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Relationship Between The Compressive Strength And Cost, And Comparison Between experimental And Model Predicted Results Oflaterite-Quarry Dust Concrete.

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Abstract: *This paper determined the relationship between the compressive strength and cost of laterite-quarry dust concrete and compared the observed experimentalresults and some selected models predicted results of laterite-quarry dust concrete. The study was done using existing data and were validated using the p-value, F statistics and normal probability plot. The relationship was determined by taken the average values of the responses for the replicated mixes into consideration and sequential F test (ρ-value) was carried out to fit the linear and quadratic models to the average values of the compressive strength and cost of laterite-quarry dust concrete at the 23 points of the vertices. Regression and correlation analysis techniques were used. The correlation value was found to be 0.896 which is very close to +1. It means there is a strong positive relationship (linear and quadratic) between the compressive strength and cost of laterite-quarry dust concrete. Simple percentage differences were used to compare the observed experimental results and the responses predicted by the selected models of interest at the check points. The replicated mixes were also taken into consideration. The percentage differences were all less than 5.2%, which is quite insignificant. This has shown that the models are adequate for predicting their various responses.*

Keywords: *Compressive strength, Cost, Laterite-quarry dust concrete, Experimental results, Model predictions*.

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I. INTRODUCTION

Laterite – quarry dust concrete has been described by [15] as concrete 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 construction industry according to [4] is more interested in applying environmentally friendly concrete in its construction projects. Among other benefits, concrete made with alternative material reduces pollution and energy use, as well as lower the cost of concrete production. Fine aggregate is an important component of concrete thatimparts the properties of concrete in its fresh and hardened state. It contributes [19] about 35% of concrete used in the construction industry.

Laterite is used as a filler in a foundation and road construction, it is cheap, environmentally friendly andabundantly available in most Nigerian communities[17, 9, and 20]. In a related view, quarry dust is sometimes usedin the production of bricks and blocks and as a filler in the construction of roads.Thecontinuous accumulation of large volume of quarry dust pollutes the air and threatens the natural environment, hence, there is need to properly incorporate it intothe structural concrete system [21, 1].

Several studies have developed models for predicting the structural properties of concrete using laterite and quarry dust as replacement for river sand. These studies include but not limited to[16, 2, 11, 10,15, 7 and 21]. Hence, the objective of this research is to determine the relationship between the compressive strength and cost of laterite-quarry dust concrete, and to compare the experimental and model predicted results of some structural properties and cost of laterite-quarry dust concrete. The models of interest are those developed by [15, 2, 11, and 16] and thestructural properties of concrete of interest are the compressive strength, flexural strength, shear strength and static modulus of elasticity.

II. DATA USED AND METHODS

The data used for this work were the same as those used by [15, 2, 11, and 16]. The material components were; Water, Ordinary Portland Cement, Laterite, Quarry dust and Crushed rock. Potable water conforming to [6] was used for both specimen preparation and curing while Ordinary Portland cement of grade 42.5 which conforms to [12] was used for all the tests.

To determine the relationship between the compressive strength and cost of laterite-quarry dust concrete, the average values of the compressive strength and cost of the replicated mixes at the 23 points of the vertices shown in Table 2 were taken into consideration and sequential F test (ρ-value) was carried out to fit their linear and quadratic models. Regression and correlation analysis techniques were used. This was done using Analysis of variance (ANOVA). A ρ-value of less than 0.05 indicated a significant term and the term was included in the model. Summary statistics (R-square, Adjusted R squared and the standard error) were also determined. Adequacy of the model was also tested using the fitted line plots for both the linear and quadratic model at 95% confidence limit.

Simple percentage differences were used to compare the observed experimental results and the responses predicted by the models developed by [15, 2, 11, and 16]at the check points. The replicated mixes were also taken into consideration. The percentage difference was calculated as:

$$\% \text{ difference} = 100\% \times (y - \hat{y}) / y \quad (5)$$

Where;
y = Observed experimental value
ŷ = Model predicted value

The models of interest are;
Extreme vertices models for predicting the compressive strength and cost of laterite-quarry dust concrete developed by [15]. The models are stated as;

Compressive strength (f_c)= $-144.9Z_1 + 139.8Z_2 + 7.0Z_3 + 12.4Z_4 + 7.1Z_5$ (6)

Cost (ŷ) = $-10100Z_1 + 99345Z_2 + 786Z_3 + 221Z_4 + 15868Z_5$ (7)

Z_1, Z_2, Z_3, Z_4 and Z_5in the models are the proportions of water, cement, laterite, quarry dust and crushed rockin the mix.

Statistical modelling of flexural strength of laterite-quarry dust concrete developed by [2].

Flexural strength (F_f) = $-67.03X_1 - 7.49X_2 + 5.27X_3 + 10.07X_4 + 7.55X_5 + 321.69X_1X_2$ (8)

X_1, X_2, X_3, X_4 and X_5in the model are the proportions of water, cement, laterite, quarry dust and crushed rockin the mix.

Mixture experiment model for predicting the static modulus of elasticity of laterite-quarry dust concrete developed by [11].

Static modulus of elasticity (E_s) = $-106.9X_1 + 91.5X_2 + 19.0X_3 + 23.9X_4 + 26.4X_5$ (9)

X_1, X_2, X_3, X_4 and X_5in the model are the proportions of water, cement, laterite, quarry dust and crushed rockin the mix.

Prediction of shear strength of laterite-quarry dust concrete developed by [16].

Shear strength (ŷ) = $-4.969X_1 - 0.407X_2 + 0.370X_3 + 0.832X_4 + 0.519X_5 + 24.124X_1X_2$ (10)

X_1, X_2, X_3, X_4 and X_5in the model are the proportions of water, cement, laterite, quarry dust and crushed rockin the mix.

III. RESULTS AND DISCUSSIONS

The real mix ratios and their average responses are presented in Table1 while the average observed responses of the compressive strength and cost at the 23 points of the vertices are shown in Table 2. The data in Table 2 were used to determine the nature of the relationship between the compressive strength and cost of laterite-quarry dust concrete.

Table 1: Real Mix Ratios and their Average Responses.

Real Mix Ratios					Average responses				Cost per m^3 (₦)
Water	Cement	Laterite	Quarry Dust	Coarse Aggregate	F_c (Nmm^{-2})	F_f (Nmm^{-2})	(GPa)	F_s (Nmm^{-2})	
0.964286	1	0.142857	1.464286	3.571429	7.19	1.88	17.5203	0.1573	20474.76
0.964286	1	0.25	1.857143	3.071429	6.81	1.89	16.6962	0.1573	19884.47
0.526316	1	0.105263	1.368421	2.263158	19.27	4.17	25.6015	0.3473	20606.64
0.714286	1	0.928571	1.428571	3.071429	12.00	2.55	21.5389	0.2123	20469.93
0.714286	1	0.142857	1.714286	3.571429	10.00	2.87	20.8565	0.2390	21129.55
0.771429	1	0.742857	0.742857	2.457143	10.00	2.38	18.9173	0.1987	23051.48
0.714286	1	0.5	1.857143	3.071429	12.00	2.75	21.2302	0.2293	20430.86
0.4	1	0.08	0.8	1.72	25.00	4.59	27.3292	0.3827	31404.96
0.964286	1	0.928571	1.178571	3.071429	7.00	1.94	16.1139	0.1620	19357.51
0.964286	1	0.803571	0.928571	3.446429	6.00	1.55	15.8961	0.1287	19875
0.666667	1	0.098765	1.049383	2.123457	13.00	3.73	20.7359	0.3113	25906.48

0.635294	1	0.435294	0.611765	2.023529	13.00	3.40	20.0373	0.2830	26198.66
0.839286	1	0.928571	1.303571	3.071429	9.00	2.28	18.2520	0.1903	19656.41
0.839286	1	0.142857	1.589286	3.571429	9.00	2.32	19.5851	0.1937	20915.54
0.606061	1	0.272727	1.575758	2.606061	15.00	3.63	23.0891	0.3040	22974.42
0.657465	1	0.337516	1.012547	2.513174	13.00	3.55	20.7691	0.2963	23793.7
0.682236	1	0.595188	1.193914	2.756546	12.00	2.98	20.3520	0.2480	21942.73
0.682236	1	0.252654	1.38075	2.912243	13.00	3.26	21.5941	0.1937	22433.27
0.590325	1	0.218616	1.194734	2.385181	15.00	3.71	22.0382	0.3040	24620.24
0.682236	1	0.252654	1.318471	2.974522	12.00	2.89	20.3670	0.2963	22311.06
0.682236	1	0.408351	1.38075	2.756546	12.00	2.89	20.1531	0.2480	21960.08
0.964286	1	0.25	1.857143	3.071429	7.00	1.86	16.1454	0.1937	19659.61
0.526316	1	0.105263	1.368421	2.263158	18.00	4.00	24.2847	0.3333	25466.1
0.771429	1	0.742857	0.742857	2.457143	10.43	2.52	18.6847	0.2097	22616.05
0.714286	1	0.142857	1.714286	3.571429	13.00	3.35	21.7687	0.2790	20951.84
0.657465	1	0.337516	1.012547	2.513174	15.00	3.32	22.6713	0.2760	24295.67
0.560139	1	0.488669	0.801278	2.263219	19.00	3.17	24.2987	0.2643	25599.67
0.47	1	0.08	0.73	1.72	27.00	5.12	28.1363	0.4270	31423.14

Legend: F_c = Compressive strength, F_f = Flexural strength, *GPa*= Static modulus of elasticity,F_s = Shearstrength,₦ = Naira.

Table 2: Average values of Compressive Strength and Cost at the 23 Points of the Vertices

Run Order	Std Order	Water	Cement	Laterite	Quarry dust	Coarse Aggregate	Comp strength	Cost per m^3 (₦)
1	93	0.964286	1	0.142857	1.464286	3.571429	7.19	20474.76
2,22	105	0.964286	1	0.25	1.857143	3.071429	6.905	19772.04
3,23	10	0.526316	1	0.105263	1.368421	2.263158	18.635	23036.37
4	6	0.714286	1	0.928571	1.428571	3.071429	12	20469.93
5,25	1	0.714286	1	0.142857	1.714286	3.571429	11.5	21040.7
6,24	21	0.771429	1	0.742857	0.742857	2.457143	10.215	22833.77
7	11	0.714286	1	0.5	1.857143	3.071429	12	20430.86
8	94	0.4	1	0.08	0.8	1.72	25	31404.96
9	7	0.964286	1	0.928571	1.178571	3.071429	7	19357.51
10	42	0.964286	1	0.803571	0.928571	3.446429	6	19875
11	54	0.666667	1	0.098765	1.049383	2.123457	13	25906.48
12	60	0.635294	1	0.435294	0.611765	2.023529	13	26198.66
13	46	0.839286	1	0.928571	1.303571	3.071429	9	19656.41
14	41	0.839286	1	0.142857	1.589286	3.571429	9	20915.54
15	38	0.606061	1	0.272727	1.575758	2.606061	15	22974.42
16,26	114	0.657465	1	0.337516	1.012547	2.513174	14	24044.69
17	75	0.682236	1	0.595188	1.193914	2.756546	12	21942.73
18	78	0.682236	1	0.252654	1.38075	2.912243	13	22433.27
19	79	0.590325	1	0.218616	1.194734	2.385181	15	24620.24
20	70	0.682236	1	0.252654	1.318471	2.974522	12	22311.06
21	80	0.682236	1	0.408351	1.38075	2.756546	12	21960.08
27	88	0.560139	1	0.488669	0.801278	2.263219	19	25599.67
28	55	0.47	1	0.08	0.73	1.72	27	31423.14

3.1 Relationship between Compressive Strength and Cost

A linear and quadratic model were fitted to the data in Table 2 and the Analysis of variance (Anova) of the linear and quadratic regression analyses are shown in Tables 3 and 4. The fitted line plots of the linear and quadratic relationship between compressive strength and cost are shown in Figures 1 and 2.

Regression Analysis: Cost (Naira) versus Compressive strength

The regression equation is

Cost (Naira) = $15635 + 564.7f_c$ (11)

S = 1517.87 R-Sq = 80.3% R-Sq(adj) = 79.4%

Table 3: Analysis of Variance for Regression

Source	DF	SS	MS	F	P
Regression	1	197579719	197579719	85.76	0.000
Error	21	48382198	2303914		
Total	22	245961917			

Regression Output

Polynomial Regression Analysis: Cost (Naira) versus Compressive strength

The regression equation is given as:

Cost (Naira) = $17714 + 262.7f_c + 9.431f_c$ (12)

S = 1513.16 R-Sq = 81.4% R-Sq(adj) = 79.5%

Table 4: Analysis of Variance for polynomial Regression

Source	DF	SS	MS	F	P
Regression	2	200168855	100084428	43.71	0.000
Error	20	45793061	2289653		
Total	22	245961917			

Regression Output

Correlation of Compressive strength and Cost (Naira)

Pearson correlation of Compressive strength and Cost (Naira) = 0.896
P-Value = 0.000

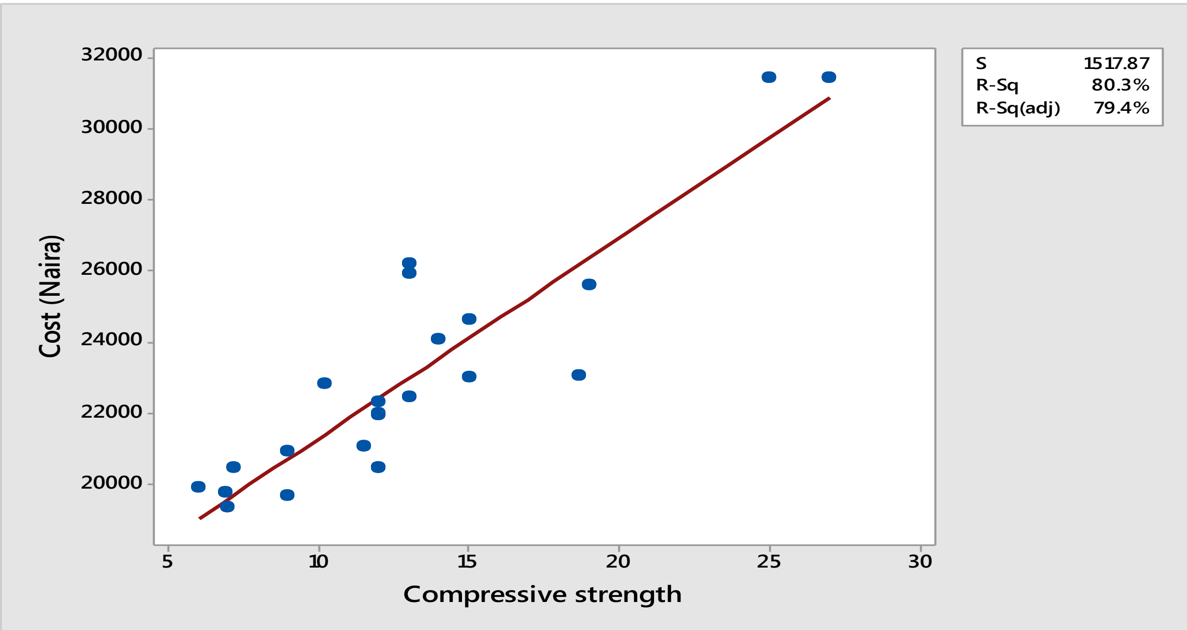

Figure 1: Linear relationship between compressive strength and cost

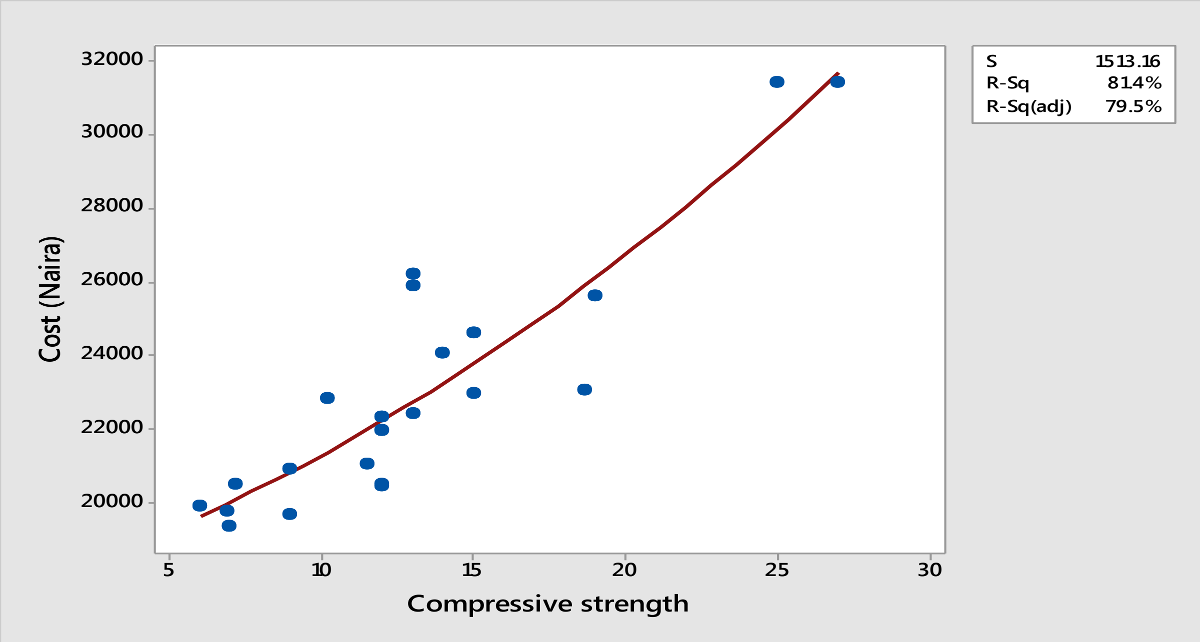

Figure 2: Quadratic relationship between compressive strength and cost

The points in Figures 1 and 2 falls reasonably to straight lines of positive slope between the compressive strength and cost and the correlation value of 0.896 is very close to +1. The *p*-significant value is also less than 0.05 level of significance (p = 0.000, p< 0.05), f = 85.76). Therefore, there is a strong positive relationship (both linear and quadratic) between the compressive strength and cost of laterite-quarry dust concrete. It can be seen that the quadratic model gives a better fit with R^2 value of 81.4% while that of linear fit is 80.3%. The linear and quadratic relationship between the compressive strength and cost can be expressed by Equations 13 and 14respectively as:

$$\text{Cost} = 15635 + 564.7f_c \qquad (13)$$
$$\text{Cost} = 17714 + 262.7f_c + 9.431f_c^{\,2} \qquad (14)$$

Where, f_c = Compressive strength.

3.2. Comparison of Experimental and Model Predicted Result

The mixes for model validation in Table 5 were used to compare the experimental and model predicted results. Simple percentage differences were used to compare their responses.

Table 5: Real Mix Ratios and Model Validation (Check Points).

Run Order	Water	Cement	Laterite	Quarry Dust	Coarse Aggregate
1	0.964286	1	0.142857	1.464286	3.571429
2,22	0.964286	1	0.25	1.857143	3.071429
3,23	0.526316	1	0.105263	1.368421	2.263158
5,25	0.714286	1	0.142857	1.714286	3.571429
7	0.714286	1	0.5	1.857143	3.071429
8	0.4	1	0.08	0.8	1.72
9	0.964286	1	0.928571	1.178571	3.071429
10	0.964286	1	0.803571	0.928571	3.446429
12	0.635294	1	0.435294	0.611765	2.023529
13	0.839286	1	0.928571	1.303571	3.071429
15	0.606061	1	0.272727	1.575758	2.606061
16,26	0.657465	1	0.337516	1.012547	2.513174
19	0.590325	1	0.218616	1.194734	2.385181
20	0.682236	1	0.252654	1.318471	2.974522
27	0.560139	1	0.488669	0.801278	2.263219

28	0.47	1	0.08	0.73	1.72
Mixes for Model Validation (Check Points)					
4	0.714286	1	0.928571	1.428571	3.071429
6,24	0.771429	1	0.742857	0.742857	2.457143
11	0.666667	1	0.098765	1.049383	2.123457
14	0.839286	1	0.142857	1.589286	3.571429
17	0.682236	1	0.595188	1.193914	2.756546
18	0.682236	1	0.252654	1.38075	2.912243
21	0.682236	1	0.408351	1.38075	2.756546

Comparison of the experimental and model predicted results of compressive strength, flexural strength and static modulus of elasticity, shear strength and cost of laterite-quarry dust concrete at the check points are presented in Tables 6 to 10.

Table 6: Comparison of Experimental and Model Predicted Compressive Strength

Run Order	Real mix ratio					Compressive strength (Nmm^{-2})		% diff. between EX and MP
	Water	Cement	Laterite	Quarry dust	Coarse agg.	Experimental (EX)	Model predicted (MP)	
4	0.714286	1	0.928571	1.428571	3.071429	12.00	11.499	4.18
6,24	0.771429	1	0.742857	0.742857	2.457143	10.22	10.454	-2.29
11	0.666667	1	0.098765	1.049383	2.123457	13.00	14.550	-11.92
14	0.839286	1	0.142857	1.589286	3.571429	9.00	8.970	0.33
17	0.682236	1	0.595188	1.193914	2.756546	12.00	12.738	-6.15
18	0.682236	1	0.252654	1.38075	2.912243	13.00	12.902	0.75
21	0.682236	1	0.408351	1.38075	2.756546	12.00	12.899	-7.49

Table 7: Comparison of Experimental and Model Predicted Flexural Strength

Run Order	Real mix ratio					Flexural strength(Nmm^{-2})		% diff. between EX and MP
	Water	Cement	Laterite	Quarry dust	Coarse agg.	Experimental (EX)	Model predicted (MP)	
4	0.714286	1	0.928571	1.428571	3.071429	2.550	2.699	-5.84
6,24	0.771429	1	0.742857	0.742857	2.457143	2.450	2.483	-1.35
11	0.666667	1	0.098765	1.049383	2.123457	3.730	3.722	0.21
14	0.839286	1	0.142857	1.589286	3.571429	2.320	2.490	-7.33
17	0.682236	1	0.595188	1.193914	2.756546	2.980	2.890	3.02
18	0.682236	1	0.252654	1.38075	2.912243	3.260	3.091	5.18
21	0.682236	1	0.408351	1.38075	2.756546	2.890	3.034	-4.98

Table 8: Comparison of Experimental and Model Predicted Statics Modulus of Elasticity

Run Order	Real mix ratio					Statics modulus of elasticity		% diff. between EX and MP
	Water	Cement	Laterite	Quarry dust	Coarse agg.	Experimental (EX)	Model predicted (MP)	
4	0.714286	1	0.928571	1.428571	3.071429	21.539	20.693	3.93
6,24	0.771429	1	0.742857	0.742857	2.457143	18.801	18.478	1.72
11	0.666667	1	0.098765	1.049383	2.123457	20.736	20.877	-0.68
14	0.839286	1	0.142857	1.589286	3.571429	19.585	19.118	2.38
17	0.682236	1	0.595188	1.193914	2.756546	20.352	21.034	-3.35
18	0.682236	1	0.252654	1.38075	2.912243	21.594	21.367	1.05
21	0.682236	1	0.408351	1.38075	2.756546	20.153	21.182	-5.11

Table 9: Comparison of Experimental and Model Predicted Shear Strength

Run Order	Real mix ratio					Shear strength(Nmm^{-2})		% diff. between EX and MP
	Water	Cement	Laterite	Quarry dust	Coarse agg.	Experimental (EX)	Model predicted (MP)	
4	0.714286	1	0.928571	1.428571	3.071429	0.212	0.222	-4.72
6,24	0.771429	1	0.742857	0.742857	2.457143	0.205	0.207	-0.98
11	0.666667	1	0.098765	1.049383	2.123457	0.311	0.314	-0.96
14	0.839286	1	0.142857	1.589286	3.571429	0.194	0.208	-7.22
17	0.682236	1	0.595188	1.193914	2.756546	0.248	0.239	3.63
18	0.682236	1	0.252654	1.38075	2.912243	0.194	0.257	-32.47
21	0.682236	1	0.408351	1.38075	2.756546	0.248	0.253	-2.02

Table 10: Comparison of Experimental and Model Predicted Cost of Mixes

Run Order	Real mix ratio					Cost of mix (Naira/m^3)		% diff. between EX and MP
	Water	Cement	Laterite	Quarry dust	Coarse agg.	Experimental (EX)	Model predicted (MP)	
4	0.714286	1	0.928571	1.428571	3.071429	20469.930	19868.025	2.94
6,24	0.771429	1	0.742857	0.742857	2.457143	22833.765	22976.163	-0.62
11	0.666667	1	0.098765	1.049383	2.123457	25906.480	25639.819	1.03
14	0.839286	1	0.142857	1.589286	3.571429	20915.540	20720.518	0.93
17	0.682236	1	0.595188	1.193914	2.756546	21942.730	21986.197	-0.2
18	0.682236	1	0.252654	1.38075	2.912243	22433.270	22346.266	0.39
21	0.682236	1	0.408351	1.38075	2.756546	21960.080	21969.219	-0.04

IV. CONCLUSIONS

The average observed responses of the compressive strength and cost were used to determine the relationship between the compressive strength and cost. The replicated mixes were taken into consideration which resulted to using 23 points at the vertices. The regression and correlation analysis were formulated in section 3.1. They were tested for their significance using the p-value and F test statistics and found adequate. The correlation value was found to be 0.896 which is very close to +1. It means there is a strong positive relationship(linear and quadratic) between the compressive strength and cost of laterite-quarry dust concrete.The experimental and model predicted results for the responses were presented in section 3.2 using the check points. The percentage differences between the experimental and models predicted results were expressed as percentage of the experimental value for the models. The percentage differences were all less than 5.2%, which is quite insignificant. This has shown that the models are adequate for predicting their various responses.In this regard, the use of models for predictions should be encouraged in the construction industry.

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