Investigation of Blended Oil Palm Nut-Husk Ash and Over-Burnt Bricks Precast Concrete for Wall Cladding

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Abstract

The suitability of Oil palm nut-husk ash (OPNHA) and crushed over-burnt bricks (COBB) was investigated for wall cladding. A mathematical model was developed and used to optimize the mix proportion that produces the maximum strength of OPNHA/COBB concrete for wall cladding, using Scheffe's simplex lattice approach. The model formulated compares favourably with the experimental data. It also satisfies the T and F - statistics. The optimum value of strength predicted by this model is 33.41996N/mm^2, at a mix ratio of 1:0:2:4:0.4 of ordinary Portland cement, OPNHA, river sand, COBB and water-cement ratio; followed by 30.84N/mm2 with 0.6:0.4:3:6:0.6 ratios . Three mixtures (optimum, medium and low strength) were selected for other tests viz: impact values, water absorption and thermal properties. The results indicate that mixtures with optimum strength showed greatest resistance to impact load, followed by that with medium and low strength. Water absorption for optimum, medium and low strength were 1.51%, 2.24% and 0.56%, respectively. Thermal conductivity of 0.5017W/mk, 0.339W/mk and 0.394W/mk were recorded for the optimum, medium and low strength mixtures. The thermal resistivity were 1.992mk/W, 2.946mk/W and 2.538mk/W for the optimum, medium and low strength mixtures. Specific heat capacity of 1.134W/kgk, 0.84W/kgk and 0.9115W/kgk and thermal diffusivity of 0.00879m2/s, 0.00989m2/s and 0.00948m2/s were observed for the optimum, medium and low strength mixtures. Thermal absorptivity values were 0.146mm-1, 0.138mm-1 and 0.141mm-1 for the optimum, medium and low strength mixtures, respectively. The values met the set standards (ACI 122R-02 2002, ASHRAE, 2009 and Building and construction Authority, 2010).

Keywords: Compressive strength, precast OPNHA concrete, Mix design, Mathematical model, Optimization, Wall cladding.

1. Introduction

Today a lot of different cladding materials with a wide spectrum of colours, profiles, and textures are available on the market. It is necessary to choose cladding materials with skill and care so that they are in harmony with the surrounding landscape and existing buildings. A badly chosen exterior cladding material can devastate the appearance of the entire farmstead. It is important to remember that some materials weather well and their appearances improve with age. Others become faded and blotchy. Non-wood materials such as metal sheets, fiber-cement sheets and similar materials are available and commonly used (CIGR, 1999) Stone, wood, metal and some other façades have great characteristics such as their familiarity for workers, their good compressive strength and aesthetic appearance; they still have several limitations (Hoigard, and Scheffler, 2007). They have poor tensile strength, probability of decay, high maintenance and cleaning costs and the need for high qualified workforce are some of the reasons that raised the need to find other cladding materials with the same characteristics yet avoid the previously mentioned limitations (Musaağaoğlu, 2005).

Precast concrete Cladding panels offer an assortment of environmental benefits ranging from erection speed and reduced site disruption, to energy savings and use of recycled materials. Precast concrete cladding is economical to manufacture, erect, and maintain. It has excellent acoustic properties, is fire resistant, and provides a watertight building skin www.kniferriverprestress.com.

As the cost of cement and other building materials is becoming high in some parts of the world; particularly in developing countries like Nigeria where only government, industries, business cooperation and few individual can afford to clad there farm buildings, this high and still rising cost can however be reduced or minimize by the use of alternative building materials that are cheap, locally available and can bring about a reduction in the overall dead weight of the buildings. Some industrial and agricultural products such as over burnt bricks and oil palm husk-ash that would otherwise litter the environment as waste or at best be put into only limited use could gainfully be employed as building material (Opeyemi, and Makinde, 2012).

The objective of this work is to investigate the suitability of OPNHA and COBB as materials for precast concrete work cladding that are rich in abundance in the study area.

2.0 Materials and Methods

2.1 The Model Approach

Simplex lattice design proposed by Scheffe (1958) was used to formulate a mathematical model which relates compressive strength of OPNHA/COBB concrete and its component ratios of cement, Oil palm nut husk Ash, sand, crushed over-burnt bricks, and water cement ratio.

The parameter to be optimized, or the objective function which is the compressive strength, *y* depends on other factors - X_1, X_2, X_3, X_4, ...*n*,- the variables (Wadso, *et.al.*, 2012). A major quality control parameter in concrete is compressive strength which depends primarily on the proportions of the constituent materials.

Assuming concrete as a unit mixture,

$$X_1 + X_2 + X_3 + X_4 + X_5 = 1 \tag{1}$$

Hence, optimizing any function *y* depending on the proportion of *n* variables,

$$X_1 + X_2 + X_3 + , \ldots , X_n = 1 \tag{2}$$

2.2 Simplex lattice method

Simplex has been defined as the structural representation of the line or planes joining the assumed positions of the constituents (atoms) of the material (Wadso, *et.al.*, 2012 and Orie, and Osadebe, 2015).

If a mixture has a total of q components and X_i be the proportions of the ith component in the mixture such that,

$X_i \geq 0$ (i = 1,2,…,q)

Since the mixture is a complete whole, or unity.

$$X_1 + X_2 + X_3 + \ldots + q = 1 \text{ or}$$

$$\Sigma X_i - 1 = 0 \quad (3)$$

where i = 1,2,3,…,q

Thus the factor space is a regular (q - 1) dimensional simplex in which, if q = 2, we have 2 point of connectivity giving a line lattice. If q = 3 a triangular lattice, if q = 4 a tetrahedron etc. Taking a whole factor space in the design, we have (q, m) simplex lattice (Orie, and Osadebe, 2015).

2.3 Development of the (5, 2) lattice model

Scheffe (1985) showed that the response function (property) in multi-component system can be approximated by a polynomial. According to Scheffe (1985), a polynomial of degree n in q variable

has C_{q+n}^{n} coefficients and is in the form:

$$\hat{y} = b0 + \Sigma biXi + \Sigma bijXiXj + \Sigma b_{ijk}X_iX_jX_k + Xk + \ldots + \Sigma bi_1 1i_2 \ldots, i_n Xi_1 Xi_2 Xi_n \quad (4)$$

$$1 \leq i \leq q \qquad 1 \leq i \leq j \leq q \qquad 1 \leq i \leq j \leq k \leq q$$

The mixture properties were described by reduced polynomials as suggested by Scheffe (1985) given as:

$$\hat{y} = b0 + b1X1 + b2X2 + b3X3 + b4X4 + b_5X_5 + b12X1X2 + b13X1X3 + b14X1X4 + b_{15}X_1X_5 + b23X2X3 + b24X2X4 + B_{25}X_2X_5 + b34X3X4 + b_{35}X_3X_5\ b_{45}X_4X_5 + b11\ X_1^2 + b22\ X_2^2 + b33\ X_3^2 + b44\ X_4^2 \quad (5)$$

The reduced second degree polynomial is written as:

$$\hat{Y} = \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 + \alpha_4 x_4 + \alpha_5 x_5 + \alpha_{12} x_1 x_2 + \alpha_{13} x_1 x_3 + \alpha_{14} x_1 x_4 + \alpha_{15} x_1 x_5 + \alpha_{23} x_2 x_3 + \alpha_{24} x_2 x_4 + \alpha_{25} x_2 x_5 + \alpha_{34} x_3 x_4 + \alpha_{35} x_3 x_5 + \alpha_{45} x_4 x_5 \quad (6)$$

In summary form,

$$\hat{y} = \sum \alpha_i x_i + \sum \alpha_{ij} x_i x_j \quad (7)$$

where, $1 \leq i \leq q$, $1 \leq i \leq j \leq q$ respectively and α_i are the coefficients of the regression equation.

Let the response function to the pure components (x_i) be denoted by (y_i) and the response to a 1:1 binary mixture of components *i* and *j* by y_{ij} from Equation 6.

$$\alpha_i = \alpha_{ij} x_i x_j \tag{8}$$

Where, i = 1 to 5

The general equation for evaluating α_i and α_{ij} are found to be of the form

$$\alpha_i = y_i \tag{9}$$

$$\alpha_{ij} = 4_{ij} + 2y_i - 2y_j \tag{10}$$

Scheffe also showed that the number of points in (q, n) lattice is given as :

$$\frac{q(q+1)}{2 \times 1} \tag{11}$$

This implies that for a (5, 2) lattice, the number of points (coefficients)

$$\frac{5(5+1)}{2 \times 1} = 15$$

The relation between the actual components and the pseudo components is according to scheffe [12] given as:

$$Z = AX \tag{12}$$

Where Z and X are the five element vectors while A is a five by five matrix. The value of the matrix A was obtained from the first five mix ratios that were selected arbitrarily.

The mix ratios are Z_1 [1:0:2:4:0.45], Z_2 [0.9:0.1:1.5:5:0.5], Z_3 [0.8:0.2:2.5:3.5:0.6], Z_4 [0.7:0.3:2:4:0.5] and Z_5 [0.6:0.4:3:6:0.6] where each of the Z ratio represent the mixture of ordinary Portland cement, (OPHA), sand, crush over burnt bricks (COBB) and the water cement ratio respectively.

The corresponding pseudo mix ratios are X_1 [1:0:0:0:0], X_2 [0:1:0:0:0], X_3 [0:0:1:0:0], X_4 [0:0:0:1:0] and X_5 [0:0:0:0:1]. The required transformation was depicted as follows:

$$Z\begin{pmatrix} 1 & 0.9 & 0.8 & 0.7 & 0.6 \\ 0 & 0.1 & 0.2 & 0.3 & 0.4 \\ 2 & 1.5 & 2.5 & 2 & 3 \\ 4 & 2.5 & 3.5 & 4 & 6 \\ 0.45 & 0.5 & 0.6 & 0.5 & 0.6 \end{pmatrix} \xrightarrow{\text{Transformation}} X\begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

Substitution of X_i and Z_i into equation 11 gives the values of A as shown below.

$$A = \begin{pmatrix} 1 & 0.9 & 0.8 & 0.7 & 0.6 \\ 0 & 0.1 & 0.2 & 0.3 & 0.4 \\ 2 & 1.5 & 2.5 & 2.5 & 3 \\ 4 & 2.5 & 3.5 & 4 & 6 \\ 0.45 & 0.5 & 0.6 & 0.5 & 0.6 \end{pmatrix}$$

Where A is the inverse transformation matrix

Thus for pseudo component [$X_1^{(i)}$, $X_2^{(i)}$, $X_3^{(i)}$, $X_4^{(i)}$ and $X_5^{(i)}$], the actual component Z is determined by equation 11as follows:

$$\begin{pmatrix} Z_1^{(i)} \\ Z_2^{(i)} \\ Z_3^{(i)} \\ Z_4^{(i)} \\ Z_5^{(i)} \end{pmatrix} = \begin{pmatrix} 1 & 0.9 & 0.8 & 0.7 & 0.6 \\ 0 & 0.1 & 0.2 & 0.3 & 0.4 \\ 2 & 1.5 & 2.5 & 2.5 & 3 \\ 4 & 2.5 & 3.5 & 4 & 6 \\ 0.45 & 0.5 & 0.6 & 0.5 & 0.6 \end{pmatrix} \bullet \begin{pmatrix} X_1^{(i)} \\ X_2^{(i)} \\ X_3^{(i)} \\ X_4^{(i)} \\ X_5^{(i)} \end{pmatrix}$$

Where Z are the actual components

This was employed to determine the actual component for point 6 to 15. The work is limited to five control points. The control points were selected from the [5, 4] lattice should the [5, 2] lattice not fit adequately. Table 1a shows the pseudo component chosen and their actual components for the experimental points and Table 1b shows the pseudo and actual components for the test points.

Table 1a : Actual (Zi) and Pseudo (Xi) Components for the fifteen Experimental Points of (5, 2) lattice.

			Pseudo	Components				Actual	Variables		
N	X_1	X_2	X_3	X_4	X_5	denoted as	Z_1	Z_2	Z_3	Z_4	Z_5
1	1	0	0	0	0	y_1	1	0	2	4	0.45
2	0	1	0	0	0	y_2	0.9	0.1	1.5	2.5	0.5
3	0	0	1	0	0	y_3	0.8	0.2	2.5	3.5	0.6
4	0	0	0	1	0	y_4	0.7	0.3	2	4	0.5
5	0	0	0	0	1	y_5	0.6	0.4	3	6	0.6
6	½	½	0	0	0	y_{12}	0.95	0.05	1.75	3.25	0.475
7	½	0	½	0	0	y_{13}	0.9	0.1	2.25	3.75	0.525
8	½	0	0	½	0	y_{14}	0.85	0.15	2	4	0.475
9	½	0	0	0	½	y_{15}	0.8	0.2	2.5	5	0.525
10	0	½	½	0	0	y_{23}	0.85	0.15	2	3	0.55
11	0	½	0	½	0	y_{24}	0.8	0.2	1.75	3.25	0.5
12	0	½	0	0	½	y_{25}	0.75	0.25	2.25	4.25	0.55
13	0	0	½	½	0	y_{34}	0.75	0.25	2.25	3.75	0.55
14	0	0	½	0	½	y_{35}	0.7	0.3	2.75	4.75	0.6
15	0	0	0	½	½	y_{45}	0.65	0.35	2.5	5	0.55

Table 1b: Actual (Zi) and Pseudo (Xi) Components for the control Points of (5, 2) lattice

N	X_1	X_2	X_3	X_4	X_5	denoted as	Z_1	Z_2	Z_3	Z_4	Z_5
1	¾	½	0	0	0	C_1	0.975	0.025	1.875	3.625	0.463
2	¼	¼	¼	0	¼	C_2	0.825	0.175	2.25	4	0.5375
3	¼	¼	0	¼	¼	C_3	0.8	0.2	2.125	4.125	0.5125
4	0	¾	¼	0	0	C_4	0.875	0.125	1.75	2.75	0.525
5	0	½	¼	¼	0	C_5	0.825	0.175	1.875	3.125	0.525

3. Materials and Method

The materials involved sand which was collected from River Benue's sand depot, the burnt bricks collected from a local bricks production site at Kiraki Quarters, Angwan Jukun in North Bank area of Makurdi and was crushed to maximum size of 14mm. Oil palm nut husk Ash (OPNHA) was also collected from oil palm mills in Owukpa area of Ogbadibo, Ordinary Portland cement was collected from Dangote Cement Company depot in Makurdi and the water for the mixing was collected from the University of Agriculture, Makurdi water works, all in Benue state, Nigeria.

3.1 The Experimental procedure

The Design Matrix for Scheffe's (5, 2) Lattice (Pseudo and Real components) was developed. This yielded fifteen mix proportions. An extra five proportions which served as control were developed. These mix proportions were used to cast sample cubes which measured 150mm x 150mm x 150mm. The samples were cured by total immersion in water for 28 days after which they were tested for their compressive strengths with the universal testing machine. The results were used to develop a mathematical model. The model was statistically tested at 95% confidence level of accuracy using the students t-statistic and the F-statistics (Osadebe, *et.al.,* 2007 and Orie, and Osadebe, 2015).

After this three different samples (optimum, medium and low strength values) were prepared and then subjected to test such as impact strength test, thermal property test (thermal conductivity, thermal resistivity, thermal absorbtivity and thermal diffusivity).

The impact load test was conducted using the dropped weight test in accordance to ACI Committee 544.2R (ACI Committee 544, 1988). In this method a concrete slab of 300mm x 300mm x 10mm for each mix and an impact ball of weight 530g and 51mm diameter was dropped from a height of 1400mm. The experimental set-up is as shown in Figure 1.

The thermal conductivity was determined using the Lee's apparatus. Spherical slabs were produced, from the three different strength samples as shown in Plate 1, and cured for 28days before it was tested. Equations 1, 2, 3 and 4 were used to compute thermal conductivity, thermal resistivity, thermal diffusivity and thermal absorbtivity (Abdullah, *et.al.,* 2013 and Wadso, *et.al.,* 2012).

$$k = \frac{mc\frac{dT}{dt}}{A\frac{(T_2 - T_1)}{x}} \tag{13}$$

$$r = \frac{1}{k} \tag{14}$$

$$\alpha = \frac{k}{c\rho} \tag{15}$$

$$\lambda = \left(\frac{\omega}{2\alpha}\right)^{1/2} \tag{16}$$

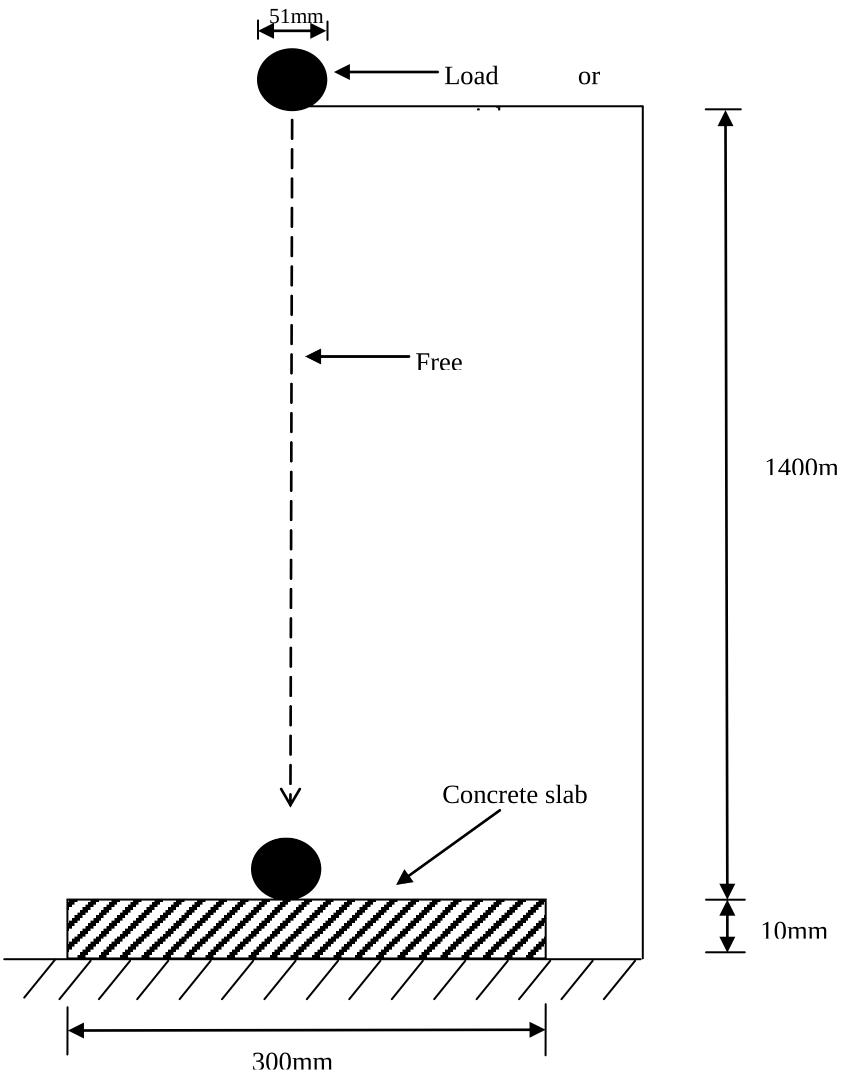


Figure 1: Schematic diagram for the impact strength test set up

Plate 1: The concrete specimen samples used for thermal properties determination

where:

k = thermal conductivity, A = area of the sample in contact with the metallic disc, m = mass of the metallic disc, $(T_1 - T_2)$ = temperature difference across the sample thickness, x = thickness of the sample, dT/dt = rate of cooling of the metallic disc at T_2, r = thermal resistivity, c = specific heat capacity, ρ = density of the sample, λ = thermal absortivity, $\omega = 2\pi$/period and $\boldsymbol{\alpha}$ = thermal diffusivity.

4.0 Results and Discussion

4.1 Compressive Strength

The results for the test performed to determine the compressive strength for the 15 actual mix proportions and the 5 control points are presented in Tables 2. The compressive strength test results presented in Table 2 show that the lowest and highest strength values of 17.78N/mm^2 and 33.42N/mm^2 respectively, recoreded are within the range of minimum values of plain concretes (17.225N/mm^2 to 20.67N/mm^2) George and Thomas, 2012), for basement walls, foundation walls, exterior walls and other vertical concrete surfaces exposed to the weather. According to International Building Code (2006), for negligible exposure, the minimum strength is 17.225N/mm^2 (2500psi), and for moderate and severe exposure the minimum strength is 20.67N/mm^2 (3000psi). The concrete compressive strength may be verified in accordance with ASTM C39 (2016). The combination that produced the optimum strength is that with 0% OPNHA (oil palm nut husk ash) and 100% OPC (ordinary Portland cement) contents, followed by the combination with 40% OPHA content as partial replacement for cement.

Adequate strength of (30.84N/mm^2) was achieved with 40% OPNHA while highest strength value was obtained with zero replacement for cement.

Table 2: The results of two repetitions each, of the 15 design points and the 5 test points of the {5, 2} lattice.

Exp.No	Repetition (r)	Response (y_r).MN/m^2	Response designation	$\sum_{r=1}^{m_i} y_r$	$\hat{y} = (\sum_{r=1}^{m_i} y_r)/m_i$	$\sum_{r=1}^{m_i} y_r^2$	$s_i^2 = \frac{1}{m_i - 1}\left[\sum_{r=1}^{m_i} y_r^2 - \frac{1}{m_i}\left(\sum_{r=1}^{m_i} y_r\right)^2\right]$
1	1	32.89					
	2	33.96	y_1	66.85	33.42	2235.03	100.58
2	1	20.09					
	2	27.91	y_2	48	24	1182.58	53.37
3	1	22.22					
	2	21.69	y_3	43.91	21.95	964.18	43.39
4	1	19.73					
	2	18.49	y_4	38.22	19.11	731.15	32.91
5	1	32.53					
	2	29.03	y_5	61.55	30.84	1900.36	85.55
6	1	25.60					
	2	26.67	y_{12}	52.27	26.13	1366.65	61.50
7	1	19.38					
	2	17.78	y_{13}	37.16	18.58	691.71	31.13
8	1	21.16					
	2	26.49	y_{14}	47.65	23.82	1149.47	51.80
9	1	17.42					
	2	20.27	y_{15}	37.69	18.84	714.33	32.17
10	1	21.68					
	2	20.62	y_{23}	42.30	21.15	895.21	40.29
11	1	21.16					
	2	19.73	y_{24}	40.17	20.44	837.02	37.95
12	1	21.16					
	2	18.49	y_{25}	39.65	19.82	789.63	35.55
13	1	20.62					
	2	18.31	y_{34}	38.93	19.47	760.44	34.23
14	1	16.89					
	2	18.67	y_{35}	35.56	17.78	633.84	28.53
15	1	18.13					
	2	18.49	y_{45}	36.62	18.31	670.58	30.18

			Control points				
1	1	29.51					
	2	29.16	C_1	58.67	29.33	1721.15	77.45
2	1	21.33					
	2	25.07	C_2	46.40	23.20	1083.47	48.79
3	1	28.27					
	2	25.05	C_3	53.34	26.67	1427.70	64.27
4	1	23.29					
	2	23.47	C_4	46.72	23.38	1093.27	49.21
5	1	22.76					
	2	21.51	C_5	44.27	22.13	980.70	44.14
						Σ =	982.99

Hence, to obtain the replication variance from Table 2,

Number of degrees of freedom for replication variance,

$$v_E = \sum_{i=1}^{20} v_i = \sum_{i=1}^{20} (m_i - 1) = 20$$

Replication variance, $s_y^2 = \sum_{i=1}^{20} \frac{s_i^2 v_i}{v_E} = \sum_{i=1}^{20} \frac{s_i^2}{v_E} = \frac{Total\ s_i^2}{20} = \frac{982.99}{20} = 49.15$

Replication error, $s_y = \sqrt{s_y^2}$ (17)

$$S_y = \sqrt{49.15} = 7.01$$

$$\therefore s_y = 7.01$$

4.2 The Regression Equation

Based on Equations (9 and 10) and Table 2, the coefficients of the second degree equation are obtained thus:

$\alpha_1 = 33.42$, $\alpha_2 = 24$, $\alpha_3 = 21.95$, $\alpha_4 = 19.11$ and $\alpha_5 = 30.84$

$\alpha_{12} = 4(26.13) - 2(33.45) - 2(24) = -10.38$

$\alpha_{13} = 4(18.58) - 2(33.45) - 2(21.95) = -36.42$

α_{14} = 4(18.82) – 2(33.4) – 2(19.11) = -9.78

α_{15} = 4(18.84) – 2(33.42) – 2(30.84) = -53.16

α_{23} = 4(21.15) – 2(24) – 2(21.95) = -7.3

α_{24} = 4(20.44) – 2(24) – 2(19.11) = -4.46

α_{25} = 4(19.82) – 2(24) – 2(30.84) = -30.4

α_{34} = 4(19.47) – 2(21.95) – 2(19.11) = -4.24

α_{35} = 4(17.78) – 2(21.95) – 2(30.84) = -34.46

α_{45} = 4(18.31) – 2(19.11) – 2(30.84) = -26.66

Thus substituting into equation 6, we have

$$\hat{y} = 33.42x_1 + 24x_2 + 21.95x_3 + 19.11x_4 + 30.84x_5 - 10.38x_1x_2 - 36.42x_1x_3 - 9.78x_1x_4 - 53.16x_1x_5 - 7.3x_2x_3 - 4.46x_2x_4 - 30.4x_2x_5 - 4.24x_3x_4 - 34.46x_3x_5 - 6.66x_4x_5 \tag{18}$$

Equation 18 is the mathematical model for the optimization of the compressive strength of a 5-component concrete mix using oil palm nut husk ash as the second component and crushed over-burnt bricks as the fourth component.

4.3 Tests for Adequacy of the Model

The model was tested for adequacy against the control points using the student t-statistics and the F-statistics to ascertain their level of significance at 95% confidence interval. The results are presented in Tables 3 and 4 respectively. The results showed that the regression model is adequate. From Table 3, it was seen that the observed or the calculated strengths from the regression equation are slightly lower than their experimental counterparts, but statistically, there is no significant difference between them. A computer program in Q Basic language was developed for the model. The desired compressive strength is entered and the program generates the proportion of the components. The flow chat of the program is as shown in Figure 2.

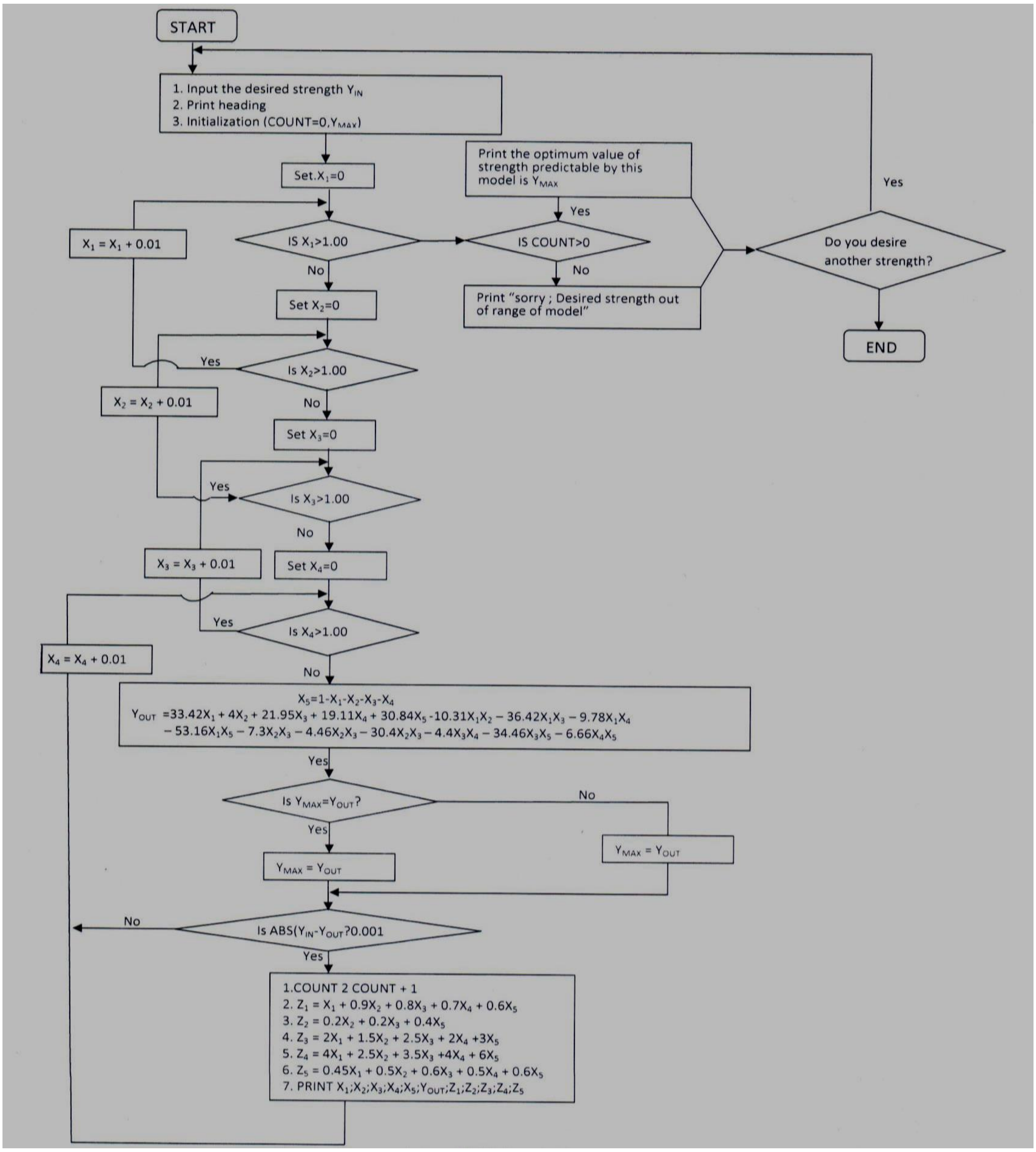


Figure 2: flow chart for the optimization of OPHA/COBB concrete compressive strength

Table 3: T – statistics for the control points

N	Response Symbol	i	j	α_i	α_{ij}	α_i^2	α_{ij}^2	ε_o	y_0	y_t	Δ_y	t
1	C_1	1	2	0.375	0.75	0.141	0.563	0.704	29.33	29.1	0.23	0.036
		1	3	0	0							
		1	4	0	0							
		1	5	0	0							
		2	3	0	0							
		2	4	0	0							
		2	5	0	0							
		3	4	0	0							
		3	5	0	0							
		4	5	0	0							
		5	-	0	0							
					Σ	0.141	0.563	0.704	29.33	29.1	0.23	0.036
Similarly												
2	C2					0.112	0.378	0.49	23.20	16.78	6.42	1.061
3	C3					0.112	0.378	0.49	26.67	18.415	8.25	1.363
4	C4					0.141	0.563	0.704	23.38	22.12	1.26	0.195
5	C5					0.016	0.75	0.766	22.13	20.53	1.6	0.243

From the t-value table, at significant level, $\alpha = 0.05$ and $t_{\alpha/l}(v_c) = t_{0.05/5}(20) = 2.528$

Table 4: F-Statistics for the Controlled Points

Respones Symbol	y_o	y_E	$(y_o - \hat{y}_o)$	$(y_E - \hat{y}_E)$	$(y_o - \hat{y}_o)^2$	$(y_E - \hat{y}_E)^2$
C_1	29.33	29.10	4.388	7.71	19.255	59.444
C_2	23.20	16.78	-1.742	-4.61	3.035	21.252
C_3	26.67	18.42	1.728	-2.97	2.986	8.820
C_4	23.38	22.12	-1.562	0.73	2.440	0.533
C_5	22.13	20.53	-2.812	-0.86	7.907	0.739
$\boldsymbol{\Sigma}/_5$	24.942	21.39			7.125	18.158

Where y_o is the Experimental values (responses), y_E is the Expected or theoretical calculated values (responses)

$$S_o^2 = \frac{(y_o - \hat{y}_o)^2}{5} = 7.125, \qquad S_E^2 = \frac{(y_E - \hat{y}_E)^2}{5} = 18.158$$

Hence, F = higher of the two values divided by the lower and F = 18.158/7.125 = 2.548

From fisher table, $F_{0.95}(4,4) = 6.39$

The F-tabulated value is greater than the F-calculated value.

4.4 Impact Strength

The result for the impact test for OPNHA/COBB concrete is as presented in Table 5, the numbers marked 1, 2, 3 and 4 represents defects with crack, the detachment, the pinholes and split. The effect on both the impact and reverse surfaces were observed and recorded. The failure mode is as shown in Plate 2 to 5. The results showed that the optimum strength sample has the highest strength followed by the medium strength sample and finally the low strength sample.

Table 5: Results for Impact test of OPNHA/COBB concrete

Material	Indentation diameter (mm)	Impact surface	Reverse surface
Optimum mix	-	4	Small cracks
Medium mix	-	2,4	Small cracks
Low mix	-	1,2,4	Cracks

Note: 1: crack, 2: detachment, 3: pinholes and 4: split

Plate 2: OPHA/COBB cladding

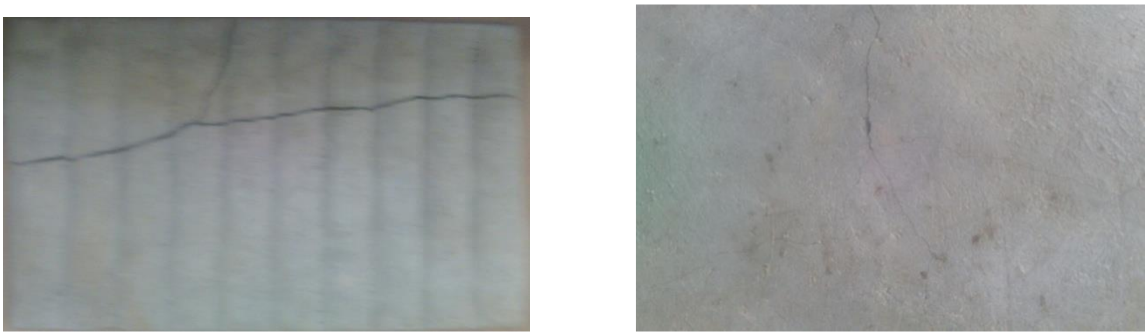
(a)

(b)

Plate 3: optimum strength mix response to impact load, showing the main surface (a) and reverse surface (b)

(a) (b)

Plate 4: Medium strength mix response to impact load, showing the main surface (a) and reverse surface (b)



(a) (b)

Plate 5: Low strength mix response to Impact Load, showing the main surface (a) and reverse surface (b)

4.5. Thermal Properties of OPNHA/COBB Concrete

The results for the thermal properties of OPNHA/COBB concrete are as presented in Table 6

4.5.1 Thermal conductivity (K)

The thermal conductivity of OPNHA/COBB concrete presented in Table 6, showed that the optimum strength mix, medium strength mix and low strength mix sample has a thermal conductivity of 0.5011W/mK, 0.339W/mK and 0.394W/mK ,respectively. This indicates that the medium strength mix sample is more suitable for cladding and other construction work having the lowest thermal conductivity values among the rest samples. With thermal conductivity indicating how quickly or easily heat flows through a material, it then means that materials with very high conductivity values, however, should be avoided because high conductivity can shorten the time lag for heat delivery (ACI 122R-02, 2002).

The thermal conductivity obtained for OPNHA/COBB concrete are lower than the range of thermal conductivity for concrete, masonry and cladding (0.8 – 1.28$Wm^{-1}k^{-1}$) given by the International Standard (2007), and are higher than 0.303W/mK, for lightweight concrete given by the Building and Construction Authority

(2010).

Table 6: Results for the thermal properties of OPNHA/COBB concrete made from the three different mix ratios

S/ No	Thermal Properties	Optimum mix	Medium mix	Low mix
1	Specific heat, Watt	10.302	8.106	9.58195
2	Heat Conductivity,W/mK	0.5017	0.339	0.394
3	Thermal Resistivity, mK/W	1.992	2.946	2.538
4	Specific Heat Capacity, W/kgK	1.34	0.824	0.9115
5	Thermal Diffusivity, m^2/s	0.00879	0.00989	0.00948
6	Thermal Absortivity, mm^{-1}	0.146	0.138	0.141

Also the thermal conductivity of OPHA/COBB concrete are lower than that of common bricks (0.769 – 0.556$Wm^{-1}k^{-1}$), Granite (20$Wm^{-1}k^{-1}$), Tile (20 $Wm^{-1}k^{-1}$) and Steel (50 $Wm^{-1}k^{-1}$) and it is higher than that of Gypsum wall board (2.222 $Wm^{-1}k^{-1}$), plywood (1.613$Wm^{-1}k^{-1}$), Catton batts (0.0412 – 0.0315$Wm^{-1}k^{-1}$), Sandstone/Limestone (12.5$Wm^{-1}k^{-1}$) and Expanded Polystyrene (0.2$Wm^{-1}k^{-1}$) as obtained from Building Envelope Design Guide (2015), ASHRAE (2009), Francis (2012) and American building material (2016).

4.5.2 Thermal resistivity (r)

The results of Table 6, show that the thermal resistivity values of optimum strength mix, medium strength mix and low strength mix sample are 1.99mK/W, 2.946mK/W and 2.538mK/W, respectively, with the medium strength sample having the highest value among the three different samples. The lower the thermal conductivity of a material, the better the material is, for insulation (ASTM C39, 2016). Since thermal conductivity is the inverse of thermal resistivity, it also follows that materials with lower thermal conductivity will have a high thermal resistivity. The thermal resistivity obtained for the three samples are higher than the range values (0.43 to 0.87m.K/W) given for concrete, masonry and cladding work (ColoradoENERGY.org.). 1.79 mK/W for insulation materials without penetration (ASTM C39, 2016) and for inside wall surface (0.12mK/W for high emissivity and 0.299mK/W for low emissivity) and outside surface, high emissivity 0.044mK/W given by Building and Construction Authority (2010).

When these were compared with some other materials it was observed that the values that were obtained for OPNHA/COBB concretes are higher than that of Common brick (1.3 – 1.8m.k/W), Granite (0.05m.k/W), Tile (0.05m.k/W) and Steel (0.02m.k/W), and they are lower than that of Gypsum wall board (0.45m.k/W), Plywood (0.62m.k/W), Catton batts (24 - 32m.k/W), Sandstone/limestone (0.08m.k/W) and Expanded polystyrene (5m.k/W) as obtained from Building Envelope Design Guide (2015), ASHRAE (2009), Francis (2012) and American building material (2016)..

4.5.3 Thermal diffusivity (α)

Table 6, shows that thermal diffusivity of optimum strength mix, medium strength mix and low strength mix sample are 0.00879m^2/s, 0.00989m^2/s and 0.00948m^2/s, respectively, with the medium strength mix sample having the highest and probably the most suitable thermal diffusivity among the three OPNHA/burnt bricks concrete samples tested. A high thermal diffusivity indicates that heat transfer through a material will be fast and the amount of storage will be small. Materials with a high thermal diffusivity respond quickly to changes in temperature. Low thermal diffusivity means a slower rate of heat transfer and a larger amount of heat storage. Materials with low thermal diffusivity respond slowly to an imposed temperature difference. Materials with low thermal diffusivities, such as concrete, masonry or cladding, are effective thermal inertia elements in a building (ASTM C39, 2016).

4.5.4 Thermal absorptivity (λ)

The thermal absorptivity values of OPHA/burnt brick concrete presented in Table 6 indicate that the optimum strength mix, medium strength mix and low strength mix sample are 0.146mm^{-1}, 0.138mm^{-1} and 0.141mm^{-1}, respectively, with the medium strength mix sample having the lowest thermal absorptivity which is more preferable for concrete, masonry and cladding work. The amount of heat absorbed by a wall depends on its absorptivity and the solar radiation incident on the wall. Absorptivity is a measure of the efficiency of receiving radiated heat and is the fraction of incident solar radiation that is absorbed by a given material, as opposed to being reflected or transmitted. For opaque materials, such as concrete and masonry, solar radiation not absorbed by the wall is reflected away from it.

5. Conclusion

From this study, the following conclusions were drawn:

1) Oil palm nut husk-ash (OPNHA) and crushed over-burnt bricks (COBB) as partial replacements of cement and total replacement of granite and river stone respectively, can be used in the production of concrete for wall cladding with good compressive strength and reduced weight (dead load). Also impact load is resisted moderately.
2) The mathematical model formulated was in good agreement with the generated data tested.
3) OPNHA/COBB is good material for the production of pre-cast wall claddings with improved thermal and insulation properties.
4) OPNHA/CBB concrete if used in construction work can reduce the cost of materials that are required for construction, since both of the materials (oil palm husk ash and crushed burnt bricks) are waste materials and can be obtained at little or no cost.
5) OPNHA/COBB concrete can be used to produce wall cladding and concrete for all kinds of residential and agricultural buildings.

It is important to note that a lot still remains to be done in order to understand fully the structural and protective performance of these materials in wall claddings.

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