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Lateritic Soil for Sustainable Concrete Production: Optimization of Mix Proportioning Using CCD

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***ABSTRACT :** Continuous mining of river sand in large volume for use as fine aggregate in concrete has led to erosion, flooding and other environmental problems. This has necessitated investigation into use of other materials to replace river sand. This study investigated the use of lateritic soil to partially replace sand in concrete production. Twenty-nine (29) combinations of variables including water to cement ratio (W/C), coarse aggregate to total aggregate ratio (CA/TA), total aggregate to cement ratio (TA/C), and lateritic soil to fine aggregate ratio (LS/FA) were generated using Central Composite Design (CCD). Three cube samples (150mm) were cast for each of the 29 mix points and the control mix. Workability of the fresh concrete was tested using slump test while compressive strength test was done on the hardened concrete samples after 28 days of curing. Response Surface Methodology (RSM) was employed in developing a regression model that predicts the compressive strength of concrete containing lateritic soil. Results from this investigation reveals that concrete slump decreases with increasing lateritic soil content. Compressive strength as high as 30.40 N/mm^2 can be obtained with a mix combination of W/C of 0.5, CA/TA of 0.6, TA/C of 4.5 and LS/FA of 0.15. The model developed has R^2 of 86.58%, adjusted R^2 of 73.15% and overall p-value of 0.001. It was concluded that: concrete workability and compressive strength decrease with increasing lateritic soil content when other constituent proportions are kept constant, other constituent proportions influence the compressive strength of concrete irrespective of lateritic soil content, the optimal replacement level of fine aggregate with lateritic soil is 15%, and that the developed model is adequate, valid and has high predictive capabilities.*

***KEYWORDS:** Concrete; Compressive strength, Lateritic soil, Constituent mix proportion, Central composite design, Modelling, Response surface methodology*

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I. INTRODUCTION

Concrete has become the predominant material in the construction world owing to its durability, versatile nature and low cost (Kromoser et al., 2025; Yan et al., 2025). The global demand for concrete implies higher demand for its constituent materials. Concrete is majorly made from water, cement, fine and coarse aggregates. The fine and coarse aggregates constitute about 70-80% of the total volume of concrete (Sidney, 2008; Pawar et al., 2016; Abdirahman, 2017). It implies therefore, that a significant volume of aggregates is required in making concrete, with the properties of these aggregates affecting the properties of the resulting concrete (Shetty, 2005; Neville and Brooks, 2010).

The most commonly used fine aggregate in the production of concrete is the river sand (Kalhara et al., 2018; Koswaththa et al., 2025). Sand is usually mined from river beds and used in concrete production. However, the continuous mining of sand in large volumes constitute serious environmental problems including floods, erosion, river bed deterioration, and reduction in diversity of aquatic life (Santhos et al., 2021; Koswaththa et al., 2025). As a result, it is imperative to find alternatives to river sand as fine aggregate in concrete production.

Laterite is a form of soil rich in aluminium and iron generally formed in hot, tropical and subtropical regions with reddish colour owing to high iron oxide content (Shoaib et al., 2022; Sooraj et al., 2025). This soil material exists in abundance in several parts of Africa and Nigeria in particular. Lateritic soil has been used by researchers in recent time as alternative fine aggregate to partially replace sand in concrete production (Zerdi et al., 2016; Shoaib et al., 2022; Oladape et al., 2022; Adeniseun et al., 2025). Most of these studies have shown that partially replacing sand with lateritic soil yielded concrete with acceptable strength and durability characteristics for diverse application in engineering. Incorporating lateritic soil in concrete will help reduce cost and solve some of the environmental problems associated with excessive mining of river sand (Dharsan and Prashanth, 2025). However, many of these previous studies have primarily focused on varying only the content of lateritic soil in the concrete mix, without varying other concrete constituent proportions. By this, the combined effects of varying other material proportions on the compressive strength of concrete have not been captured.

Response Surface Methodology (RSM) is a tool that uses mathematical techniques to design experiments, carry out product design and improvement, model relationships between variables, and optimize designs (Carley et al., 2004; Lamidi et al., 2023). RSM is quite useful in showing the interactive effects of several factors on a performance criterion. Central Composite Design (CCD) is a technique used in RSM useful in building three-level factorial experiment, resulting in accurate and efficient optimization and prediction, while allowing the designer to understand the effects of varying factors (variables) on response parameters (Olaoye, 2020; Bhattacharya, 2021).

This study seeks to investigate the compressive strength of concrete using lateritic soil as partial replacement of sand while also using CCD to generate mix combinations with varying water to cement ratio (W/C), coarse aggregate to total aggregate ratio (CA/TA), total aggregate to cement ratio (TA/C), and lateritic soil to fine aggregate ratio (LS/FA). This study also developed a regression model based on RSM to predict the compressive strength of concrete containing lateritic soil.

II. LITERATURE REVIEW

Zerdi et al. (2016) investigated the compressive strength at 7, 21 and 28 days for concrete produced by partially replacing sand with laterite at 0, 15 and 30%. At 28 days of curing, the compressive strength was found to decrease from 32.97 N/mm2 to 26.95 N/mm2 when sand was replaced with laterite at 15%. There is however, an increase in strength (29.41 N/mm2) at 30% replacement of sand with laterite as compared to 15%. This study has shown an indication of improved compressive strength between 15 and 30% laterite content.

Oladape et al. (2022) used laterite to partially replace sand in the production of hollow sandcrete blocks and interlocking bricks. Laterite was used to replace sand at 0, 10, 20 and 30%. The results from this study showed a continuous decrease in the compressive strength of both sandcrete blocks and interlocking bricks as the lateritic content increases. All the interlocking bricks produced using laterite satisfied minimum strength requirements of the Nigerian Building and Road Research Institute (NBRRI).

In a bid to find alternative for use of river sand in concrete, Adeniseun et al. (2025) investigated the compressive strength of concrete cubes when river sand was replaced with laterite between 0 - 30%. The outcome of this study revealed a continuous decrease in compressive strength as laterite content increases. Optimum compressive strength was obtained at 10% replacement of river sand with laterite.

The compressive and tensile strengths of concrete containing laterite as partial replacement for sand at 0, 7.5, 15, 22.5 and 30% were investigated by Shoaib et al. (2022). The outcome of the study showed increase in both tensile and compressive strengths as the percentage content of laterite increases. Higher strengths were recorded at 22.5% replacement of sand with laterite.

Most of these previous studies focused on the effect of lateritic soil content on concrete characteristics without varying other concrete constituent proportions. Hence, failing to capture the combined effect of varying other material proportions on the compressive strength of laterized concrete.

III. MATERIALS AND METHODS

A. MATERIALS

The materials used for this study include: Dangote brand of 42.5N Portland Limestone Cement (PLC) obtained from a retail outlet in Makurdi, river sand (fine aggregate) free from deleterious materials obtained from the bed of river Benue in Makurdi, crushed granite (coarse aggregates), lateritic sand (used as partial replacement of sand) was obtained from a laterite deposit at Ikpayongo, Benue state, and potable water obtained from the Civil Engineering Department, Joseph Sarwuan Tarka University, Makurdi used in mixing and curing concrete. The materials were tested and their respective properties are presented in Table 1.

Table 1: Properties of constituent materials

Material	Properties
River sand	Specific gravity:2.6 Water absorption: 2.0% Loose bulk density: 1625.5kg/m^3
Granite	Specific gravity:2.7 Water absorption:0.27% Loose bulk density: 1566kg/m^3 Aggregate Crushing Value (ACV): 15.75% Aggregate Impact Value (AIV): 18.65%
Laterite	Specific gravity:2.40 Water absorption: 10.81% Loose bulk density: 1400.5kg/m^3 Moisture content: 22% Liquid limit: 40.48% Plastic limit: 20% Plasticity index: 20.48%

B. METHODS

Central Composite Design

Central Composite Design (CCD) in Minitab 21 was used in generating the combinations of variables of design in this study. This fractional factorial design method has the advantage of measuring the effects on the performance of the response parameter when the design variables are changing. With this, a commendably accurate prediction is achieved (Olaoye, 2020).

The proportions of the concrete constituent materials were assigned range of values and adopted as independent variables in this investigation. These independent variables are:

a. Water to Cement ratio (W/C)
   W/C (x_1) = 0.4, 0.5, 0.6 (1)
b. Coarse Aggregate to Total Aggregate ratio (CA/TA)
   CA/TA (x_2) = 0.55, 0.6, 0.65 (2)
c. Total Aggregate to Cement ratio (TA/C)
   TA/C (x_3) = 3, 4.5, 6 (3)
d. Lateritic Sand to Fine Aggregate ratio (LS/FA)
   LS/FA (x_4) = 0.1, 0.15, 2 (4)

Where: TA= Total Aggregate = FA+CA

Outside the assigned values, two axial points exist in CCD. These points are –α and α.

The five coded factor levels used in this investigation are: -1, 0, 1, -1.412 and 1.4142. These coded values are converted to uncoded values using equation (5)

$$x_{uncoded} = \frac{x_{min}+x_{max}}{2} \pm \alpha\left(\frac{x_{min}-x_{max}}{2}\right) \quad (5)$$

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

Concrete Mix Composition

The absolute volume equation given in equation (6) was used in computing the weight of each constituent material.

$$\frac{Ww}{1000} + \frac{Wc}{1000Gs_c} + \frac{W_{LS}}{1000Gs_{LS}} + \frac{W_{CA}}{1000Gs_{CA}} + \frac{W_{FA}}{1000Gs_{FA}} + AV = 1 \quad (6)$$

Where:
W_w =Weight of water, W_c =Weight of cement, W_{LS} =Weight of Lateritic soil, W_{FA} =Weight of fine aggregate, W_{CA} =Weight of coarse aggregate, Gs_C =Specific gravity of cement, Gs_{LS} =Specific gravity of lateritic sand, Gs_{CA}=specific gravity of coarse aggregate, Gs_{FA} =Specific gravity of fine aggregate and AV=air void=2%=0.02

The weights of these materials were expressed in terms of the variables chosen as shown in Equations (7) to (11).

$$W_w = W_c \times \frac{W_w}{W_c} \quad (7)$$

$$W_{TA} = \frac{W_{TA}}{W_c} \times W_c \quad (8)$$

$$W_{CA} = \frac{W_{CA}}{W_{TA}} \times \frac{W_{TA}}{W_C} \times W_C \quad (9)$$

$$W_{FA} = W_{TA} - W_{CA} = \frac{W_{TA}}{W_C} \times W_C \times \left(1 - \frac{W_{CA}}{W_{TA}}\right) \quad (10)$$

$$W_{LS} = \frac{W_{LS}}{W_{FA}} \times W_{FA} = \frac{W_{LS}}{W_{FA}} \times \frac{W_{TA}}{W_C} \times \left(1 - \frac{W_{CA}}{W_{TA}}\right) \times W_c \quad (11)$$

The weight of cement (Wc), per cubic meter of concrete can be gotten by substituting equations (7), (8), (9) (10) and (11) into equation (6) and rearranging.

$$W_C = \frac{1 - AV}{\frac{\left(\frac{W_W}{W_C}\right)}{1000} + \frac{1}{1000Gs_C} + \frac{\left(\frac{W_{LS}}{W_{FA}} \times \frac{W_{TA}}{W_C} \times \left(1 - \frac{W_{CA}}{W_{TA}}\right)\right)}{1000Gs_{LS}} + \frac{\left(\frac{W_{TA}}{W_C} \times \left(1 - \frac{W_{CA}}{W_{TA}}\right)\right)}{1000Gs_{FA}} + \frac{\left(\frac{W_{CA}}{W_{TA}} \times \frac{W_{TA}}{W_C}\right)}{1000SG_{CA}}} \quad (12)$$

The quantity of cement required for a unit volume of concrete is obtained using equation (12). Thereafter, quantities of other constituent materials are gotten using equations (7) to (11) for the 29 mix combinations generated using CCD in Minitab 21. Table 2 presents uncoded mix proportion combinations as well as required weights of constituent materials per cubic meter of concrete.

In addition to the 29 mix combinations generated, an additional sample point containing 0% lateritic sand was created. This was done using weight batching of the common 1:2:4 mix ratio (translating to a CA/TA=0.67 and TA/C=6) and W/C ratio of 0.5. The weights of constituent materials required for the control mix are presented in Table 3.

Table 2: Weights of concrete constituents required per cubic meter of concrete mix

Mix	Uncoded Design Variables				Weight of Constituent Materials					
	W/C	CA/TA	TA/C	LS/FA	Water (kg/m³)	Cement (kg/m³)	Total Fines (kg/m³)	Granite (kg/m³)	Sand (kg/m³)	Laterite (kg/m³)
1	0.40	0.55	6.00	0.10	110.43	276.07	745.40	911.04	670.86	74.54
2	0.60	0.55	3.00	0.10	156.80	261.34	352.81	431.21	317.53	35.28
3	0.60	0.55	6.00	0.10	156.81	261.35	705.64	862.45	635.08	70.56
4	0.50	0.53	4.50	0.15	134.25	268.51	568.75	639.53	483.43	85.31
5	0.60	0.55	6.00	0.20	156.81	261.35	705.64	862.45	564.52	141.13
6	0.60	0.65	6.00	0.20	156.81	261.35	548.83	1019.26	439.07	109.77
7	0.50	0.60	4.50	0.08	134.25	268.51	483.31	724.96	444.99	38.32
8	0.64	0.60	4.50	0.15	165.80	258.49	465.28	697.92	395.49	69.79
9	0.40	0.65	6.00	0.20	110.43	276.07	579.75	1076.68	463.80	115.95
10	0.60	0.55	3.00	0.20	156.81	261.34	352.81	431.21	282.25	70.56
11	0.50	0.60	6.62	0.15	134.26	268.51	711.16	1066.74	604.48	106.67
12	0.50	0.60	4.50	0.15	134.25	268.51	483.31	724.96	410.81	72.50
13	0.50	0.60	4.50	0.22	134.25	268.51	483.31	724.97	376.64	106.67
14	0.50	0.60	2.38	0.15	134.25	268.50	255.47	383.21	217.15	38.32
15	0.40	0.65	3.00	0.10	110.43	276.06	289.87	538.33	260.88	28.99
16	0.60	0.65	3.00	0.10	156.80	261.34	274.41	509.62	246.97	27.44
17	0.50	0.60	4.50	0.15	134.25	268.51	483.31	724.96	410.81	72.50
18	0.50	0.60	4.50	0.15	134.25	268.51	483.31	724.96	410.81	72.50
19	0.50	0.60	4.50	0.15	134.25	268.51	483.31	724.96	410.81	72.50

20	0.50	0.67	4.50	0.15	134.25	268.51	397.87	810.40	338.19	59.68
21	0.36	0.60	4.50	0.15	100.16	279.33	502.79	754.18	427.37	75.42
22	0.60	0.65	3.00	0.20	156.81	261.34	274.41	509.62	219.53	54.88
23	0.40	0.55	3.00	0.10	110.43	276.06	372.69	455.51	335.42	37.27
24	0.60	0.65	6.00	0.10	156.81	261.35	548.83	1019.26	493.95	54.88
25	0.50	0.60	4.50	0.15	134.25	268.51	483.31	724.96	410.81	72.50
26	0.40	0.65	6.00	0.10	110.43	276.07	579.75	1076.68	521.78	57.98
27	0.40	0.55	3.00	0.20	110.43	276.06	372.69	455.51	298.15	74.54
28	0.40	0.55	6.00	0.20	110.43	276.07	745.40	911.04	596.32	149.08
29	0.40	0.65	3.00	0.20	110.43	276.06	289.87	538.33	231.89	57.97

Table 3: Weights of concrete constituents required per cubic meter for the control mix

Mix	**Variables**				**Weight of Constituent Materials**					
	W/C	**CA/TA**	**TA/C**	**LS/FA**	**Water (kg/m³)**	**Cement (kg/m³)**	**Total Fines (kg/m³)**	**Granite (kg/m³)**	**Sand (kg/m³)**	**Laterite (kg/m³)**
1	0.50	0.67	6.00	0.00	134.26	268.51	531.65	1079.41	531.65	0.00

Slump Test

Slump test was used in testing the workability of the different mix samples in accordance with the provisions of BS EN 12350-2 (2009).

Casting and Curing of Cube Samples

Three concrete cube samples (150mm) were cast per mix point. A total of 90 cubes were cast (including control samples). Hardened concrete cubes were cured using total immersion in curing tank for 28 days in accordance with specifications of BS EN 12390-2 (2000).

Compressive Strength Test

Compressive strength test was carried out on all the cube samples after 28 days of curing. This was done in accordance to BS EN 12390-3 (2002).

IV. RESULTS AND DISCUSSION

A. SLUMP

Table 4 presents the slump for the 29 samples. The slump is seen to vary between 0 and 210 mm.

Zero (0 mm) slump was recorded for mixes 1, 9, 11, 21, 26 and 28. This lack of slump is associated with the fact that the mixes have low water to cement ratios (W/C) with relatively high total aggregate to cement ratio (TA/C). This reduces the amount of water available in the concrete mix.

Slump values ranging between 0 and 40mm were recorded for mixes 3, 4, 5, 6, 7, 12, 13, 15, 17, 18, 19, 20, 23, 25, 27 and 29. These low slump values are as a result of low W/C ratio in some mixes and high lateritic soil content in others. Mixes in this category are classified as slump class S1 (BS EN 206-1, 2000) or low workability concrete (Shetty, 2005).

Mix 24 recorded a slump of 90mm. This is classified as slump class S2 (BS EN 206-1, 2000) and considered medium workability concrete (Shetty, 2005).

Mixes 2, 8, 10, 14, 22 and 16 recorded slump values of 170, 175, 212, 200, 202, and 210mm respectively. These are classified as slump class S4 (BS EN 206-1, 2000) and regarded as very high workability concrete. The high slump in these mixes is as a result of high W/C ratio with corresponding low TA/C ratio. This combination results in more water in the concrete mix.

The effect of lateritic soil content on the workability of concrete can be seen in mixes with constant W/C, CA/TA and TA/C. Mixes 7, 12 and 13 with lateritic soil content of 8, 15 and 22%

recorded slump values of 27, 15 and 10mm respectively, showing continuous decrease in slump as the lateritic soil content increased. Similarly, mixes 2 and 10, 15 and 29, 16 and 22, 6 and 24, 23 and 27, and 3 and 5 show decrease in slump values as the lateritic soil content increased from 10 to 20% at constant W/C, CA/TA and TA/C. Workability of concrete containing lateritic soil decreases as the lateritic soil content increases (Garba *et al*., 2024).

Table 4: Slump

Mix No.	W/C(x_1)	CA/TA(x_2)	TA/C(x_3)	LS/FA(x_4)	Slump(mm)
1	0.40	0.55	6.00	0.10	0
2	0.60	0.55	3.00	0.10	170
3	0.60	0.55	6.00	0.10	25
4	0.50	0.53	4.50	0.15	15
5	0.60	0.55	6.00	0.20	20
6	0.60	0.65	6.00	0.20	25
7	0.50	0.60	4.50	0.08	27
8	0.64	0.60	4.50	0.15	174
9	0.40	0.65	6.00	0.20	0
10	0.60	0.55	3.00	0.20	212
11	0.50	0.60	6.62	0.15	0
12	0.50	0.60	4.50	0.15	15
13	0.50	0.60	4.50	0.22	10
14	0.50	0.60	2.38	0.15	200
15	0.40	0.65	3.00	0.10	25
16	0.60	0.65	3.00	0.10	210
17	0.50	0.60	4.50	0.15	16
18	0.50	0.60	4.50	0.15	16
19	0.50	0.60	4.50	0.15	15
20	0.50	0.67	4.50	0.15	17
21	0.36	0.60	4.50	0.15	0
22	0.60	0.65	3.00	0.20	202
23	0.40	0.55	3.00	0.10	27
24	0.60	0.65	6.00	0.10	90
25	0.50	0.60	4.50	0.15	15
26	0.40	0.65	6.00	0.10	0
27	0.40	0.55	3.00	0.20	14
28	0.40	0.55	6.00	0.20	0
29	0.40	0.65	3.00	0.20	23

B. COMPRESSIVE STRENGTH

Table 5 shows the result of the 28 days compressive strength of all the concrete cube samples.

Highest compressive strengths with an average of 30.40 N/mm^2 were obtained from mixes 12, 17, 18, 19 and 25 with constituent mix proportions of W/C=0.5, CA/TA=0.6, TA/C=4.5 and LS/FA=0.15. This high strength is as a result of moderate value of the total aggregate to cement ratio (TA/C) with a relatively moderate water to cement ratio (W/C). This allows for higher cement content in the mix, resulting in higher strength. The strength of concrete has generally been found to be inversely proportional to aggregate to cement ratio (Soudki *et al*., 2001; Saloma *et al*., 2020).

A compressive strength of 3.88 N/mm^2 was obtained with a constituent mix proportion of W/C=0.4, CA/TA=0.55, TA/C=6 and LS/FA=0.2. This is the lowest strength obtained in this investigation. The low strength is attributed to a high TA/C ratio, resulting in less cement in the mixture. The low strength is also attributed to LS/FA value of 0.2. This translates to lateritic soil replacing 20% of the fine aggregate. It has been reported that compressive strength decreases with increase in lateritic soil content (Oladape *et al*., 2022; Adiniseun *et al*., 2025).

The control specimen (0% lateritic soil content) with a mix ratio of 1:2:4 translating to W/C=0.5, CA/TA=0.67, TA/C=6 and LS/FA=0 yielded a compressive strength of 25.40 N/mm^2 at 28 days of age. This strength is lower when compared to mixes 12,13, 15, 17, 18, 19, 20 and 25. This implies that higher strengths are obtained even with the inclusion of lateritic soil in the concrete mix.

From the foregoing analysis, earlier claims that compressive strength decreases with increasing lateritic soil content only holds when other constituent proportions are kept constant, as strength of concrete containing lateritic soil depends largely on the proportions of other constituent materials. This investigation reveals a 15% optimal replacement level of fine aggregate with lateritic soil.

Table 5: Compressive Strength

Mix No.	W/C(x_1)	CA/TA(x_2)	TA/C(x_3)	LS/FA(x_4)	Compressive Strength (N/mm^2)
Control	0.50	0.67	6.00	0.00	25.40
1	0.40	0.55	6.00	0.10	5.45
2	0.60	0.55	3.00	0.10	12.76
3	0.60	0.55	6.00	0.10	10.37
4	0.50	0.53	4.50	0.15	13.33
5	0.60	0.55	6.00	0.20	6.99
6	0.60	0.65	6.00	0.20	15.41
7	0.50	0.60	4.50	0.08	14.22
8	0.64	0.60	4.50	0.15	9.87
9	0.40	0.65	6.00	0.20	8.42
10	0.60	0.55	3.00	0.20	11.29
11	0.50	0.60	6.62	0.15	15.04
12	0.50	0.60	4.50	0.15	30.26
13	0.50	0.60	4.50	0.22	26.73
14	0.50	0.60	2.38	0.15	21.63
15	0.40	0.65	3.00	0.10	26.90
16	0.60	0.65	3.00	0.10	18.96
17	0.50	0.60	4.50	0.15	30.43
18	0.50	0.60	4.50	0.15	30.35
19	0.50	0.60	4.50	0.15	30.43
20	0.50	0.67	4.50	0.15	27.73
21	0.36	0.60	4.50	0.15	30.17
22	0.60	0.65	3.00	0.20	18.34
23	0.40	0.55	3.00	0.10	23.59
24	0.60	0.65	6.00	0.10	18.73
25	0.50	0.60	4.50	0.15	30.37
26	0.40	0.65	6.00	0.10	10.55
27	0.40	0.55	3.00	0.20	22.90
28	0.40	0.55	6.00	0.20	3.88
29	0.40	0.65	3.00	0.20	29.01

C. EFFECTS OF CONSTITUENT MATERIAL PROPORTIONS ON COMPRESSIVE STRENGTH

The result of this investigation shows that lower values of TA/C yielded higher compressive strengths while higher TA/C values resulted in lower compressive strengths. From Table 5, mixes 2 and 3, 1 and 23, 15 and 26, and 24 and 16 have shown that even when other parameters are kept constant, higher strengths are recorded at lower TA/C values and vice versa. Previous studies have also shown that strength of concrete is inversely proportional to the TA/C ratio (Soudki *et al*., 2001; Saloma *et al*., 2020). This assertion, however, is not true for all values of TA/C. Fig. 1 shows a plot of compressive strength against TA/C for three mixes with the same W/C, CA/TA, and LS/FA ratio. It is observed that compressive strength is highest at TA/C value of 4.5 and decreases at a lower TA/C of 2 and higher TA/C of 6.62. This indicates attainment of maximum strength around the mid values of TA/C. Corroborating this finding, Shariq *et al*. (2012) found the optimal value of TA/C to be ranging between 3.9 and 4.6.

From Table 5, the effect of coarse aggregate content (CA/TA) can be seen when other constituent proportions are kept constant in mixes 1 and 26, 3 and 24, 2 and 16, and 23 and 25. The compressive strength values are seen to be higher when CA/TA increases from 0.55 to 0.65. It has been observed that concrete compressive strength, elastic modulus and flexural strength increase with increase in the coarse aggregate content (Wang *et al*., 2011; Kaya *et al*., 2024). However, from Fig. 2, it will be observed that values of CA/TA above 0.6 resulted in lower compressive strength for mixes with constant W/C, TA/C and LS/FA. This implies that using CA/TA value above 0.6 reduces compressive strength.

The effect of lateritic soil content (LS/FA) on the compressive strength of concrete is shown in Fig. 3. It is observed that for constant values of W/C, CA/TA, and TA/C, the compressive strength decreased when LS/FA ratio increased from 0.15 to 0.22, 0.1 to 0.2, and 0.1 to 0.2 for mixes 13 and 17, 23 and 27, and 6 and 24 respectively. Compressive strength decreases with increasing lateritic soil content (Oladape *et al*., 2022; Adeniseun *et al*., 2025).

From Table 5, it will be observed that the samples with the highest compressive strengths (Mixes 12, 17, 18, 19 and 25) were obtained with a constituent mix combination of W/C of 0.5, CA/TA of 0.6, TA/C of 4.5, and LS/FA of 0.15 (15% lateritic soil content). This shows a higher strength value compared to mixes with 0 and 10% lateritic soil contents. The implication of this is that, aside the lateritic soil content, other constituent proportions collectively determine the compressive strength of concrete, emphasizing the importance of CCD in generating combinations of mix composition in investigations geared towards improving concrete properties.

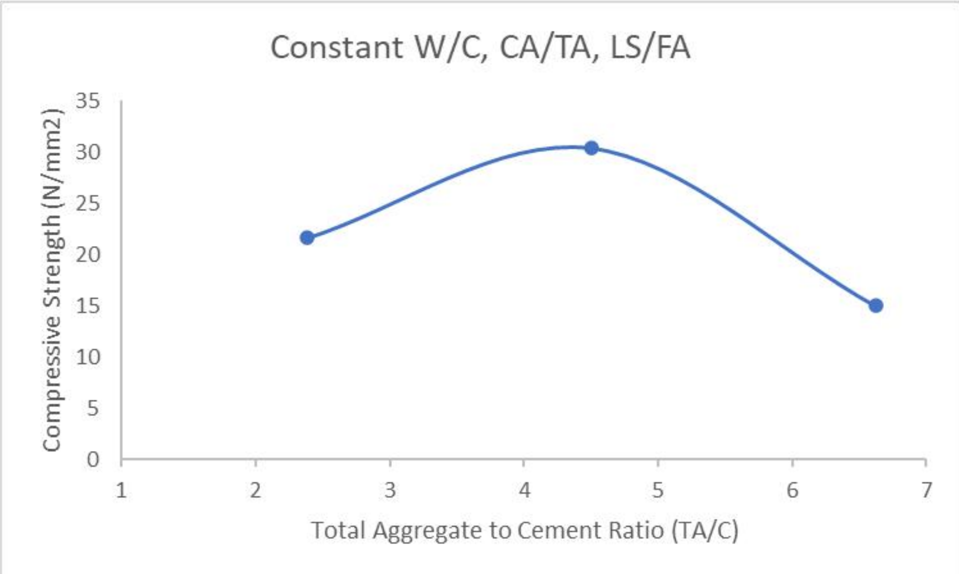

Fig. 1. Effect of TA/C on the compressive strength of concrete

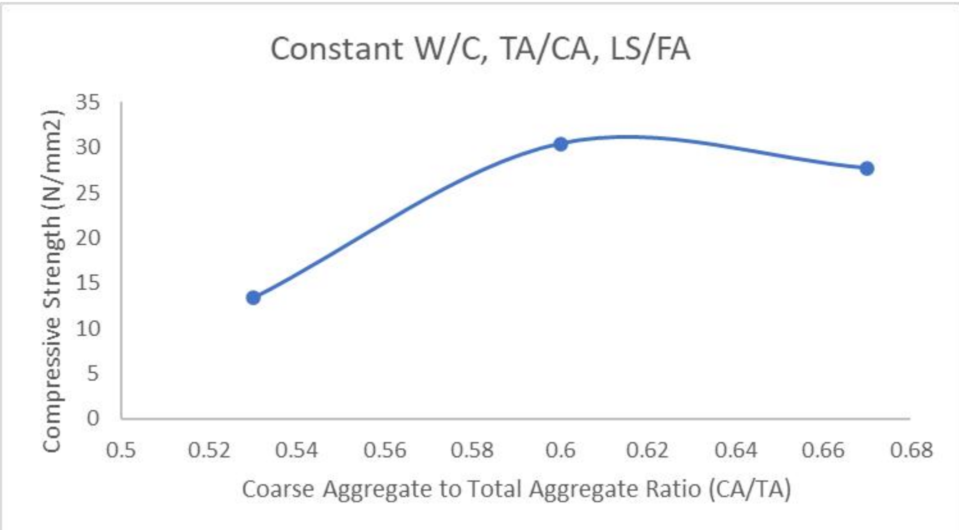

Fig. 2. Effect of CA/TA on the compressive strength of concrete

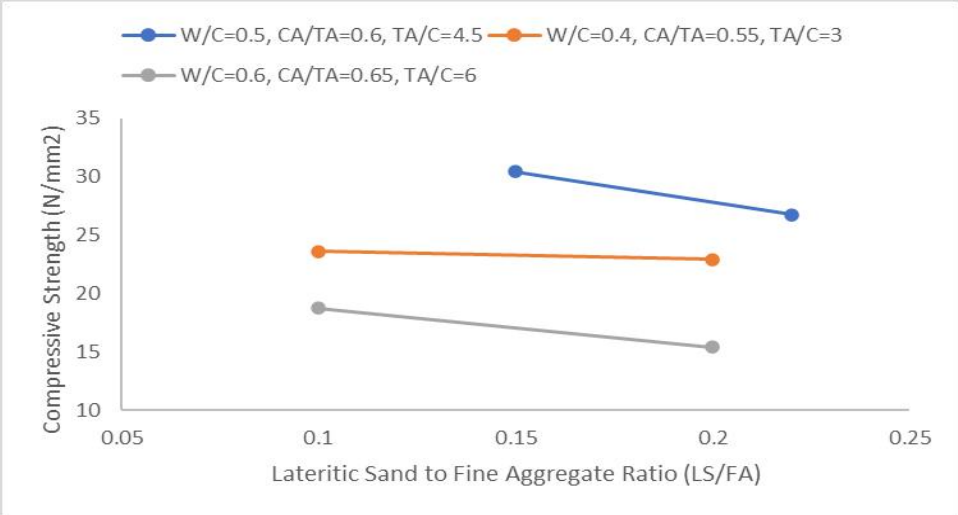

Fig. 3. Effect of LS/FA on the compressive strength of concrete

D. MODELLING AND STATISTICAL VALIDATION

REGRESSION MODEL

Response surface methodology (RSM) in Minitab 21 was used in developing a full quadratic model at 95% confidence level. The experimental data in Table 5 was used in developing model that relates the independent variables (W/C, CA/TA, TA/C, LS/FA) to the response parameter (compressive strength). The model developed for predicting the 28 days compressive strength of concrete containing lateritic soil is as displayed as Equation (13).

$$\begin{aligned} \mathit{Compressive\ strength} &= -492 + 129x_1 + 1495x \\ &- 1.878x_3^2 - 1278x_4^2 + 13 \\ &+ 79x_2x_4 - 8.1x_3x_4 \end{aligned} \quad (13)$$

STATISTICAL VALIDATION OF THE MODEL

Analysis of Variance

Table 6 presents the result for analysis of variance for the developed model.

The regression model's overall p-value is 0.001. This value implies that the developed model is highly significant. A model with a p-value close to zero is highly usable in predicting responses and has an excellent overall significance (Triola, 2018). It is observed that some of the linear, quadratic and interactive times have p-values less than 0.05, implying that they are statistically significant while others are statistically insignificant. Fig. 4 is a pareto plot showing the standardized effect of these terms on the model equation.

From Table 6, the coefficient of determination (R^2) for the model equation is 86.58%. This value is considerably high and implies that 86.58% of the variations in the response (compressive strength) are explained by the design variables. The value of R^2 however, increases with addition of variables and its value alone is not a good measure of fitness of a model (Montgomery and Runger, 2003). The adjusted coefficient of determination (R^2 Adj) is a better measure of fitness. The R^2 Adj value for the developed regression equation is 73.15%. This is satisfactory and gives an indication of a good fit.

Table 6: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	14	1898.14	135.581	6.45	0.001
Linear	4	785.32	196.329	9.34	0.001
x_1	1	107.48	107.476	5.11	0.040
x_2	1	240.74	240.741	11.45	0.004
x_3	1	435.02	435.016	20.69	0.000
x_4	1	2.08	2.085	0.10	0.757

Square	4	837.23	209.307	9.96	0.000
x_1^2	1	104.72	104.721	4.98	0.042
x_2^2	1	89.42	89.424	4.25	0.058
x_3^2	1	163.21	163.214	7.76	0.015
x_4^2	1	91.02	91.015	4.33	0.056
2-Way Interaction	6	275.59	45.932	2.18	0.107
x_1x_2	1	7.52	7.521	0.36	0.559
x_1x_3	1	258.00	258.004	12.27	0.004
x_1x_4	1	2.65	2.649	0.13	0.728
x_2x_3	1	0.88	0.879	0.04	0.841
x_2x_4	1	0.62	0.620	0.03	0.866
x_3x_4	1	5.92	5.917	0.28	0.604
Pure Error	4	0.02	0.005		
R-sq				86.58%	
R-sq(adj)				73.15%	

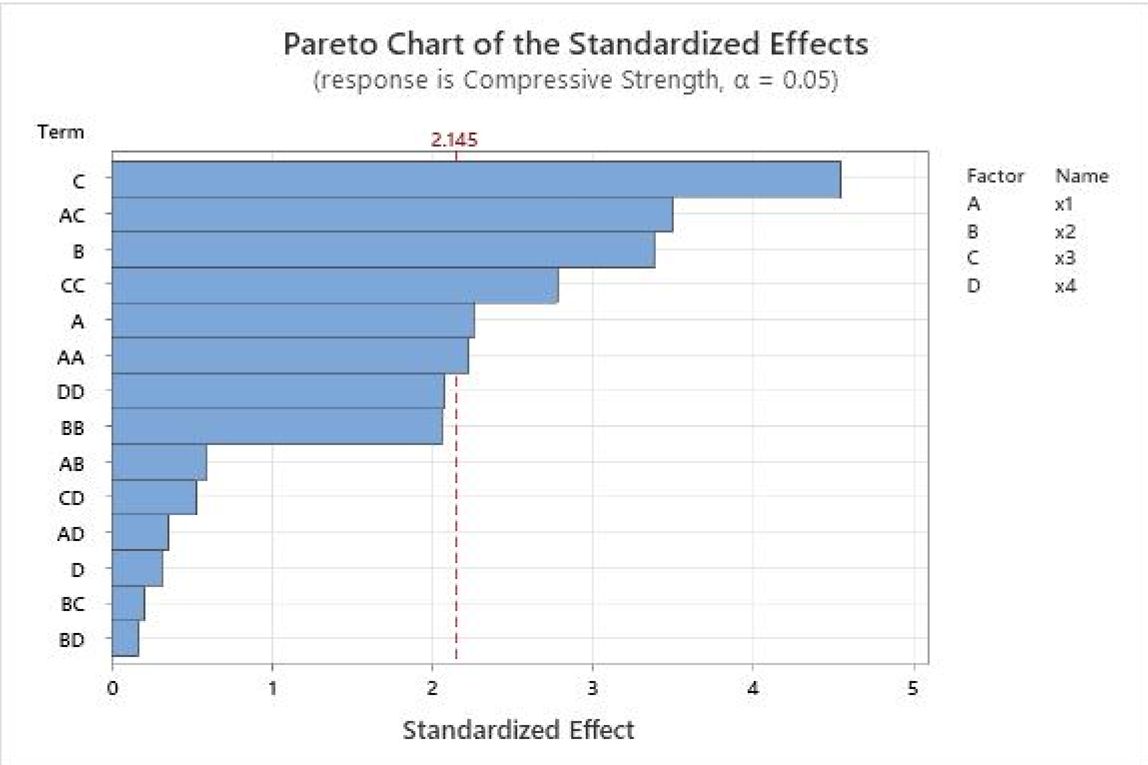

Fig. 4. Pareto Plot

Residual Plots

Fig. 5 shows the normal probability plot for the developed model. The model is validated since the plot of residual against the normal percent of probability assumes a straight line.

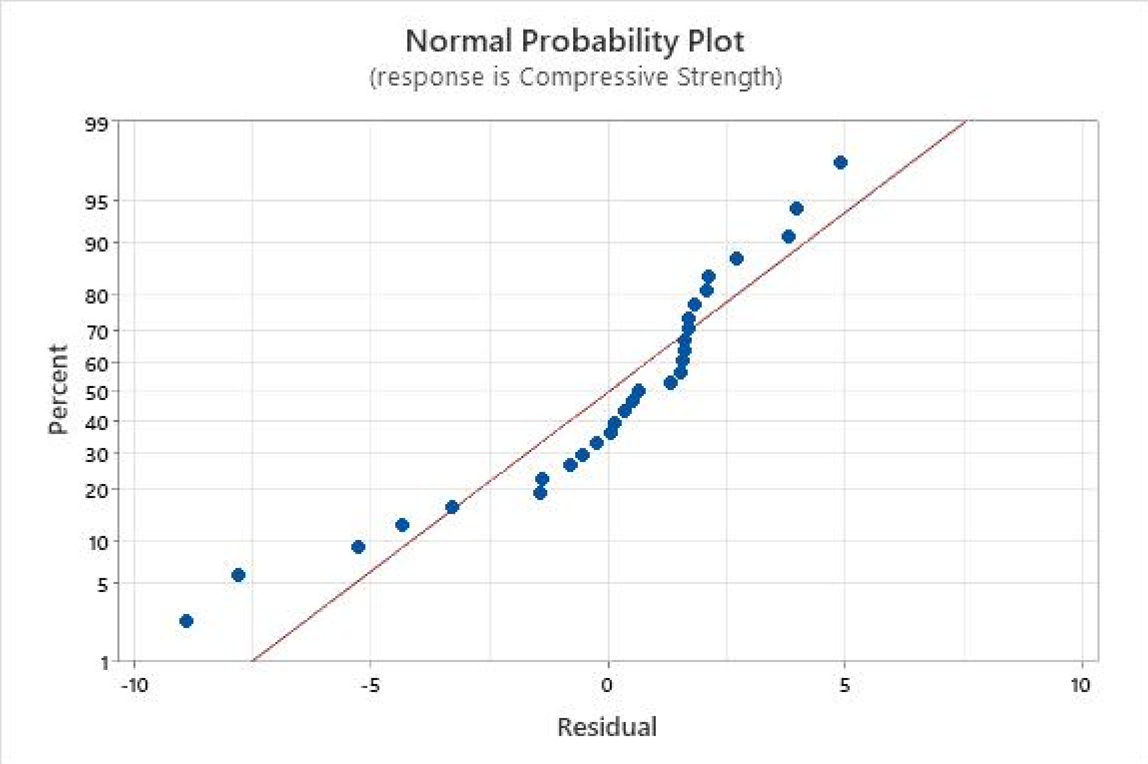

Fig. 5. Normal Probability Plot

Fig. 6 presents the plot of residuals versus fitted values. The plot has an irregular pattern. This is a further indication that the developed model is well fitted and adequate. Good residual plots have no regular patterns and appear wider or thinner when observed from either side (Triola, 2018).

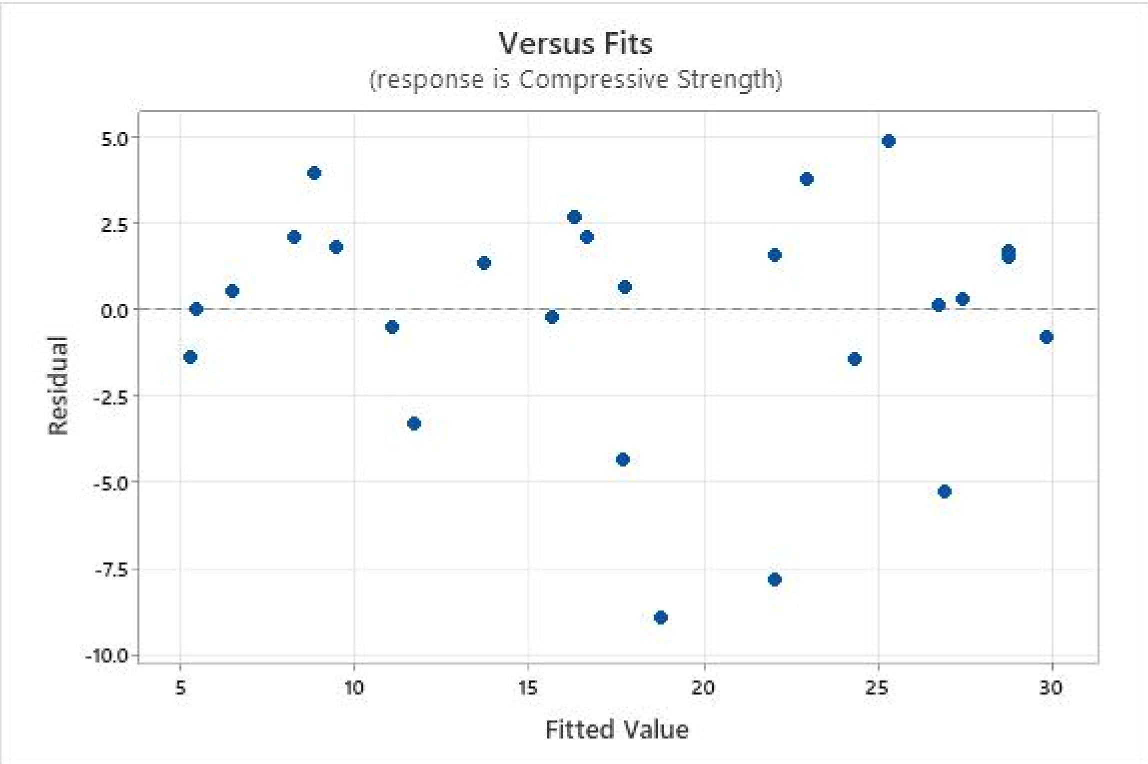

Fig. 6. Residual Versus Fits Plot

Volume-5, Issue-2, pp-1--13

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V. CONCLUSION

Based on the findings of this study, the following conclusions have been reached:

1. Workability of concrete decreases as the percentage replacement of lateritic soil with sand increases.
2. Compressive strength decreases with increase in lateritic soil content when other concrete constituent proportions are kept constant.
3. Proportions of other concrete constituent materials influence the compressive strength of concrete irrespective of the volume of the lateritic soil in the mix.
4. Compressive strength as high as 30.40 N/mm2 can be obtained in concrete containing lateritic soil.
5. The highest compressive strength (30.40 N/mm2) was obtained with concrete mix proportion of W/C=0.5, CA/TA=0.6, TA/C=4.5 and LS/FA=0.15.
6. The optimal replacement level of fine aggregate with lateritic soil is 15%.
7. Model developed for predicting compressive strength of concrete containing lateritic soil is adequate, valid and has high predictive capabilities.

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