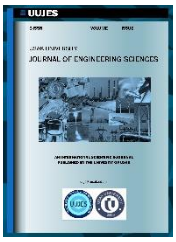

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Research article

OPTIMUM MIX PROPORTIONING AND MODELING OF COMPRESSIVE STRENGTH OF CONCRETE CONTAINING QUARRY DUST USING RESPONSE SURFACE METHODOLOGY

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Abstract

Over dependence on the sole use of river sand as fine aggregate in producing concrete over the years, has raised serious environmental concerns. Incessant mining of river sand accelerates the deterioration of the river bed, causes floods, and affects the diversity of aquatic life negatively. In this study, the possibility of using quarry dust to partially replace river sand in producing concrete was investigated. Central Composite Design (CCD) in Minitab was used to generate 31 mixes with different combinations of water to cement (W/C), Quarry dust to Sand (Q/S), Sand to Total Aggregate (S/TA) and Total Aggregate to Cement (TA/C) ratios. The fresh concrete was tested for workability using slump test. Three (3) concrete cubes were cast per sample point and tested for compressive strength at 28 days of curing. A regression model was developed and analyzed using response surface methodology (RSM) at 95% confidence level. Results obtained showed that compressive strength up to 27.44Mpa can be achieved with combination of W/C of 0.36, Q/S of 0.3, S/TA of 0.4 and TA/C of 3. Model developed has overall P value of 0, R2 value of 75.69% and Adjusted R2 value of 66.85% and validated to be well fitted. It was concluded among others, that quarry dust can be used as a constituent material in structural concrete, optimum percentage replacement of sand with quarry dust is 30% and that the developed model is valid, adequate and well fitted.

Keywords: *Optimum mix proportioning; Modeling; Compressive strength; quarry dust; concrete; response surface methodology.*

1. Introduction

Concrete is a construction material predominantly consisting of three principal constituents; water, cement and aggregates. Aggregates are considered the dominant constituent as they make up 70-80% of the total concrete volume [1,2,3].

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Since aggregates make up a significant volume of the concrete, their properties, to a great extent determines the property of the concrete made from their use. This is corroborated by Shetty [4] that pastes and aggregates are some of the important factors that affect the strength of concrete. Additionally, physical, thermal, mechanical and chemical properties of aggregates influence the most important characteristic properties of concrete [5]. The importance of studying the properties of aggregates, as they affect desirable concrete properties cannot be over emphasized.

On the basis of size, aggregates are classified into two; coarse and fine aggregates. Fine aggregates are defined as aggregates that are less than 4.75mm in size and should therefore pass through the No. 4 standard sieve or lesser sieve sizes. River sand is the most commonly used fine aggregate in the construction industry [6]. Unfortunately, over dependence on this source of fine aggregate for concrete production over the years, has raised serious environmental issues. Continuous river sand mining leads to deterioration of the river bed, floods arising from changes in flow direction of the river, and negative effect on diversity of aquatic life [7]. As a result, there is need to find alternative materials to the over utilized river sand.

Several researchers have studied different materials as either partial or full replacements of river sand. Some of these materials include; industrial by-products, crushed brick grit, manufactured sand, Quarry dust, demolition waste etc. [7,8,9].

Quarry dust is a by-product obtained from the final stages of crushing rocks in quarry sites. This material has particles with sizes ranging between 0-4.75mm [10]. This material has been used in highway construction, hollow sandcrete block production and several other applications in the construction industry. Interestingly, it is a cheap construction material. By combining the characteristics of affordability and particle size, this material can be used in combination with river sand in production of concrete.

This study seeks to optimize the quantity of quarry dust and develop a model for compressive strength of concrete containing quarry dust. Effects of different combinations of values of Water to Cement (W/C), Quarry dust to River Sand (Q/S), River Sand to Total Aggregate (S/TA) and Total Aggregate to Cement (TA/C) ratios on the compressive strength of concrete were studied. The mix combinations as well as model development were done using Central Composite Design of Response Surface Methodology (RSM) embedded in the MINITAB 21 software.

2. Literature Review

Balamurugan and Perumal [11] studied the variation in strength of concrete when sand is replaced with quarry dust from 10 to 100% (at 10% interval) with a constant slump of 60mm. The authors obtained maximum compressive strength when sand is replaced by 50% of quarry dust. The authors concluded that quarry dust can be used in concrete up to a maximum of 50% when partially replaced with sand.

Sethis et al [12] investigated the effects on compressive strength and split tensile strengths of M20 concrete when sand is partially replaced with saw dust at 0, 10, 20 and 30%. The study concluded that compressive strength and split tensile strength of concrete increases by use of quarry dust up to 10% and 0% replacement, respectively. Also, workability of the concrete increases as percentage of quarry dust increases.

Lwin and Zaw [13] investigated the effect of partially replacing sand with quarry dust on the compressive strength of concrete. Sand was replaced with quarry dust at 0, 25, 50, 75 and 100% for M-25 concrete mix. The authors concluded among others, that increasing quarry dust content increases compressive strength but decreases workability of concrete.

3. Materials and Method

3.1 Materials

The materials used for this research are as follows:

3.1.1 Portland Limestone Cement (PLC)

Portland Limestone Cement of grade 42.5N was used for this study. The cement was obtained from a retail outlet in Makurdi, Benue state, Nigeria.

3.1.2 Fine Aggregates (River Sand)

The fine aggregate used for this study was river sand obtained from river bed of the river Benue. The sand is clean, sharp and free from organic matter.

3.1.3 Fine Aggregate (Quarry Dust)

The quarry dust used for this study was obtained from a crushing plant in Ushongo Local Government Area of Benue State, Nigeria.

3.1.4 Coarse Aggregates (Granite)

Granite, obtained from local suppliers in Makurdi was used as coarse aggregate for this study.

3.1.5 Water

Potable water sourced from the Civil Engineering Department, Joseph Sarwuan Tarka University was used for mixing and curing concrete.

The properties of the materials used for this study are summarized in Table 1.

Table 1 Properties of constituent materials

Material	Properties
Portland limestone Cement (PLC)	Brand: Dangote 3x Classification: CEM II B-L 42.5N Specific gravity: 3.14
River sand	Specific gravity:2.7 Water absorption: 2.6% Loose bulk density: 1539.5kg/m^3 Fineness Modulus: 2.85
Quarry dust	Specific gravity:2.6 Water absorption: 2.85% Loose bulk density: 1664.5kg/m^3 Fineness Modulus: 2.89
Granite	Specific gravity:2.9 Water absorption:0.79% Loose bulk density: 1433kg/m^3 Aggregate Crushing Value (ACV): 13.73% Aggregate Impact Value (AIV): 17.65%

3.2 Methods

3.2.1 Factor Setting

Factor setting for the design was carried out using Central Composite Design (CCD). This is the most common fractional factorial design in RSM. Generally, it measures the effect of changing one or design factors (variables) on the performance characteristic (response). With this, opportunity is provided to understand how different design factors affect the response, arising in a reasonably excellent prediction of interactions [14].

Values were assigned to proportions of the concrete constituents and are considered to be the independent variables in the experimental design. The independent variables and the range of values attached to them are:

$$W/C\ (x_1) = 0.4, 0.5, 0.6 \tag{1}$$

$$Q/S\ (x_2) = 0.2, 0.3, 0.4 \tag{2}$$

$$S/TA\ (x_3) = 0.35, 0.4, 0.45 \tag{3}$$

$$TA/C\ (x_4) = 3, 4.5, 6 \tag{4}$$

Where: W/C= Water to Cement ratio, Q/S= Quarry dust to Sand Ratio, S/TA=Fine Aggregate to Total Aggregate ratio, TA/C= Total Aggregate to Cement Ratio and TA= Total Aggregate = FA+CA

There are three factor levels in CCD; the lower level, centre point and the upper level, which are assigned coded values of -1, 0 and 1 respectively. In addition, there are two axial points. This translates to a total of five points for each variable. These axial points denoted by –α and α and calculated using equation (5).

$$\alpha = 2^{\frac{k}{4}} \tag{5}$$

Where K= number of design factors.

In this study, four variables are considered, therefore, $\alpha = 2^{\frac{4}{4}} = 2$. However, after trial mixes in the laboratory, thus value was reduced to 1.4142 on the minitab software, since a value of α=2 resulted in more extreme values of mix proportions.
The five coded factor levels for this study are: -1, 0, 1, -1.412 and 1.4142.
The RSM in Minitab was used to generates thirty-one (31) coded values for each of the design variables. To convert coded values to uncoded values, equation (6) was used.

$$x_{uncoded} = \frac{x_{min} + x_{max}}{2} \pm \alpha \left(\frac{x_{min} - x_{max}}{2}\right) \tag{6}$$

Where: α= coded value, x_{min}= minimum value of the design variable, x_{max}=maximum value of the design variable.

3.2.2 Design of Concrete Mix Composition

The method of absolute volume was used in calculating mix composition.
The absolute volume equation is given as:

$$\frac{W_W}{1000} + \frac{W_c}{1000SG_C} + \frac{W_Q}{1000SG_Q} + \frac{W_S}{1000SG_S} + \frac{W_{CA}}{1000SG_{CA}} + AV = 1 \tag{7}$$

Where:
WW=Weight of water, WC=Weight of cement, WQ=Weight of quarry dust Ws=Weight of sand, WCA=Weight of coarse aggregate, SGC=Specific gravity of cement, SGQ=Specific gravity of quarry dust SGS=specific gravity of sand, SGCA=Specific gravity of coarse aggregate and AV=air void=2%=0.02

To incorporate the variables of the design, the weights of sand, quarry dust and coarse aggregates were expressed in terms of the S/TA and TA/C ratios and weight of water was expressed in terms of W/C ratio.

$$W_w = W_c \times \left(\frac{W_W}{W_c}\right) \tag{8}$$

$$W_Q = \left(\frac{W_Q}{W_S}\right)\left(\frac{W_S}{W_{TA}}\right)\left(\frac{W_{TA}}{W_C}\right)W_c \tag{9}$$

$$W_S = \left(\frac{W_S}{W_{TA}}\right)\left(\frac{W_{TA}}{W_C}\right)W_c \tag{10}$$

$$W_{CA} = W_{TA} - W_S - W_Q = \left(\frac{W_{TA}}{W_C}\right)W_c\left(1 - \frac{W_S}{W_{TA}} - \left(\frac{W_S}{W_{TA}}\right)\left(\frac{W_Q}{W_S}\right)\right) \tag{11}$$

The weight of cement, Wc for a unit volume of concrete can be derived from equation (7) and substituting equation (8), (9) (10) and (11) into (7)

$$W_C = \frac{1 - AV}{\frac{\left(\frac{W_W}{W_c}\right)}{1000} + \frac{1}{1000SG_C} + \frac{\left(\frac{W_Q}{W_S}\right)\left(\frac{W_S}{W_{TA}}\right)\left(\frac{W_{TA}}{W_C}\right)}{1000SG_Q} + \frac{\left(\frac{W_S}{W_{TA}}\right)\left(\frac{W_{TA}}{W_C}\right)}{1000SG_S} + \frac{\left(\frac{W_{TA}}{W_C}\right)\left(1 - \frac{W_S}{W_{TA}} - \left(\frac{W_S}{W_{TA}}\right)\left(\frac{W_Q}{W_S}\right)\right)}{1000SG_{CA}}} \tag{12}$$

Equation (12) was used in calculating the proportions of concrete constituents required per cubic meter of concrete mix for the 31 selected points. Combinations for the 31 selected coded points and their uncoded values as well as the constituent proportions are as presented in Table 2.

Table 2 Proportions of concrete constituents required per cubic meter of concrete mix

Mix	Uncoded Values				Proportions of Constituents				
	W/C	Q/S	S/TA	TA/C	Water (kg/m³)	Cement (kg/m³)	Quary Dust (kg/m³)	Sand (kg/m³)	Granite (kg/m³)
1	0.36	0.3	0.4	3	200.76	559.88	201.56	671.86	806.23
2	0.5	0.16	0.4	6	165.68	331.37	126.12	795.28	1066.80
3	0.5	0.3	0.33	6	165.99	331.97	196.77	655.90	1139.18
4	0.4	0.2	0.35	4.5	169.15	422.88	133.21	666.03	1103.71
5	0.6	0.4	0.35	6	192.06	320.10	268.89	672.21	979.51
6	0.4	0.2	0.45	3	218.59	546.47	147.55	737.74	754.13
7	0.64	0.3	0.4	4.5	244.55	381.27	205.88	686.28	823.54
8	0.6	0.4	0.45	3	293.97	489.95	264.57	661.43	543.84
9	0.5	0.3	0.4	6	165.20	330.40	237.89	792.96	951.55

10	0.5	0.3	0.47	6	164.42	328.84	278.62	928.72	765.68
11	0.5	0.3	0.4	6.62	153.67	307.34	244.20	814.01	976.81
12	0.4	0.4	0.35	4.5	168.57	421.41	265.49	663.73	967.14
13	0.6	0.2	0.45	4.5	232.30	387.16	156.80	784.00	801.42
14	0.5	0.3	0.4	6	165.20	330.40	237.89	792.96	951.55
15	0.6	0.4	0.35	3	295.55	492.59	206.89	517.22	753.66
16	0.6	0.2	0.35	3	296.35	493.92	103.72	518.62	859.42
17	0.5	0.3	0.4	4.5	201.73	403.47	217.87	726.24	871.49
18	0.5	0.3	0.4	3	259.01	518.03	186.49	621.63	745.96
19	0.4	0.2	0.35	4.5	169.15	422.88	133.21	666.03	1103.71
20	0.5	0.3	0.4	6	165.20	330.40	237.89	792.96	951.55
21	0.4	0.2	0.45	3	218.59	546.47	147.55	737.74	754.13
22	0.5	0.44	0.4	4.5	201.19	402.39	319.72	724.30	766.73
23	0.6	0.4	0.45	4.5	231.35	385.58	312.32	780.81	642.00
24	0.6	0.2	0.35	6	192.74	321.23	134.92	674.58	1117.87
25	0.5	0.3	0.4	4.5	201.73	403.47	217.87	726.24	871.49
26	0.6	0.2	0.45	4.5	232.30	387.16	156.80	784.00	801.42
27	0.4	0.4	0.35	3	219.06	547.64	230.01	575.02	837.89
28	0.5	0.3	0.4	2.38	293.54	587.07	167.58	558.59	670.31
29	0.5	0.3	0.4	4.5	201.73	403.47	217.87	726.24	871.49
30	0.4	0.4	0.45	4.5	167.41	418.52	339.00	847.50	696.83
31	0.4	0.4	0.45	4.5	167.41	418.52	339.00	847.50	696.83

3.2.3 Workability Test

To check the workability of the different concrete mixes, slump test was carried out on the fresh concrete in accordance with specifications of BS EN 12350-2 [15].

3.2.4 Curing

In accordance with specifications of BS EN 12390-2 [16], the concrete cube samples were cured for 28 days. This was done by total immersion of samples in curing tank.

3.2.5 Compressive Strength Test

Three (3) cube samples (150mm) were prepared for each mix and tested for compressive strength at 28 days of curing in accordance to BS EN 12390-3 [17].

4. Results and discussion

4.1 Slump

The result for slump test for the 31 sample points is presented in Table 3. The workability of the mixes showed variations in slumps from very low slump to very high slump, and in some cases, there was no slump at all (0 slump).

Concrete mixes 3, 4, 5, 6, 9, 10, 11, 14, 19, 20, 22, 30 and 31 yielded zero slump. These situations arise due to low water/cement (W/C) combined with relatively high quarry dust to sand (Q/S) ratio (between 20 to 40%). Quarry dust concrete requires more water than conventional river sand concrete during mix to achieve high workability or consistency. This is corroborated by Sethis et al [12], that the workability of concrete containing quarry dust decreases with increase in quarry dust content.

Concrete mix 1, 2, 12, 17, 21, 23, 24, 25, 27 and 29 resulted in slump values between 0 to 40mm. This is classified as slump class S1 [18] or as very low or low slump [4]. The low slump values are as a result of low water to cement (W/C) ratio combined with relatively high sand to total aggregate (S/TA) ratio. Uddin et al [19] asserts that workability and compressive strength of concrete reduces with excess proportion of sand volume.

Mix 7, 13 and 26 gave slump values of 90, 55 and 55mm respectively. These can be classified as slump class S2 [18] and can be regarded as medium slump [4].

Concrete mix 18 and 28 have slump values of 100 and 155mm respectively. While mixes 8,15 and 16 have slump values of 175, 175 and 210mm respectively. These two categories are classified as slump class S3 and S4, respectively. They are also classified as concrete mixes with high slump. The high slump is as a result of very low total aggregate to cement (TA/C) ratio (≤3) combined with a relatively higher water to cement (W/C) ratio (≥0.5). This is corroborated by Salain [20] that generally, given a constant TA/C ratio, slump increases with increase in W/C ratio.

Table 3 Slump

Mix No.	Slump(mm)	Class [18]	Class [4]
1	20	S1	Very low
2	10	S1	Very low
3	0	-	-
4	0	-	-
5	0	-	-
6	0	-	-
7	90	S2	Medium
8	175	S4	Very high
9	0	-	-
10	0	-	-
11	0	-	-
12	40	S1	Low
13	55	S2	Medium
14	0	-	-
15	175	S4	Very high
16	210	S4	Very high
17	35	S1	Low
18	100	S3	High
19	0	-	-
20	0	-	-
21	25	S1	Low
22	0	-	-
23	10	S1	Very low
24	10	S1	Very low
25	30	S1	Low
26	55	S2	Medium
27	10	S1	
28	155	S3	Very high
29	35	S1	Low
30	0	-	-
31	0	-	-

4.2 Compressive Strength

The result for the compressive strength of all concrete mixes is presented in Table 1.
The lowest compressive strength (8.92Mpa) was obtained for concrete mix 10 with a composition of W/C=0.5, Q/S=0.3, S/TA=0.47 and= TA/C=6. This is due to the high total

aggregate to cement (TA/C) ratio. While the highest compressive strength (27.44Mpa) was obtained for concrete mix 1 with mix composition of W/C=0.36, Q/S=0.3, S/TA=0.4 and= TA/C=3. The high compressive strength is as a result of a lower total aggregate to cement (TA/C) ratio and a relatively lower water to cement (W/C) ratio. This results in a thicker mix paste owing to more cement content. This finding is same as that of Saloma et al [21] that the total aggregate to cement ratio is inversely proportional to the compressive strength of concrete.

Table 4 Compressive Strength at 28 Days

Mix No.	W/C(x_1)	Q/S(x_2)	S/TA(x_3)	TA/C(x_4)	Compressive Strength (Mpa)
1	0.36	0.3	0.4	3	27.44
2	0.5	0.16	0.4	6	16.29
3	0.5	0.3	0.33	6	11.25
4	0.4	0.2	0.35	4.5	24.25
5	0.6	0.4	0.35	6	11.53
6	0.4	0.2	0.45	3	22.47
7	0.64	0.3	0.4	4.5	14.61
8	0.6	0.4	0.45	3	12.07
9	0.5	0.3	0.4	6	15.47
10	0.5	0.3	0.47	6	8.92
11	0.5	0.3	0.4	6.62	19.52
12	0.4	0.4	0.35	4.5	14.51
13	0.6	0.2	0.45	4.5	20.41
14	0.5	0.3	0.4	6	15.54
15	0.6	0.4	0.35	3	18.89
16	0.6	0.2	0.35	3	19.85
17	0.5	0.3	0.4	4.5	16.86
18	0.5	0.3	0.4	3	12.83
19	0.4	0.2	0.35	4.5	23.96
20	0.5	0.3	0.4	6	15.27
21	0.4	0.2	0.45	3	21.92
22	0.5	0.44	0.4	4.5	10.86
23	0.6	0.4	0.45	4.5	15.91
24	0.6	0.2	0.35	6	16.85
25	0.5	0.3	0.4	4.5	16.27
26	0.6	0.2	0.45	4.5	20.18
27	0.4	0.4	0.35	3	22.06
28	0.5	0.3	0.4	2.38	18.44
29	0.5	0.3	0.4	4.5	16.58
30	0.4	0.4	0.45	4.5	10.95
31	0.4	0.4	0.45	4.5	11.69

4.3 Relationship between the Variables and Compressive Strength

Fig. 1 shows the relationship between S/TA and 28-day compressive strength. With constant W/C (0.5), Q/S (0.3) and TA/C (6) in mixes 3, 9 and 10 with S/TA=0.33, 0.4 and 0.47, compressive strengths increased with increasing S/TA but decreased when S/TA=0.47. This implies that compressive strength increases with increasing S/TA up to 40%. Pramod et al [22] also reported that compressive strength increases with increase in sand content.

The relationship between TA/C and 28-day compressive strength is as shown in Fig. 2. Considering mixes 17, 18 and 11 with constant W/C (0.5), Q/S (0.3) and S/TA (0.4), the compressive strength continued to increase slightly as the TA/C ratio increased from 3 to 6. This finding is same as that of Salain [20], that there is slight increase in compressive strength when the ratio of total aggregate to cement is increased.

Fig. 3 shows the relationship between Q/S and 28-day compressive strength for three different water to cement ratios. It is observed that for all values of water/cement ratio (W/C), the compressive strength of the concrete decreased with increase quarry dust content.

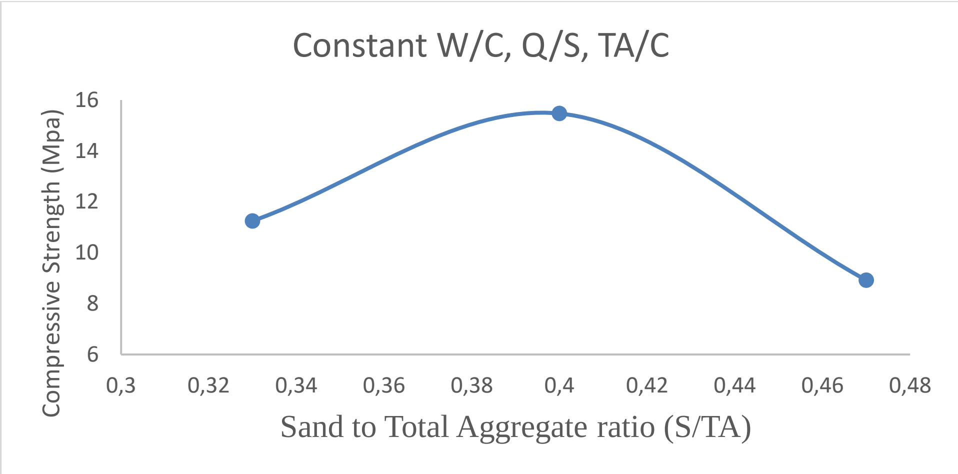

Fig. 1 Relationship between S/TA and 28 day compressive strength

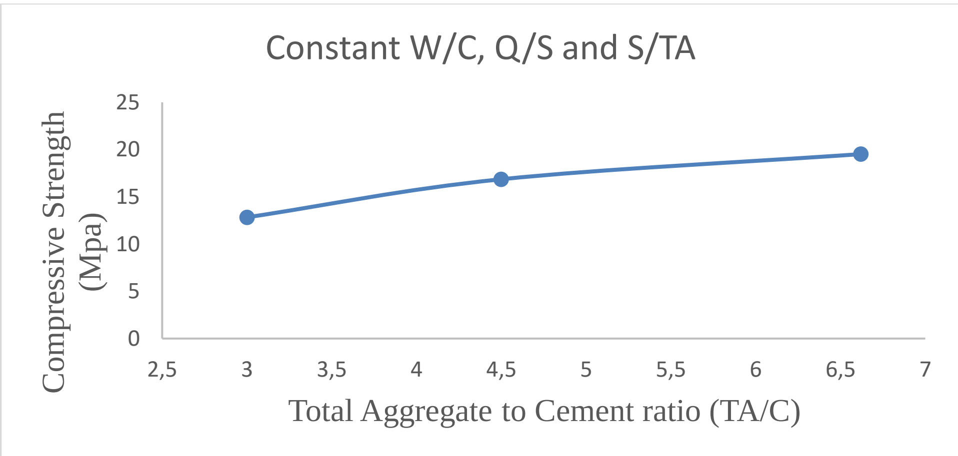

Fig. 2 Relationship between TA/C and 28 day compressive strength

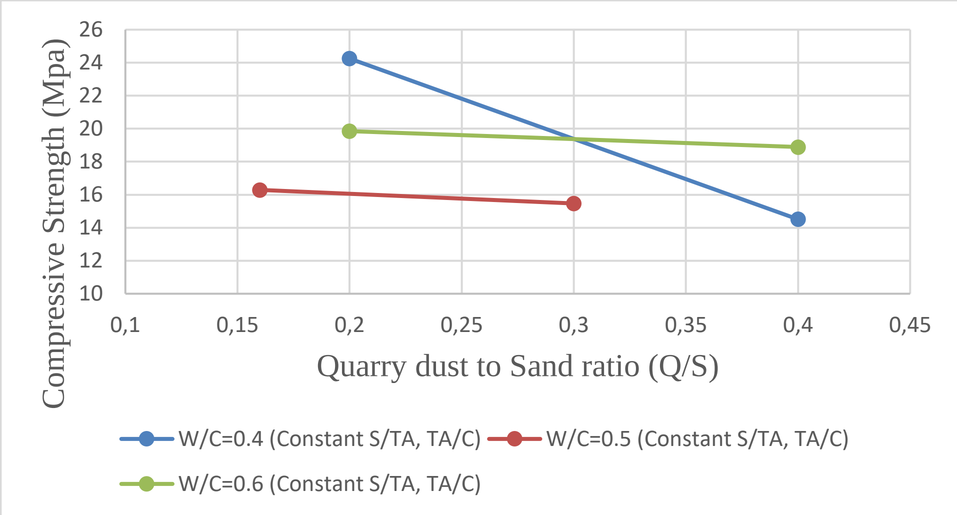

Fig. 3 Relationship between Q/S and 28 day compressive strength

4.4 Modeling Statistical Analysis and Validation

4.4.1 Regression Model

Results obtained from laboratory experiments were modeled and analyzed using Response Surface Methodology (RSM) with the aid of the MINITAB 21 software at 95% confidence level. To be able to arrive at a model function of higher accuracy, stepwise elimination of insignificant polynomial terms with lower effect on the model was carried out using the software. This was done using a default α_in=0.15 and α_out=0.15. Equation 13 was hence, developed as the model for predicting 28 days compressive strength of concrete containing Ushongo quarry dust.

Compressive strength,

$$C_{28} = 88.9 - 459x_1 - 30.04x_2 + 371x_3 - 6.43x_4 + 320.2x_1^2 - 681x_3^2 + 0.614x_4^2 + 309x_1x_3 \quad (13)$$

To show the effect of the variables on the response (compressive strength), contour and surface plots are presented in Fig. 4 and 5 respectively. The plots were generated to show the interaction of two variables on the compressive strength while holding mid-values of the remaining two variables.

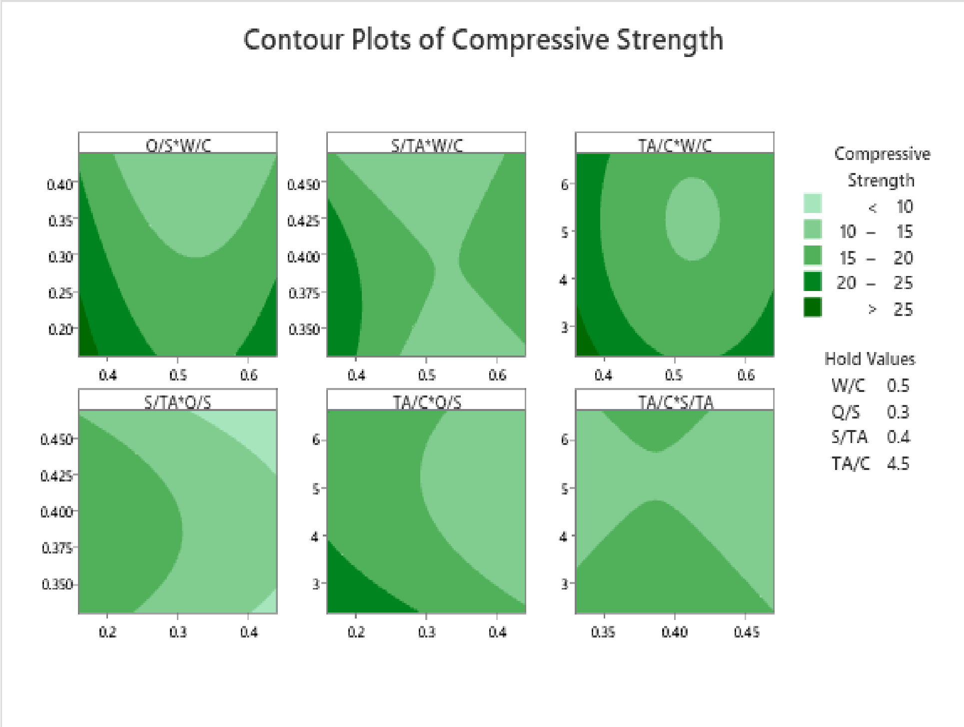

Fig. 4 Contour plots of compressive stsrength

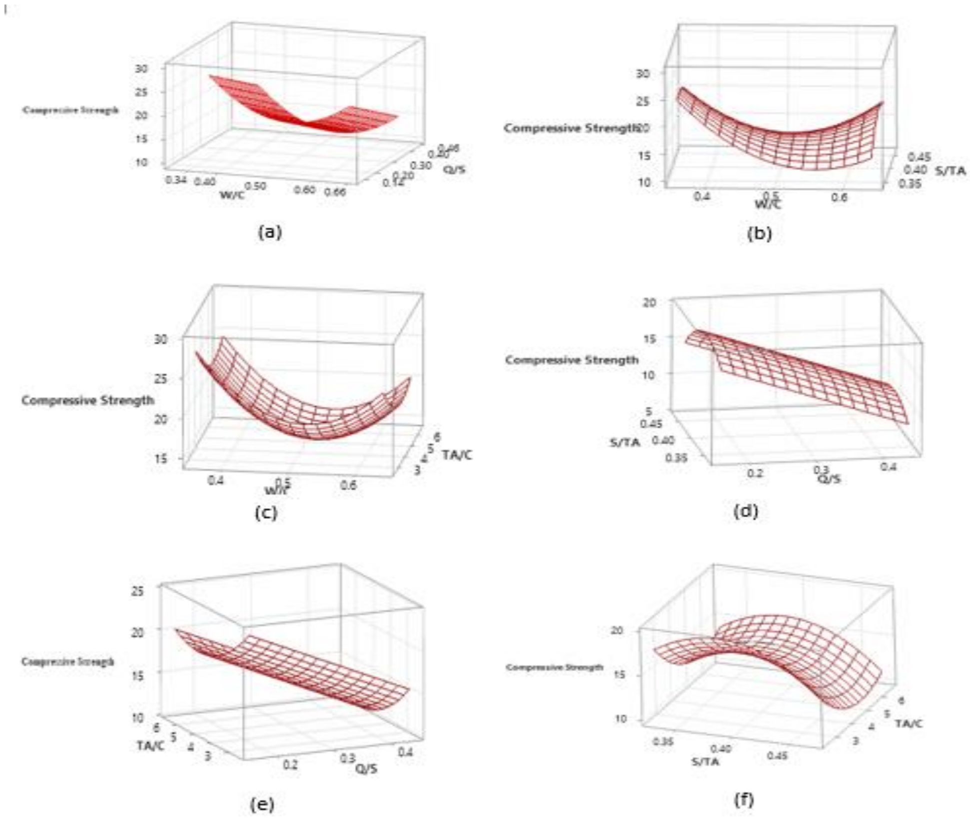

Fig. 5 Surface plots of compressive strength versus variables

4.4.2 Analysis and Validation

Analysis of Variance

The result for analysis of variance is presented in Table 5.

The overall P-value for the model was obtained to be 0. This indicates that the model so developed is highly significant. A regression equation with a value of zero or very close to zero indicates a good overall significance and usability of the model for prediction [23]. It is observed that some of the linear terms, quadratic and interactive terms are statistically significant in the model ($p \leq 0.05$) while others are statistically insignificant ($p > 0.05$). The pareto chart of the standardized effects of these polynomial terms on the model equation is presented in Fig. 6.

The coefficient of determination (R^2) for the model is 75.69%, and is reasonably high. This implies that 75.69% of the total variation of the compressive strength can be explained by the variables in the design. However, in statistics, the use of R^2 is not a good measure of fitness for a regression model since it always increases with addition of a variable [24]. As a result, its best to make use of the adjusted coefficient of determination (R^2 Adj), which is basically an adjusted R^2 value for the particular sample size and number of variables [23]. The Adjusted R^2 for this model is 66.85%. This is reasonably high and an acceptable adjustment. It is hence, satisfactory.

Table 5 Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	8	473.430	59.179	8.56	0.000
Linear	4	266.323	66.581	9.63	0.000
W/C	1	44.272	44.272	6.40	0.019
Q/S	1	176.083	176.083	25.47	0.000
S/TA	1	18.300	18.300	2.65	0.118
TA/C	1	27.443	27.443	3.97	0.059
Square	3	85.792	28.597	4.14	0.018
W/C*W/C	1	75.060	75.060	10.86	0.003
S/TA*S/TA	1	28.286	28.286	4.09	0.055
TA/C*TA/C	1	16.725	16.725	2.42	0.134
2-Way Interaction	1	34.304	34.304	4.96	0.036
W/C*S/TA	1	34.304	34.304	4.96	0.036
Error	22	152.078	6.913		
Pure Error	8	0.707	0.088		
Total	30	625.509			
R-sq			75.69%		
R-sq(adj)			66.85%		
R-sq(pred)			46.60%		

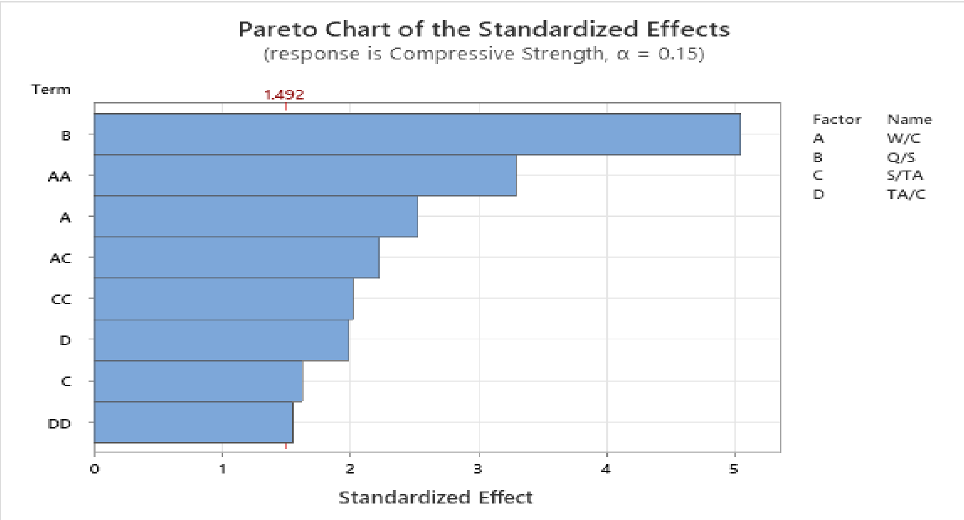

Fig. 6 Pareto chart of standardized effects of the polynomial term

Residual Plots

The normal plots of the residual values of the compressive strength is as shown in Fig. 7. The plot of the residuals against the normal percent of probability agrees with the straight line, hence, validating the suitability of the model. This situation implies that the model can be used in navigating the design space [25].

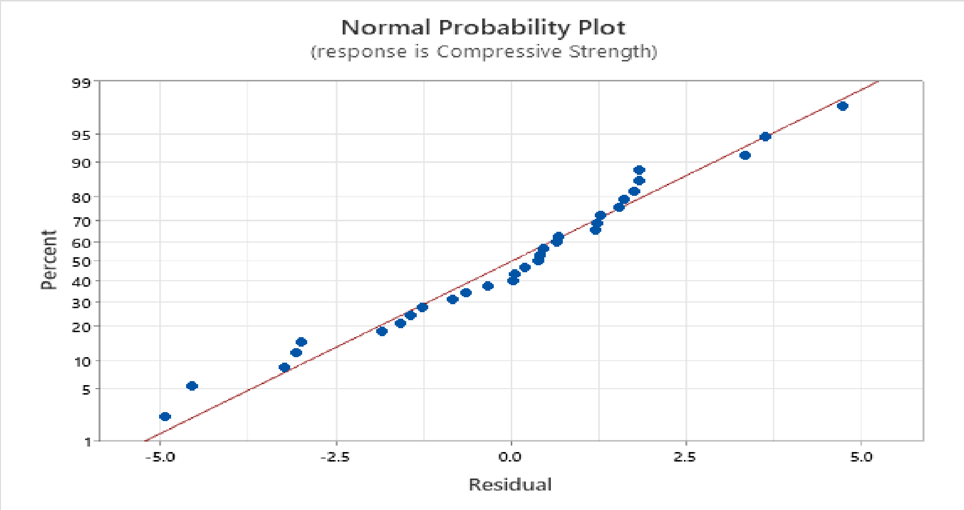

Fig. 7 Normal Probability Plot

The plot of the residuals versus fitted values is presented in Fig. 8. The plot shows no regular pattern and hence, implies that the model is adequate and well fitted. Good residual plots should not have an obvious pattern and shouldn't become thinner or wider when observed from left to right [23].

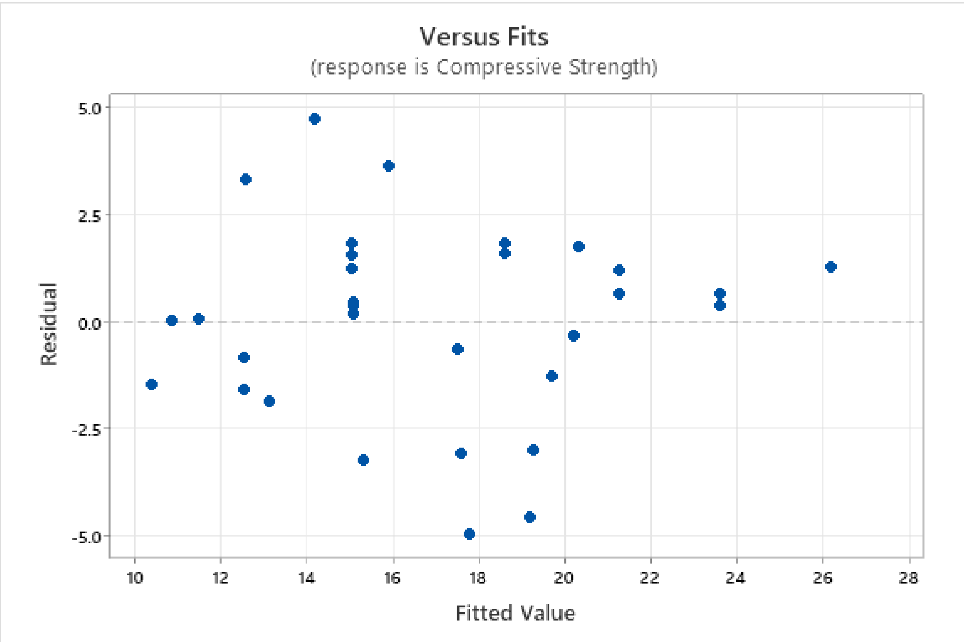

Fig. 8 Residual Versus Fits Plot

5. Conclusion

The following conclusions can be drawn from this study:

1. Results from the physical properties of Ushongo quarry dust shows it can be used as a fine aggregate material in structural concrete production.
2. The highest compressive strength (27.44Mpa) was obtained with a combination of Water to Cement ratio (W/C) of 0.36, Quarry dust to Sand ratio (Q/S) of 0.3, Sand to Total Aggregate ratio (S/TA) of 0.4 and Total Aggregate to Cement ratio (TA/C) of 3.
3. The optimal percentage replacement of sand with quarry dust is 30%.
4. The regression model developed for predicting the 28-day compressive strength of concrete containing Ushongo quarry dust is valid, adequate and well fitted.

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