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Mix Design of Palm Bunch Ash-Cementitious Composite Using Regression Theory

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ABSTRACT: This article presents a model developed from regression theory, for the design of Palm Bunch Ash (PBA)-cement concrete mixtures. PBA-cement concrete is actually a pozzolanic-cementitious composite with five components. The achievement of a desired performance criterion of any pozzolanic-cementitious composite is to a large extent, dependent on adequate proportioning of its components. The conventional mix design method of trial batches is too laborious, time-consuming and expensive for designing mixtures of the five component pozzolanic-cementitious composite i.e. PBA-cement concrete. In this work, a model for designing of PBA-cement concrete mixtures was developed from Osadebe's regression theory. The adequacy of the mix design model was verified using statistical t-test. The model is quite useful and practical for designer's to quickly get relatively accurate information on mix proportions and the corresponding strengths of PBA-cement composite with fixed raw materials, and fixed curing conditions and periods.

KEYWORDS: Mix design, Palm Bunch Ash (PBA), Pozzolana, Composite, Regression Theory.

I. INTRODUCTION

Some agricultural and industrial wastes contain significant portion of pozzolanic materials, and so can be used as SCMs. Palm bunch is an agricultural bye-product, which is gradually finding its way into the construction industry. Its relevance in the construction industry stems from the pozzolanic property of its ash. Already, the ash of other wastes e.g. shells and fibre from oil palm trees, have been used for making cement [13]. Tests conducted on PBA by [4] showed that PBA is a pozzolanic material with a pozzolanic Activity Index (PAI) of 76.9 precent. This value is greater than the minimum value of 70 percent specified by [2] for pozzolanic materials. Extensive research has shown that pozzolanas are known to have produced concrete having almost the same behaviour as normal concrete beyond the ages of 28 days [10]; [11] and [9]. In this work, a model was developed from regression theory by [12], for the mix design of the pozzolanic-cementitious composite, PBA-cement concrete

II MATERIALS

The five materials used in producing the test specimen i.e. PBA-cement concrete cubes, are cement, fine aggregate, coarse aggregates, palm bunch ash and water. Ibeto brand of portland cement was used in producing cubic PBA-cement concrete specimen tested in compression. The cement conforms to requirements of [5]. The physical and chemical properties of the cement were tested and presented in Table 1 and 2 respectively.The PBA used for this investigation was obtained by burning empty palm bunches. Open burning method was used. The ashes were cooled, pulverized (by grinding) and sieved using a 150mm BS sieve. The physical and chemical properties of the PBA are shown in Table 1 and 3 respectively.

The fine aggregate was sharp river sand obtained from Otamiri River in Imo State of Nigeria. In order to eliminate unwanted materials, it was washed and then dried for seven days. The grain size distribution of the sharp river sand shows that the sand is well graded and falls into zone 2 of the grading chart. The coarse aggregate was crushed granite

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rock (chippings) sourced from Ishiagu quarry site in Ebonyi State of Nigeria. The maximum size of the coarse aggregate is 20mm. Piped municipal water supply conforming to [8] was used for the production of the PBA-cement concrete cubes. Initial and final setting times are given in Table 8. The mix proportions of these constituent materials of concrete are shown in Table 4.

TABLE 1: PHYSICAL PROPERTIES OF IBETO CEMENT AND PALM BUNCH ASH.

Properties	Values
Moisture content	0.003
Specific gravity	3.16
Finess	190 plus
pH	9.25
PALM BUNCH ASH	
Water Absorption	79.31%
Bulk density	2334Kg/m^3
Apparent porosity	91.96%
Shrinkage	2.63%
Modulus of plasticity	2.64
Modulus of rupture	9.40Kg/cm^3
Specific gravity	2.26
< 150µm grain size < 38µm grain size	100% 5%

Source: http:/OPFA concrete properties.org

TABLE 2: CHEMICAL COMPOSITION OF IBETO CEMENT

S/No	Oxides	Mass Fraction %
1	Alumina (Al_2O_3)	6.04
2	Lime (CaO)	67.53
3	Silicate (SiO_2)	20.41
4	Magnesium Oxide	1.30
5	Iron Oxide (Fe_2O_3)	2.29
6	Potassium Oxide (K_2O)	0.83
7	Sodium oxide (Na_2O)	0.25
8	Titanium Oxide	0.20
9	Loss on Ignition	2.62
Total		98.85

Source: Project development institute (PRODA) Emene.

TABLE 3: CHEMICAL COMPOSITION OF PALM BUNCH ASH (PBA)

S/No	Oxide	Percentage Mass (%)
1	Silicate (SiO_2)	48.65
2	Alumina (Al_2O_3)	2.52
3	Iron oxide (Fe_2O_3)	3.62
4	Lime (CaO)	14.02
5	Magnesium oxide (MgO)	6.13
6	Potassium Oxide (K_2O)	17.55
7	Manganese (MnO_2)	0.37
8	Sulphate (SO_2)	2.49
9	Titanium Oxide TiO_2)	0.34
10	Phosphorous (P_2O_5)	3.40
11	Loss on ignition (LOI)	0.13
Total		100%

Source: http://OPFAConcrete properties.org

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TABLE 4: MIX PROPORTION OF CONSTITUENT MATERIALS USED IN PRODUCING THE CONCRETE BEAMS

Point of observation	Mix No.	Water-cement ratio	Cement	PBA	Sand	Granite chippings
1	Mix-01	0.62	0.95	0.05	2	4
2	Mix-02	0.59	0.90	0.1	2	3
3	Mix-03	0.57	0.85	0.15	1.5	3
4	Mix-04	0.55	0.80	0.20	1.3	2.4
5	Mix-05	0.5	0.75	0.25	1.5	2
12	Mix-06	0.605	0.925	0.075	2	3.5
13	Mix-07	0.595	0.9	0.1	1.75	3.5
14	Mix-08	0.585	0.875	0.125	1.65	3.2
15	Mix-09	0.56	0.85	0.15	1.75	3
23	Mix-10	0.58	0.875	0.125	1.75	3
24	Mix-11	0.570	0.85	0.15	1.65	2.7
25	Mix-12	0.545	0.825	0.175	1.75	2.5
34	Mix-13	0.56	0.825	0.175	/1.4	2.7
35	Mix-14	0.535	0.80	0.20	1.5	2.5
45	Mix-15	0.525	0.775	0.225	1.4	2.2
C1	Mix-16	0.5933	0.9	0.1	1.8333	3.333
C2	Mix-17	0.5867	0.833	0.1167	1.766	3.133
C3	Mix-18	0.5567	0.8	0.1167	1.60	2.80
C4	Mix-19	0.565	0.868	0.15	1.70	2.85
C5	Mix-20	0.58	0.868	0.12	1.80	3.2
C6	Mix-21	0.573	0.875	0.1325	1.75	3.1
C7	Mix-22	0.5825	0.860	0.125	1.70	3.1
C8	Mix-23	0.571	0.875	0.14	1.71	2.98
C9	Mix-24	0.56	0.85	0.15	1.75	3
C10	Mix-25	0.56	0.8375	0.1625	1.575	2.85
C11	Mix-26	0.566	0.85	0.15	1.65	2.88
C12	Mix-27	0.575	0.8725	0.1275	1.80	3.1
C13	Mix-28	0.575	0.865	0.135	1.71	2.98
C14	Mix-29	0.583	0.875	0.125	1.69	3.12
C15	Mix-30	0.576	0.87	0.13	1.73	3.14

III THEORITICAL BACKGROUND

In the course of this work, the regression theory by [12], was used to formulate the response equation for the mix design of PBA-cementitious composite. Osadebe assumed that the following response function, F(Z), is continuous and differentiable with respect to its predictors, Z_i.

$$F(Z) = \sum F^m(Z^{(0)}) * (Z_i - Z^{(0)}) / m! \qquad (1)$$

Where $0 \leq m < \alpha$;m = the degree of polynomial of the response function.

Osadebe assumed that the response function, F(Z) is continuous and differentiable with respect to its predictors, Z_i. By making use of Taylor's series, the response function could be expanded in the neighbourhood of a chosen point:

$$Z^{(0)} = Z_1^{(0)} , Z/_2^{(0)} , Z_3^{(0)} , Z_4^{(0)} , Z_5^{(0)} \qquad (2)$$

Expanding Eqn. (1) up to the second order gives:

$$F(Z) = F_o(Z^{(0)}) * (Z_i - Z^{(0)})^0 / 0! + \sum F^1(Z^{(0)}) * (Z_i - Z^{(0)})^1 + \sum F^{11}(Z^{(0)}) * (Z_i - Z^{(0)})^2/2! + \sum F^{11}(Z^{(0)}) * (Z_i - Z^{(0)})(Z_j - Z^{(0)})/2! \qquad (3)$$

Where $1 \leq i \leq 5$

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For the sake of convenience, $Z^{(0)}$ is chosen as the origin. Let the predictor, Z_i, be called fractional portion and S_i be the actual portion of each mixture component. The total quantity of concrete, S, is obtained by summing up the actual portions of each mixture component, S_i, that is:

$$\sum S_i = S \quad (4)$$

$$S_1 + S_2 + S_3 + S_4 /+ S_5 = S \quad (5)$$

To obtain a unit quantity of concrete, divide Eqn. (5) by S:

$$S_1/S + S_2/S + S_3/S + S_4/S + S_5/S = S/S \quad (6)$$

Let $Si/S = z_i$ (fractional portion) (7)

Then, $z_1 + z_2 + z_3 + z_4 + z_5 = 1$ (8)

Experience shows that when $\sum z_i = 1$, the values of the coefficients are so large that the regression becomes too sensitive. Consequently, the use of other predictors to determine the response gives outrageous values. To correct this shortcomings, a system of z that yields $\sum z = 10$, is adopted. Thus Eqn. (8) is multiplied by 10:

$$10z_1 + 10z_2 + 10z_3 + 10z_4 + 10z_5 = 10 \quad (9)$$

Let $10z_i = Z_i$ (10)

Therefore;

$$Z_1 + Z_2 + Z_3 + Z_4 + Z_5 = 10 \quad (11)$$

The assumption that $Z^{(0)}$ is taken as the origin implies that:

$$Z_1^{(0)} = Z_2^{(0)} = Z_3^{(0)} = Z_4^{(0)} = Z_5^{(0)} = 0 \quad (12)$$

Let:

$$b_o = F(0) \quad (13)$$

$$b_i = \partial F(0) / \partial Z_i \quad (14)$$

$$b_{ij} = \partial^2 F(0) / \partial Z_i \partial Z_j \quad (15)$$

$$b_{ii} = \partial^2 F(0) / \partial Z_i^2 \quad (16)$$

Substituting Eqns. (13) to (16) into Eqn. (3), yields;

$$F(Z) = b_o + \sum b_i Z_i + \sum\sum b_{ij} Z_i Z_j + \sum\sum b_{ii} Z_i^2 \quad (17)$$

Where $1 \le i \le 5$ for $\sum b_i Z_i$

$1 \le i \le 4$ and $1 \le j \le 5$ for $\sum\sum b_{ij} Z_i Z_j$

$1 \le i \le 5$ for $\sum\sum b_{ii} Z_i^2$

Multiplying Eqn. (8) by b_o gives the following expression for b_o;

$$b_o = b_o z_1 + b_o z_2 + b_o z_3 + b_o z_4 + b_o z_5 \quad (18)$$

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Similarly, multiplying Eqn. (8) by Z_i yields the following expressions for Z_i:

$$z_1 = z_1^2 + z_1z_2 + z_1z_3 + z_1z_4 + z_1z_5 \quad (19)$$
$$z_2 = z_1z^2 + z_2^2 + z_2z_3 + z_2z_4 + z_2z_5 \quad (20)$$
$$z_3 = z_1z_3 + z_2z_3 + z_3^2 + z_3z_4 + z_3z_5 \quad (21)$$
$$z_4 = z_1z_4 + z_2z_4 + z_3z_4 + z_4^2 + z_4z_5 \quad (22)$$
$$z_5 = z_1z_5 + z_2z_5 + z_3z_5 + z_4z_5 + z_4z_5 \quad (23)$$

Rearranging the Eqns. (19) – (23) gives the following expressions for Z_i^2:

$$z_1^2 = z_1 - z_1z_2 - z_1z_3 - z_1z_4 - z_1z_5 \quad (24)$$
$$z_2^2 = z_2 - z_1z_2 - z_2z_3 - z_2z_4 - z_2z_5 \quad (25)$$
$$z_3^2 = z_3 - z_1z_3 - z_2z_3 - z_3z_4 - z_3z_5 \quad (26)$$
$$z_4^2 = z_4 - z_1z_4 - z_2z_4 - z_3z_4 - z_4z_5 \quad (27)$$
$$z_5^2 = z_5 - z_1z_5 - z_2z_5 - z_3z_5 - z_4z_5 \quad (28)$$

Substituting Eqns. (24) – (28) into Eqn. (16), and factorizing, yields Eqn. (29):

$$Y = (b_o + b_1 + b_{11})z_1 + (b_o + b_2 + b_{22})z_2 + (b_o + b_3 + b_{33})z_3 + (b_o + b_4 + b_{44})z_4 + (b_o + b_5 + b_{55})z_5 + (b_{12} - b_{11} - b_{22})z_1z_2 + (b_{13} - b_{11} - b_{33})z_1z_3 + (b_{14} - b_{11} - b_{44})z_1z_4 + (b_{15} - b_{11} - b_{55})z_1z_5 + (b_{23} - b_{22} - b_{33})z_2z_3 + (b_{24} - b_{22} - b_{33})z_2z_4 + (b_{25} - b_{22} - b_{55})z_2z_5 + (b_{34} - b_{33} - b_{44})z_3z_4 + (b_{35} - b_{33} - b_{55})z_3z_5 + (b_{45} - b_{44} - b_{55})z_4z_5 \quad (29)$$

Let, $\alpha_i = b_o + b_i + b_{ii}$ (30)
and, $\alpha_{ij} = b_{ij} + b_{ii} + b_{jj}$ (31)

Substituting Eqns. (30) – (31) into Eqn. (29) gives;

$$Y = \alpha_1z_1 + \alpha_2z_2 + \alpha_3z_3 + \alpha_4z_4 + \alpha_5z_5 + \alpha_{12}z_1z_2 + \alpha_{13}z_1z_3 + \alpha_{14}z_1z_4 + \alpha_{15}z_1z_5 + \alpha_{23}z_2z_3 + \alpha_{24}z_2z_4 + \alpha_{25}z_2z_5 + \alpha_{34}z_3z_4 + \alpha_{35}z_3z_5 + \alpha_{45}z_4z_5 \quad (32)$$

Presenting it in a compact form, Eqn. (32) becomes:

$$Y = \sum\alpha_iz_i + \sum\alpha_{ij}z_iz_j \quad (33)$$

The Eqns. (32) and (33) are the regression equations when the system of $\sum z = 1$ is used. Thus for the system of $\sum z = 10$ adopted in this work,

$$Y = \sum\alpha_iZ_i + \sum\alpha_{ij}Z_iZ_j \quad (34)$$

Where $10z_i = Z_i$; and $1 \le i \le j \le 5$

The Eqn. (33) is the response function at any point of observation. $\alpha_i$and$\alpha_{ij}$are the coefficients of the regression equation, while Z_i and Z_j are the predictors when the system $\sum z = 10$.

Coefficient of the Regression Equation

The different points of observation will have different predictors at constant coefficients. At the nth observation point, the response function, $Y^{(n)}$ will have corresponding predictor, $Z_i^{(n)}$. That is to say;

$$Y^{(n)} = \sum\alpha_iZ_i^{(n)} + \sum\alpha_{ij}Z_i^{(n)}Z^{(n)} \quad (35)$$

where $1 \le i \le j \le 5$ and $n = 1, 2, 3, \ldots, 15$.

Eqn. (35) can be put in matrix form as follows;

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$$[Y^{(n)}] = [Z^{(n)}][\alpha] \qquad (36)$$

Expanding Eqn. (36) gives the following matrix;

$$\begin{bmatrix} Y^{(1)} \\ Y^{(2)} \\ Y^{(3)} \\ \cdot \\ \cdot \\ Y^{(15)} \end{bmatrix} = \begin{bmatrix} Z_1^{(1)} & Z_2^{(1)} & Z_3^{(1)} & \cdots & Z_n^{(1)} \\ Z_1^{(2)} & Z_2^{(2)} & Z_3^{(2)} & \cdots & Z_n^{(2)} \\ Z_1^{(3)} & Z_2^{(3)} & Z_3^{(3)} & \cdots & Z_n^{(3)} \\ \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & & \cdot \\ Z_1^{(15)} & Z_2^{(15)} & Z_3^{(15)} & \cdots & Z_n^{(15)} \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \cdot \\ \cdot \\ \alpha_{45} \end{bmatrix} \qquad (37)$$

Rearranging the above Eqn. (37) gives Eqn. (38)

$$\begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \cdot \\ \cdot \\ \cdot \\ \alpha_{45} \end{bmatrix} = \begin{bmatrix} Z_1^{(1)} & Z_2^{(1)} & Z_3^{(1)} & \cdots & Z_n^{(1)} \\ Z_1^{(2)} & Z_2^{(2)} & Z_3^{(2)} & \cdots & Z_n^{(2)} \\ Z_1^{(3)} & Z_2^{(3)} & Z_3^{(3)} & \cdots & Z_n^{(3)} \\ \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & & \cdot \\ Z_1^{(15)} & Z_2^{(15)} & Z_3^{(15)} & \cdots & Z_n^{(15)} \end{bmatrix}^{-1} \begin{bmatrix} Y^{(1)} \\ Y^{(2)} \\ Y^{(3)} \\ \cdot \\ \cdot \\ \cdot \\ Y^{(15)} \end{bmatrix} \qquad (38)$$

The Table 5 shows the actual mix proportions, $S_i^{(n)}$ and their corresponding fraction portions, $Z_i^{(n)}$. The values of the fractional portions, $Z_i^{(n)}$, were used to develop the $Z^{(n)}$ matrix and inverse $Z^{(n)}$ matrix given in Tables 6 and 7 respectively. The values of the $Y^{(n)}$ matrix are determined from laboratory compressive strength tests on concrete specimen. With the values of the matrices $Y^{(n)}$ and $Z^{(n)}$ known, the values of the constant coefficients, α_i of Eqn. (32) can be determined.

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TABLE 5: VALUES OF ACTUAL MIX PROPORTIONS AND THEIR CORRESPONDING FRACTIONAL PORTIONS WHEN ∑Z = 10

	S1	S2	S3	S4	S5	S	Z1	Z2	Z3	Z4	Z5
1	0.62	0.95	0.05	2	4	7.62	0.081364829	0.124671916	0.00656168	0.262467192	0.524934383
2	0.59	0.9	0.1	2	3	6.59	0.08952959	0.136570561	0.015174507	0.303490137	0.455235205
3	0.57	0.85	0.15	1.5	3	6.07	0.093904448	0.140032949	0.024711697	0.247116969	0.494233937
4	0.55	0.8	0.2	1.3	2.4	5.25	0.104761905	0.152380952	0.038095238	0.247619048	0.457142857
5	0.5	0.75	0.25	1.5	2	5	0.1	0.15	0.05	0.3	0.4
6	0.605	0.925	0.075	2	3.5	7.105	0.085151302	0.130190007	0.010555947	0.281491907	0.492610837
7	0.595	0.9	0.1	1.75	3.5	6.845	0.086924763	0.131482834	0.014609204	0.255661066	0.511322133
8	0.585	0.875	0.125	1.65	3.2	6.435	0.090909091	0.135975136	0.019425019	0.256410256	0.497280497
9	0.56	0.85	0.15	1.75	3	6.31	0.088748019	0.134706815	0.023771791	0.277337559	0.475435816
10	0.58	0.875	0.125	1.75	3	6.33	0.091627172	0.138230648	0.019747235	0.276461295	0.473933649
11	0.57	0.85	0.15	1.65	2.7	5.92	0.096283784	0.143581081	0.025337838	0.278716216	0.456081081
12	0.545	0.825	0.175	1.75	2.5	5.795	0.094046592	0.142364107	0.030198447	0.301984469	0.431406385
13	0.56	0.825	0.175	1.4	2.7	5.66	0.098939929	0.145759717	0.030918728	0.247349823	0.477031802
14	0.535	0.8	0.2	1.5	2.5	5.535	0.096657633	0.144534779	0.036133695	0.27100271	0.451671183
15	0.525	0.775	0.225	1.4	2.2	5.125	0.102439024	0.151219512	0.043902439	0.273170732	0.429268293
16	0.593333	0.9	0.1	1.833333	3.333333	6.759999	0.087771167	0.133136114	0.014792902	0.271203147	0.493096671
17	0.586667	0.883333	0.116667	1.766667	3.133333	6.486667	0.090441979	0.136176714	0.017985662	0.272353583	0.483042062
18	0.556667	0.833333	0.166667	1.6	2.8	5.956667	0.093452765	0.139899209	0.027979909	0.268606588	0.470061529
19	0.565	0.85	0.15	1.7	2.85	6.115	0.092395748	0.139002453	0.024529845	0.278004906	0.466067048
20	0.58	0.88	0.12	1.8	3.2	6.58	0.088145897	0.133738602	0.018237082	0.273556231	0.486322188
21	0.573	0.8675	0.1325	1.75	3.1	6.423	0.089210649	0.135061498	0.02062899	0.272458353	0.482640511
22	0.5825	0.875	0.125	1.7	3.1	6.3825	0.091265178	0.137093615	0.019584802	0.26635331	0.485703094
23	0.571	0.86	0.14	1.71	2.98	6.261	0.091199489	0.137358249	0.022360645	0.27311931	0.475962306
24	0.5685	0.8575	0.1425	1.71	3.03	6.3085	0.090116509	0.135927717	0.022588571	0.271062852	0.480304351
25	0.56	0.8375	0.1625	1.575	2.85	5.985	0.093567251	0.139933166	0.027151211	0.263157895	0.476190476
26	0.566	0.85	0.15	1.66	2.88	6.106	0.092695709	0.139207337	0.024566001	0.271863741	0.471667213
27	0.575	0.8725	0.1275	1.8	3.1	6.475	0.088803089	0.134749035	0.01969112	0.277992278	0.478764479
28	0.575	0.865	0.135	1.71	2.98	6.265	0.091779729	0.138068635	0.021548284	0.272944932	0.47565842
29	0.583	0.875	0.125	1.69	3.12	6.393	0.091193493	0.13686845	0.019552636	0.264351635	0.488033787
30	0.576	0.87	0.13	1.73	3.14	6.446	0.089357741	0.134967422	0.020167546	0.268383494	0.487123798

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TABLE 6: VALUES OF MATRIX OF ACTUAL MIX PROPORTIONS AND CONTROL MIX PROPORTIONS WHEN ∑Z = 10

	Z_1	Z_2	Z_3	Z_4	Z_5	$Z_1 Z_2$	$Z_1 Z_3$	$Z_1 Z_4$	$Z_1 Z_5$	$Z_2 Z_3$	$Z_2 Z_4$	$Z_2 Z_5$	$Z_3 Z_4$	$Z_3 Z_5$	$Z_4 Z_5$
1	0.81364829	1.24671916	0.065616798	2.624671916	5.249343832	1.014390918	0.053388996	2.135559827	4.271119653	0.081805719	3.272228767	6.544457533	0.172222567	0.344445133	13.77780533
2	0.895295903	1.365705615	0.151745068	3.034901366	4.552352049	1.222710641	0.135856738	2.717134758	4.075702138	0.207239092	4.144781835	6.217172752	0.460531315	0.690796972	13.81593945
3	0.939044481	1.400329489	0.247116969	2.471169687	4.942339374	1.314971679	0.232053826	2.320538256	4.641076513	0.346045179	3.460451786	6.920903571	0.610667962	1.221335924	12.21335924
4	1.047619048	1.523809524	0.380952381	2.476190476	4.571428571	1.596371882	0.399092971	2.594104308	4.789115646	0.580498866	3.77324263	6.965986395	0.943310658	1.741496599	11.31972789
5	1	1.5	0.5	3	4	1.5	0.5	3	4	0.75	4.5	6	1.5	2	12
6	0.851513019	1.30190007	0.105559465	2.814919071	4.926108374	1.108584859	0.089885259	2.396940236	4.194645414	0.137427875	3.664743337	6.413300839	0.297141352	0.519997365	13.86659641
7	0.869247626	1.314828342	0.146092038	2.556610665	5.113221329	1.142911415	0.126990157	2.222327751	4.444655502	0.192085952	3.361504161	6.723008322	0.373500462	0.747000925	13.07251618
8	0.909090909	1.35975136	0.194250194	2.564102564	4.972804973	1.2361376	0.176591086	2.331002331	4.520731793	0.264131966	3.486541948	6.761778324	0.498077421	0.965968332	12.75078198
9	0.88748019	1.347068146	0.237717908	2.773375594	4.754358162	1.195496294	0.210969934	2.4613159	4.219398685	0.320222222	3.735925919	6.404444433	0.659281045	1.130196076	13.18562089
10	0.916271722	1.382306477	0.197472354	2.764612954	4.739336493	1.266568336	0.180938334	2.533136672	4.342520009	0.272967314	3.821542393	6.551215531	0.545934628	0.935887933	13.10243106
11	0.962837838	1.435810811	0.253378378	2.787162162	4.560810811	1.382452977	0.24396229	2.68358519	4.39132122	0.363803415	4.001837564	6.548461468	0.706206629	1.155610847	12.71171932
12	0.940465919	1.42364107	0.301984469	3.019844694	4.314063848	1.338885907	0.284006101	2.840061015	4.057230021	0.429917493	4.299174931	6.141678472	0.911946197	1.302780282	13.02780282
13	0.989399293	1.457597173	0.309187279	2.473498233	4.770318021	1.442145613	0.305909675	2.447277404	4.719749279	0.450670504	3.605364033	6.953202063	0.764774189	1.47492165	11.7993732
14	0.966576332	1.445347787	0.361336947	2.7100271	4.516711834	1.397038963	0.349259741	2.619448055	4.365746759	0.522257556	3.916931672	6.528219453	0.979232918	1.632054863	12.24041147
15	1.024390244	1.512195122	0.43902439	2.731707317	4.292682927	1.54907793	0.449732302	2.798334325	4.39738251	0.663890541	4.130874479	6.491374182	1.199286139	1.884592504	11.72635336

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TABLE 7: VALUES OF INVERSE MATRIX OF ACTUAL MIX PROPORTIONS WHEN ∑Z = 10

Z_1	Z_2	Z_3	Z_4	Z_5	$Z_1 Z_2$	$Z_1 Z_3$	$Z_1 Z_4$	$Z_1 Z_5$	$Z_2 Z_3$	$Z_2 Z_4$	$Z_2 Z_5$	$Z_3 Z_4$	$Z_3 Z_5$	$Z_4 Z_5$
116128.8	9650.68889	401200.0223	153125	6.07127E-09	-67308.03334	-437304.2334	276061.5	1.38081E-07	124658.8	-77880.8889	-4.23112E-08	-498331.5556	-2.2568E-07	1.22883E-07
94586.90761	10487.88615	279486.989	93519.56251	427.5	-63606.09151	-328915.2555	193795.173	12900.4164	109388.097	-63784.44801	-4231.33515	-324840.984	-21506.62995	12292.3125
1103.2236	1232.875506	1045.985773	52.06250015	577.5	-2355.781167	-2186.521167	552.1230003	1751.9084	2181.529	-545.1662223	-1723.877283	-498.3315561	-1572.65955	385.2291667
418.06368	15.44110223	1310.040889	245.0000001	20	-161.53928	-1499.3288	662.5476001	191.11728	284.9344001	-124.6094223	-35.82082667	-1139.043556	-326.7864	140.0833333
104.51592/	47.28837556	81.87755559	15.31250001	5	-141.34687	-187.4161	82.81845002	47.77932	124.6588	-54.51662223	-31.34322333	-71.19022226	-40.8483	17.51041667
-420328.1917	-40260.26138	-1350404.477	-485978.9376	-427.5	262164.7899	1525254.694	-933639.9931	-27234.2124	-469117.7771	284187.3636	8261.17815	1628333.953	47241.05895	-28051.6875
-94586.90761	-3983.32184	-361266.29	-147511.43	-577.5	39375.19951	373895.1195	-243486.243	15767.1756	-76976.809	49610.12623	-3201.4863	463946.6783	-29880.5314	18876.22917
		15	75						01		83		5	
-102611.4077	-8894.074881	-356658.632	-141120	-20.00000001	60738.76929	387576.4948	-249117.8976	2994.17072	-112834.0224	71775.02721	-859.69984	451061.2481	-5391.9756	3362
-109265.5879	-8346.880821	-389819.042	-150077.8125	-5.000000004	60718.57688	418125.3192	-265101.8585	1544.86468	-114276.5028	71704.93441	-416.41711	486300.4081	-2818.5327	1733.53125
-116128.8	-18915.35022	-314737.3236	-98000.00002	-2000	94231.24668	387326.6067	-220849.2	-31852.88	-154576.912	87226.59557	12537.28933	353103.5023	50651.892	-28016.66667
-107581.7203	-11308.19471	-319066.5994	-103337.9375	-632.5	70431.12609	374832.2	-217315.6128	-16818.32064	-121319.725	69609.9385	5368.646397	364849.8889	28083.20625	-15794.39583
-100979.7981	-11943.69257	-289136.2589	-95928.21877	-525	70108.04753	345688.9965	-202822.3841	-14811.5892	-118675.1776	68909.0105	5014.915733	334629.6396	24304.7385	-13833.22917
-162.58032	-972.3069056	-14.32857221	-70.4375	-382.5	834.6196133	-124.9440667	220.8492	-573.35184	276.0302	-482.8615111	1249.25133	71.19022221	-183.81735	315.1875
-528.3860401	-797.1469022	-542.4388058	-10.71875008	-475	1319.237453	1093.260584	-193.2430502	-1114.8508	-1246.588	218.0664889	1253.728933	177.9755558	1021.2075	-175.1041667
-104.51592	-8.68562	-736.898	-137.8125	-5	-60.57723	562.2483	-248.45535	-47.77932	160.2756	-70.09279999	-13.43281	640.712	122.5449	-52.53125

IV EXPERIMENTAL WORKS.

The test specimen were concrete cubes that were cast in steel moulds measuring 150x150x150mm. A total of ninety concrete cubes were produced and tested in compression.Three concrete cubes were produced from each mix proportion. The base of each mould was clamped in order to prevent leakage of mortar during concrete casting. Then, a thin layer of engine oil was applied to the inner walls of the mould to ease the removal of concrete cubes. Each mould was filled with concrete in three equal layers as specified by [6] and each layer was given 35 blows with a tamping rod. Then, the concrete cubes were cured in water for 28 days. Thereafter, the concrete cubes were demoulded and tested in compression. The concrete specimen were loaded at a constant rate in the compression testing machine until fracture occurred. The load causing failure was recorded in each case, and then the compressive strength calculated and reported to the nearest 0.5N/mm^2.

V EXPERIMENTAL RESULTS AND ANALYSIS

The compressive strength results obtained from laboratory test, are given in Table 9.

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TABLE 8: INITIAL AND FINAL SETTING TIMES FOR DIFFERENT PERCENTAGE REPLACEMENT OF CEMENT WITH PBA

S/No	Percentage of Cement Replacement	Initial Time (Minutes)	Final Setting Time (Minutes)
1	0	47	520
2	5	52	532
3	10	60	550
4	15	72	570
5	20	85	610
6	36	96	702

TABLE 9: 28TH DAY COMPRESSIVE STRENGTH RESULTS OF PBA-CEMENT CONCRETE MIXTURES.

Point of observation	Mix No.	Replicates of compressive strengths (N/mm^2)			Mean compressive strength (N/mm^2)
		1	2	3	
1	Mix-01	17.11	15.44	14.77	15.77
2	Mix-02	16.44	16.00	17.70	16.74
3	Mix-03	20.20	21.30	21.11	20.88
4	Mix-04	18.22	20.00	19.55	19.26
5	Mix-05	16.66	16.00	17.55	16.74
12	Mix-06	19.11	17.77	18.44	18.44
13	Mix-07	16.22	10.11	12.44	12.92
14	Mix-08	15.22	10.11	12.44	12.59
15	Mix-09	18.93	17.55	16.18	17.55
23	Mix-10	18.22	17.55	17.33	17.70
24	Mix-11	17.11	16.88	17.55	17.18
25	Mix-12	11.55	11.11	12.22	11.63
34	Mix-13	17.77	17.77	15.11	16.83
35	Mix-14	19.34	18.77	20.77	19.63
45	Mix-15	17.34	16.89	16.45	16.89
C1	Mix-16	16.45	17.56	17.11	17.04
C2	Mix-17	16.30	16.17	16.13	16.20
C3	Mix-18	15.76	15.78	15.92	15.82
C4	Mix-19	15.39	16.00	15.47	15.62
C5	Mix-20	16.83	17.33	17.11	17.09
C6	Mix-21	16.90	17.16	17.81	17.29
C7	Mix-22	16.07	15.10	15.30	15.49
C8	Mix-23	15.88	16.07	16.35	16.10
C9	Mix-24	14.98	14.18	15.56	14.91
C10	Mix-25	16.44	16.00	16.22	16.22
C11	Mix-26	16.40	16.51	14.40	15.77
C12	Mix-27	16.88	17.77	19.00	17.88
C13	Mix-28	18.10	15.89	16.00	16.66
C14	Mix-29	15.96	16.00	16.25	16.07
C15	Mix-30	14.33	16.56	16.33	15.74

Determination of the coefficients of the Regression Equation

The value of the mean compressive strengths for Mix-01 to Mix-15 (given in Table 9), were substituted into Eqn. (31) to obtain the following coefficients of the regression equation:

α_1 = 543359.2553 α_2 =313798.1097 α_3 = 5179.4744
α_4 = 1912.4872 α_5 = -107.94572 α_6 = 167665.1147
α_7 = 58850.2475 α_8 =48221.0717 α_9 = 55061.3301
α_{10} = 29709.33107 α_{11} = -36630.52621 α_{12} = 30868.154
α_{13} = -669.52042 α_{14} = 45020065 α_{15} = -155.56604

Determination of the final Regression Equation

Substituting the above regression coefficients into the Eqn. (32) yeilds the following regression equation;

$$Y = 543359.2553Z_1 + 313798.1097Z_2 + 5179.4744Z_3 + 1912.4872Z_4 - 107.94572Z_5 + 167665.1147Z_1Z_2 + 58850.2475Z_1Z_3 + 48221.0717Z_1Z_4 - 55061.33Z_1Z_5 - 29709.33102\ Z_2Z_3 - 36630.52621Z_2Z_4 - 30868.154\ Z_2Z_5 - 669.5204\ Z_3Z_4 - 450.20065\ Z_3Z_5 - 155.56604\ Z_4Z_5 \quad (39)$$

The Eqn. (39) is the final regression equation needed for the mix design of palm bunch ash-cementitious composite. Specifically, it can be used to determine the mix proportions of the constituents of palm bunch ash-cementitious composite when the compressive strength of the palm bunch ash-cementitious composite is known.

Test of Adequacy

The F-test was used to check the adequacy of the formulated regression equation at 95 percent confidence level. The F-test calculations are as follows:

TABLE 10: F-TEST CALCULATION

Control points	Mix No.	Y_e	Y_m	$Y_e - \hat{Y}_e$	$Y_m - \hat{Y}_m$	$(Y_e - \hat{Y}_e)$	$(Y_m - \hat{Y}_m)$
C1	Mix-16	17.04	17.6006	0.78	1.5622	0.6084	2.4405
C2	Mix-17	16.20	16.038	0.06	0.0009	0.0036	0.0008
C3	Mix-18	15.82	15.0876	0.44	-0.9508	0.1936	0.9040
C4	Mix-19	15.62	15.0876	0.64	-0.9508	0.4096	0.9040
C5	Mix-20	17.09	15.372	0.83	-0.6604	0.6889	0.441
C6	Mix-21	17.29	17.072	1.03	1.0336	1.0609	1.0683
C7	Mix-22	15.49	16.165	-0.77	0.63661	0.5929	0.40527
C8	Mix-23	16.10	15.757	-0.16	0.2814	0.0256	0.0792
C9	Mix-24	14.91	15.512	-1.35	-0.5264	1.8225	0.2771
C10	Mix-25	16.22	15.962	-0.04	-0.0764	0.0016	0.0058
C11	Mix-26	15.77	15.986	-0.49	-0.0764	0.2401	0.00574
C12	Mix-27	17.88	16.86	1.62	0.8216	2.624	0.6750
C13	Mix-28	16.66	16.213	0.4	0.17461	0.1600	0.0305
C14	Mix-29	16.04	15.621	-0.19	-0.4174	0.0361	0.1743
C15	Mix-30	15.74	16.265	-0.52	0.2266	0.2704	0.0514
Sum		243.9	240.576			8.7382	7.4984
Mean		16.26	16.0384			0.5825	0.5356

The varince of the replicates of the compressive strength test results at any arbitrary point can be calculated from the Eqn.(40) as given by [7];

$$S_e^2 = [\Sigma(Y_e - \hat{Y}_e)^2]/(n-1) \quad (40)$$

$$= (8.7382)/14 = 0.6242 = S_1^2$$

Similarly,

$$S_m^2 = [\Sigma(Y_m - \hat{Y}_m)^2]/(n-1) \quad (41)$$

$$= (7.498)/14 = 0.5357 = S_2^2$$

Therefore the calculated F-value is given by:

$$F_{cal} = S_1^2 / S_2^2 \quad (42)$$

$$= (0.6242) / 0.5357$$

$$= 1.1653$$

From standard statistical table, the value of F = 2.44 and 1/F = 0.4094.

Since the value of F_{cal} (i.e. 1.1653) is greater than the value of 1/F and less than the value of F i.e. the condition $1/F < S_1^2 / S_2^2 < F$ (i.e. 0.4094 < 1.1653 < 2.44), is satisfied. Thus, the null hypothesis is accepted. This implies that, there is no significant difference between the experimental results and the results obtained from the formulated regression equation.

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Comparison of Experimental and Predicted Results

The results from the controlled laboratory tests and those obtained from the formulated regression equation are compared in Table (11). The comparison show that the percentage difference ranges from a minimum of 0.838709677% to a maximum of 5.7046%.Since the maximum percentage difference between the predicted value and the controlled experimental values is negligible, the formulated regression equation can be used for the designing of mixtures of palm bunch ash-cementitious composites.

TABLE 11: COMPARISON OF EXPERIMENTAL AND PREDICTED RESULTS

PTS. OF OBSER-VATION	MIX NOS.	EXPERIMENTAL COMPRESSIVE STRENGTH (MPA)	PREDICTED COMPRESSIVE STRENGTH (MPA)	DIFFERENCE	PERCENTAGE DIFFERENCE
C1	Mix -16	17.04	17.60	-0.56	-3.286384977
C2	Mix -17	16.20	16.04	0.16	0.987654321
C3	Mix -18	15.82	15.09	0.73	4.614412137
C4	Mix -19	15.62	15.09	0.53	3.393085787
C5	Mix -20	15.50	15.37	0.13	0.838709677
C6	Mix -21	17.29	17.07	0.22	1.272411799
C7	Mix -22	15.49	16.17	-0.68	-4.389928986
C8	Mix -23	16.10	15.76	0.34	2.111801242
C9	Mix -24	14.91	15.51	-0.60	-4.024144869
C10	Mix -25	16.22	15.96	0.26	1.602959309
C11	Mix -26	15.77	16.00	-0.23	-1.458465441
C12	Mix -27	17.88	16.86	1.02	5.704697987
C13	Mix -28	16.66	16.21	0.45	2.701080432
C14	Mix -29	16.07	15.62	0.45	2.800248911
C15	Mix -30	15.74	16.27	-0.53	-3.367217281

VI CONCLUSION

Test conducted on PBA-Cementitious composite shows that it has the same behaviour as normal concrete beyond the ages of 28 days. A response function based on the Regression Theory by Osadebe, has been formulated for the mix desi/gn of PBA-Cementitious composite.The formulated regression function was tested for adequacy and found adequate.The use of the regression function will simplify the process and reduce the cost of the mix design of PBA-cement concrete mixtures.

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