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Cost Predictions and Implications of Using Periwinkle Shell Ash in the Partial Replacement of Cement for Rigid Pavement

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Abstract
The cost implication of using periwinkle shell ash in the partial replacement of cement for rigid pavement construction is presented. Cost optimization model was developed to predict the cost of PSA cement concrete. Regression models relating compressive strength and cost per cubic metre of PSA cement concrete were also developed. Calcined PSA (at 800^0C) was used in the preparation of concrete specimens. Design mixes developed using Scheffe's simplex lattice theory was represented in kilogram per cubic metres with concrete density assumed to be 2400 Kg/m^3. Scheffe's second-degree polynomial was used in the derivation of the cost optimization model and regression analysis was used in the derivation of relationship models using cost estimations from design trial mixes. These mathematical models were subjected to validation test using Fisher's test with the aid of results from control mixes. The mean absolute percentage error (MAPE) method was adopted in comparing model values and experimental values of PSA cement concrete. From the results of this study, the cost of cement concrete was reduced with introduction of periwinkle shell ash. The average amount saved in using periwinkle shell ash in cement replacement for concrete production was discovered to be ₦1 792.52 per cubic metre. The derived models' values compared well with experimental values' as evident from the F-statistics and MAPE studies conducted.

Keywords: Periwinkle shell ash, rigid pavement, cost implication.

1. Introduction
The concept of quality road provision with reduction in the financial implications due to the ever-increasing cost of constituent materials has always been encouraged all over the world most especially, in developing countries like Nigeria. Rigid pavement is one pavement type whose major load bearing component is a concrete slab. The high cost involved in the construction of this pavement type despite its numerous advantages often discourage the construction industry from its production. This increase is usually attributed to the cost of cement which is always on the rise.

In order to ensure production of low-cost rigid pavements and other construction applications requiring the use of cement, researchers are consequently considering the use of locally available alternative materials most especially, those occurring in waste forms from different sectors of the economy [1]. The selection of locally available materials depends on the factors, such as, economy, compatibility and availability [2]. The quality of concrete is a measure of the quality of component materials which is reflected by the measured mechanical properties of the concrete such as compressive strength [3].

Some of these locally available materials, are pozzolanic materials. These materials are called pozzolanic materials because they contain siliceous and aluminous oxides in satisfactory percentages ([4]; [5]). Some possible replacements have been detected from the mining industry, commercial industry and even from the agricultural industry.

Periwinkle shell ash (PSA), a product from periwinkle shells of the agricultural industry, occurring in abundance in the Tropics was used in the study in the partial replacement of cement for concrete production. Periwinkle shells have been found to possess siliceous and aluminous oxides [6].

Although there have been different researches on the application of periwinkle shell ash in partial replacement of cement ([7], [8]), there is no study on the financial implications involved in the usage of periwinkle shell ash in cement concrete production for rigid pavement. This study was aimed at evaluating the effect of PSA usage in the partial replacement of cement on the cost of cement concrete production and also determination of cost per cubic metre predictive models using Scheffe's optimization theory and regression analysis. Apart from cost per cubic metre optimization models, relationship models between cost per cubic metre and compressive strength were also developed from regression analysis.

2. Materials and Methods

2.1. Materials

All materials used in this study were sourced locally within the Port Harcourt City Metropolis.

- Dangote 3X (R. 425, CB 4227) Portland cement which met the requirements of BS 12 [9] was used in this study. This cement was obtained from a local cement store in Port Harcourt, Rivers State.
- Uniformly graded river sand and granite were used as fine and coarse aggregates respectively. These aggregates were obtained from a construction site in Port Harcourt. The sand was a zone II sand with a fineness modulus of the medium class according to IS – 383 [10] and IS - 2386 [11] respectively. The granite also met the requirements of a coarse aggregate according to both specifications.
- Calcined periwinkle shells at 800^{0}C (being the optimum calcination temperature of periwinkle shells according to [8] was used in the production of PSA through a granulation process. These periwinkle shells were obtained from a waste assemblage in Port Harcourt. These burnt periwinkle shells were allowed to cool freely in the furnace and finely crushed and sieved where the portion passing sieve No. 200 (75µm) was used for the purpose of experiments.
- Water free of dirt and other organic matter was used for experimental purpose in this study. This water was obtained from the Civil Engineering laboratory, University of Port Harcourt.

2.2. Methods

2.2.1. Research Design

This study involved experimental investigations to determine the effect of PSA usage as partial replacement of cement on the cost per cubic metre construction of rigid pavement. The study also involved development of cost predictive models in the form of optimization and relationship models. Scheffe's simplex lattice theory was used in the design of experimental matrix where the cost per cubic metre and compressive strengths of hardened concrete specimens were determined. In developing the cost per cubic metre optimization and relationship models, the cost estimations of PSA cement concrete of design trial mixes were used. The cost estimations of design control mixes were adopted in validating derived models. Cubic moulds of 150mm size were used in production of PSA cement concrete and were cured by complete immersion in water before determination of compressive strength after 28 days of curing.

2.2.2. Classification of Materials

The chemical composition of PSA was determined in a chemical laboratory in Port Harcourt. This substance was classified appropriately according to BS EN 197 – 1 [12].

The aggregates were classified using gradation, fineness modulus and USCS method of classification. The gradation and fineness modulus were determined according to IS – 383 [10] and IS - 2386 [11] respectively. The USCS method uses the coefficients of uniformity and curvature obtained from the particle size distribution curve in the classification aggregates. The coefficients were obtained using Equations (1) and (2) respectively.

Coefficient of Uniformity, $C_U = \frac{D_{60}}{D_{10}}$ (1)

Coefficient of Curvature, $C_C = \frac{D_{30}^2}{D_{60} X\, D_{10}}$ (2)

Where:

D_{60} = particle size corresponding to 60% finer particles

D_{30}= particle size corresponding to 30% finer particles

D_{10}= particle size corresponding to 10% finer particles

An aggregate is considered well graded when these conditions are met: $4<C_U<6$ and $1<C_C<3$, otherwise, it is considered a uniformly graded soil.

2.2.3. Design Matrix Development

Scheffe [13] uses the simplex lattice concept in combining mixture components. Jackson [14] defined a simplex as a structural representation (shapes) of lines or planes joining assumed points of constituent materials of a mixture and which such points are equidistant from each other. According to Scheffe [13], a (q, m) mixture, with q being the number of component materials and m being the maximum number of component interactions, has number of points given as;

$$N=\frac{(q+m-1)!}{(q-1)!\,m!} \quad (3)$$

Where; q = number of components materials; m = maximum number of interactions

Application of Equation (3) for a (5, 2) component mixtures gave a value of 15 number of experimental points giving rise to the simplex lattice shown in Figure 1. The five component materials used in this study were; PSA, water, cement, sand and granite.

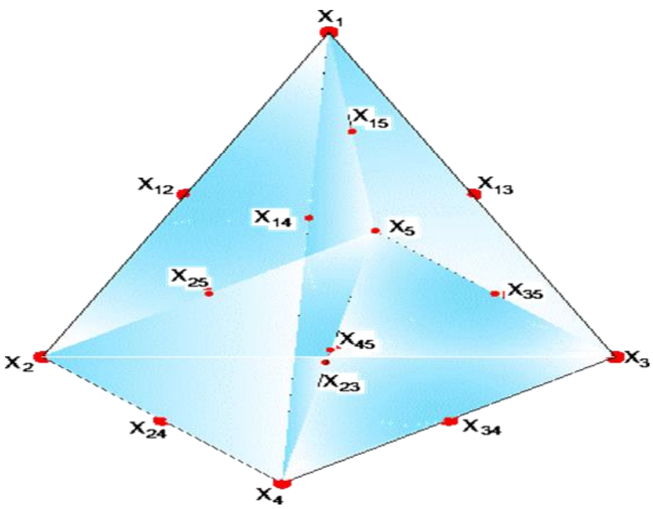


Figure 1. (5, 2) simplex lattice adopted in this study.

According to Scheffe, mixture proportions are being represented in pseudo (theoretical) mix ratios. Pure substance exists at the vertices points and the method rely on the condition that the summation of all pseudo mix ratios at any point must be equal to 1. Mathematically;

$$\sum_{i=1}^{q} x_i = 1 \qquad (4)$$

To achieve the condition of Equation (4), actual mix ratios must be converted to pseudo mix ratios. The relationship between pseudo and actual mix ratios is given by;

$$Z = [A]X \qquad (5)$$

Where:
Z = column matrix of real component ratio.
X = column matrix of pseudo component ratio.
[A]= coefficient matrix which is the transpose of the permutation matrix.

Matrix A was obtained as the transpose of the permutation matrix. This permutation matrix was obtained from intelligent and conservative guesses of cement concrete mix ratios. In this study, the PSA was limited in the range of 5% and 25%, consequently limiting the cement ratio in the mix to range of 75% to 95%. The water binder ratio was limited between 0.4-0.6. The fine aggregate was limited to the range of 1 – 2.5 while the coarse aggregate was between 2- 5. At the vertices, where pure substances were assumed to exist, the mix ratios are given as; (0.45, 0.95, 0.05, 2, 4), (0.5, 0.90, 0.10, 1, 2), (0.55, 0.85, 0.15, 1.75, 3.5), (0.40, 0.80, 0.20, 1.25, 2.50) and (0.60, 0.75, 0.25, 2.5, 5.00) for these points, resulting in the permutation matrix $[P]^0$ represented by Equation (6). In Kilogram per cubic metre, where the density of cement concrete was assumed to be 2400Kg/m^3, $[P]^0$ gave rise to $[P]^1$ represented by Equation (7).

$$[P]^0 = \begin{Bmatrix} 0.45 & 0.95 & 0.05 & 2 & 4 \\ 0.50 & 0.90 & 0.10 & 1 & 2 \\ 0.55 & 0.85 & 0.15 & 1.75 & 3.5 \\ 0.40 & 0.80 & 0.20 & 1.25 & 2.50 \\ 0.60 & 0.75 & 0.25 & 2.50 & 5.00 \end{Bmatrix} \qquad (6)$$

$$[P]^1 = \begin{Bmatrix} 144.9664 & 306.0403 & 16.10738 & 644.2953 & 1288.591 \\ 266.6667 & 480 & 53.33333 & 533.3333 & 1066.667 \\ 194.1176 & 300 & 52.94118 & 617.6471 & 1235.294 \\ 202.1053 & 404.2105 & 101.0526 & 631.5789 & 1263.158 \\ 158.2418 & 197.8022 & 65.93407 & 659.3407 & 1318.681 \end{Bmatrix} \qquad (7)$$

With a corresponding pseudo mix matrix;

$$[X] = \begin{Bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{Bmatrix} \qquad (8)$$

The transpose of matrix $[P]^0$ becomes;

$$[A] = \begin{Bmatrix} 0.45 & 0.50 & 0.55 & 0.40 & 0.60 \\ 0.95 & 0.90 & 0.85 & 0.80 & 0.75 \\ 0.05 & 0.10 & 0.15 & 0.20 & 0.25 \\ 2 & 1 & 1.75 & 1.25 & 2.50 \\ 4 & 2 & 3.50 & 2.50 & 5.00 \end{Bmatrix} \qquad (9)$$

With the pseudo mix proportions of the centre or interaction points of Figure 1 being;
X_{12} [0.5 0.5 0 0 0] X_{14} [0.5 0 0 0.5 0] X_{23} [0 0.5 0.5 0 0] X_{25} [0 0.5 0 0 0.5] X_{35} [0 0 0.5 0 0.5]
X_{13} [0.5 0 0.5 0 0] X_{15} [0.5 0 0 0 0.5] X_{24} [0 0.5 0 0.5 0] X_{34} [0 0 0.5 0.5 0] X_{45} [0 0 0 0.5 0.5]

Tables 1 and 2 represent the trial and control mix designs of PSA cement concrete mixes respectively after proper application of Equation 5. The actual mix ratios were expressed in kilogram per cubic metre.

Table 1: Design Matrix for Trial Mixes.

N	Pseudo Component					Real component				
	X_1	X_2	X_3	X_4	X_5	Z_1(water)	Z_2(cement)	Z_3(PSA)	Z_4(sand)	Z_5(granite)
1	1	0	0	0	0	144.9664	306.0403	16.10738	644.2953	1288.591
2	0	1	0	0	0	266.6667	480	53.33333	533.3333	1066.667

3	0	0	1	0	0	194.1176	300	52.94118	617.6471	1235.294
4	0	0	0	1	0	202.1053	404.2105	101.0526	631.5789	1263.158
5	0	0	0	0	1	158.2418	197.8022	65.93407	659.3407	1318.681
6	½	½	0	0	0	190.795	371.5481	30.12552	602.5105	1205.021
7	½	0	½	0	0	168.4211	303.1579	33.68421	631.5789	1263.158
8	½	0	0	½	0	161.9048	333.3333	47.61905	619.0476	1238.095
9	½	0	0	0	½	152.2659	246.5257	43.50453	652.568	1305.136
10	0	½	½	0	0	223.0088	371.6814	53.09735	584.0708	1168.142
11	0	½	0	½	0	223.8342	422.7979	74.6114	559.5855	1119.171
12	0	½	0	0	½	194.1176	291.1765	61.76471	617.6471	1235.294
13	0	0	½	½	0	190.795	331.3808	70.29289	602.5105	1205.021
14	0	0	½	0	½	173.5849	241.5094	60.37736	641.5094	1283.019
15	0	0	0	½	½	168.4211	261.0526	75.78947	631.5789	1263.158

Table 2: Design Matrix for Control Mixes.

N	Pseudo Component					Real component				
	X_1	X_2	X_3	X_4	X_5	Z_1(water)	Z_2(cement)	Z_3(PSA)	Z_4(sand)	Z_5(granite)
1	1/3	1/3	1/3	0	0	192	345.6	38.4	607.9872	1216.013
2	1/3	1/3	0	1/3	0	189.4737	371.9158	49.13684	596.5053	1192.968
3	1/3	0	1/3	1/3	0	173.2074	321.6602	49.47191	618.5659	1237.095
4	1/3	1/3	0	0	1/3	202.1053	296.447	45.59408	627.064	1254.162
5	¼	¼	¼	¼	0	190.795	351.4644	50.20921	602.5105	1205.021
6	¼	¼	¼	0	¼	180.9695	297.307	47.39677	624.7756	1249.551
7	¼	¼	0	¼	¼	178.626	311.4504	54.96183	618.3206	1236.641
8	0	¼	¼	¼	¼	192.5636	309.9804	65.75342	610.5675	1221.135
9	3/10	1/10	1/5	1/5	1/5	172.2988	297.607	50.47136	626.541	1253.082
10	1/5	1/5	1/10	3/10	1/5	180.8858	315.1515	57.80886	615.3846	1230.769
11	1/5	1/5	1/5	3/10	1/10	185.6567	330.701	56.0838	609.1861	1218.372
12	1/5	1/5	1/5	1/5	1/5	181.8182	309.0909	54.54545	618.1818	1236.364
13	3/20	¼	1/5	1/5	1/5	186.9043	315.2267	56.7222	613.7156	1227.431
14	1/5	1/5	3/20	¼	1/5	181.3579	312.0829	56.1565	616.8009	1233.602
15	¼	1/5	1/5	1/5	3/20	181.3579	316.6858	51.55351	616.8009	1233.602

2.2.4. Optimization Model Development

For a (q, m) polynomial, where q represents the number of variables and m represents the degree of the polynomial, Equation (10) gives the general form;

$$\underset{i\le 1\le q}{\overset{n}{Y}} = b_0 + \sum_{i\le 1\ge j\le q} b_i X_i + \sum_{1\le 1\le j\le q} b_{ij} X_j X_{ij} + \ldots\ldots\ldots + \sum b_{ijk} + \sum b_{i1i2\ldots\ldots\ldots} \; in \; X_{i1} X_{i2} \ldots\ldots X_{in} \quad (10)$$

Where; $1 \le i \le q$, $1 \le i \le j \le q$, $1 \le i \le j \le k \le q$, and b is the constant coefficient.
x is the pseudo component for constituents i , j , and k

For (5, 2) polynomial, Equation (10) becomes;

$$\tilde{Y} = b_0 + b_1X_1 + b_2X_2 + b_3 X_3 + b_4 X_4 + b_5 X_5 + b_{12}X_{12}X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{15}X_1X_5 + b_{25} X_2X_5 + b_{24}X_2X_4 + b_{23}X_2X_3 + b_{25}X_3X_5 + b_{34}X_3X_4 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{44}X_4^2 + b_{55}X_5^2 \quad (11)$$

Equation (4) also becomes;

$$X_1 + X_2 + X_3 + X_4 + X_5 = 1 \quad (12)$$

Multiplying through by constant b_0, yields Equation (13).

$$b_0X_1 + b_0X_2 + b_0X_3 + b_0X_4 + b_0X_5 = b_0 \quad (13)$$

Again, multiplying Equation (12) by X_1, X_2, X_3, X_4, and X_5 in succession and rearranging, Equation (14) was produced.

$$\left.\begin{aligned} X_1^2 &= X_1 - X_1X_2 - X_1X_3 - X_1X_4 - X_1X_5 \\ X_2^2 &= X_2 - X_1X_2 - X_2X_3 - X_2X_4 - X_2X_5 \\ X_3^2 &= X_3 - X_1X_3 - X_2X_3 - X_3X_4 - X_3X_5 \\ X_4^2 &= X_4 - X_1X_4 - X_2X_4 - X_3X_4 - X_4X_5 \\ X_5^2 &= X_5 - X_1X_5 - X_2X_5 - X_3X_5 - X_4X_5 \end{aligned}\right\} \quad (14)$$

Substituting Equations (13) and (14) into Equation (11), Equation (15) was obtained after necessary transformation.

$$\tilde{Y} = (b_0 + b_1 + b_{11}) X_1 + (b_0 + b_2 + b_{22}) X_2 + (b_0 + b_3 + b_{33}) X_3 + (b_0 + b_4 + b_{44}) X_4 + (b_0 + b_5 + b_{55}) X_5 + (b_{12} - b_{11} - b_{22}) X_1X_2 + (b_{13} - b_{11} - b_{33}) X_1X_3 + (b_{14} - b_{11} - b_{44}) X_1X_4 + (b_{15} - b_{11} - b_{55}) X_1X_5 + (b_{23} - b_{22} - b_{33}) X_2X_3 + (b_{24} - b_{22} - b_{44}) X_2X_4 + (b_{25} - b_{22} - b_{55}) X_2X_5 + (b_{34} - b_{33} - b_{44}) X_3X_4 + (b_{35} - b_{33} - b_{55}) X_3X_5 + (b_{45} - b_{44} - b_{55}) X_4X_5 \quad (15)$$

Denoting; $B_i = b_0 + b_i + b_{ii}$ and
$B_{ij} = b_{ij} – b_{ii} - b_{jj}$

The resultant reduced second degree polynomial in 5 variables is presented by Equation (16).

$$\tilde{Y} = B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_5X_5 + B_{12}X_1X_3 + B_{13}X_1X_3 + B_{14}X_1X_4 + B_{15}X_1X_5 + B_{23}X_2X_3 + B_{24}X_2X_4 + B_{25}X_2X_5 + B_{34}X_3X_4 + B_{35}X_3X_5 + B_{45}X_4X_5 \quad (16)$$

The number of coefficients has reduced from 20 in Equation (11) to 15 in Equation (16). Thus, the reduced second degree polynomial in q-variables in general form is;

$$\tilde{Y} = \sum_{1 \le i \le q} B_i X_i + \sum_{1 \le i \le q} B_{ij} X_i X_j \quad (17)$$

Where, Y is a dependent variable (cost per cubic metre of PSA cement concrete).
Substituting the lattice coordinates of pure substance occurrence into Equation (16) yielded;

$$\left.\begin{aligned} Y_1 &= B_1 \\ Y_2 &= B_2 \\ Y_3 &= B_3 \\ Y_4 &= B_4 \\ Y_5 &= B_5 \end{aligned}\right\} \quad (18)$$

For interaction point X_{12} of Figure 1;

$$Y_{12} = ½ X_1 + ½ X_2 + ¼ X_1X_2$$
$$= ½B_1 + ½B_2 + ¼B_{12} \quad (19)$$

From Equation (18); $B_i = Y_i$, where i = 1, 2, 3,…….n. Then substituting into Equation (19) yielded:

$$Y_{12} = (½)Y_1 + (½)Y_2 + (¼) B_{12} \quad (20)$$

Simplifying Equation (20), yielded:

$$B_{12} = 4Y_{12} – 2Y_1 – 2Y_2 \quad (21)$$

Similarly, Equations (22) to (25) were developed. Thus:

$$B_{13}= 4Y_{13} – 2Y_1 – 2Y_3 \quad (22)$$
$$B_{14}= 4Y_{14} – 2Y_1 – 2Y_4 \quad (23)$$
$$B_{15}= 4Y_{15} – 2Y_1 – 2Y_5 \quad (24)$$
$$B_{23} = 4Y_{23} – 2Y_2 – 2Y_3 \quad (25)$$

Generalizing, Equations (18) to (25), Equation (26) was formed.

$$\left.\begin{aligned} B_i &= Y_i \\ B_{ij} &= 4Y_{ij} – 2Y_i – 2Y_j \end{aligned}\right\} \quad (26)$$

2.2.5. Relationship Models' Development

Regression analysis was employed in relating the compressive strength and cost per cubic metre of PSA cement concrete. These models were in linear, polynomial, logarithmic, exponential and power (General and ACI-0.5) forms.

Linear regression model: $Y = Dx + C$ (27)
Second degree Polynomial model: $Y = Dx^2 + Cx + E$ (28)
Logarithmic model: $Y = D\,Inx + C$ (29)
Exponential model: $Y = De^{CX}$ (30)
General Power model: $Y = Dx^C$ (31)
0.5- power model: $Y = Dx^{0.5}$ (32)

Where; D, C and E are regression constants and Y, X represents response parameters; Cost per cubic metre and compressive strength of PSA cement concrete respectively.

2.2.6. Compressive Strength Test

The compressive strength of the hardened concrete was carried out in accordance to appropriate specifications [15]. The apparatus used for this test were: Universal Testing Machine, cube moulds (150mm x 150mm x 150mm), trowel and shovel. The specimens were cured by complete immersion in water and the compressive strength determined after 28 days.
The value of compression load at which concrete specimen failed was recorded and the compressive strength determined according to Equation (33) [15].

$$Fc = \frac{P}{A} \quad (33)$$

Where;
Fc = compressive strength; P= Load at failure (N); A= Cross sectional area of test cube (mm^2).

2.2.7. Cost Analysis

Table 3 presents the current prices of cement concrete constituents. These prices were used to estimate the cost of cement concrete for both the modified and the unmodified cement concrete in naira per cubic metre. The density of concrete was assumed as 2400Kg/m^3. Because there is no established price for periwinkle shell ash procurement, the total amount spent in this study to obtain 250Kg of the substance from procurement of the waste shells to processing of it was used as the basis for obtaining cost of PSA. This amount was ₦5,000.

Table 3. Current Market Prices of Concrete Constituents.

S/N	Constituents	Market procurement pattern	Unit Cost (₦ per Kg)
1	Cement	₦2,600 for 1 bag (50Kg)	52.00
2	Granite	₦200,000 for 30 tonnage (30,000Kg)	6.67
3	Sand	₦26,000 for 30 tonnage (30,000Kg)	0.867
4	Water	₦3,500 for 1000Kg	3.50
5	PSA	₦5,000 for 250Kg	20.00

The cost of concrete constituents as shown in Table 3 were used to determine the cost per cubic metre of cement concrete. According to Nworuh and Unaeza [16], the factors given in Table 4 can be used in offsetting the current prices given in Table 3 to take care of future change in prices.

Table 4. Optimal Values of PFF from Year 1 to Year 10

Number of years	PFF
1	1.2326
2	1.4638
4	1.9300
6	2.3939
8	3.3260
10	3.3260

Source: Nworuh and Unaeza [16].

2.2.8. Models' validation

These models were validated using F- statistics at 5% level of significance. The F-statistics is given as the ratio of variance between the predicted/model response value and that of experimental value. The following hypothesis were adopted in validation of models;

Null Hypothesis: H_0 = there is no significant difference between the experimental and predicted responses.

Alternate Hypothesis: H_1= there is a significant difference between the experimental and predicted responses.

Mathematically, the F-test is represented by Equation (34).

$$F = \frac{S_1^2}{S_2^2} \quad (34)$$

Where; S_1^2 = Larger of both variances

S_2^2 = Smaller of both variance

S^2 is obtained from Equation (35)

$$S^2 = \frac{1}{n-1}\left[\sum (Y - \bar{Y})^2\right] \quad (35)$$

Where : $\bar{Y}$= Average mean of response, Y

Y = Means of response

The deviation of all developed model values' from experimental values' were determined using the mean absolute percentage error formula given by Equation (36).

$$\ddot{X} = \frac{1}{n}\sum\left(\frac{/exp.value - mod.value/}{exp.value} \times 100\right) \quad (36)$$

Where:

$\ddot{X}$= Mean absolute percentage error value (MAPE)

Exp. Value= Experimental value

Mod. Value = model value

n = number of control points considered = 15

Although, there is no generally accepted maximum value for the mean absolute percentage error (MAPE), an error value of less than 5% is generally accepted in most practices.

1. Results and Discussion

1.1 Classification of Periwinkle Shell Ash

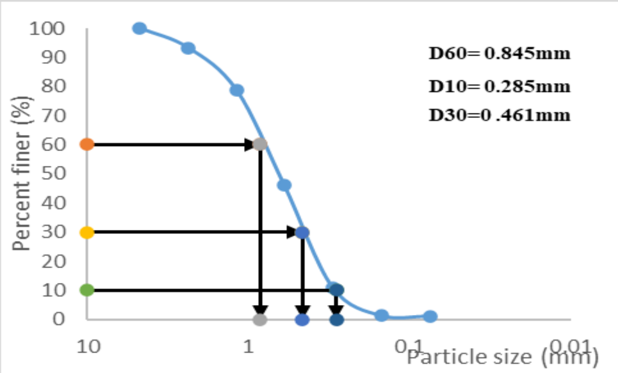
Table 5 presents the result of the oxide composition of PSA used in this study.The chemical analysis shows that PSA met the requirement of a pozzolan with respect to its silica oxide content according to BS EN 197-1 [12] which stipulates a minimum value of 25% for a substance to have a cementitious property. With a value of 6.89% for loss on ignition, PSA met the requirement of ASTMC618 [17] which stipulates a value of not more than 10%. The sulphur trioxide (SiO_3) didn't meet the specification with a value of 1.22% according to ASTMC618 [17] which stipulates a value between 4-5%. The combine acidic oxides of (Al_2O_3+ SiO_2+ Fe_2O_3) with a value of 50.89%, met the requirements of ASTMC618 [17] for a Class C pozzolan.

Table 5. Oxide Composition Results of PSA.

Oxide	CaO	Al_2O_3	Fe_2O_3	MgO	SiO_2	Na_2O	K_2O	SO_3	TiO_2	LOI	(Al_2O_3+ SiO_2+ Fe_2O_3)
Value (%)	38.85	11.04	5.3	1.13	34.55	0.11	0.15	1.22	0.18	6.89	50.89

1.2 Classification of Aggregates

The particle size distribution curves of sand and granite used in this study are presented in Figures 2 and 3 respectively. The gradation of sand was determined from the particle size distribution as a zone II sand. The fineness modulus were determined as 2.694 and 4.384 for the sand and granite respectively. The coefficient of uniformity and coefficient of curvature were determined as 2.965 and 0.882 and 1.821 and 1.122 for sand and granite respectively with the aid of Equations (1) and (2). The aggregates were thus classified as uniformly graded aggregates.



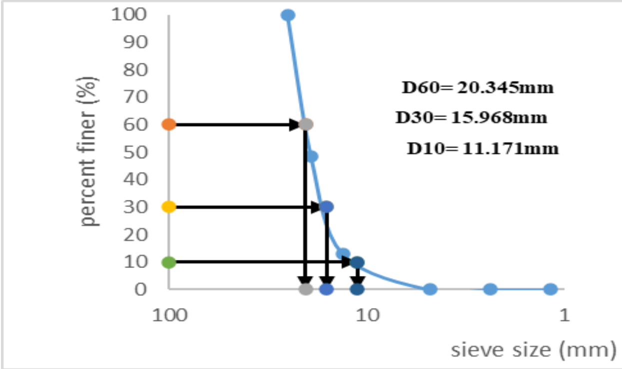


Fig. 2: Particle Size Distribution of sand. **Fig. 3:** Particle Size Distribution of granite.

Table 6: Cost Estimate (in Naira per Cubic Metre) of Cement Concrete (Trial Mixes).

S/N	Cost estimate of cement concrete with PSA						Cost estimate of cement concrete without PSA				
	Water	Cement	PSA	Sand	Granite	Total (N/m^3)	Water	cement	sand	Granite	Total (N/m^3)
TP1	507.38	15914.09	322.15	552.16	8594.90	25890.7	507.38	16751.68	552.16	8594.90	26406.1
TP2	933.33	24960.00	1066.67	457.07	7114.67	34531.7	933.33	27733.33	457.07	7114.67	36238.4
TP3	679.41	15600.00	1058.82	529.32	8239.41	26106.9	679.41	18352.94	529.32	8239.41	27801.1
TP4	707.37	21018.95	2021.05	541.26	8425.26	32713.9	707.37	26273.68	541.26	8425.26	35947.6
TP5	553.85	10285.71	1318.68	565.05	8795.60	21518.9	553.85	13714.29	565.05	8795.60	23628.8
TP6	667.78	19320.50	602.51	516.35	8037.49	29144.6	667.78	20887.03	516.35	8037.49	30108.7
TP7	589.47	15764.21	673.68	541.26	8425.26	25993.9	589.47	17515.79	541.26	8425.26	27071.8
TP8	566.67	17333.33	952.38	530.52	8258.10	27641.0	566.67	19809.52	530.52	8258.10	29164.8
TP9	532.93	12819.34	870.09	559.25	8705.26	23486.9	532.93	15081.57	559.25	8705.26	24879.0
TP10	780.53	19327.43	1061.95	500.55	7791.50	29462.0	780.53	22088.50	500.55	7791.50	31161.1
TP11	783.42	21985.49	1492.23	479.56	7464.87	32205.6	783.42	25865.28	479.56	7464.87	34593.1
TP12	679.41	15141.18	1235.29	529.32	8239.41	25824.6	679.41	18352.94	529.32	8239.41	27801.1
TP13	667.78	17231.80	1405.86	516.35	8037.49	27859.3	667.78	20887.03	516.35	8037.49	30108.7
TP14	607.55	12558.49	1207.55	549.77	8557.74	23481.1	607.55	15698.11	549.77	8557.74	25413.2
TP15	589.47	13574.74	1515.79	541.26	8425.26	24646.5	589.47	17515.79	541.26	8425.26	27071.8
Average						27367.17					29159.69

Table 7: PSA Cement Concrete Response Result for Model Development (Trial Mixes).

S/N	Responses' test result of cement concrete							With PSA	Without PSA
	Z_1	Z_2	Z_3	Z_4	Z_5	Response symbol	Response Cost (₦/m³)	Response Strength (N/mm²)	Response Strength (N/mm²)
TP1	507.38	15914.09	322.15	552.16	8594.90	Y_1	25890.7	17.35	16.48
TP2	933.33	24960.00	1066.67	457.07	7114.67	Y_2	34531.7	25.90	20.05
TP3	679.41	15600.00	1058.82	529.32	8239.41	Y_3	26107.0	20.65	20.85
TP4	707.37	21018.95	2021.05	541.26	8425.26	Y_4	32713.9	22.26	23.20
TP5	553.85	10285.71	1318.68	565.05	8795.60	Y_5	21518.9	16.80	21.90
TP6	667.78	19320.50	602.51	516.35	8037.49	Y_{12}	29144.6	27.55	27.05
TP7	589.47	15764.21	673.68	541.26	8425.26	Y_{13}	25993.9	21.24	18.22
TP8	566.67	17333.33	952.38	530.52	8258.10	Y_{14}	27641.0	24.44	25.93
TP9	532.93	12819.34	870.09	559.25	8705.26	Y_{15}	23486.9	15.03	19.85
TP10	780.53	19327.43	1061.95	500.55	7791.50	Y_{23}	29462.0	24.90	25.90
TP11	783.42	21985.49	1492.23	479.56	7464.87	Y_{24}	32205.6	23.58	29.48
TP12	679.41	15141.18	1235.29	529.32	8239.41	Y_{25}	25824.6	15.86	20.79
TP13	667.78	17231.80	1405.86	516.35	8037.49	Y_{34}	27859.3	16.94	27.18
	607.55	12558.49	1207.55	549.77	8557.74		23481.1		

TP14						Y_{35}		15.25	16.06
TP15	589.47	13574.74	1515.79	541.26	8425.26	Y_{45}	24646.5	12.94	18.10

3.3. Cost Implications of PSA Usage

Table 6 presents the result of the cost implications of using PSA in the partial replacement of cement for concrete production. Table 6 was obtained with the aid of the combine action of Table 1 and Table 3. The result showed that the cost per cubic metre of cement concrete was reduced on introduction of PSA. For every mix design considered, the cost per cubic metre of cement concrete was reduced with addition of PSA. The result revealed an average cost of production of PSA cement concrete of ₦ 27367.17 against the average cost of ₦ 29159.69 obtained for cement concrete without PSA. This resulted in an average savings of ₦ 1792.52 per cubic metre of cement concrete production. This had no negative impact on the quality of cement concrete produced. In fact, from Table 7, which presented the results of trial mixes for the responses and used in the development of all models derived in this study, the strength of concrete increased with addition of PSA to an optimum value. Thus, providing a low-cost concrete with additional advantage of improved quality at least within the optimal percentage bracket.

3.4. Models' Development

3.4.1. Cost per cubic metre Optimization Model

Table 7 in association with Equation (26), was used to derive the optimization model coefficients of cost per cubic metre of PSA cement concrete. Thus:

$B_1 = Y_1 = 25890.7$ $B_{12} = 4Y_{12} - 2Y_1 - 2Y_2 = -4266.4$
$B_{24} = 4Y_{24} - 2Y_2 - 2Y_4 = -5668.8$
$B_2 = Y_2 = 34531.7$ $B_{13} = 4Y_{13} - 2Y_1 - 2Y_3 = -19.6$
$B_{25} = 4Y_{25} - 2Y_2 - 2Y_5 = -8802.8$
$B_3 = Y_3 = 26106.9$ $B_{14} = 4Y_{14} - 2Y_1 - 2Y_4 = -6645.2$
$B_{34} = 4Y_{34} - 2Y_3 - 2Y_4 = -6204.4$
$B_4 = Y_4 = 32713.9$ $B_{15} = 4Y_{15} - 2Y_1 - 2Y_5 = -871.6$
$B_{35} = 4Y_{35} - 2Y_3 - 2Y_5 = -1327.2$
$B_5 = Y_5 = 21518.9$ $B_{23} = 4Y_{23} - 2Y_2 - 2Y_3 = -3429.6$
$B_{45} = 4Y_{45} - 2Y_4 - 2Y_5 = -9879.6$

Substituting the above values into Equation (16), the optimization model for the cost per cubic metre of PSA cement concrete becomes;

$$\tilde{Y}_{cs}=25890.7X_1+34531.7X_2+26106.9X_3+32713.9X_4+21518.9X_5-4266.4X_1X_2-19.6X_1X_3-6645.2X_1X_4-871.6X_1X_5-3429.6X_2X_3-5668.8X_2X_4-8802.8X_2X_5-6204.4X_3X_4-1327.2X_3X_5-9879.6X_4X_5 \quad (37)$$

Equation (37) is the derived cost per cubic metre optimization model of PSA cement concrete.

3.4.2 Relationship Models'

Figures 4 to 9 presented the relationship between cost per cubic metre and compressive strength of PSA cement concrete. The relationship models are displayed on the figures. These models could be used in determination of the cost per cubic metre of PSA cement concrete for any desired compressive strength and vice versa.

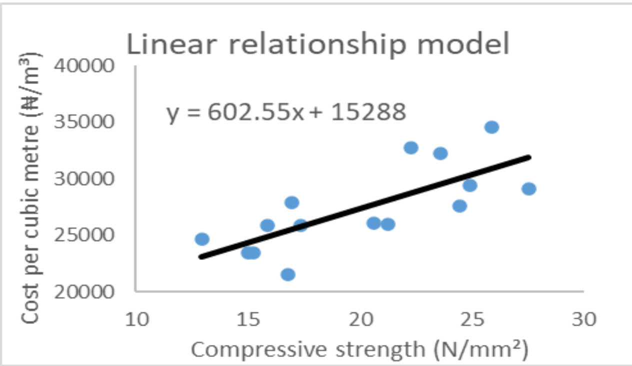


Fig. 4: Linear model of Responses.

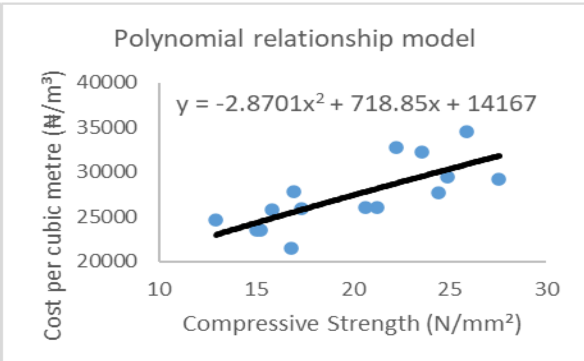


Fig. 5: Polynomial model of Responses.

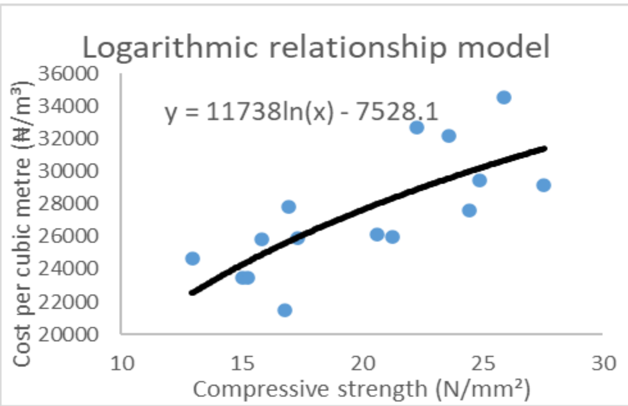


Fig. 6: Logarithmic model of Responses.

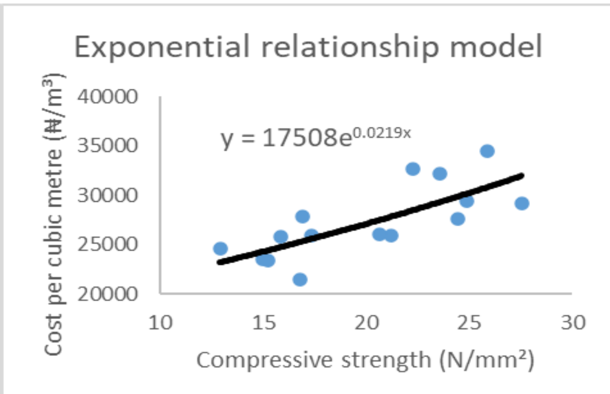


Fig. 7: Exponential model of Responses.

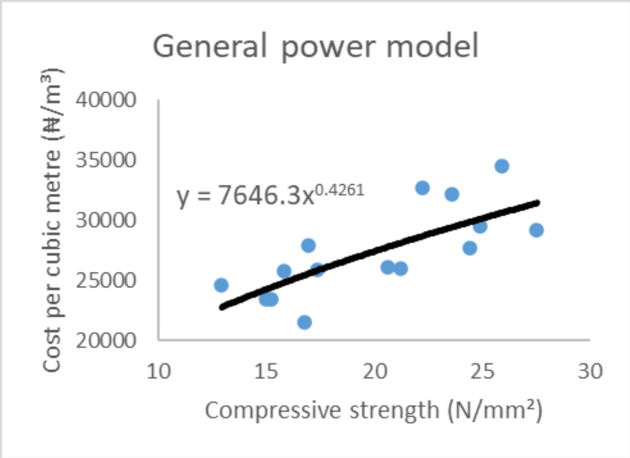


Fig. 8: General power model of Responses.

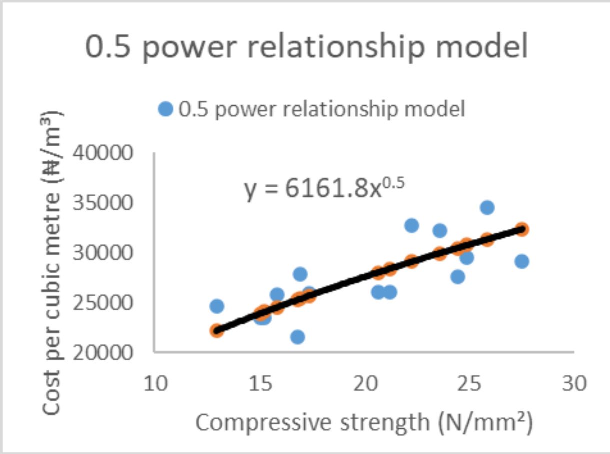


Fig. 9: 0.5 power model of Responses.

3.5. Validation of Models

All models developed were validated using the F-statistics with the aid of results of responses from control mixes (Table 8).

Table 8: Experimental Values of Responses for Model Validation (Control Points).

S/N	Result of Responses for Control points						
	Water	cement	PSA	Sand	Granite	Exp. value Cost (₦/m^3)	Exp. value Strength (N/mm^2)
CP1	672.00	17971.20	768.00	521.05	8110.81	28043.1	24.18
CP2	663.16	19339.62	982.74	511.21	7957.10	29453.8	23.32
CP3	606.23	16726.33	989.44	530.11	8251.42	27103.5	22.45
CP4	707.37	15415.25	911.88	537.39	8365.26	25937.2	20.65
CP5	667.78	18276.15	1004.18	516.35	8037.49	28502.0	23.15
CP6	633.39	15459.96	947.94	535.43	8334.51	25911.2	19.59
CP7	625.19	16195.42	1099.24	529.90	8248.40	26698.1	17.96
CP8	673.97	16118.98	1315.07	523.26	8144.97	26776.3	16.05
CP9	603.05	15475.56	1009.43	536.95	8358.06	25983.0	19.82
CP10	633.10	16387.88	1156.18	527.38	8209.23	26913.8	19.52
CP11	649.80	17196.45	1121.68	522.07	8126.54	27616.5	20.68
CP12	636.36	16072.73	1090.91	529.78	8246.55	26576.3	19.55
CP13	654.17	16391.79	1134.44	525.95	8186.97	26893.3	19.50
CP14	634.75	16228.31	1123.13	528.60	8228.12	26742.9	19.02
CP15	634.75	16467.66	1031.07	528.60	8228.12	26890.2	20.05

3.5.1 Cost per cubic metre Optimization Model Validation

The F- statistics for the cost per cubic metre optimization model is presented in Table 9. With the aid of Table 8, Equations (34) and (35), the F-value was obtained as 1.014. The F- tabulated from fishers' table for a level of significance of 5% and degree of freedom of (15-1=14), the value was obtained as 2.483. This implies that the null hypothesis is accepted and there is no significant difference between the predicted and actual cost per cubic metre of PSA cement concrete as the F- calculated (1.014) was far less than the F-tabulated (2.483).

Table 10 showed the result of the comparative analysis of cost optimization model using the mean absolute percentage error method (MAPE). The MAPE value of the optimization model value and experimental value analysis is 0.97% much lower than the 5% benchmark set in this study.

Table 9: F- Statistics for Optimization Model.

S/N	Exp.Value=Y^e_e	Opt.Model Value=Y^{mm}	Y_e-$\hat{Y}_e$	Y^m-$\hat{Y}^m$	$(Y_e-\hat{Y}_e)^2$	$(Y^m-\hat{Y}^m)^2$
1	28043.1	27958.682	973.68667	1151.23040	9.48066E+05	1.325E+06
2	29453.8	29175.804	2384.38667	2368.35240	5.68530E+06	5.609E+06
3	27103.5	26781.877	34.08667	-25.57460	1.16190E+03	6.541E+02
4	25937.2	25740.572	-1132.213	-1066.87960	1.28191E+06	1.138E+06
5	28502	28171.175	1432.587	1363.72340	2.05230E+06	1.860E+06
6	25911.2	25842.225	-1158.213	-965.22660	1.34146E+06	9.317E+05
7	26698.1	26405.4	-371.313	-402.05160	1.37874E+05	1.616E+05
8	26776.3	26510.825	-293.113	-296.62660	8.59154E+04	8.799E+04
9	25983	25653.672	-1086.413	-1153.77960	1.18029E+06	1.331E+06
10	26913.8	26642.212	-155.613	-165.23960	2.42155E+04	2.730E+04
11	27616.5	27335.772	547.087	528.32040	2.99304E+05	2.791E+05
12	26576.3	26267.812	-493.113	-539.63960	2.43161E+05	2.912E+05
13	26893.3	26606.88	-176.113	-200.57160	3.10159E+04	4.023E+04

14	26742.9	26439.501	-326.513	-367.95060	1.06611E+05	1.354E+05
15	26890.2	26579.365	-179.213	-228.08660	3.21174E+04	5.202E+04
	$\hat{Y}_e$= 27069.413	$\hat{Y}^m$=26807.4516			∑=1.345E+07	∑=1.327E+07

Table 10: MAPE Analysis of Cost per Cubic metre Optimization Model Values and Actual Values Comparison.

Cost Per Cubic Metre Values			
S/N	**Y_e**	**Y^m**	**APE**
1	28043.1	27958.682	0.30
2	29453.8	29175.804	0.94
3	27103.5	26781.877	1.19
4	25937.2	25740.572	0.76
5	28502	28171.175	1.16
6	25911.2	25842.225	0.27
7	26698.1	26405.4	1.10
8	26776.3	26510.825	0.99
9	25983	25653.672	1.27
10	26913.8	26642.212	1.01
11	27616.5	27335.772	1.02
12	26576.3	26267.812	1.16
13	26893.3	26606.88	1.07
14	26742.9	26439.501	1.13
15	26890.2	26579.365	1.16
	Mape		**0.97**

Y_e= Actual value; Y^m= Model value; APE= Absolute percentage error

3.5.2. Relationship Models' Validation

Following similar algorithm for the optimization model, the summary of validation tests for the relationship models' is presented in Table 11. The relationship models all compared closely to the experimental values. The calculated F-values were all lower than the tabulated F-value of 2.483. Hence, the null hypothesis was accepted for all derived models signifying that there was no significant difference between model values and experimental values. These models can thus, be used in predicting the cost per cubic metre of PSA cement concrete for any desired strength and vice versa.

Table 11: Summary of Validation test for Relationship models.

Model type	F- value	F- tab	MAPE value (%)	MAPE threshold (%)	Decision
Linear	1.752	2.483	2.996	5.00	Accept H_0
Polynomial	1.745	2.483	3.117	5.00	Accept H_0
Logarithmic	1.626	2.483	3.574	5.00	Accept H_0
Exponential	1.743	2.483	2.745	5.00	Accept H_0
General power	1.620	2.483	3.180	5.00	Accept H_0
0.5 power	2.257	2.483	3.930	5.00	Accept H_0

2. Conclusions

Based on the outcome of this study, cost predictions and implications of using periwinkle shell ash in the partial replacement of cement for rigid pavement, the following conclusions were made;

- Calcined periwinkle shell ash is cementitious and can be used in the partial replacement of cement for concrete production.
- The introduction of PSA in cement concrete production reduces the cost of production of cement concrete.
- An average savings of ₦ 1792.52 per cubic metre would be ensured in cement concrete production process on the introduction of PSA.
- This reduction in the financial aspect of concrete production has no consequence on the concrete quality especially within the optimum bracket of cement replacement with PSA.
- The derived cost per cubic metre optimization model can be used satisfactorily in predicting the cost per cubic metre of PSA cement concrete for any mix design and vice versa.
- The relationship models developed can all be used satisfactorily in relating the compressive strength and cost per cubic metre of PSA cement concrete as evident from the F- statistics and MAPE studies conducted.

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