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ModelsForPredicting The Compressive Strength And Cost Of Laterite–Quarry Dust Concrete Using Extreme Vertices Design.

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--*ABSTRACT*--
Excessive mining of river sand for construction activities has negative effect on our natural environment and has caused acute shortage and price increase of river sand. The search for alternative materials to partially or wholly replace river sand in concrete works has led to the use of laterite and quarry dust. This paper developed models for predicting the 28th day compressive strength and cost of laterite-quarry dust concrete using [5,2] extreme vertices design. Adequacy of the models were confirmed using the p-value, F statistics and normal probability plots. The compressive strength model can predict the strength of laterite-quarry dust concrete for both reinforced and non-reinforced concrete design for domestic and commercial constructions, while the cost model can predict the cost implication at the early stage of the project.
KEYWORDS:*Model,Compressive strength, Cost, Laterite, Quarry dust, Laterite-quarry dust concrete, Extreme vertices design.*

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I. INTRODUCTION

Laterite – quarry dust concrete is produced by mixing cement, water, laterite and quarry dust as fine aggregate, and coarse aggregate in proper proportions to achieve a specified strength property. The conventional concrete, which is produced by mixing cement, water, river sand and coarse aggregate is a major component used in vast infrastructural developments in the world.Saeed and Shahid (2008) revealed that fine aggregate contributes about 35% of concrete used in the construction industry, and river sand has been the most popular choice for fine aggregate component of concrete. For onetonne of cement, about six to seventonnes of sandis needed for concrete and masonry works in the construction industry (Greenfact, 2017). This has led to the constant and unregulated mining of river sand.Excessive mining of river sand erodes nearby lands and causes damages to public infrastructures like houses, bridges, pipelines, and electricity lines (Ashraf, Maah, Yussoff, Wajid, and Mahmood, 2011).It hasalso caused price increase and acute shortage in the availability of river sand in most countries including Nigeria.The need to protectthe natural environment from degradation and distortion has led to the search for alternative materials to river sand for concrete and other construction works. Such alternative materials include laterite and quarry dust.

Again, the construction industry has reportedly been involved in cost spillover due to cost indeterminacy (Egwunatum and Oboreh, 2015). Building contracts are completed at sums much higher than the estimated cost (Ganiyu and Zubairu, 2010). For any construction project, it is necessary to know the cost of completing each item of work at the design stage, which include the cost of materials and labour. One of the challenges in estimating the cost of concrete work is being able to determine the required proportions of the constituents to achieve the specified property (Seeley, 1996; Ashworth, 2010). Usually, to achieve a specified concrete grade, construction professionals resort to trial and error method which impacts negatively on the budget and duration of a project. Hence, the objective of this research is to develop reliable models for predicting the 28^{th} day compressive strength and cost of $1m^3$ of concrete using laterite and quarry dust as fine aggregate.The models can also ensure a long service life for the concrete structure(Muller, Anders, Breiner, and Vogel, 2013; Palika, Rajendra, and Maneek, 2014) and study the interactions of the components through the use of Cox response trace plot.

II. MIXTURE EXPERIMENT AND CANONICAL POLYNOMIAL (MODEL)

The mixture of two or more components to make an end product or means to an end product is termed mixture experiment. It is an experiment that the response is dependent on the proportions of the constituent materials(Cornel, 2002). The constituents of the mixture can either be measured by volume or mass. The constituent proportions must be constrained to sum to 1 andnone must have a negative value. The statement above can be stated mathematically as:

$0 \leq x_i \leq 1$ (1)

i = 1,2,3,4…q and$\Sigma x_i = 1$

Where q = the number of mixture components

$$\sum_{i=1}^{q} x_i = x_1 + x_2 + x_3 + x_4 \ldots + x_q = 1.0 \quad (2)$$

If the compressive strength or costis denoted by y and x_1, x_2, x_3, x_4, and x_5 are the constituents of the mixture, then the equation can be represented as:

$$y = f(x_1, x_2, x_3, x_4, x_5) \quad (3)$$

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

$$\hat{y} = b_0 + \sum_{1 \leq i \leq q} bix_i + \sum_{1 \leq i \leq j \leq q} bijx_ij + \sum_{1 \leq i \leq j \leq k \leq q} bijkx_ix_jx_k + \sum bi_1i_2i_nxi_1xi_2xi_m \quad (4)$$

The second degree polynomial is the most commonly used polynomial to fitting mixture experiment data, and when the number of components, q = 5, and M = 2, the number of terms will be fifteen (15) and equation (4) can be written as:

$$\hat{y} = \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_4x_4 + \beta_5x_5 + \beta_{12}x_1x_2 + \beta_{13}x_1x_3 + \beta_{14}x_1x_4 + \beta_{15}x_1x_5 + \beta_{23}x_2x_3 + \beta_{24}x_2x_4 + \beta_{25}x_2x_5 + \beta_{34}x_3x_4 + \beta_{35}x_3x_5 + \beta_{45}x_4x_5 \quad (5)$$

III. EXTREME VERTICES DESIGN

Extreme vertices designs are the mixture designs that cover 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 (L_i) and upper (U_i) bound (Cornell, 2002). With q, components, the constants are written as;

$$0 \leq L_i \leq X_i \leq U_i \leq 1, \qquad i = 1, 2 \ldots q \quad (6)$$

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.

IV. MATERIALS

The materials used for this work are; Water, Ordinary Portland Cement, Laterite soil, Quarry dust and Coarse Aggregate (Crushed rock). Potable water conforming to the specification of BS EN 1008: (2002) was used for both specimen preparation and curing, and it was sourced from 9th mile Enugu State, Nigeria.Unicem brand of Ordinary Portland cement of grade 42.5 which conforms to NIS:444 (2003) was used for all the tests. Laterite soil was obtained from Umuchigbo community in Iji-Nike, Enugu East Local Government Area of Enugu State, Nigeria. It has a bulk density of 1240kg/m^3, specific gravity of 2.60 and fineness modulus of 3.03. Quarry dust was obtained from the quarry site of Jinziang quarry (Nigeria) company limited in Ezillo, Ishielu Local Government Area of Ebonyi State. It has a bulk density of 1695kg/m^3, specific gravity of 2.79 and fineness modulus of 2.74. Coarse aggregate (Crushed rock) was also obtained from the same quarry site.

V. EXPERIMENTAL DESIGN

The experiment was designed and analyzed with Minitab 17. An extreme vertices (5,2) design with fifteen runs were used to formulate the models. The fifteen runs were augmentedwith six additional check points which included the centroid and axial runs. An additional seven runs were used to validate the model. The experiment was performed in the standard order (StdOrder) and run order (RunOrder) of the design respectively. However, Table 1 show bounds of the five mixture components. The proportions were constrained above and below andwere gotten through several trial mixes using ratios 1:1:1.5, 1:1:2, 1:1.5:3, 1:2:4, and 1:3:6.

Table1: Bounds of 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: Authors field work, (2020)

The set constraints are:
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 = $0.430 \leq x_5 \leq 0.500$.

5.1 Compressive Strength Test and Cost of 1m^3 of Laterite – Quarry DustConcrete.

Concrete cubes of 150mm weremoulded in accordance to BS EN 12390-1 (2000) and tested for their compressive strength (f_c). Aggregates were used in their dry condition and batching of the materials were done by weight using a weighing balance of 50kg capacity. Mixing of the constituents were done manually using shovel and the cubes were cured in a curing tank for twenty eight (28) days. A total number of eighty four (84) specimens were produced. The compressive strength test was done in accordance to BS EN 12390-3 (2002) using controls wizard basic testing machine with a testing capacity of 2000kN. The machine conforms to the requirement of BS EN 12390-4 (2000). Three samples each were tested for a particular mix ratio, and the average value was taken as the compressive strength. The compressive strength (f_c) was determined from the relationship;

f_c= *crushing load (N)/cross-sectional area (mm^2)* (7)

The production cost of laterite – quarry dust concrete includes the cost of materials, labour, profit and overhead. The cost was increased by 35% to incorporate the cost of labour and 25% to incorporate the profit and overhead, making it a total of 60%. Table 2shows the (5,2) design matrix components in real ratios and their responses (Average compressive strength result and cost of materials per m^3). The data on Table 2 were used for model formulation.

Table 2:(5,2) Design Matrix Components in Real Ratios and their Responses

Run Order	Std Order	Water	Cement	Laterite	Quarry dust	Coarse Aggregate	*Av.f_c (Nmm^2)*	Total Cost of materials per m^3 (Naira)
1	93	0.964286	1	0.142857	1.464286	3.571429	7.19	20474.76
2	105	0.964286	1	0.25	1.857143	3.071429	6.81	19884.47
3	10	0.526316	1	0.105263	1.368421	2.263158	19.27	20606.64
4	6	0.714286	1	0.928571	1.428571	3.071429	12.00	20469.93
5	1	0.714286	1	0.142857	1.714286	3.571429	10.00	21129.55
6	21	0.771429	1	0.742857	0.742857	2.457143	10.00	23051.48
7	11	0.714286	1	0.5	1.857143	3.071429	12.00	20430.86
8	94	0.4	1	0.08	0.8	1.72	25.00	31404.96
9	7	0.964286	1	0.928571	1.178571	3.071429	7.00	19357.51
10	42	0.964286	1	0.803571	0.928571	3.446429	6.00	19875
11	54	0.666667	1	0.098765	1.049383	2.123457	13.00	25906.48
12	60	0.635294	1	0.435294	0.611765	2.023529	13.00	26198.66
13	46	0.839286	1	0.928571	1.303571	3.071429	9.00	19656.41
14	41	0.839286	1	0.142857	1.589286	3.571429	9.00	20915.54
15	38	0.606061	1	0.272727	1.575758	2.606061	15.00	22974.42
16	114	0.657465	1	0.337516	1.012547	2.513174	13.00	23793.7
17	75	0.682236	1	0.595188	1.193914	2.756546	12.00	21942.73
18	78	0.682236	1	0.252654	1.38075	2.912243	13.00	22433.27
19	79	0.590325	1	0.218616	1.194734	2.385181	15.00	24620.24
20	70	0.682236	1	0.252654	1.318471	2.974522	12.00	22311.06
21	80	0.682236	1	0.408351	1.38075	2.756546	12.00	21960.08
22	14	0.964286	1	0.25	1.857143	3.071429	7.00	19659.61
23	101	0.526316	1	0.105263	1.368421	2.263158	18.00	25466.1
24	112	0.771429	1	0.742857	0.742857	2.457143	10.43	22616.05
25	92	0.714286	1	0.142857	1.714286	3.571429	13.00	20951.84
26	69	0.657465	1	0.337516	1.012547	2.513174	15.00	24295.67
27	88	0.560139	1	0.488669	0.801278	2.263219	19.00	25599.67
28	55	0.47	1	0.08	0.73	1.72	27.00	31423.14

Source: Researcher's work, (2019). *Av.f_c*= Average compressive strength results

5.2 Model Equation for Compressive Strength

The second degree polynomial (model) of Equation (5) was fitted to the data of the 28 compressive test result at 95% confidence limit (α = 0.05). The estimated regression coefficient and the analysis of variance (Anova) tables are shown in Tables 3 and 4 respectively while the normal probability plot of the residual is shown in Figure 1. Therefore, the model equation for compressive strength is given as;

$$f_c = -144.9Z_1 + 139.8Z_2 + 7.0Z_3 + 12.4Z_4 + 7.1Z_5 \quad (8)$$

Table 3: Estimated Regression Coefficients for Compressive strength (component proportions)

Term	Coef	SE Coef	T	P	VIF
Water	-144.9	18.084	*	*	72.494
Cement	139.8	7.075	*	*	23.839
Laterite 7.0	7.587	*	*	5.082	
Quarry dust	12.4	7.064	*	*	34.976
Coarse Agg	7.1	6.306	*	*	129.108

S = 1.31924 PRESS = 66.3681
R-Sq = 94.33% R-Sq(pred) = 90.61% R-Sq(adj) = 93.35%

Regression Output

The*p*-significant value is less than 0.05 level of significance ($p = 0.000$, $p < 0.05$), f = 95.75) and the normal probability plot of Figure 1 also show that the residuals fall reasonably close to the reference lines. Therefore, the conclusion is that Equation (8) is adequate for predicting the 28th day compressive strength of laterite – quarry dust concrete.

Table 4: Analysis of Variance for Compressive strength (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	4	666.572	666.572	166.643	95.75	0.000
Linear	4	666.572	666.572	166.643	95.75	0.000
Residual Error	23	40.029	40.029	1.740		
Lack-of-Fit	18	32.612	32.612	1.812	1.22	0.448
Pure Error	5	7.417	7.417	1.483		
Total	27	706.601				

Regression Output

5.3Model Equation for Cost

A similar analysis gave the model equation for cost as:

$$\hat{y} = -10100Z_1 + 99345Z_2 + 786Z_3 + 221Z_4 + 15868Z_5 \quad (9)$$

The regression source is significant at 95% confidence limit since the *p*-value is less than 0.05 level of significance, ($p = 0.000$, $p < 0.05$), f = 67.40), indicating the adequacy of the model to predict the cost of producing laterite – quarry dust concrete mixes.

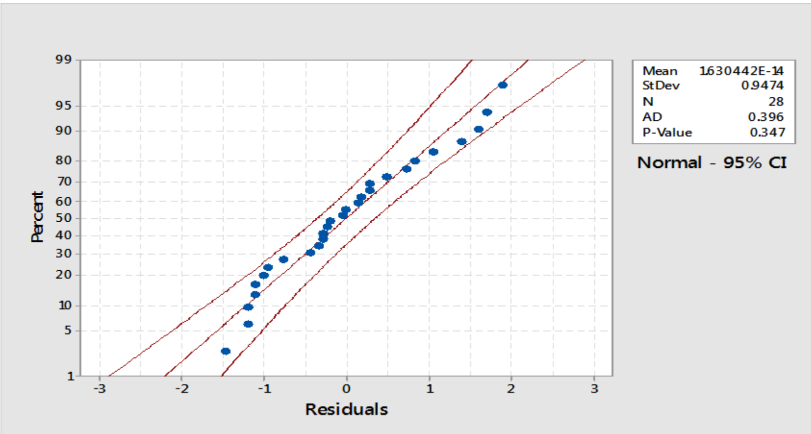
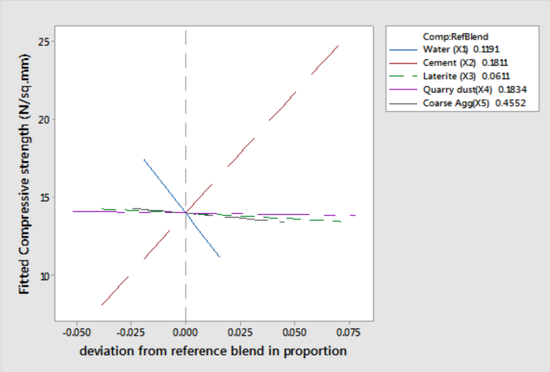


Figure 1: Normal probability plot for compressive strength

5.4Response trace plots

The Cox response plots for both compressive strength and cost are shown in Figures 2 and 3. The reference blend is taken to be the centroid of the vertices where the component proportions are: Water = 0.1191, Cement = 0.1811, Laterite = 0.0611, Quarry dust = 0.1834, and Coarse aggregate = 0.4552 for both the compressive strength and cost.



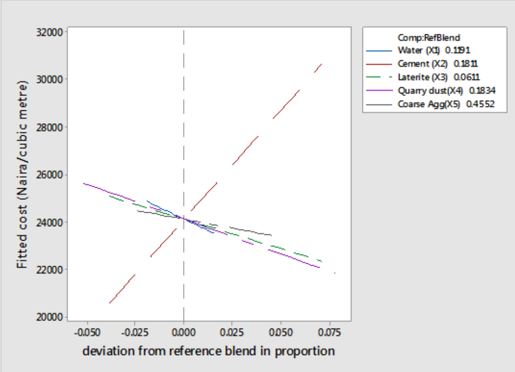


Figure 2: Response trace plot for compressive strength.Figure 3: Response trace plot for cost.

VI. DISCUSSION OF RESULTS

It can be seen from the compressive strength model that $\beta_2 > \beta_4 > \beta_5 > \beta_3 > \beta_1$indicates that cement contributes more to the strength of laterite-quarry dust concrete, followed by quarry dust, crushed rock, laterite and water. For cost model, $\beta_2 > \beta_5 > \beta_3 > \beta_4 > \beta_1$indicates that cement cost more in producing 1m^3 of laterite-quarry dust concrete followed by crushed rock, laterite, quarry dust and water. Depending on the percentage proportions, the use of laterite and quarry dust as fine aggregate in concrete produces good compressive strength for different construction usage. At 9.9% laterite and 90.1% quarry dust, the compressive strength of 27N/mm^2 cost ₦31,423.14 while compressive strength of 6N/mm^2 cost ₦19,875 at 46.4% laterite and 53.6% quarry dust. The compressive strength responses in Table 2 falls within the nominal and design mix concrete evident in Mudavath (2018). The models were tested for their significance using the p-value and F test statistics. They were found adequate. For the cox response trace plots, as the proportion of cementincreases, and the other mixture component decreases, the compressive strength increases. As the cement proportion decreases while the other component increases, the compressive strength decreases. As the proportion of quarry dustdecreases and the other component increases, the strength of the concrete increases moderately. If it increases and the other component decreases, the strength of the concrete increases. As the proportion of coarse aggregate decreases and the other component increases, the strength of concrete decreases moderately, but if it increases moderately, the strength of concrete increases. As the proportion of laterite increases and the other components decreases, the strength of concrete decreases. If the component of laterite decreases and the other proportion increases, the strength of the concrete increases. As the proportion of water increases, and the other components decreases, the concrete forms laitance and the strength decreases. If the proportion of water decreases and the other components increases, the strength of the concrete increases.

VII.CONCLUSION AND RECOMMENDATION

Models for predicting the compressive strength and cost of laterite-quarry dust concrete were developed. This study has shown that laterite and quarry dust are suitable alternative to river sand in concrete production. The compressive strength model can be used to predict the strength of laterite-quarry dust concrete that can be used for levelling, blinding and every other non-reinforced and reinforced concrete design for both domestic and commercial construction, while the cost model can be used to determine the cost implication at the early stage of the project. These models will be very beneficial in the reduction of the number of trial mixes, use of arbitrary mixes and cost indeterminacy. Thus, they will help to greatly reduce the time, effort, and resources needed in meeting the requirements of a given response. In this regards, the use of laterite and quarry dust as alternative to river sand in concrete production should be encouraged as this has shown to produce a reliable concrete strength. This is more so in areas where the river catchment is very small and areas close to quarry site.

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