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Compressive Strength Modelling of Palm Nut Fiber Concrete Using Scheffe's Theory

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Abstract

In this research study, a mathematical-model is developed to optimize the palm-nut-fiber reinforced concrete's compressive strength using Scheffe's (5, 2) simplex-lattice design. Palm-nut-fiber which is an agricultural residue obtained after the processing of palm-oil is utilized as the fifth component in concrete consisting of water, cement, fine and coarse-aggregates. Fibers are used to help fresh concrete to keep it from cracking and plastic shrinkage and also for a concrete structure of complicated or complex geometry where the use of the conventional rebar is unreliable. The compressive-strength of Palm-nut-fiber were obtained for the different componential ratios using Scheffe's Simplex method and for the control points which will be utilized for the validation of the Scheffe's model. The model's adequacy was tested using student's t-test and ANOVA at 5% critical value. The statistical result indicates a good relationship between the values obtained from the developed Scheffe's model and the control laboratory results. The maximum value of compressive strength of the palm-nut fiber concrete obtained was 31.53N/mm^2 corresponding to mix ratio of 0.525:1.0:1.45:1.75:0.6 and minimum value of compressive strength obtained was found to be 17.25N/mm^2 corresponding to mix ratio of 0.6:1.0:1.8:2.5:1.2. For water, cement, fine aggregate, coarse-aggregate and palm nut fiber respectively. Using the developed Scheffe's simplex model, the proportion of the mixture ingredients to a certain prescribed compressive strength value can be estimated with a high degree of accuracy and also providing the solution in less amount of time.

Keywords: Scheffe's Model; Palm-nut-fiber; Concrete Compressive Strength; MATLAB; Simplex Method

Introduction

Concrete require material with ductility capacity to help is absorb many sources of stresses which it cannot resist on its own due to its brittle capacity. In most cases, steel reinforcement is utilized in order to enhance the concrete's strength performance [1]. Addition of reinforcement in concrete changes the failure type of the concrete from brittle failure to ductile failure where we observe the formation of failure cracks before there exists tremendous loss of strength; this induces plastic deformation capacity after yielding of the material under stress. By so doing, the prospect of total collapse of the structure without early warning signs will be properly taken care of while maintenance culture will be embraced to avert the crises from happening [2]. Utilization of fiber in concrete mixes to obtain a fiber-reinforced concrete is seriously gaining much popularity as a viable alternative to enhancement of concrete durability and strength performance. Fiber concrete is specifically utilized for the construction of complex or irregular geometry structures such as tunneling, loading decks, concrete pads, bridge decks, thin unbounded layers and concrete slabs [3,4]. The major role of fibers in concrete is to alter its cracking mechanism, this structural behavior modification causes the macro cracking to turn into micro cracking. This reduction in the cracking failure mechanism will eventually improve the permeability property of the cracked concrete while also enhances its ultimate cracking strain property [5]. Fiber reinforced concrete does not fail totally after the occurrence of the initial crack, the fibers arrange in a matrix form at distinct locations and is able to absorb loads at failure region unlike the unreinforced concrete material [6].

Empirical method of concrete mix design consists of series of extensive tests majorly centered on the bases of trial and error which involves rough estimates based on practical experience without a theoretical or statistical methodological approach [7]. In order to limit the number of trial and error tests before obtaining of optimal combination ratio for the concrete mixed with palm nut fiber, developing an analytical method which will rationalize the initial trial mix into a systematic and logical process. This will help in locating the optimum combination for the mixture ingredients in consuming less resources based on laid down knowledge of certain empirical relationships, specific weights of mixture ingredients and results from past literatures [8]. Scheffe's method is a mixture model technique utilized for the adjustment of statistical significance levels to account for multiple comparison in a linear regression analysis. It is very essential for a special case of regression analysis termed analysis of variance, when performing evaluation of simultaneous confidence levels for regression analysis involving objective functions [9]. The use of palm nut fiber which is a solid agricultural waste as a fifth component in concrete mixture is investigated in this research study. Where the idea in this research work is to integrate totally the fiber material in concrete mixture and not as partial replacement using statistical method to determine the optimum mixture combination of the concrete mixture whose ingredients are cement, fiber, fine aggregate, coarse aggregate and water. Through the statistical method, Scheffe's simplex second order regression model is developed to optimize the compressive strength property of the palm nut fiber concrete. The recycling, utilization and re-use of agricultural solid waste fiber material such as palm nut fiber using statistical approach has been found to be a beneficial technique in engineering practice [10,11].

The use of Scheffe's simplex lattice design to achieve mixture design have been applied in several civil engineering applications to proffer solutions in such areas as soil stabilization, geotechnical material science, pavement materials modifications and concrete technology [10]. Okere *et al*. [12]; in their work on the flexural strength of soilcrete blocks made with laterite and the optimization using Scheffe's simplex lattice design method. Laboratory tests were carried out with respect to the calculated Scheffe's design point. Statistical analysis was carried out to validate the developed mathematical model. The maximum response value of the 1.452N/mm^2 was obtained. From the research results, lateritic soil which is readily available and affordable has been used successfully to produce soilcrete blocks. Also, Alaneme *et al*. [13]; in their research study on the utilization of Scheffe's theory for the optimization of the flexural strength property of the palm-nut fiber concrete. The concrete mixture has five components namely; cement, water, coarse aggregates, fine aggregates and an agricultural waste known as palm-nut fiber. The optimal combination of 0.525:1.0:1.45:1.75:0.6 was obtained at a strength value of 11.40 N/mm^2 while the minimum combination ratio of 0.6:1.0:2.0:2.8:1.1 for water, cement, fine and coarse aggregate and palm nut fiber respectively was obtained at a strength vale of 5.35 N/mm^2. Furthermore Chijioke Chiemela *et al*. [14]; in their work the use of Scheffe's theory to model the compressive strength property of concrete when provided with componential ratios while also predicting the corresponding portions of the mixture ingredients with prescribed value of compressive strength vale of concrete obtained from substitution of the conventional river sand as the fine aggregates by quarry dust. The developed model was further tested for adequacy with the control point's response value. This statistical analysis method used are f-statistics and student's t-test at 95% confidence level. The result shows that there is no significant difference between the predicted and measured values.

Palm-nut fiber is used in this research work to enhance sustainable infrastructural development through re-use of solid wastes derived from agricultural or industrial processes, this is achieved through substitution of the conventional concrete ingredients. Concrete compressive strength property is generally impacted through adequate proportioning of its ingredients. Scheffe's optimization method was used to model the concrete compressive strength behavior and obtain the optimum combination ratio for the mixture ingredients which is water, cement, fine and coarse aggregate and palm nut fiber. This investigation will add to existing knowledge on optimization of concrete mixture blended with waste fiber materials as admixture. The benefits from this study will avail better decision making on determination of concrete grade and batching of its ingredients required for structural use [15-16].

Materials and Methods

Mathematical Modelling and Mix Proportion Formulation

Scheffe formulated a model for the assessment of the response of a particular characteristic of a mixture with respect to some variations in the proportions of its component materials [17]. In his simplex lattice model, he considered experiments whereby the desired response obtained is relatively proportional to the ratio of ingredients combination. A mixture experiments is utilized in a scenario whereby the independent variables which are the ingredients' combination ratio is actually not independent but they are interrelated by some of series of imposed constraints which enable a homogenous mixture to be obtained [18].

Lattice is a properly arranged settings of space with points that are uniformly distributed in a simplex; $a\{q,m\}$ simplex is a structural representation of the intersecting hyper-planes between the experimental points of the mixture; q represents the total number of mixture components while m represents the order of the regression polynomial [19,20]. The factor space takes a form of a regular $(q-1)$ simplex due to the imposed sum to one constraint on the mixture design; this is presented in eqn. 1 below

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

$x_i \geq 0$ for concentration of the components in the mixture and q represents the total number of mixture components. The points division along the simplex by each component on a straight line takes m+1 values equally spaced from each other ranging from point 0 to 1; it is mathematically represented in eqn.2 below

$$x_i = 0, \frac{1}{m}, \frac{2}{m}, \ldots, 1 \text{ for } i = 1, 2, \ldots, q \tag{2}$$

Scheffe observed mixtures experiments whereby the response parameter depends on the ratio of the components' combination and not on the quantity of the mixture [9]. The sought for parameter or property of interest is presented using equation of a polynomial form as shown in eqn. 3 below

$$y = b_o + \sum b_i x_j + \sum b_{ij} x_i x_j + \sum b_{ijk} x_i x_j x_k + \ldots + e \quad (3)$$

Where b_o, b_i, b_{ij}, b_{ijk} are constants, x_i, x_j, x_k represents the pseudo components and for second order polynomial the canonical order is expressed in eqn. 4 below

$$y = b_o + \sum b_i x_i + \sum b_{ij} x_i x_j + e \quad (4)$$

Further expansion of Equation (4) by substituting $(0 \le i \le j \le 5)$ into the values of i and j transforms to

$$Y = b_o + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_{11}X_1^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{15}X_1X_5 + b_{22}X_2^2 + b_{23}X_2X_3 + b_{24}X_2X_4 + b_{25}X_2X_5 + b_{33}X_3^2 + b_{34}X_3X_4 + b_{35}X_3X_5 + b_{44}X_4^2 + b_{45}X_4X_5 + b_{55}X_5^2 \quad (5)$$

Multiplying eqn. (1) by b_o

$$b_0 = b_0\left(X_1 + X_2 + X_3 + X_4 + X_5\right) \quad (6)$$

Multiplying in succession Eqn. (1) by X_1, X_2, X_3, X_4, and X_5 and Substituting Equations (6) into Equation (4) we obtained the general second order polynomial model form for five component mixture. This is presented in eqn. 7

$$\widehat{Y} = \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_{12}X_1X_2 + \beta_{13}X_1X_3 + \beta_{14}X_1X_4 + \beta_{15}X_1X_5 + \beta_{23}X_2X_3 + \beta_{24}X_2X_4 + \beta_{25}X_2X_5 + \beta_{34}X_3X_4 + \beta_{35}X_3X_5 + \beta_{45}X_4X_5 \quad (7)$$

thus eqn. 7 could be presented as follows;

$$y = \sum \beta_i x_i + \sum \beta_{ij} x_i x_j \text{ Where } i \ge 1 \text{ and } i \le j \le 5 \quad (8)$$

Where X_i represents the pseudo components for the mixture design while β_i represents the response coefficients of Scheffe's optimization equation. This coefficient can be expressed as β_i which is for the pure or binary blends and as β_{ij} which is for the ternary blends or the combination of the mixture components. They can be defined as follows;

$$\beta_i = Y_i \text{ and } \beta_{ij} = 4Y_{ij} - 2Y_i - 2Y_j$$

Thus

$$\begin{aligned} &\beta_{12} = 4Y_{12} - 2Y_1 - 2Y_2, \beta_{13} = 4Y_{13} - 2Y_1 - 2Y_3, \beta_{14} = 4Y_{14} - 2Y_1 - 2Y_4, \beta_{15} = 4Y_{15} - 2Y_1 - 2Y_5, \\ &\beta_{23} = 4Y_{23} - 2Y_2 - 2Y_3, \beta_{24} = 4Y_{24} - 2Y_2 - 2Y_4, \beta_{25} = 4Y_{25} - 2Y_2 - 2Y_5, \beta_{34} = 4Y_{34} - 2Y_3 - 2Y_4, \\ &\beta_{35} = 4Y_{35} - 2Y_3 - 2Y_5, \beta_{45} = 4Y_{45} - 2Y_4 - 2Y_5 \end{aligned} \quad (9)$$

Eqn. 9 shows the relationship between Scheffe's regression coefficients and the actual response

Number of Coefficients: The number of coefficients for the Scheffe's five component mixture can be computed using eqn. (10). This number also moderates the number of runs for the experiment and also for the control points too.

$$n = \frac{(P + M - 1)!}{M!(P - 1)!} \quad (10)$$

Where P which is the total amount of mixture components is 5 and M which is the polynomial order is 2

$$N = \frac{(5 + 2 - 1)!}{2!(5 - 1)!} = N = \frac{6!}{2!4!} = 15$$

Five Component Factor Space: The points on the vertices of the factor space represent pure or binary component blends which indicates hundred percent mixture of a single mixture component. The pure or binary blend are assigned at the vertex of the simplex factor space. For the five-component mixture, we have five vertices and ten spread in between the vertices of the simplex. All mixture interior to the perimeter of the simplex region are blends of all of the q-components. The factor space is the space within which all the experimental points will be distributed [20].

The first five pseudo component for the {5, 2} simplex represents the position of the binary blend of the mixture which are located at the vertices of the tetrahedron simplex.

A1 [1:0:0: 0:0], **A2** [0:1:0:0:0], **A3** [0:0:1:0:0], **A4** [0:0:0:1:0], A5 [0:0:0:0:1].

While the next ten other pseudos mix ratios remaining which are located at mid points of the lines joining the vertices of the simplex is presented below

A12 [0.5:0.5:0:0:0], **A13** [0.5:0:0.5:0:0], **A14** [0.5:0:0:0.5:0], **A15** [0.5:0:0:0:0.5], **A23** [0:0.5:05:0:0], **A24** [05:0:0:0.5:0], **A25** [0:0.5:0:0:0.5], **A34** [0:0:0.5:05:0], **A35** [0:0:0.5:0:0.5], **A45** [0:0:0:0.5:0.5].

The actual and pseudo components are related with a mathematical expression in eqn. 11

$$Z = AX \tag{11}$$

Where Z represents the concentration of the actual components, X represents the respective value for the pseudo components and A which is $n \times n$ matrix where n is equal to the total number of mixture ingredients; for this design, we obtain a five by five matrix which is obtained from the first five run of the mixture ratios. These mix ratios are shown in eqn. 12;

$\mathbf{Z_1}$ [0.45:1.0:1.25:1.45:0.2], $\mathbf{Z_2}$ [0.5:1.0:1.35:1.6:0.4], $\mathbf{Z_3}$ [0.55:1.0:1.55:1.9:0.8], $\mathbf{Z_4}$ [0.6:1.0:1.8:2.5:1.2], $\mathbf{Z_5}$ [0.65:1.0:2.0:3.0:1.8].

Substitution of X_i and Z_i into Equation (11) using the corresponding pseudo components to determine the corresponding actual mixture components.

$\mathbf{Z_1}$ = water cement ratio; $\mathbf{Z_2}$ = cement; $\mathbf{Z_3}$= fine aggregate; $\mathbf{Z_4}$ = coarse aggregate; $\mathbf{Z_5}$ = palm nut fiber

Substituting the obtained initial five run of mixes, we have the [A] matrix

$$\begin{pmatrix} 0.45 & 0.5 & 0.55 & 0.60 & 0.65 \\ 1.0 & 1.0 & 1.0 & 1.0 & 1.0 \\ 1.25 & 1.35 & 1.55 & 1.8 & 2.0 \\ 1.45 & 1.6 & 1.9 & 2.5 & 3.0 \\ 0.2 & 0.4 & 0.8 & 1.2 & 1.8 \end{pmatrix}$$

The [A] matrix is further used to calculate the real proportion [Z] by applying eqn. (11); substituting the respective values of the pseudo components to obtain the matrix table shown in Table 1 and Table 2 for the control points.

ACTUAL						PSEUDO				
Z1	Z2	Z3	Z4	Z5	RESPONSE	X1	X2	X3	X4	X5
0.45	1	1.25	1.45	0.2	Y1	1	0	0	0	0
0.5	1	1.35	1.6	0.4	Y2	0	1	0	0	0
0.55	1	1.55	1.9	0.8	Y3	0	0	1	0	0
0.6	1	1.8	2.5	1.2	Y4	0	0	0	1	0
0.65	1	2	3	1.8	Y5	0	0	0	0	1
0.475	1	1.3	1.525	0.3	Y12	0.5	0.5	0	0	0
0.5	1	1.4	1.675	0.5	Y13	0.5	0	0.5	0	0
0.525	1	1.525	1.975	0.7	Y14	0.5	0	0	0.5	0
0.55	1	1.625	2.225	1	Y15	0.5	0	0	0	0.5
0.525	1	1.45	1.75	0.6	Y23	0	0.5	0.5	0	0
0.55	1	1.575	2.05	0.8	Y24	0	0.5	0	0.5	0
0.575	1	1.675	2.3	1.1	Y25	0	0.5	0	0	0.5
0.575	1	1.675	2.2	1	Y34	0	0	0.5	0.5	0
0.6	1	1.775	2.45	1.3	Y35	0	0	0.5	0	0.5
0.625	1	1.9	2.75	1.5	Y45	0	0	0	0.5	0.5

Table 1: Matrix Table for Scheffe's {5, 2} - Lattice Polynomial for Compressive Strength Test

ACTUAL					PSEUDO	PSEUDO				
Z1	Z2	Z3	Z4	Z5	RESPONSE	X1	X2	X3	X4	X5
0.525	1	1.4875	1.8625	0.65	C1	0.25	0.25	0.25	0.25	0
0.5375	1	1.5375	1.9875	0.8	C2	0.25	0.25	0.25	0	0.25
0.55	1	1.6	2.1375	0.9	C3	0.25	0.25	0	0.25	0.25
0.5625	1	1.65	2.2125	1	C4	0.25	0	0.25	0.25	0.25
0.575	1	1.675	2.25	1.05	C5	0	0.25	0.25	0.25	0.25
0.55	1	1.59	2.09	0.88	C12	0.2	0.2	0.2	0.2	0.2
0.51	1	1.425	1.735	0.54	C13	0.3	0.3	0.3	0.1	0
0.515	1	1.445	1.785	0.6	C14	0.3	0.3	0.3	0	0.1
0.53	1	1.52	1.965	0.72	C15	0.3	0.3	0	0.3	0.1
0.545	1	1.58	2.055	0.84	C23	0.3	0	0.3	0.3	0.1
0.56	1	1.61	2.1	0.9	C24	0	0.3	0.3	0.3	0.1
0.585	1	1.73	2.365	1.16	C25	0.1	0	0.3	0.3	0.3
0.57	1	1.67	2.275	1.04	C34	0.1	0.3	0	0.3	0.3
0.555	1	1.595	2.095	0.92	C35	0.1	0.3	0.3	0	0.3
0.54	1	1.535	1.945	0.74	C45	0.1	0.3	0.3	0.3	0

Table 2: Mixture Proportion of Control Points for Compressive Strength Test

Mixture Design Component Ratio Formulation

The mixture ingredients ratio formulation design is achieved using Scheffe's simplex-lattice design approach of {5, 2} simplex; possessing five components and at second order regression polynomial. From the design, fifteen experimental points which are required to satisfy the condition of m+1 point for intersecting q components in a simplex factor space are utilized. Fifteen extra points will also be designed which represents the control points which are used for the validation of the generated Scheffe's model. The mixture design is initiated by setting the mixture points at the vertices of the simplex; since we have five vertices representing the binary or pure blends. These points represent the first five points of the design fifteen Scheffe's coefficients with their corresponding pseudo components in binary vales. The remaining ten points represents the ternary points of the simplex factor space and are obtained by utilizing the mathematical relationship between the actual and pseudo component ratios expressed in equation 11 above. The mathematical equation is also used to calculate the actual ratio values for the control points whose corresponding pseudo component values were obtained based on the sum to one constraint; these mixture proportions are then taken to the laboratory to generate their respective responses in terms of compressive strength value [13].

Materials

The materials assessed for this research study are mixture of coarse and aggregate, cement, water, and palm nut fiber. The cement used is Dangote Limestone Portland cement (LPC) conforming to British Standard Institution BS 12 (1978). For the fine aggregate material used, the grain size ranges from 0.05 - 4.5 mm collected from a river bed in Mkpat Enin, Akwa Ibom State, Nigeria and was prepared to BS EN 12620 [21]. The type of water used for the mixture experiment is a borehole clean water which satisfies ASTM C1602-12 [22] requirement of water for use in concrete mixtures. For the Coarse aggregate the grain size ranges from 12.5 mm to 4.75 mm and conforms to BS EN 12620. Also, for the agricultural waste palm nut fiber, it was sourced from a palm oil mill at Oboro in Ikwuano L.G.A, Abia state.

Methods

The methods for this research is firstly materials sample collection and preparation characterization of the materials and gradation of the aggregates used, mixing of the ingredients with the ratios derived according to Scheffe's simplex method, curing of the concrete samples for 28 days and crushing tests to obtain its compressive strength responses. The model will be developed with these laboratory responses; finally test of adequacy of the developed Scheffe's regression model using analysis of variance (ANOVA) and student's t-test [23,24].

Compressive Strength Test: The test specimens used for the compressive strength experiments were concrete cubes. They were cast in steel mould measuring 150mm*150mm*150mm. The mould and its base were damped together during concrete casting to prevent leakage of mortar. Engine oil was spread with a soft brush across the inner surface of the moulds to ensure easy removal of the set concrete cubes. Batching of all the constituent material was done by weight using a weighing balance of 50kg capacity based on the adapted water cement ratios and mix ratios. A number of 30 mix proportions were used to produce 90 concrete cube which implies three replicates for each experimental point. Fifteen (15) out of the 30 mix ratios will be for the control points which will be used to produce 45 cubes for the conformation of the adequacy of the developed mathematical model for the optimization of compressive strength of palm nut fiber reinforced concrete. Curing commenced 24hours after moulding. The specimens were removed from the moulds and were placed in clean water for curing. After 28days of curing the specimens were taken out of the curing tank and compressive strength determined. Three concrete cubes will be cast for each mixture and cured at 28 days in which the average compressive strength will be determined after crushing in accordance with BS EN 12390 [1,25].

The compressive strength was then calculated using the formula below:

$$\text{Compressive strength} = \frac{\text{average failure load}(\text{N})}{\text{cross-sectional area}(\text{mm}^2)} = \frac{P}{A} \qquad (12)$$

Results and Discussion

Characterization of Test Materials

The physical and chemical properties test results of the mixture ingredients namely were presented so as to observe the general engineering behavior of the test materials which is very influential to the response parameters. The physicochemical properties of the mixture ingredients were presented.

Chemical Properties of Palm-nut: The physical and chemical properties of the fiber used for the experiment is presented in Table 3 below; the results obtained indicated that the agricultural waste called palm-nut possesses high carbon content and oxygen at 54.88% and 38.22% respectively while possessing low content of Sulfur and Nitrogen at 0.28% and 0.32% respectively. The hemicellulose content is quite low when compared with other natural fibers. The palm-nut fiber possessed about 55% cellulose, 14% Hemi-cellulose, 25% lignin and 0.8% wax. Cellulose content is responsible for long fiber chain that, hemi-cellulose leads to disintegration of cellulose micro-fibrils which decreases the fiber strength as reported by Pradeep [26].

Elements	N	H	C	Mg	Ca	O	Na	Si	Cl	S
Atomic percentage (%)	0.32	1.85	54.88	0.35	1.78	38.22	0.69	0.78	0.85	0.28

Parameters	Moisture content (%)	Ash (%)	higher heating value (MJ/Kg)	Specific gravity	fiber size (mm)	Water absorption (%)
Values	37.5	6.23	19.44	1.24	12 - 20	21.8

Table 3: Chemical Properties of Palm-nut Fiber

Physical Properties of Aggregates: The aggregates physical properties with respect to water absorption, specific gravity, fineness modulus and particle size distribution analysis results were used to evaluate the physical properties of the aggregates. The results are presented in Table 4 below; from the results, the coarse aggregate produced a fineness modulus and specific gravity result of 6.88 and 2.68 respectively while the fine aggregates produced 2.79 and 2.62 respectively.

Physical and Mechanical Properties	Coarse Aggregate	Fine Aggregates
Specific gravity	2.68	2.62
Water absorption (%)	0.22	-
Fineness Modulus	6.88	2.79

Table 4: Physical properties of Aggregate Materials

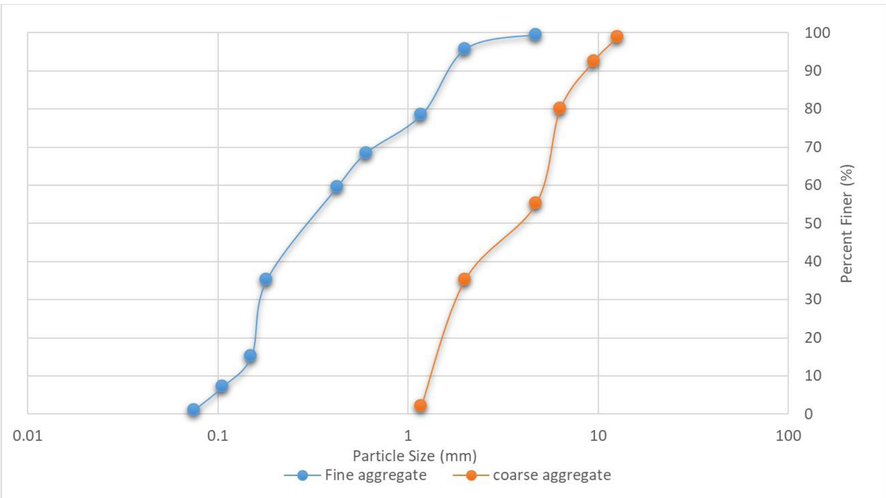

Figure 1: Grain Size Distribution of Aggregate Materials

The Particle Size Distribution of Aggregates in the Concrete Mix: The grain size distribution test results for the coarse and fine aggregates which is plotted on a semi-log graph through a cumulative frequency curve so as to obtain its gradation parameters. The result is presented in Figure 1 below; From the sieve analysis results, for the coarse aggregates, 98.86% and 2.07% finer was obtained for 12.7 mm and 1.18 mm sieve sizes respectively; while for the fine aggregates, 99.47% and 1.02% finer was obtained for 4.75 mm and 0.075 mm sieve sizes respectively. From the gradation results for the test fine aggregate. It implies that the material (sand) falls within zone 2 grading limits for fine aggregates BS 882 [27], which is within acceptable specifications suitable for construction purposes and also satisfying the specification of upper and lower limits of percentage by mass passing as specified by BS 882 [27].

Using British standard soil classification system detailed in BS 5930. For the coarse aggregates, it comprises of 19.87% of medium gravel, 44.92% of fine gravel and 33.14% of coarse sand while for the fine aggregates, it comprises of 4.28% of fine gravel, 27.31% of coarse sand, 8.77% of medium sand and 58.62% of fine sand. This result shows that the fine aggregates falls within zone 2 according to the grading limits BS 882 [28].

Compressive Strength (Response, Yi)

The laboratory response values in terms of compressive strength of the concrete cube samples cured for 28 days was obtained for the fifteen different mixture design points with a total of three replicates for each design point. The values are utilized for the development of the Scheffe's model for the optimization of the compressive strength property of palm-nut fiber concrete. The results are presented in Figure 2 below; from the results, we observe that points corresponding to Y_1 and Y_{23} generated the maximum value at 30.29 MPa and 31.53 N/mm^2 respectively while Y_4 and Y_{45} generated the minimum values at 17.25 N/mm^2 and 18.30 N/mm^2 respectively [29].

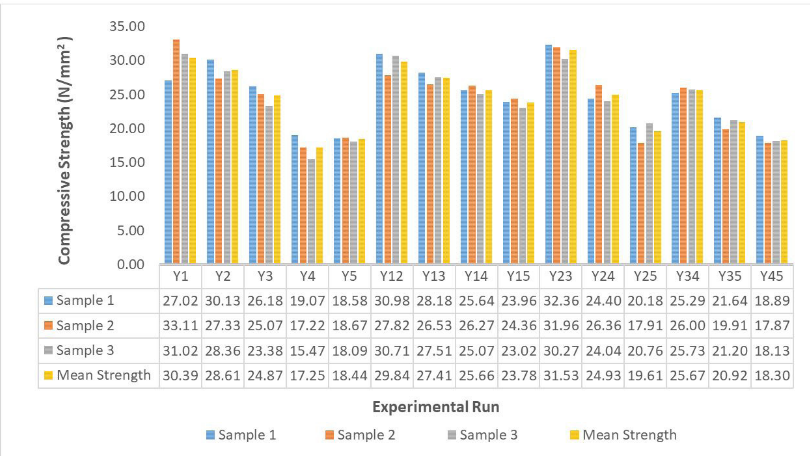

Figure 2: The Compressive Strength (Laboratory Response, Yi)

The laboratory responses for the control points which were also cured for 28 days for the fifteen design points are presented in fig. 3 below; from the results, points corresponding to C_{14} and C_4 produced the maximum compressive strength value at 27.7 N/mm^2 and 27.5 N/mm^2 while point corresponding to C_{24} and C_{45} produced the minimum compressive strength values of 18.9 MPa and 19.7 N/mm^2 respectively.

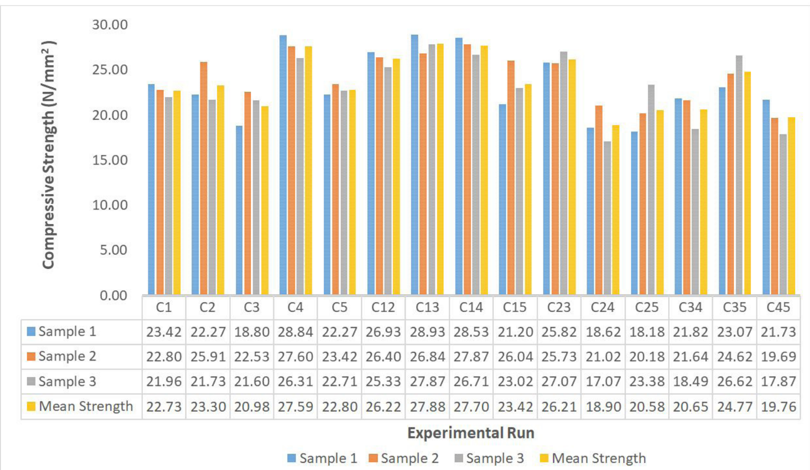

Figure 3: The Compressive Strength (Laboratory Response, Yi) for the Control points

Regression Equation for Compressive Strength

The model equation is generated firstly by substituting the response values in eqn. 9 which shows the relationship between the obtained response and the model coefficients to obtain the Scheffe's coefficients. After which these coefficients values are substituted into Eqn. (7) to give us the model equation shown in eqn. 15 below;

$$\hat{Y} = 30.39X_1 + 28.61X_2 + 24.87X_3 + 17.25X_4 + 18.44X_5 + 1.36X_1X_2 - 0.89X_1X_3 + 7.37X_1X_4 - 2.55X_1X_5 + 19.14X_2X_3 + 8.02X_2X_4 - 15.64X_2X_5 + 18.45X_3X_4 - 2.96X_3X_5 + 1.80X_4X_5 \quad (15)$$

Test Results and Replication Variance

Mean responses, Y and the variances of replicates Si^2 were obtained from Eqns. (16 - 19) below

$$Y = \frac{\sum_{i=1}^{N} Y_i}{n} \quad (16)$$

$$Si^2 = [\frac{1}{n-1}][\sum Y_i^2 - [\frac{1}{n(\sum y_i)^2}]]$$

Where 1≤ i ≤ n. The eqn. is expanded as follows;

$$Si^2 = [\frac{1}{n-1}][\sum_{i=1}^{2}[Y_I - Y]^2]$$

(18)

Where Yi represents the laboratory responses; Y represents the average laboratory responses for each experimental point; n is the counts or observations at every point; (n - 1) is the degrees of freedom; Si2 represents the variance at each design point.

For all the design points, number of degrees of freedom,

$$V_e = (\sum n) - 2 = 30 - 2 = 28$$

Replication Variance for Compressive Strength

Figure 4 presents the laboratory results and computation of the replication variance at each design point.

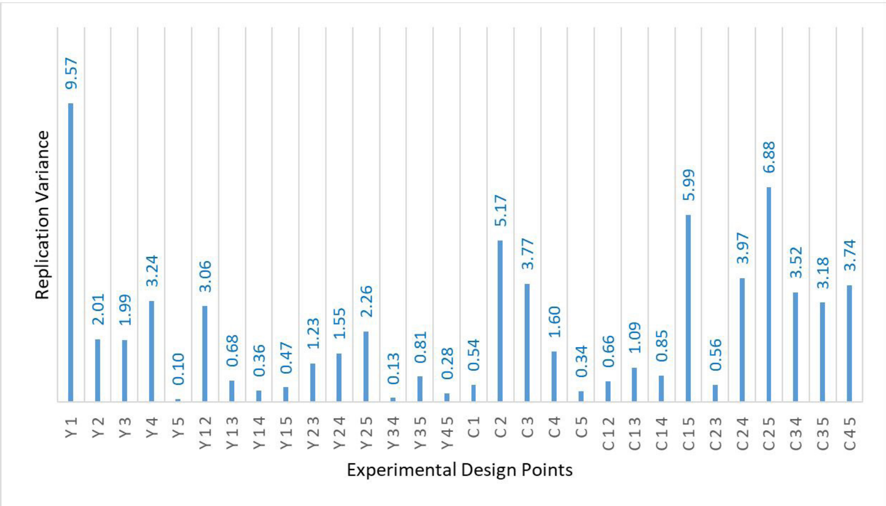

Figure 4: The Replication Variance of the Experimental Test Result

$$sy^2 = \left(\frac{1}{V_e}\right)\sum_{i=1}^{N} Si^2 \quad (19)$$

$Sy^2 = 69.61/28 = 2.485901$
Where Si^2 is the variance at each point
$Sy = 1.576674$

Scheffe's Model Test for Adequacy and Validation

The control points of the experiment will be used to test suitability or validity of the model. This adequacy test of the model is carried out using statistical tool for determining differences among means using hypothesis. Analysis of variance ANOVA and the student's t-test method was the statistical tool used. The values generated from the model for the control points which were gotten by substituting the corresponding pseudo-components values X_1, X_2, X_3, X_4 and X_5 Scheffe's model equation expressed in Eqn. (15). Statistical analysis was carried out to test the statistical significance between the experimental and model results shown in Figure 5 below. The test for adequacy of the model was done using ANOVA and student's t-test at 95% confidence level on the data sets.

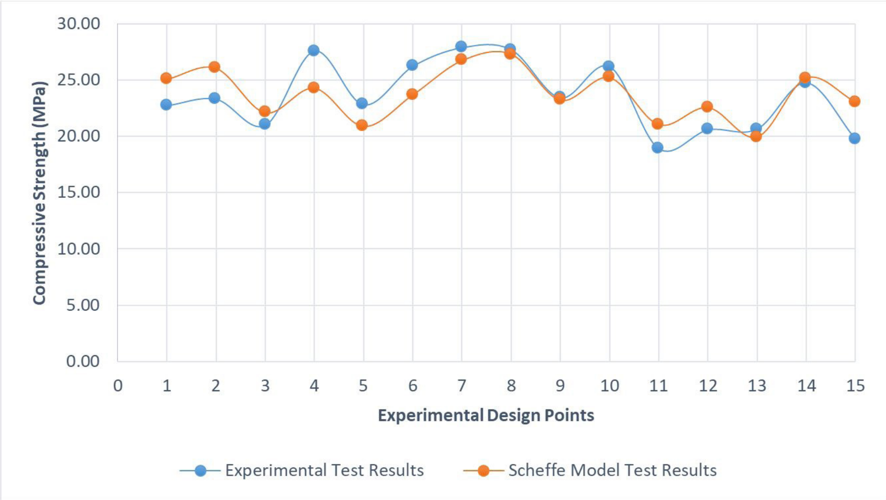

Figure 5: The Experimental and Model Results for the Control Points

Null Hypothesis

There is no significant difference between the experimental results and the values predicted by the generated Scheffe's model.

Alternative Hypothesis

There is a significant difference between the experimental results and the values predicted by the generated Scheffe's model.

The control experimental values and the obtained control model results are plotted in the graph presented in Figure 5; these two data sets are compared statistically the test statistical significance between them using student's t-test and analysis of variance (ANOVA).

Student's t-Test Compressive Strength Property: A two-tail student's test is used to test the two means and from the results, if calculated t Stat is greater t Critical two-tail, we accept the alternate hypothesis. From the result, t stat value is -0.36331 calculated using the formula below;

$$t_{stat} = \frac{\Sigma(lab - model)}{\sqrt{\frac{(15 * \Sigma(lab - model)^2) - (\Sigma(\text{lab} - \text{model}))\hat{}2}{(15-1)}}}$$

$$\frac{(-2.84)}{\sqrt{\frac{(15 * 57.69) - (-2.84^2)}{(15-1)}}} = \mathbf{-0.36331}$$

Critical value = 0.05 and 0.025 for two tail (t-distribution Table).

$t_{critical}$ value obtained from t-distribution Table 2.145; from the obtained results, we observe that t_{stat} is less than $t_{critical}$ value. Therefore, we reject the alternate hypothesis that there is no significant difference between the lab and model results. This indicates that the response predicted by Scheffe's model is in good relationship with the corresponding experimental or actual result.

Analysis of Variance for Compressive Strength Property: For the ANOVA test presented in Table 5, if F-value > F crit, we accept the alternate hypothesis. F-value and F crit of 0.038285 and 4.195972 respectively was calculated which indicates that F crit is greater than F-value. Therefore, we accept null hypothesis which implies a good relationship among the experimental and model predicted values. The computed statistical results are in agreement with the results presented by Alaneme *et al.* [13]; hence, the Scheffe's model generated is adequate for use in compressive strength estimation. The statistical results imply that there is no significance difference between the Scheffe's model predicted results and the experimental control results.

Summary						
Groups	Count	Sum	Average	Variance		
Lab	15	353.4963	23.56642	9.220254		
Model	15	356.3394	23.75596	4.855368		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.269443	1	0.269443	0.038285	0.846285	4.195972
Within Groups	197.0587	28	7.037811			
Total	197.3281	29				

Table 5: ANOVA

Discussion of Results

Scheffe's simplex lattice model was utilized to evaluate the mechanical property of the fiber reinforced concrete with respect to its compressive strength. The optimum compressive strength of 31.53Nmm^2 corresponding to mix ratio of 0.525:1.0:1.45:1.75:0.6 for water, Limestone Portland cement (LPC), fine aggregate, coarse aggregate and palm-nut fiber respectively was obtained within the design factor space. The lowest compressive strength obtained was 17.25Nmm^2 corresponding to mix ratio of 0.6:1.0:1.8:2.5:1.2. The addition of fiber as a fifth component significantly enhanced the compressive strength of the concrete sample by improving its toughness property. The maximum value of compressive strength was achieved through addition of 5.5% by weight of palm-nut fiber with water-cement ratio of 0.53. The minimum compressive strength was achieved at 11.12% by weight addition of palm-nut fiber with water-cement ratio of 0.6. The bond of the natural fibers in composites is very satisfactory. By using the developed mathematical model, the compressive strength of all the design points in the factor space can be derived. This is an application of Scheffe's theory to design a five-component concrete using second order polynomial. The results achieved in this investigation indicates that both the maximum and minimum compressive strength of 31.53 N/mm^2 and 17.25Nmm^2 respectively were within the standard compressive strength property of Portland Limestone cement concrete as recommended in [30].

Conclusion

This research study investigates the utilization of solid waste from palm processing in concrete production to reduce the quantity of more expensive conventional concrete ingredients thereby enhancing green technology for construction works. Scheffe's second order regression polynomial model was developed for optimization of the palm-nut fiber concrete's compressive strength. The maximum compressive strength obtained for the designed factor space is 31.53Nmm^2 with a mix proportion corresponding to mix ratio 0.525:1.0:1.45:1.75:0.6 for water, cement, fine and coarse aggregate and palm nut fiber respectively. The lowest compressive strength was found to be 17.25Nmm^2 corresponding to mix ratio of 0.6:1.0:1.8:2.5:1.2; this result was observed to fall within specified requirements for structural concrete as reported by Neville [29]. The test of adequacy of the generated model was done using analysis of variance (ANOVA) and student's t-test at 95% confidence level. The p-value of 0.84 from the ANOVA statistical results obtained indicate that there is a good relationship between the control laboratory values and computed model results.

NOTATIONS

q =number of components
k = degree of dimensional space
X_i = proportion of ith components of mixtures
m = order of the Scheffe's polynomial
X_1 = proportion of water cement ratio
X_2 = proportion of ordinary Portland cement
X_3 = proportion of fine aggregate
X_4 = proportion of coarse aggregate
X_5 = proportion of palm nut fiber
n = order of polynomial regression
Z = actual components
X = pseudo components
$Y_1, Y_2, Y_3, Y_4, Y_5, Y_{12}, Y_{13}, Y_{14}, Y_{15}, Y_{23}, Y_{24}, Y_{25}, Y_{34}, Y_{35}, Y_{45}$ = responses from treatment mixture proportions
$C_1, C_2, C_3, C_4, C_5, C_{12}, C_{13}, C_{14}, C_{15}, C_{23}, C_{24}, C_{25}, C_{34}, C_{35}, C_{45}$ = responses from control mixture proportions
$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_{12}, \beta_{13}, \beta_{14}, \beta_{15}, \beta_{23}, \beta_{24}, \beta_{25}, \beta_{34}, \beta_{35}, \beta_{45}$, = model coefficients
Y = optimized compressive strength of palm nut fiber concrete

Conflicts of Interest

There are no recorded conflicts of interests in this research work. We also affirm that the content of this work is original and has followed the journal template. Compliance with Ethical Standards was strictly observed.

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