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Prediction of Shear Strength and Water Absorption of Laterite–Quarry Dust Concrete

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ABSTRACT: *This paper developed models for predicting the 28th day shear strength and water absorption of laterite-quarry dust concrete using [5, 2] extreme vertices design. The models were formulated using existing data and were validated using the p-value, F statistics and normal probability plot. The shear strength were determined as a function of the flexural strength while the percentage water absorption were based on the permeability of water at the hardened state of the laterite-quarry dust concrete beams. A second degree polynomial was fitted to the data of the shear strength and the percentage water absorption results. Several mix proportions were generated using Minitab 17, and converted to ratios. Their shear strength and percentage water absorption were obtained using the developed models. The minimum and maximum shear strength predictable by the model are 0.20Nmm^{-2} and 0.41Nmm^{-2} while the percentage water absorption are 2.82% and 6.34% respectively. The shear strength and percentage water absorption of laterite-quarry dust concrete for both domestic and commercial construction work can be predicted using these models.*

KEYWORDS: *Model, Shear strength, Water absorption, Laterite-quarry dust concrete, Extreme Vertices Design.*

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I. INTRODUCTION

Recent development has shown that local materials that are readily available in our communities are better alternatives to partially or wholly replace river sand in producing concrete of good performance and quality. This can be achieved by proper proportioning of the constituents and good workmanship. Such alternatives include laterite and quarry dust. The use of alternative material for concrete production reduces the use of river sand, thus preventing excessive mining of sand to avoid environmental degradation and distortion and to find more use for laterite and quarry dust. Laterite–quarry dust concrete according to Orji, Anya and Ngwu (2020) is the mixture of cement, water, laterite and quarry dust as fine aggregate, and coarse aggregate in proper proportion to achieve a desired strength property. Works by Orji, Anya and Ngwu (2020), Ukpata, Ephraim, and Akeke (2012), Manasseh (2010), Ukpata and Ephraim (2012) and Orji, Ugwu and Anya (2020) show that concrete of good quality can be produced with the sand fully replaced with a combination of laterite and quarry dust.

Inadequately designed and constructed concrete structure exhibit failures, and one of such is the shear failure. Shear strength is the ability of any concrete to resist shearing. Failure in concrete is undesirable, hence, the strength and behavior of any concrete member should be of paramount importance. Shear failure according to Eypor and Sigurour (2014) is hazardous and can rarely be predicted. It often happens explosively. Radmila and Zeljka (2015) classified shear failure into three, namely; diagonal tension failure, diagonal compressive failure, and splitting or true shear failure. Several works have been carried out for decades to study this phenomenon and improve on the methodology for predicting the shear strength of conventional concrete members. These studies have led to the rules of empirical equations used in estimating the shear resistance of concrete structure. Each of these empirical equations according Amani and Moeini, (2012) yield good results just for a particular dataset. Amani and Moeini (2012) also stated that it is difficult to establish an overall model to provide accurate estimation of shear strength, hence, exact values of shear strength are unknown.

Anya, Orji and Enebe (2021) developed model for predicting the flexural strength of laterite-quarry dust concrete using the extreme vertices design. The model was tested for its significance and found adequate. However, the components were expressed in their actual proportions. Durable concrete is dense, water tight and able to resist to a large extent, changes from adverse effects of the elements and mechanical damages. One of the properties of concrete that is used as an indicator for durability, based on the permeability of its hardened state according to Long, Henderson and Montgomery (2001) and Neville (2011) is the water absorption. To this effect, the objective of this research is to develop a reliable mathematical model for predicting the 28th day shear strength and water absorption of laterite-quarry dust concrete using the extreme vertices design in which the component proportions are expressed in real ratios.

II. EXTREME VERTICES DESIGN AND MODEL FORMATION

Extreme vertices design is the mixture design that covers a sub-portion within the simplex. It is used when constituent materials are restricted to both lower L_i and upper U_i bounds or when linear constraints are added to several constituents. Constituents of a mixture can either be measured by volume or mass, and their proportions must be constrained to sum to 1. None must have a negative value. Mixture experiment is one in which the response is dependent on only the proportions of the constituent materials (Cornell, 2002). The statement above can be stated mathematically as:

$$\sum_{i=1}^{q} x_i = x_1 + x_2 + x_3 + x_4 \ldots + x_q = 1.0 \qquad (1)$$

Where, i = 1, 2, 3……..

q = the number of mixture component

x_i = proportion of constituent i

If the response is denoted by y and x_1, x_2, x_3, x_4, and x_5 are the constituents of the mixture (water, cement, laterite, quarry dust, and crushed rock), then the equation can be represented as:

$$y = f(x_1,\ x_2,\ x_3,\ x_4,\ x_5) \qquad (2)$$

A general form of a polynomial of degree M, in q variables is given by Akhnazarova and Kafarou (1982) as;

$$\hat{y} = b_0 + \sum_{1\le i\le q} bix_i + \sum_{1\le i\le j\le q} bijx_ij + \sum_{1\le i\le j\le k\le q} bijkx_ix_jx_k + \sum bi_1i_2i_nxi_1xi_2xi_m \qquad (3)$$

When the number of components, q = 5, and M = 2, the number of terms will be fifteen (15) and equation (3) can be written as:

$$\hat{y} = \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_4x_4 + \beta_5x_5 + \beta_{12}x_1x_2 + \beta_{13}x_1x_3 + \beta_{14}x_1x_4 + \beta_{15}x_1x_5 + \beta_{23}x_2x_3 + \beta_{24}x_2x_4 + \beta_{25}x_2x_5 + \beta_{34}x_3x_4 + \beta_{35}x_3x_5 + \beta_{45}x_4x_5 \qquad (4)$$

In a restricted region mixture experiments, all components do not take values between 0, to 1. Some or all of the components lie between the lower (L_i) and upper (U_i) bound limits. For instance, when a valid blend or mixture is to be formed, we require at least, L_i, but not more than U_i of constituent i, and similar bounds are specified for the other constituent proportions as well (Cornell, 2002). With q, components, the constraints are written as;

$$0 \le L_i \le X_i \le U_i \le 1, \qquad i = 1, 2 \ldots q \qquad (5)$$

The design point's location on the boundaries of the region that are chosen depends on the degree of the equation to be used to model the surface over the region. For example, suppose we wish to fit a second degree model to data collected at various combinations of X_i, i = 1, 2, 3 … q over the region (5), where the form of the model is

$$\eta = \sum_{i=I}^{q} \beta_i \; X_i + \sum_{i<j}^{q} \beta_{ij} \; X_i \; X_j \qquad (6)$$

Then a minimum of $q + \frac{q(q-1)}{2}$
(7)

Distinct points are needed at which to collect observation. In general, the set of design points would consist of at least q, extreme vertices, the midpoint of at least $\frac{q(q-1)}{2}$ edges, and a subset of the face centroids. However, it is important to know that the upper – and lower – bound constraints on the X_i must be consistent before any further analysis. Hence, the following steps are adopted to detect and adjust inconsistent constraints.

2.1. Detecting Inconsistent Constraints

Equation (1) is said to be consistent when, upon listing the feasible combination for the region, each and every constituent proportion (not necessarily all simultaneously) attains its lower bound, X_i = L_i and each constituent proportion attains its upper bound, X_i = U_i (Cornell, 2002). To check the consistency or to detect any inconsistencies in Equation (1), first we calculate the range of each X_i component R_i

$R_i = U_i - L_i, \qquad i = 1, 2, 3 \dots q$
(8)
Where;
R_i = *Range of component i*
U_i = *Upper bound of component i*
L_i = *Lower bound of component i*

Then, calculate $R_L = 1 - \sum L_i$
(9)
to ascertain if U_i is attainable or not.
Where;
R_L = *Range of the lower bound*
$\sum Li$ = *Summation of all the values of the lower bounds.*
If for any component i, R_i is greater than R_L (that is, for any i, $R_i > R_L$) then U_i is unattainable. To ascertain whether L_i is attainable or not, we calculate
$R_u = \sum U_i - 1$
(10)
Where:
R_u = *Range of the upper bound*
$\sum U_i$ = *Summation of all the values of the upper bound.*

If for any i, R_i is greater than R_u (that is, for any i, $R_i > R_u$) then L_i of that component is unattainable.
For instance, a set of constraints for three constituents of X_1, X_2 and X_3 respectively are given in Table 1 as;

Table 1: Bounds of Three Constituents

	X_1	X_2	X_3
Lower bound (L)	0.2	0.2	0.18
Upper bound (U)	0.4	0.6	0.7

Source: Cornell (2002).

The set constraints are as follows:
$0.2 \leq X_1 \leq 0.4$, $0.2 \leq X_2 \leq 0.6$, $0.18 \leq X_3 \leq 0.7$

Ranges of each constituents are:
$R_1 = 0.4 – 0.2 = 0.2$
$R_2 = 0.6 – 0.2 = 0.4$
$R_3 = 0.7 – 0.18 = 0.52$.

Range of the lower bound, $R_L = 1 - \sum L_i$
$\sum L_i = 0.2 + 0.2 + 0.18 = 0.58$
$R_L = 1 – 0.58 = 0.42$

While:
Range of the upper bound, $R_u = \sum U_i – 1$
$\sum U_i = 0.4 + 0.6 + 0.7 = 1.7$
$R_u = 1.7 – 1 = 0.7$

Since $R_3 = 0.52 > R_L$, this means that the upper bound, $U_3 = 0.7$, is not attainable. To make U_3, attainable, it has to be replaced by the implied upper bound; $U_3 = L_3 + R_L = 0.18 + 0.42 = 0.6$.

III. MATERIALS AND METHODS

The primary data used in this work were taken from previous studies by Orji, Anya and Ngwu (2020) who developed models for predicting the 28th day compressive strength and cost of laterite-quarry dust concrete and Anya, Orji and Enebe (2021) who developed model for predicting the 28th day flexural strength of laterite-quarry dust concrete. The material components were; Water, Ordinary Portland Cement, Laterite, Quarry dust and Crushed rock. Potable water conforming to the specification of BS EN 1008 (2002) was used for both specimen preparation and curing. It was sourced from 9th mile, Enugu State, Nigeria. Ordinary Portland cement of grade 42.5 which conforms to NIS 444 (2003) was used for all the tests. Laterite was sourced from Umuchigbo in Iji-Nike, Enugu East Local Government Area of Enugu State while quarry dust and crushed rock were sourced from Jinziang quarry (Nigeria) company limited in Ezillo, Ishielu Local Government Area of Ebonyi State. Physical property tests were conducted on the laterite and quarry dust and several trial mixes of concrete were carried out to determine the lower (L_i) and upper bound (U_i) of each constituent using ratios 1:1:1.5, 1:1:2, 1:1.5:3, 1:2:4, and 1:3:6. River sand was replaced with a maximum of 40% laterite and 60% quarry dust in the trial mixes. The lower (L_i) bounds of the five constituents of water, cement, laterite, quarry dust and crushed rock according to Orji, Anya and Ngwu (2020) and Anya, Orji and Enebe (2021) are 0.100, 0.140, 0.020, 0.130 and 0.430 respectively while the upper bounds (U_i) are 0.135, 0.250, 0.130, 0.260 and 0.500 respectively. The set constraints of the constituents can be stated as:

Water = $0.100 \le X_1 \le 0.135$, Cement = $0.140 \le X_2 \le 0.250$, Laterite = $0.020 \le X_3 \le 0.130$, Quarry dust = $0.130 \le X_4 \le 0.260$, Coarse aggregate = $0.430 \le X_5 \le 0.500$.

The design matrix consisted of 15 design points and 7 check points with replications of the vertices and the centroid, given a total of 28 runs. 84 numbers of laterite-quarry dust concrete beams of 600 x 150 x 150mm were prepared in accordance to BS EN 12390-1 (2000) and tested for their flexural strength after 28 days of curing in accordance to BS EN 12390-5 (2000) using the fine spavy computerized universal testing machine (UTM). The three point load system was used and three samples were tested for each mix ratio and the average taken as the flexural strength for the mix. Shear strengths were determined from the flexural test results and the results of the shear strength were used to develop the model equation for predicting the shear strength of laterite-quarry dust concrete. After the beams were tested for their flexural strengths, they were completely dried and weighed on a 50kg weighing machine. The weight of each of the samples were taken and they were immediately immersed in water for 24 hours. Their weights were also taken after immersion. The difference between the weights before and after immersion, expressed as a percentage of the dry weight, gave the percentage water absorption. A second degree polynomial was fitted to the data of the shear strength and water absorption using Minitab 17. Sequential F test (ρ-value) were carried out to fit linear and quadratic models to the shear strength and water absorption results and the chosen models were the highest order models with significant terms. These were done using Analysis of variance (ANOVA). A ρ-value of less than 0.05 indicates a significant term and the term was included in the models. Summary statistics (R-square, Adjusted R squared, PRESS, and the standard error) for each model coefficient were also determined. Adequacy of the models were also tested using the normal probability plots at 95% confidence limit. Different mix proportions were generated using Minitab 17 and converted to ratios. The mix ratios were substituted into the shear strength and water absorption models to predict their various responses for the given mix ratios. Each of the mix proportions were summed to 1. The shear strengths and water absorption of the beams were determined using Equations 11 and 12.

$$F_s = {}^{F}/_{A} \qquad (11)$$

Where:
F_s = *shear strength*
F = *shear load at failure*

A = *Cross-sectional area of the test specimen*

$$Wa = \frac{ws - wd}{wd} \times 100\% \qquad (12)$$

Where:
wa = *Water absorption*
wd = *Dry weight of concrete*
ws = *Weight of concrete after soaking in water for 24 hours*

IV. RESULTS AND DISCUSSIONS

To detect any inconsistencies in the constraints, the range of each of the constituents of water, cement, laterite, quarry dust and crushed rock are:

Water, $R_1 = 0.135 – 0.100 = 0.035$
Cement, $R_2 = 0.250 – 0.140 = 0.11$
Laterite, $R_3 = 0.130 – 0.020 = 0.11$
Quarry dust, $R_4 = 0.260 – 0.130 = 0.13$
Crushed rock $R_5 = 0.500 – 0.430 = 0.07$

Range of the lower bound, $R_L = 1 - \sum L_i$
$\sum L_i = 0.100 + 0.140 + 0.020 + 0.130 + 0.430 = 0.82$
$R_L = 1 – 0.82 = 0.18$

While:
Range of the upper bound, $R_u = \sum U_i – 1$
$\sum U_i = 0.135 + 0.250 + 0.130 + 0.260 + 0.500 = 1.275$
$R_u = 1.275 – 1 = 0.275$

Since, none of the ranges of the constituent is greater than $R_L = 0.18$ and $R_u = 0.275$, the lower L_i and upper U_i bounds of the constituents are attainable. Therefore, the constraints are consistent. The laterite has a bulk density of 1240kg/m^3, specific gravity of 2.60 and fineness modulus of 3.03 while the quarry dust has a bulk density of 1695kg/m^3, specific gravity of 2.79 and fineness modulus of 2.74. The results of the selected mix proportions and their corresponding flexural strength test results are presented in Tables 2. The design matrix components in real ratios shown in Table 3 was derived by dividing the values of each of the constituent materials of the mixes in Table 2 by that of the cement. The design matrix components in real ratios and the average shear strength and water absorption is presented in Table 3.

Table 2: (5, 2) Selected Mix Proportions and their Corresponding Flexural Strength Test Result

Run Order	Std Order	Pt Type	Water	Cement	Laterite	Quarry dust	Crushed Rock	*Av. F_f (Nmm^{-2})*
1	93	1	0.135	0.14	0.02	0.205	0.5	1.88
2	105	1	0.135	0.14	0.035	0.26	0.43	1.89
3	10	1	0.1	0.19	0.02	0.26	0.43	4.17
4	6	1	0.1	0.14	0.13	0.2	0.43	2.55
5	1	1	0.1	0.14	0.02	0.24	0.5	2.87
6	21	1	0.135	0.175	0.13	0.13	0.43	2.38
7	11	1	0.1	0.14	0.07	0.26	0.43	2.75
8	94	1	0.1	0.25	0.02	0.2	0.43	4.59
9	7	1	0.135	0.14	0.13	0.165	0.43	1.94
10	42	2	0.135	0.14	0.1125	0.13	0.4825	1.55
11	54	2	0.135	0.2025	0.02	0.2125	0.43	3.73
12	60	2	0.135	0.2125	0.0925	0.13	0.43	3.40
13	46	2	0.1175	0.14	0.13	0.1825	0.43	2.28
14	41	2	0.1175	0.14	0.02	0.2225	0.5	2.32
15	38	2	0.1	0.165	0.045	0.26	0.43	3.63
16	114	0	0.119091	0.181136	0.061136	0.183409	0.455228	3.55

17	75	-1	0.109545	0.160568	0.095568	0.191705	0.442614	2.98
18	78	-1	0.109545	0.160568	0.040568	0.221705	0.467614	3.26
19	79	-1	0.109545	0.185568	0.040568	0.221705	0.442614	3.71
20	70	-1	0.109545	0.160568	0.040568	0.211705	0.477614	2.89
21	80	-1	0.109545	0.160568	0.065568	0.221705	0.442614	2.89
22	14	1	0.135	0.14	0.035	0.26	0.43	1.86
23	101	1	0.1	0.19	0.02	0.26	0.43	4.00
24	112	1	0.135	0.175	0.13	0.13	0.43	2.52
25	92	1	0.1	0.14	0.02	0.24	0.5	3.35
26	69	0	0.119091	0.181136	0.061136	0.183409	0.455228	3.32
27	88	-1	0.109545	0.195568	0.095568	0.156705	0.442614	3.17
28	55	2	0.1175	0.25	0.02	0.1825	0.43	5.12

Source: Anya, Orji and Enebe (2021). *Av. F_f* = Average flexural strength results.

Table 3: (5, 2) Design Matrix Components in Real Ratios and the Average Shear Strength and Water Absorption Test Result.

Run Order	Std Order	Pt Type	Water	Cement	Laterite	Quarry Dust	Crushed Rock	F_s (Nmm^{-2})	*Wa* (%)
1	93	1	0.964286	1	0.142857	1.464286	3.571429	0.1573	4.70
2	105	1	0.964286	1	0.25	1.857143	3.071429	0.1573	4.05
3	10	1	0.526316	1	0.105263	1.368421	2.263158	0.3473	3.33
4	6	1	0.714286	1	0.928571	1.428571	3.071429	0.2123	4.63
5	1	1	0.714286	1	0.142857	1.714286	3.571429	0.2390	3.31
6	21	1	0.771429	1	0.742857	0.742857	2.457143	0.1987	4.73
7	11	1	0.714286	1	0.5	1.857143	3.071429	0.2293	4.65
8	94	1	0.4	1	0.08	0.8	1.72	0.3827	3.33
9	7	1	0.964286	1	0.928571	1.178571	3.071429	0.1620	3.39
10	42	2	0.964286	1	0.803571	0.928571	3.446429	0.1287	4.74
11	54	2	0.666667	1	0.098765	1.049383	2.123457	0.3113	3.45
12	60	2	0.635294	1	0.435294	0.611765	2.023529	0.2830	4.97
13	46	2	0.839286	1	0.928571	1.303571	3.071429	0.1903	3.42
14	41	2	0.839286	1	0.142857	1.589286	3.571429	0.1937	3.40
15	38	2	0.606061	1	0.272727	1.575758	2.606061	0.3040	3.42
16	114	0	0.657465	1	0.337516	1.012547	2.513174	0.2963	3.42
17	75	-1	0.682236	1	0.595188	1.193914	2.756546	0.2480	3.90
18	78	-1	0.682236	1	0.252654	1.38075	2.912243	0.1937	3.40
19	79	-1	0.590325	1	0.218616	1.194734	2.385181	0.3040	3.41
20	70	-1	0.682236	1	0.252654	1.318471	2.974522	0.2963	3.45
21	80	-1	0.682236	1	0.408351	1.38075	2.756546	0.2480	3.36
22	14	1	0.964286	1	0.25	1.857143	3.071429	0.1937	3.40
23	101	1	0.526316	1	0.105263	1.368421	2.263158	0.3333	3.35
24	112	1	0.771429	1	0.742857	0.742857	2.457143	0.2097	3.86
25	92	1	0.714286	1	0.142857	1.714286	3.571429	0.2790	3.31
26	69	0	0.657465	1	0.337516	1.012547	2.513174	0.2760	3.35
27	88	-1	0.560139	1	0.488669	0.801278	2.263219	0.2643	3.36
28	55	2	0.47	1	0.08	0.73	1.72	0.4270	3.34

Legend: F_s = Shear Strength, *Wa* = Water Absorption.

4.1. Model equation for shear strength

A second degree polynomial (model) was fitted to the shear strength test result in Table 3 at 95% confidence limit ($\alpha = 0.05$). The estimated regression coefficient and the analysis of variance (Anova) are shown in Tables 4 and 5 respectively while the normal probability plot of the residual is shown in Figures 1. Taking X_1, X_2, X_3, X_4 and X_5 as the proportion of the constituents and β_1, β_2, β_3, β_4 and β_5 as the coefficient of the constituents in relation to Equation 4, Water = $-4.969X_1$, Cement = $-0.407X_2$, Laterite = $0.370X_3$, Quarry dust = $0.832X_4$, Crushed rock = $0.519X_5$, and Water/cement = $24.124X_1X_2$. Therefore, the model equation for shear strength is given as;

$$\hat{y} = -4.969X_1 - 0.407X_2 + 0.370X_3 + 0.832X_4 + 0.519X_5 + 24.124X_1X_2 \quad (13)$$

Table 4: Estimated Regression Coefficients for Shear Strength (component proportions)

Term	Coef	SE Coef	T	P	VIF
Water	-4.969	1.5342	*	*	1620.16
Cement	-0.407	1.0114	*	*	1512.63
Laterite	0.370	0.2301	*	*	14.51
Quarry dust	0.832	0.2470	*	*	132.77
Coarse Agg	0.519	0.2191	*	*	484.07
Water*Cement	24.124	10.4502	2.31	0.031	2205.58

S = 0.0236753 PRESS = 0.0193155
R-Sq = 91.24% R-Sq(pred) = 86.28% R-Sq(adj) = 89.25%

Regression Output

Table 5: Analysis of Variance for Shear strength (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	0.128496	0.128496	0.025699	45.85	0.000
Linear	4	0.125509	0.100054	0.025013	44.63	0.000
Quadratic	1	0.002987	0.002987	0.002987	5.33	0.031
Water*Cement	1	0.002987	0.002987	0.002987	5.33	0.031
Residual Error	22	0.012331	0.012331	0.000561		
Lack-of-Fit	17	0.010504	0.010504	0.000618	1.69	0.293
Pure Error	5	0.001827	0.001827	0.000365		
Total	27	0.140828				

Regression Output

Since the *p*-significant value in Table 5 is less than 0.05 level of significance ($p = 0.000$, $p < 0.05$), f = 45.85) and the normal probability plot in Figure 1 show that the residuals fall reasonably close to the reference lines. Therefore, Equation (13) is adequate for predicting the 28th day shear strength of laterite–quarry dust concrete.

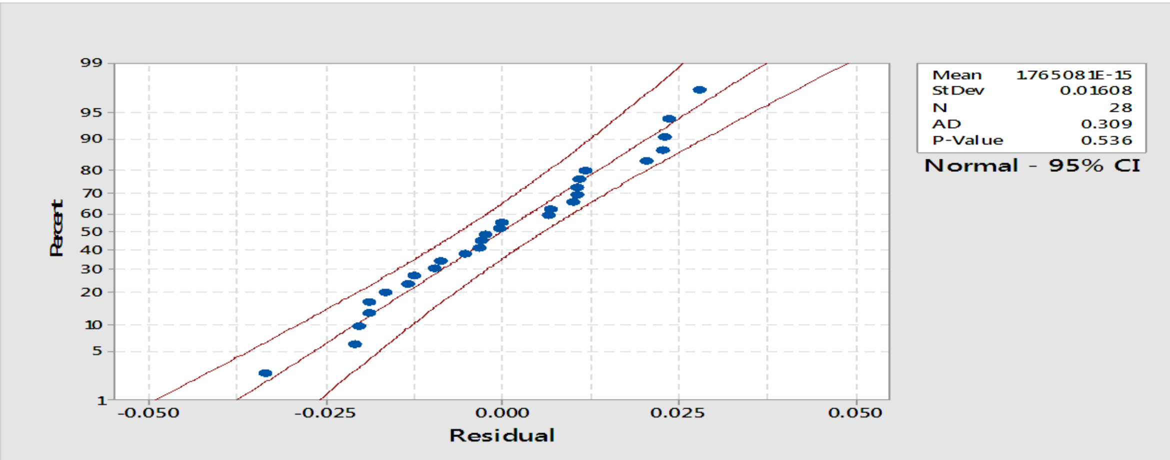

Figure 1: Normal probability plot for shear strength residual

4.2 Model Equation for Water Absorption

A second degree polynomial (model) was also fitted to the water absorption test result in Table 3 at 95% confidence limit ($\alpha = 0.05$). The estimated regression coefficient and the analysis of variance (Anova) are also shown in Tables 6 and 7 respectively while the normal probability plot of the residual is also shown in Figures 2. Taking X_1, X_2, X_3, X_4 and X_5 as the proportion of the constituents and β_1, β_2, β_3, β_4 and β_5 as the coefficient of the constituents in relation to Equation 4, Water = $368X_1$, Cement = $72X_2$, Laterite = $67X_3$, Quarry dust = $119X_4$, Crushed rock = $-52X_5$, Water/cement = $-691X_1X_2$, Water/laterite = $-1009X_1X_3$, Water/quarry dust = -1149X_1X_4, Cement/quarry dust = -239X_2X_4. Therefore, the model equation for water absorption is given as;

$$\hat{y} = 368X_1 + 72X_2 + 67X_3 + 119X_4 - 52X_5 - 691X_1X_2 - 1009X_1X_3 - 1149X_1X_4 - 239X_2X_4 \quad (14)$$

Table 6: Estimated Regression Coefficients for Water absorption (component proportions)

Term	Coef	SE Coef	T	P	VIF
Water	368	61.065	*	*	15553.9
Cement	72	23.639	*	*	5007.5
Laterite	67	14.412	*	*	345.1
Quarry dust	119	18.216	*	*	4376.2
Coarse Agg	-52	9.388	*	*	5384.9
Water*Cement	-691	193.270	-3.58	0.002	4571.7
Water*Laterite	-1009	173.377	-5.82	0.000	750.2
Water*Quarry dust	-1149	178.960	-6.42	0.000	5553.1
Cement*Quarry dust	-239	67.200	-3.56	0.002	1697.0

S = 0.304130 PRESS = 4.23320
R-Sq = 79.75% R-Sq(pred) = 51.23% R-Sq(adj) = 71.23%

Regression Output

Table 7: Analysis of Variance for Water Absorption (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	8	6.9231	6.9231	0.86539	9.36	0.000
Linear	4	2.5070	4.3234	1.08086	11.69	0.000
Quadratic	4	4.4161	4.4161	1.10403	11.94	0.000
Water (X*Cement (	1	0.2202	1.1827	1.18269	12.79	0.002
Water (X*Laterite	1	0.1709	3.1357	3.13571	33.90	0.000
Water (X*Quarry d	1	2.8559	3.8150	3.81497	41.25	0.000
Cement (*Quarry d	1	1.1692	1.1692	1.16921	12.64	0.002
Residual Error	19	1.7574	1.7574	0.09249		
Lack-of-Fit	14	1.1651	1.1651	0.08322	0.70	0.724
Pure Error	5	0.5924	0.5924	0.11847		
Total	27	8.6805				

Regression Output.

Since the *p*-significant value in Table 7 is less than 0.05 level of significance ($p = 0.000$, $p < 0.05$), f = 9.36) and the normal probability plot in Figure 2 show that the residuals fall reasonably close to the reference lines. Therefore, Equation (14) is adequate for predicting the 28th day water absorption of laterite–quarry dust concrete.

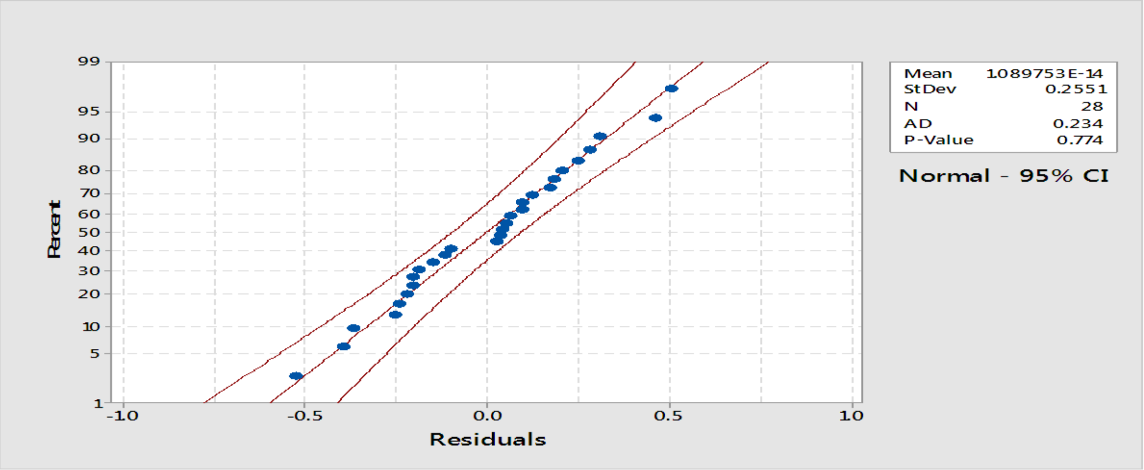

Figure 2: Normal probability plot water absorption residual

Several mix proportions were generated and converted to ratios in Table 8. The shear strength and water absorption of the mixes were obtained using the developed models.

Table 7: Shear Strength and Water Absorption of Laterite-Quarry Dust Concrete for Several Mix Ratios.

Components in Real Ratios					F_s (Nmm^{-2})	Wa (%)
Water	Cement	Laterite	Quarry Dust	Coarse		
0.68	1	0.6	0.98	2.97	0.23	3.63
0.53	1	0.11	1.37	2.26	0.33	3.57
0.66	1	0.34	1.01	2.51	0.27	3.83
0.71	1	0.54	0.88	2.49	0.24	4.18
0.54	1	0.08	0.52	1.86	0.40	6.33
0.54	1	0.08	0.66	1.72	0.41	4.80
0.4	1	0.08	0.66	1.86	0.39	3.48
0.51	1	0.19	0.73	2.22	0.33	3.76
0.67	1	0.1	1.05	2.12	0.31	3.67
0.71	1	0.93	1.43	3.07	0.22	4.57
0.68	1	0.6	1.19	2.76	0.24	3.87
0.79	1	0.25	1.38	2.8	0.23	3.84
0.77	1	0.74	0.74	2.46	0.21	4.46
0.51	1	0.19	0.89	2.05	0.34	3.54
0.64	1	0.2	0.79	2.41	0.29	4.66
0.47	1	0.08	0.73	1.72	0.41	3.72
0.64	1	0.44	0.61	2.02	0.30	5.10
0.43	1	0.48	0.57	1.87	0.34	4.76
0.4	1	0.22	0.52	1.86	0.37	4.25
0.68	1	0.25	1.38	2.91	0.26	3.61
0.47	1	0.08	0.52	1.93	0.39	4.97
0.71	1	0.5	1.86	3.07	0.25	4.84
0.59	1	0.19	0.73	2.13	0.33	4.64
0.71	1	0.14	1.79	3.5	0.25	3.71
0.54	1	0.15	0.52	1.79	0.40	6.03
0.56	1	0.49	0.8	2.26	0.29	4.01
0.57	1	0.74	0.94	2.46	0.26	4.32
0.68	1	0.12	1.51	2.49	0.28	3.38
0.71	1	0.54	1.32	3.57	0.23	3.23
0.63	1	0.09	0.6	2.33	0.32	6.34
0.4	1	0.08	0.8	1.72	0.40	3.36
0.71	1	0.93	0.93	3.57	0.20	2.98
0.47	1	0.29	0.52	1.72	0.38	5.00
0.59	1	0.22	1.19	2.39	0.30	3.49
0.54	1	0.22	0.52	1.72	0.39	5.73
0.79	1	0.6	1.08	2.76	0.21	3.97
0.54	1	0.15	0.59	1.72	0.40	5.26
0.61	1	0.68	0.68	2.23	0.26	4.35
0.68	1	0.25	1.32	2.97	0.25	3.54
0.79	1	0.25	1.21	2.97	0.22	4.21
0.76	1	0.32	0.73	2.82	0.22	5.71
0.76	1	0.11	0.94	2.82	0.24	5.36
0.59	1	0.27	0.73	2.05	0.32	4.48
0.58	1	0.09	0.56	2.08	0.36	6.34
0.4	1	0.08	0.52	2	0.38	3.61
0.48	1	0.62	0.62	2.05	0.30	4.65
0.71	1	0.14	1.71	3.57	0.25	3.48

0.71	1	0.32	1.86	3.25	0.25	4.39
0.51	1	0.35	0.73	2.05	0.33	4.06
0.71	1	0.93	1.18	3.32	0.21	3.77
0.51	1	0.09	0.56	2.15	0.36	4.77
0.59	1	0.19	0.81	2.05	0.33	4.18
0.51	1	0.38	0.67	2.56	0.29	3.30
0.61	1	0.12	1.58	2.76	0.29	3.75
0.71	1	0.71	1.64	3.07	0.24	4.70
0.51	1	0.1	0.95	2.56	0.31	2.82
0.61	1	0.27	1.58	2.61	0.29	4.21
0.4	1	0.36	0.52	1.72	0.37	4.88
0.57	1	0.74	0.74	2.66	0.25	3.82
0.45	1	0.09	1.05	1.95	0.37	3.25
0.71	1	0.14	1.86	3.43	0.26	3.93
0.68	1	0.41	1.38	2.76	0.25	3.82
0.79	1	0.3	1.38	2.76	0.23	3.77
0.4	1	0.22	0.66	1.72	0.39	4.12
0.54	1	0.08	0.59	1.79	0.40	5.56
0.76	1	0.24	1.32	2.63	0.24	3.71

Legend: F_s= Shear Strength, Wa= Water Absorption.

V. CONCLUSIONS

The bulk densities of laterite and quarry dust were found to be 1240kg/m3 and 1695kg/m3. They compared favorably with the bulk densities derived by Anzar (2015), Duggal (2012) and Okafor and Egbe (2016). The specific gravities were found to be 2.60 and 2.79 which also compared favorably with the specific gravities derived by Anya (2015), Opara, Eziefula and Eziefula (2018) and Osuji and Akinwamide (2018). The sieve analysis indicated that both laterite and quarry dust fall within zone II of the grading of fine aggregate as given in BS 882 (1992) and they are both suitable for making concrete. Model equations for predicting the shear strength and water absorption of laterite-quarry dust concrete were developed. X_1, X_2, X_3, X_4 and X_5 in the models are the proportions of water, cement, laterite, quarry dust and crushed rock in the mix. The developed models were tested for their significance using the p-value and F test statistics and found adequate. The minimum and maximum shear strength predictable by the model in Table 7 are 0.20Nmm^{-2} and 0.41Nmm^{-2}, while the percentage water absorption are 2.82% and 6.34% respectively. These models can be used to predict the shear strength and water absorption of laterite-quarry dust concrete for both domestic and commercial constructions and they will be very beneficial in the reduction of the number of trial mixes, use of arbitrary mixes and cost indeterminacy. In this regard, the use of models for predictions should be encouraged in the construction industry.

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