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Strength Optimization Models for A Multi-Variant Binder Concrete using Osadebe's Optimized Mixes

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***Abstract*—** Cement production has now inevitably become associated with increased health risks and unpalatable economic implications. As a result, it has become imperative that concrete be produced from locally sourced, naturally occurring and eco-friendly materials that can either partially or fully replace cement in concrete, and yet maintain its structural viability and constructional adequacy. This paper therefore focused on assessing the structural and strength properties of a three-binder concrete with Rice Husk Ash (RHA) and Mound Soil (MS) as partial replacements of Ordinary Portland Cement (OPC). Compressive strength tests were conducted on the concrete cubes after 28 days of curing. The laboratory work was done with the guidance of the provisions of the Osadebe's model for the actual components of the MS-RHA concrete. There were ten (10) test points and ten (10) control points taken for this research. The highest compressive strength predicted in this work was 35.0N/mm^2 corresponding to a Water/Cement ratio of 0.55 with mix ratio of 0.55:1:1:2 for a 10% replacement of OPC with 5% each of RHA and MS. The least value predicted by the model was 15.20N/mm^2 with W/C ratio of 0.47 in mix ratio 0.47:1:5:8. The adequacy of the model was tested using the student's t-test and passed for adequacy, with $t_{calculated}$ = 0.303, less than t_{table} = 2.262, thereby annulling the alternate hypothesis and sustaining the null hypotheses respectively proposing significant and insignificant differences between the experimental and predicted values.

I. INTRODUCTION

Concrete is practically the basic and most common construction material at present, and it is estimated that globally, the consumption of cement, which is its basic component, has reached 10 billion metric tons annually. [1,2]. Concrete is produced from a blend of various components such as cement, fine and coarse aggregates and water [3], and is classified as a composite inter material comprising binder, filler or aggregates and then water [4]. Sometimes admixtures are added to concrete to accentuate certain desired properties of the concrete, but alternatively optimum concrete (strength) properties can be achieved by optimization. In this situation, optimization can be done using mathematical modelling, which is the process of mathematically representing a phenomenon for the purpose of gaining better understanding [5]. Optimization can be said to refer to any activity or process aiming at achieving maximum results with minimal inputs or investments [6].

This study seeks to optimize the strength properties of concrete having Ordinary limestone cement, mound soil and rice husk ash as binders. Rice Husk Ash (RHA) is an agricultural waste obtained from rice husks which are the outer coatings of rice paddy burned in open air in rice mills. It is estimated that global rice production has reached 700 million tons with countries like China and India being notable farmers of the grain. According to [7], the chemical composition of rice husk is 50% of cellulose, 25 – 30% of lignin, 15 – 20% of silica, 30 – 50% organic carbon, and 10 – 15% of water (or moisture) and that by percentage of weight, the rice husk contributes 20% to the total weight of rice with a low bulk density of 90 – 150kg/m^3. The disposal of RHA is a problem to waste managers but if RHA, which is a proven pozzolan, and a more natural, local and affordable material is used in concrete to partially replace the more expensive cement, then the problem of its disposal will be significantly solved [8].

The influence of various RHA sources on the properties of road subgrade materials has been investigated by [9]. It has been reported that RHA obtained from various states of Nigeria can be used for sub-grade stabilization because of their pozzolanic properties.

Replacing OPC with up to 30% RHA reduces chloride penetration, decreases permeability, and improves strength and corrosion resistance properties at an optimal replacement proportion of 25% [10]. According to [11], compressive strength is converted to their corresponding tensile strength by multiplying them with a conversion factor 0.8, and available literature provide that the tensile strength of concrete is about 10 – 12% of the compressive strength, or computed from empirical formulas.

Mound-building termites are largely considered to be a threat, especially to the agroindustry. They are known to be destructive to crops, trees, and general manmade structures. However, research has further revealed that not all species of termites pose negative impacts on humans' socio-economic activities [12]. A termite mound is a mixture of clay components and organic carbon cemented by secretions, excreta, or saliva deposited by the termites. The mounds could be conical, lenticular cathedral or mushroom-like, depending on the species, temperature, clay availability, level of termite presence in an area and general site conditions [13]. Mound soils result from termite activities over time and serve as shelter for the termites and are predominantly clay. This clay is exceptionally improved by the secretions from the termites in building the mound [14]. These secretions improve on the plasticity of the mound soil, making it a better moulding material than the surrounding soil. Mound clay has been reported to perform better at dam construction than ordinary clay without the termite secretions [15]. Following the need for affordable materials for construction of functional, adequate and low-cost housing for the teeming populace, the search is now for local materials to serve as alternatives for the more expensive conventional building materials [16]. Hence, with a view to decreasing the cost of building construction, effective steps are now being taken to partially replace cement with industrial waste [17], agricultural waste [18] and plastic waste materials [19].

The assessment of the performance of Termite-Mound Powder (TMP) as partial replacement for cement in the production of lateritic blocks was studied by [20]. The concern of the researchers was clearly on the over-dependence on cement, increase in construction costs, health concerns with the toxic emissions of cement production and usage. The results of the research showed that the compressive strength of the bricks increased with curing, reaching an optimum value at 10%, but decreased with increase in percentage TMP.

The spatial variation of the chemical properties of Rice Husk Ash has been investigated using X-ray fluorescence (XRF) technology [21]. The results of the study showed that Rice Husk Ash (RHA) varies in pozzolanic properties depending on the location they are found, and that RHA can be used as a partial replacement to OPC due to its chemical composition.

It has been reported that termite mound soil is silty-sand, with sand and silt constituting over 80% of particle size and <30% gravel fraction, and has specific gravity ranging from 2.59 to 2.68 and maximum dry density ranging from 1.63 – 1.84g/cm^3 which are higher than those of the surrounding soil [22].

II. MATERIALS AND METHODS

The mound soil (MS) was obtained as a disturbed sample from a termite mound in an open field in Calabar, Nigeria.

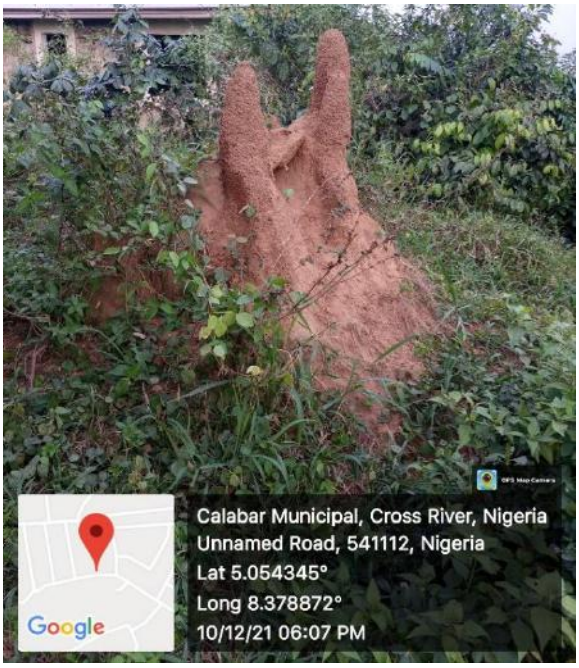

Fig.1: Termite mound

A digger was used to claw open the hard termite mound and the mound clods were collected in an airtight nylon bag for the avoidance of moisture loss. In all, 15kg of the sample was collected and taken to the laboratory. 93g of the collected sample was used to determine the natural moisture content and the rest of it was crushed and spread out on a pan in a damp-free area to air-dry under room temperature. To obtain the finest particle sizes, the crushed, air-dried mound soil was passed through the smallest aperture-sized sieve and the residue collected in the pan was kept ready for the concrete still under dry condition. The RHA sample was also collected as a disturbed sample from a heap in the Obubra rice mill in Cross River State of Nigeria.

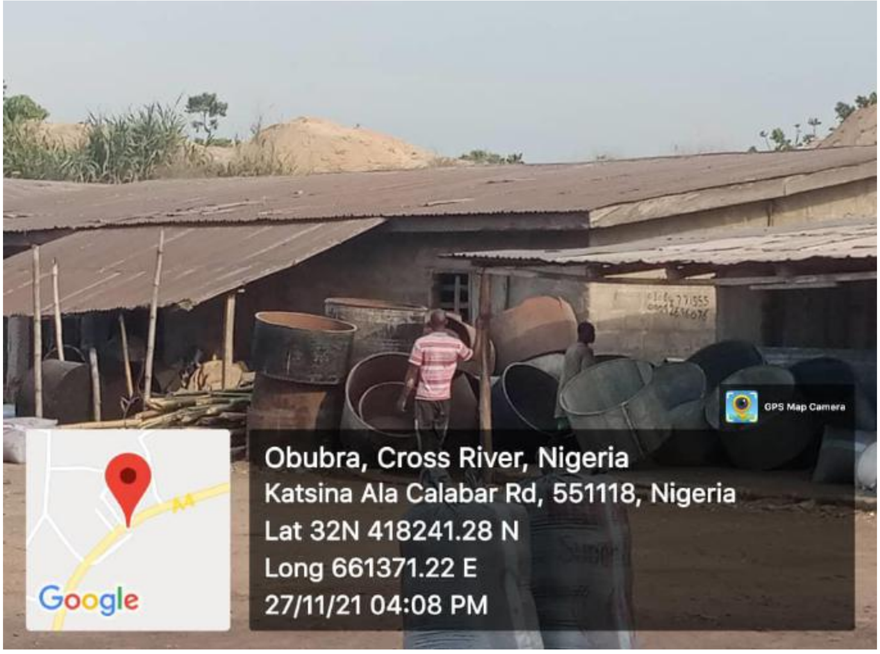

Fig. 2: Location of Rice Mill in Obubra, Cross River State, Nigeria

It was transported under airtight condition to the laboratory where 29g of it was oven-dried to determine its natural moisture content. The rest of it, 10.5kg, was sieved to remove all unwanted materials contained in the sample before being used for the research work.

OPC was obtained from the Lafarge cement producing company in Akamkpa Local Government Area of Cross River State, Nigeria, and the fine and coarse aggregates were respectively obtained from the dredged Calabar river and Saturn Quarry, all in Cross River State, Nigeria. 15-22mm average coarse aggregate size was adopted for this research work, and fine aggregate classified as fine sand with particle size range of 125-250μm.

The procedure for producing this three-binder concrete followed the usual concrete production procedure except for the use of three distinct materials as binder in the same concrete mix. To achieve this three-binder concrete, OPC was replaced with both RHA and MS, simultaneously, in predetermined percentages. Adopting the provision of 1:2:4 concrete mix ratio for this study, the binder constituent of the concrete matrix was split to accommodate OPC, RHA and MS such that 10, 20, 30, 40, and 50% of OPC was replaced by equal amounts each of RHA and MS. These percentages were measured out volumetrically using a calibrated container. The conventional concrete with 100%OPC was also produced to serve as the standard basis for comparison, giving a sum total of six (6) different batches of concrete.

The tests carried out were to determine the workability of the concrete, determine water absorption percentages, and determine compressive, flexural and tensile strengths. Workability was assessed by conducting slump tests on fresh mixes of the conventional and test concrete in accordance with BS EN 12350-2:2009. For determination of percentage water absorption, the fresh concrete was cast into 150m^3 moulds, demoulded and weighed after setting, and then cured in a water tank. Each batch of concrete had 15 cubes cast, 3 cubes for 5 curing ages, in order to have an average value. The curing ages were 3, 7, 14, 21 and 28 days. Water absorption tests assess the capillary action of concrete and is basically the difference in dry and wet weights of the concrete cubes before and immediately after curing. It therefore serves as a durability check on concrete to predict the rate of possible ingress of corrosive fluids into concrete.

The compressive strength of a material is basically its ability to carry the loads on its surface without any crack or deflection. This procedure was carried out on the hardened concrete cubes of 150mm x 150mm x 150mm dimensions in accordance with the provisions of BS EN 12390-3:2019. The procedure was conducted such that the moulds were first cleaned and oiled internally and then the freshly mixed concrete was placed in the moulds in approximately 5cm thick layers. Each layer of concrete was compacted with 35 strokes using a tamping rod of 16mm diameter, 60cm in length and bullet-pointed at lower end and top surface of concrete was always smoothened with a trowel before being left to harden. The cast concrete cubes were left to harden for 24 hours after which they were cured and tested for 3, 7, 14, 21 and 28 days using a Universal Test Machine (UTM), from which loading was generated across the entire surface area of two opposite faces of the test sample. The loading was in such a manner as to flatten the sample, tending to shorten the sample in the direction of the applied load, while expanding it in the direction perpendicular to the load. Loading was applied on each sample gradually at the rate of 140 kg/cm^2 per minute until it failed. Compressive strength for each cube sample was then computed as the load at failure divided by the area of the cube sample, expressed mathematically as:

$$\sigma = \frac{F}{A} \quad (1)$$

where F is the applied load in (N) and A the cross-sectional area in (mm^2).

According to I.S. 456-2000,

Flexural strength $f_s = 0.7\sqrt{f_{ck}}$

(2) *where f_{ck} is the compressive strength cylinder of concrete in MPa (N/mm^2).*

Likewise, tensile strength can be computed as follows;

$$F_{ct} = \frac{2P}{\pi L d} \quad (3)$$

Where F_{ct} = Tensile strength of concrete

P = Maximum load in N/Sqm

L = Length of the specimen (300mm)

D = Diameter of the specimen (150mm)

2.1 OSADEBE'S OPTIMIZATION THEORY

The mixes of the elemental components of the MS-RHA concrete were guided by a mathematical component developed by Osadebe (Osabebe 2016). Osadebe developed an optimized mixes model, which is an application of Talyor's series. The model showed that concrete is multivariant unit mass whose strength is dependent on the variation in the volume of the constituent material. His regression equation is another form of experimental model. He expressed the response Y as a function of the proportions of the components of the mixture Z, where the sum of all the proportions must add up to 1. That is,

$$Z_1 + Z_2 + \ldots + Z_q = \sum_i^q Zi = 1 \quad (4)$$

where q is the number of mixture components and Z_i the proportion of the components in the mixture.

Osadebe assumed that the response Y is continuous and differentiable with respect to its predictors and can be expanded in the neighbourhood of a chosen point Z_0 using Taylor's Series.

$$Z(0) = \left(Z_1^{(0)}, Z_2^{(0)}, \ldots, Z_q^{(0)}\right)^r \quad (5)$$

$$Y(Z) = \sum_{m=0}^{q} F^m\,(Z)^{(0)}\left(Z_i - Z^{(0)}\right) \quad (6)$$

Expanding to second order:

$$Y(Z) = F\left(Z^{(0)}\right) + \sum_{i=1}^{q} \frac{\partial f\left(Z^{(0)}\right)}{\partial Z_i}\left(Z_i - Z^{(0)}\right) + \frac{1}{2!}\sum_{i=1}^{q-1}\sum_{i=1}^{q} \frac{\partial^2 f\left(Z^0\right)}{\partial Z_i \partial Z_i}\left(Z_i - Z_i^{(0)}\right)\left(Z_i - Z_i^{(0)}\right) + \sum_{i=1}^{q} \frac{\partial^2 f\left(Z^{(0)}\right)}{\partial Z_i}\left(Z_i - (0)\right) \quad (7)$$

For convenience, the point Z^0 can be taken as the origin without loss in generality of the formulation and thus:

$$Z_1^{(0)} = Z_1^{(0)} + Z_2^{(0)} + Z_3^{(0)} + \cdots Z_q^{(0)} = 0 \quad (8)$$

Let:

$$b_0 = F(0), b_i = \frac{\partial F(0)}{\partial Z_i}, b_{ij} = \frac{\partial^2 F(0)}{2i\partial Z_i \partial j}, b_{ii} = \frac{\partial^2 F(0)}{2i\partial Z_i^2} \quad (9)$$

Substituting equation (6) into equation (3) gives:

$$Y(Z) = b_0 + \sum_{i-1}^{q} b_i Z_i + \sum_{i\le j\le q}^{q} b_{ij} Z_i Z_j + \sum_{i-1}^{q} b_{ii} Z_i^2 \quad (7)$$

Multiplying equation (3) by b_0 gives the expression:

$$b_0 = b_0 Z_1 + b_0 Z_2 + \cdots + b_0 Z_q \quad (8)$$

Multiplying equation (3) successively by Z_1, $Z_2 \ldots Z_q$ and rearranging, gives respectively:

$$Z_1^2 = Z_1 - Z_1 Z_2 - \cdots + Z_1 Z_q$$

$$Z_2^2 = Z_2 - Z_1 Z_2 - \cdots - Z_2 Z_q$$

$$Z_q^2 = Z_1 - Z_1 Z_q - \cdots + Z_{(q-1)} \quad (9)$$

Substituting Equations (5) and (6) into Equation (7) and simplifying yields:

$$Y(Z) = \sum_{i-1}^{q} \beta_i Z_i + \sum_{i\le j\le q}^{q} \beta_{ij} Z_i Z_j \quad (10)$$

Where:

$$\beta_i = b_0 + b_i \dots \dots + b_{ii} \quad (11)$$

$$\beta_{ij} = b_{ij} - b_{ii} - b_{ij} \quad (12)$$

Equation (8) is Osadebe's regression model equation. It is defined if the unknown constant coefficients, β_i and β_{ij} are uniquely determined. If the number of constituents, q, is 4, and the degree of the polynomial, m, is 2, the number of coefficients, N is now the same as that for the Scheffe's (4,2) model given by:

$$N = C_m^{(q+m-1)} = C_m^{(4+2-1)} = 10 \quad (13)$$

$$N = \frac{(q+m-1)!}{M!\,(\llbracket q+m-1 \rrbracket - M)!} = \frac{(q+m-1)!}{m!\,(q-1)!} = \frac{(4+2-1)!}{2!\,(4-1)!} = \frac{5!}{2!\,3!} = 10$$

2.1.1 Coefficients of Osadebe's Regression Equation

The least number of experimental runs or independent responses necessary to determine the coefficients of the Osadebe's regression coefficients is N. Let $y^{(k)}$ be the response at point *k* and the vector corresponding to the set of component proportions (predictors) at point *k* be $y^{(k)}$.

That is:

$$Z^{(k)} = \left(Z_1^{(k)}, Z_2^{(k)}, \dots Z_q^{(k)}\right) \quad (14)$$

Substituting gives:

$$Y^{(k)} = \sum_{i-1}^{q} \beta_i Z_i^{(k)} + \sum_{i \le j \le q}^{q} \beta_{ij} Z_i^{(k)} Z_j^{(k)} \quad (15)$$

Where k = 1, 2, … N

Substituting the predictor vectors at each of the *N* observation points successively into Equation (15) gives a set of *N* linear algebraic equations which can be written in matrix form as:

$$Z\,\beta = Y \quad (16)$$

Where:

β is a vector whose elements are the estimates of the regression coefficients:

$$\begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta 10 \end{bmatrix} = \begin{bmatrix} Z_1^{(1)}, Z_1^{(2)}, \dots, & Z_1^{(10)} \\ Z_2^{(1)}, & Z_2^{(2)}, \dots, Z_2^{(10)}, \\ Z_3^{(1)} Z_4^{(1)}, & Z_3^{(2)}, Z_4^{(3)} \cdots, Z_3^{(10)} Z_4^{(10)} \end{bmatrix} \begin{bmatrix} y(1) \\ y(2) \\ \vdots \\ y(10) \end{bmatrix}$$

2.1.2 Osadebe's Method

$$Z_1 + Z_2 + \dots + Z_q = \sum_{i=1}^{q} Zi = 1 \quad (17)$$

Where q is the number of mixture components and Z_i the proportion of the components in the mixture.

Z_1 = Water/Cement Ratio

Z_2 = Binder (OPC and RHA)

Z_3 = Fine aggregates (Sand)

Z_4 = Coarse Aggregates (Granite)

Osadebe assumed that the response Y is continuous and differentiable with respect to its predictors and can be expanded in the neighbourhood of a chosen point Z_0 using Taylor's series. $Z(0) = \left(Z_1^{(0)}, Z_2^{(0)}, \dots, Z_q^{(0)}\right)^r$

(18)

$$Y(z) = \sum_{m=0}^{q} F^m (Z)^{(0)} \left(Z_i - Z^{(0)}\right) \quad (19)$$

Expanding to second order:

$$Y(Z) = F\left(Z^{(0)}\right) + \sum_{i=1}^{q} \frac{\partial f(z^{(0)})}{\partial z_i}\left(Z_i - Z^{(0)}\right) + \frac{1}{2!}\sum_{i=1}^{q-1}\sum_{i=1}^{q} \frac{\partial^2 f(z^0)}{\partial z_i \partial z_i}\left(Z_i - Z_i^{(0)}\right)\left(Z_i - Z_i^{(0)}\right) + \sum_{i-1}^{q} \frac{\partial^2 f(z^{(0)})}{\partial z_i}\left(Z_i - (0)\right) \quad (20)$$

For convenience, the point Z^0 can be taken as the origin without loss in generality of the formulation and thus:

$$Z_1^{(0)} = Z_1^{(0)} + Z_2^{(0)} + Z_3^{(0)} + \cdots Z_q^{(0)} = 0 \quad (21)$$

Let:

$$b_0 = F(0), b_i = \frac{\partial F(0)}{\partial z_i}, b_{ij} = \frac{\partial F(0)}{2i\partial Z_i \partial j}, b_{ii} = \frac{\partial^2 F(0)}{2i\partial Z_i^2} \quad (22)$$

Substituting equation (13) into Equation (22) into Equation (17) gives:

$$Y(Z) = b_0 + \sum_{i-1}^{q} b_i Z_i + \sum_{i \le j \le q}^{q} b_{ij} Z_i Z_j + \sum_{i-1}^{q} b_{ii} Z_i^2 \quad (23)$$

Multiplying Equation (3.19) by b_0 gives the expression:

$$b_0 = b_0 Z_1 + b_0 Z_2 + \cdots \dots + b_0 Z_q \quad (24)$$

Multiplying Equation (17) by Z_1, Z_2 …Z_q and rearranging gives respectively:

$$Z_1^2 = Z_1 - Z_1 Z_2 - \cdots \dots \dots + Z_1 Z_q$$

$$Z_2^2 = Z_2 - Z_1 Z_2 - \cdots \dots \dots - Z_2 Z_q$$

$$Z_q^2 = Z_1 - Z_1 Z_q - \cdots \dots \dots - Z_{(q-1)} \quad (25)$$

Substituting Equations (21) and (17) into Equation (24) and simplifying yields

$$Y(Z) = \sum_{i-1}^{q} \beta_i Z_i + \sum_{i \le j \le q}^{q} \beta_{ij} Z_i Z_j \quad (26)$$

Where

$$\beta_i = b_0 + b_i \dots \dots + b_{ii} \quad (27)$$

$$\beta_{ij} = b_{ij} - b_{ii} - b_{ij} \quad (28)$$

Osadebe's regression model equation is defined if the unknown constant coefficients, β_i and β_{ij} are uniquely determined. If the number of constituents, q, is 6, and the degree of the polynomial, m, is 2 then the regression equation is given as:

$$Y = \beta_1 Z_1 + \beta_2 Z_2 + \beta_3 Z_3 + \beta_4 Z_4 + \beta_5 Z_5 + \beta_6 Z_6 + \beta_{12} Z_1 Z_2 + \beta_{13} Z_1 Z_3 + \beta_{14} Z_1 Z_4 + \beta_{15} Z_1 Z_5 + \beta_{16} Z_1 Z_6 + \beta_{23} Z_2 Z_3 + \beta_{24} Z_2 Z_4 + \beta_{25} Z_2 Z_5 + \beta_{26} Z_2 Z_6 + \beta_{34} Z_3 Z_4 + \beta_{35} Z_3 Z_5 + \beta_{36} Z_3 Z_6 + \beta_{45} Z_4 Z_5 + \beta_{46} Z_4 Z_6 \quad (29)$$

Therefore, Equation (29) is the mathematical model based on Osadebe's second degree regression method.

2.1.3 Actual and Pseudo Components

The requirement of the simplex as given in Equation (1) makes it impossible to utilize the conventional concrete mixes at any given water-cement ratio, requiring a transformation of the actual components to meet this requirement. Table 1 below gives the actual (Zi) and Pseudo (Xi) components for Osadebe's (4,2) Simplex Lattice.

Table 1: Actual (Z_i) and Pseudo (X_i) components for Osadebe's (4,2) Simplex Lattice

PSEUDO COMPONENTS					RESPONSE COMPONENT	COMPONENT'S FRACTION			
S/N	X_1	X_2	X_3	X_4		Z_1	Z_2	Z_3	Z_4
1	1	0	0	0	Y_1	0.08	0.229885	0.229885	0.45977
2	0	1	0	0	Y_2	0.074	0.16835	0.252525	0.505051
3	0	0	1	0	Y_3	0.07	0.155039	0.310078	0.465116
4	0	0	0	1	Y_4	0.048	0.095238	0.285714	0.571429
5	0.5	0.5	0	0	Y_{12}	0.058	0.13459	0.269179	0.538358
6	0.5	0	0.5	0	Y_{13}	0.053	0.111359	0.278396	0.556793
7	0.5	0	0	0.5	Y_{14}	0.044	0.086881	0.347524	0.521286
8	0	0.5	0.5	0	Y_{23}	0.035	0.107181	0.321543	0.535906
9	0	0.5	0	0.5	Y_{24}	0.064	0.116959	0.233918	0.584795
10	0	0	0.5	0.5	Y_{34}	0.059	0.09901	0.247525	0.594059
CONTROL									
11	0.5	0.25	0.25	0	C_1	0.121	0.21978	0.21978	0.43956
12	0.25	0.25	0.25	0.25	C_2	0.098	0.245902	0.245902	0.491803
13	0	0.25	0.25	0.5	C_3	0.059	0.134409	0.268817	0.537634
14	0	0.25	0	0.75	C_4	0.056	0.277778	0.277778	0.555556
15	0.75	0	0.25	0	C_5	0.038	0.096154	0.288462	0.576923
16	0	0.5	0.25	0.25	C_6	0.038	0.306212	0.306212	0.568679
17	0.25	0	0.5	0.25	C_7	0.028	0.080972	0.323887	0.566802
18	0.75	0.25	0	0	C_8	0.038	0.333087	0.333087	0.555144
19	0	0.75	0.25	0	C_9	0.035	0.072046	0.345821	0.54755
20	0	0.4	0.4	0.2	C_{10}	0.032	0.345543	0.345543	0.552868

Table 2: Mix ratios and Components fractions

MIX RATIOS					COMPONENT'S FRACTION			
S/N	S_1	S_2	S_3	S_4	Z_1	Z_2	Z_3	Z_4
1	0.35	1	1	2	0.08	0.229885	0.229885	0.45977

2	0.44	1	1.5	3	0.074	0.16835	0.252525	0.505051
3	0.45	1	2	3	0.07	0.155039	0.310078	0.465116
4	0.5	1	3	6	0.048	0.095238	0.285714	0.571429
5	0.43	1	2	4	0.058	0.13459	0.269179	0.538358
6	0.5	1	2.5	5	0.053	0.111359	0.278396	0.556793
7	0.43	1	4	6	0.044	0.086881	0.347524	0.521286
8	0.48	1	3	5	0.035	0.107181	0.321543	0.535906
9	0.51	1	2	5	0.064	0.116959	0.233918	0.584795
10	0.33	1	2.5	6	0.059	0.09901	0.247525	0.594059
CONTROL								
11	0.55	1	1	2	0.121	0.21978	0.21978	0.43956
12	0.6	1	1.5	3	0.098	0.245902	0.245902	0.491803
13	0.44	1	2	4	0.059	0.134409	0.268817	0.537634
14	0.5	1	2.5	5	0.056	0.277778	0.277778	0.555556
15	0.4	1	3	6	0.038	0.096154	0.288462	0.576923
16	0.43	1	3.5	6.5	0.038	0.306212	0.306212	0.568679
17	0.35	1	4	7	0.028	0.080972	0.323887	0.566802
18	0.51	1	4.5	7.5	0.038	0.333087	0.333087	0.555144
19	0.48	1	4.8	7.6	0.035	0.072046	0.345821	0.54755
20	0.47	1	5	8	0.032	0.345543	0.345543	0.552868

The design matrix as shown in Table 1 above for the X_i experimental points are called "Pseudo-components" and the Z_i are the actual experimental components. $X = AZ$ (30)

Where A is the inverse of Z matrix and $Z = AX^T$ (31)

Where A is the inverse of Z matrix, X^T is the transpose of matrix X.

Table 3: Table of Z based on Table 1 above

S/N	Z_1	Z_2	Z_3	Z_4	Z_1Z_2	Z_1Z_3	Z_1Z_4	Z_2Z_3	Z_2Z_4	Z_3Z_4
1	0.08	0.23	0.23	0.46	0.0184	0.0184	0.0368	0.0529	0.1058	0.1058
2	0.074	0.17	0.25	0.50	0.01258	0.0185	0.037	0.0425	0.085	0.125
3	0.07	0.15	0.31	0.46	0.0105	0.0217	0.0322	0.0465	0.069	0.1426
4	0.048	0.09	0.29	0.57	0.00432	0.01392	0.02736	0.0261	0.0513	0.1653
5	0.058	0.13	0.27	0.54	0.00754	0.01566	0.03132	0.0351	0.0702	0.1458
6	0.053	0.11	0.28	0.56	0.00583	0.01484	0.02968	0.0308	0.0616	0.1568
7	0.044	0.09	0.35	0.52	0.00396	0.0154	0.02288	0.0315	0.0468	0.182
8	0.035	0.11	0.32	0.54	0.00385	0.0112	0.0189	0.0352	0.0594	0.1728
9	0.064	0.12	0.23	0.58	0.00768	0.01472	0.03712	0.0276	0.0696	0.1334
10	0.059	0.10	0.25	0.59	0.0059	0.01475	0.03481	0.025	0.059	0.1475

Table 4: A – MATRIX

-455.2052666	1231.517063	-329.5748234	1451.381393	1520.989399	-2951.096174	-242.3070516	189.0269454	-898.5654534	498.8569095
28.7378845	-74.17043571	-150.5895161	272.009771	1355.244197	-1495.259042	79.06907765	-62.22066845	-598.5258808	649.5471997
31.4292578	-120.8119741	52.31786573	-60.59243082	-164.4715106	183.659049	36.15497648	-7.831935186	229.871365	-178.8325261
16.49078415	-60.57761478	40.20793539	-1.699017758	-131.3955939	151.7695847	-20.98871224	1.403439453	108.7568777	-103.0241121
630.5140751	-1169.460543	1136.478253	-2694.600553	-9001.388201	10812.93239	-85.03428736	55.70317468	3987.521238	-3703.865421
533.527126	-1801.678994	555.4710208	-528.1650934	-1340.705199	3923.218799	-64.10675484	-733.6523825	1615.968522	-2169.188493
395.0617582	-928.5083578	41.42664627	-2023.903241	-336.5379614	1317.532051	558.2372404	-35.45072095	-211.0309414	1207.228613
-74.77219454	275.3029098	161.0875805	-642.211443	-1309.61652	1137.259042	-152.8427479	324.4615608	-19.7915436	296.2371682
-59.24098412	89.85381071	87.47532632	-92.89319842	-1116.013127	1476.504624	-62.98148708	-45.80747567	740.2713048	-1018.698351
-92.07247351	368.2259919	-188.6576047	128.777518	519.0654225	-643.3258078	-4.841902355	17.06642128	-623.4819767	519.5055037

Table 5: X-MATRIX

1.0E+00	3.0E-13	4.5E-13	1.4E-12	1.5E-14	3.4E-14	7.5E-14	6.4E-14	1.6E-13	2.6E-13
-7.1E-15	1.0E+00	-5.7E-14	-1.1E-13	-1.3E-15	-1.8E-15	-1.1E-14	-1.8E-14	-2.8E-14	-7.1E-14
-1.8E-15	0.0E+00	1.0E+00	2.8E-14	4.4E-16	8.9E-16	1.8E-15	8.9E-16	1.8E-15	7.1E-15
-2.7E-15	-1.8E-15	-3.6E-15	1.0E+00	0.0E+00	-2.2E-16	-4.4E-16	0.0E+00	-8.9E-16	-5.3E-15
-3.4E-13	-3.4E-13	-1.3E-12	-2.3E-12	1.0E+00	-6.4E-14	-1.1E-13	-8.5E-14	-2.6E-13	-3.4E-13
-4.3E-14	-1.1E-13	0.0E+00	2.3E-13	-3.6E-15	1.0E+00	-1.4E-14	-2.1E-14	-1.4E-14	0.0E+00
1.4E-14	1.4E-14	1.1E-13	0.0E+00	2.7E-15	1.1E-14	1.0E+00	1.4E-14	5.7E-14	1.4E-13
-7.1E-15	-3.6E-15	4.3E-14	2.8E-14	4.4E-16	4.4E-15	1.8E-15	1.0E+00	0.0E+00	7.1E-15
-1.4E-14	0.0E+00	2.8E-14	0.0E+00	-8.9E-16	-3.6E-15	-7.1E-15	0.0E+00	1.0E+00	0.0E+00
3.6E-15	-7.1E-15	-2.8E-14	-1.1E-13	-1.8E-15	-1.8E-15	-3.6E-15	-3.6E-15	-1.8E-14	1.0E+00

Table 6: Matrix of X – Transpose

1.00E+00	-7.11E-15	-1.78E-15	-2.66E-15	-3.41E-13	-4.26E-14	1.42E-14	-7.11E-15	-1.42E-14	3.55E-15
2.98E-13	1.00E+00	0.00E+00	-1.78E-15	-3.41E-13	-1.14E-13	1.42E-14	-3.55E-15	0.00E+00	-7.11E-15
4.55E-13	-5.68E-14	1.00E+00	-3.55E-15	-1.25E-12	0.00E+00	1.14E-13	4.26E-14	2.84E-14	-2.84E-14
1.42E-12	-1.14E-13	2.84E-14	1.00E+00	-2.27E-12	2.27E-13	0.00E+00	2.84E-14	0.00E+00	-1.14E-13
1.51E-14	-1.33E-15	4.44E-16	0.00E+00	1.00E+00	-3.55E-15	2.66E-15	4.44E-16	-8.88E-16	-1.78E-15
3.38E-14	-1.78E-15	8.88E-16	-2.22E-16	-6.39E-14	1.00E+00	1.07E-14	4.44E-15	-3.55E-15	-1.78E-15
7.46E-14	-1.07E-14	1.78E-15	-4.44E-16	-1.14E-13	-1.42E-14	1.00E+00	1.78E-15	-7.11E-15	-3.55E-15
6.39E-14	-1.78E-14	8.88E-16	0.00E+00	-8.53E-14	-2.13E-14	1.42E-14	1.00E+00	0.00E+00	-3.55E-15
1.60E-13	-2.84E-14	1.78E-15	-8.88E-16	-2.56E-13	-1.42E-14	5.68E-14	0.00E+00	1.00E+00	-1.78E-14
2.56E-13	-7.11E-14	7.11E-15	-5.33E-15	-3.41E-13	0.00E+00	1.42E-13	7.11E-15	0.00E+00	1.00E+00

Table 7: Z - MATRIX

-455.2053	1231.5171	-329.5748	1451.3814	1520.9894	-2951.0962	-242.3071	189.0269	-898.5655	498.8569
28.7379	-74.1704	-150.5895	272.0098	1355.2442	-1495.2590	79.0691	-62.2207	-598.5259	649.5472
31.4293	-120.8120	52.3179	-60.5924	-164.4715	183.6590	36.1550	-7.8319	229.8714	-178.8325
16.4908	-60.5776	40.2079	-1.6990	-131.3956	151.7696	-20.9887	1.4034	108.7569	-103.0241
630.5141	-1169.4605	1136.4783	-2694.6006	-9001.3882	10812.9324	-85.0343	55.7032	3987.5212	-3703.8654

533.5271	-1801.6790	555.4710	-528.1651	-1340.7052	3923.2188	-64.1068	-733.6524	1615.9685	-2169.1885
395.0618	-928.5084	41.4266	-2023.9032	-336.5380	1317.5321	558.2372	-35.4507	-211.0309	1207.2286
-74.7722	275.3029	161.0876	-642.2114	-1309.6165	1137.2590	-152.8427	324.4616	-19.7915	296.2372
-59.2410	89.8538	87.4753	-92.8932	-1116.0131	1476.5046	-62.9815	-45.8075	740.2713	-1018.6984
-92.0725	368.2260	-188.6576	128.7775	519.0654	-643.3258	-4.8419	17.0664	-623.4820	519.5055

RESPONSES		**REGRESSION COEFFICIENTS**
Y_1	42.37	49880.88029
Y_2	35.00	19056.25884
Y_3	32.89	-4524.982663
Y_4	24.51	-2307.113416
Y_{12}	20.95	-152307.2228
Y_{13}	15.17	-55556.10739
Y_{14}	43.375	-32556.01398
Y_{23}	35.525	-12610.26213
Y_{24}	33.385	-18182.54649
Y_{34}	24.88	12903.1295

III. RESULTS AND DISCUSSION

The laboratory responses for the twenty design points for the compressive strength are as presented in the table below. Two replicate experimental observations were conducted for each of the points, and of the twenty points, ten are control points. Table 8 also presents the mean values computed from the replicate compressive strength values.

Table 8: Results of Compressive strength test (Laboratory Responses)

Exp. No. (N)	**Repetition**	**Response**	**Point**	$\sum_{i=1}^{n} Y_i$	$\bar{Y} = \frac{(\sum_{i=1}^{n} Y_i)}{n}$
1	A	42.80	Y_1	85.47	42.37
	B	42.67			
2	A	35.20	Y_2	70.00	35.00
	B	34.80			
3	A	32.22	Y_3	65.78	32.89
	B	33.56			
4	A	23.87	Y_4	49.03	24.51
	B	25.16			
5	A	21.78	Y_{12}	41.91	20.95
	B	20.13			
6	A	15.24	Y_{13}	30.35	15.17
	B	15.11			

7	A	44.08	Y_{14}	86.75	43.375
	B	42.67			
8	A	37.52	Y_{23}	71.05	35.525
	B	33.52			
9	A	29.21	Y_{24}	66.77	33.385
	B	37.56			
10	A	25.88	Y_{34}	49.76	24.88
	B	23.88			
11	A	20.91	Y_{C1}	42.54	21.27
	B	21.63			
12	A	13.89	Y_{C2}	30.80	15.4
	B	16.91			
13	A	42.67	Y_{C3}	88.03	44.015
	B	45.36			
14	A	35.30	Y_{C4}	72.10	36.05
	B	36.80			
15	A	33.39	Y_{C5}	67.75	33.875
	B	34.36			
16	A	26.06	Y_{C6}	50.50	25.25
	B	24.44			
17	A	20.19	Y_{C7}	43.17	21.585
	B	22.98			
18	A	16.00	Y_{C8}	31.26	15.63
	B	15.26			
19	A	19.68	Y_{C9}	41.91	20.955
	B	22.23			
20	A	14.24	Y_{C10}	30.35	15.175
	B	16.11			

From the regression equation given in equation 29:

$$Y = \beta_1 Z_1 + \beta_2 Z_2 + \beta_3 Z_3 + \beta_4 Z_4 + \beta_5 Z_5 + \beta_6 Z_6 + \beta_{12} Z_1 Z_2 + \beta_{13} Z_1 Z_3 + \beta_{14} Z_1 Z_4 + \beta_{15} Z_1 Z_5 + \beta_{16} Z_1 Z_6 + \beta_{23} Z_2 Z_3 + \beta_{24} Z_2 Z_4 + \beta_{25} Z_2 Z_5 + \beta_{26} Z_2 Z_6 + \beta_{34} Z_3 Z_4 + \beta_{35} Z_3 Z_5 + \beta_{36} Z_3 Z_6 + \beta_{45} Z_4 Z_5 + \beta_{46} Z_4 Z_6$$

The predictive responses from the model are as tabulated below:

MODEL RESPONSE SYMBOL	**RESPONSE FROM PREDICTIVE MODEL**
Y_{m1}	42.4
Y_{m2}	35.0
Y_{m3}	32.9
Y_{m4}	24.5

Y_{m5}	20.9
Y_{m6}	15.2
Y_{m7}	43.4
Y_{m8}	35.5
Y_{m9}	33.4
Y_{m10}	24.9

Testing model adequacy

The t-test was the tool utilized in assessing the adequacy of the model. The two hypotheses of emphasis were that:

(1). There is no significant difference between the experimental and predicted compressive strength values of the MS-RHA concrete, at 95% accuracy, for the null hypothesis (h_0)

(2). There is a significant difference between the experimental and predicted values of the compressive strength of MR-RHA concrete at 95% accuracy, for the alternate hypothesis (h_i).

Let Y_E represent experimental responses, Y_M be model responses, and N be the number of observations, hence:

$D_i = Y_E - Y_M$

Given that: D_A (mean of difference Y_E and Y_M) $= \frac{\sum D_i}{N}$ (32)

S^2 (Variance of difference of D_i and D_A) $= \frac{\sum(D_A - D_i)^2}{N-1}$ (33)

$$t_{calculated} = \frac{D_A \times N^{0.5}}{S} \quad (34)$$

Results are as tabulated below:

Table 9: Student t-test for the optimization model

Control points	Y_E	Y_M	$D_i = Y_E - Y_M$	$D_A - D_i$	$(D_A - D_i)^2$
C1	42.37	42.40	-0.03	-0.03	0.0009
C2	35.00	35.00	0.00	-0.06	0.0036
C3	32.89	32.90	-0.01	-0.05	0.0025
C4	24.51	24.50	0.01	-0.07	0.0049
C_5	20.95	20.90	0.05	-0.11	0.0121
C_6	15.17	15.20	-0.03	-0.03	0.0009
C_7	43.37	43.40	-0.03	-0.03	0.0009
C_8	35.52	35.50	0.02	-0.08	0.0064
C_9	33.38	33.40	-0.02	-0.04	0.0016
C_{10}	24.88	24.90	-0.02	-0.04	0.0016
		$\sum D_i$	**-0.06**	$\sum(D_A - D_i)^2$	**0.0354**

From Equations (32) to (34):

$D_A = \frac{\sum D_i}{N} = \frac{-0.06}{10} = -0.006$

$S^2 = \frac{\sum(D_A - D_i)^2}{N-1} = \frac{0.0354}{10-1} = 0.00393 \therefore s = 0.0627$

$$t_{calculated} = \frac{D_A \times N^{0.5}}{S} = \frac{-0.006 \times 10^{0.5}}{0.0627} = -0.303$$

Allowable total variation in t-test:

Degree of Freedom = N – 1 = 9

5% significance for two-tailed test = 2.5% = 0.025

∴ 100% – 2.5% = 97.5% = 0.975

From t-table (see Appendix A),

Allowable total variation in t-test = $t_{(0.975,\, N-1)} = t_{(0.975,\, 9)} =$ 2.262

Since $t_{calculated} < t_{table}$, we accept the null hypothesis and reject the alternate hypothesis.

IV. CONCLUSION

On the strength of the research results, it can be concluded that:

1. RHA and MS can simultaneously replace OPC in concrete.
2. The Osadebe's mathematical model can be used as a predictive tool for RHA – MS concrete compressive strength.
3. The highest compressive strength predicted in this work is 35.0N/mm^2 corresponding to a water/cement ratio of 0.55 in a mix ratio of 0.55:1:1:2 for a 10% replacement of OPC with 5% each of RHA and MS.
4. The compressive strength predictions ranged from 35.0N/mm^2 to 15.2N/mm^2, indicating that the RHA-MS concrete can be used as structural as well as mass concrete.
5. Cost saving of 10% can be achieved for OPC in concrete works.
6. Furthermore, it has been established from this work that structural concrete can be achieved from a multivariant binder using more natural occurring and eco-friendly admixtures while maintaining the same strength and ensuring environmental sustainability.

APPENDIX A

***t* Table**

cum. prob	$t_{.50}$	$t_{.75}$	$t_{.80}$	$t_{.85}$	$t_{.90}$	$t_{.95}$	$t_{.975}$	$t_{.99}$	$t_{.995}$	$t_{.999}$	$t_{.9995}$
one-tail	0.50	0.25	0.20	0.15	0.10	0.05	0.025	0.01	0.005	0.001	0.0005
two-tails	1.00	0.50	0.40	0.30	0.20	0.10	0.05	0.02	0.01	0.002	0.001
df											
1	0.000	1.000	1.376	1.963	3.078	6.314	12.71	31.82	63.66	318.31	636.62
2	0.000	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925	22.327	31.599
3	0.000	0.765	0.978	1.250	1.638	2.353	3.182	4.541	5.841	10.215	12.924
4	0.000	0.741	0.941	1.190	1.533	2.132	2.776	3.747	4.604	7.173	8.610
6	0.000	0.718	0.906	1.134	1.440	1.943	2.447	3.143	3.707	5.208	5.959
7	0.000	0.711	0.896	1.119	1.415	1.895	2.365	2.998	3.499	4.785	5.408
8	0.000	0.706	0.889	1.108	1.397	1.860	2.306	2.896	3.355	4.501	5.041
9	0.000	0.703	0.883	1.100	1.383	1.833	2.262	2.821	3.250	4.297	4.781
11	0.000	0.697	0.876	1.088	1.363	1.796	2.201	2.718	3.106	4.025	4.437
12	0.000	0.695	0.873	1.083	1.356	1.782	2.179	2.681	3.055	3.930	4.318
13	0.000	0.694	0.870	1.079	1.350	1.771	2.160	2.650	3.012	3.852	4.221
14	0.000	0.692	0.868	1.076	1.345	1.761	2.145	2.624	2.977	3.787	4.140

16	0.000	0.690	0.865	1.071	1.337	1.746	2.120	2.583	2.921	3.686	4.015
17	0.000	0.689	0.863	1.069	1.333	1.740	2.110	2.567	2.898	3.646	3.965
18	0.000	0.688	0.862	1.067	1.330	1.734	2.101	2.552	2.878	3.610	3.922
19	0.000	0.688	0.861	1.066	1.328	1.729	2.093	2.539	2.861	3.579	3.883
21	0.000	0.686	0.859	1.063	1.323	1.721	2.080	2.518	2.831	3.527	3.819
22	0.000	0.686	0.858	1.061	1.321	1.717	2.074	2.508	2.819	3.505	3.792
23	0.000	0.685	0.858	1.060	1.319	1.714	2.069	2.500	2.807	3.485	3.768
24	0.000	0.685	0.857	1.059	1.318	1.711	2.064	2.492	2.797	3.467	3.745
26	0.000	0.684	0.856	1.058	1.315	1.706	2.056	2.479	2.779	3.435	3.707
27	0.000	0.684	0.855	1.057	1.314	1.703	2.052	2.473	2.771	3.421	3.690
28	0.000	0.683	0.855	1.056	1.313	1.701	2.048	2.467	2.763	3.408	3.674
29	0.000	0.683	0.854	1.055	1.311	1.699	2.045	2.462	2.756	3.396	3.659
40	0.000	0.681	0.851	1.050	1.303	1.684	2.021	2.423	2.704	3.307	3.551
60	0.000	0.679	0.848	1.045	1.296	1.671	2.000	2.390	2.660	3.232	3.460
80	0.000	0.678	0.846	1.043	1.292	1.664	1.990	2.374	2.639	3.195	3.416
100	0.000	0.677	0.845	1.042	1.290	1.660	1.984	2.364	2.626	3.174	3.390
z	0.000	0.674	0.842	1.036	1.282	1.645	1.960	2.326	2.576	3.090	3.291
	0%	50%	60%	70%	80%	90%	95%	98%	99%	99.8%	99.9%
	Confidence Level										

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