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Modeling the Strength Properties of OPC/RPFA Concrete

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ABSTRACT

This study developed mathematical models for the prediction of the Compressive, strength characteristics of OPC/RPFA concrete. Ordinary Portland Cement (OPC) was replaced with 10% RPFA, 15% RPFA, 20% RPFA, 25% RPFA and 30% RPFA using a mix ratio of 1:2:4 for the concrete and water-cement ratio of 0.5. The concrete cubes were removed from the moulds and cured in a water tank for 7, 14, 21, and 28 days. Several tests were conducted on Raffia Palm Fuel Ash, (RPFA) and OPC/RPFA concrete. The tests included a sieve analysis test, specific gravity test, slump test, Rapid Chloride Permeability Test (RCPT), water absorption test, Thermogravimetric analysis test (TGA), chemical composition test, and compressive strength test. A design matrix was produced using "Design Expert 10". The line of best fit was decided for each of the strength properties. The developed models showed that the cubic and quartic models of the independent variable (RPFA) significantly affected the compressive strength of the material (dependent variable-OPC/RPFA concrete). The models produced showed an accuracy of 99.28% for the compressive strength. For the compressive strength properties, there was a correlation between the predicted values from the models and the actual values from the experiments. Thus, the models were validated.

1. Introduction

Concrete is the second most utilized material after water by man for construction purposes. Its usage is second only to that of water, an important component needed to promote the hydraulic action of cement, a principal binder in concrete. [1] Apart from water and cement, other constituents of concrete include aggregates (coarse and fine) as well as admixtures. The process of cement production consumes lots energy and is a major contributor to global warming.

The urgent need for affordable and eco-friendly building materials in providing adequate housing for the teaming population of the world has become a major worry to researchers. The cost of most building materials continues to increase as the majority of the global population becomes poorer. This thereby the reason for the urgent need to use alternative local materials as total or partial replacement for cement in concrete. The quest has led to the discovery of the potentials of agricultural wastes and other pozzolanas as cementitious materials. The utilization of agricultural

waste products in cement production is an eco-friendly method of disposal of large amounts of materials that would have constituted pollution to land, water and air [2].
According to Sooraj [4], for concrete production, the reduction of cement content in concrete can be achieved by utilization of supplementary cementitious materials such as fly ash, blast furnace slag, natural pozzolans, and biomas ash. Raffia palm, also known as Raphiahookeri is the largest palm in Africa and is restricted to the tropics, the ideal ecological condition for its growth. Similar to palm oil, the raffia palm is one of the most economically utilized plants in Africa.
Over the past few years, many researches have been conducted on the possibility of replacing cement with pozzalanic materials. Safiuddin et al [5], proposed the use of Palm Oil Fuel Ash (POFA) as partial replacement ranging from 0-30% by weight of the total cement in the production of concrete. Karim et al [6], discovered that the concrete produced using a particular level of Palm Oil Fuel Ash (POFA) replacement achieved same or more strength when compared to Ordinary Portland Cement (OPC) concrete. Nowkhare et al [7], carried out experimental research on the strength performance of concrete using Portland pozzolana Cement and Sugarcane Bagasse Ash (SCBA). They were able to show that the finely grounded SCBA can replace cement and also contributes to higher compressive strengths than normal concrete. Umeonyiagu [8], developed mathematical models for predicting the compressive strength characteristics of Sugar Cane Bagasse Ash Concrete (SCBAC) using Scheffe's (5, 2) polynomial. A study was conducted to investigate the acid resistance of concrete containing Sugar Cane Straw Ash (SCSA) by Obilade [9]. He used SCSA to partially replace Portland cement by weight of cement in order to produce SCSA concrete. Olatusi and Olutoge [10], conducted an investigation into the strength properties of Palm Kernel Shell Ash concrete. The main goal of their work was to increase the quantity and also lower the cost of construction materials used by the construction industry in developing countries, by reducing the volume of cement usage in concrete works. SooraJ [11] investigated on the effect of Palm Oil Fuel Ash (POFA) on the compressive, flexural and the tensile properties of concrete. The experimental results revealed that POFA is an excellent pozzolana which serves as a useful substitute for cement in concrete.
Under this study, the effect of Raffia Palm Fuel Ash (RPFA) substitution on the compressive, properties of concrete will be investigated. The optimum percentage replacement and strength of RPFA-based concrete specimens and the rate of water absorption will be evaluated after curing in water for 28 days.

2. Methodology

2.1 Materials

The type of cement selected for this study is Ordinary Portland Cement (OPC). Elephant Supaset conforming to the Nigerian cement standards (NIS 444-1: 2003) and EN 197-1:2011 specifications, was used in all concrete mixtures. Raffia Palm Fuel Ash (RPFA) is a material produced from the process of recycling local Raffia palm fiber or from burning local palm dead fronds which were obtained from Mbutu, Aboh Mbaise Local Government Area, Imo State in the eastern region of Nigeria. The local palm ash is sourced from wastage by the process of heating the raw material in an oven for 7 hours. The local palm firewood is first produced which turns into local palm coal and after burning the waste together with those from the straw we get the Raffia Palm Fuel Ash. In this research, Raffia Palm Fuel Ash passing 425 µm sieve is used. 10%, 15%, 20% 25% and 30% Raffia of Palm Fuel Ash (RPFA) will be used as a replacement for OPC.
The coarse and fine aggregates used are crushed granite and river sand, respectively from local quarries Abakaliki in Nigeria. The grading of the fine aggregates conformed to BS 882 (1992). Sieve analyses for both RPFA and sand were conducted with sieve sizes No. 4, 10, 40, 100, and 200. The concrete mix ratio of 1:2:4 was kept constant in all the concrete mixtures with a water/cement ratio of 0.50.

The water used for the study was obtained from a borehole or underground water extracted using a submersible pump. The water was clean and portable. It conformed to BS EN 1008:2002 requirements.
Six concrete mixtures were prepared inside the laboratory using neat OPC and six percentage replacement levels (0%, 10%, 15%, 20%, 25%, and 30%) of Raffia Palm Fuel Ash to OPC. The concrete constituents were weighed in required proportions and mixed in a concrete mixer.

2.2 Mix Proportions of Concrete Specimens

Batching by weight was used in this study. RPFA were used to replace OPC at dosage levels of 0%,10%,15%, 20% ,25% and 30% replacement by weight of cement. The amount of ingredients used are calculated as follows:

$No. of\ Cubes\ per\ Batch = 48\ \ (Twelev\ cubes\ each\ for\ ages\ 7, 14, 21\ and\ 28\ days\ tests)$

Batch are Control Mix, 0% RPFA Replacement, 10% RPFA Replacement, 15% RPFA Replacement, 20% RPFA Replacement,25% RPFA Replacement,30% RPFA Replacement

$Size\ of\ each\ cube = 150mm \times 150mm \times 150mm$

$Volume\ of\ \ each\ Cube\ =\ 150mm^3\ =\ 3.375 \times 10^{-3}m$

$Volume\ of\ 48\ cubes = 48 \times 3.375 \times 10^{-3} = 0.162\ m^3$

$conrete\ mix\ ratio\ of\ 1:2:4 = Cement: Sand: Coarse\ Aggregate$

$Volume\ of\ Cement = \frac{1}{7} \times 0.162 = 0.023\ m^3$

$Standard\ mass\ of\ Concrete\ per\ unit\ volume\ = 2400\ kg$

Therefore,

$Mass\ of\ cement\ in\ one\ Batch = 2400 \times 0.023 = 55.2kg$

Similarly,

$Volume\ of\ sand = \frac{2}{7} \times 0.162\ m^3 = 0.046\ m^3$

$Mass\ of\ sand = 2400\ \times 0.046 = 110.4kg$

$Volume\ of\ Coarse\ Aggregate = \frac{4}{7} \times 0.162m^3 = 0.093\ m^3$

$Mass\ \ of\ Coarse\ Aggregate = 2400$ x 0.093 =223.2kg

The water to cement ratio used in the course of this study was 0.5 and this was helpful in the estimation of the amount or weight of water required in each batch

$Mass\ of\ water = 0.5 \times mass\ of\ binder\ (Cement)$= $0.5 \times 55.2 = 27.6\ kg$

For 10% of OPC Replacement with RPFA:

$Mass\ of\ RPFA\ =\ 0.1 \times 55.2 = 5.52kg$

$Mass\ of\ OPC = 55.2 - 5.52 = 49.68kg$

For 15% of OPC Replacement with RPFA:

$Mass\ of\ RPFA\ =\ 0.15 \times 55.2 = 8.28kg$

$Mass\ of\ OPC = 55.2 - 8.28 = 46.92kg$

For 20% of OPC Replacement with RPFA:

$Mass\ of\ RPFA\ =\ 0.2 \times 55.2 = 11.04kg$

$Mass\ of\ OPC = 55.2 - 11.04 = 44.16kg$

For 25% of OPC Replacement with RPFA:

$Mass\ of\ RPFA\ =\ 0.25 \times 55.2 = 13.8kg$

$Mass\ of\ OPC = 55.2 - 13.8 = 41.4kg$

For 30% of OPC Replacement with RPFA:

$Mass\ of\ RPFA\ =\ 0.3 \times 55.2 = 16.56kg$

$$Mass\ of\ OPC = 55.2 - 16.56 = 38.64kg$$

2.3 Concrete Production

Oiled metallic moulds, free from impurities were arranged close to the platform. The concrete was placed into the moulds in three layers. Each layer was compacted 25 times using a rammer. The excess concrete on the mould was removed and levelled with the help of a hand trowel. The fresh concrete was left in the mould for 24 hours. The specimens were demoulded the next day and immersed in a water tank for 28 days. This procedure was followed in accordance with BS 1881: Part 111, 1983. At the end of the curing period, the specimens were taken for a crushing test.

2.4 Test

The effect of Raffia palm fibre ash (RPFA) substitution on concrete specimens was assessed by measuring the following mechanical and durability properties: The chemical composition analysis was conducted to determine the mineralogical analysis of RPFA, and chemical composition analysis for RPFA was determined for silica, Ca, K, Mg, Na, Al, and Fe. Loss on Ignition was done as per the standard method (IS 269-1989).

Slump tests were conducted on the wet concrete to determine its workability. A slump cone mould of diameters 200 mm and 100 mm, and a height of 300 mm was filled with concrete in three layers of equal volume. Each layer was given 25 blows using a rammer. The slump cone mould was lifted vertically and the change in height of the concrete was measured to the nearest millimetre of 1mm. Compressive strengths were determined at intervals of 3, 7, 14, and 28 days of curing on 150 mm cube mortar specimens, as per BS 1881: Part 116 (1983), and tested using a compression testing machine at a standard loading rate.

3. Results and Discussion

3.1 Experimental Mix Design

The concrete mix design for Compressive Strength Tests is shown in Table 1.

Table 1: Concrete Mix Design for compressive strength test

Constituent Materials	0% RPFA (Control)	10 % RPFA	15% RPFA	20 % RPFA	25% RPFA	30 % RPFA
Cement (kg)	55.2	49.68	46.92	44.16	41.4	38.64
RPA (kg)	0.0	55.52	8.28	11.04	13.8	16.56
Fine Aggregate (kg)	110.4	110.4	110.4	110.4	110.4	110.4
Coarse Aggregates (kg)	223.2	223.2	223.2	223.2	223.2	223.2
Water-Cement Ratio	0.5	0.5	0.5	0.5	0.5	0.5
Water (kg)	27.6	27.6	27.6	27.6	27.6	27.6

3.2. Strength Characteristic Tests Results

The compressive strength development for OPC/RPFA concrete alongside the curing periods is given in Table 2.

Table 2: The Compressive Strength Test Results of 7 to 28 days curing

Amount of Cement (%)	Amount of RPFA (%)	Design Strength (N/mm^2)			
		7 Days	14 Days	21 Days	28 Days
100	0	11.34	18.52	20.60	22.54
90	10	8.28	15.10	16.75	19.32
85	15	7.43	13.72	15.18	17.89
80	20	6.58	12.34	13.61	16.405
75	25	5.98	11.82	12.79	15.41
70	30	5.38	11.30	11.97	14.36

Concrete specimens prepared with 100% OPC registered the highest early strength, followed by 10% RPFA,15% RPFA, 20% RPFA, 25% RPFA and 30% RPFA OPC/RPFA specimens (Table 1). The 7-day compressive strength of 100% OPC, 10% RPFA,15% RPFA, 20% RPFA,25% RPFA, and 30% RPF OPC/RPFA specimens were 11.34, 8.28, 7.43,6.58,5.98, and 5.38 N/mm^2, respectively. Similar to early strength development, the 28-day strength development was the highest in 100% OPC specimens and the lowest strengths were achieved in both 25% and 30% RPFA OPC/RPFA specimens with little difference (Figure 1, Table 4). The 28-day compressive strength of 100% OPC specimens was 22.54 N/mm^2 which is about 14.3%,20.6%, 27.2%,31.6%, and 36.3% more than that of 10% RPFA,15% RPFA, 20% RPFA,25% RPFA, and 30% RPFA OPC/RPFA specimens, respectively.

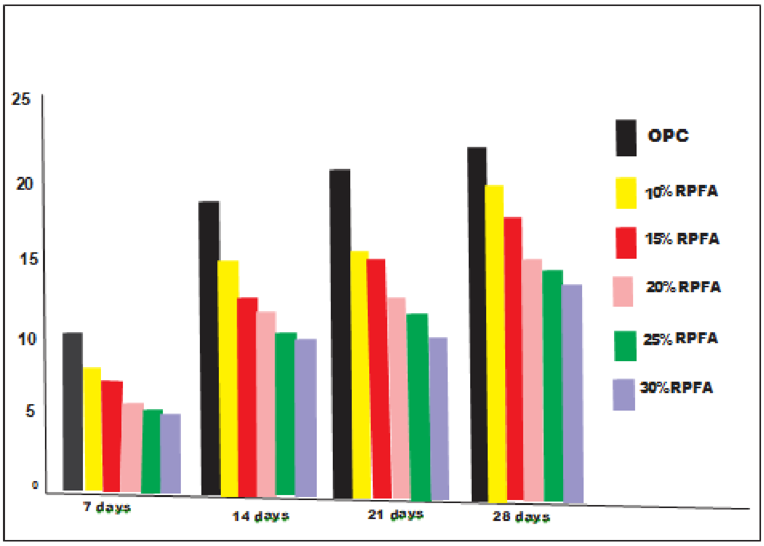

Figure 1. Bar Chart of the Compressive Strength Development of OPC/RPFA concretes at Different Ages

3.3 Slump Test

The slump test is a popular method used to determine the consistency of concrete. The variation in level between the height of the mould and that of the greatest point of the subsided wet concrete when the mould is removed is known as the slump. The workability of concrete increases as the measured height of the slump increases.

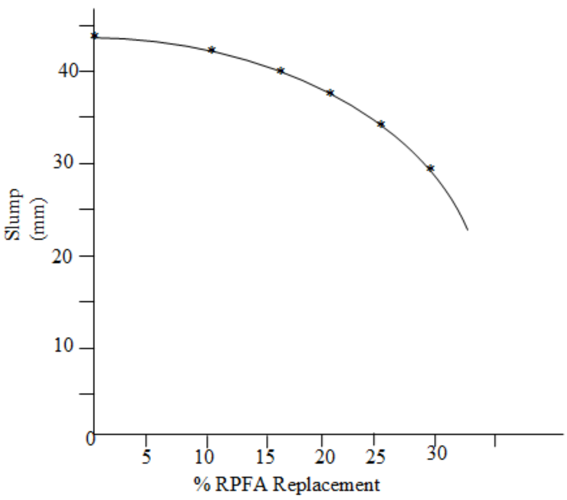

Figure 2: Percentage Replacement of OPC with RPFA in OPC/RPFA Concrete

From Figure 2 above, 100% OPC (0%RPFA replacement) has the highest slump of 43.6mm which indicates concrete of higher workability. As the substitution of RPFA increases from 10% to 30% in the OPC/RPFA concrete, the slump decreases from 42.1mm, 39.05mm, 36mm, 33mm, and 30mm respectively which shows decreasing workability of concrete.

3.4 Fineness Test Results

Based on the finite test, the fineness of RPFA was measured by sieving it on a standard sieve. The proportion of RPFA of which particle sizes are greater than 90 microns was determined to be 0.8%.

3.5 Sieve Analysis Test for RPFA

The result of the sieve analysis test conducted on Raffia Palm Fuel Ash (RPFA) is displayed in Table 3.The result is displayed on the sieve analysis graph shown in Figure 3.

Table 3: Sieve Analysis Result Table for RPFA

Sieve Size (mm)	Percentage Passing
0.600	100.00%
0.425	54.66%
0.300	28.37%
0.212	13.40%
0.150	7.06%
0.075	2.81%
0.063	0.77%

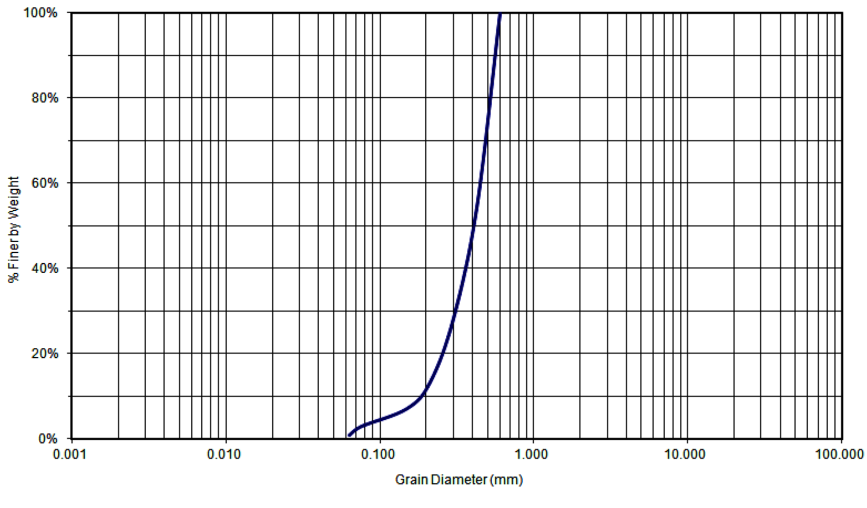

Figure 3. Particle Size Distribution Curve for RPFA

3.6: Modeling of the Compressive Strengths of OPC/Raffia Palm Fuel Ash (RPFA) Concrete

The *p-value for linear (<0.0001), quadratic (<0.0001), cubic (<0.0001) and quartic terms (0.0109) are* less than the level of significance (0.05), thereby rejecting the null hypothesis of no relationship between the dependent and the independent variables, also the lower the p-value and higher the predicted R-squared value, the greater the statistical significance of the results. Since the linear, quadratic, cubic and quartic terms are statistically significant, we observe that the cubic term with the highest predicted R- square value of 0.9928 indicates that the model parameters can 99.28% accurately predict the variation in the dependent variable and the response (Compressive strength). This also conformed with the quartic term of 99.27% accuracy. Therefore, the cubic and quartic models of the independent variable significantly affect the compressive strength of the material (dependent variable).

Table 4: Design Matrix

RUN	FACTOR 1 A:CEMENT/RPFA (%)	FACTOR 2 B: TIME (DAYs)	RESPONSE 1 COMPRESSIVE STRENGTH N/mm²
1	70	14	11.3
2	100	7	11.34
3	80	14	12.34
4	90	14	15.1
5	85	14	13.72
6	75	21	12.49
7	90	28	19.32
8	70	28	14.36
9	90	21	16.75
10	70	21	11.97
11	90	7	8.28
12	75	28	15.41
13	75	7	5.98
14	100	21	20.6
15	85	21	15.18
16	100	28	22.54
17	70	7	5.38
18	80	21	13.61
19	85	28	17.89
20	75	14	11.82
21	85	7	7.43
22	80	28	16.45
23	100	14	18.52
24	80	7	6.58

Table 5: Compressive Strength Analysis

	Sequential p-value	**Lack of Fit p-value**	**Adjusted R-Squared**	**Predicted R-Squared**	
Linear	< 0.0001		0.9090	0.8900	
2FI	**Table 4.14 Line of Best Fit Source**		0.9101	0.8892	
Quadratic			0.9659	0.9557	
Cubic	< 0.0001		0.9982	0.9928	Suggested
Quartic	0.0109		0.9992	0.9927	Aliased

Table 6: Sequential Model Sum of Squares (Type 1)

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Mean vs Total	4383.73	1	4383.73			
Linear vs Mean	450.25	2	225.13	115.83	< 0.0001	
2FI vs Linear	2.44	1	2.44	1.27	0.2726	
Quadratic vs 2FI	25.25	2	12.63	17.32	< 0.0001	
Cubic vs Quadratic	12.57	4	3.14	80.18	< 0.0001	Suggested
Quartic vs Cubic	0.38	4	0.096	5.85	0.0109	Aliased
Residual	0.16	10	0.016			
Total	4874.79	24	203.12			

Table 7: Model Summary Statistics

Source	Std. Dev	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	1.39	0.9169	0.9090	0.8900	54.00	
2FI	1.39	0.9219	0.9101	0.8892	54.43	
Quadratic	0.85	0.9733	0.9659	0.9557	21.77	
Cubic	0.20	0.9989	0.9982	0.9928	3.53	Suggested
Quartic	0.13	0.9997	0.9992	0.9927	3.58	

The model with the lowest predicted residual error sum of squares (PRESS), and a higher predicted R-Squared with a very low Standard deviation (SD) of the independent variables will have a major impact on the compressive strength of the material. Thus from the above model summary statistics, we observed that the cubic model has the lowest value of Predicted residual error sum of squares (PRESS) of 3.53 (that is, the sum of the squares of all the resulting prediction errors is 3.53%), with 99.28% prediction accuracy between the factors or independent variables and the compressive strength of the material and with SD of 0.20 which shows that the data are clustered closely around the mean (more reliable). {\displaystyle \operatorname {PRESS} =\sum _{i=1}^{n}(y_{i}-{\hat {y}}_{i,-i})^{2}}Therefore, from the model summary results, the cubic model of the independent variable considerably affect the compressive strength of the material (dependent variable).

The statistical significance is checked using the analysis of variance (ANOVA) table. The overall model *p-value* (<0.0001) is less than the level of significance (0.05). Therefore, the model hypothesis is statistically significant. The *p-value* for the linear terms for both factors (Cement/RPFA and Time), are also lower than the level of significance. Therefore, the linear terms significantly affect the compressive strength of the material. Also, the interaction between the Cement/RPFA and Time was observed to be statistically significant to the compressive strength since the p-value is <0.0001. Consequently, the *p-value* for the square terms (quadratic) for both

factors is also observed to be lower than the level of significance. Therefore, the quadratic terms for Cement/RPFA and Time significantly affect the compressive strength of the material.
Whereas the p-value for the cubic term shows that only the factor 'Time' significantly affects the compressive strength while Cement/RPFA effect is insignificant because its p-value (0.5233) is greater than the level of significance (0.05).

Table 8: ANOVA for Response Surface Cubic model

Analysis of variance table [Partial sum of squares - Type III]						
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob> F**	
Model	490.52	9	54.50	1390.39	< 0.0001	significant
A-CEMENT/RPA	17.14	1	17.14	437.38	< 0.0001	
B-TIME	2.83	1	2.83	72.31	< 0.0001	
AB	2.44	1	2.44	62.30	< 0.0001	
A^2	4.27	1	4.27	108.94	< 0.0001	
B^2	21.68	1	21.68	553.08	< 0.0001	
A^2B	0.084	1	0.084	2.14	0.1660	
AB^2	0.70	1	0.70	17.93	0.0008	
A^3	0.017	1	0.017	0.43	0.5233	
B^3	11.77	1	11.77	300.23	< 0.0001	
Residual	0.55	14	0.039			
Cor Total	491.07	23				

Table 9: Final Equation in Terms of Coded Factors

COMPRESSIVE STRENGTH	=
+14.69	
+4.21	* A
+1.72	* B
+0.65	* AB
+1.01	* A^2
-2.17	* B^2
-0.19	* A^2B
-0.59	* AB^2
-0.14	* A^3
+3.52	* B^3

The model for the prediction of the Compressive Strength characteristic of the OPC/RPFA concrete is: $+14.69 + 4.21A + 1.72B + 0.65AB + 1.01A^2 – 2.17B^2 – 0.19A^2B - 0.59AB^2 – 0.14A^3 + 3.52B^3$ - - - - - - - - (4.1)

The above equation shows how the compressive strength of the material can be predicted from the independent variables (A = Cement/RPFA, B= Time) and if all terms are set to zero, the compressive strength value will be 14.69N/mm^2

The residuals follow approximately a straight line in the pp-plot (normal probability plot) in Figure 4, indicating there is a normal distribution for the residuals.

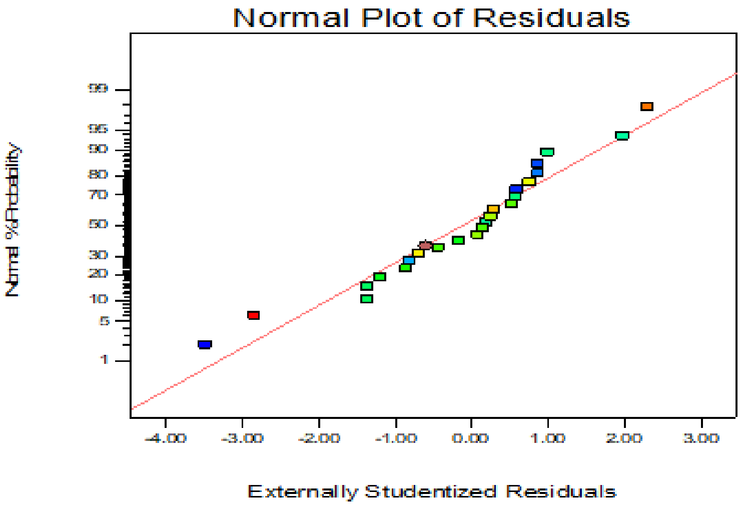

Figure 4. Normal Plot Vs Residual

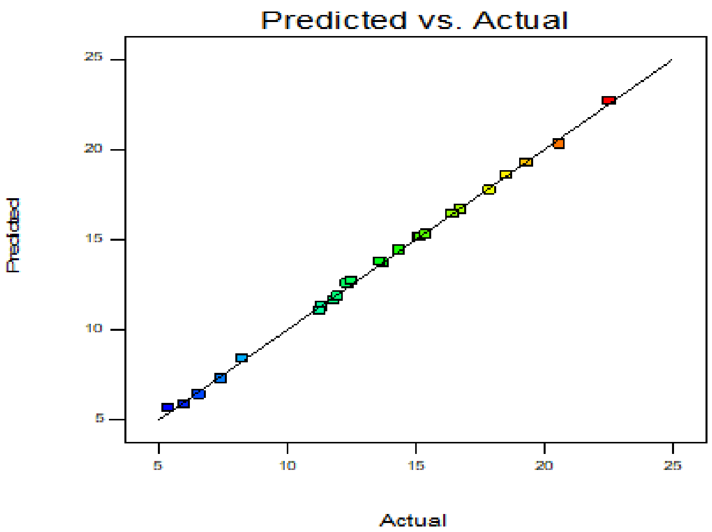

Figure 5 Predicted Value Vs. Actual Value

From Figure 5, there was a perfect correlation between the actual values and the predicted values, which signifies that there is a very good agreement with the model predictions and experimental results.

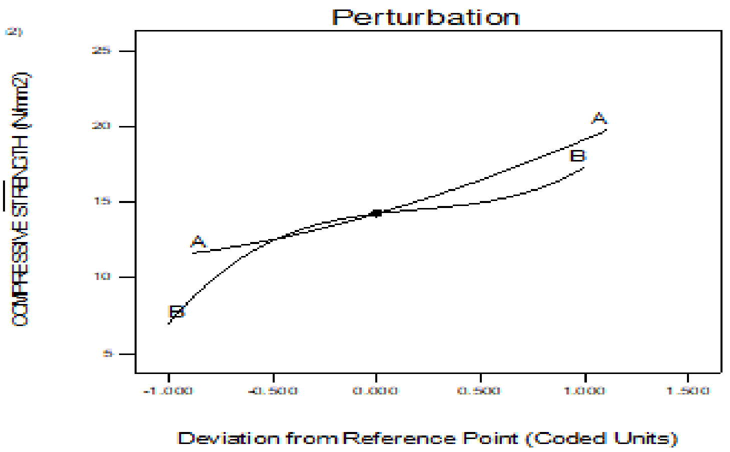

Figure 6. Perturbation Graph for the Compressive Strength Test

The use of the perturbation graph is to compare the effects of all the factors at a particular point in the design space as shown in Figure 6. Therefore, from Figure 7, we observed that compressive strength is very sensitive to variation of the Time (curvature) whereas it is insensitive to changes in % Cement/RPFA

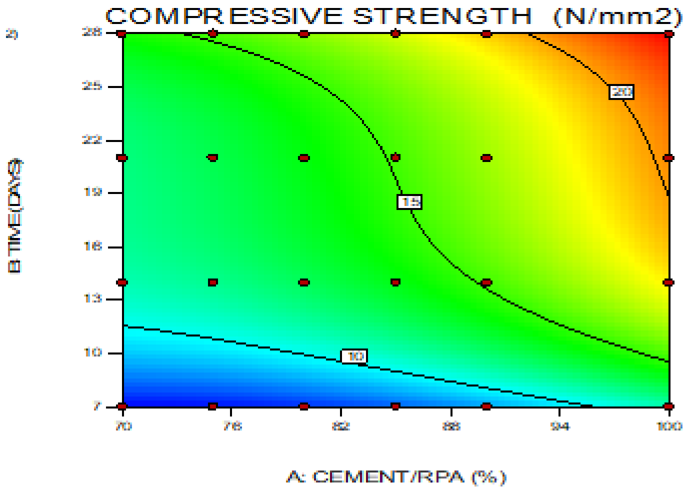

Figure 7. Contour Plot of Compressive Strength Vs %Cement/RPFA and Time

From Figure 7, we observed that the minimum compressive strength of<10N/mm^2 was obtained between 70% to 95% of cement/RPFA within 7 to 12 days whereas the maximum compressive strength 0f +20N/mm^2 was seen between 95% to 100% cement/RPA and within 19 to 28 days. It shows that as %cement/RPA increase with time (days), the compressive strength increases.

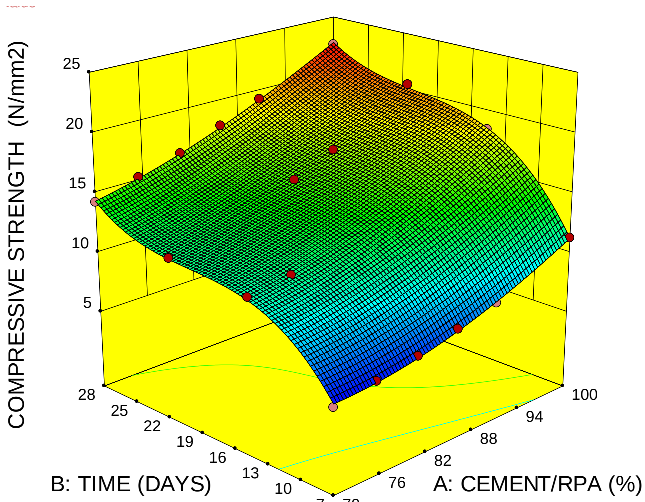

Figure 8. Surface Plot for the Compressive Strength

From Figure 8 Surface Plot, we observed that as Cement/RPFA (%) and Time (days) increase, the compressive strength of the material increases simultaneously and vice versa.

5. Conclusion

The purpose of this study is to derive models for the prediction of the Compressive Strength characteristics of OPC/RPFA concrete. Ordinary Portland Cement (OPC) was replaced with 10% RPFA, 15% RPFA, 20% RPFA, 25% RPFA, and 30% RPFA using a concrete mix ratio of 1:2:4 and a water-cement ratio of 0.5. The concrete cubes were de-moulded and cured in a water tank for 7, 14, 21, and 28 days. Several tests were conducted on fresh and hardened RPFA concrete. The tests include sieve analysis, specific gravity, slump test, chemical composition test, and compressive strength test. A design matrix was produced using “Design Expert 10”. The line of best fit was decided for each of the strength properties. The models produced showed an accuracy of 99.28% for the compressive strength. For all the strength properties, there was a predicted correlation between the predicted values from the models and the actual values from the experiments.

Based on the results of this study, the following conclusions were made:

1. The strength of concrete increased with days of curing and decreased with an increasing percentage of RPFA replacements of binder in concrete.
2. The use of RPFA to partially replace cement led to a lower water absorption rate and a reduced setting time of concrete.
3. The use of RPFA will reduce the amount and cost of cement used in the production of concrete.
4. The use of RPFA will reduce the environmental pollution arising from the indiscriminate dumping of raffia palm wastes.
5. Compressive strength of OPC/RPFA concrete specimens was found to be smaller when compared with those of normal OPC concrete.
6. The 28th-day compressive, flexural, and tensile strength of the OPC/RPFA concretes with 10% RPFA were about comparable to the 28th-day strengths of the 100% OPC concrete.
7. The models produced were extremely accurate (above 92%) for each strength property.

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