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Prediction of Fresh and Hardened Properties of Concrete Containing Nanostructured Cassava Peel Ash Using Ibearugbulem's Approach

Chidobere D. Nwa-David[a,b]*, **David O. Onwuka**[b], **Fidelis C. Njoku**[b], **Owus M. Ibearugbulem**[b]

[a]Civil Engineering Dept., Faculty of Engineering, Michael Okpara University of Agriculture, Umudike, Nigeria
[b]Civil Engineering Dept., Faculty of Engineering, Federal University of Technology, Owerri, Nigeria
*Corresponding author Email: nwadavid.chidobere@mouau.edu.ng

HIGHLIGHTS

- Compressive strength of NCPA-Cement Composites at 28 days was obtained and varied with their initial and final setting time.
- An optimization model was formulated.
- The adequacy of the model was verified with Fisher's statistical tool.
- Visual Basic program was designed for the prediction and optimization of the developed model.

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ABSTRACT

Statistical methods such as Scheffe's and Osadebe's models are commonly employed for the optimization of concrete properties. Despite their prediction suitability, attention is drawn to their drawback. Ibearugbulem's model has been developed to address these shortcomings. In this study, Ibearugbulem's optimization method was employed to formulate a mathematical model for prediction and strength-optimization of nanostructured cassava peel ash (NCPA)-cement composite. The variation of 28 days compressive strength and initial and final setting time of NCPA-concrete was evaluated. Based on the establishment of a spatial domain for each concrete mixture variable, the response function is expressed as a multivariable function for the proportions of the constituent materials. Applying the variational approach, the response function was developed within the specified spatial domain and was optimized. There were 51 observation points. Twenty-six observation points were used to formulate the model and the remaining twenty-five points were used to test the adequacy of the formulated model. The observation points on the odd serial number are the ones selected for the formulation of the model. The ones on the even serial numbers are the ones used for testing the adequacy of the model. Fisher's statistical tool was used in the analysis and the calculated value of fisher of 1.11 was lower than the fisher value of 1.94 derived from the statistical f-distribution table. This result proved that there was no significant difference between the laboratory compressive strength values and the modeled strength values at a 95% confidence level. This shows that the formulated model is reliable, safe, and recommended for concrete production.

1. Introduction

The erudition of the compressive strength of concrete is indispensable in the analysis and design of structural concrete elements. The quality of concrete is largely determined by its compressive property. Prediction and optimization of this property are needed for the performance and sustainability evaluation of concrete.

Concrete does a composite material constitute cement, water, fine aggregates, and coarse aggregates in a calculated mix measure. It is globally the most-used construction material with its increasing demand for infrastructural development in both developing and developed countries [1]. The availability of its constituents determines its overall production cost. As demand for concrete rises, the need for cement production increases but the environmental effect such as the depletion of the ozonosphere due to the emission of greenhouse gas and the cost implication of cement production has led researchers to develop alternative and suitable replacement materials for the binder.

Cassava peel ash is one of the many alternative materials for cement in concrete production. Cassava peel ash has been used in [2-5] but the effect of its nanostructured form on the compressive strength of concrete which was not considered in previous studies distinguishes this study. Nanostructured materials incorporated in cement composites improve their compressive and

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flexural strength at an early age due to its high surface-to-volume ratio [6-8]. Eco-friendly concrete is produced with the use of nanosized-cassava-peel-ash (NCPA).

The production cost of cement composites is also decided by the vast time and energy spent in performing trial mixes for desired behaviors. Most scholars such as [9-13] adopted soft computing techniques for the optimization of concrete properties in order to handle the complex problem involving the incorporation of admixtures. Concrete mix materials within the mixture matrix have also been modeled with regression models [14, 15].

Statistical models such as Scheffe's, Osadebe, axial designs, process variables, orthogonal block designs inverse terms, inert components, log contrast models, mixtures with additive effect, and K-models [16], have gained more attention among researchers than soft tools such as Artificial Neural Network (ANN), Fuzzy Logic (FL), and Adaptive Neuro-Fuzzy Inference System (ANFIS), due to their ability to perform predictions more quickly and easily.

Scheffe's simplex theory was adopted by Akobo et al. [17], to optimize the compressive strength of rubberized concrete. Recycled rubber tire chips served as a partial replacement for coarse aggregates in the concrete mixes. The replacement levels considered were 5%, 10%, 20%, and 30%. The adequacy of the model was verified with T-test statistical tool.

Alaneme and Elvis [18] applied Scheffe's (5, 2) simplex-lattice function to optimize the palm-nut-fiber reinforced concrete's compressive strength. The model was tested using a student's t-test and ANOVA at a 5% critical value. The result showed a good relationship between the values derived from Scheffe's model and the experimental data. The highest value of compressive strength of the palm-nut fiber concrete obtained was 31.53N/mm^2 corresponding to a mix ratio of 0.525:1.0:1.45:1.75:0.6 and least 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.

Scheffe's and Osadebe's Models were adopted by Mama and Osadebe [19]. They predicted the compressive strength of concrete blocks using an alluvial deposit. The application of Osadebe's model was confirmed to be easier than Scheffe's model because the actual mix ratio is usually used instead of the pseudo-components ratio that needs to be transformed into a real component ratio in Scheffe's.

Oba et al. [20] used Scheffe's simplex theory to investigate the compressive strength of concrete. 5% of fine aggregate was partially replaced with saw-dust ash (SDA). The mix comprised of five components: water-cement ratio, cement, sand, SDA, and granite. 28 days' compressive strengths were determined experimentally using thirty (30) concrete mix ratios. The outcome of the first fifteen strength values was applied for the calibration of the model constant coefficients, while those from the second fifteen were used for the model verification using Scheffe's design. The authors ascertained the adequacy of the model using a two-tailed t-test with 5% significance.

Ibearugbulem et al. [21] formulated a new model that predicts 28th-day flexural strengths of periwinkle shell-river gravel Concrete. The mix ratios used in their study were selected arbitrarily from Scheffe's simplex latex structure for a four-component mixture. Different constituent materials were batched by mass except for the sandstone and periwinkle shells which were volumetrically combined at a mix ratio of 1:1. The adequacy of the model was confirmed with Fisher's test.

Previous studies did not consider the partial replacement of the binder. NCPA was not applied in any of the studies. The concept of nanosization in concrete production is scarce in the literature. The interval of percentage replacement applied in this paper was not captured previously. 1.5% replacement intervals were employed here to detect the slightest impact. Ibearugbulem's model was not considered in their statistical approach except in [21]. However, the authors in [21] did not consider compressive strength. The need for a predetermined set of mixes before the formulation of the model is a great challenge to the application of former models. Antecedent authors did not consider writing a visual basic computer program for their study. This gap in the literature is addressed in this study. A new approach was introduced and developed by Ibearugbulem to surmount this challenge [22]. In this approach, a set of mixes that had already been carried out can be modeled without employing a predetermined number of mixes.

In this study, a computer program was written with Visual Basic 6.0 based on the formulated model. It was written to predict various mix ratios corresponding to the desired compressive-strength value. Application of Visual Basic was preferred to other programming languages such as Python and Matlab because it is easy to learn and understand. It takes little or no time to program compared to others and it gives a comprehensive, interactive and context-sensitive online help system. The Visual Basic program is user-friendly and can anticipate with realistic accuracy, the optimum value of compressive strength and the corresponding mix ratios.

In this research, the regression model developed by Ibearugbulem for a four-component-mixture is employed to formulate a new model for the prediction of the 28th-day compressive strengths of NCPA-concrete. This study will enhance construction activities as the the time wasted in applying trial mixes is eliminated. The pollution of the environment with cassava peels is also curtailed as it is utilized in the formation of lightweight-concrete.

2. Theoretical section

2.1 Derivation of the fundamental equation of the mathematical model

The mixed quantity (x_i) of each component on a particular observation point is determined by dividing the individual component (s_i) by the sum of the components (S). That is:

$$x_i = \frac{s_i}{S} \quad (1)$$

$$S = s_1 + s_2 + s_3 + s_4 \quad (2)$$

In this work, the spatial domain, in which the model is restricted to, are mix ratio domains given as:

$$s_{1min} \leq s_1 \leq s_{1max} \tag{3}$$

$$s_{2min} \leq s_2 \leq s_{2max} \tag{4}$$

$$s_{3min} \leq s_3 \leq s_{3max} \tag{5}$$

$$s_{4min} \leq s_4 \leq s_{4max} \tag{6}$$

From Equation 1,

$$s_i = x_i \,.\, S \quad [where\ 1 \leq i \leq 4\,] \tag{7}$$

Substituting Equation 7 into Equation 2 gives the sum of all the mix quantities to be unity as:

$$x_1 + x_2 + x_3 + x_4 = 1 \tag{8}$$

The equations above were obtained from Ibearugbulem's new optimization-model [21, 23, 24].
The relationship between S and x_1 is:

$$\mathrm{S} = -9{,}618{,}754.09\mathrm{x}_1^3 + 3{,}272{,}467.70\mathrm{x}_1^2 - 371{,}430.83\mathrm{x}_1 + 14{,}071.24 \tag{9}$$

The response function to be adopted herein is a quadratic function of the component proportions given as:

$$\mathrm{y} = \mathrm{a}_1\mathrm{x}_1 + \mathrm{a}_2\mathrm{x}_2 + \mathrm{a}_3\mathrm{x}_3 + \mathrm{a}_4\mathrm{x}_4 + \mathrm{a}_5\mathrm{x}_1{}^2 + \mathrm{a}_6\mathrm{x}_2{}^2 + \mathrm{a}_7\mathrm{x}_3{}^2 + \mathrm{a}_8\mathrm{x}_4{}^2 + \mathrm{a}_9\mathrm{x}_1\mathrm{x}_2 + \mathrm{a}_{10}\mathrm{x}_1\mathrm{x}_3 + \mathrm{a}_{11}\mathrm{x}_1\mathrm{x}_4 + \mathrm{a}_{12}\mathrm{x}_2\mathrm{x}_3 + \mathrm{a}_{13}\mathrm{x}_2\mathrm{x}_4 + \mathrm{a}_{14}\mathrm{x}_3\mathrm{x}_4 \tag{9a}$$

$$y = [x_i]\,[a_i] \tag{9b}$$

Equation 9b was used to obtain the array response equation for the set of mix ratios used in the formulation as:

$$[y^k] = [x_i{}^k]\,[a_i] \tag{9c}$$

Where k denotes the mix number (or observation point number); $[a_i]$ is the coefficient vector, and $[x_i]$ is the shape function vector. They are:

$$[a_i] = [a_1\ a_2\ a_3\ a_4\ a_5\ \ a_6\ a_7\ a_8\ a_9\ a_{10}\ a_{11}\ a_{12}\ a_{13}\ a_{14}]^T \tag{10}$$

$$[x_i] = [x_1\ \ x_2\ \ x_3\ \ x_4\ \ x_1{}^2\ \ x_2{}^2\ \ x_3{}^2\ \ x_4{}^2\ \ x_1x_2\ \ x_1x_3\ \ x_1x_4\ \ x_2x_3\ \ x_2x_4\ \ x_3x_4] \tag{11}$$

Pre-multiplying both sides of Equation 9c with a weighting function (transpose of the shape function) for the set of mixes for the formulation gives the weighted response equation (WRE) as:

$$[x_i{}^k]^T[y^k] = [x_i{}^k]^T.[x_i{}^k]\,[a_i] \tag{12a}$$

This multiplication did not change the generality of the regression function as the weighting function can easily cancel out from both the left and right hand sides of equation 12a. It is clear from here that the approach used in the original work of Ibearugbulem's model (Ibearugbulem et al., 2013) is weighted response approach (WRA).
The weighted response equation (Equation 12a) can be rewritten as:

$$[F] = [CC]\,[a_i] \tag{12b}$$

Where the weighted response vector, F and CC matrix are defined as:

$$[F] = [x_i{}^k]^T[y^k] \tag{13}$$

$$[CC] = [x_i{}^k]^T.[x_i{}^k] \tag{14}$$

In simpler words, [CC] is the matrix whose arbitrary element CCij is obtained by array multiplication of transpose of Column "i" with Column "j" of the shape function vector.

2.2 Fitting the model with the mixes used herein

Table 2 contains the values of quantities of mix components, xi. Ensure to normalize and approximate xi at four decimal places such that condition of Equation 8 will not be violated. The summation of xi in each mix ratio in Table 2, was ensured to be equal to unity (in accordance with Equation 8). The values of xi in Table 2 were used to determine the shape function and weighted response.

The transpose of the response of the odd number mix ratios is taken directly from Table 1 and is given as:

$[y^k]$= [20.5 21.2 21.8 22.5 23 23.4 24 23.6 23.1 22.6 22.3
21.7 21.1 20.5 19.3 18.7 18.1 17.1 16.3 16 15.6 14.9 14.3
13.7 13.2 12.3]

The shape function for the 26 mixes (mix A1, A3, A5 to A51) is taken from Table 2 and substituted into Equations 1 and 2. The transpose of the shape function is:

$[x^k] =$

5.103	0.118	0.000	0.296	0.587	0.014	0.000	0.088	0.344	0.000	0.035	0.069	0.000	0.000	0.174
5.291	0.117	0.006	0.294	0.583	0.014	0.000	0.087	0.340	0.001	0.034	0.068	0.002	0.003	0.172
5.494	0.116	0.012	0.292	0.580	0.014	0.000	0.086	0.336	0.001	0.034	0.067	0.003	0.007	0.170
5.707	0.116	0.017	0.291	0.576	0.013	0.000	0.085	0.332	0.002	0.034	0.067	0.005	0.010	0.168
5.935	0.115	0.023	0.289	0.573	0.013	0.001	0.084	0.328	0.003	0.033	0.066	0.007	0.013	0.166
6.179	0.114	0.029	0.287	0.570	0.013	0.001	0.083	0.325	0.003	0.033	0.065	0.008	0.016	0.164
6.444	0.114	0.034	0.286	0.567	0.013	0.001	0.082	0.321	0.004	0.032	0.064	0.010	0.019	0.162
6.726	0.113	0.040	0.284	0.563	0.013	0.002	0.081	0.317	0.004	0.032	0.064	0.011	0.022	0.160
7.030	0.112	0.045	0.283	0.560	0.013	0.002	0.080	0.314	0.005	0.032	0.063	0.013	0.025	0.158
7.359	0.112	0.050	0.281	0.557	0.012	0.003	0.079	0.310	0.006	0.031	0.062	0.014	0.028	0.157
7.721	0.111	0.056	0.279	0.554	0.012	0.003	0.078	0.307	0.006	0.031	0.062	0.016	0.031	0.155
8.110	0.110	0.061	0.278	0.551	0.012	0.004	0.077	0.304	0.007	0.031	0.061	0.017	0.033	0.153
8.535	0.110	0.066	0.276	0.548	0.012	0.004	0.076	0.300	0.007	0.030	0.060	0.018	0.036	0.151
9.003	0.109	0.071	0.275	0.545	0.012	0.005	0.076	0.297	0.008	0.030	0.060	0.020	0.039	0.150
9.525	0.109	0.076	0.273	0.542	0.012	0.006	0.075	0.294	0.008	0.030	0.059	0.021	0.041	0.148
10.097	0.108	0.081	0.272	0.539	0.012	0.007	0.074	0.291	0.009	0.029	0.058	0.022	0.044	0.147
10.735	0.107	0.086	0.270	0.536	0.012	0.007	0.073	0.287	0.009	0.029	0.058	0.023	0.046	0.145
11.451	0.107	0.091	0.269	0.533	0.011	0.008	0.072	0.284	0.010	0.029	0.057	0.024	0.048	0.143
12.271	0.106	0.096	0.268	0.530	0.011	0.009	0.072	0.281	0.010	0.028	0.056	0.026	0.051	0.142
13.194	0.106	0.100	0.266	0.528	0.011	0.010	0.071	0.278	0.011	0.028	0.056	0.027	0.053	0.140
14.255	0.105	0.105	0.265	0.525	0.011	0.011	0.070	0.275	0.011	0.028	0.055	0.028	0.055	0.139
15.487	0.105	0.110	0.263	0.522	0.011	0.012	0.069	0.273	0.011	0.028	0.055	0.029	0.057	0.138
16.956	0.104	0.115	0.262	0.519	0.011	0.013	0.069	0.270	0.012	0.027	0.054	0.030	0.059	0.136
18.688	0.104	0.119	0.261	0.517	0.011	0.014	0.068	0.267	0.012	0.027	0.054	0.031	0.062	0.135
20.789	0.103	0.124	0.259	0.514	0.011	0.015	0.067	0.264	0.013	0.027	0.053	0.032	0.064	0.133
23.395	0.102	0.128	0.258	0.511	0.011	0.016	0.067	0.262	0.013	0.026	0.052	0.033	0.066	0.132

The shape function and its transpose were substituted into Equation 14 to obtain CC matrix. This CC matrix as obtained was copied from Microsoft Excel worksheet and pasted on Microsoft word page to discharge inherent formulas and approximate the values to enable it have acceptable inverse. In the same manner, the transpose of the shape function and the response vector from the first ten mixes were Substituted into Equation 13 to obtain the weighted response vector.

The CC matrix and the weighted response vector are respectively presented as:

CC Matrix =

0.313	0.186	0.789	1.564	0.034	0.016	0.218	0.859	0.02	0.087	0.172	0.05	0.1	0.433
0.186	0.155	0.469	0.929	0.02	0.015	0.126	0.497	0.016	0.05	0.1	0.041	0.082	0.251
0.789	0.469	1.985	3.936	0.087	0.041	0.55	2.161	0.05	0.218	0.433	0.126	0.251	1.09
1.564	0.929	3.936	7.802	0.172	0.082	1.09	4.285	0.1	0.433	0.859	0.251	0.497	2.161
0.034	0.02	0.087	0.172	0.004	0.002	0.024	0.095	0.002	0.01	0.019	0.005	0.011	0.048
0.016	0.015	0.041	0.082	0.002	0.002	0.011	0.043	0.002	0.004	0.009	0.004	0.008	0.022
0.218	0.126	0.55	1.09	0.024	0.011	0.153	0.6	0.014	0.061	0.12	0.034	0.068	0.303
0.859	0.497	2.161	4.285	0.095	0.043	0.6	2.357	0.053	0.238	0.472	0.134	0.266	1.189
0.02	0.016	0.05	0.1	0.002	0.002	0.014	0.053	0.002	0.005	0.011	0.004	0.009	0.027
0.087	0.05	0.218	0.433	0.01	0.004	0.061	0.238	0.005	0.024	0.048	0.014	0.027	0.12
0.172	0.1	0.433	0.859	0.019	0.009	0.12	0.472	0.011	0.048	0.095	0.027	0.053	0.238
0.05	0.041	0.126	0.251	0.005	0.004	0.034	0.134	0.004	0.014	0.027	0.011	0.022	0.068
0.1	0.082	0.251	0.497	0.011	0.008	0.068	0.266	0.009	0.027	0.053	0.022	0.043	0.134
0.433	0.251	1.09	2.161	0.048	0.022	0.303	1.189	0.027	0.12	0.238	0.068	0.134	0.6

[F]=

55.31158
30.30701
139.2038
275.9776
6.11834
2.512252
38.75287
152.3172
3.267576
15.39816
30.52751
8.223579
16.3036

Substituting the CC matrix and the weighted response vector obtained hitherto into equation (12b) and solving the equation gave the coefficient vector of the model as:

$[a_i]$ = [346.22 238.41 -959.49 -54.01 -29.42 -83.29 -41.26 951.8 409.29 107.42 146.28 -278.29 29.14 -216.73]^T (15)

3. Materials

The materials used for this study include, Ordinary Portland Cement, Nanostructured Cassava Peel Ash (NCPA), water, sharp-river sand, and granite chippings. Each of these materials is discussed below.

1) The *BUA* brand of Ordinary Portland Cement that conformed to the requirements of [25] was used. It was purchased at the local market in Owerri Municipal area of Imo State.
2) Cassava peels were collected from cassava peels dump site at a garri processing centre in Owerri district of Imo State. The cassava peels were gathered and dried under the sun. The cassava peel will be burnt in a kiln at a temperature of about 500ºC to 850ºC in 60minutes in a control incineration set-up to prevent pollution. The burnt material was collected and sieved thoroughly with a nano-sieve of size 200nm, to produce fine nanostructured ash as shown in Figure 1 and 2. The chemical composition and physical characteristics of the NCPA was determined and presented in Table 1. From this table, it is observed that NCPA contains 61.70% SiO_2, 12.50% Al_2O_3 and 2.52% Fe_2O_3. This gives 76.72% of SiO_2+ Al_2O_3+Fe_2O_3 which is in line with ASTM C 618 [26] requirement of 70% minimum for pozzolanas. Thus, NCPA meets the requirement for a pozzolana. The Loss of Ignition (LOI) of 5.07 and SO_3 of 2.10 all fall within agreeable limits of [26]. NCPA has a lower specific gravity of 2.11 when compared with the specific gravity of cement (3.04). This implies that partially replacing OPC with NCPA will result to reduced weight of concrete members. The nanostructured cassava peel ash is 1.4 times lighter than cement.
3) Water that is suitable for drinking was obtained from a borehole at the laboratory. The water was clean, fresh, free from dirt, unwanted chemicals or rubbish that may affect the desired quality of concrete, and it conformed to the requirements of [27].
4) The sand was obtained from Imo River, Imo State of Nigeria. It was sieved through 10mm British Standard test sieve to remove cobbles to satisfy the requirements of [28]. It has physical properties of 1650kg/m^3, 2.65 and 2.92 corresponding to its values of uncompacted bulk density, specific gravity and fineness modulus respectively. The river sand is uniformly graded because it has coefficient of uniformity and coefficient of curvature values of 2.70 and 0.96 respectively obtained from Figure 3.
5) The crushed granite was sourced from the quarry site at Ishiagu, Ebonyi State, Nigeria. The maximum size of aggregate used for this work is 20mm diameter. It conformed to the requirements of [28]. It has physical properties of 1520kg/m^3, 2.75 and 3.28 corresponding to its values of uncompacted bulk density, specific gravity and fineness modulus respectively. The coarse aggregate is well-graded because it has coefficient of uniformity and coefficient of curvature values of 1.83 and 1.24 respectively obtained from Figure 4.

Table 1: Chemical Composition of BUA brand of OPC and Nanostructured Cassava Peel Ash (NCPA)

Materials	Chemical Composition (%)								
	SiO_2	***Fe_2O_3***	***Al_2O_3***	***CaO***	***SO_3***	***MgO***	***Na_2O***	***K_2O***	***LOI***
Cement	18.22	2.72	5.11	60.14	3.31	1.25	0	0.08	7.23
NCPA	61.70	2.52	12.50	9.42	2.10	6.32	0.05	6.82	5.07

Figure 1: Cassava Peels

Figure 2: Nanostructured Cassava Peel Ash

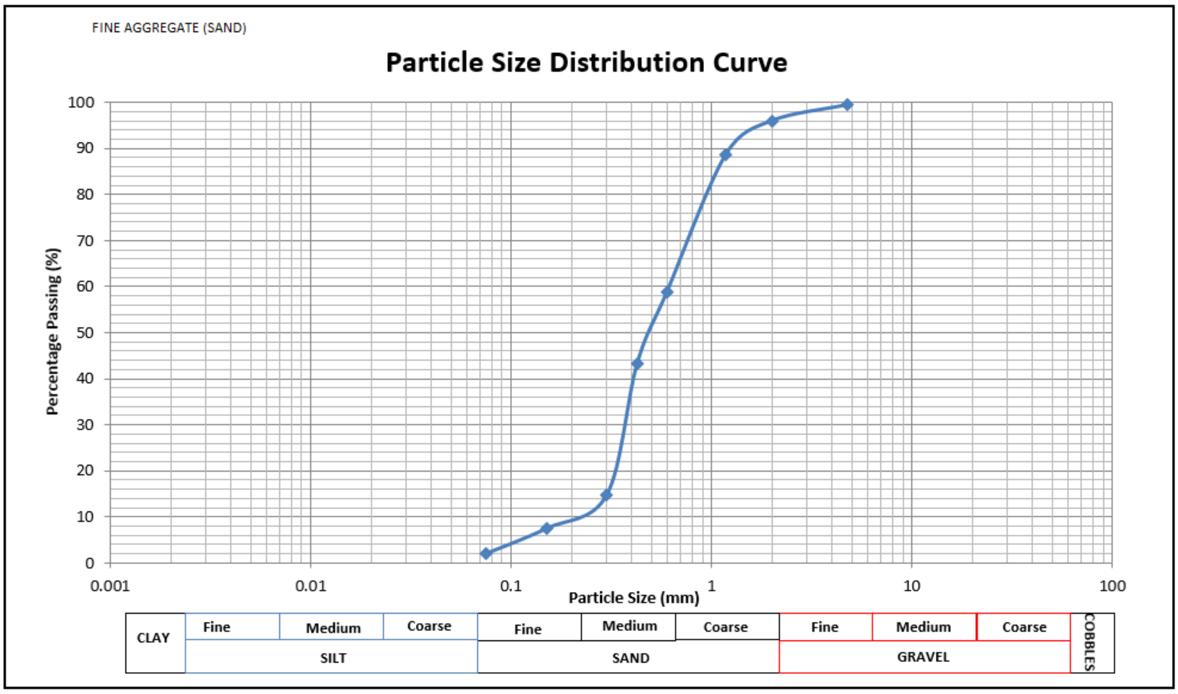

Figure 3: Particle size distribution curve for river sand

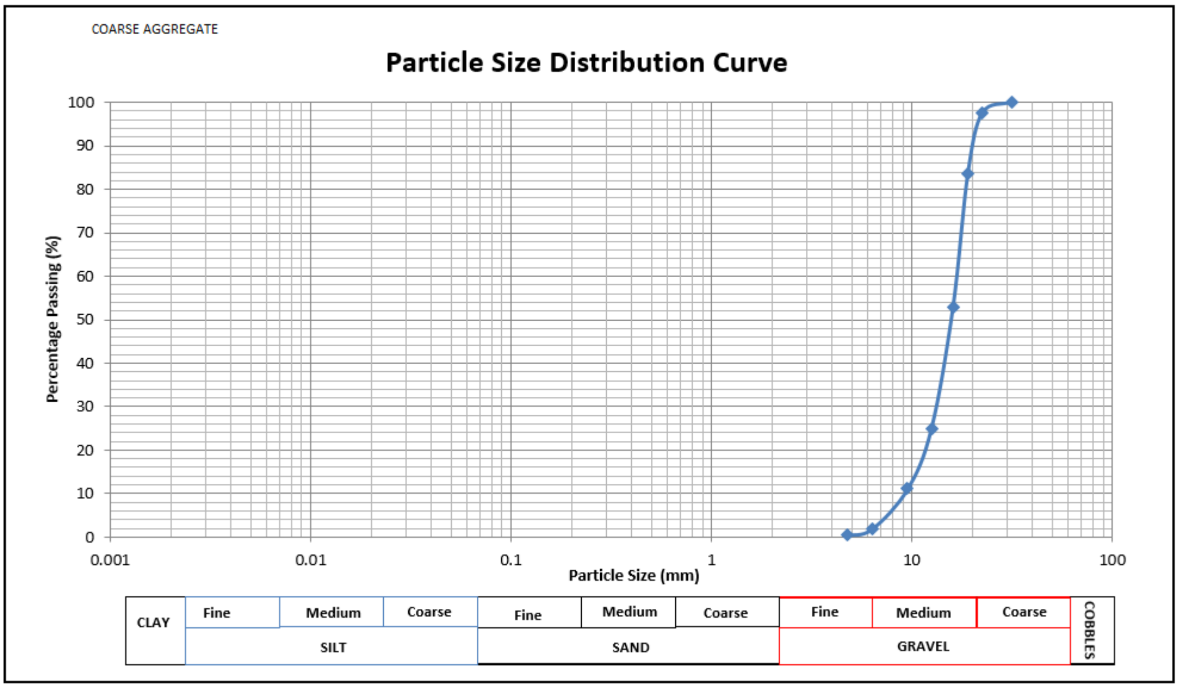

Figure 4: Particle size distribution curve for the granite

4. Methods

The materials were batched by mass in their dried state. After mixing properly to a consistent state, the concrete was cast into the moulds and de-moulded after 24hrs. The cubes were cured for 28 days after which they were crushed in their saturated surface dry (SSD) state using the Universal Compression Machine and the compressive strength was determined in accordance to [29].

Fifty-one mixes were used, which gave a total of 153 cubes. Twenty-six observation points were used to formulate the model and the remaining twenty-five points are used to test the adequacy of the formulated model. The observations point on the odd serial number is the ones selected for the formulation of the model. The ones on the even serial numbers are the ones used for testing the adequacy of the model. They are presented on Table 2 and Table 3 respectively.

Table 2: Mix ratios for odd serial numbers and their corresponding compressive strength values

S/No	W/C	N/C	S/C	G/C	28days Strength (N/mm^2)	X_1	X_2	X_3	X_4
A1	0.600	0.000	1.510	2.993	20.5	0.118	0.000	0.296	0.587
A3	0.618	0.031	1.556	3.086	21.2	0.117	0.006	0.294	0.583
A5	0.638	0.064	1.607	3.185	21.8	0.116	0.012	0.292	0.580
A7	0.659	0.099	1.659	3.290	22.5	0.116	0.017	0.291	0.576
A9	0.682	0.136	1.716	3.401	23.0	0.115	0.023	0.289	0.573
A11	0.706	0.176	1.776	3.521	23.4	0.114	0.029	0.287	0.570
A13	0.732	0.220	1.842	3.651	24.0	0.114	0.034	0.286	0.567
A15	0.759	0.266	1.911	3.789	23.6	0.113	0.040	0.284	0.563
A17	0.789	0.316	1.987	3.938	23.1	0.112	0.045	0.283	0.560
A19	0.822	0.370	2.068	4.100	22.6	0.112	0.050	0.281	0.557
A21	0.857	0.429	2.157	4.277	22.3	0.111	0.056	0.279	0.554
A23	0.895	0.493	2.254	4.468	21.7	0.110	0.061	0.278	0.551
A25	0.937	0.562	2.359	4.677	21.1	0.110	0.066	0.276	0.548
A27	0.983	0.639	2.475	4.906	20.5	0.109	0.071	0.275	0.545
A29	1.035	0.725	2.604	5.162	19.3	0.109	0.076	0.273	0.542
A31	1.091	0.818	2.745	5.443	18.7	0.108	0.081	0.272	0.539
A33	1.154	0.923	2.903	5.756	18.1	0.107	0.086	0.270	0.536
A35	1.224	1.040	3.080	6.107	17.1	0.107	0.091	0.269	0.533
A37	1.305	1.175	3.283	6.509	16.3	0.106	0.096	0.268	0.530
A39	1.395	1.326	3.511	6.962	16.0	0.106	0.100	0.266	0.528
A41	1.500	1.500	3.774	7.482	15.6	0.105	0.105	0.265	0.525
A43	1.621	1.701	4.079	8.086	14.9	0.105	0.110	0.263	0.522
A45	1.765	1.942	4.442	8.807	14.3	0.104	0.115	0.262	0.519
A47	1.935	2.226	4.871	9.656	13.7	0.104	0.119	0.261	0.517
A49	2.142	2.570	5.390	10.687	13.2	0.103	0.124	0.259	0.514
A51	2.398	2.998	6.035	11.964	12.3	0.102	0.128	0.258	0.511

Table 3: Mix ratios for even serial numbers and their corresponding compressive strength values

S/No	W/C	N/C	S/C	G/C	28days Strength (N/mm^2)	X_1	X_2	X_3	X_4
A2	0.609	0.015	1.533	3.039	20.8	0.117	0.003	0.295	0.585
A4	0.628	0.047	1.581	3.134	21.5	0.117	0.009	0.293	0.581
A6	0.649	0.081	1.632	3.236	22.2	0.116	0.015	0.292	0.578
A8	0.670	0.117	1.687	3.345	22.7	0.115	0.020	0.290	0.575
A10	0.693	0.156	1.745	3.460	23.1	0.115	0.026	0.288	0.571
A12	0.718	0.197	1.808	3.584	23.7	0.114	0.031	0.287	0.568
A14	0.745	0.242	1.876	3.719	24.2	0.113	0.037	0.285	0.565
A16	0.774	0.290	1.948	3.862	23.3	0.113	0.042	0.283	0.562
A18	0.805	0.342	2.026	4.017	22.9	0.112	0.048	0.282	0.559
A20	0.839	0.398	2.111	4.185	22.5	0.111	0.053	0.280	0.556
A22	0.876	0.460	2.204	4.370	22.0	0.111	0.058	0.279	0.552
A24	0.916	0.527	2.305	4.570	21.6	0.110	0.063	0.277	0.549
A26	0.960	0.600	2.415	4.789	20.7	0.110	0.068	0.276	0.546
A28	1.009	0.681	2.538	5.032	20.2	0.109	0.074	0.274	0.543
A30	1.062	0.770	2.673	5.299	19.0	0.108	0.079	0.273	0.540
A32	1.121	0.869	2.822	5.595	18.3	0.108	0.084	0.271	0.538
A34	1.188	0.980	2.989	5.926	17.3	0.107	0.088	0.270	0.535
A36	1.263	1.106	3.180	6.304	16.5	0.107	0.093	0.268	0.532
A38	1.348	1.248	3.393	6.728	16.1	0.106	0.098	0.267	0.529
A40	1.445	1.409	3.638	7.212	15.8	0.105	0.103	0.265	0.526
A42	1.558	1.597	3.920	7.772	15.1	0.105	0.108	0.264	0.523
A44	1.691	1.818	4.255	8.436	14.6	0.104	0.112	0.263	0.521
A46	1.846	2.077	4.646	9.212	14.0	0.104	0.117	0.261	0.518
A48	2.033	2.389	5.117	10.145	13.5	0.103	0.121	0.260	0.515
A50	2.263	2.772	5.694	11.289	12.6	0.103	0.126	0.259	0.513

Legend: W = water; C = cement; N = NCPA; S = sand; G = granite

5. Results and Discussion

Substituting the model coefficients into equation (9a) gives the response function for the mix ratios used herein as:

$$y_1 = 346.22\,x_1 + 238.41\,x_2 - 959.49\,x_3 - 54.01\,x_4 - 29.42\,x_1^2 - 83.29\,x_2^2 - 41.26\,x_3^2 + 951.80\,x_4^2 + 409.29\,x_1x_2 + 107.42\,x_1x_3 + 146.28\,x_1x_4 - 278.29\,x_2x_3 + 29.14\,x_2x_4 - 216.73\,x_3x_4 \quad (16)$$

5.1 Visual Basic program for prediction and optimization of the developed model

The visual basic program in accordance to the algorithm below and equation (16) was invoked to select the best mix ratios corresponding to a particular desired compressive strength value and vice versa. To optimize the response function (equation (9)), iteration principle was employed. Since there are four variables, three iterating factors (e_1 = 0.001, e_2 = 0.001 and e_3 = 0.001) were used. The constraints are as set in equation (2) to equation (7). Start the iteration with the first quantities, x_{1min}, x_{2min}, x_{3min} and x_{4min}. Substitute these quantities into equation (1) to get the first set of mix ratios,1[s_1, s_2, s_3 and s_4]. Note: n [ ] denotes nth set. Substitute the first quantities, x1min, x_{2min}, x_{3min} and x_{4min} (That is: 1[x_1, x_2, x_3 and x_4]) into the response function. The first response is taken as ym (optimum response). Now, add the iterating factors (e_1, e_2, and e_3) to the first set of quantities, that is, $x_{1min} + e_1$, $x_{2min} + e_2$ and $x_{3min} + e_3$ respectively, to obtain the second set of quantities, 2[x_1, x_2 and x_3]. Subtract their sum from unity (that is 1) to obtain 2[x_4]. Divide 2[x_1, x_2, x_3 and x_4] by 2[x_2] to get 2[s_1, s_2, s_3 and s_4]. These mix ratios, 2[s_1, s_2, s_3 and s_4] must be subjected the constraints of equation (3) to equation (6). If they pass the tests, then substitute them into the response function. The second response is compared with the first one. If it is more than the first one then it replaces it, if not the first one is retained as ym. This procedure is continued within loop until all the possible combinations of the quantities have been used.

5.2 Test of adequacy of the model

The predicted compressive strength values for the control-mixes as obtained from the program are presented in Table 4. They were compared with the results from the laboratory as shown on Table 4 using F-statistics test at 95% level of confidence. The experimental results varied slightly from the outcome of the formulated model as shown in Table 4. The greatest 28th day strength obtained experimentally and from the model were 24.20N/mm^2 and 22.62N/mm^2 which occurred at 19.5% and 16.5% NCPA replacement respectively. The maximum percentage difference between the experimental outcome and the model solution is 7.3% which is less than 10%. This validates the reliability of the model as it gives exact and accurate solution. Beyond these percentage replacements, the compressive strength of the concrete decreased as the percentage of NCPA replacement increased. This shows that NCPA-Concrete is suitable for structural concrete works provided the replacement does not exceed 20%.

Table 4: F-statistic test of 28days compressive strength model based on Ibearugbulem's approach

Control Point	y_l (N/mm^2)	y_m (N/mm^2)	y_l-$\bar{y_l}$	y_m-$\overline{y_m}$	$(y_l$-$\bar{y_l})^2$	$(y_m$-$\overline{y_m})^2$
A2	20.80	21.84	1.43	2.46	2.0449	6.029596
A4	21.50	22.15	2.13	2.77	4.5369	7.647495
A6	22.20	22.38	2.83	3.00	8.0089	8.98891
A8	22.70	22.53	3.33	3.15	11.0889	9.925044
A10	23.10	22.61	3.73	3.23	13.9129	10.42187
A12	23.70	22.61	4.33	3.23	18.7489	10.46077
A14	24.20	22.55	4.83	3.17	23.3289	10.04628
A16	23.30	22.42	3.93	3.04	15.4449	9.230384
A18	22.90	22.22	3.53	2.84	12.4609	8.076276
A20	22.50	21.96	3.13	2.58	9.7969	6.671562
A22	22.00	21.64	2.63	2.26	6.9169	5.102334
A24	21.60	21.26	2.23	1.88	4.9729	3.534581
A26	20.70	20.82	1.33	1.44	1.7689	2.087244
A28	20.20	20.33	0.83	0.95	0.6889	0.898666
A30	19.00	19.78	-0.37	0.40	0.1369	0.163671
A32	18.30	19.19	-1.07	-0.19	1.1449	0.036039
A34	17.30	18.55	-2.07	-0.83	4.2849	0.694725
A36	16.50	17.85	-2.87	-1.53	8.2369	2.353662
A38	16.10	17.11	-3.27	-2.27	10.6929	5.161977
A40	15.80	16.33	-3.57	-3.05	12.7449	9.328338
A42	15.10	15.50	-4.27	-3.88	18.2329	15.04941
A44	14.60	14.62	-4.77	-4.76	22.7529	22.63458
A46	14.00	13.72	-5.37	-5.66	28.8369	32.08842
A48	13.50	12.77	-5.87	-6.61	34.4569	43.697
A50	12.60	11.79	-6.77	-7.59	45.8329	57.65935
	19.37	19.38			12.84298	11.51953

Where y_l, and y_m are laboratory and predicted values of compressive strength respectively.

$$\bar{y_l} = \frac{\sum y_l}{n} = 19.368$$

$$\overline{y_m} = \frac{\sum y_m}{n} = 19.380$$

$$S_l^{\,2} = \frac{12.84298}{24} = 0.535124$$

$$S_m^{\,2} = \frac{11.51953}{24} = 0.47998$$

The F-statistic is given by:

$$F = \frac{0.535124}{0.47998} = 1.114888$$

From standard statistical table, $F_{0.95} = (24, 24) = 1.94$

The calculated value of F (1.11) is less than the F-value (1.94) obtained from standard statistical table. The model is therefore adequate for the prediction and optimization of compressive strength of NCPA-cement composites.

5.3 Setting Time and Compressive Strength

The R^2-values displayed in Figures 5 to 8 also demonstrated the adequacy of the developed model. The R-squared values of the formulated model is higher than 0.8 more than those obtained from the experimental study. A better and improved performance is achieved with the model which is a major advantage of optimization modelling.

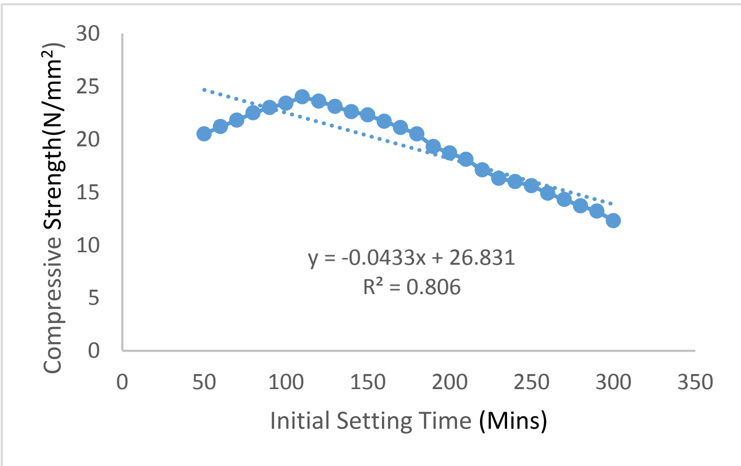

Figure 5: Variation of experimental initial setting time and 28days compressive strength

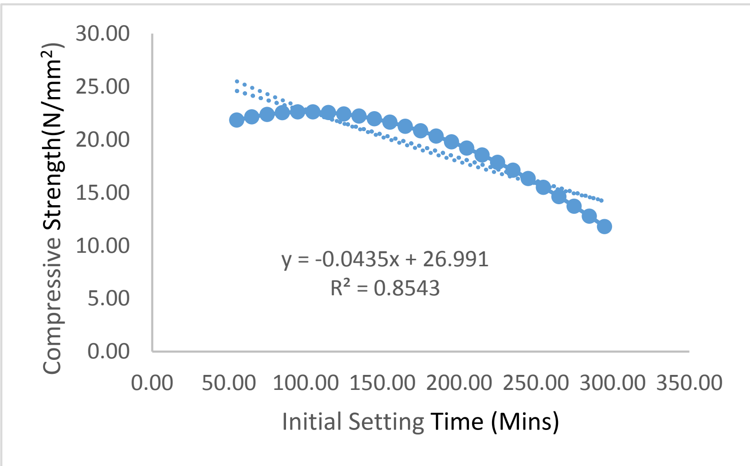

Figure 6: Variation of modelled initial setting time and 28days compressive strength

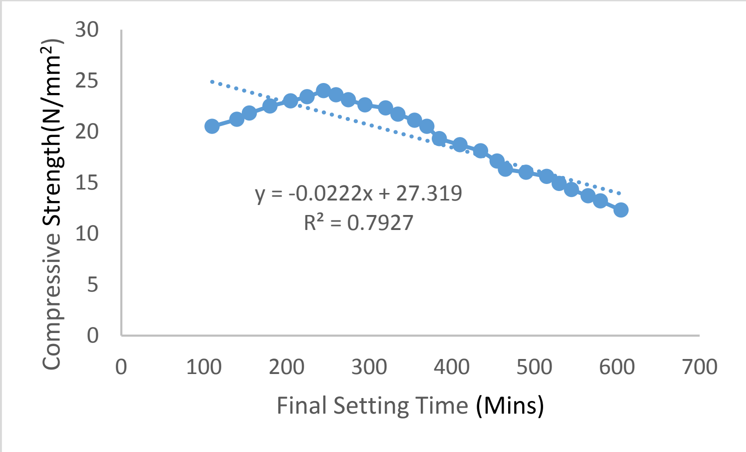

Figure 7: Variation of experimental final setting time and 28days compressive strength

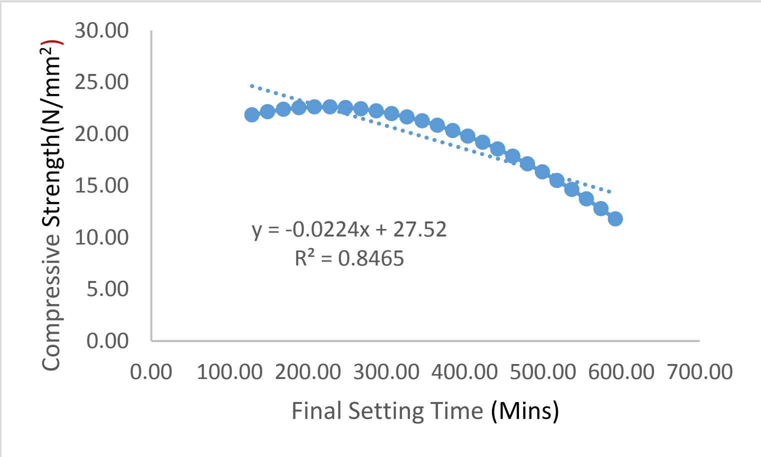

Figure 8: Variation of modelled final setting time and 28days compressive strength

6. Conclusion

Based on Ibearugbulem's new regression function, an excellent mathematical model that predicts and optimizes the compressive-strength of NCPA-cement composites, have been formulated. At 95% confidence level, the developed model was confirmed to be reliable and adequate. With an iterative approach, the optimum values of compressive strength value and mix ratios can be estimated using the written short Visual Basic program, which predicts the desired mix ratios when the strength is known. For easy forecast of compressive strengths of lightweight-concretes whose mix ratios are within the boundaries provided in this research work, this model is recommended for use in concrete and construction industry.

Author contributions

All authors contributed equally to this work.

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Data availability statement

Not applicable.

Conflicts of interest

The authors declare that there is no conflict of interest.

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Appendix 1

```
Private Sub STARTMNU_Click()


    Text1.Text = " "
'ReDim A(50), ZZ(22), AA(6, 6), BB(6, 6), ZY(6)
 Text1.Text = Text1.Text + (" ") & vbCrLf
5   QQ = InputBox("WHAT DO YOU WANT TO DO? TO CALCULATE MIX RATIOS GIVEN DESIRED
28days strength OR CALCULATING 28dys strength GIVEN MIX RATIO?", "IF THE 28days strength IS
KNOWN TYPE 1 ELSE TYPE 0", "TYPE 1 OR 0 and CLICK OK")
   If QQ <> 1 And QQ <> 0 Then EE = InputBox("No Way! You must ENTER 1 or 0", , "CLICK OK and do
so"): GoTo 5
   If QQ = 0 Then GoTo 30
ym = 0
yy = InputBox("WHAT IS 28dys strength?"): yy = yy * 1
Text1.Text = Text1.Text + CStr("28dys strength     " & "   " & " w/c        " & "     c          " & "     N/c       " & "
S/c         " & "     G/c") & vbCrLf
   For z1 = 0.1 To 0.119 Step 0.00025
   For z2 = 0# To 0.128 Step 0.00025
   For z3 = 0.257 To 0.296 Step 0.00025
   z4 = 1 - z1 - z2 - z3
   S = -9618754.09 * z1 ^ 3 + 3272467.7 * z1 ^ 2 - 371430.83 * z1 + 14071.24
   s1 = z1 * S: s2 = z2 * S: s3 = z3 * S: s4 = z4 * S

      Y = 346.22* z1+238.41  * z2 + −959.49* z3 + −54.01* z4
      Y = Y + −29.42* z1 ^ 2 −83.29* z2 ^ 2 + −41.26* z3 ^ 2 +951.80* z4 ^ 2
      Y = Y +409.29* z1 * z2 +107.42* z1 * z3 +146.28* z1 * z4 −278.29 * z2 * z3
      Y = Y + 29.14 * z2 * z4 + −216.73 * z3 * z4

      If s1 < 0.6 Then GoTo 20
      If s1 > 2.4 Then GoTo 20
      If s2 < 0 Then GoTo 20
      If s2 > 3 Then GoTo 20
      If s3 < 1.51 Then GoTo 20
      If s3 > 6.04 Then GoTo 20
      If s4 < 2.993 Then GoTo 20
      If s4 > 11.97 Then GoTo 20
      If Y > ym Then ym = Y: w1 = z1: w2 = z2: w3 = z3: w4 = z4
10     If Y > yy - 0.01 And Y < yy + 0.01 Then GoTo 15 Else GoTo 20
15     ' s1 = z1: s2 = z2: s3 = z3: s4 = z4
      Text1.Text = Text1.Text + CStr(Format(Y, "0.000") & vbTab & "        ") & vbTab
      Text1.Text = Text1.Text + CStr(Format(s1, "0.000") & "  ") & vbTab
      Text1.Text = Text1.Text + CStr(Format(1, "0.000") & "  ") & vbTab
      Text1.Text = Text1.Text + CStr(Format(s2, "0.000") & "  ") & vbTab
      Text1.Text = Text1.Text + CStr(Format(s3, "0.000") & "  ") & vbTab
      Text1.Text = Text1.Text + CStr(Format(s4, "0.000")) & vbCrLf
20
    Next z3
    Next z2
    Next z1
     Text1.Text = Text1.Text + CStr("OPTIMUM 28dys strength PREDICTABLE BY THIS MODEL IS ") &
vbCrLf
      Text1.Text = Text1.Text + CStr(Format(ym, "0.00")) & vbCrLf
      S = -9618754.09 * w1 ^ 3 + 3272467.7 * w1 ^ 2 - 371430.83 * w1 + 14071.24
```

```
        s1 = w1 * S: s2 = w2 * S: s3 = w3 * S: s4 = w4 * S
        Text1.Text = Text1.Text + CStr(" THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:") &
vbCrLf
        Text1.Text = Text1.Text + CStr("     WATER =" & vbTab & vbTab & Format(s1, "0.000")) & vbTab
       Text1.Text = Text1.Text + CStr("     CEMENT =" & vbTab & vbTab & Format(1, "0.000")) & vbTab
        Text1.Text = Text1.Text + CStr("    Cassava Peel Ash =" & vbTab & Format(s2, "0.000")) & vbTab
        Text1.Text = Text1.Text + CStr("     SAND =" & vbTab & vbTab & Format(s3, "0.000")) & vbTab
        Text1.Text = Text1.Text + CStr("    GRAVEL =" & vbTab & Format(s4, "0.000")) & vbCrLf

GoTo 40
30 ' Calculating 28dys strength when mix ratios are known
        s1 = InputBox("ENTER THE VALUE OF W/c"): s1 = s1 * 1
        s2 = InputBox("ENTER THE VALUE OF N/c"): s2 = s2 * 1
        s3 = InputBox("ENTER THE VALUE OF s/c"): s3 = s3 * 1
        s4 = InputBox("ENTER THE VALUE OF g/c"): s4 = s4 * 1
       S = s1 + s2 + s3 + s4
       z1 = s1 / S: z2 = s2 / S: z3 = s3 / S: z4 = s4 / S

       Y = 346.22* z1+238.41  * z2 + −959.49* z3 + −54.01* z4
       Y = Y + −29.42* z1 ^ 2 −83.29* z2 ^ 2 + −41.26* z3 ^ 2 +951.80* z4 ^ 2
       Y = Y +409.29* z1 * z2 +107.42* z1 * z3 +146.28* z1 * z4 −278.29 * z2 * z3
       Y = Y + 29.14 * z2 * z4 + −216.73 * z3 * z4

       Text1.Text = Text1.Text + CStr("28dys strength =" & vbTab & Format(Y, "0.000") & ",") & vbTab
        Text1.Text = Text1.Text + CStr("     WATER =" & vbTab & vbTab & Format(s1, "0.000")) & vbTab
        Text1.Text = Text1.Text + CStr("      CEMENT   =" & vbTab & Format(1, "0.000") & ",") & vbTab
        Text1.Text = Text1.Text + CStr("      Cassava Peel Ash  =" & vbTab & Format(s2, "0.000") & ",") & vbTab
        Text1.Text = Text1.Text + CStr("      SAND  =" & vbTab & Format(s3, "0.000") & ",") & vbTab
        Text1.Text = Text1.Text + CStr("      GRAVEL  =" & vbTab & Format(s4, "0.000") & ",") & vbCrLf

40


End Sub

Private Sub STOPMNU_Click()
End
End Sub
```