which had become scarce due to the past – way building construction boomed.

These blocks were rectangular in shape and had more or less the same size as the bricks. During the past five decades, the block shapes has steadily evolved from non-interlocking partially interlocking to fully interlocking to multiply interlocking shapes.

The most commonly used material for the production of interlocking concrete tiles in construction industries is concrete. Concrete is made up of cement, aggregate and water mixed in an appropriate proportion to give the required properties both in fresh and hardened state. The most frequently used coarse aggregate for this purpose is granite chippings, which is sourced from quarries all over the country. The natural supply of granite is limited and continuous mining and quarrying of this material leads to its eventual depletion. There are several environmental problems associated with this practice, which ranges from occupation of agricultural lands by waste dust and danger to human health. Also the cost of mining, quarrying and transportation of this material to construction site affects the overall cost of construction.

This trend has led many researchers into the quest for alternative and affordable materials for use in concrete. Local pit gravel which is available in most States of the Nigerian Federation is a potential alternative to granite chippings in concrete production. The successful utilization of pit gravel as aggregate in concrete production would create a viable market for this material and in turn reduction in the strain on the supply of granite chippings. In addition, since the cost of this locally available material (pit gravel) is several times less than that of granite chippings, replacement of granite with this material as coarse aggregate will significantly reduce the cost of the concrete.

It is not just enough to partially or wholly replace coarse aggregate with pit gravel in concrete, finding the best combination of these ingredients to achieve the best result should be of paramount importance to the engineer. To achieve this, optimization principle which is a process on minimizing or maximizing value for a function of several variables while at the same time satisfying a number of other imposed requirements are needed. This process involves using statistical techniques which includes fitting empirical models to the data for each performance criterion. In these models, each response which may represent the resultant concrete property such as strength is expressed as an algebraic function of all the component proportions such as w/c ratio, cement content, percentage pit gravel replacement e.t.c. In the search for the best formulation, the main objective is to determine the optimum levels of the components or key ingredients. The ingredients are the independent variables and the dependent variable or response is the factor to be optimized. When various responses are involved, the term combined response optimization is preferable. Hence, as regards the replacement of granite with pit gravel, the optimum combination of the aggregates would be that corresponding to the target properties of the concrete at a reduced cost and this form the bases for the research work.

Statement of Problem

Granite is a major constituent of concrete production in Nigeria. The increasing wave of construction projects by government and individuals alike has put a lot of strain on the supply of this material; this has led to high cost of concrete production and consequently made availability of cheap and affordable houses for the Nigeria people impossible. In most parts of the country, local pit gravel is available in large quantity. This material when utilized will reduce the environment, health hazard associated with mining and quarrying of granite.

To obtain concrete that will meet the desired properties, an appropriate mix design has to be done and followed during the production of concrete. Therefore, the need to provide the appropriate mix proportion that will yield the desired properties at low cost is imperative.

Objective of Study

The main objective of this study is to develop a mathematical model for predicting the mix design parameter for interlocking concrete tiles made with local pit gravel as a partial replacement of granite in concrete. The specific objectives are:

i. To determine the engineering characteristics (compressive strength and workability) of concrete containing pit gravel.
ii. To determine the percentage replacement of granite with Pit gravel that will optimize compressive strength and workability of normal weight concrete.
iii. To determine the effect of different percentage replacement of pit gravel on the compressive strength and workability of normal weight concrete.
iv. To develop a mathematical model for predicting concrete strength of grades C25/30 for a given mix proportion

Scope and Limitations

The scope of the work will be limited to factors affecting the characteristic strength of concrete made by partially replacing granite chipping with locally available pit gravel.

OPTIMIZATION OF CONCRETE MIX DESIGN

Concrete Mix Design

Concrete mix design is the procedure for determining the mix proportions of a particular concrete, with the goal of producing an economic and durable concrete that will meet certain prescribed specification; like consistency, strength and durability (1983). There are two major approaches to concrete mix design, namely the empirical method and statistical method (Simon et al, 1997)

In the empirical method, the guidelines established in Design Codes are followed; added to the historic data or any past experiences the concrete designer might have acquired, working with the same or similar materials. There are a number of Codes of practices that have established guidelines for concrete mix design. The British Standards Institute has the **Design of Normal Concrete Mixes** (Teychenne, et al; 1975, and 1992), while American Concrete Institute (ACI) has ACI Committee 211: standard practice for selecting proportions for Normal, Heavyweight, and Mass Concrete" (1995). In using the empirical methods, trial mixes and further trial mixes are inevitable until all the specified critical are met. By this method, it is however difficult, if not impossible to achieve a truly optimal mixture for all desired criteria. Optimization of multiple concrete criteria can only be attempted using the more scientific statistical method.

The statistical method makes use of some vital theories of experimental statistics to formulate mathematical models, for the prediction of concrete mix ratios and their target strength, within a specified confidence interval – that is, an established probability of acceptance. While the statistical method will require initial technical and experimental investments, it produces an optimized concrete mix in which all specified factors are taken care of and at a much cheaper overall cost. The statistical however has the limitation of being particularized. A model once determined, can only be used to design concrete within the chosen boundaries of the model space, as the model will effectively interpolate not extrapolate.

Statistical Design of Experiment (DOE)

Experiments have always been tools for tackling practical problems and for testing theoretical hypotheses in engineering. Concrete mix designs are certainly experimental processes and the principles of Design of Experiment can be applied to them. Traditionally, experimentation demands an investment of resources, effort and time; especially they involve complex processes. An efficient way of enhancing the value of research and cutting down the process development time is through the Design of Experiment – a process that require the planning and optimization of experiment processes at every stage, from inception through research and development, to engineering and production.

The statistical design of experiment (DOE) is an efficient procedure for planning experiments so that the data obtained can be analyzed to yield valid and objective conclusions. An experiment design is the laying out of a detailed experiment plan in advance of doing the experiment. Well-chosen experimental designs maximize the amount of information that can be obtained for a given amount of experimental effort. Experimental data are used to derive an empirical model linking the outputs and inputs. The data thus obtained are then processed by the methods of classical regression or correlation analysis. (Naliman, 1965; Akhnaarova, 1972; Himmessblan, 1970; Nalimov, 1960;Stepanov, 1976) Design of experiment can be used effectively in choosing between alternative outcomes (Objective Functions) of an experiment; select the key factors affecting an experimental response (the Objective Function); or for response surface modelling (RSM).

A mixture experiment like concrete mix design, involves mixing various proportions of two or more components to make different compositions of an end product. Special issues arise when analyzing mixtures of component that must sum to a constant. For example, if you wanted to optimize the taste of fruit-punch, consisting of the juices of five fruits, then the sum of the proportions of all juices in each mixture must be 100%.

To attain our experimental goals in an optimal manner we must define the characteristic of the end product we want to optimize- that is, the Objective Function. Our objective function might be to minimize cost; to maximise profit; to achieve a certain compressive or tensile strength in the hardened concrete; or to achieve a certain workability index in the wet concrete, etc. The objective function is the dependent variable or the response variable in the experiment; while the other variables and inputs that affect its outcome are the independent variables. Most often, the independent variable fall into certain regions or limits; and they may be constrained to satisfy certain bounds or functional relationships; these are generally called constraints.

Scheffe's Simplex-Lattice Design

When studying the behaviour of multi-component mixtures like concrete, in which the properties of the resultant mixture will depend only on the component ratio (e.g. Water : Cement : Fine Aggregate : Coarse Aggregate); the space containing the factors is a regular simplex . Consider a two component mixture for example; the factor space of a mixture containing only components A and B is the straight line shown in Figure 2.3, with the ends representing (100% A ; 0% B) and (0% ; 100% B). Every other possible mix of these two components is represented by

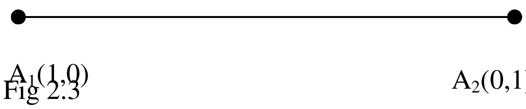


Fig 2.3

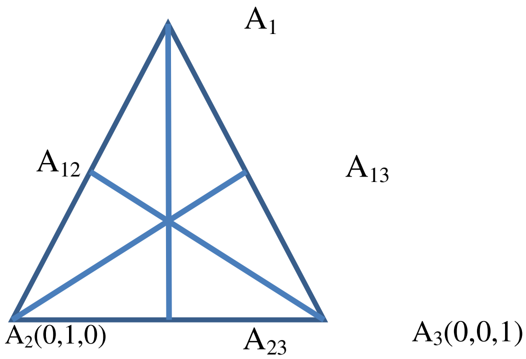
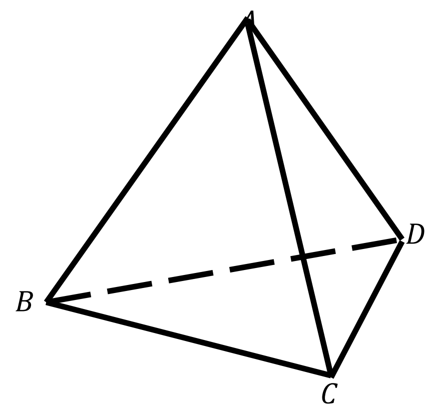


Fig 2.4

Some point on that line. Figure 2.3 therefore depicts a binary system – a system with components A and B – and its simplex is one-dimensional simplex.

On the other hand, for a three component mixture – a ternary system – the factor space will be an equilateral triangle (a two-dimensional space), which is denoted as a regular 2-simplex. For the regular 2-simplex shown in Figure 2.4 for components A, B and C; every point in the triangle corresponds to a certain composition of the ternary system; and every possible composition is represented by one distinct point in the triangle. The composition may be expressed as molar, weight, volume fraction or even percentage. The vertices of the triangle represent simple compositions, e.g. (100% A ; 0% B ; 0% C) or (0% A ; 100% B ; 0% C) or (0% A ; 0% B ; 100% C). The sides of the triangle represent binary systems of only A and B; or B and C; or A and C. The interior of the triangle represents three component compositions.

A four component mixture – a quaternary system – yields a three dimensional factor space with the shape of a tetrahedron, as shown in Figure 2.3 – a regular 3-simplex – where each vertex of the tetrahedron represents a single components mixture; each edge represents a binary system; a face represents a ternary system and points inside the tetrahedron correspond to the four component mixture.



$Fig. 2.5: Quatenary\ System$

The two most important features of a simplex lattice can therefore be summarized as follows: For a q component mixture, the sum of the component ratios must be equal to unity; that is

$$\sum_{i=1}^{q} x_i = x_1 + x_2 + x_3 + \cdots + x_q = 1 \quad 2.11$$

Where, $x_i \geq 0$ as no component can have a ratio less than zero. And the factor space will be a reqular $(q-1)$ – simplex.

The response or objective function of any component mixture is a function of the independent variables, say; $y = f(x_1, x_2, x_3, \ldots x_q)$; and analytically this function yields a **response surface.** The challenge of optimization is to locate the extremum or turning point on this response surface. Response surfaces can be represented and interpreted graphically for the one and two-dimensional simplexes. The response surface of the regular 2-simplex being a surface over the equilateral triangular base. However, for the quaternary systems and higher, it is not possible to represent the response surface graphically.

By far the more general approach to the study of multi-component mixtures is to develop a mathematical model for the response surface no matter the number of components involved. In doing this, the **response function** is assumed to be a continuous function of the independent variables, and with sufficient accuracy, it can be approximated by a polynomial. The response surfaces in multi-component systems are generally complex and high degree polynomials are usually required to adequately describe them. The complexity of the mathematical model will depend on the number of components, q, in the mixture and the degree, n, of the polynomial chosen for the model.

For a three-component system for example, if we chose to use a second-degree polynomial for the model ; the response function will be of the form

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 \quad 2.12$$

The coefficient b_0 is the **free term** of the regression equation; the coefficients b_1, b_2 and b_3 are the **linear terms** of the regression equation (corresponding to each of the independent variables); the coefficients b_{12}, b_{13} and b_{23} are the **interaction terms** of the regression equation (corresponding to the interaction between each pair of independent variables); and the coefficients b_{11}, b_{22} and b_{33} are the **quadratic terms** of the regression equation (corresponding to the quadratic effect of each independent variable). The constraint of the normalization condition of Equation 2.11 becomes, in this case;

$$x_1 + x_2 + x_3 = 1 \quad 2.13$$

Equation 2.13 can be used to eliminate the quadratic terms in Equation 2.3 by multiplying it in succession with $b_0, x_1, x_2, and x_3$ as follows;

$$\begin{aligned} b_0 &= b_0x_1 + b_0x_2 + b_0x_3 \\ x_1^2 &= x_1 - x_1x_2 - x_1x_3 \\ x_2^2 &= x_2 - x_1x_2 - x_2x_3 \\ x_3^2 &= x_3 - x_1x_3 - x_2x_3 \end{aligned} \quad 2.14$$

Substituting into Equation 2.12 yields;

$$y = (b_0 + b_1 + b_{11})x_1 + (b_0 + b_2 + b_{22})x_2 + (b_0 + b_3 + b_{33})x_3 + (b_{12} - b_{11} - b_{22})x_1x_2 + (b_{13} - b_{11} - b_{33})x_1x_3 + (b_{23} - b_{22} - b_{33})x_2x_3 \quad 2.15$$

Since the sum or difference of constant coefficients is another coefficient, we can redefine the coefficients of the regression equation thus;

$$y = \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_{12}x_1x_2 + \beta_{13}x_1x_3 + \beta_{23}x_2x_3 \quad 2.16$$

Equation 2.12 is the second-degree polynomial for the ternary system regression model and it has ten coefficients, and as a necessity, ten experimental trials will be required to determine the ten coefficients. Equation 2.16 however is the reduced second-degree polynomial for the same model, and as can be seen, has only six coefficients – thus, requiring only six trials to determine.

The complexity of the needed regression model and the number of experimental trials required to determine it will therefore vary with the number of components, (q), in a mixture and the degree of the polynomial, (n), chosen for the model – hence a $(\boldsymbol{q}, \boldsymbol{n})$**Model or Simplex Lattice** will be;

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2| + b_{44}x_4^2 \quad 2.17$$

$$And\ x_1 + x_2 + x_3 + x_4 = 1 \quad 2.18$$

This model has 15 coefficient and it will require 15 trials to determine the value of the coefficients. The reduced regression equation for the same (4,2) lattice will be;

$$y = \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_4x_4 + \beta_{12}x_1x_2 + \beta_{13}x_1x_3 + \beta_{14}x_1x_4 + \beta_{23}x_2x_3 + \beta_{24}x_2x_4 + \beta_{34}x_3x_4 \quad 2.19$$

This model has 10 coefficients and it will require 10 trials to determine the value of the coefficients.

The reduced second-degree polynomial in q variables can therefore be expressed as:

$$y = \sum_{1\le i\le q} \beta_i x_i \sum_{1\le i<j\le q} \beta_{ij}x_ix_j \quad 2.20$$

And it will contain C_{q+1}^2 coefficients. Following the procedure used above, it can be shown that the reduced third degree polynomial for a q component mixture will be;

$$y = \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_{12}x_1x_2 + \beta_{13}x_1x_3 + \beta_{23}x_2x_3 + \gamma_{12}x_1x_2(x_1 - x_2) + \gamma_{13}x_1x_3(x_1 - x_3) + \gamma_{23}x_2x_3(x_2 - x_3) + \beta_{123}x_1x_2x_3 \quad 2.21$$

While the general expression for the reduced third degree polynomial for a q component will be:

$$y = \sum_{1\le i\le q} \beta_i x_i + \sum_{1\le i<j\le q} \beta_{ij}x_ix_j + \sum_{1\le i<j\le q} \gamma_{ij}x_ix_j(x_i - x_j) + \sum_{1\le i<j<k\le q} \beta_{ijk}x_ix_jx_k \quad 2.22$$

At present, the most common simplexes are the simplex-lattice proposed by Scheffe (1958; 1963). These designs provide a uniform scatter of points over the $(\boldsymbol{q-1})$ **−simplex** Zedginidze, 1971; Novik, 1968). Simplex-lattice designs are saturated designs and the points form a $(\boldsymbol{q}, \boldsymbol{n})$ **−lattice** on the simplex. For each component, there exist $(\boldsymbol{n+1})$ similar levels and all possible combinations are derived with such values of component concentrations. For a quadratic or $(\boldsymbol{q}, \boldsymbol{2})$ **−lattice** for example, every factor must be used at the following levels; $0; \frac{1}{2}$ *and* 1. On the other hand, for a cubic or $(q, 3)$ **−lattice**, every factor must be used at the levels $0; \frac{1}{3}; \frac{2}{3}$ *and* 1. Figure 2.4 (a and b) show the factor levels for a $(3, 2)$ **−lattice** and a $(3, 3)$ **−lattice,** with their experimental design matrixes shown in Tables 2.2 and 2.3 respectively.

Figure 2.4 (a and b): The Second (3, 2) and Third Degree (3, 3) Lattices for Three Component Mixtures

Table 2.3: The Second-Order Simplex-Lattice Design for A Ternary Mixture - $(3, 2)$ −Lattice

N	x_1	x_2	x_3	y
1	1	0	0	y_1
2	0	1	0	y_2
3	0	0	1	y_3
4	1/2	1/2	0	y_{12}
5	1/2	0	1/2	y_{13}
6	0	1/2	1/2	y_{23}

Table 2.4: The Third-Order Simplex-Lattice Design for A Ternary Mixture - $(3, 3)$ −Lattice

N	x_1	x_2	x_3	y
1	1	0	0	y_1
2	0	1	0	y_2
3	0	0	1	y_3
4	2/3	1/3	0	y_{112}
5	1/3	2/3	0	y_{122}
6	0	2/3	1/3	y_{223}
7	0	1/3	2/3	y_{233}
8	2/3	0	1/3	y_{113}
9	1/3	0	2/3	y_{133}
10	1/3	1/3	1/3	y_{123}

For a four component mixture, the factor levels for a second order, $(4, 2)$ **−lattice** and a third order, $(4, 3)$ **−lattice**, are shown in Figure 2.5 (a and b). Of course this is the highest component mixture that can be shown pictorially since it will yield a three-dimensional figure. Five component mixtures and higher cannot be shown graphically. The experimental design matrixes corresponding to the $(4, 2)$ **−lattice** and the $(4, 3)$ **−lattice**, are shown in Tables 2.4 and 2.5 respectively.

Figure 2.5 (a and b): The Second (4, 2) and Third Degree (4, 3) Lattices for Four Component Mixtures

Table 2.5: The Second-Order Simplex-Lattice Design for A Quaternary Mixture – $(4, 2)$ −Lattice

N	x_1	x_2	x_3	x_4	y
1	1	0	0	0	y_1
2	0	1	0	0	y_2
3	0	0	1	0	y_3
4	0	0	0	1	y_4
5	1/2	1/2	0	0	y_{12}
6	1/2	0	1/2	0	y_{13}
7	1/2	0	0	1/2	y_{14}
8	0	1/2	1/2	0	y_{23}
9	0	1/2	0	1/2	y_{24}
10	0	0	1/2	1/2	y_{34}

Table 2.6: The Third-Order Simplex-Lattice Design for A Quaternary Mixture – $(4, 3)$ −Lattice

N	x_1	x_2	x_3	x_4	y
1	1	0	0	0	y_1
2	0	1	0	0	y_2
3	0	0	1	0	y_3
4	0	0	0	1	y_4
5	2/3	1/3	0	0	y_{112}
6	1/3	2/3	0	0	y_{122}
7	0	2/3	1/3	0	y_{223}
8	0	1/3	2/3	0	y_{233}
9	0	0	2/3	1/3	y_{334}
10	0	0	1/3	2/3	y_{344}
11	2/3	0	1/3	0	y_{113}
12	1/3	0	2/3	0	y_{133}
13	2/3	0	0	1/3	y_{114}
14	1/3	0	0	2/3	y_{144}
15	0	2/3	0	1/3	y_{224}

16	0	1/3	0	2/3	y_{244}
17	1/3	1/3	1/3	0	y_{123}
18	1/3	1/3	0	1/3	y_{124}
19	1/3	0	1/3	1/3	y_{134}
20	0	1/3	1/3	1/3	y_{234}

The number coefficients can be obtained using this equation for all Order simplex lattice N= $\frac{q.(q+1).(q+2)......(q+m-1)!}{m!}$ Where m is the order of the polynomial equation,and q is the number of components in the mix.

Determination of Model Equation for Compressive Strength

From Equation 3.13,

$$y = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{14} x_1 x_4 + \beta_{15} x_1 x_5 + \beta_{23} x_2 x_3 + \beta_{24} x_2 x_4 + \beta_{25} x_2 x_5 + \beta_{34} x_3 x_4 + \beta_{35} x_3 x_5 + \beta_{45} x_4 x_5 \ldots\ldots.\ldots \qquad 4.1$$

From table 4.1, the responses y_i are given as:

$y_1 = 30.80N/mm^2$

$y_2 = 32.40N/mm^2$

$y_3 = 34.53N/mm^2$

$y_4 = 42.00N/mm^2$

$y_5 = 44.70N/mm^2$

$y_{12} = 30.30N/mm^2$

$y_{13} = 30.80N/mm^2$

$y_{14} = 32.50N/mm^2$

$y_{15} = 31.70N/mm^2$

$y_{23} = 34.20N/mm^2$

$y_{24} = 35.80N/mm^2$

$y_{25} = 33.67N/mm^2$

$y_{34} = 35.50N/mm^2$

$y_{35} = 33.30N/mm^2$

$y_{45} = 45.80N/mm^2$

$y_{C_1} = 34.70N/mm^2$

$y_{C_2} = 34.20N/mm^2$

$y_{C_3} = 34.33N/mm^2$

$y_{C_4} = 35.85N/mm^2$

$y_{C_5} = 33.73N/mm^2$

$y_{C_6} = 33.30N/mm^2$

$y_{C_7} = 35.30N/mm^2$

Coefficient of the regression model are derived using *Eqn* 3.21, 3.22 and 3.23

$\beta_i = \mathrm{y}_i$ and $\beta_{ij} = 4\mathrm{y}_{ij} - 2\mathrm{y}_i - 2\mathrm{y}_j$, therefore,

$\beta_1 = 30.80, \beta_2 = 32.40,\ \beta_3 = 34.53,\ \beta_4 = 42.00,$

$\beta_5 = 44.70$

$\beta_{12} = 4\mathrm{y}_{12} - 2\mathrm{y}_1 - 2\mathrm{y}_2$

$$= (4 \times 30.30) - (2 \times 30.80) - (2 \times 32.40) = -5.20$$

$\beta_{13} = -7.46$

$\beta_{14} = -15.6$

$\beta_{15} = -24.2$

$\beta_{23} = 2.94$

$\beta_{24} = -5.6$

$\beta_{25} = -19.52$

$\beta_{34} = -11.06$

$\beta_{35} = -25.26$

$\beta_{45} = 9.8$

Substituting the constants $\beta_i and \beta_{ij}$ into *Equation* 4.1, *we have*

$$\boldsymbol{y = 30.8x_1 + 32.4x_2 + 34.53x_3 + 42.0x_4 + 44.7x_5 - 5.2x_1x_2 - 7.46x_1x_3 - 15.6x_1x_4 - 24.2x_1x_5 + 2.94x_2x_3 - 5.6x_2x_4 - 19.52x_2x_5 - 11.06x_3x_4 - 25.26x_3x_5 + 9.8x_4x_5} \qquad \mathbf{4.2}$$

CONCLUSION AND RECOMMENDATION

CONCLUSIONS

i. The two mathematical models generated as can be seen in equations 4.2 and 4.4can be used for the prediction of the strength and density of interlocking concrete tiles.

ii. Ugwuaji Pit Gravel concrete tiles as aninterlocking concrete paving block is not just feasible but also improves some engineering properties of concrete like Workability and density if thoroughly washed before use, to get rid of deleterious material that may be attached on it in its natural state.

iii. As the percentage replacement of Granite with Ugwuaji Pit Gravel increases, the compressive strength of the interlocking concrete tiles also increases. This peak at 10% replacement and then starts to decline. The density also increases with increase in percentage replacement of the Ugwuaji Pit Gravel up to 31.8% replacement even though it peaks at 16% replacement. The same is the case for workability as it increases with increase in percentage replacement of granite with Ugwuaji pit Gravel.

iv. The optimum mix proportion is the with percentage replacement between 10 and 16%, within this range, the properties of interlocking concrete tile such as strength, density and workability is improved. Beyond this range of replacement, the properties especially strength and density starts to decline.

RECOMMENDATIONS

i. The use of Ugwuaji pit Gravel as replacement for granite up to 16% should be encouraged as a means of encouraging the economy of rural communities.

ii. The use of Ugwuaji pit Gravel as partial replacement of granite should be done where workability of the concrete for interlocking tilesneed to be improved.

iii. Further research should be carried to determine the effects of Ugwuaji pit Gravel replacement on other properties of concrete including the flexural strength and the durability of concrete.

iv. Further research should also be carried out to determine the exact pencentage replacement at which increase in Ugwuaji pit Gravel replacement reduces the compressive strength of concrete.

v. The partial replacement of granite chippings with Ugwuaji pit Gravel should be commercialized in the interlocking concrete tile industry to reduce the cost of concrete tiles since this ingredient is locally available and are very cheap when compared with granite chippings

5.3 CONTRIBUTIONTO KNOWLEDGE

This mathematical model developed can be used to predict the compressive strength and density of a given concrete mix containing Ugwuaji pit Gravel. Thus this serves as a tool in mix design of Ugwuaji pit Gravel concrete for the production of interlocking concrete tiles. It will help the commercial producer to avoid trial and error which in most case results to waste of labor and material and in effect waste money.

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MODEL OPTIMIZATION PROGRAM OF INERLOCKING TILE CONCRETE MIX PROPORTIONS USING UG
WUAJI PIT GRAVEL
CORRESPONDING TO A DESIRED STRENGTH
BY ENEZE OBINNA

ENTER DESIRE STRESS? 25

COUNT   X1     X2     X3     X4     X5     Y      Z1     Z2     Z3     Z4     Z5

 1    0.05   0.11   0.22   0.22   0.11  25.00   0.70   0.40   1.43   0.58   1.95
 2    0.05   0.16   0.38   0.00   0.16  25.00   0.76   0.43   1.54   0.56   2.16
 3    0.05   0.22   0.11   0.33   0.00  25.00   0.70   0.40   1.43   0.50   2.03
 4    0.16   0.16   0.16   0.05   0.22  25.00   0.76   0.43   1.54   0.54   2.18
 5    0.27   0.16   0.05   0.27   0.00  25.00   0.76   0.43   1.54   0.39   2.34
THE POLYNOMIAL OUTPUT IS 30.04848
THE MAXIMUM VALUE OF STRESS IS 44.80408 N/SQ.MM




Press any key to continue
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MODEL OPTIMIZATION PROGRAM OF INERLOCKING TILE CONCRETE MIX PROPORTIONS USING UG
WUAJI PIT GRAVEL
CORRESPONDING TO A DESIRED STRENGTH
BY ENEZE OBINNA

ENTER DESIRE STRESS? 50

COUNT   X1     X2     X3     X4     X5     Y      Z1     Z2     Z3     Z4     Z5

THE POLYNOMIAL OUTPUT IS 30.04848
SORRY DESIRE STRESS OUT OF RANGE




Press any key to continue
```

