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Comparison of Compressive Strength and Cost of River Sand and Model Predicted Laterite–Quarry Dust Concrete

S.E. Orji[1], I.C. Ugwu[2], U.C. Anya[3]
[1]Department of Building, Enugu State University of Science and Technology, Agbani, Nigeria
[2]Department of Urban & Regional Planning, Enugu State University of Science and Technology, Agbani, Nigeria
[3]Department of Civil Engineering, Federal University of Technology, Owerr, Nigeria

***Abstract**: The search for alternative materials to river sand in concrete and masonry works has led to the use of laterite and/or quarry dust. Formulation of models for predicting the structural strength and cost including concrete proportioning using locally available material is a growing trend in the construction industry. This paper developed models for predicting the 28th day compressive strength and cost of laterite-quarry dust concrete using [5,2] extreme vertices design and also produced the compressive strength of river sand concrete using mix ratios 1:1.5:3, 1:2:4, and 1:3:6. The cost of each of the mix ratios of the river sand concrete were developed using the traditional estimation method. Adequacy of the models were confirmed using the p-value, and F statistics. The compressive strength and cost of the river sand concrete were compared to the model predicted laterite-quarry dust concrete. The study revealed that the model predicted higher compressive strength and cheaper cost for laterite-quarry dust concrete.*

***Keywords:**Comparison,Compressive strength, Cost, Model, Laterite, Quarry dust, Laterite-quarry dust concrete, Extreme vertices design.*

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I. Introduction

The search for alternative materialsto partially or fully replace river sand in concrete and masonry works has led to the use of laterite and/or quarry dust. This is evident in the works of Zerdi, Hussain, Ali and Ansari (2016), Salau and Busari (2015), Prakesh and Rao (2016a, 2016b), Manasseh (2010), Dongapure, and Mangalgi (2014) and Ukpata, Ephraim, and Akeke, (2012). Laterite is obtained intentionally from a borrow pit or through various forms of excavations for substructure works, while quarry dust is obtained from a quarry site. Quarry dust is a waste product in the quarrying process and it continuous accumulation pollutes the natural air to become a threat to the environment. It is logical that one way it can be properly utilized is to incorporate it into the structural concrete system (Ukpata, *et al.,* 2012; Anya 2015).

Again, formulation of models for predicting the parameters of construction activities including concrete proportioning, strength and cost using locally available material is a growing trend in the construction industry. This is also evident in the works of Anya and Osadebe (2015), Anya, Osadebe, Anike, and Onyia (2015), Otunyo and Jephter (2018), Onwuka, Anyaogu, Chijioke, and Okoye (2013), Egwunatum and Oboreh (2015), Kadiri (2015), Ganiyu and Zubairu (2010), Al-Zwainy and Hadhal (2016), Lowe, Emsley, and Harding (2006), and Ukpata, *et al.,* (2012). According to Hans (2016), simplified modelling of complex material behavior represents one of the most powerful tools for design in practice. Irrespective of the gains made by using models, some construction professionals prefers the use of the traditional methods which has been termed by Seeley (1996) and Ashworth (2010) as uneconomical, wasteful, and gives poor representation. Hence, the objective of this work is to compare the compressive strength and cost of $1m^3$ of concrete produced with river sand as fine aggregate, using the traditional quantity surveying method of estimation and model predicted compressive strength and cost of concrete produced with laterite and quarry dust as fine aggregate using the extreme vertices design.

II. Mixture Experiment And Model Development

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 and none must have a negative value. The statement above can be stated mathematically as:

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

i = 1, 2, 3, 4…q and $\sum x_i = 1$
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 cost 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:

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

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:

$$\hat{y} = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{14} x_1 x_4 + \beta_{15} x_1 x_5 + \beta_{23} x_2 x_3 + \beta_{24} x_2 x_4 + \beta_{25} x_2 x_5 + \beta_{34} x_3 x_4 + \beta_{35} x_3 x_5 + \beta_{45} x_4 x_5 \quad (4)$$

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;

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

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. 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, River Sand 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 and river sand was obtained from Amokpo Nike, both in Enugu East Local Government Area of Enugu State, Nigeria. The laterite has a bulk density of 1240kg/m^3, specific gravity of 2.60 and fineness modulus of 3.03 while the river sand has a bulk density of 1540kg/m^3, specific gravity of 2.70 and fineness modulus of 2.88. 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 augmented with 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 and were 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
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 = $0.100 \le x_1 \le 0.135$, 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 = $0.430 \le x_5 \le 0.500$.

On the other hand, conventional concrete of water, cement, river sand, and crushed rock was produced using the generally used mix ratios of 1:1.5:3, 1:2:4, and 1:3:6. These mix ratios are used as a rule of thumb in Nigeria irrespective of their strength.

5.1 Compressive Strength Test and Cost of 1m^3 of Concrete.

Concrete cubes of 150mm were moulded for both river sand concrete and laterite-quarry dust concrete 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) cubes of laterite-quarry dust concrete were produced for model formulation, while a total of nine (9) cubes of river sand concrete were produced for the sake of comparison. 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)* (6)

The production cost of concrete was increased by 60% to include the cost of materials, labour, profit and overhead. Table 2 shows the (5,2) design matrix components in real ratios for laterite-quarry dust concrete and their responses. The data on Table 2 were used for model formulation.

Table 2: (5,2) Design Matrix Components in Real Ratios for Laterite-Quarry dust concrete

Run Order	Std Order	Water	Cement	Laterite	Quarry dust	Coarse Agg.	*Av.f_c (Nmm^2)*	Total Cost of materials per m^3(₦)
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. Therefore, the model equation for compressive strength is given as;

$$f_c = -144.9Z_1 + 139.8Z_2 + 7.0Z_3 + 12.4Z_4 + 7.1Z_5 \quad (7)$$

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). Therefore, the researcher concluded 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

5.3 Model Equation for Cost

A similar analysis gave the model equation for cost as:

$$\hat{y} = -10100Z_1 + 99345Z_2 + 786Z_3 + 221Z_4 + 15868Z_5 \quad (8)$$

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.

5.4 Compressive Strength and Cost of Conventional River Sand Concrete

Table 5 presents the compressive strength testand cost of concrete produced with river sand as fine aggregate. The quantity surveying method ofestimation was used to determine their cost and the prices of materials were based on the prevailing market prices in Enugu State, Nigeria. Density of cement was taken as 1440kg, while the average ratio of dry to wet concrete was taken to be 1.5. A bag of 50 kg cement was bought for ₦2,200 while 7 tonnes of river sand and 10 tonnes of crushed rock cost ₦12,000 and ₦40,000 respectively.

Table 5: Compressive Strength and Cost of River Sand Concrete

Cement	River Sand	Coarse Aggregate	Comp. Strength *(Nmm^2)*	Cost per m^3 (₦)
1	1.5	3	25.49	33939.60
1	2	4	18.79	28651.90
1	3	6	12.43	22772.25

Source: Researcher's work (2019).

5.5 Compressive Strength and Cost of laterite-quarry dust Concrete

Table 6 presents the compressive strength test and cost of laterite-quarry dust concrete. Several mix ratios were generated and substituted into the compressive strength and cost models to predict their various responses. The mix proportions were summed to 1.

Table 6: Compressive Strength Result and Cost of Laterite-Quarry dust Concrete

Water	Cement	Laterite	Quarry dust	Coarse Agg.	Combined Fine Agg.	Comp. Strength (Nmm^2)	Cost per m^3 (₦)
0.4	1	0.08	0.66	1.86	0.74	25.95	31257.06
0.4	1	0.22	0.52	1.86	0.74	25.76	31276.83
0.4	1	0.08	0.8	1.72	0.88	26.13	30709.41
0.4	1	0.08	0.52	2	0.6	25.76	31804.70
0.4	1	0.22	0.66	1.72	0.88	25.94	30729.19
0.53	1	0.11	1.37	2.26	1.48	18.49	24761.97
0.51	1	0.19	0.73	2.22	0.92	19.88	27954.50
0.51	1	0.19	0.89	2.05	1.08	20.07	27406.86
0.51	1	0.35	0.73	2.05	1.08	19.88	27426.63
0.51	1	0.1	0.95	2.56	1.05	18.76	26352.88
0.68	1	0.6	0.98	2.97	1.58	12.58	22533.76
0.68	1	0.6	1.19	2.76	1.79	12.76	21986.11
0.68	1	0.25	1.38	2.91	1.63	12.93	22346.21
0.68	1	0.25	1.32	2.97	1.57	12.87	22502.68
0.68	1	0.41	1.38	2.76	1.79	12.92	21969.16

Source: Researcher's work (2019).

5.6 Comparison of Compressive Strength and Cost of River Sand Concrete and Model Predicted Compressive Strength and Cost of Laterite-Quarry Dust Concrete.

Table 7 compares the compressive strength and cost of producing $1m^3$ of concrete produced with river sand as fine aggregate and model predicted compressive strength and cost of laterite-quarry dust concrete.

Table 7: Strength and Cost of River Sand Concrete and Laterite-Quarry Dust Concrete

River Sand Concrete			Laterite-Quarry Dust Concrete		
Mix ratios	Comp. strength (Nmm^2)	Cost per m^3(₦)	Mix ratios	Comp. strength (Nmm^2)	Cost per m^3(₦)
0.54:1:1.5:3	25.49	33939.60	0.4:1:0.08:0.66:1.86	25.95	31257.06
			0.4:1:0.22:0.52:1.86	25.76	31276.83
			0.4:1:0.08:0.8:1.72	26.13	30709.41
			0.4:1:0.08:0.52:2	25.76	31804.70
			0.4:1:0.22:0.66:1.72	25.94	30729.19
0.59:1:2:4	18.79	28651.90	0.53:1:0.11:1.37:2.26	18.49	24761.97
			0.51:1:0.19:0.73:2.22	19.88	27954.50
			0.51:1:0.19:0.89:2.05	20.07	27406.86
			0.51:1:0.35:0.73:2.05	19.88	27426.63
			0.51:1:0.1:0.95:2.56	18.76	26352.88
0.67:1:3:6	12.43	22772.25	0.68:1:0.6:0.98:2.97	12.58	22533.76
			0.68:1:0.6:1.19:2.76	12.76	21986.11
			0.68:1:0.25:1.38:2.91	12.93	22346.21
			0.68:1:0.25:1.32:2.97	12.87	22502.68
			0.68:1:0.41:1.38:2.76	12.92	21969.16

Source: Researcher's work (2019).

VI. Discussion Of Findings

Models for predicting the compressive strength and cost of concrete using laterite and quarry dust as fine aggregate were formulated. These models were tested for their significance using the p-value and F test statistics and were found to be adequate. The component proportions were within bounds and summed to 1.

Several mix ratios were generated and substituted into the models to predict their various responses. The compressive strength and cost of producing $1m^3$ of conventional river sand concrete using ratios 1:1.5:3, 1:2:4, and 1:3:6 were produced and compared to themodel predicted laterite-quarry dust concrete. Table 7 indicates that the model predicted a higher compressive strength using laterite and quarry dust as fine aggregate except for ratios 0.53:1:0.11:1.37:2.26 and 0.51:1:0.1:0.95:2.56 which predicted $18.49Nmm^2$ and $18.76Nmm^2$ respectively. These values are slightly lower than the $18.79Nmm^2$ produced using ratio 0.59:1:2:4 of the conventional river sand concrete. Table 7 also indicates that the model predicted cost of laterite-quarry dust concretes are cheaper than the conventional river sand concrete. This has shown that laterite and quarry dust are effective for concrete works and cost efficient.

VII. Conclusion And Recommendation

Models for predicting the 28th day compressive strength and cost of laterite-quarry dust concrete were formulated using [5,2] extreme vertices design. A statistical comparison of compressive strength and cost of model predicted laterite-quarry dust and river sand concrete were carried out. Mix ratios of 1:1.5:3, 1:2:4, and 1:3:6 were used and the cost of each of the ratios were developed using the traditional estimation method. It was revealed that the models predicted higher compressive strength and cheaper cost for laterite-quarry dust concrete. The compressive strength model can be used to predict the compressive strength of laterite-quarry dust concrete for both domestic and commercial constructions and the cost model can be used to determine the cost implication of such project. These models can be used at the early stage of any project and they 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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