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The Impact of Granite, as Sand Replacement, in a Standard Concrete Mixture, Using a Well-Defined Model

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Abstract

The study is centered on the impact of granite fine in achieving the best concrete mixture. Here the sharp is completely replaced with the granite fine and a model was used to carry out the investigation. The work deals more on the investigation of the physical characteristics of the fine aggregates, in addition investigates the effect of partial replacement on the workability and also the extent compression of the concrete mixture. The latter part of the work deals with formulation of a well-defined model for the aim of optimizing the concrete mixture. In the list of experiment carried out include sieve analysis and specific gravity. The manner of water absorption revealed that sharp sand is moderately graded and well-suited for concrete mixture, also the granite fine is poorly graded and with its texture appearing to be finer. The specific gravity of sharp sand was lower than that of granite fine. With the ration of 2.64:2.75 suggesting a denser material, whereas its water absorption (4.63%) exceeded that of sharp sand (2.05%). This means greater porosity and higher water demand. The strength test conducted as well as the its workability showed that the mix composition significantly influenced concrete performance. From the result obtained, in Mix N1 which contains about 90% sharp sand, the highest slump value of 24 cm (true slump) was recorded. Also, less than 11% granite fine was recorded, which shows superior workability and cohesion. On the other hand, Mix N5 and Mix C24 produced the lowest slump value of about 16 cm (collapse slump), showing reduced workability due to excessive granite fine content. The Mix N45 having a ratio of 0.43:1:0.63:0.53:1.65, comprising 54% sharp sand and 46% granite fine appear to display the compressive strength of 22.89 N/mm². This result not only provided optimal particle packing but also enhances the interfacial bonding.In the other derivation, the Mix N1 recorded the minimum strength of about 13.11 N/mm², showing that minimal granite fine content reduces matrix compactness. For the research, Scheffe's model was fomulated and validated to dictate the concrete strength as a function of the mix proportions. Using the Student's t-test, the model's accuracy was crosschecked. The calculated t-value (1.70) was less than the tabulated value (2.145) at a 95% confidence level and 14 degrees of freedom. This shows that no significant difference exists between experimental and predicted results. Thus, findings from the research shows the statistical reliability of the formulations and also confirms it to be suitable for concrete optimization within the investigated range. To achieve an effective balance between strength and workability, from the findings, it is recommended that granite fine be used as a partial replacement for sharp sand to achieve an optimized combination between strength and workability.

Keywords: American Concrete Institute, Superplasticizers, profile sheet, polystyrene beads, Agro fibre, Degrees of freedom

1.1 INTRODUCTION

Concrete is a fundamental material extensively used in construction due to its durability, strength and versatility. It is a composite material composed of cement, water, fine aggregates (such as sharp sand), and coarse aggregates (such as granite). The quality of concrete is highly dependent on the properties of these constituents and their mix proportions (Ukpata, Ewa & Alaneme 2023). The demand for fine aggregates, particularly sharp sand, has significantly increased due to rapid urbanization and infrastructure development. However, excessive mining of river sand has led to environmental degradation, including riverbank erosion, loss of aquatic life, and reduced groundwater recharge. In response to these challenges, researchers have explored alternative materials that can partially or fully replace sharp sand in concrete production. One such alternative is granite fines, a byproduct of quarrying and stone crushing processes. Granite fines have been identified as a sustainable and economical alternative to sharp sand due to their abundance and potential to improve the mechanical properties of concrete (Alaneme, Iro, Milad, Olaiya & Otu 2024). Studies suggest that granite fines, when properly incorporated, can enhance the compressive strength, durability, and workability of concrete (Ettu, Ibearugbulem & Ezeh 2013). However, achieving an optimal mix ratio of granite fines in concrete remains a significant challenge, as excessive replacement may negatively affect workability and bonding within the matrix (Ephraim & Egbebike, 2019).

To address this issue, Scheffe's Simplex Method is used for mix design optimization. Scheffe's Simplex Method is a mathematical modeling technique that determines the most effective combination of concrete constituents to maximize strength and performance (Anyaogu & Ezeh, 2013). This optimization approach ensures that the right proportions of cement, fine aggregates, coarse aggregates, and water are used to achieve the best possible concrete properties. This study investigates the use of granite fines as a partial replacement for sharp sand in concrete and employs Scheffe's Simplex Method to determine the optimal mix design. By doing so, the research aims to provide a cost-effective and environmentally friendly solution for sustainable concrete production.

1.2 STATEMENT OF PROBLEM

High demand for sharp sand in both building and construction projects has led to increased mining, which poses serious environmental problems. Constant evacuation of sharp sand contributes to high degradation of land areas, soil erosion, and the destruction of natural habitats. The negative impact of this tells more not only on the ecosystems and but also on the water bodies. The continuous removal will also reduces the availability of sharp sand for future use. Additionally, quarrying activities generate large amounts of granite fines, which are often discarded as waste, leading to pollution and improper land use. Using alternative materials like granite fines helps utilize the negative environmental impact of both sharp sand mining and quarry waste disposal.

Both the environmental challenges, the high cost of sharp sand and its scarcity have made the production of concrete very difficult. The increasing price of fine aggregates, also affects construction budgets, making affordable housing and infrastructure projects more difficult to achieve. As already stated, the, granite fines remain underutilized, despite being a readily available by product of quarrying and also could serve as a cost-effective alternative, helping to reduce overall construction costs, when it is properly incorporated. However, the lack of proper mix design optimization has limited its widespread adoption. This study, therefore, seeks to investigate the potential of using granite fines as a partial replacement for sharp sand and develop an optimized mix ratio using Scheffe's Simplex Method to ensure maximum strength, durability, and economic feasibility in concrete production.

1.3 OBJECTIVES OF STUDY

The main objective of this study is to investigate the use of granite fine as partial replacement of sharp sand in the optimization of concrete using Scheffe's simplex method.

The specific objectives are:

i. To analyze the characteristics of granite fine and sharp sand to know their suitability as fine aggregates in concrete.
ii. To determine the compressive strength and workability of concrete produced using granite fines as a partial replacement for sharp sand.
iii. To develop an optimized concrete mix design incorporating granite fines using Scheffe's Simplex Method.

1.4 CONCRETE OPTIMIZATION TECHNIQUE

Concrete optimization involves improving the mix design to achieve better strength, durability, and sustainability while minimizing cost and environmental impact. With the increasing use of granite fines as a partial replacement for fine aggregates, various optimization techniques are required to ensure the best performance of concrete (Singh et al., 2016). Cox (1957) maintains that the act of proportioning is called optimization and the approach of achieving it is called mix design or modeling.

Nwaokonobi and Osadebe (2008), stated that mix design of concrete is a means of producing the most economical and durable concrete that meet with certain properties as strength, consistency and durability by properly and systematically combining the ingredients at relative proportions. Two categories of mix design methods exist. One of them is the empirical method and the other is the statistical method. The empirical method relies on the information from historical data laid down rules (codes) for mixtures of new material other than the ones used in the past. Furthermore the use of trial mixes and repeated mixes enable all specified areas to be met is inevitable. Hence, it will be difficult if not impossible to achieve an optimal mixture for desired criteria with a historical information method of mix design.

One widely used technique for concrete mix optimization is the Scheffe's Simplex Method, which helps in determining the optimal combination of cement, aggregates, water, and admixtures. Scheffe's Simplex Method is a statistical experimental design technique used for optimizing mix proportions in multi-component systems, such as concrete. Developed by Henry Scheffe in 1958, this method helps engineers systematically determine the optimal mix ratio for concrete by evaluating the interaction of multiple components (Scheffe, 1958). The method is commonly applied in concrete mix design to achieve maximum compressive strength, durability, and workability while minimizing material costs and waste (Ezeh & Ibearugbulem, 2010). In recent years, many researchers have used Scheffe's method to carry out one form of optimization project or the other. To buttress this point, Nwaokonobi and Osadebe (2008) applied Scheffe's model to optimize the mix proportion of Clay-Rice Husk Cement Mixture for Animal Building. Ezeh and Ibearugbulem (2009) applied

Scheffe's model to optimize the compressive cube strength of River Stone Aggregate Concrete. Scheffe's model was used by Ezeh and others (2010a) to optimize the compressive strength of cement-sawdust Ash Sandcrete Block. Again Ezeh and others (2010b) optimized the aggregate composition of laterite/sand hollow blocks using Scheffe's simplex method. The work of Ibearugbulem (2006) and Okere (2006) were based on the use of scheffe's mathematical model in the optimization of compressive strength of Periwinkle Shell Granite Aggregate Concrete and optimization of the Modulus of Rupture of Concrete respectively and many more.

1.4.1 The Simplex Lattice Design

Simplex is a factor space or a polygon. According to Aggarwal (2002)., a simplex lattice is a structural representation of lines joining the atoms of a mixture, and these atoms are constituent components of the mixture. For this case of granite fine partial replacement of sharp sand, the constituents are water, cement, granite fine, sharp sand and coarse aggregate. Thus a simplex of five component mixture is a four dimensional solid. Obam (2009), mixture components are subject to a new constraint that the sum of all the components must be equal to 1. That is:

$X_1 + X_2 + X_3 + \ldots + X_q = 1;$

This implies that $\sum_{i=1} X_i = 1$ (i)

The (q, m) simplex lattice design are characterized by the symmetric arrangement of points within the experimental region and a well chosen polynomial equation to represent the response surface over the entire simplex region Aggarwal (2002). The (q, m) simplex lattice design is given by Scheffe according to Nwaokonobi and Osadebe (2008) contains; ${}^{q+m-1}C_m$ where each components proportions take (m+1) equally spaced values $X_i = 0, \frac{1}{m}, \frac{2}{m}, \frac{3}{m}, \ldots, 1$; i= 1,2,…q ranging between 0 and 1 and all possible mixture with these component proportions are used, and m is the scheffe's polynomial degree, which in this study is 2.

According to Obam (2009), a Scheffe's polynomial function of degree, m in the q variable $X_1, X_2, X_3, X_4, \ldots, X_q$ is given in the form of:

$Y = b_0 + \sum bixi + \sum bijxj + \sum bijxjxk + \sum bij_2 + \ldots i_nxi_2x_n$ (ii)

Where b = constant coefficient and Y = the response (the response is a polynomial function of the pseudo component of the mix) which represents the property under this study which in this case is the compressive strength.

2.10.2 Number of Coefficients

In Scheffe's Simplex model, the number of coefficients in a polynomial equation depends on the degree of the model and the number of mixture components. The general equation for determining the number of coefficients is:

Number of coefficients= $\frac{d!(n-1)!}{(n+d-1)!}$ (iii)

where:

n = Number of mixture components (e.g., cement, sand, granite fines, water, etc.)
d = Degree of the polynomial model

For example, in a second-degree polynomial model with five components (cement, fine aggregate, granite fine, coarse aggregate, and water):

Number of coefficients= $\frac{2!(5-1)!}{(5+2-1)!}$ =15

This means that the quadratic model for a five-component concrete mix will have 15 coefficients.

1.4.2 Relationship Between Pseudo And Actual Components

In Scheffe's simplex mix design, the relationship between the pseudo and actual components is given as:

$$Z= A*X \quad \text{(iv)}$$

Where z is the actual component; X is the pseudo component and A is the coefficient of the relationship.

$$X= A^{-1}*Z \quad \text{v}$$

1.4.3 Scheffe's Regression Equation

The regression equation by Scheffe (1958), otherwise known as response, is given in Eqn (2). Hence for scheffe's (5,2) simplex lattice, the regression equation for five component mixtures has been derived from Eqn (20) by Nwachukwu and others (2017) and is given as follows:

$$Y= b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_{11}X^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{15}X_1X_5 + b_{22}X_2X_4 + b_{23}X_2X_3 + b_{24}X_2X_4 + b_{25}X_2X_5 + b_{33}X_3^3 + b_{34}X_3X_4 + b_{35}X_3X_5 + b_{44}X_4^4 + b_{45}X_4X_5 + b_{55}X_5^5 \quad \text{(vi)}$$

$$Y= \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_{12}X_1X_2 + \beta_{13}X_1X_3 + \beta_{14}X_1X_4 + \beta_{15}X_1X_5 + \beta_{23}X_2X_3 + \beta_{24}X_2X_4 + \beta_{25}X_2X_5 + \beta_{34}X_3X_4 + \beta_{35}X_3X_5 + \beta_{45}X_4X_5 \quad \text{vii7)}$$

Where

$ß_1 = b_0 + b_1 + b_{11}$; $ß_2 = b_0 + b2 + b22$;ß3 = b0 + b3 + b33;ß4 = b0 + b4 + b44; ß5 = b0 + b5 + b55; ß12 = b12 – b11 – b22; ß13 = b13 – b11 – b33;ß14 = b14 – b11 – b44; ß15 = b15 – b11 – b55; ß23 = b23 – b22 – b33; ß24 = b24 – b22 – b44; ß25 = b25 – b22 – b55 ; ß34 = b34 – b35 – b44; ß35 = b35 – b33 – b55; ß45 = b45 – b44 – b55 (viii)

Hence,

$$Y= X_1(2X_1-1)Y_1 + X_2(2X_2-1)Y_2 + X_3(2X_3-1)Y_3 +X_4(2X_4-1)Y_4 + X_5(ZX_5-1)Y_5 + 4Y_{12}X_1X_2 + 4Y_{13}X_1X_3 + 4Y_{14}X_1X_4 + 4Y_{15}X_1X_5 + 4Y_{23}X_2X_3 + 4Y_{24}X_2X_4 + 4Y_{25}X_2X_5 + 4Y_{34}X_3X_4 + 4Y_{35}X_3X_5 \; 4Y_{45}X_4X_5 \quad (9)$$

Eqn (9) is the mixture design model for optimization concrete mix that comprises five components. Y_1, Y_2..... Y_{45} is determined through laboratory tests.

1.4.4 Actual And Pseudo Mix Ratios

The requirement of simplex lattice design that $\sum_{i=1} X_i = 1$ make it impossible to use the conventional mix ratios such as 1:2:4, 1:3:6, etc., at a given water/cement ratio for the actual mix ratio. This necessitates the transformation of the actual components (ingredients) proportions to meet the above criterion. Such transformed ratios, x_1, x_2, x_3, for the ith experimental points are called pseudo components or coded components. Based on experience and previous knowledge from literature, the following arbitrary prescribed mix proportions which corresponds to water\cement ratio, cement, granite fine, sharp sand and granite, were chosen for the five points or vertices;

A1 (0.60: 1: 1.53: 0.17: 2.0); A2 (0.55: 1: 1.28: 0.32 :1.80); A3 (0.50: 1: 0.96: 0.24: 1.70);

A4 (0.40: 1: 0.60: 0.40: 1.80); A5 (0.45:1: 0.65: 0.65: 1.50).

For the pseudo mix ratios. we have the following corresponding mix ratios at the vertices:

A1 (1: 0: 0 :0 :0); A2 (0: 1: 0: 0: 0); A3 (0: 0: 1: 0: 0); A4 (0: 0: 0: 1: 0); A3 (0: 0: 0: 0: 1).

According to Ibearugbulem (2007), it is only in the pseudo aspect that a pure component is used at the vertices. Pure components in the pseudo aspect may not be the pure component in the actual aspect. Substituting the mix ratios from point 1 of simplex into equation (4)

Z= A*X

In matrix form;

$$\begin{bmatrix} Z1 \\ Z2 \\ Z3 \\ Z4 \\ Z5 \end{bmatrix} = \begin{bmatrix} A11 & A12 & A13 & A14 & A15 \\ A21 & A22 & A23 & A24 & A25 \\ A31 & A32 & A33 & A34 & A35 \\ A41 & A42 & A43 & A44 & A45 \\ A51 & A52 & A53 & A54 & A55 \end{bmatrix} \begin{bmatrix} X1 \\ X2 \\ X3 \\ X4 \\ X5 \end{bmatrix}$$

To develop the values of the constant (A), only points of the two are at the vertices and mid points two are used for a pentagonal simplex at the points as in the simplex lattice design.

1.5 METHODOLOGY

The various stages involved in evaluating the characteristics of granite fines and sharp sand in order to know their suitability for use as fine aggregates in concrete production. A sieve analysis was carried out to determine the particle size distribution of both granite fines and sharp sand. The following is the procedures involved in carrying out the test: Derivation of a representative of dry sample of about 500g of the fine aggregate by weighing in a digital weighing balance and record as Mds. After this Weigh each standard sieve size and arrange them in descending order of size: 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm, 150 µm, and a pan at the bottom, and record as M1.Ensure that the sieves are clean and properly fitted.

Mount the sieve stack on a mechanical sieve shaker and shake continuously for 10 to 15 minutes to allow proper separation of particles according to size. Then pour the dried sample carefully onto the top sieve (4.75 mm) and cover the sieve stack with a lid to prevent material loss during shaking. After thorough mixture, carefully remove each sieve, and weigh the sieve plus the material collected in it separately then record the weight M2 retained.

Determine the percentage retained on each sieve using:

$$\text{Th Amnt Retained ,\%} = Mds/(M2 - M1\ )\ \times 100$$

Specific Gravity Test: Weigh the pycnometer on a digital weighing balance and record the weight (B)Measure 500g of oven dried sample and fill in the pycnometer then weigh and record Fill up the pycnometer which is containing the sample with distilled water and allow to soak, then weigh and record. Pour out the contents in the pycnometer and rinse properly

Fill the empty pycnometer with distilled water, then weigh and record.

Water Absorption Test: Take about 500 g of the fine aggregate (sand or quarry dust) sample, Sieve the material through a 5 mm sieve to remove coarse particles.

Wash the sample gently over the 250 µm sieve to remove silt, clay, and dust particles.

Dry the washed sample in the oven at 105°C for 24 hours or until constant weight is achieved. Cool the sample to room temperature before weighing. Weigh the dry sample (after cooling) and record this as W_1 (g) the oven-dry weight of the aggregate. Immerse the dried sample in clean water at room temperature (20–25°C) for 24 hours.

After 24 hours, remove the sample from water and spread the particles on a dry absorbent cloth and allow the surface moisture to evaporate. Gently roll or pat the aggregate in the cloth until it appears surface dry that is no visible film of water on the particle. Immediately weigh the surface-dry sample and record the weight as W_2 (g)the saturated surface-dry weight. Calculate the **percentage of water absorption** by using the formula:

$$\text{Water Absorption (\%)} = (W2 - W1) * \left(\frac{1}{(W1)}\right) * 100$$

Considering

Oven-dry weight of the aggregate (g) as W_1 and Saturated surface-dry weight of the aggregate (g) as W_2

Method to determine the compressive strength and workability of concrete produced using granite fines as a partial replacement for sharp sand.

To determine the compressive strength and workability of concrete produced using granite fines as a partial replacement for sharp sand, there are standard concrete casting and testing procedures that was followed.

Materials Preparation: All constituent materials cement, fine aggregate (sharp sand and granite fines), coarse aggregate (granite stones), and water were prepared in accordance with BS EN 12390-2:2019 and BS 5328:1997. Granite fines were used to replace sharp sand at different proportions.

Concrete Batching and Mixing: Volumetric batching was employed to determine the proportion of materials required for concrete production. This method involves computing the quantity of each constituent (water, cement, sharp sand, granite fine, and gravel) based on the total volume of concrete to be produced.

The unit weight of concrete was taken as 24 kN/m^2, corresponding to a mass density of 24000 N/m^2. To convert this to mass density in kilograms per cubic meter, the gravitational constant (9.81 m/s^2) was used.

Volumetric computation

Unit weight of concrete = $24kN/m^2$

Mass density of one Concrete cube = $24000N/m^2$

Density of concrete = $\frac{24000}{9.81}$

$= 2447kg/m^3$

Total Volume, V = $(0.15\times0.15\times 0.15)\ m^3$

$= 3.375\times10^{-3}m^3$

Mass of one Cube = $2447\ kg/m^3\times3.375\times10^{-3}m^3$,

$= 8.26kg.$

Mass of two cubes = $8.26kg\times2 = 16.52kg$.

Adding 10% due to lose to shrinkage and other factors. Therefore, mass of two cubes = 18.17kg. Recalling from our mix ratio = w:c:s:gf:gr, where: W = mass of water, C = mass of cement, S = mass of sharp sand, Gf = mass of granite fine Gr = mass of gravel, Let X be the sum of the ratios:

i.e $x = w + c + s + gf + gr$.

For a Particular mix ratio:

W = w $\times \frac{18.17}{X}$,

C = C $\times \frac{18.17}{X}$,

S = S $\times \frac{18.17}{X}$,

Gf = Gf $\times \frac{18.17}{X}$,

Gr = Gr $\times \frac{18.17}{X}$

Mixing of Concrete element: The Mixing of concrete was done manually until a uniform mix was achieved. After this, the granite fines was introduced as partial replacements for sharp sand. This was done at specified levels. The cement, sand, granite fines, and coarse aggregate were first mixed thoroughly and this helps to form a uniform color. Immediately after this, the required quantity of water was added gradually and the mixing continued until a homogenous mixture was achieved.

Slump Test: The workability of the fresh concrete was determined immediately after mixing using the Slump Test in accordance with BS EN 12350-2:2019.

A slump cone (300 mm high, 200 mm base, and 100 mm top) was filled with fresh concrete in three equal layers, each tamped 25 times with a tamping rod.

The cone was carefully lifted vertically, and the subsidence (slump) of the concrete was measured to the nearest 5 mm.

The result indicated whether the concrete mix was true slump, shear slump, or collapse slump, reflecting its workability and consistency.

Casting and Curing of Concrete Cubes: Concrete cubes were cast to determine compressive strength according to BS EN 12390-3:2019. A total of 60 cubes were cast using the 30mix ratios obtained where two samples were cast for each mix

Standard 150 mm × 150 mm × 150 mm cube moulds were cleaned, assembled, and lightly oiled before use. The moulds were filled in three equal layers, each tamped 25 times with a standard tamping rod to eliminate air voids. The top surface was leveled and smoothed with a trowel. After casting, the specimens were left in the moulds for 24 hours at room temperature (approximately 20°C). They were then demoulded and placed in a curing tank containing clean water maintained at 20°C, in line with BS EN 12390-2:2019. The cubes were cured for 28 days to monitor strength development over time.

Compressive Strength Test: The compressive strength of the concrete cubes was determined at the end of each curing period using a Compression Testing Machine (CTM) in accordance with BS EN 12390-3:2019. Each cube was wiped dry, centered on the machine's platen, and subjected to a uniform load at a rate of 0.6 ± 0.2 MPa/s until failure occurred.

The maximum load at failure was recorded, and the compressive strength (f_a) was calculated using:

f_c = p/A

Taking f_c=Compressive strength(N/mm^2)

P= Maximum load at failure (N),

A = Cross-sectional area of the cube (mm^2), and

Lenght = Width = 150mm

For each mix and curing age, the average compressive strength of the two cubes was computed.

Method to develop an optimized concrete mix design incorporating granite fine using Scheffe's Simplex Method

To develop an optimized concrete mix design incorporating granite fines as partial replacement for sharp sand, Scheffe's Simplex Lattice Design was applied as the experimental technique.

The Model design:: The approach (statistical) is particularly effective for optimizing component proportions in multivariable systems like concret. Mostly in several mixture ingredients to influence the behaviour . The process started with the identification of the main mix constituents. These comprises of the cement, granite fines, sharp sand, coarse aggregate (granite), and water. Here a {5,2} Simplex Lattice Design was adopted

Where; Number of components (**q**) = 5,

Degree of polynomial (**m**) = 2 (Quadratic model)

The total number of experimental points (**N**) in a simplex lattice design is given by the formula:

N = (q+m -1)/(m!(q-1))

Substituting $q = 5$ and $m = 2$:

N = (5+2-1)!/(2!(5-1)!)

N = 6! / (2!X4!) = 15

Therefore, the {5,2} Simplex Lattice Design produces 15 distinct mix combinations (experimental runs).

The simplex points which is a five component mixture and this was analyzed using four dimensional simplex lattice and the 15 mixture points which was generated consists of pure blends (each component = 1, others = 0), binary blends (two components = 0.5 each, others = 0).

Table 1: The design points

MIX PTS	X1	X2	X3	X4	X5
N1	1.0	0	0	0	0
N2	0	1.0	0	0	0
N3	0	0	1.0	0	0
N4	0	0	0	1.0	0
N5	0	0	0	0	1.0
N12	0.5	0.5	0	0	0
N13	0.5	0	0.5	0	0
N14	0.5	0	0	0.5	0
N15	0.5	0	0	0	0.5
N23	0	0.5	0.5	0	0
N24	0	0.5	0	0.5	0
N25	0	0.5	0	0	0.5
N34	0	0	0.5	0.5	0
N35	0	0	0.5	0	0.5
N45	0	0	0	0.5	0.5

The table above shows the design points which are arranged within the experimental region of the simplex to ensure uniform coverage and to capture both main effects and interaction effects between components.

The Actual Ratio and Control mix Ratio: From the information from the literature, the following arbitrary prescribed mix proportions which corresponds to water\cement ratio, cement, granite fine, sharp sand and granite, were chosen for the five points or vertices;

N1 (0.60: 1: 1.53: 0.17: 2.0); N2 (0.55: 1: 1.28: 0.32 :1.80); N3 (0.50: 1: 0.96: 0.24: 1.70); N4 (0.40: 1: 0.60: 0.40: 1.80); N5 (0.45: 1: 0.65: 0.65: 1.50).

Each mix corresponds to a specific replacement level of granite fines for sharp sand, that is, 10%, 20%, 30%, 40% and 50% replacement.

For the pseudo mix ratios. we have the following corresponding mix ratios at the vertices:

N1 (1: 0: 0 :0 :0); N2 (0: 1: 0: 0: 0); N3 (0: 0: 1: 0: 0); N4 (0: 0: 0: 1: 0); N5 (0: 0: 0: 0: 1).

Let N stand for any point on the factor space.

For the transformation of the actual component, z to pseudo component, x and vice versa, the following equation is used;

Z= X*A

In matrix form;

$$\begin{bmatrix} Z1 \\ Z2 \\ Z3 \\ Z4 \\ Z5 \end{bmatrix} = \begin{bmatrix} X1 \\ X2 \\ X3 \\ X4 \\ X5 \end{bmatrix} * \begin{bmatrix} A11 & A12 & A13 & A14 & A15 \\ A21 & A22 & A23 & A24 & A25 \\ A31 & A32 & A33 & A34 & A35 \\ A41 & A42 & A43 & A44 & A45 \\ A51 & A52 & A53 & A54 & A55 \end{bmatrix}$$

Control points: For the purpose of this research, fifteen different controls were predicted which according to Scheffe, their summation should not be more than one.

Pseudo mixes of ternary and quinary blends (combinations of three or more components according to lattice spacing) were used for the control points.

C_1 = (0.25, 0.25, 0.25, 0.25, 0) C_2 = (0.25, 0.25, 0.25, 0, 0.25) C_3=(0.25, 0.25, 0, 0.25, 0.25), $C_{4=}$ (0.25, 0, 0.25, 0.25, 0.25), C_5 (0, 0.25, 0.25, 0.25, 0.25) $C_{12=}$(0.20,0.20,0.20,0.20), C_{13} (0.30, 0.30, 0.30, 0.1, 0), C_{14} = (0, 30, 0.3, 0.3, 0, 0.1) C_{15}= (0.30, 0.30, 0, 0.3, 0.10,) C_{23}= (0.30, 0, 0.30, 0.30, 0.1) C_{24} = (0, 0.30, 0.30, 0.30, 0.1) C_{25} = (0.10, 0.30, 0.30, 0.30) C_{34} = (0.3, 0.1, 0.3, 0.3, 0) C_{35} = (0.3, 0.3, 0.1, 0.3, 0) C_{45}= (0.1, 0.2, 0.3, 0.4, 0).

To obtain the values of the actual mixes for the control point, we substitute values into the equation

$$\begin{bmatrix} Z1 \\ Z2 \\ Z3 \\ Z4 \\ Z5 \end{bmatrix} = \begin{bmatrix} X1 \\ X2 \\ X3 \\ X4 \\ X5 \end{bmatrix} * \begin{bmatrix} A11 & A12 & A13 & A14 & A15 \\ A21 & A22 & A23 & A24 & A25 \\ A31 & A32 & A33 & A34 & A35 \\ A41 & A42 & A43 & A44 & A45 \\ A51 & A52 & A53 & A54 & A55 \end{bmatrix}$$

For C= 1

$$\begin{bmatrix} Z1 \\ Z2 \\ Z3 \\ Z4 \\ Z5 \end{bmatrix} = \begin{bmatrix} 0.60 & 0.55 & 0.50 & 0.40 & 0.45 \\ 1.0 & 1.0 & 1.0 & 1.0 & 1.0 \\ 1.53 & 1.28 & 0.96 & 0.60 & 0.65 \\ 0.17 & 0.32 & 0.24 & 0.40 & 0.65 \\ 2.00 & 1.80 & 1.70 & 1.80 & 1.50 \end{bmatrix} \begin{bmatrix} 0.25 \\ 0.25 \\ 0.25 \\ 0.25 \\ 0 \end{bmatrix} = \begin{bmatrix} 0.51 \\ 1.0 \\ 1.09 \\ 0.28 \\ 1.83 \end{bmatrix}$$

The rest of the control points were gotten using the same formula above, thus the table 3.3 below shows the mix ratios for control points

Response of experimental and control points From model Simplex lattice

The responses of the experimental points for the (5,2) simplex lattice were obtained using the second-degree Scheffé mixture model expressed as

$Y= X_1(2X_1-1)Y_1+ X_2(2X_2-1)Y_2 + X_3(2X_3-1)Y_3 +X_4(2X_4-1)Y_4 + X_5(2X_5-1)Y_5 + 4Y_{12}X_1X_2 + 4Y_{13}X_1X_{13} + 4Y_{14}X_1X_4+ 4Y_{15}X_1X_5 + 4Y_{23}X_2X_3 + 4Y_{24}X_2X_4 + 4Y_{25}X_2X_5 + 4Y_{34}X_3X_4 + 4Y_{35}X_3X_5\ 4Y_{45}X4X_5.$

Each Xi represents the pseudo-component proportion of cement, fine aggregate, granite fine, coarse aggregate, and water, respectively, constrained such that X1+X2+X3+X4+X5=1. The (5,2) simplex lattice generates 15 distinct experimental points, including five pure components.

For each experimental mix, the measured response that is the compressive strength was substituted into the model equation;

Thus we have;

Y= 13.11(2X1-1)X1 + 16.45(2X2-1)X2 + 20(2X3-1)X3 +18.88(2X4-1)X4 + 20.45(2X5-1)X5 + 4(14.89)X1X2 + 4(20.23)X1X3 + 4(21.56)X1X4 + 4(21.56)X1X5 + 4(17.11)X2X3 + 4(19.11)X2X4 + 4(18.23)X2X5 + 4(17.33)X3X4 + 4(16.22)X3X5 + 4(22.89)X4X5.

The values for response of the experimental points from scheefe's (5,2) simplex model was gotten by replacing the pseudo-component ratios X1,X2,X3,X4,X5 with their corresponding proportions from the mixture matrix. The values gotten are the predicted response which for any mix proportion within the experimental region was obtained by substituting the respective component ratios into the fitted equation.

Test of the adequacy of the model using Students's T- Test

The test for adequacy of the optimization function, obtained from the (5,2) simplex design, was done using statustical student's t-test at 95% accuracy level. The compressive strength at the control points (C_1, C_2, C_3, C_4, C_5, C_{12}, C_{13}, C_{14}, C_{15}, C_{23}, C_{24}, C_{25}, C_{34}, C_{35} and C_{45}) . Two hypotheses were considered in the test namely:

Null Hypothesis: At 95% accuracy level, that there is no significant difference between the laboratory concrete cube strength and the cube strength results obtained from the optimization function.

Alternative Hypothesis: At a 95% accuracy level, there is a significant difference between the laboratory concrete cube strength and concrete cube strength obtained from the optimization model.

1.6 RESULTS

The results of the test carried out in this work is presented and analysed here.

Result for the Characteristics of granite fine and sharp sand.

Table 2 : Result for sharp sand

Sieve Analysis Data Sheet						
Mass of Dry Sample; Mds (g) =		500.00	Sample Type: Sharp Sand	Sieve method: Dry Sieve		REF: 1377-2
Sieve Size / Sieve opening	Mass of Weighting Sieve; (M1)	Mass of Sieve + Soil Retained (M2)	Mass of Sample Retained on each Sieve; (M2-M1)	Percentage Retained on each Sieve; ((M2-M1)/Mds)x100	Cumulative percentage Retained; Zr	percentage passing; 100-Zr
(mm)	(g)	(g)	(g)	(%)	(%)	(%)
4	562.15	592.95	30.80	6.16	6.16	93.84
2.36	535.44	561.14	25.70	5.14	11.30	88.70
1.18	365.82	421.11	55.29	11.06	22.36	77.64
0.6	346.86	492.08	145.22	29.04	51.40	48.60
0.3	358.22	547.48	189.26	37.85	89.25	10.75
0.15	339.48	386.76	47.28	9.46	98.71	1.29
0.075	339.03	344.54	5.51	1.10	99.81	0.19
			0.94	0.19	100.00	0.00
D10 =	0.3	Weight Check		Percentage		
D30 =	0.43	Weight of Coarse Fraction (g) =		6.16	Maximum Aggregate Size (Identified) (mm)	4
D60 =	0.7	Weight of Sand Fraction (g) =		93.65	Percentage Passing 4.75mm Sieve (%)	93.8
Cc =	0.88	Weight of Fine collected (g) =		0.19	Percentage Passing 75µm Sieve (%)	0.19
Cu =	2.33	Weight of Materials Accounted for (g)		100.00		

Table 3: Result for granite fine

Sieve Analysis Data Sheet						
Mass of Dry Sample; Mds (g) =		500.00	Sample Type: Granite Fine	Sieve method: Dry Sieve		REF: 1377-2
Sieve Size / Sieve opening	Mass of Weighting Sieve; (M1)	Mass of Sieve + Soil Retained (M2)	Mass of Sample Retained on each Sieve; (M2-M1)	Percentage Retained on each Sieve; ((M2-M1)/Mds)x100	Cumulative percentage Retained; Zr	percentage passing; 100-Zr
(mm)	(g)	(g)	(g)	(%)	(%)	(%)
4	562.15	562.15	0.00	0.00	0.00	100.00
2.36	535.44	606.57	71.13	14.23	14.23	85.77
1.18	365.82	474.18	108.36	21.67	35.90	64.10
0.6	346.86	431.72	84.86	16.97	52.87	47.13
0.3	358.22	433.50	75.28	15.06	67.93	32.07
0.15	339.48	404.53	65.05	13.01	80.94	19.06
0.075	339.03	407.64	68.61	13.72	94.66	5.34
			26.71	5.34	100.00	0.00
D10 =	0.09	Weight Check		Percentage		
D30 =	0.28	Weight of Coarse Fraction (g) =		0.00	Maximum Aggregate Size (Identified) (mm)	4
D60 =	1.00	Weight of Sand Fraction (g) =		94.66	Percentage Passing 4.75mm Sieve (%)	100.00
Cc =	11.11	Weight of Fine collected (g) =		5.34	Percentage Passing 75µm Sieve (%)	5.34
Cu =	0.87	Weight of Materials Accounted for (g)		100.00		

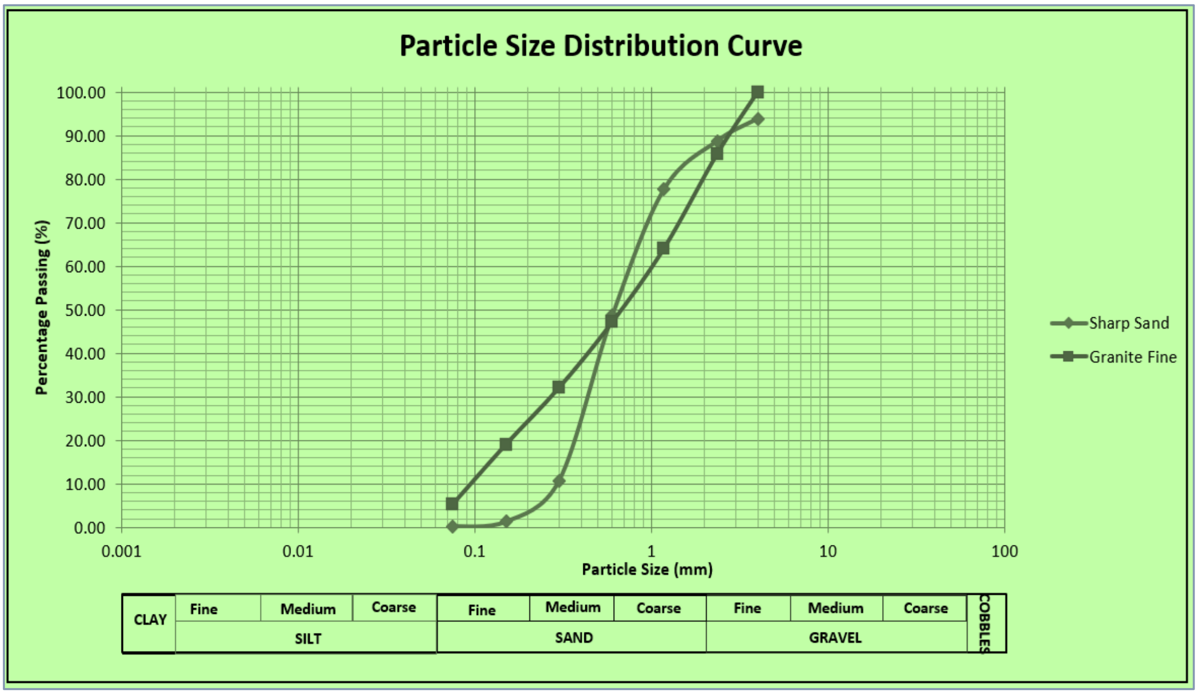

Fig 1 Graph for Sharp Sand and Granite fine (Sieve Analysis)

Table 4: Specific gravity result

SPECIFIC GRAVITY					
MTRIAL TYPE	WT OF EMPTY BOTTLE (g)	WT OF BOTTLE + SOIL (g)	WT OF BOTTLE + SOIL +WATER (g)	WT OF BOTTLE + WATER (g)	SPECIFIC GRAVITY
SHARP SAND	152.89	808.18	1080.56	673.69	2.64
GRANITE FINE	152.89	788.44	1077.72	673.69	2.75

Table 5: Water absorption result

WATER ABSORPTION				
MTRIAL TYPE	W_1 = OVEN-DRY WT (G)	W_2 = SATRATD SURFACE DRY WEIGHT (G)	INCREASE IN WT (G)	WATER ABSRPTN (%)
Sharp Sand	500.00	510.25	10.25	2.05 %
Granite Fine (Quarry Dust)	500.00	523.15	23.15	4.63 %

Result for workability and compressive strength test on the concrete

Table 6: Batching for concrete mix

Sample	W/C ratio	Cement	Sharp sand	Granite fine	Gravel
N1	2.15	3.58	5.4	0.609	7.17
N2	2.01	3.67	4.69	1.17	6.60
N3	2.06	4.12	3.96	0.99	7.02
N4	1.73	4.32	2.59	1.73	7.78
N5	1.94	4.32	2.81	2.81	6.48
N12	2.02	3.52	4.99	0.88	6.72
N13	2.08	3.78	4.72	0.79	6.99
N14	2.0	3.98	4.26	1.15	7.14
N15	2.01	3.80	4.14	1.55	6.65
N23	2.05	3.88	4.34	1.08	6.79
N24	1.9	3.96	3.72	1.42	7.14
N25	1.97	3.94	3.82	1.93	6.5
N34	1.90	4.22	3.29	1.35	7.39
N35	2.00	4.18	3.29	1.35	7.39
N45	1.84	4.28	2.63	2.27	7.07
C1	1.97	3.86	4.21	1.08	7.07
C2	2.6	4.92	5.46	1.72	8.6
C3	1.93	3.87	3.95	1.51	6.89
C4	1.95	3.99	3.75	1.47	6.98
C5	1.96	4.0	3.69	1.69	7.2
C12	1.96	3.93	3.93	1.41	6.92
C13	2.03	3.76	4.48	0.98	6.89
C14	2.03	3.76	4.52	1.05	6.78
C15	1.94	3.81	4.16	1.25	6.98
C23	1.98	3.81	4.16	1.25	6.98
C24	1.94	4.0	3.72	1.41	7.04
C25	1.97	3.95	3.95	1.22	7.11
C34	2.03	3.98	4.22	0.63	7.29
C35	1.97	3.80	4.25	1.10	7.03
C45	1.92	4.01	3.77	1.24	7.19

Table 7: Slump test result

Sample	Slump (cm)	Mix ratio (W : C : S : Gf : Gr)
N1	24	0.60 : 1.0 : 1.53 : 0.17 : 2.00
N2	21	0.55 : 1.0 : 1.28 : 0.32 : 1.80
N3	18	0.50 : 1.0 : 0.96 : 0.24 : 1.70
N4	17.5	0.40 : 1.0 : 0.60 : 0.40 : 1.80

N5	16	0.45 : 1.0 : 0.65 : 0.65 : 1.50
N12	22	0.57 : 1.0 : 1.41 : 0.25 : 1.90
N13	20	0.55 : 1.0 : 1.25 : 0.21 : 1.75
N14	20	0.50 : 1.0 : 1.07 : 0.29 : 1.75
N15	21	0.53 : 1.0 : 1.09 : 0.41 : 1.80
N23	23	0.53 : 1.0 : 1.12 : 0.28 : 1.65
N24	20	0.48 : 1.0 : 0.94 : 0.36 : 1.75
N25	20	0.50 : 1.0 : 0.97 : 0.49 : 1.65
N34	20	0.45 : 1.0 : 0.78 : 0.45 : 1.83
N35	22	0.48 : 1.0 : 0.81 : 0.53 : 1.75
N45	21	0.43 : 1.0 : 0.63 : 0.28 : 1.78
C1	17.5	0.57 : 1.0 : 1.09 : 0.35 : 1.75
C2	23	0.53 : 1.0 : 1.11 : 0.39 : 1.70
C3	21	0.50 : 1.0 : 1.02 : 0.37 : 1.76
C4	23	0.49 : 1.0 : 0.94 : 0.40 : 1.83
C5	16	0.48 : 1.0 : 0.87 : 0.36 : 1.80
C12	20	0.50 : 1.0 : 1.00 : 0.26 : 1.83
C13	16.5	0.54 : 1.0 : 1.09 : 0.28 : 1.80
C14	22	0.54 : 1.0 : 1.20 : 0.33 : 1.74
C15	17.5	0.51 : 1.0 : 1.09 : 0.31 : 1.79
C23	17	0.50 : 1.0 : 0.99 : 0.31 : 1.80
C24	16	0.50 : 1.0 : 0.99 : 0.31 : 1.80
C25	20	0.50 : 1.0 : 1.0 : 0.31 : 1.79
C34	17	0.51 : 1.0 : 1.06 : 0.16 : 1.83
C35	18	0.52 : 1.0 : 1.12 : 0.29 : 1.85
C45	22	0.48 : 1.0 : 0.94 : 0.31 : 1.79

Table 8: Compressive strength test result for actual mixes

Mixes	Failure load (kN)	Area (mm^2)	Strength (N/mm^2)	Average (N/mm^2)	ID
N1	310.00	22500.00	13.78	13.11	N1
N1	280.00	22500.00	12.44		
N2	380.00	22500.00	16.89	16.44	N2
N2	360.00	22500.00	16.00		
N3	350.00	22500.00	15.56	20.00	N3
N3	550.00	22500.00	24.44		
N4	460.00	22500.00	20.44	18.89	N4
N4	390.00	22500.00	17.33		
N5	390.00	22500.00	17.33	20.44	N5
N5	530.00	22500.00	23.56		
N12	350.00	22500.00	15.56	14.89	N12
N12	320.00	22500.00	14.22		
N13	470.00	22500.00	20.89	20.22	N13
N13	440.00	22500.00	19.56		
N14	450.00	22500.00	20.00	21.56	N14
N14	520.00	22500.00	23.11		
N15	540.00	22500.00	24.00	21.56	N15
N15	430.00	22500.00	19.11		
N23	400.00	22500.00	17.78	17.11	N23
N23	370.00	22500.00	16.44		
N24	540.00	22500.00	24.00	19.11	N24
N24	320.00	22500.00	14.22		
N25	400.00	22500.00	17.78	18.22	N25
N25	420.00	22500.00	18.67		
N34	300.00	22500.00	13.33	17.33	N34
N34	480.00	22500.00	21.33		
N35	320.00	22500.00	14.22	16.22	N35
N35	410.00	22500.00	18.22		
N45	450.00	22500.00	20.00	22.89	N45
N45	580.00	22500.00	25.78		

Table 9 Summary of responses from scheffe's (5,2) simplex model

Actual points	Experimental test result	Scheffe's model result	Control points	Experimental test result	Scheffe's model results
N1	13.11	13.11	C1	15.56	19.81
N2	16.45	16.45	C2	12.67	19.62
N3	20.00	20.00	C3	16.89	17.28
N4	18.88	18.88	C4	18.23	18.75
N5	20.45	20.45	C5	21.11	16.50
N12	14.89	14.89	C12	18.45	18.49

N13	20.23	20.23	C13	20.45	20.15
N14	21.56	21.56	C14	19.56	20.00
N15	21.56	21.56	C15	20.00	17.41
N23	17.11	17.11	C23	18.23	20.15
N24	19.11	19.11	C24	13.33	17.22
N25	18.23	18.23	C25	18.00	18.92
N34	17.33	17.33	C34	20.89	20.83
N35	16.22	16.22	C35	16.45	18.70
N45	22.89	22.89	C45	13.56	19.48

Table 10 Students T- Test between lab result and model result.

Points	Y_E	Y_M	$D_i = Y_E - Y_M$	$D_A - D_i$	$(D_A - D_I)^2$
C1	15.6	19.8	-4.3	2.92	8.528
C2	12.7	19.6	-6.9	5.617	31.560
C3	16.9	17.3	-0.4	-0.940	0.883
C4	18.3	18.8	-0.5	-0.805	0.648
C5	21.1	16.5	4.6	-5.936	35.235
C_{12}	18.5	18.5	-0.04	-1.286	1.655
C_{13}	20.5	20.2	0.3	-1.631	2.660
C_{14}	19.6	20.0	-0.4	-0.891	0.794
C_{15}	20.0	17.4	2.5	-3.923	15.387
C_{23}	18.3	20.2	-1.9	0.596	0.356
C_{24}	13.3	17.2	-3.8	2.561	6.560
C_{25}	18.0	18.9	-0.9	-0.411	0.169
C_{34}	20.9	20.8	0.1	-1.388	1.928
C_{35}	16.5	18.7	-2.3	0.926	0.857
C_{45}	13.6	19.5	-5.9	4.589	21.0568
			$\sum Di = -19.9$		$\sum (DA - Di) = 128.277$

Considering N as 15 and substituting into the Equation, DA, gives

$DA = \frac{\sum Di}{N}$

DA = -1.3284, $S^2 = \frac{\sum (DA - Di)^2}{N-1}$

The standard deviation of the difference between D_A and D_i,

S = $\sqrt{S}$

Therefore, $D_i = \frac{\sum Di}{N} = \frac{-19.93}{15} = -1.32867$,

$S^2 = \frac{\sum(DA-Di)^2}{N-1} = \frac{128.2766}{14} = 9.1626$

S = $\sqrt{S}$ = $\sqrt{9.1626}$ = 3.0269.

Actual value of total variation in t- test

$t_{calculated} = \frac{DAN^{0.5}}{S} = \frac{-1.32867(15)^{0.5}}{3.0269} = -1.70006$,

$|t_{calculated}| = 1.70$

Allowable value of total variation in t- test. Degree of freedom = N-1 =15-1 = 14

At 5% significance level, for the two tailed test = 2.5% . 100 – 2.5% = 97.5% = 0.975

Allowable total variation in t- test i.e $t_{table} = t_{(0.97514)}$ = 2.14 (obtained from the statistical table).

Therefore, $t_{table} < t_{calculated}$

1.7 CONCLUSION

The experimental evaluation of sharp sand and granite fine as fine aggregates were conducted and the sieve analysis showed that sharp sand is moderately and as a result of the making it suitable for general concrete work. The granite fine on the other hand is poorly graded (Cu = 0.87, Cc = 11.11) and also showing finer texture. The result from the specific gravity test shows that granite fine (2.75) is denser than sharp sand (2.64) and capable of enhancing the concrete density. However, its higher water absorption (4.63%) compared to sharp sand (2.05%) suggests higher porosity and the need for more water to maintain workability.

The result from the slump test and compressive strength results, the mixture proportion, greatly the behaviour of the concrete. The maximum slump result of 24cm (true slump) took place in Mix N1, containing 90% sharp sand and 10% granite fine, showing superior workability and cohesion. Conversely, Mix N5 and Mix C24 had the lowest slump result and this shows reduced workability due to excess granite fine and its water absorption characteristics.The Mix N45 displyed the highest compressive strength result at a mix ratio of 0.43: 1 : 0.63 : 0.53 : 1.65, containing 54% sharp sand and 46% granite fine. This blend optimized particle packing and interfacial bonding. In contrast, Mix N1, with 13.11N/mm² and a ratio of 0.60: 1: 1.53: 0.17 : 2.00, showed the lowest strength, suggesting that very low granite fine replacement reduces matrix compactness and load-bearing capacity.

The Simplex model behaviour confirmed a strong relationship between the predicted and experimental results, validating the model's suitability for predicting concrete characteristics involving sharp sand and granite fine mixtures.

This study centered on cross examination of the adequacy of the developed predictive model by comparing experimental values (YE) with model-predicted values (YM) using the Student's t-test. The research confirmed that the calculated t-value (|1.70|) was lower than the tabulated t-value (2.145) at 95% confidence level and 14 degrees of freedom meaning that there is no significant statistical difference between the experimental data and the model predictions. Therefore, the model is considered statistically adequate, reliable, and suitable for predicting the response variable within the experimental domain.

1.8 RECOMMENDATION

It is recommended that **granite fine should be used as a partial replacement for sharp sand** rather than a total substitute to balance both workability and strength performance in concrete. Based on the results, it is recommended that **granite fine replacement be limited to about 45–50%**, as demonstrated by Mix N45, which achieved the most desirable balance of compressive strength and workability. Also for mixes containing higher granite fine proportions, **use of super plasticizers or water adjustments** should be considered to maintain adequate workability.

For improved precision, future studies should incorporate more experimental runs and include additional influencing factors such as admixture type or curing conditions also validation techniques such as ANOVA, residual, or sensitivity analysis should be employed to strengthen confidence in the model's accuracy.

Declaration of Conflicting Interests

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