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Development of Mix Design Model for Concrete with Palm Oil Fuel Ash (POFA) as Pozzolan Material

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Abstract: This study aims at the development of mix design equation for prediction of compressive strength of concrete produced with different proportions of, fine aggregate, coarse aggregate, water content, cement content and palm oil fuel ash (POFA) for partial replacement of concrete. The investigation was carried out for a period of 28 days curing age. The concrete design model was developed via the multiple linear regression technique, and the results obtained from the experiment for each mix design were fitted into model. It was observed that the compressive strength predicted by the model were comparable to those obtained from the experiment, with correlation coefficient, R^2 of 0.9751 (97.51%). Thus, the high prediction recorded indicated that the developed concrete mix design model for partial replacement of cement can be used to forecast the strength of concrete given a specific mix concrete design prior to production of the concrete, thereby saving cost and time.

Keywords: POFA, Compressive Strength, Mix Parameters and Mix Design Model

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I. INTRODUCTION

Concrete is a versatile construction engineering material owing to the benefits it provides in term of strength, durability, adoptability and economy (Zain and Abd 2009). Advancement in material technology and the need for high strength concrete has facilitated research on the exploitation of various agricultural wastes. The conversion of these wastes to structural materials is of immense benefit to not only the civil profession, but also the management of the environment (Mostafa and Uddin, 2015).

Many studies have investigated pozzolan materials as partial replacement of cement for concrete, which remarkable achievements were recorded (Bhatnagar *et al*., 2015; Gajera, 2015; Ahmad and Ado, 2016; Mohamed *et al*., 2016; Usman *et al*., 2018). It has also been reported that the utilization of cementitious materials and wastes for concrete in structures will help in the reduction of greenhouse emission (Mohamad *et al*., 2016). Cementitious materials possess special properties like silica, metallic oxide that make them excellent structure materials (Priyanka and Bhat, 2015; Ephraim and Ode, 2017).

Investigation on optimum dose of cement replacement level with POFA in the production of HSC has been performed, which reported a range of 5% to 15% replacement ratio as appropriate for obtaining of high strength of concrete with POFA (Sooraj, 2013 and Ranjbar *et al*., 2016). Also, water binder ratio played important role for performance of pozzolan concrete, as it influences the workability and strength of concrete. Ode *et al*. (2018) showed that water binder ratio has capacity to improve or reduce the workability of high strength concrete production process.

Although, effect of cement content and water binder ratio on the compressive strength of concrete had been widely studied, it is imperative to formulate a guiding model that can be applied in the study of concrete mix design. This would reduce cost, wastage and time often expended during experimental process.

Therefore, by developing a suitable model for concrete mix design, it is will be possible to forecast the strength of concrete given the parameters involved in the mix. Also, it will help in obtaining pre-information on the possible outcome of what compressive strength of concrete, especially with pozolan material should be.

Hence, it is the objective of this study to develop a concrete mix design model for compressive strength of partial replacement concrete. In achieving this, the multiple linear regression equation was used.

II. MATERIALS AND METHODS

The materials used to carry out this research includes, binders, aggregates and fluids Portland Limestone Cement (PLC Grade 42.5), Palm oil fuel ash (retained at 212microns sieve), Coarse aggregate (12mm maximum), fine aggregate less than (5mm), Water, Chemical admixture (AuraCast 200)

2.1 Sample collection and Preparation

Empty palm fruit bunches (palm husks) were obtained from a local palm oil processing industry in Elele, Ikwerre Local Government Area of River State, Nigeria. They were air dried, burn to ashes and grindded. The collected ash was oven dried and passed through 412micronsieve retained at 212micron. The choice of Portland limestone Cement was adopted based on the track record and satisfactory results in concrete works previously done. The cement was lump free and in tandem with America Concrete Institute (ACI) compilation 17, for high strength concrete, manufactured by Dangote Group of Company Plc. The coarse aggregates occupied 58% of all total volume of the POFA concrete. Consideration was given to smaller aggregates sizes to achieve a high concrete strength because of less severe concentration of stress around the particle, which are caused by differences between the elastic moduli of paste and aggregate. 12mm coarse aggregate size was used in this investigation free from dust before used in the aggregate. Natural sand from Umuechem river in Rivers state was used. The sand particle size ranges from 4.75mm to 600microns with fineness modulus and specific gravity. The water used for this investigation is suitable for drinking, and contained no salt or sulphate. It was obtained from the tap at civil engineering laboratory of Rivers State University and meets BS 3148 requirements for mixing and curing of concrete specimen. The Auracast 200, which complies with EN934-2, was used as superplaticizer to improve the workability of the concrete mixes.

2.2 Concrete Mix Design

The concrete mix design was performed as presented in Table1. The dimension of the cubes was 150mm x150mm x 150mm. The specimens were casted and properly vibrated using electric power vibrating table, wrapped with cellophane for 48hours and remove from mold. The specimens were cured in water curing tank for 28 days prior to testing.

Table 1: Concrete Mix Design Formulation

Cement (kg/m^3)	POFA (kg/m^3)	Water (kg/m^3)	F.A (kg/m^3)	C.A (kg/m^3)	f_{cu} (N/mm^2)
650	0	143	707	899.9	83.4
650	0	163	694	883.4	73.2
650	0	175.5	688	876	70.4
601.5	48.75	143	707	899.9	73.8
601.5	48.75	163	694	883.4	65.8
601.5	48.75	175.5	688	876	60.7
585	65	143	707	899.9	64.5
585	65	163	694	883.4	59.7
585	65	175.5	688	876	58.2
568.75	81.25	143	707	899.9	58.4
568.75	81.25	163	694	883.4	52
568.75	81.25	175.5	688	876	48.7
552.5	97.5	143	707	899.9	56.5
552.5	97.5	163	694	883.4	50.3
552.5	97.5	175.5	688	876	46.4

2.3 Development of POFA Concrete Mix Design

The prediction of compressive strength of concrete for partial replacement of cement can be made through a mix design equation. In this work, the multiple linear regression equation was applied to develop the mix design equation as expressed and developed as follows.

$$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 + e \quad (3.1)$$

Where: y is the dependent variable (compressive strength), x_i is the variables in the mix, subscript a_i is constant of the regression, i = 1, 2,3,4,5 and e is the error. However, the error can be accounted for by rewriting equation (3.1) as:

$$e = y - a_0 - a_1x_1, -a_2x_2 - a_3x_3 - a_4x_4 - a_5x_5 \quad (3.2)$$

The sum of squares of the residual error can be expressed as:

$$S_r = \sum e^2 \quad (3.3)$$

Combining equations (3.2) and (3.3) gives:

$$S_r = \sum e^2 = \sum\left(y - a_o - a_1x_1 - a_1x_o - a_2x_2 - a_3x_3 - a_4x_4 - a_5x_5\right)^2 \quad (3.4)$$

Differentiating equation (3.4) partially w.r.t. regression constants give:

$$\frac{\partial S_r}{\partial a_0} = -2\sum(y - a_0 - a_1x_1, -a_2x_2 - a_3x_3 - a_4x_4 - a_5x_5) \quad (3.5)$$

$$\frac{\partial S_r}{\partial a_1} = -2\sum(y - a_0 - a_1x_1, -a_2x_2 - a_3x_3 - a_4x_4 - a_5x_5)\, x_1 \quad (3.6)$$

$$\frac{\partial S_r}{\partial a_2} = -2\sum(y - a_0 - a_1x_1, -a_2x_2 - a_3x_3 - a_4x_4 - a_5x_5)\, x_2 \quad (3.7)$$

$$\frac{\partial S_r}{\partial a_3} = -2\sum(y - a_0 - a_1x_1, -a_2x_2 - a_3x_3 - a_4x_4 - a_5x_5)\, x_3 \quad (3.8)$$

$$\frac{\partial S_r}{\partial a_4} = -2\sum(y - a_0 - a_1x_1, -a_2x_2 - a_3x_3 - a_4x_4 - a_5x_5)\, x_4 \quad (3.9)$$

$$\frac{\partial s_r}{\partial a_5} = -2\sum(y - a_0 - a_1x_1, -a_2x_2 - a_3x_3 - a_4x_4 - a_5x_5)\, x_5 \quad (3.10)$$

Minimizing error and simplifying equations (3.5) to (3.10) we have:

$$\sum a_0 + a_1\sum x_1 + a_2\sum x_2 + a_3\sum x_3 + a_4\sum x_4 + a_5\sum x_5 = \sum y \quad (3.11)$$

But $\sum a_0$= n (total number of samples). Hence, equation (3.11) becomes:

$$n + a_1\sum x_1 + a_2\sum x_2 + a_3\sum x_3 + a_4\sum x_4 + a_5\sum x_5 = \sum y \quad (3.12)$$

$$a_0\sum x_1 + a_1\sum x_1^2 + a_2\sum x_1x_2 + a_3\sum x_1x_3 + a_4\sum x_1x_4 + a_5\sum x_1x_5 = \sum x_1y \quad (3.13)$$

$$a_0\varepsilon\sum x_2 + a_1\sum x_1x_2 + a_2\sum x_2^2 + a_3\sum x_2x_3 + a_4\sum x_2x_4 + a_5\sum x_2x_5 = \sum x_2y \quad (3.14)$$

$$a_0\sum x_3 + a_1\sum x_1x_3 + a_2\sum x_2x_3 + a_3\sum x_3^2 + a_4\varepsilon x_3x_4 + a_5\sum x_3x_5 = \sum x_3y \quad (3.15)$$

$$a_0\sum x_4 + a_1\sum x_1x_4 + a_2\sum x_2x_4 + a_3\sum x_3x_4 + a_4\sum x_4^2 + a_5\sum x_4x_5 = \sum x_4y \quad (3.16)$$

$$a_0\sum x_5 + a_1\sum x_1x_5 + a_2\sum x_2x_5 + a_3\sum x_3x_5 + a_4\sum x_4x_5 + a_5\sum x_5^2 = \sum x_5y \quad (3.17)$$

Arranging equations (3.12) to (3.17) in matrix form gives:

$$[A][X] = [B] \quad (3.18)$$

$$\begin{bmatrix} n & \sum x_1 & \sum x_2 & \sum x_3 & \sum x_4 & \sum x_5 \\ \sum x_1 & \sum x_1^2 & \sum x_1x_2 & \sum x_1x_3 & \sum x_1x_4 & \sum x_1x_5 \\ \sum x_2 & \sum x_1x_2 & \sum x_2^2 & \sum x_2x_3 & \sum x_2x_4 & \sum x_2x_5 \\ \sum x_3 & \sum x_1x_3 & \sum x_2x_3 & \sum x_3^2 & \sum x_2x_4 & \sum x_3x_5 \\ \sum x_4 & \sum x_1x_4 & \sum x_2x_4 & \sum x_3x_4 & \sum x_4^2 & \sum x_4x_5 \\ \sum x_5 & \sum x_1x_5 & \sum x_2x_5 & \sum x_3x_5 & \sum x_4x_5 & \sum x_5^2 \end{bmatrix} \begin{Bmatrix} a_o \\ a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{Bmatrix} = \begin{Bmatrix} \sum y \\ \sum x_1y \\ \sum x_2y \\ \sum x_3y \\ \sum x_{41}y \\ \sum x_5y \end{Bmatrix} \quad (3.19)$$

So, the developed mix concrete design equation can be expressed as:

$$f_{cu} = \alpha + a_1C + a_2P + a_3W + a_4FA + a_5CA \quad (3.20)$$

Where: f_{cu} represents the compressive strength, C is the cement content, P is the POFA content, W is water content, FA is fine aggregate and CA is coarse aggregate.

III. RESULTS AND DISCUSSION

The formulated mix design for pozzolan material as partial replacement for cement was tested with experimental data. The fitted experimental data was simulated at every given mix parameters, and the predicted results compared with those obtained from the experimental analysis as shown in Figure 1. The constants of the mix design model for compressive strength of POFA concrete prediction is shown in the given equation: $f_{cu} = -9008.7 + 13.8699C + 13.6108P - 0.2616W - 4.6943FA + 3.8130CA$.

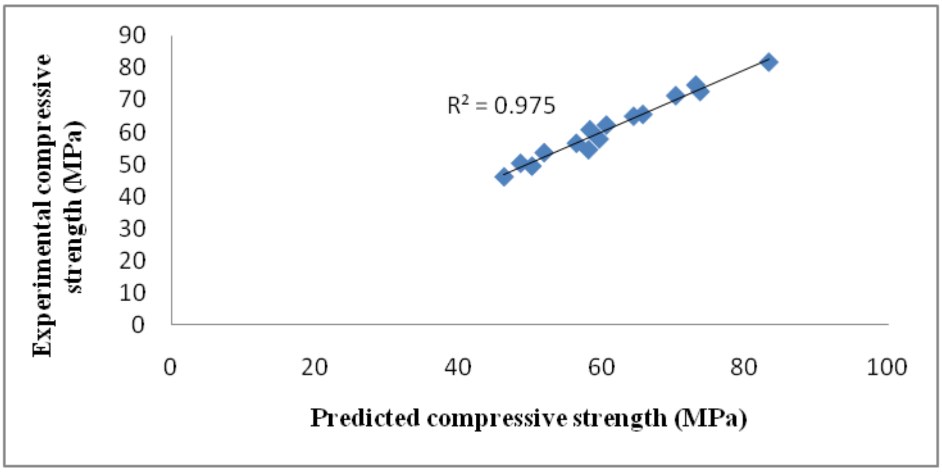

Figure 1: Comparison of predicted and experimental compressive strength at 28 days curing

Figure 1 shows the plot of predicted against the measured values of compressive strength of concrete obtained from the mix design. The correlation coefficient, R^2 was obtained as 0.9751, which implied that 97.51% of compressive strength values obtained from the experiment have been accounted for by the mix design model. Hence, the developed concrete mix design model for partial replacement of cement can be used to predict the compressive strength of concrete at any given mix parameters. The numerical values predicted by the model as against the corresponding measured values are presented in Table 2.

Table 2: Experimental and Predicted Compressive Strength of Concrete

Experiment (N/mm^2)	**Predicted (N/mm^2)**
83.4	81.7814
73.2	74.6615
70.4	71.3416
73.8	72.6187
65.8	65.4988
60.7	62.1789
64.5	64.9412
59.7	57.8213
58.2	54.5014
58.4	60.7311
52	53.6113
48.7	50.2913
56.5	56.5211
50.3	49.4012
46.4	46.0813

IV. CONCLUSION

In the days where saving of cost and high performance of concrete become imperative, it is expedient that techniques are developed such as formulation of mathematical model, as tools to achieving these. Thus, this concrete design model when accurately applied will help suggest the expected range of compressive strength of concrete at any given mix parameters. Again, the model will help in applying the right proportions of mix parameters necessary to give the best concrete performance, rather than using any mix proportion that may not give right strength of concrete.

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