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The Application OfScheffe's Model For The Optimization Of Mussel Shells Fibre Reinforced Concrete (MSFRC)

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ABSTRACT

Mussel shells (MS) are typical examples of Seashells, a class of Mollusk shells commonly seen in typical beaches.This research study is focused at usingScheffe's Second Degree Polynomial Model to optimize the compressive strength of Mussel Shells Fibre Reinforced Concrete (MSFRC).Scheffe's Second Degree Polynomial (5,2) model developed by Nwachukwu and others (2017) for five component mixture will be used to optimize the mix ratio that will produce the maximum strength of MSFRC.Using Scheffe's Simplex method, the compressive strength of MSFRC was evaluated for different mix ratios. Control experiments were also carried out and the compressive strength determined. After the tests have been conducted, the adequacy of the model was tested using Student's t-test. The test statistics found the model adequate for predicting the compressive strength ofMSFRC when the mix ratio is known. Highest compressive strength for the Scheffe's(5,2) model was obtained as 28.75 MPa. Since structural concrete elements are generally made with concrete having a compressive strength of 20 to 35 MPa (or 20 to35 N/mm^2) according to the American Concrete Institute (ACI), it then means that optimized MSFRC based on Scheffe's model can produce the required compressive strength needed in major construction projects as well as light-weight structures such as construction of walkways, pavement slabs ,building , bridges etc, still maintaining economic and safety advantages.

Keywords: MSFRC, Scheffe's(5,2) Polynomial Model, Optimization, Compressive strength ,Mixture Design

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1.INTRODUCTION

Due to high cost of construction materials especially the conventional reinforcement, there have been urgent needs to partially or wholly replace this all important material with environmentally friendly construction material from the Mussel shells fibres. Mussel Shell Fibres (MSF) is a special type of Mollusks shells. In general, mollusks (molluscs) as animal groups are important ecosystem engineers, helping to structure aquatic bottom environments and providing habitat, protection, and food to a wide array of other taxa. Mollusks have been historically important to humans in many ways, and are today an economically important group worldwide. Mollusks are economically important as food. However, after being used as food, their shells can pose as a menace to the environment. But, this shortcoming can be overturned by converting these shells that are seen as wasteor aquaculture by product into use in jewelry, as musical instruments, as spoons, as decorative item, and as construction materials. The seashells are the remnants of molluks that are found in the beaches. Typical examples of mollusks shells or seashells include mussel shells, snail shells, oyster shells, clams shells, scallops shells, chitons shells, periwinkle shells, to mention but a few. It is interesting to note that most mollusks produce a shell from a structure called a mantle. Mollusks with one shell, such as snails, are univalves while mollusks with two shells, such as clams, are bivalves. Specifically, Mussel Shells (MS) can be composted and used in the garden. When used in the garden, the shells enrich the soil and can help grow healthy and productive plants. In the construction industry, mussel shells can be used in concrete production, either as cement (as a result of high calcium carbonate content), aggregate or conventional reinforcement replacements. Mollusks shells, such as mussel shells are rich in calcium carbonate which makes up about 95 percent of their composition. Similarly, the rich calcium carbonate can be converted to useable calcium oxide catalyst upon calcination. Figure 1 shows a typical example of a mussel shells. MSF is obtained when the source MS are grinded into matrices or strips or fillers to form fibres.

Generally,an optimization problem is one requiring the determination of the optimal value of a given function, known as the objective function, subject to a set of stated restrictions, limitations, or constraints placed on the concerned variables. In every optimization problem there is always need for an objective function which might be to maximize profit or benefit, to minimize cost or to minimize the use of material resources. To be specific, optimization of the concrete mixture design is a process of search for a mixture for which the sum of the costs of the ingredients is lowest, yet satisfying the required performance of concrete, such as strength, workability and durability etc. The objective of mix design, according to Shacklock (1974), is to determine the most appropriate proportions in which to use the constituent materials to meet the needs of construction work On the account of the widely varying properties of the constituent materials, the conditions that prevail at the site of work, the exposure condition, and the conditions that are demanded for a particular work for which the mix is designed, the design of concrete mix according to (Shetty, 2006) has not being a simple task. By definition, concrete mix design according to Jackson and Dhir (1996) remains the procedure which, for any given set of condition, the proportions of the constituent materials are chosen so as to produce a concrete with all the required properties for the minimum cost. From the above definition, the cost of any concrete includes, in addition to that of the materials themselves, the cost of the mix design, of batching, mixing and placing the concrete and of the site supervision. In the context of the above guidelines, the empirical mix design methods and procedures proposed by Hughes (1971), ACI- 211(1994) and DOE (1988) seems to be more complex and time consuming as they involve a lot of trial mixes and complex statistical calculations before the desired strength of the concrete can be reached. Thus, optimization of the concrete mixture design proves to be the fastest method, best option, most convenient and the most efficient way of selecting concrete mix ratios /proportions for better efficiency and better performance of concrete when compared with usual empirical methods .Typical examples of optimization model is Scheffe's Polynomial Model. It could be in the form of Scheffe's Second Degree Model or Scheffe's Third Degree Model. Thus, in this present study, Scheffe's Second Degree Model for five components mixtures (namely Water/Cement Ratio, Cement, Fine Aggregate, Coarse Aggregate and Mussel Shells Fibre will be in focus.

In the world of construction industry, none is most widely used than concrete. Due to its vast plethora of applications in construction compared with other materials, as well as its availability and global impact, concrete simply, in the long run, is universally preferred. Concrete, according to Oyenuga (2008) is a composite inert material comprising of a binder course (cement), mineral filter or aggregates and water. There is a general believe that concrete which is classified as the most widely used construction material has been undergoing changes both as a material and due to technological advancement. Concrete, being a homogeneous mixture of cement, sand, gravel and water is very strong in carrying compressive forces and hence is gaining increasing importance as building materials throughout the world (Syal and Goel, 2007). Concrete, according to Neville (1990), plays an important part in all building structures owing to its numerous advantages that ranges from low built in fire resistance, high compressive strength to low maintenance. However, there are drawbacks. According to Shetty (2006), plain concrete possesses a very low tensile strength, limited ductility and little resistance to cracking. That is, unreinforced (plain) concrete is brittle in nature, and is characterized by low tensile strength but high compressive strength. As a result of this situation, stakeholders in the construction industries have been in continuous search for the improvement and upgrading of the concrete properties in critical areas. In line with this, attempts have been made in the past to improve the tensile properties of concrete members by way of using conventional reinforced steel bars. Although both these methods provide tensile strength to the concrete members, they however, do not increase the inherent tensile strength of concrete itself. Based on suggested further researches and recent developments in concrete technology, it has been established that the addition of fibres to concrete would act as crack arrester and would substantially improve its static as well as dynamic properties. This type of concrete is known as Fibre reinforced concrete (FRC). FRC is a composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed.Combining fibres with concrete can produce a range of materials which possess enhanced tensile strength, compressive strength, elasticity, toughness, and durability etc. This is accomplished by limiting or controlling the start, spread, or spread persistence of cracks. Mussel Shells Fibre Reinforced Concrete (MSFRC)is concrete mixture where the conventionally steel reinforcement in concrete production is partially or wholly replaced with Mussel Shells Fibre (MSF).

Compressive strength of concrete is the strength of hardened concrete measured by the compression test. According to Ettu (2001), the major aim of engineering design is to ensure that the structure being designed will not reach a Serviceability Limit State (SLS), which is connected with deflection, cracking, vibration etc, and Ultimate Limit State (ULS), which is generally connected with collapse. Thus, the strength of a concrete is of utmost importance during concrete production in order to avert problems associated with SLS and ULS. Subsequently, concrete's compressive strength is one of the most important properties of concrete that require close examination and investigation due to its crucial role. It is a measure of the concrete's ability to resist loads which tend to compress it. It is measured by crushing cylindrical concrete specimens in a universal testing machine (UTM). Further, the compressive strength of the concrete cube test also provides an idea about all the characteristics of concrete under investigation.

This recent study examines the application of Scheffe's Second Degree Polynomial Model in the optimization of the compressive strength of MSFRC.There are a lot of researches that are related to the present work, especially in the areas of mussel shells, other mollusks shells and seashells and optimization applications , but none has been able to address the subject matter in detail. For example, let us examine the work of Bamigboye and others (2021). This work investigates the prospects and challenges pertaining to the sustainable use of seashells as binder in concrete production. Agbede and Manasseh (2009) investigated the suitability of Periwinke shell as parial replacement for river gravel in concrete. Peceno and others (2019) investigated the substitution of coarse aggregates with mollusc-shells waste in acoustic-absorbing concrete. The works of Alla and Asadi (2021) focused on the experimental investigation of snail shell based cement mortar. Adewuyi and others (2015) , in their own contribution examined the utilization of mollusc shells for concrete production for sustainable environment. Mohammad and other (2017) carried out a review on seashells ash as partial cement replacement.Gonzalez and others (2015) investigated the effects of seashell aggregates in concrete properties. Oyedepoo (2016) examined the evaluation of the properties of lightweight concrete using periwinkle shells as a partial replacement for coarse aggregate. Gigante and others (2020) investigated the evaluation of mussel shells powder as reinforcement for PLA-based biocomposites. And Melo and others (2019) carried out an extensive work on high- density polyethylene/mollusc shell –waste composites, effects of particle size and coupling agent on morphology, mechanical and thermal properties. Recent works on optimization show that many researchers have used Scheffe's method to carry out one form of optimization work or the other. For example, Nwakonobi and Osadebe (2008) used 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 block using Scheffe's simplex method. The work of Ibearugbulem (2006) and Okere(2006) were based on the use of Scheffe' model in the optimization of compressive strength of Perwinkle Shell- Granite Aggregate Concrete and optimization of the Modulus of Rupture of Concrete respectively. Obam (2009) developed a mathematical model for the optimization of strength of concrete using shear modulus of Rice Husk Ash as a case study. The work of Obam (2006) was based on four component mixtures, that is Scheffe's (4,2) and Scheffe's (4,3) where comparison was made between second degree model and third degree model. Nwachukwu and others (2017) developed and employed Scheffe's Second Degree Polynomial model to optimize the compressive strength of Glass Fibre Reinforced Concrete (GFRC). Also, Nwachukwu and others (2022a) developed and used Scheffe's Third Degree Polynomial model, Scheffe's (5,3) to optimize the compressive strength of GFRC where they compared the results with their previous work, Nwachukwu and others (2017). Nwachukwu and others (2022c) used Scheffe's (5,2) optimization model to optimize the compressive strength of Polypropylene Fibre Reinforced Concrete (PFRC). Again, Nwachukwu and others (2022d) applied Scheffe's (5,2) mathematical model to optimize the compressive strength of Nylon Fibre Reinforced Concrete (NFRC). Nwachukwu and others (2022b) applied Scheffe's (5,2) mathematical model to optimize the compressive strength of Steel Fibre Reinforced Concrete (SFRC). Furthermore, Nwachukwu and others (2022e) used Scheffe's Third Degree Regression model, Scheffe's (5,3) to optimize the compressive strength of PFRC. Nwachukwu and others (2022f) applied Modified Scheffe's Third Degree Polynomial model to optimize the compressive strength of NFRC. Again, Nwachukwu and others (2022g) applied Scheffe's Third Degree Model to optimize the compressive strength of SFRC. In what is termed as introduction of six component mixture and its Scheffe's formulation ,Nwachukwu and others (2022h) developed and use Scheffe's (6,2) Model to optimize the compressive strength of Hybrid-Polypropylene – Steel Fibre Reinforced Concrete (HPSFRC). Finally , Nwachukwu and others (2022 i) applied Scheffe's (6,2) model to optimize the Compressive Strength of Concrete Made With Partial Replacement Of Cement With Cassava Peel Ash (CPA) and Rice Husk Ash (RHA). From the works reviewed so far, it appears that the subject matter has not been fully addressed as it can be envisaged that no work has been done on the use of Scheffe's Second Degree Polynomial Model to optimize the compressive strength of MSFRC. Henceforth,the need for this present research work.

Fig.1 : A Typical Example Of A Mussel Shells

2. BACKGROUND OF SCHEFFE'S OPTIMIZATION THEORY

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 MSFRC mixture, the constituent elements are the water, cement, fine aggregate (sand), coarse aggregate and mussel shell fibre. Thus, a simplex of five-component mixture is a four-dimensional solid. See Nwachukwu and others (2017) According to Obam (2009), mixture components are subject to the constraint that the sum of all the components must be equal to 1. That is:

$$X_1 + X_2 + X_3 + \dots + X_q = 1 \ ; \quad \Rightarrow \sum_{i=1}^{q} X_i = 1 \qquad \textbf{(1)}$$

where $X_i \geq 0$ and $i = 1, 2, 3\dots q$, and q = the number of mixtures

2.1. SCHEFFE'S (5,2) SIMPLEX LATTICE DESIGN

The Scheffe's(q, m) ,e.gScheffe'(5,2) simplex lattice design are characterized by the symmetric arrangements of points within the experimental region and a wellchosen polynomial/optimization equation to represent the response surface over the entire simplex region (Aggarwal, 2002). The (q, m) simplex lattice design given by Scheffe, according to Nwakonobi and Osadebe (2008) contains ${}^{q+m-1}C_m$ points where each components proportion takes (m+1) equally spaced values $X_i = 0, \frac{1}{m}, \frac{2}{m}, \frac{3}{m}, \dots, 1; \quad i = 1, 2, \dots, q$ ranging between 0 and 1 and all possible mixture with these component proportions are used, and m is scheffe's polynomial degee, which in this present study is 2.

For example a (3, 2) lattice consists of ${}^{3+2-1}C_2$ i.e. ${}^4C_2$ = 6 points. Each X_i can take m+1 = 3 possible values; that is $x = 0, \frac{1}{2}, 1$ with which the possible design points are: $(1, 0, 0), (0, 1, 0), (0, 0, 1), \left(\frac{1}{2}, \frac{1}{2}, 0\right), \left(0, \frac{1}{2}, \frac{1}{2}\right), \left(\frac{1}{2}, 0, \frac{1}{2}\right)$.

To evaluate the number of coefficients/ or terms/ ordesign points required for a given lattice , the following general formula is applied:

$k = \frac{(q+m-1)!}{(q-1)!\,.\,m!}$ Or ${}^{q+m-1}C_m$ **2(a-b)**

Where k = number of coefficients/ terms / points

q = number of components/mixtures = 5 in this present study

m = number of deqree of polynomial = 2 in this present work

Using either of Eqn. (2), $k_{(5,2)} = 15$

This implies that the possible design points for Scheffe's (5,2) lattice can be as follows:

A_1 (1,0,0,0,0,); A_2 (0,1,0,0,0,); A_3 (0,0,1,0,0,); A_4 (0,0,0,1,0,), A_5 (0,0,0,0,1,);; A_{12} (0.67,0.33, 0, 0, 0,); A_{13} (0.67, 0, 0.33,0,0,); A_{14} (0.67, 0, 0, 0.33,0,); A_{15} (0.67, 0, 0, 0,0.33,); A_{23} (0,0.50,0.50, 0,0,); A_{24} (0, 0.50, 0, 0.50, 0,); A_{25}, (0, 0.50, 0, 0,0.50,);; A_{34} (0.50, 0.50, 0, 0,0,); A_{35} (O.50, 0,0.50, 0,0,); A_{45} (0.50, 0, 0, 0,0.50, 0); **(3)**

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

$$Y = b_0 + \sum b\mathrm{i}\, x\mathrm{i} + \sum b\mathrm{ij}x\mathrm{j} + \sum b\mathrm{i}jxjxk + + \sum b\mathrm{i}^{\mathrm{j}}{}_2 + \dots \mathrm{i}_n x\mathrm{i}_2 x\mathrm{i}_n \textbf{(4)}$$

where ($1 \leq i \leq q$, $1 \leq i \leq j \leq k \leq q$, $1 \leq i_1 \leq i_2 \leq \dots \leq i_n \leq q$ respectively) , b = constant coefficients and Y is the response (the response is a polynomial function of pseudo component of the mix) which represents the property under study, which ,in this case is the compressive strength.

This research work is based on the (5, 2) simplex. The actual form of Eqn. (4) has already been developed by Nwachukwu and others (2017) and will be subsequently applied here.

2.2. ESTABLISHED RELATIONSHIP BETWEEN PSEUDO AND ACTUAL COMPONENTS.

In Scheffe's mixture design, the relationship between the pseudo components and the actual components is given as:Z = A * X **(5)**where Z is the actual component; X is the pseudo component and A is the coefficient of the relationship

Re-arranging the equation, we have : $X = A^{-1} * Z$ **(6)**In this research work a five component concrete mixture components viz:cement, sand as fine aggregate, granite as coarse aggregate, water/cement (w/c) ratio and mussel shell will be on focus .

2.3. FORMULATION OF POLYNOMIAL EQUATION FOR MSFRC SCHEFFE'S (5, 2) LATTICE

The polynomial equation by Scheffe(1958), describing the response is given in Eqn.(4). But, for Scheffe's (5,2) simplex lattice, the polynomial equation for five component mixtures has been derived from Eqn.(4) by Nwachukwu and others (2017) and the simplified version is given as follows:

$Y = ß_1X_1 + ß_2X_2 + ß_3X_3 + ß_4X_4 + ß_5X_5 + ß_{12}X_1X_2 + ß_{13}X_1X_3 + ß_{14}X_1X_4 + ß_{15}X_1X_5 +$
$ß_{23}X_2X_3 + ß_{24}X_2X_4 + ß_{25}X_2X_5 + ß_{34}X_3X_4 + ß_{35}X_3X_5 + ß_{45}X_4X_5$ **(7)**

2.4 .DETERMINATION OF THE COEFFICIENTS OF THE MSFRCSCHEFFE'S (5, 2) POLYNOMIAL

From the work of Nwachukwu and others (2022h), the coefficients of theScheffe's (5, 2) polynomial can be expressed as follows. :

$\beta_1 = Y_1$; $\beta_2 = Y_2$; $\beta_3 = Y_3$; $\beta_4 = Y_4$; and $\beta_5 = Y_5$ **8(a-e)**

$\beta_{12} = 4Y_{12} - 2Y_1 - 2Y_2$; $\beta_{13} = 4Y_{13} - 2Y_1 - 2Y_3$; $\beta_{14} = 4Y_{14} - 2Y_1 - 2Y_4$;
9(a-c)

$\beta_{15} = 4Y_{15} - 2Y_1 - 2Y_5$; $\beta_{23} = 4Y_{23} - 2Y_2 - 2Y_3$; $\beta_{24} = 4Y_{24} - 2Y_2 - 2Y_4$; **10(a-c)**

$\beta_{25} = 4Y_{25} - 2Y_2 - 2Y_5$; $\beta_{34} = 4Y_{34} - 2Y_3 - 2Y_4$; $\beta_{35} = 4Y_{35} - 2Y_3 - 2Y_5$; **11(a-c)**

$\beta_{45} = 4Y_{45} - 2Y_4 - 2Y_5$ **(12)**

Where Y_i = Response Function (or Compressive Strength) for the pure component, i

2.5. EVALUATING ACTUAL AND PSEUDO MIX PROPORTIONS FOR THE MSFRC SCHEFFE'S (5,2) DESIGN LATTICE AT INITIAL EXPERIMENTAL POINT AND CONTROL POINT

2.5.1.AT THE INITIAL EXPERIMENTAL TEST POINTS

The requirement of simplex lattice design from Eqn.(1) makes it impossible to use the conventional mix ratios such as 1:2:4, 1:1.3:6, 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. Based on experience and previous knowledge from literature, the following arbitrary prescribed mix proportions were chosen for the five points/vertices.

A_1 (0.67:1: 1.7: 2:0.5); A_2 (0.56:1:1.6:1.8:0.8); A_3 (0.5:1:1.2:1.7:1); A_4 (0.7:1:1:1.8:1.2) and A_5 (0.75:1:1.3:1.2:1.5), which represent water/cement ratio, cement, fine aggregate, coarse aggregate and mollusc shell fibre.

For the pseudo mix ratio, we have the following corresponding mix ratios at the vertixes: A_1(1:0:0:0:0), A_2(0:1:0:0: 0), A_3(0:0:1:0:0), A_4(0:0:0:1:0), and A_5(0:0:0:0:1)

For the transformation of the actual component, Z to pseudo component, X, and vice versa ,Eqns.(5)and (6) are used..

Substituting the mix ratios from point A_1 into Eqn. (5) gives:

$$\begin{Bmatrix} 0.67 \\ 1 \\ 1.7 \\ 2 \\ 0.5 \end{Bmatrix} = \begin{pmatrix} A_{11} & A_{12} & A_{13} & A_{14} & A_{15} \\ A_{21} & A_{22} & A_{23} & A_{24} & A_{25} \\ A_{31} & A_{32} & A_{33} & A_{34} & A_{35} \\ A_{41} & A_{42} & A_{43} & A_{44} & A_{45} \\ A_{51} & A_{52} & A_{53} & A_{54} & A_{55} \end{pmatrix} \begin{Bmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{Bmatrix} \quad \textbf{(13)}$$

Transforming the R.H matrix and solving , we obtain:

$$\begin{Bmatrix} Z_1 \\ Z_2 \\ Z_3 \\ Z_4 \\ Z_5 \end{Bmatrix} = \begin{pmatrix} 0.67 & 0.56 & 0.5 & 0.7 & 0.75 \\ 1 & 1 & 1 & 1 & 1 \\ 1.7 & 1.6 & 1.2 & 1 & 1.3 \\ 2 & 1.8 & 1.7 & 1.8 & 1.2 \\ 0.5 & 0.8 & 1 & 1.2 & 1.5 \end{pmatrix} \begin{Bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \\ X_5 \end{Bmatrix} \quad \textbf{(14)}$$

Thus

$$\begin{Bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \\ X_5 \end{Bmatrix} = \begin{pmatrix} 3.99 & 10.37 & -2.14 & -3.05 & -4.62 \\ -4.88 & -21.46 & 5.40 & 5.95 & 7.31 \\ -1.78 & 17.83 & -3.49 & -4.20 & -4.62 \\ 1.04 & -9.24 & 0.37 & 3.28 & 2.69 \\ 1.63 & 3.49 & -0.13 & -1.98 & -0.77 \end{pmatrix} \begin{Bmatrix} Z_1 \\ Z_2 \\ Z_3 \\ Z_4 \\ Z_5 \end{Bmatrix} \quad \textbf{(15)}$$

Considering the mix ratios at the midpoints, we have
A_{12} (0.5, 0.5, 0, 0, 0); A_{13} (0.5, 0, 0.5, 0, 0); A_{14} (0.5, 0, 0, 0.5, 0); A_{15} (0.5, 0, 0, 0, 0.5); A_{23} (0, 0.5, 0.5, 0,0); A_{24} (0, 0.5, 0, 0.5, 0); A_{25} (0, 0.5, 0, 0, 0.5); A_{34} (0, 0, 0.5, 0.5, 0); A_{35} (0, 0, 0.5, 0, 0.5) and A_{45} (0, 0, 0, 0.5, 0.5)
Substituting these pseudo mix ratios in turn into Eqn. (15) will give the corresponding actual mix ratio
For point A_{12}

$$\begin{Bmatrix} Z_1 \\ Z_2 \\ Z_3 \\ Z_4 \\ Z_5 \end{Bmatrix} = \begin{pmatrix} 0.67 & 0.56 & 0.5 & 0.7 & 0.75 \\ 1 & 1 & 1 & 1 & 1 \\ 1.7 & 1.6 & 1.2 & 1 & 1.3 \\ 2 & 1.8 & 1.7 & 1.8 & 1.2 \\ 0.5 & 0.8 & 1 & 1.2 & 1.5 \end{pmatrix} \begin{pmatrix} 0.5 \\ 0.5 \\ 0 \\ 0 \\ 0 \end{pmatrix} = \begin{Bmatrix} 0.62 \\ 1 \\ 1.65 \\ 1.90 \\ 0.65 \end{Bmatrix} \quad \textbf{(16)}$$

Hence comparing
$Z_1 = 0.62$, $Z_2 = 1$, $Z_3 = 1.65$, $Z_4 = 1.9$, $Z_5 = 0.65$
The rest are shown in Table 1
Hence to generate the polynomial coefficients, fifteen experimental tests will be carried out and the corresponding mix ratio are as depicted in Table 1.

Table 1: Actual Mix Ratios For TheMSFRCScheffe's (5, 2) Simplex Lattice

S/N	Points	Water/Cement Ratio (Z_1)	Cement (Z_2)	Fine Aggregate(Z_3)	Coarse Aggregate(Z_4)	Mussel Shell Fibre (Z_5)	Response Y
1	1	0.67	1	1.70	2.00	0.50	Y_1
2	2	0.56	1	1.60	1.80	0.80	Y_2
3	3	0.50	1	1.20	1.70	1.00	Y_3
4	4	0.70	1	1-00	1.80	1.20	Y_4
5	5	0.75	1	1.30	1.20	1.50	Y_5
6	12	0.62	1	1.65	1.90	0.65	Y_{12}
7	13	0.59	1	1.45	1.85	0.75	Y_{13}
8	14	0.69	1	1.35	1.90	0.85	Y_{14}
9	15	0.71	1	1.50	1.60	1.00	Y_{15}
10	23	0.53	1	1.40	1.75	0.90	Y_{23}
11	24	0.63	1	1.30	1.80	1.00	Y_{24}
12	25	0.66	1	1.45	1.50	1.15	Y_{25}
13	34	0.60	1	1.10	1.75	1.10	Y_{34}
14	35	0.63	1	1.25	1.45	1.25	Y_{35}
15	45	0.73	1	1.15	1.50	1.50	Y_{45}

2.5.2. AT THE EXPERIMENTAL (.CONTROL) POINT

For the purpose of this research, fifteen different controls were predicted which according to Scheffe, their summation should not be more than one
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, 0.20), C_{13} = (0.30, 0.30, 0.30, 0.10, 0), C_{14} = (0.30, 0.30, 0.30, 0, 0.10), C_{15} = (0.30, 0.30, 0, 0.30, 0.1), C_{23} = (0.30, 0, 0.30, 0.30, 0.1), C_{24} = (0, 0.30, 0.30, 0.30, 0.10), C_{25} = (0.10, 0.30, 0.30, 0.30, 0), C_{34} = (0.30, 0.10, 0.30, 0.30, 0), C_{35} = (0.30, 0.30, 0.10, 0.30, 0), C_{45} = (0.10, 0.20, 0.30, 0.40, 0),
Substituting into Eqn.(16) , we obtain the values of the actual mixes as follows:

Control 1 C_1

$$\begin{Bmatrix} Z_1 \\ Z_2 \\ Z_3 \\ Z_4 \\ Z_5 \end{Bmatrix} = \begin{pmatrix} 0.67 & 0.56 & 0.5 & 0.7 & 0.75 \\ 1 & 1 & 1 & 1 & 1 \\ 1.7 & 1.6 & 1.2 & 1 & 1.3 \\ 2 & 1.8 & 1.7 & 1.8 & 1.2 \\ 0.5 & 0.8 & 1 & 1.2 & 1.5 \end{pmatrix} \begin{pmatrix} 0.25 \\ 0.25 \\ 0.25 \\ 0.25 \\ 0 \end{pmatrix} = \begin{Bmatrix} 0.61 \\ 1 \\ 1.38 \\ 1.8 \\ 0.5 \end{Bmatrix} \quad \textbf{(17)}$$

The rest are depicted in Table 2

Table 2: Actual (Z_i) and Pseudo (X_i) Component of MSFRC Scheffe's (5, 2) Simplex Lattice

S/N	**POINTS**	**PSEUDO COMPONENTS**					**CONTROL POINTS**	**ACTUAL COMPONENTS**				
		Water(X_1)	**Cement (X_1)**	**Fine Aggregate (X_3)**	**Course Aggregate (X_4)**	**MusselShell (X_5)**		**Water(Z_1)**	**Cement (Z_2)**	**Fine Aggregate (Z_3)**	**Course Aggregate (Z_4)**	**Mussel Shell(Z_5)**
1	**1**	0.25	0.25	0.25	0.25	0.00	C_1	0.61	1	1.38	1.83	0.50
2	**2**	0.25	0.25	0.25	0.00	0.25	C_2	0.62	1	1.45	1.68	0.80
3	**3**	0.25	0.25	0.00	0.25	0.25	C_3	0.67	1	1.40	1.70	1.00
4	**4**	0.25	0.00	0.25	0.25	0.25	C_4	0.66	1	1.30	1.68	1.20
5	**5**	0.00	0.25	0.25	0.25	0.25	C_5	0.63	1	1.28	1.63	1.50
6	**12**	0.20	0.20	0.20	0.20	0.20	C_{12}	0.64	1	1.36	1.70	0.65
7	**13**	0.30	0.30	0.30	0.10	0.00	C_{13}	0.59	1	1.45	1.83	0.75
8	**14**	0.30	0.30	0.30	0.00	0.10	C_{14}	0.59	1	1.48	1.77	0.85
9	**15**	0.30	0.30	0.00	0.30	0.10	C_{15}	0.65	1	1.42	1.80	1.00
10	**23**	0.30	0.00	0.30	0.30	0.10	C_{23}	0.64	1	1.30	1.77	0.90
11	**24**	0.00	0.30	0.30	0.30	0.10	C_{24}	0.60	1	1.27	1.71	1.00
12	**25**	0.10	0.30	0.30	0.30	0.00	C_{25}	0.60	1	1.31	1.79	1.15
13	**34**	0.30	0.10	0.30	0.30	0.00	C_{34}	0.62	1	1.33	1.83	1.10
14	**35**	0.30	0.30	0.10	0.30	0.00	C_{35}	0.63	1	1.41	1.85	1.25
15	**45**	0.10	0.20	0.30	0.40	0.00	C_{45}	0.61	1	1.25	1.79	0.50

The actual component as transformed from Eqn. (17) , Table (1) and (2) were used to measure out the quantities of Water/Cement Ratio (Z_1), Cement (Z_2), Fine Aggregate (Z_3), Coarse Aggregate (Z_4), and Mussel Shell Fibre (Z_5) in their respective ratios for the concrete cube strength test.

3. MATERIALS AND METHODS

3.1 MATERIALS

In this research work, the constituent materials under investigation are Water/Cement ratio, Cement, Fine and Coarse Aggregates and MSF. The water is obtained from potable water from the clean water source. The cement is Dangote cement, a brand of Ordinary Portland Cement obtained from local distributors, which conforms to British Standard Institution BS 12 (1978). The fine aggregate, whose size ranges from 0.05 - 4.5mm was procured from the local river. Crushed granite (as a coarse aggregate) of 20mm size was obtained from a local stone market and was downgraded to 4.75mm. The mussel shells used in this experimental research were obtained as a waste from the aquaculture industry. It was then washed with hot soapy water, calcinated at 200 _C for1 h, dried and crushed into smaller pieces and grinded into matrices or strips or fillers to form fibres. The mussel shells, after being washed and grinded as above were dried in a ventilated electric oven at a temperature of 110 _C for 24 h before being processed further..

3.2. METHOD

3.2.1. SPECIMEN PREPARATION / BATCHING/ CURING

The specimen for the compressive strength is concrete cubes. They were cast in steel mould measuring 15cm*15cm*15cm. The mould and its base were damped together during concrete casting to prevent leakage of mortar. Thin engine oil was applied to the inner surface of the moulds to make for easy removal of the cubes. Batching of all the constituent material was done by weight using a weighing balance of 50kg capacity based on the adapted mix ratios and water cement ratios. A total number of 30 mix ratios were to be used to produce 60 prototype concrete cubes. Fifteen (15) out of the 30 mix ratios were as control mix ratios to produce 30 cubes for the conformation of the adequacy of the mixture design given by Eqn. (7), whose coefficients are given in Eqns. (8) – (12). Curing commenced 24hours after moulding. The specimens were removed from the moulds and were placed in clean water for curing. After 28 days of curing the specimens were taken out of the curing tank.

3.2.2. COMPRESSIVE STRENGTH TEST

Compressive strength testing was done in accordance with BS 1881 – part 116 (1983) - Method of determination of compressive strength of concrete cube and ACI (1989) guideline. In this present study, two samples were crushed for each mix ratio. In each case, the compressive strength was then calculated using Eqn.(18)

$$\text{Compressive Strength} = \frac{\text{Average failure Load (N) } P}{\text{Cross- sectional Area (mm}^2) \quad A} \quad \textbf{(18)}$$

4.RESULTSPRESENTATION AND DISCUSSION

4.1 MSFRC RESPONSES FOR THE INITIAL EXPERIMENTAL TEST

The results of the compressive strength (response) test based on Eqn. (18) are shown in Table 3

Table 3:MSFRC Compressive Strength (Response) Test Results Based on Eqn.(18)

S/N	POINTS	EXPERIMENT NO	RESPONSE Y_I, N/mm^2	RESPONSE SYMBOL	$\sum Y_I$	AVERAGE RESPONSE Y, N/mm^2
1	1	1A 1B	23.34 24.36	Y_1	47.70	23.85
2	2	2A 2B	27.32 26.43	Y_2	53.75	26.88
3	3	3A 3B	21.98 22.18	Y_3	44.16	22.08
4	4	4A 4B	23.00 23.14	Y_4	46.14	23.07
5	5	5A 5B	20.55 21.12	Y_5	41.67	20.84
6	12	6A 6B	28.77 28.73	Y_{12}	57.50	28.75
7	13	7A 7B	19.55 19.48	Y_{13}	39.03	19.52
8	14	8A 8B	19.54 18.98	Y_{14}	38.52	19.26
9	15	9A 9B	25.65 24.87	Y_{15}	50.52	25.26
10	23	10A 10B	23.45 24.24	Y_{23}	47.69	23.85
11	24	11A 11B	24.86 23.88	Y_{24}	48.74	24.37
12	25	12A 12B	21.65 22.21	Y_{25}	43.86	21.93
13	34	13A 13B	18.26 18.22	Y_{34}	36.48	18.24
14	35	14A 14B	26.43 27.43	Y_{35}	53.86	26.93
15	45	15A 15B	19.76 19.75	Y_{45}	39.51	19.76

4.2. MSFRC RESPONSES FOR THE EXPERIMENTAL (CONTROL) TEST POINTS

The response (compressive strength) from experimental (control) tests is shown in Table 4

Table 4: MSFRC Response of Control Points from Experimental (control) Tests (5, 2) Simplex Lattice

S/N	POINTS	EXPERIMENT NO	RESPONSE N/mm^2	Z_1	Z_2	Z_3	Z_4	Z_5	AVERAGE RESPONSE	
1	C1	1A 1B	22.43 23.12	0.61	1	1.38	1.83	0.5	22.78	10.42
2	C2	2A 2B	26.76 25.78	0.62	1	1.45	1.68	0.8	26.27	9.04

3	C3	3A 3B	20.32 20.44	0.67	1	1.4	1.7	1	20.38	7.33
4	C4	4A 4B	22.21 22.56	0.66	1	1.3	1.68	1.2	22.39	7.89
5	C5	5A 5B	19.86 20.21	0.63	1	1.28	1.63	1.5	20.04	12.81
6	C12	6A 6B	27.46 26.32	0.64	1	1.36	1.7	0.65	26.89	10.77
7	C13	7A 7B	19.55 19.48	0.59	1	1.45	1.83	0.75	19.52	7.6
8	C14	8A 8B	19.86 20.32	0.59	1	1.48	1.77	0.85	20.09	8.1
9	C15	9A 9B	24.32 23.86	0.65	1	1.42	1.8	1	24.09	7.05
10	C23	10A 10B	25.21 26.18	0.64	1	1.3	1.77	0.9	25.70	7.25
11	C24	11A 11B	23.23 22.43	0.6	1	1.27	1.71	1	22.83	8.04
12	C25	12A 12B	22.22 23.32	0.6	1	1.31	1.79	1.15	22.77	7.96
13	C34	13A 13B	19.45 20.12	0.62	1	1.33	1.83	1.1	19.79	8.14
14	C35	14A 14B	26.76 26.42	0.63	1	1.41	1.85	1.25	26.59	10.54
15	C45	15A 15B	20.12 20.28	0.61	1	1.25	1.79	1.35	20.20	11.02

4.3. SCHEFFE’ S (5,2) MODEL FOR THE MSFRC RESPONSES.

By substituting the values of the compressive strengths (responses) from Table 3 into Eqns.(8) through (12), we obtain the coefficients of the Scheffe’s second degree polynomial for MSFRC as follows:

$\beta_1 = 23.85$; $\beta_2 = 26.88$; $\beta_3 = 22.08$; $\beta_4 = 23.07$; $\beta_5 = 20.84$;$\beta_{12} = 13.54$; $\beta_{13} = 13.78$; $\beta_{14} = 16.8$; $\beta_{15}=11.66$; $\beta_{23}=2.52$;$\beta_{24} = -2.52.$; $\beta_{25}=-7.72$;$\beta_{34}= 17.34$;$\beta_{35}= 21.88$;$\beta_{45}=-52.90$ **(19)**

Substituting the values of these coefficients in Eqn.(19) into Eqn. (9) yieldthe polynomial model for the optimization of the compressive strength of MSFRC based on Scheffe’s (5,2) lattice as given in Eqn.(20)

$Y = 23.85X_1+ 26.88X_2+ 22.08X_3+ 23.07X_4+ 20.84X_5 + 13.54 X_1X_2+ 13.78X_1X_3 +16.8X_1X_4 +11.66X_1X_5 +2.54X_2X_3 – 2.54X_2X_4– 7.72X_2X_5 +17.84X_3X_4 + 21.88X_3X_5 -52.90X_4X_5$ **(20)**

4.4. SCHEFFE’S (5,2) MODEL RESPONSES FOR MSFRCAT CONTROL POINTS

By substituting the pseudo mix ratio of points C_1, C_2, C_3, C_4, C_5, … C_{45} of Table 2 into Eqn.(20) yields the second degree model responses for the control points of MSFRC.

4.5.: VALIDATION OF MSFRC MODEL RESULTS USING STUDENT’S – T -TEST

Here, the test of adequacy is performed to determine the correlation between the compressive strength results (lab responses) given in Table 4 and model responses from the control points based on Eqn.(20). Here, we employ the use of Student’s – T – test as the means of validating the Scheffe’sModel. The procedures/steps involved for using the Student’s – T - test have been explained by Nwachukwu and others (2022 c). The result of the test shows that there is no significant difference between the experimental results and model responses. Therefore, the model is adequate for predicting the compressive strength of MSFRC based on Scheffe’s (5,2) lattice.

4.6. DISCUSSION OF RESULTS

The maximum compressive strength of MSFRC based on Scheffe's (5,2) lattice is 28.75MPa . This corresponds to mix ratio of 0.62:1.00:1.65:1.90:1.65 for Water/Cement Ratio, Cement, Fine Aggregate, Coarse Aggregate and Mussel Shell Fibre respectively. Similarly, the minimum compressive strength is 18.24 MPa which also correspond to the mix ratio of 0.60:1.00:1.10:1.75: 1.10 for Water/Cement Ratio, Cement, Fine Aggregate, Coarse Aggregate and Mussel Shells Fibre respectively. The maximum value from theScheffe's model is greater than the minimum value specified by the American Concrete Institute for the compressive strength of good concrete. Thus, theScheffe's model can be used to determine the MSFRC compressive strength of all points (1 - 45) in the simplex based on Scheffe's Second Degree Model**.**

5. CONCLUSION

Scheffe's Second Degree Polynomial (5,2) was used to formulate a model for predicting the compressive strength of MSFRC cubes. Firstly, the Scheffe's method was used to predict the mix ratio for predicting the compressive strength of MSFRC. By using Scheffe's (5,2) simplex model, the values of the compressive strength were determined at all 15 points (1- 45). The results of the student's t-test validated the strengths predicted by the models and the corresponding experimentally observed results. The optimum attainable compressive strength predicted by the model based on Scheffe's (5,2) model is28.75MPa.Expectedly, the maximum value meets the minimum standard requirement (of 20 MPa) stipulated by American Concrete Institute (ACI), for the compressive strength of good concrete. Thus, with the Scheffe's (5,2) model, any desired strength, given any mix proportions can be easily predicted and evaluated and vice versa.Therefore, the utilization of thisScheffe's optimization model has solved the problem of having to go through vigorous, time-consuming and laborious mixture design procedures in other to obtain the desired strength.Finally, it can be deduced that the Mussel Shell (MS) that resulted to Mussel Shell Fibre(MSF) that should have posed as a menace to the environment is now being utilized as a substantial concrete component with capacity of increasing the concrete's compressive strength.

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