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Original Research Article

Statistical Modelling of Flexural Strength of Laterite-Quarry Dust Concrete

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Abstract

With the growing emphasis on sustainability, the construction industry is more interested in applying environmental friendly concrete in its construction projects. This paper developed model for predicting the 28th day flexural strength of laterite-quarry dust concrete using (5, 2) extreme vertices design of Minitab 17. Physical property test 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) limit of each of the components. River sand was replaced with a maximum of 40% laterite and 60% quarry dust in the trial mixes. Several mix proportions were generated using the extreme vertices design. The design matrix consisted of fifteen (15) design points and seven (7) check points with replications of the vertices and the centroid, given a total of twenty eight (28) runs. Eighty four (84) numbers of laterite-quarry dust concrete beams of 600 x 150 x 150mm were prepared and tested for their flexural strength after 28 days of curing. A second degree polynomial was fitted to the data of the flexural strength test result and adequacy of the model was confirmed using the p-value, F statistics and normal probability plot. Several mix proportions were generated and their flexural strength obtained using the developed model. The minimum and maximum flexural strength predictable by the model are 2.44N/mm^2 and 4.95N/mm^2. The model can help predict the flexural strength of laterite-quarry dust concrete for both reinforced and non-reinforced concrete design for domestic and commercial constructions.

Keywords: Statistical Model, Flexural strength, Concrete, Laterite, Quarry dust, Laterite-quarry dust concrete, Extreme Vertices design.

INTRODUCTION

Laterite and quarry dust have been identified as possible alternatives for river sand in concrete works. This is evident in the works of [1] that between 15 to 30% of sand can be replaced with laterite in the production of concrete [2, 3] revealed that 40% replacement of sand with quarry dust in concrete production induced higher compressive strength but decreases the workability as the replacement increases, [4] found that up to 40% of sand can be replaced with quarry dust in the production of sandcrete blocks. According to [5], 25% of laterite to 75% of river sand with 19.5mm and 12.5mm coarse aggregate particle sizes gave satisfactory results in terms of workability and compressive strength respectively at 28 days of curing compared to normal concrete [6-10] have all shown that normal concrete can be produced with the sand fully replaced with a combination of laterite and quarry dust.

Laterite–quarry dust concrete is produced by mixing cementitious material, water, laterite and quarry dust as fine aggregate, and coarse aggregate to achieve a specified strength property. Ordinarily, the most important property of concrete is the compressive strength, however, another parameter that is also important is the flexural strength, especially when a pavement or retaining structure is been designed. The flexural strength property of concrete according to [11] is particularly important when the concrete structure has no steel reinforcement. For instance, unreinforced concrete roads and runways rely on their flexural strengths to safely distribute concentrated loads. [12] Argued that flexural strength provides two useful parameters. These are crack strength, which is controlled by the matrix, and flexural strength or modulus of rupture, which is determined by the maximum load that can be attained.

Few studies have been done on the flexural strength of laterite-quarry dust concrete.[13] Investigated the flexural characteristics of concrete using lateritic sand and quarry dust as fine aggregate. The proportion of lateritic sand was varied from 0% to

100% against quarry dust at interval of 25% using mix ratio of 1:1.5:3 and water cement ratio of 0.65 and obtained a flexural strength of 3.28N/mm^2 for 50% laterite to 50% quarry dust and 2.88N/mm^2 for 25% laterite to 75% quarry dust. This work used a single mix ratio and not much information as regards the properties of other mix ratios can be obtained from it. [14] Used two mix proportions of 1:2.15:3.32 with water cement ratio of 0.55 for concrete grade 20 and 1:1.98:3.14 with water cement ratio of 0.52 for concrete grade 25 and obtained a range of 2.747N/mm^2 for 0% quarry dust to 100% laterite and 3.662N/mm^2 for 100% quarry dust to 0% laterite. Again, not much information as regards the properties of other mix ratios can be obtained from them. These works did not also pay attention to models that can predict the flexural strength of laterite-quarry dust concrete.

Predicting the strength of concrete early in the design stage can be very helpful. The behavior of structural concrete subjected to different types of loading and actions depends primarily on its composition and proportions. At the design stage, usually only the concrete grade and the dimension of members are known, but no details of the concrete proportioning and their effects are known [15, 16]. Therefore, mathematical model that can predict the parameter of the composition of concrete including proportioning at the design stage would be of great importance. Hence, the objective of this research is to develop a reliable model for predicting the 28th day flexural strength of laterite-quarry dust concrete with several mix ratios using the extreme vertices design.

MIXTURE EXPERIMENT AND STATISTICAL MODELLING

The mixture of two or more components to make an end product or means to an end product cannot be overemphasized. A mixture experiment is one in which the response is dependent on the proportions of the constituent materials [17]. The constituents of the mixture can either be measured by volume or mass. The constituent proportions must be constrained to sum to 1 and none must have a negative value. The statement above can be stated mathematically as:

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

Where,
i = 1, 2, 3……..
q = the number of mixture component
x_i = proportion of constituent i

If the flexural strength 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:

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

A general form of a polynomial of degree M, in q variables is given as;

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

The number of terms in Equation (3) is C_m^{q+n}; that is (q+m) combination M. [18], by substituting the identity $x_1 + x_2 + \text{---} x_q = 1$, in Equation (3) reduced the number of terms in the model to C_m^{q+m-1}; and this number of terms is equal to the number of points associated with the design. This can be illustrated by considering the derivation of a second degree model for a ternary system. For such a system, the general form of the model reduces to:

$$\hat{y} = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 \quad \dots\dots\dots (4)$$

Since $x_1 + x_2 + x_3 = 1$ …………………. (5)

Multiplying Equation (5) by b_0 gives:

$b_0 = b_0x_1 + b_0x_2 + b_0x_3$ ……………. (6)

Multiplying Equation (5) successively by x_1, x_2, and x_3 and rearranging gives:

$x_1^2 = x_1 - x_1x_2 - x_1x_3$
$x_2^2 = x_2 - x_1x_2 - x_2x_3$
$x_3^2 = x_1 - x_1x_3 - x_2x_3$ ………………… (7)

Substituting Equations (6) and (7) into Equation (4) and simplifying gives:

$\hat{y} = (b_0 + b_1 + b_{11})x_1 + (b_0 + b_2 + b_{22}) + x_2(b_0 + b_3 + b_{33})x_3 + (b_{13} - b_{11} - b_{33})x_1x_3 + (b_{23} - b_{22} - b_{33})x_2x_3$ ………………………………….. (8)

If we let

$\beta_i = b_0 + b_i + b_{ii}$, and $\beta_{ij} = b_{ij} + b_{ii} + b_{ij}$ ………………… (9)

Then:
$\hat{y} = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3$ …………………….. (10)

Similarly, when the number of components, q = 5, and M = 2, it gives

$$\hat{y} = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{14} x_1 x_4 + \beta_{15} x_1 x_5 + \beta_{23} x_2 x_3 + \beta_{24} x_2 x_4 + \beta_{25} x_2 x_5 + \beta_{34} x_3 x_4 + \beta_{35} x_3 x_5 + \beta_{45} x_4 x_5$$ ………… (11)

The number of terms are fifteen (15). In summary, the reduced second degree model for q components is given as:
$\hat{y} = \sum_{1 \le i \le q} \beta_i x_i + \sum_{1 \le i \le j \le q} \beta_{ij} x_i x_j$ ……………………………………..…… (12)

The reduced form is called the canonical polynomial or simply the (q, m) model. The number of terms in the reduced model is the minimum number of experimental runs necessary to determine the model coefficients (k) and is given as:
$k = C_m^{(q+m-1)} = k = \frac{(q+m-1)!}{m!(q-1)!}$ ……….…… (13)

Where
q = number of components
m = Degree of model
! = Factorial

Statistical modeling is a subfield of mathematics. It is a mathematical relationship between one or more random variables and other non-random variables. It application to raw data helps in providing intuitive visualizations that aid in identifying relationships between variables and making predictions. It is flexible and can adjust with the introduction of new data. Statistical models have been adjudged to perform predictions much more quickly than other modelling techniques when fitted. It is simpler to implement in software and can be used to define confidence interval for prediction [19].

Extreme vertices design is a mixture design that covers a sub-portion within the simplex. It is used when components are restricted to lower L_i and upper U_i bounds or when linear constraints are added to several components. In a restricted mixture experiment, all components do not take values between 0, to 1, some or all of the components lie between some lower (¬) and upper ( ) bound [17]. With q, components, the constraints are written as;

$0 \le L_i \le X_i \le U_i \le 1$, i = 1, 2q …. (14)

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. However, it is important to know that the upper – and lower – bound constraints on the X_i must be consistent before any further analysis. Constraints are said to be consistent when, upon listing the feasible combinations for the region, each and every component proportion (not necessarily all simultaneously) attains its lower bound ($X_i = L_i$) and each and every component proportion attains its upper bound ($X_i = U_i$). To check the consistency or to detect any inconsistencies in the constraints, first we calculate the range of each X_i component R_i

$R_i = U_i - L_i$, i = 1, 2, 3 … q ………………….….. (15)

Where;
R_i = Range of component i
U_i = Upper bound of component i
L_i = Lower bound of component i

Then, calculate $R_L = 1 - \sum L_i$ ……………………. (16)
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
$R_u = \sum U_i - 1$ ……………………………..…… (17)

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.

MATERIALS AND METHODS

The materials used for this work were the same as those used by [8]; models for predicting the structural properties and cost of concrete using laterite and quarry dust as fine aggregate, and [9]; extreme vertices models for predicting the 28th day compressive strength and cost 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 [20] was used for both specimen preparation and curing, and it was sourced from 9th mile Enugu State, Nigeria. Ordinary Portland cement of grade 42.5 which conforms to [21] was used for all the tests. Laterite was obtained from Umuchigbo community in Iji-Nike, Enugu East Local Government Area of Enugu State, Nigeria while quarry dust and crushed rock were obtained from the quarry site of Jinziang quarry (Nigeria) company limited in Ezillo, Ishielu Local Government Area of Ebonyi State. Physical property test 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 component, using ratios 1:1:1.5, 1:1:2, 1:1.5:3, 1:2:4, and 1:3:6. The fine aggregate component was replaced with a maximum of 40% laterite and 60% quarry dust in the trial mixes. Table 1 show bounds of five mixture components.

Table-1: Bounds of the Five Mixture Components

	Water	Cement	Laterite	Quarry dust	Coarse aggregate
Lower bound	0.100	0.140	0.020	0.130	0.430
Upper bound	0.135	0.250	0.130	0.260	0.500

Source: Researcher's work (2020).

The set constraints are as follows:

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

Using Equations (15), (16) and (17), the component proportions in Table 1 were found to be consistent. The lower and upper bound values of the components were inputted into the extreme vertices design of Minitab 17 to generate several mix proportions. 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 [22] and tested for their flexural strength after 28 days of curing in accordance to [23]. A second degree polynomial was fitted to the data of the flexural strength test result using Minitab 17. Sequential F test (ρ-value) was carried out to fit linear and quadratic models to the flexural test result and the chosen model was the highest order model with significant terms. This was 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 model. Summary statistics (R-square, Adjusted R squared, PRESS, and the standard error) for each model coefficient were also determined. Adequacy of the model was also tested using the normal probability plots at 95% confidence limit. The flexural strength was tested 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. Different mix proportions were generated using Minitab 17 and converted to ratios. The mix ratios were substituted into the flexural strength model to predict their various responses for the given mix ratios. Each of the mix proportions were summed to 1. Flexural strength was determined using Equation (18).

$$F_f = \frac{Fa}{bd^2} \text{ .... (18)}$$

Where:
F_f = flexural strength
F = failure load
a = distance between the supporting rollers
b = width of the beam
d = depth of the beam

RESULTS AND DISCUSSIONS

The results of the physical property tests of laterite and quarry dust and the flexural strength test results are presented in Tables 2 and 3 respectively.

Table-2: Physical Properties of Laterite and Quarry Dust

Property	Laterite	Quarry dust
Bulk density (kg/m^3)	1240	1695
Specific gravity	2.60	2.79
Moisture content (%)	4.3	4.3
Fineness modulus	-	2.74

Source: Researcher's work (2020).

Table-3: (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

Run Order	Std Order	Pt Type	Water	Cement	Laterite	Quarry dust	Crushed Rock	Av. F_f (Nmm^{-2})
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: Researcher's work (2020). Av. $F_{f.}$ = Average flexural strength results.

The second degree polynomial (model) was fitted to the data of the flexural strength test result in Table-3. The estimated regression coefficient and the analysis of variance (Anova) tables are shown in Tables 4 and 5 respectively while the normal probability plot of the residual is shown in Figure-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 11, water = $-67.03X_1$, cement = $-7.49X_2$, Laterite = $5.27X_3$, Quarry dust = $10.07X_4$, Coarse aggregate = $7.55X_5$, and water/cement = $321.69X_1X_2$. Therefore, the model equation for flexural strength is given as;

$$F_f = -67.03X_1 - 7.49X_2 + 5.27X_3 + 10.07X_4 + 7.55X_5 + 321.69X_1X_2 \ldots\ldots\ldots\ldots\ldots (19)$$

Table-4: Estimated Regression Coefficients for Flexural strength (component proportions)

Term	Coef	SE Coef	T	P	VIF
Water	-67.03	14.021	*	*	1620.16
Cement	-7.49	9.243	*	*	1512.63
Laterite	5.27	2.102	*	*	14.51
Quarry dust	10.07	2.257	*	*	132.77
Coarse Agg	7.55	2.002	*	*	484.07
Water*Cement	321.69	95.501	3.37	0.003	2205.58
S = 0.216360	PRESS = 1.92162				
R-Sq = 94.98%	R-Sq(pred) = 90.63%			R-Sq(adj) = 93.84%	

Regression Output

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

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	19.4828	19.4828	3.89657	83.24	0.000
Linear	4	18.9517	15.3864	3.84659	82.17	0.000
Quadratic	1	0.5312	0.5312	0.53115	11.35	0.003
Water*Ceme	1	0.5312	0.5312	0.53115	11.35	0.003
Residual Error	22	1.0299	1.0299	0.04681		
Lack-of-Fit	17	0.8635	0.8635	0.05079	1.53	0.338
Pure Error	5	0.1664	0.1664	0.03327		
Total	27	20.5127				

Regression Output

Since the p-significant value in Table-5 is less than 0.05 level of significance ($p = 0.000$, $p < 0.05$), $f = 83.24$) and the normal probability plot in Figure-1 show that the residuals fall reasonably close to the reference lines. Therefore, the conclusion is that Equation (19) is adequate for predicting the 28th day flexural strength of laterite–quarry dust concrete.

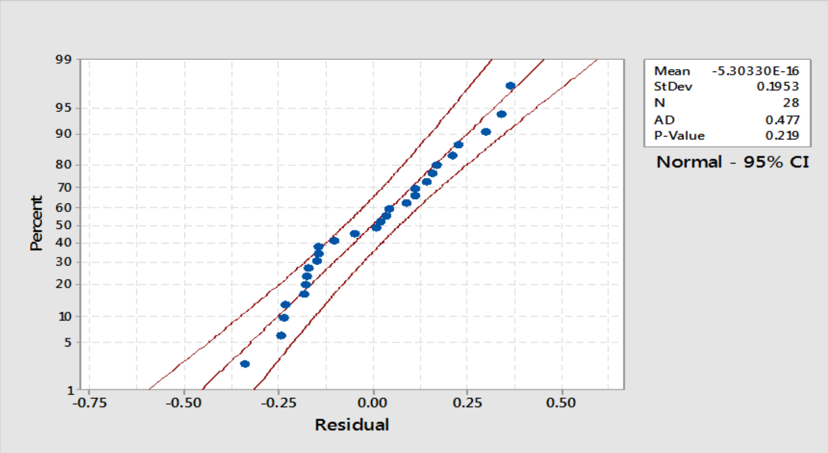

Fig-1: Normal probability plot for flexural strength residual

Several mix proportions were generated and converted to ratios in Table-6. The flexural strength of the mixes were obtained using the developed model.

Table-6: Flexural Strength of Laterite-Quarry Dust Concrete for Several Mix Ratios

Components in Ratios					Responses
Water	Cement	Laterite	Quarry Dust	Coarse Aggregate	F_f (Nmm^{-2})
0.68	1	0.6	0.98	2.97	2.80
0.53	1	0.11	1.37	2.26	3.96
0.66	1	0.34	1.01	2.51	3.21
0.71	1	0.54	0.88	2.49	2.85
0.54	1	0.08	0.52	1.86	4.86
0.54	1	0.08	0.66	1.72	4.95
0.4	1	0.08	0.66	1.86	4.74
0.51	1	0.19	0.73	2.22	4.04
0.67	1	0.1	1.05	2.12	3.72
0.51	1	0.19	0.89	2.05	4.13
0.64	1	0.2	0.79	2.41	3.49
0.47	1	0.08	0.73	1.72	4.89
0.64	1	0.44	0.61	2.02	3.63
0.43	1	0.48	0.57	1.87	4.11
0.4	1	0.22	0.52	1.86	4.58
0.68	1	0.25	1.38	2.91	3.09
0.47	1	0.08	0.52	1.93	4.76
0.71	1	0.5	1.86	3.07	2.99
0.59	1	0.19	0.73	2.13	3.95
0.71	1	0.14	1.79	3.5	3.07
0.54	1	0.15	0.52	1.79	4.82
0.56	1	0.49	0.8	2.26	3.51
0.57	1	0.74	0.94	2.46	3.21
0.68	1	0.12	1.51	2.49	3.32
0.71	1	0.54	1.32	3.57	2.79
0.63	1	0.09	0.6	2.33	3.87
0.4	1	0.08	0.8	1.72	4.83
0.71	1	0.93	0.93	3.57	2.52
0.47	1	0.29	0.52	1.72	4.64
0.59	1	0.22	1.19	2.39	3.59

Components in Ratios					Responses
Water	**Cement**	**Laterite**	**Quarry Dust**	**Coarse Aggregate**	**F_f (Nmm^{-2})**
0.54	1	0.22	0.52	1.72	4.78
0.79	1	0.6	1.08	2.76	2.44
0.54	1	0.15	0.59	1.72	4.86
0.61	1	0.68	0.68	2.23	3.20
0.68	1	0.25	1.32	2.97	3.06
0.79	1	0.25	1.21	2.97	2.62
0.76	1	0.32	0.73	2.82	2.72
0.76	1	0.11	0.94	2.82	2.90
0.59	1	0.27	0.73	2.05	3.91
0.58	1	0.09	0.56	2.08	4.36
0.4	1	0.08	0.52	2	4.66
0.48	1	0.62	0.62	2.05	3.72
0.71	1	0.14	1.71	3.57	3.05
0.71	1	0.32	1.86	3.25	3.04

Source: Researcher's work (2020). F_f = Flexural Strength.

CONCLUSION

The bulk densities of laterite and quarry dust were found to be 1240kg/m^3 and 1695kg/m^3. Similarly, the specific gravities were found to be 2.60 and 2.79. The sieve analysis indicated that both laterite and quarry dust falls within zone II of the grading of fine aggregate as given in [24] and are both suitable for making concrete. Model equations for predicting the flexural strength of laterite-quarry dust concrete as a function of the proportions of the constituents in the mix were developed. X_1…..X_5 in the model are the proportions of water, cement, laterite, quarry dust and crushed rock in the mix. The model was tested for its significance and found adequate. The minimum and maximum flexural strength predictable by the model are 2.44N/mm^2 and 4.95N/mm^2 corresponding to mix proportions of 0.127045:0.160568:0.095568:0.174205:0.442614 (ratio, 0.79:1:0.6:1.08:2.76) and 0.135:0.25:0.02:0.165:0.43 (ratio, 0.54:1:0.08:0.06:1.72) respectively. These values compared favorably with the values of the normal conventional concrete of 3.82N/mm^2 for ratio 1:2:4. They also compared well with the flexural strength of laterite-quarry dust concrete of 2.88N/mm^2 and 3.28N/mm^2 derived by [13] and 2.6165 N/mm^2 - 3.662N/mm^2, 3.122 N/mm^2 – 4.317 N/mm^2 for normal concrete derived by [14].. This model can be used to predict the flexural strength of laterite-quarry dust concrete for both domestic and commercial constructions. It can be used at the early stage of any project and it will be very beneficial in the reduction of the number of trial mixes, use of arbitrary mixes and cost indeterminacy. In this regards, the use of models for predictions should be encouraged in the construction industry.

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