International Journal of Engineering Research and Development
e-ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 11, Issue 03 (March 2015), PP.43-49

Prediction of Compressive Strength and Water Absorption of Sand-Quarry dust Blocks Using Osadebe's Regression Model

C. U. Anya[1], N. N. Osadebe[2],E. E. Anike[3]andW.O. Onyia[4]
[1, 3]Federal University of Technology, Owerri, Nigeria
[2]University of Nigeria, Nsukka
[4]Enugu State University of Science and Technology, Agbani, Nigeria

Abstract:-Block manufacturers in Nigeria are faced with the problem of mix proportioning to meet the compressive strength and water absorption requirements. This paper developed new models for predicting the 28th day compressive strength and water absorption of sand-quarry dust blocks using Osadebe's regression model which expresses the response as a function of the proportions of the mixture components. The models were formulated using existing data and were validated using the F statistic and probability plots. A comparison of the models and the existing ones based on Scheffe's simplex lattice models showed that there is no statistical difference between them. The new models however have wider range of application and are more user friendly.

Keywords:- Sand-quarry dust blocks, Osadebe's regression model, mix proportioning, Scheffe's simplex lattice model, Compressive strength, Water absorption.

I. INTRODUCTION

Partial replacement of sand with quarry dust in the production of concrete and sandcrete block is now a common practice in Nigeria. The practice is highly encouraged as it has been shown by many researchers [1-6] to improve the structural characteristics of the concrete and sandcrete blocks. Block manufacturers in Nigeria are confronted with the problem of mix proportioning to meet the minimum requirements of Nigeria Industrial standard for sandcrete blocks [7]. The problem is even compounded when the sand is partially replaced with quarry dust as in sand-quarry dust blocks. There is therefore the need to develop models that could be used to predict the structural characteristics of sand-quarry dust blocks. Such models, if developed using statistical approaches, can also be used for studying mixture components' interactions and optimization [8, 9].

Anya and Osadebe [10] developed models for predicting the compressive strength and water absorption of sand-quarry dust blocks using a statistical approach based on Scheffe's simplex lattice design. Through the models, they studied the mixture components' interactions. However, the components were expressed in pseudo ratios which have to be transformed to their actual real component ratios. Expressing the components' proportions in pseudo ratios enabled the individual component contribution to be evaluated but made the model less user friendly. Also the models can be applied only to mixes within the simplex.

The objective of this work is to develop friendlier models with wider range of application for predicting the 28th day compressive strength and water absorption of sand-quarry dust by the use of Osadebe'sregression model in which the components' proportions are expressed in actual proportions.

II OSADEBE'S REGRESSION EQUATION

The Osadeberegression equation is another form of mixture experiment models. Osadebe[11] expressed the response, *Y* as a function of the proportions of the constituents of the mixture, Z_i. For mixture experiments, the sum of all the proportions must add up to 1. That is,

$$Z_1 + Z_2 + \cdots + Z_q = \sum_{I=1}^{q} Z_i = 1 \quad (1)$$

*q*is the number of mixture components and Z_i, the proportion of component *i* in the mix
Osadebe assumed that the response *Y* is continuous and differentiable with respect to its predictors, and can be expanded in the neighborhood of a chosen point, *Z(0)* using Taylor's series.

$$Z(0) = \left(Z_1^{(0)}, Z_2^{(0)}, \ldots, Z_q^{(0)}\right)^T \quad (2)$$

Thus,

$$Y(Z) = F(Z^{(0)}) + \sum_{i=1}^{q} \frac{\partial f(Z^{(0)})}{\partial Z_i}(Z_i - Z^{(0)}) + \frac{1}{2!}\sum_{i=1}^{q-1}\sum_{j=1}^{q} \frac{\partial^2 f(Z^0)}{\partial Z_i \partial Z_j}(Z_i - Z_i^{(0)})(Z_j - Z_j^{(0)}) + \frac{1}{2!}\sum_{i=1}^{q} \frac{\partial^2 f(Z^{(0)})}{\partial Z_i^2}(Z_i - Z^{(0)}) \ldots \quad (3)$$

For convenience, the point Z^0 can be taken as the origin without loss in generality of the formulation and thus;

$$Z_1^{(0)} = 0,\ Z_2^{(0)} = 0, \ldots, Z_q^{(0)} = 0 \quad (4)$$

Let:

$$b_0 = F(0), \quad b_i = \frac{\partial F(0)}{\partial Z_i}, \quad b_{ij} = \frac{\partial^2 F(0)}{\partial Z_i \partial Z_j}, \quad b_{ii} = \frac{\partial^2 F(0)}{\partial Z_i^2} \quad (5)$$

Substituting Equation (4) into Equation (1) gives:

$$Y(Z) = b_0 + \sum_{i=1}^{q} b_i Z_i + \sum_{i \le j \le q}^{q} b_{ij} Z_i Z_j + \sum_{i=1}^{q} b_{ii} Z_i^2 \quad (6)$$

Multiplying Equation (1) by b_0 gives the expression:

$$b_0 = b_0 Z_1 + b_0 Z_2 + \cdots \ldots \ldots + b_0 Z_q \quad (7)$$

Multiplying Equation (1) successively by Z_1, Z_2 … $Z_q$and rearranging, gives respectively:

$$Z_1{}^2 = Z_1 - Z_1 Z_2 - \ldots \ldots \ldots \ldots . -Z_1 Z_q$$

$$Z_2{}^2 = Z_2 - Z_1 Z_2 - \quad \ldots \ldots \ldots . - Z_2 Z_q$$

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$$Z_q{}^2 = Z_1 - Z_1 Z_q - \ldots \ldots \ldots \ldots . -Z_{(q-1)} (8)$$

Substituting Equations (7) and (8) into Eq. (6) and simplifying yields

$$Y(Z) = \sum_{i=1}^{q} \beta_i Z_i + \sum_{i \le j \le q}^{q} \beta_{ij} Z_i Z_j \quad (9)$$

Where

$$\beta_i = b_0 + b_i \ldots \ldots + b_{ii} \quad (10)$$

$$\beta_{ij} = b_{ij} - b_{ii} - b_{ij} \quad (11)$$

Equation (9) is Osadebe's regression model equation. It is defined if the unknown constant coefficients, β_i and β_{ij} are uniquely determined. If the number of constituents, *q*, is 4, and the degree of the polynomial, *m*, is 2 then the Osadebe regression equation is given as:

$$Y = \beta_1 Z_1 + \beta_2 Z_2 + \beta_3 Z_3 + \beta_4 Z_4 + \beta_{12} Z_1 Z_2 + \beta_{13} Z_1 Z_3 + \beta_{14} Z_1 Z_4 + \beta_{23} Z_2 Z_3 + \beta_{24} Z_2 Z_4 + \beta_{34} Z_3 Z_4 \quad (12)$$

The number of coefficients, *N* is now the same as that for the Scheffe's {4, 2} model given by [12] as:

$$N = C_m^{(q+m-1)} = C_2^{(4+2-1)} = 10$$

Osadebe's model has been applied by some researchers [13 -15] in solving various problems of concrete mix proportioning.

2.1 Determination of the coefficients of Osadebe'sregression equation

The least number of experimental runs or independent responses necessary to determine the coefficients of the Osadebe's regression coefficients is *N*.

Let $Y^{(k)}$ be the response at point *k* and the vector corresponding to the set of component proportions (predictors) at point *k* be $Z^{(k)}$. That is:

$Z^{(k)} = \{ Z_1^{(k)}, Z_2^{(k)}, \ldots\ldots, Z_q^{(k)} \}$ (13)

Substituting the vector of Eq. (13) into Equation (9) gives:

$$Y^{(k)} = \sum_{i=1}^{q} \beta_i Z_i^{(k)} + \sum_{i \le j \le q}^{q} \beta_{ij} Z_i^{(k)} Z_j^{(k)} \quad (14)$$

Where $k = 1, 2, \ldots, N$

Substituting the predictor vectors at each of the *N* observation points successively into Eq. (9) gives a set of *N* linear algebraic equations which can be written in matrix form as:

$$\boldsymbol{Z\beta} = \boldsymbol{Y} \quad (15)$$

Where

$\boldsymbol{\beta}$is a vector whose elements are the estimates of the regression coefficients.

Z is an *N xN* matrix whose elements are the mixture component proportions and their functions .
Y is a vector of the observations or responsesat the various *N* observation points.
The solution to Equation (15) is given as:

$$\boldsymbol{\beta} = \boldsymbol{Z}^{-1}\boldsymbol{Y} \qquad (16)$$

The Osadebe model is fitted to only the number of points necessary to define the polynomials. To validate the model, additional measurements are taken at the so called check or control points. The *F* statistic is determined from the observed and model predicted responses at the check points as follows:
Let the sample variances for the observed and predicted values at the check points be S_o^2 and S_p^2 and the population variances, σ_1^2 and σ_2^2 respectively.If S_o^2 and S_p^2 are equal we conclude that the errors from the experimental procedures are similar and hence the sample variances are estimates of the same population variance. The hypotheses can be stated as:

Ho: $\sigma_1^2 = \sigma_2^2$
Ha: $\sigma_1^2 \neq \sigma_2^2$

The test statistic *F* is given as:

$$F = {S_1^2}/{S_2^2} \qquad (17)$$

Where
S_1^2 isthe greater of S_o^2 and S_p^2 and S_2^2 isthe lesser of S_o^2 and S_p^2
The calculated value of *F* is compared to the text values for the appropriate level of confidence, α and degrees of freedom. The null hypothesis is accepted if the calculated value of *F* is less than the text value. That is:

$$F \leq F_{\alpha(v1,v2)} \quad (18)$$

The calculation of variances and subsequent determination of the *F* values and the limits can be easily done using standard any of the readily available statistical software.

III. MATERIAL AND METHODS.

The Primary data used in this work were taken from a previous study by Anya and Osadebe [10] who developed simplex lattice models for predicting the 28th day Compressive strength and Water absorption of Sand-quarry dust blocks. The responses were expressed as functions of the pseudo ratios of the components. River sand with specific gravity of 2.65, bulk density of 1564kg/m^3 and fineness modulus of 2.76 was used. The corresponding values for the quarry dust were 2.74, 1296kg/m^3 and 2.97. Ordinary Portland cement that conformed to NIS: 444 [16] was also used. The pseudo ratios were transformed to actual component ratios using the relationship:

$$\boldsymbol{R} = \boldsymbol{AP} \qquad 19)$$

Where ***R*** and ***P*** are respectively the vectors containing the actual and pseudo ratios of the components and ***A*** is a transformation matrix, its elements defined the vertices of the simplex and was obtained after trial mixes as:

$$\boldsymbol{A} = \begin{pmatrix} 0.52 & 0.61 & 0.75 & 1 \\ 1 & 1 & 1 & 1 \\ 5.4 & 3.6 & 9 & 6 \\ 0.6 & 2.4 & 1 & 4 \end{pmatrix} \qquad (20)$$

The elements of each column of ***A*** represented the components' proportions at a vertex in the followingorder: Water (X_1), Cement (X_2), Sand (X_3) and Quarry dust (X_4). The design matrix consisted of 15 independent mixes with 5 replications giving a total of 20 runs.
Table 1 shows the design matrix in pseudoand real ratios together with the experimental test results for compressive strength and water absorption as obtained by Anya and Osadebe [10].

Table 1: Experimental test results

Run Order	Pseudo components units				Components in real ratios				Response	
	Water (X_1)	Cement (X_2)	Sand (X_3)	Quarry dust (X_4)	Water	Cement	Sand	Quarry dust	*Yc* (*Nmm*$^{-2}$)	*Yw* (%)
1	1	0	0	0	0.52	1	5.4	0.6	4.49	4.06
2	0	0.5	0	0.5	0.805	1	4.8	3.2	3.50	5.48
3	0.625	0.125	0.125	0.125	0.62	1	5.7	1.3	3.67	5.41
4	0.25	0.25	0.25	0.25	0.72	1	6	2	3.34	6.14
5	0.25	0.25	0.25	0.25	0.72	1	6	2	3.40	6.00
6	0.125	0.125	0.125	0.625	0.86	1	6	3	3.19	6.53

7	0	0	1	0	0.75	1	9	1	2.80	7.71
8	0	0	0.5	0.5	0.875	1	7.5	2.5	3.07	6.86
9	0	0	1	0	0.75	1	9	1	2.72	8.00
10	0.125	0.125	0.625	0.125	0.735	1	7.5	1.5	3.04	6.95
11	0	0.5	0.5	0	0.68	1	6.3	1.7	3.39	6.02
12	1	0	0	0	0.52	1	5.4	0.6	4.65	4.26
13	0	0	0	1	1	1	6	4	2.98	7.13
14	0	1	0	0	0.61	1	3.6	2.4	5.19	3.24
15	0.5	0	0	0.5	0.76	1	5.7	2.3	3.2	6.50
16	0	0	0	1	1	1	6	4	2.84	7.36
17	0.5	0	0.5	0	0.635	1	7.2	0.8	3.09	6.80
18	0	1	0	0	0.61	1	3.6	2.4	5.27	3.16
19	0.5	0.5	0	0	0.565	1	4.5	1.5	4.91	3.54
20	0.125	0.625	0.125	0.125	0.665	1	4.8	2.2	4.01	4.78

Legend: Yc =Compressive strength, Yw = Water Absorption

Source: Adapted from Anya and Osadebe[10]

The Osadebe model can be fit to any 10 of the 15 distinct mixes of Table 1, with the actual component ratios converted to components' proportions. The remaining mixes will be used to validate the model. Table 2 shows the 10 distinct mixes selected for the model formulation and those for model validation and the average experimental values of the compressive strength and water absorption. Cells with two Run Order numbers indicate replicated mixes. The response for such mixes is taken as the average response of the replicated mixes

Table 2: Data for Formulating and Validating Osadebe'sModels

Run Order	Components in actual ratios				Component proportions					
	Water	Cement	Sand	Quarry dust	Water (Z_1)	Cement (Z_2)	Sand (Z_3)	Quarry dust (Z_4)	*Yc* *(Nmm^{-2})*	*Yw* *(%)*
1,12	0.52	1	5.4	0.6	0.069149	0.132979	0.718085	0.079787	4.57	4.16
19	0.565	1	4.5	1.5	0.074686	0.132188	0.594844	0.198282	4.91	3.54
17	0.635	1	7.2	0.8	0.065906	0.103788	0.747275	0.083031	3.09	6.80
15	0.76	1	5.7	2.3	0.077869	0.102459	0.584016	0.235656	3.20	6.50
14,18	0.61	1	3.6	2.4	0.080158	0.131406	0.473061	0.315375	5.23	3.20
11	0.68	1	6.3	1.7	0.070248	0.103306	0.650826	0.175620	3.39	6.02
2	0.805	1	4.8	3.2	0.082101	0.101989	0.489546	0.326364	3.50	5.48
7,9	0.75	1	9.0	1.0	0.063830	0.085106	0.765958	0.085106	2.76	7.86
8	0.875	1	7.5	2.5	0.073684	0.084211	0.631579	0.210526	3.07	6.86
13,16	1	1	6.0	4.0	0.083333	0.083333	0.500000	0.333334	2.91	7.25
MIXES FOR MODEL VALIDATION										
3	0.62	1	5.7	1.3	0.071926	0.116009	0.661253	0.150812	3.67	5.41
4	0.72	1	6	2	0.074074	0.102881	0.617284	0.205761	3.34	6.14
5	0.72	1	6	2	0.074074	0.102881	0.617284	0.205761	3.40	6.00
6	0.86	1	6	3	0.07919	0.092081	0.552486	0.276243	3.19	6.53
10	1	7.5	1.5	14	0.068468	0.093153	0.698649	0.13973	3.04	6.95
20	0.665	1	4.8	2.2	0.076746	0.115407	0.553952	0.253895	4.01	4.78

Z_1, Z_2, Z_3 and Z_4respectively are the proportions of Water, Cement, Sand and Quarrydust in a mix.

IV. RESULTS AND DISCUSSION

A. *Model equations for Compressive strength*.

Referring to Eq.15 the elements of the matrix **Z** are as given in Table 3.

Table 3: Elements of ZMatrix

Z_1	Z_2	Z_3	Z_4	Z_1Z_2	Z_1Z_3	Z_1Z_4	Z_2Z_3	Z_2Z_4	Z_3Z_4
0.069149	0.132979	0.718085	0.079787	0.009195	0.049655	0.005517	0.095490	0.010610	0.057294
0.074686	0.132188	0.594844	0.198282	0.009873	0.044427	0.014809	0.078631	0.026211	0.117947
0.065906	0.103788	0.747275	0.083031	0.006840	0.04925	0.005472	0.077558	0.008618	0.062047
0.077869	0.102459	0.584016	0.235656	0.007978	0.045477	0.018350	0.059838	0.024145	0.137627

0.080158	0.131406	0.473061	0.315375	0.010533	0.037920	0.025280	0.062163	0.041442	0.149192
0.070248	0.103306	0.650826	0.175620	0.007257	0.045719	0.012337	0.067234	0.018143	0.114298
0.082101	0.101989	0.489546	0.326364	0.008373	0.040192	0.026795	0.049928	0.033286	0.159770
0.063830	0.085106	0.765958	0.085106	0.005432	0.048891	0.005432	0.065188	0.007243	0.065188
0.073684	0.084211	0.631579	0.210526	0.006205	0.046537	0.015512	0.053186	0.017729	0.132964
0.083333	0.083333	0.500000	0.333334	0.006944	0.041667	0.027778	0.041667	0.027778	0.166667

The vector $\boldsymbol{Y}$ is given as: $\boldsymbol{Y} = [4.57\ 4.91\ 3.09\ 3.20\ 5.23\ 3.39\ 5.23\ 3.50\ 2.76\ 3.07\ 2.91]^T$.
The regression coefficients as obtained from Eq. 16 are then:
$\beta_1 = -13653.5830$, $\beta_2 = 403.0600$, $\beta_3 = -39.5593$, $\beta_4 = -146.7508$ $\beta_{12} = 16606.7737$,
$\beta_{13} = 15312.3765$, $\beta_{14} = 16763.7698$, $\beta_{23} = -673.5780$, $\beta_{24} = -738.2746$ $\beta_{34} = 32.3042$

The model equation is therefore:

$$Yc = -13653.5830Z_1 + 403.0600Z_2 - 39.5593Z_3 - 146.7508Z_4 + 16016.3378Z_1Z_2 + 15312.3765Z_1Z_3 + 16763.7698Z_1Z_4 - 673.5780Z_2Z_3 - 738.2746Z_2Z_4 + 32.3042Z_3Z_4 \quad (21)$$

The analysis of variance for the Osadebe compressive strength model using, Microsoft Excel [17], at $\alpha = 0.05$ is presented in Table 4 while the probability plot of the residuals, made using Minitab 16 [18], is shown in Figure 1.The calculated F statistic of 1.162 is less than the critical value of 5.05 as shown in Table 4. The probability plot of Figure 1 also shows that all the points lie very close to the reference line. The conclusion therefore is that Equation 21 is adequate for predicting the 28th day strength of sand-quarry dust blocks

Table 4: Analysis of Variance for Osadebe's compression strength model

Run No	Yc_{exp}	Yc_{pre}		Yc_{exp}	Yc_{pre}
3	3.67	3.73	*Mean*	3.4617	3.441
4	3.34	3.41	S^2	0.1423	0.122
5	3.40	3.41	*n*	*6*	*6*
6	3.19	3.13	*df*	*5*	*5*
10	3.04	3.04	*F*	*1.162*	
20	4.01	4.05	*P(F<=f)*	*0.436*	
			F Critical	*5.050*	

Legend:
S^2 = Variance, df = Degree of freedom,
n = Number of observations.
Yc_{exp} = Experimental result, Yc_{pre} = Predicted result

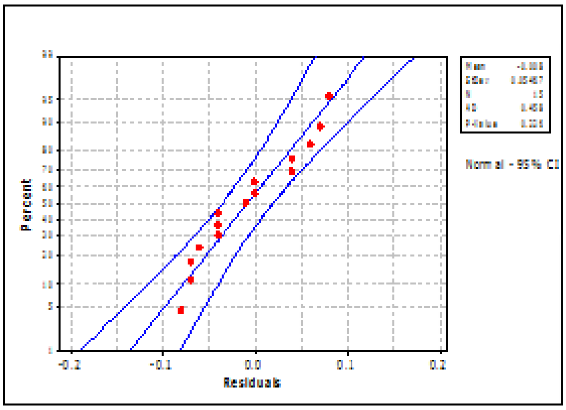

Fig. 1: Probability plot for Compressive strength model

B. Model Equation for Water Absorption.

A similar analysis for water absorption but with the vector $\boldsymbol{Y}$ given as:
$\boldsymbol{Y} = [4.16\ 3.54\ 6.80\ 6.50\ 3.20\ 6.02\ 5.48\ 7.855\ 6.86\ 7.245]^T$. gave the following model equation

$$Yw = 61578.1777Z_1 + 712.6279Z_2 + 194.6094Z_3 + 751.9472Z_4 - 80741.2249Z_1Z_2 - 68542.9441Z_1Z_3 - 76073.6701Z_1Z_4 + 208.7371Z_2Z_3 + 814.1958Z_2Z_4 - 198.4964Z_3Z_4. \quad (22)$$

C. Comparison of Compressive Strength Models.

The Scheffe's simplex lattice model as obtained by [10]for the Compressive strength of Sand-quarry dust blocks is:

$$Yc = 4.5540X_1 + 5.2167X_2 + 2.7694X_3 + 2.9256X_4 - 0.1162X_1X_2 - 2.3200X_1X_3 - 2.1427X_1X_4 - 2.4238X_2X_3 - 2.2465X_2X_4 + 1.1097X_3X_4 \quad (23)$$

A statistical comparison of Osadebe's model of Eq. 21 and the Scheffe's simplex lattice model of Eq. 23 is made here using 15 arbitrarily chosen mix ratios. The pseudo and actual mix proportions of the 15 mix ratios and the models' predicted values are presented in Table 5. A single factor anova for the models' results at 95% confidence limit ($\alpha = 0.05$) is presented in Table 6. The *p-value* of 0.98 shows that there is no statistical difference between the two models. A similar analysis made for the water absorption models gave a *p*-value of 0.975, indicating that there is no significant difference between the Osadebe and Scheffe's water absorption models.

Table 5: Model predicted compressive strength results for 15 arbitrarily chosen mixes

Pseudo ratios				**Actual components' proportions**				**Model predicted Compressive strength (Nmm^{-2})**	
Water (X_1)	Cement (X_2)	Sand (X_3)	Quarry dust (X_4)	Water (Z_1)	Cement (Z_2)	Sand (Z_3)	Quarry dust (Z_4)	Scheffe	Osadebe
0.2	0.4	0.2	0.2	0.075070	0.107550	0.593676	0.223704	3.62	3.60
0.4	0.4	0.2	0	0.071650	0.119019	0.642704	0.166627	4.06	4.01
0.1	0.2	0.3	0.4	0.075384	0.094349	0.600057	0.230210	3.15	3.22
0	0.4	0.4	0.2	0.073344	0.098580	0.615142	0.212934	3.30	3.35
0	0	0.4	0.6	0.075630	0.084034	0.605042	0.235294	3.13	3.07
0.1	0.1	0.6	0.2	0.069598	0.091216	0.684119	0.155067	2.98	3.04
0.9	0	0.1	0	0.068362	0.125897	0.725167	0.080574	4.17	4.12
0	0.8	0.1	0.1	0.078341	0.118161	0.517547	0.285951	4.38	4.31
0.2	0.6	0	0.2	0.079103	0.118064	0.524203	0.278630	4.26	4.17
0.3	0.1	0.3	0.3	0.073161	0.098600	0.638927	0.189312	3.15	3.22
0.3	0.2	0.5	0	0.067647	0.103595	0.708588	0.120170	3.20	3.22
0.3	0.5	0.1	0.1	0.075391	0.118540	0.583215	0.222854	4.17	4.11
0.3	0.3	0.2	0.2	0.074174	0.107654	0.613629	0.204543	3.56	3.55
0.5	0	0.25	0.25	0.071926	0.103119	0.66512	0.159835	3.21	3.23
0	0.25	0.1	0.65	0.080671	0.091933	0.524017	0.303379	3.13	3.18

Table 6: Single factor Anova for Scheffe's and Osadebe's Compressive strength models.

SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Scheffe	15	53.47	3.5646667	0.2515695		
Osadebe	15	53.387778	3.5591852	0.2075697		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0002254	1	0.0002254	0.0009816	0.9752279	4.1959718
Within Groups	6.4279496	28	0.2295696			
Total	6.4281749	29				

V. CONCLUSION AND RECOMMENDATION

Models for predicting the 28th day Compressive strength and Water absorption of Sand-quarry dust blocks based on the actual components' proportions were formulated using Osadebe's model. A statistical comparison of the models with those based on Scheffe's simplex design in which the components' proportions are expressed as pseudo ratios showed that there is no statistical difference between the models. Each of these models has a unique feature. Unlike the simplex lattice model which is boundedOsadebe's model in components proportion is unbounded and therefore has a wider range of application and is easier to use. However it should be noted that since the blocks are removed from the mold immediately after compaction while still very fresh, it may be difficult to determine, when using the Osadebe's model, if a mix outside the simplex is moldable. The Scheffe's model enabled an assessment of the contributions of each of the components to the response property to be studied.

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