



OPTIMIZATION MODEL FOR COMPRESSIVE STRENGTH OF SANDCRETE BLOCKS USING CASSAVA PEEL ASH (CPA) BLENDED CEMENT MORTAR AS BINDER

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ABSTRACT

This research work applies Scheffe's second degree simplex theory to formulate a regression model for the optimization of the compressive strength of sandcrete blocks using cassava peel ash (CPA) blended Portland cement (OPC) as binder material for different mix ratios as multivariate functions with the proportions of the sandcrete block ingredients serving as variables. The experimental values of the compressive strength were obtained by performing destructive strength tests on the blocks after curing for 28 days, with a binder-aggregate ratio of 1:8 and water binder ratio ranging from 0.45 to 0.60, the OPC being replaced with CPA at 0 – 30% for the respective water-binder ratios. The optimization model from the Scheffe's mixture method for a (4, 2) factor space was found to be $y = f(x) = 1.95x_1(2x_1-1) + 1.84x_2(2x_2-1) + 1.81x_3(2x_3-1) + 1.79x_4(2x_4-1) + 6.08x_1x_2 + 5.72x_1x_3 + 1.89x_1x_4 + 7.28x_2x_3 + 1.80x_2x_4 + 7.16x_3x_4$. The model was tested using the student t- test at 95% accuracy and found to be accurate. Thus, the model can be used to predict any desired compressive strength value for CPA- OPC blended sandcrete blocks given any water-cement ratio between 0.45 and 6.0 and vice versa.

Keywords: Sandcrete Blocks, Cassava Peel Ash, Optimization Model, Scheffe's Simplex design and Student t-test.

INTRODUCTION

Predictive modeling is the name given to a collection of mathematical techniques employed to derive mathematical relationships that are generated using experimental data between a dependent variable and a number of independent variables with the sole aim of measuring and inserting the values of the predators into the model to predict or determine the value of the target variable within the shortest possible time [1]. Thus the use of predictive modeling saves time, energy and resources [1].

Mathematical modeling has found various applications in concrete technology, the commonest being the application of predictive models like those derived from Henry Scheffe's mixture models to predict concrete properties like strength [2–6]. Scheffe's mixture model is a single step multiple comparison



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procedure which applies to a set of estimates of all possible contrasts among the factor level means [7]. The model's accuracy can be tested using the student t-test, Fisher's test or other statistical tools.

Concrete and concrete based materials are used extensively in the construction industry and it is generally required that the strength of these products be tested after 28 days curing before they are used. The use of predictive models saves this time by making use of data from previous experimentations to predict target strengths given the water binder ratio and vice versa, which translates to saving of resources.

Sandcrete blocks are building units that are used in the construction of walls and partitions and are usually hollow blocks of varying dimensions, the main constituents being cement, sand and water with the cement acting as the binder. Cement is the most expensive of these constituents and thus reducing the cost of the binder will lead to the reduction in the overall cost of construction. Secondary cementitious materials, known as pozzolana have been used successfully in partial replacement of OPC as binder material in concrete, mortar and the production of sandcrete blocks [8–11]. The pozzolanic properties of CPA have been reported by a number of researchers who have used it successfully in partial replacement of OPC [12–14]. Its use in concrete improves concrete workability, strength and other desirable properties.

In this present work, a predictive model is developed to determine the compressive strength of sandcrete blocks when an OPC-CPA blend is used as binder. The level of replacement of OPC with CPA is between 0 and 30% and a water binder ratio of between 0.45 and 0.6 is used. The model is developed from Scheffe's (4, 2) simplex design for a four component factor space and its reliability tested using the student t-test.

MATERIALS AND METHODS

Materials

The materials used for this research include cassava peels, cement, fine aggregates (sand) and water.

1. Cassava peels: These were collected from a cassava processing mill in Makurdi, Benue state, Nigeria.
2. Fine Aggregates: The fine aggregates used for this research work is river sand, collected from river Benue in Makurdi.
3. Cement: The cement used is grade 42.5 ordinary Portland cement produced by Dangote cement industries plc at the Gboko plant, in Benue state. It was purchased from a retailer in Makurdi.
4. Water: portable water obtained from the water works of the University of Agriculture Makurdi was used for both the production and curing of the blocks.



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Methodology

The methodology for the research work was divided into three parts, viz; characterization of the materials used, production and testing of sandcrete blocks and model development.

In the first part, the materials used for the research work were characterized for specific gravity, setting times, consistency, moisture content, grain size analysis and oxide composition in accordance with the provisions of BS812, BS4550, BS12 and other relevant codes. The CPA used was obtained by calcining cassava peels in a muffle furnace (Calbolite model CWF1400) at 600°C for 2 hours.

The second part of the experimental program involved casting, curing and crushing of 90 number of 450x225x150 non-load bearing sandcrete blocks using OPC-CPA blend at 0, 5, 10, 15, 20, 25 and 30% replacement of OPC with CPA respectively and a water-binder ratios of between 0.45 and 0.6 and a binder aggregate ratio of 0.8. Manual molding was employed and the blocks cured in water for 28 days after which destructive compressive strength tests were performed on them accordingly to obtain the experimental values of the compressive strength used for the model development.

The final part of the experimental program involve the development of the optimization model for the four component (4, 2) factor space using Scheffe's mixture method for a second degree polynomial and testing the accuracy of the model using the student t-test.

RESULTS AND DISCUSSIONS

Preliminary Investigations

The result of material characterization is presented in tables 1 and 2 and figure 1.

Table 1. Characterization of OPC, CPA and sand

S/No.	Property Tested	Material tested		
		OPC	Sand	CPA
1.	Specific Gravity	3.04	2.58	2.32
2.	Setting Times (Mins.): Initial (Final)	47(402)	-	-
3	Moisture content (%)	-	3.0	-
4	Standard consistency (%)	28	-	-
5	Soundness (mm)	1.0	-	-
6	Clay and silt content (%)	-	2.4	-
7	Bulking (%)	-	2.0	-



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Table 2. Oxide composition of CPA and OPC

Oxide	CaO	Fe ₂ O ₃	Al ₂ O ₃	SiO ₂	MgO	K ₂ O	Na ₂ O	SO ₃	LOI
CPA	8.53	1.41	12.80	58.02	5.02	7.67	0.03	2.18	4.19
OPC	65.57	6.83	5.60	16.20	-	0.48	-	2.15	0.09

The result of the particle size distribution of the fine aggregate used in the research is presented in figure 1.

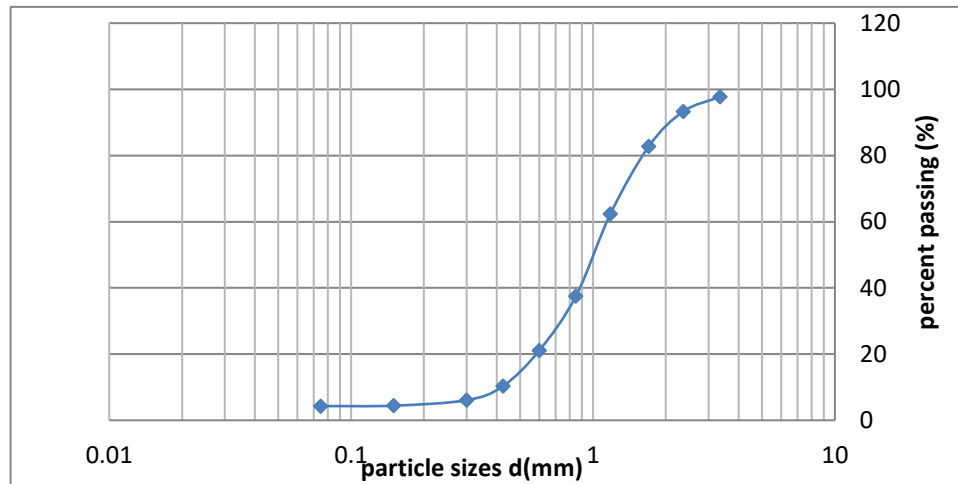


Figure 1. Result of Sieve analysis

$$Cu = \frac{D_{60}}{D_{10}} = 2.67$$

$$Cc = \frac{D_{30}^2}{D_{60} \times D_{10}} = 0.91$$

The result of the characterization of the materials presented in tables 1 and 2 and figure 1 indicates that the materials used for this research meet the specifications of the relevant codes for construction materials. The CPA meets the requirement of ASTM C618 for pozzolanic materials.

Tests on Sandcrete Blocks

Table 3 gives the result of the water absorption and compressive strength of the sandcrete blocks at 28 days of curing.



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Table 3. 28 day strength of Sandcrete blocks

S/No	Weight [Kg]	% water absorbed	w/c	% Replacement	Compressive Strength [N/mm ²]
1	16.52	11.48	0.45	5	1.96
2	16.50	11.46	0.45	10	1.90
3	16.52	11.52	0.50	5	1.95
4	16.72	11.53	0.50	10	1.84
5	16.65	11.53	0.50	15	1.81
6	16.62	11.30	0.50	20	1.79
7	16.82	11.44	0.50	25	1.52
8	16.52	11.54	0.50	30	1.43
9	16.52	11.43	0.55	5	1.89
10	16.52	11.48	0.55	10	1.82
11	16.51	11.49	0.55	15	1.80
12	16.51	11.51	0.55	20	1.79
13	16.51	11.50	0.55	25	1.51
14	16.53	11.42	0.55	30	1.42
15	16.54	11.36	0.60	5	1.90
16	16.53	11.54	0.60	10	1.81
17	16.54	11.56	0.60	15	1.79
18	16.54	11.57	0.60	20	1.76
19	16.53	11.58	0.60	25	1.48
20	16.52	11.53	0.60	30	1.39

Model development

Simon et al., (1997), gave the general regression equation as

$$y = b_0 + \sum b_i X_i + \sum b_{ij} X_i X_j + \sum b_{ijk} X_i X_j X_k + \dots + \sum b_{i_1, i_2, \dots, i_n} X_{i_1}, X_{i_2}, \dots, X_{i_n} + e \text{ ----- (1)}$$

Where,

$$1 \leq i \leq q, 1 \leq i \leq j \leq q, 1 \leq i \leq j \leq k \leq q \text{ and } 1 \leq i; 1 \leq \dots \leq i_n \leq q \text{ respectively}$$

Since we are dealing with a four component mixture (i.e. OPC, CPA, water and Sand), we expand eqn. 1 up to second order (4, 2) polynomial. Thus we have,



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$$y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_{11}X_1^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{22}X_2^2 + b_{23}X_2X_3 + b_{24}X_2X_4 + b_{33}X_3^2 + b_{34}X_3X_4 + b_{44}X_4^2 + e \text{ ----- (2)}$$

According to Scheffe (1958) and Obam (1998), the summation of all pseudo components must equate to 1, i.e. $\sum X_i = 1$ or $X_1 + X_2 + X_3 + X_4 = 1$ ----- (3)

Multiplying eqn. (3) by b_0 and X_i respectively, we obtain

$$b_0X_1 + b_0X_2 + b_0X_3 + b_0X_4 = b_0 \text{ ----- (4)}$$

$$X_1^2 = X_1 - (X_1X_2 + X_1X_3 + X_1X_4) \text{ ----- (5)}$$

$$X_2^2 = X_2 - (X_1X_2 + X_2X_3 + X_2X_4) \text{ ----- (6)}$$

$$X_3^2 = X_3 - (X_1X_3 + X_3X_3 + X_3X_4) \text{ ----- (7)}$$

$$X_4^2 = X_4 - (X_1X_4 + X_2X_4 + X_3X_4) \text{ ----- (8)}$$

Substituting eqn. (4) to (8) into eqn. (2) and re-arranging, we obtain

$$y = Y_0 + Y_1X_1 + Y_2X_2 + Y_3X_3 + Y_4X_4 + Y_{11}X_1^2 + Y_{12}X_1X_2 + Y_{13}X_1X_3 + Y_{14}X_1X_4 + Y_{23}X_2X_3 + Y_{24}X_2X_4 + Y_{34}X_3X_4 + b_{44}X_4^2 + e \text{ ----- (9)}$$

Where $Y_i = b_0 + b_i + b_{ij}$ and $Y_{ij} = b_{ij} - b_{ii} - b_{jj}$

Eqn. (9) can be written as eqn. (10) by dropping the e (estimated error) term without loss of generality.

$$y = Y_0 + Y_1X_1 + Y_2X_2 + Y_3X_3 + Y_4X_4 + Y_{11}X_1^2 + Y_{12}X_1X_2 + Y_{13}X_1X_3 + Y_{14}X_1X_4 + Y_{23}X_2X_3 + Y_{24}X_2X_4 + Y_{34}X_3X_4 + b_{44}X_4^2 \text{ -----(10)}$$

Let n_i be the compressive strength of the pure components (i.e. first four mix ratios) and n_{ij} of the mixture (remaining six mix ratios). Substituting for n_i and n_{ij} and the corresponding pseudo mix ratios into eqn. (10) gives respectively

$$n_i = Y_i \text{ ----- (11)}$$

$$n_{ij} = 0.5Y_i + 0.05Y_j + 0.25Y_{ij} \text{ ----- (12)}$$

Re-arranging eqn. (11) and (12) gives



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$$Y_i = n_i \text{-----} (13)$$

$$Y_{ij} = 4n_i - 2n_{ij} - 2n_j \text{-----} (14)$$

Substituting eqns. 13 and 14 into 10 and collecting like terms yields

$$y = f(x) = n_1X_1(1 - 2X_2 - 2X_3 - 2X_4) + n_2X_2(1 - 2X_1 - 2X_3 - 2X_4) + n_3X_3(1 - 2X_1 - 2X_2 - 2X_4) + n_4X_4(1 - 2X_1 - 2X_2 - 2X_3) + 4n_{12}X_1X_2 + 4n_{13}X_1X_3 + 4n_{14}X_1X_4 + 4n_{23}X_2X_3 + 4n_{24}X_2X_4 + 4n_{34}X_3X_4 \text{-----} (15)$$

Multiplying eqn. 3 by 2, subtracting 1 from both sides and re-arranging, we have

$$2X_1 - 1 = 1 - 2X_2 - 2X_3 - 2X_4 \text{-----} (16)$$

Using the same logic,

$$2X_2 - 1 = 1 - 2X_1 - 2X_3 - 2X_4 \text{-----} (17)$$

$$2X_3 - 1 = 1 - 2X_1 - 2X_2 - 2X_4 \text{-----} (18)$$

$$2X_4 - 1 = 1 - 2X_1 - 2X_2 - 2X_3 \text{-----} (19)$$

Substituting eqns. 16 – 19 into eqn. 15 gives

$$f(x) = n_1X_1(2X_1 - 1) + n_2X_2(2X_2 - 1) + n_3X_3(2X_3 - 1) + n_4X_4(2X_4 - 1) + 4n_{12}X_1X_2 + 4n_{13}X_1X_3 + 4n_{14}X_1X_4 + 4n_{23}X_2X_3 + 4n_{24}X_2X_4 + 4n_{34}X_3X_4 \text{-----} (20)$$

Where, n_i and X_i are the coefficients of response and pseudo components of the mix respectively.

Equation 20 is the Scheffe’s optimization or the response function for the optimization of the compressive strength of sandcrete blocks (using OPC-CPA blend as binder) consisting of four components.

Model Optimization

Scheffe (1958) and Obam. (1998) related the actual mix ratios with the pseudo mix ratios by the formulation,

$$Z = AX \text{-----} (21)$$

Where, Z = Actual mix ratios



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X = Corresponding pseudo mix ratios

A = coefficient of relation matrix.

A is obtained by transposing the first four actual mix ratios. The matrices are $Z_1[0.45:0.95:0.05:8.0]$; $Z_2[0.50:0.90:0.10:8.0]$; $Z_3[0.55:0.80:0.20:8.0]$ and $Z_4[0.60:0.85:0.15:8.0]$. These and the corresponding pseudo mix ratios can be expressed in matrix notation as follows

$$\begin{bmatrix} 0.45 & 0.95 & 0.05 & 8.0 \\ 0.50 & 0.90 & 0.10 & 8.0 \\ 0.55 & 0.80 & 0.20 & 8.0 \\ 0.60 & 0.85 & 0.15 & 8.0 \end{bmatrix} = A \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Substituting X_i and Z_i into eqn. (i) give the values of the relation matrix.

$$A = \begin{bmatrix} 0.45 & 0.50 & 0.55 & 0.6 \\ 0.95 & 0.90 & 0.80 & 0.85 \\ 0.05 & 0.10 & 0.20 & 0.15 \\ 8.00 & 8.00 & 8.00 & 8.00 \end{bmatrix}$$

These four pure components are located at the vertices of the tetrahedron simplex as shown in figure 2 (a) and (b) for real and pseudo components respectively.



Figure 2. (a) A (4, 2) simplex lattice in actual factor space, **(b)** Simplex lattice in pseudo factor space

Six other pseudo mix ratios located at the mid-point of the line joining the vertices are used to find the corresponding real or actual mix ratios. These are given in table 4.



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Table 4. Ten mix ratios (actual and pseudo) obtained from Scheffe’s (4, 2) factor space

Points	Actual Mix Ratios				Pseudo Mix Ratios			
	Water Z_1	CPA Z_2	OPC Z_3	Sand Z_4	water X_1	CPA X_2	OPC X_3	Sand X_4
N1	0.45	0.05	0.95	8	1	0	0	0
N2	0.50	0.10	0.90	8	0	1	0	0
N3	0.55	0.15	0.85	8	0	0	1	0
N4	0.60	0.20	0.80	8	0	0	0	1
N5	0.475	0.075	0.925	8	$\frac{1}{2}$	$\frac{1}{2}$	0	0
N6	0.500	0.100	0.900	8	$\frac{1}{2}$	0	$\frac{1}{2}$	0
N7	0.525	0.125	0.875	8	$\frac{1}{2}$	0	0	$\frac{1}{2}$
N8	0.525	0.125	0.875	8	0	$\frac{1}{2}$	$\frac{1}{2}$	0
N9	0.550	0.150	0.850	8	0	$\frac{1}{2}$	0	$\frac{1}{2}$
N10	0.575	0.175	0.825	8	0	0	$\frac{1}{2}$	$\frac{1}{2}$

Substituting n_i, n_j, n_{ij} and the corresponding pseudo mix ratios into eqn (20) and solving, we obtain the model equation as shown in eqn. 22.

$$y = 1.95X_1(2X_1 - 1) + 1.84X_2(2X_2 - 1) + 1.81X_3(2X_3 - 1) + 1.79X_4(2X_4 - 1) + 6.08X_1X_2 + 5.72X_1X_3 + 1.89X_1X_4 + 7.28X_2X_3 + 1.80X_2X_4 + 7.16X_3X_4 - - - - - (22)$$

Ten extra points are used to test the model’s validity. These are labeled c_i and c_j and the result of the experimental and model predicted values of the compressive strength are given in table 5.



Table 5. Experimental and Predicted values of Compressive Strengths

Points	% replacement	W/C	Experimental	Predicted
N ₁	5	0.45	1.96	1.96
N ₂	10	0.45	1.90	1.90
N ₃	5	0.5	1.95	1.95
N ₄	10	0.5	1.84	1.84
N ₅	15	0.5	1.81	1.81
N ₆	20	0.5	1.79	1.79
N ₇	25	0.5	1.52	1.52
N ₈	30	0.5	1.43	1.43
N ₉	5	0.55	1.92	1.93
N ₁₀	10	0.55	1.82	1.82
C ₁	15	0.55	1.80	1.80
C ₂	20	0.55	1.78	1.78
C ₃	25	0.55	1.51	1.50
C ₄	30	0.55	1.42	1.41
C ₅	5	0.60	1.90	1.91
C ₆	10	0.60	1.81	1.80
C ₇	15	0.60	1.79	1.77
C ₈	20	0.60	1.76	1.75
C ₉	25	0.60	1.48	1.49
C ₁₀	30	0.60	1.39	1.40

Model Validation

The validation of the second degree polynomial model was carried out using the student t-test at 95% accuracy level. The two hypotheses tested are that:

- There is no significant difference between the experimental values of the compressive strength of the sandcrete blocks and the predicted values from the model at 95% accuracy. This is the null hypothesis (h_0).
- There is a significant difference between the experimental values of the compressive strength of the sandcrete blocks and the predicted values from the model at 95% accuracy. This is the alternate hypothesis (h_1).

Given that, y_E = Responses from experiment



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y_M = Responses from model

N = Number of observations,

Then $D_i = y_E - y_M$

$$D_A \text{ (mean of difference of } y_E \text{ and } y_M) = \frac{\sum D_i}{N}$$

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

$$t_{\text{calculated}} = \frac{D_A \times N^{0.5}}{S}$$

The result is presented in table 6.

Table 6. Student t – test for the optimization model

O. P	y_E	y_M	$D_i = y_E - y_M$	$D_A - D_i$	$(D_A - D_i)^2$
C ₁	1.80	1.80	0.00	-0.005	0.000025
C ₂	1.78	1.78	0.00	-0.005	0.000025
C ₃	1.51	1.50	0.01	0.005	0.000025
C ₄	1.42	1.41	0.01	0.005	0.000025
C ₁₂	1.90	1.91	-0.01	-0.015	0.000225
C ₁₃	1.81	1.80	0.01	0.005	0.000025
C ₁₄	1.79	1.77	0.02	0.015	0.000225
C ₂₃	1.76	1.75	0.01	0.005	0.000025
C ₂₄	1.48	1.49	-0.01	-0.015	0.000225
C ₃₄	1.39	1.40	0.01	0.005	0.000025
$\sum D_i$			0.05	$\sum (D_A - D_i)^2$	0.002275

O. P = observation point

$$D_A = \frac{\sum D_i}{N} = \frac{0.05}{10} = 0.005$$

$$S^2 = \frac{\sum (D_A - D_i)^2}{N-1} = 0.0002528$$

$$S = 0.0159$$

Actual value of total variation



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$$t_{calc.} = \frac{D_A X N^{0.5}}{s} = 0.994$$

Allowable total variation in t- test

Degree of freedom = $N - 1 = 9$

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

$1 - 2.5 = 97.5\% = 0.975$

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.

CONCLUSIONS

The following conclusions are made from the strength of this research work:

1. CPA can be used in partial replacement of OPC in the production of sandcrete blocks
2. Scheffe's simplex theory can be applied in generating a mathematical model for a (4, 2) factor space for the compressive strength of sandcrete blocks using CPA-OPC blend as binder.
3. The model for the optimization of the compressive strength of sandcrete blocks using CPA-OPC blend as binder has been obtained as $y = 1.95X_1(2X_1 - 1) + 1.84X_2(2X_2 - 1) + 1.81X_3(2X_3 - 1) + 1.79X_4(2X_4 - 1) + 6.08X_1X_2 + 5.72X_1X_3 + 1.89X_1X_4 + 7.28X_2X_3 + 1.80X_2X_4 + 7.16X_3X_4$, and has been tested using the student t-test and found to be adequate for prediction of the compressive strength of sandcrete blocks within a water-binder ratio of 0.60 and replacement of OPC with 0 to 30% of CPA.
4. The optimum compressive strength predicted by the model is 1.96N/mm^2 corresponding to a water binder ratio of 0.45 at 5% replacement of OPC with CPA and a mix ratio of 0.45:0.5:0.95:8.

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