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Strength Optimization of Black Cotton Soil Stabilized with Waste Glass Powder and Cement

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ABSTRACT

This study investigates the stabilization of black cotton soil (BCS) using waste glass powder (WGP) blended with cement. Black cotton soil is a problematic soil characterized by low bearing capacity and high swelling and shrinkage properties; thus, stabilization is necessary. Many agricultural lands are composed of black cotton soils, which are unsuitable for construction unless replaced or treated with appropriate materials. Civil engineering projects located in areas with soft or weak soils traditionally improve soil properties through stabilization. This study employed waste glass powder (WGP) blended with cement for the stabilization of black cotton soil (BCS) for highway construction. Central composite design (CCD) of response surface methodology was used to design the experiment and perform optimization. The experimental results showed that the optimal mixture consisted of 9.4% WGP and 4% cement, resulting in significant improvements in the soil's geotechnical properties. The optimized mixture achieved an optimum moisture content (OMC) of 11.9%, maximum dry density (MDD) of 1.47 g/cm³, and reduced linear shrinkage of 4.3%. The stabilized soil also exhibited enhanced strength, with unconfined compressive strength (UCS) values of 308.8 N/mm² at 7 days and 770 N/mm² at 28 days. Additionally, the soaked and unsoaked California Bearing Ratio (CBR) values were 42.8% and 78.3%, respectively. The findings of this study demonstrate the potential of using WGP and cement to stabilize black cotton soil, providing a sustainable and effective solution for geotechnical applications.

KEYWORDS:

Black cotton soil, Waste Glass Powder, Optimization, Stabilization

1.0 Introduction

India's land area (Nooraien *et al*., 2020). In Nigeria, BCS occurs in the low-lying parts of the North-Eastern states (Gombe, Borno, Yobe, Adamawa, Taraba, and Bauchi) as shallow deposits rarely exceeding 2 m in thickness (Akanbi, 2010). The soil is characterized by high swelling and shrinkage, low bearing capacity, and significant volume change with moisture variation, making it problematic for construction (Etim *et al*., 2017; Miao *et al*., 2017)

Expansive soils, such as black cotton soils (BCS), expand with increased moisture content due to the clay mineral montmorillonite (Uday *et al.,* 2023). BCS is unreliable in construction projects due to excessive volume change, low shear strength, and high compressibility, posing risks to structures like runways, roads, and dams (Matawal, 2012).

Shanmugavadivu (2021) notes that BCS is clayish in nature, characterized by enormous volume changes and swell-shrinking potential. Due to these problems, researchers have explored various stabilization methods, including the use of fly ash (Nanda, 2021; Chethan & Ravi, 2021), industrial waste (Majeed & Tangri, 2021; Garg et al., 2021), coal bottom ash (Navagireet et al., 2021), lime, cement, and other materials (Mai-Bade *et al*., 2021; Premkumar *et al*., 2021). These methods aim to improve soil properties, reduce plasticity, and counter swelling potential.
Jayaganesh (2020) found that adding polymeric resins, such as poly vinyl alcohol and epoxy resin, can increase specific gravity, reduce liquid limit and plasticity index, and decrease swelling potential. Other studies have utilized waste materials like fly ash, industrial waste, and coal bottom ash to stabilize BCS (Kankia *et al*., 2021; Akinwande & Aderinola, 2020). Ibrahim (2019) analysed twenty disturbed samples of OPC-stabilised black cotton soil, mixing cement (2–8 %) with waste glass (5–20 %) at optimum moisture. Regression linked soaked CBR to MDD, waste glass, cement content, liquid limit and plastic limit, showing the variables predict CBR well.

2.0 Literature Review

2.1 Stabilization of black cotton soil

This method helps to alter the properties of black cotton soil to enhance its physical properties and engineering performance.

Omisande (2020) mixed Ilaro black cotton soil with 0–50 % fly ash and tested index properties, compaction, and CBR (BS 1377-1990). Fly ash cut plasticity and raised strength; the best CBR and swell control appeared at 30–40 % fly ash, with 30 % recommended as optimum for civil works.

Annafi (2020) looked at how mixing time affects lime- and iron-ore-tailings-treated black cotton soil meant for subgrade. He used 0–10 % lime and 0–10 % iron-ore tailings, performed Atterberg limits, compaction, UCS and CBR tests, and analysed the data with MINI-TAB. Liquid limit fell as lime and IOT rose, but it jumped up an hour after mixing. Plastic limit also dropped with more additives. UCS and CBR climbed in the first two hours, peaking at 8 % lime + 8 % IOT.

Aliyu *et al*. (2022) examined mining-tailing waste (MTW) as an additive to ordinary Portland cement (OPC)-stabilised black cotton soil. They blended 0–8 % OPC with 0–20 % MTW, then ran Atterberg limits, sieve analysis, compaction, soaked CBR and UCS tests. Adding MTW improved compaction, soaked CBR and UCS; the best mix was 20 % MTW with 8 % OPC, giving a 4-day soaked CBR of 35 % and a 7-day UCS of 1273 kN/m², meeting Nigerian sub-base specs.

Rizgar *et.al.* (2020), studies the effect of WGP with highly expansive soil and concluded that the WGP was used at various percentages, from 2.5%–25%. The LL, PL, PI, and LS decrease as the percentages of WGP increases. It can be seen that the majority percentages of WGP consist of silica, which is about 72 % so expansive soil replaced with non-plastic material; therefore, the LL was reduced (from 44.20% –22.28%), PL was slightly changed (from 24.81 % to 16.44 %), PI was significantly decreased from 19.39 % to 5.84 %, and the LS was reduced from 9.17 % to 2.63 % when the WGP added up to 25 % by dry weight of the soil.

Bhagwan *et al*. (2021) mixed 0–6 % quick lime with 0–30 % waste glass powder (WGP) and found that WGP sharply reduced the soil's consistency limits and swelling, confirming its effectiveness in controlling expansive behavior.

Nilesh *et al*. (2021) added 5–10 % crushed glass to black cotton soil and observed a strong increase in CBR and compressive strength, with the highest CBR achieved at those percentages.

Ahmad (2020) combined 6 % ordinary Portland cement with 6 % treated bone ash and reported that the blend met sub-base requirements, offering a low-cost solution.

Anigilaje (2019) mixed up to 10 % cement kiln dust (CKD) with BCS and recorded UCS values of 357–529 kN/m² and CBR values of 7–19 %, with 10 % CKD being optimal. Gabriel (2020) added 0–0.75 % bagasse fiber, noting a drop in MDD, a rise in OMC, and peak UCS and CBR at 0.75 % fiber, while swelling also decreased.

KPrabin (2020) used 2–8 % E-waste and demonstrated improved index and engineering properties, positioning the stabilized soil as a green construction material. Onkar (2020) tested 2–8 % E-waste and found the highest UCS (2.63 kN/m²) at 5 % dosage, along with a 2 % increase in MDD and a 5 % decrease in OMC, confirming 5 % as the optimum level.

Akinola & Rapheal (2022) collected expansive black-cotton soil from a borrow pit at Igbo-Ora, Oyo State (7°24′45″ E, 3°18′34″ N), at depths of 0.3–1.0 m. They performed CBR tests according to BS 1377 (1990) and found the natural soil's CBR very low, classifying it as poor and unsuitable for sub-base or base layers without stabilization.

Umaru *et al*. (2023) mixed the same type of soil with 10 % groundnut shell ash (GSA) and 10 % metakaolin (MK). The untreated soil (A-7-6, CH) had a soaked CBR of 1.67 % and a UCS of 128 kN/m². Adding GSA + MK raised the CBR to 3.26 % and the 28-day UCS to 482 kN/m², but the values still fell short of standard pavement requirements, indicating that GSA + MK alone cannot fully stabilize the soil.

Abdulkarim *et al*. (2015) evaluated the effect of waste glass powder (WGP) on properties of cement-stabilized adobe bricks. Cement was fixed at 4% while waste glass passing through sieve size 150 µm at different percentages 2, 4, 6, 8 and 10 % by weight were used as partial replacement of dry soil. The result of the soil moisture content was 12.2% while the specific gravity was 2.2. The result of the submersion test showed that, 4% Cement + 10% WGP and 4% Cement + 8% WGP meet the performance standard while the control bricks (100% clay) did not survive an hour in water submersion. The results for Maximum Dry Density and Optimum Moisture Content of the soil sample were 1.79kg/m^3 and 15% respectively. The liquid limit was 25.3%, plastic limit was 19.7 % and plasticity index was 7%. Highest compressive strength value of 1.45 N/mm^2 was observed at 4% cement + 10% waste glass powder blend, compared to the control (100% clay) with lowest compressive strength value of 0.21N/mm^2. Addition of the cement and WGP showed significant increase in strength of the stabilized adobe bricks after 28 days of curing. Waste glass powder in cement-stabilized earth blocks acts as filler and partially as a binder.

3.0 Materials and Methods

3.1 Materials

The soil used for this study is black cotton soil and was obtained from Yamaltu-Deba Local Government Area of Gombe state. The location lies approximately on latitude 10^0 16'N and longitude11^0 21'E. In the laboratory, the soil was air dried, pulverized and sieved with British Standard Sieve No. 4 which is of 4.75 mm aperture as required for the tests. The water used for the research work was clean and portable water in accordance with BS EN 1008:2002, and was obtained from the tap at Abubakar Tafawa Balewa University, Bauchi. Ordinary Portland cement was used throughout the research was obtained from the open market in yelwa, Bauchi and its, properties conform to specifications of BS 12: Part 2: Clause 5 (1971). Broken waste uniform glass bottles were obtained from post-consumer waste. The glass was cleaned and crushed into smaller sizes and then finely ground with a grinding machine to achieve a finer particle size, and an average particle size of < 300 µm.

3.2 Methods

3.2.1 Experimental Design

The statistical software package used for experimental design, analysis and optimization responses was Central Composite Design of Design-Expert software 13 face centred design space. The software was used for design, analysis optimization of responses. The factor level is in Table 1 and factor combination in Table 2.

Table 1: Factor and Factor Levels of Mixture

Factor	Units	Low	Middle	High
GP	%	5	7.5	10
Cement	%	2	4	6

The responses are

(1) CBR (Unsoaked)
(2) CBR (Soaked)
(3) UCS at 28 days

3.2.2 Hydrometer Analysis of Black Cotton Soil According to ASTM Standards

Hydrometer analysis is a laboratory test used to determine the particle size distribution of fine-grained soils, such as black cotton soil, that pass through a 75µm (No. 200) sieve. This test is essential in geotechnical engineering to understand the behaviour of soils in various construction and environmental applications. The procedure follows the ASTM D422 standard.

4.0 RESULTS AND DISCUSSIONS

4.1 Properties of Black Cotton Soil

The properties of black cotton soil used is presented in Table 2

Table 2: Index Properties of the BCS

Property	Value
Natural moisture content (%) Percentage passing BS No 200 sieve	30.2 77
Liquid limit (%)	68
Plastic limit (%)	35
Plasticity index (%)	33
Linear shrinkage (%)	18.8
Specific gravity	2.63
Maximum Dry Density (MDD) (mg/m³)	1.51
Optimum Moisture Content (OMC) %	16.8
UCS (kN/m²)	124
Soaked CBR (%)	18
Unsoaked CBR (%)	34
Dominant clay mineral	Montmorillonite
AASHTO Classification	A - 7 – 6 (Fair to poor)
NBRRI Classification	High swell potential
UCSC Classification Colour	CH Greyish black

The natural black cotton soil (BCS) has a low unconfined compressive strength (UCS) of 124 kN/m² (≈ 124 N/mm²), well below the minimum required by Nigeria General Specification (1997). Its Atterberg limits—liquid limit 68 %, plastic limit 35 %, plasticity index 33 %—indicate high plasticity. Sieve analysis (77 % passing BS No 200) and the limits classify it as A-7-6 (AASHTO) and CH (high-plasticity clay, USCS). The soaked CBR is 18 % and unsoaked CBR is 34 %, also failing the specification. The soil is dark grey and rich in montmorillonite clay.

4.1.1Particle size analysis for BCS

The result of the dry sieve particle size distribution and hydrometer test is presented in Tables 3 and 4.

Table 3: Dry Sieve for BCS

Sieve (mm)	% Passing
4.75	100
2.36	99.4
1.18	97.2
0.6	96.9
0.425	94.7
0.3	87.4
0.15	81.5
0.075	77.2

Hydrometer analysis result is shown in Table 4 and Figure 1.

Table 4: Hydrometer Test

Sieve size (mm)	% Finer
0.064	67.4
0.054	52.7
0.039	42.9
0.028	34.2
0.020	29.8
0.015	25.5
0.010	21.61
0.007	18.5
0.005	7.37

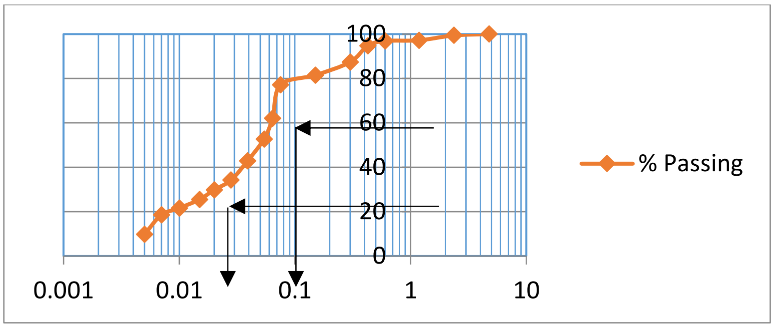


Figure 1: Particle size distribution graph for BCS

Result

$D_{60} = 0.06$

$D_{30} = 0.02$

$D_{10} = 0.005$

$C_U = 0.06 / 0.005 = 12$

$C_C = (0.02)^2 / (0.06 \times 0.005) = 1$

Table 5: XRF Results of the Cement and WGP

Oxide Composition	Cement	WGP
SiO_2	18.8	73.4
Al_2O_3	5.3	3.19
Fe_2O_3	4.8	2.31
CaO	62.9	13.8
MgO	1.34	0.52
Loss in Ignition (LOI)	3.4	7.51

In Table 5, the oxide composition of SiO_2, Al_2O_3, and Fe_2O_3 in waste glass powder are 73.4%, 3.19% and 2.31% respectively and the combined of 78.9% is more than 70% thus, it is classified as pozzolan according to ASTM C 618 (2005) classification of Pozzolans, which helps to activate the CaOH in the soil as a result of cement hydration to form cementitious compounds.

4.2 Performance Evaluation and Analysis of Test Results

The result of all the results is shown in Table 6.

Table 6: OMC Result

Run	Factor 1 A: WGP	Factor 2 B: Cement	Response 1 OMC %	Response 2 MDD mg/m^3	Response 3 Linear shrinkage %	Response 4 UCS at 7 days N/mm^2	Response 5 UCS at 28 days N/mm^2	Response 6 SCBR %	Response 7 UCBR %
1	4	5	10.9	1.55	6.1	210	400	18.9	87
2	7	5	11.7	1.53	4.9	260	560	38.5	79
3	7	4	11.4	1.57	5	270	610	37.8	75
4	4	4	9.3	1.51	6.5	225	455	18.1	71
5	10	3	12.4	1.53	4.5	305	654	38.0	58
6	10	5	11.9	1.38	4	320	842	42.0	78
7	4	3	9.2	1.5	6.8	200	372	13.5	48
8	7	4	11.4	1.57	5	270	610	37.8	75
9	7	3	9.8	1.58	5.5	245	533	36.6	56
10	7	4	11.4	1.57	5	270	610	37.8	75
11	7	4	11.4	1.57	5	270	610	37.8	75
12	7	4	11.4	1.57	5	270	610	37.8	75
13	10	4	11.7	1.43	4.3	307	805	43.8	78

4.2.1 Optimum moisture content (OMC)

The analysis of variance is shown in Table 7 and the Fit statistics in Table 8

Table 7: ANOVA for OMC

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	10.07	3	3.36	15.14	0.0007
A-WGP	7.26	1	7.26	32.74	0.0003
B-Cement	1.60	1	1.60	7.22	0.0249
AB	1.21	1	1.21	5.46	0.0443
Residual	2.00	9	0.2218		
Lack of Fit	2.00	5	0.3992		
Pure Error	0.0000	4	0.0000		
Cor Total	12.07	12			

The Model F-value of 15.14 implies the model is significant. The P-values less than 0.05 indicate model terms are significant. In this case A, B, AB are significant model terms.

Table 8: Fit Statistics for OMC

Parameter	Value
R^2	0.8346
Adjusted R^2	0.7795
Predicted R^2	0.6214
Adeq Precision	12.6326

The Predicted R^2 of 0.6214 is in reasonable agreement with the Adjusted R^2 of 0.7795; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio of 12.63 is greater than 4 and considered desirable. The model equation for OMC is shown in equation 1.

$$OMC = 1.30256 + 1.1\,WGP + 1.8\,cement - 0.183333 * WGP\,(cement) \quad \ldots (1)$$

Figure 2 shows 3D surface graph of interaction between WGP and cement and the influence on optimum moisture content. The 3-D surface reveals that increase in WGP and cement causes a significant increase in OMC.

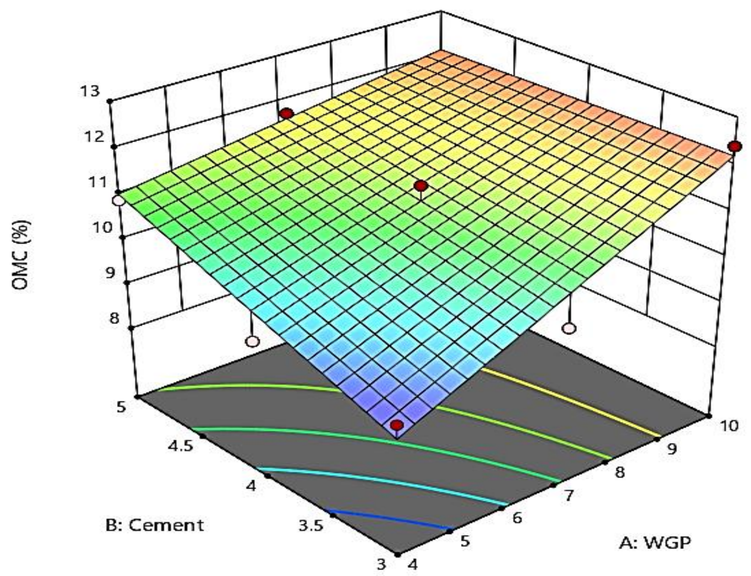


Figure 2: 3D Response Graph of Effect of WGP and Cement on OMC

4.2.2Result of Maximum dry density (MDD)

The ANOVA for MDD is presented in Table 9 and Fit statistics in Table 10.

Table 9: ANOVA for MDD

Source	Sum of Squares	f	Mean Square	F-value	p-value
Model	0.0438	5	0.0088	69.75	< 0.0001
A-WGP	0.0081	1	0.0081	64.30	< 0.0001
B-Cement	0.0038	1	0.0038	29.89	0.0009
AB	0.0100	1	0.0100	79.71	< 0.0001
A^2	0.0191	1	0.0191	152.04	< 0.0001
Residual	0.0009	7	0.0001		
Lack of Fit	0.0009	3	0.0003		
Pure Error	0.0000	4	0.0000		
Cor Total	0.0446	12			

The Model F-value of 69.75 implies the model is significant. P-values less than 0.05 indicate model terms are significant. In this case A, B, AB, A^2 are significant model terms.

Table 10: Fit Statistics for MDD

Parameters	Values
R^2	0.9803
Adjusted R^2	0.9663
Predicted R^2	0.8634
Adeq Precision	28.8820

The Predicted R^2 of 0.8634 is in reasonable agreement with the Adjusted R^2 of 0.9663; i.e. the difference is less than 0.2. Adeq Precision ratio of 28.9 indicates an adequate signal. The model equation for MDD is shown in Equation 2.

$$\text{MDD} = 0.86 + 0.184\,\text{wgp} + 0.076\text{cement} + -0.02\,\text{wgp(cement)} - 0.009\text{wgp}^2 + 0.002\text{cement}^2 \quad \text{... (2)}$$

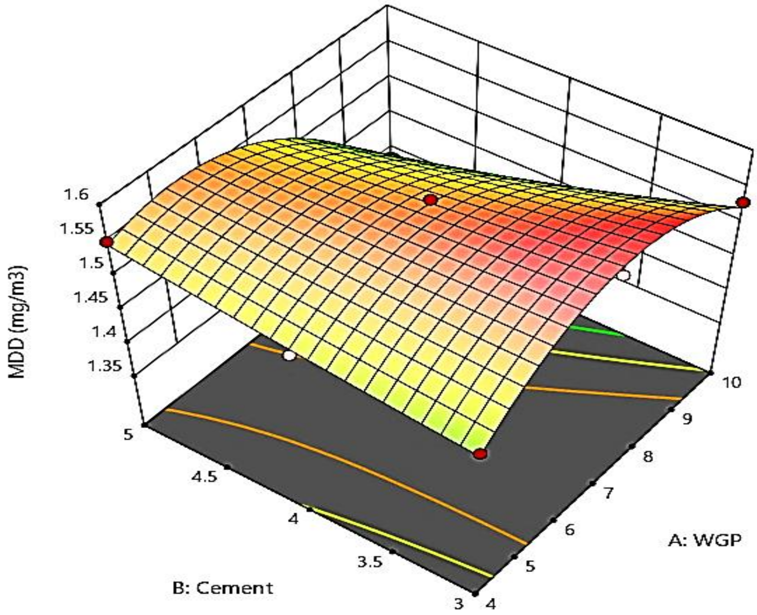


Figure 3: 3-D Response Graph of Effect of WGP and Cement on MDD

Figure 3 shows the 3D surface graph of interaction between WGP and cement and the influence on maximum dry density. The 3-D surface reveals the correlation between the MDD and the independent variables (WGP and Cement). The graph shows that increase in WGP shows significant increase in MDD from 4 to 7% before it declines while cement caused slight increase in MDD from 3 to 5%.

4.2.3 Result of Linear shrinkage

The ANOVA result of linear shrinkage is presented in Table 11 and the Fit statistics in Table 12.

Table 11: ANOVA for Linear Shrinkage

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	8.14	5	1.63	264.29	< 0.0001
A-WGP	7.26	1	7.26	1179.02	< 0.0001
B-Cement	0.5400	1	0.5400	87.70	< 0.0001
AB	0.0100	1	0.0100	1.62	0.2432
A²	0.2155	1	0.2155	34.99	0.0006
B²	0.0174	1	0.0174	2.82	0.1369
Residual	0.0431	7	0.0062		
Lack of Fit	0.0431	3	0.0144		
Pure Error	0.0000	4	0.0000		
Cor Total	8.18	12			

The Model F-value of 264.29 implies the model is significant. P-values less than 0.05 indicate model terms are significant. In this case A, B, A^2 are significant model terms. Values greater than 0.1 indicate the model terms are not significant.

Table 12: Fit Statistics for Linear Shrinkage

Parameter	Value
R^2	0.9947
Adjusted R^2	0.9910
Predicted R^2	0.9641
Adeq Precision	52.5227

In Table 13, the Predicted R^2 of 0.9641 is in reasonable agreement with the Adjusted R^2 of 0.9910; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio of 52.5227 indicates an adequate signal. The model equation for linear shrinkage is shown in Equation 3.

$$\text{LS} = 12 - 0.87\ \text{wgp} - 1.05\ \text{cement} + 0.017\ \text{wgp}\ (\text{cement}) + 0.03\ \text{wgp}^2 + 0.079\ \text{cement}^2 \quad \ldots (3)$$

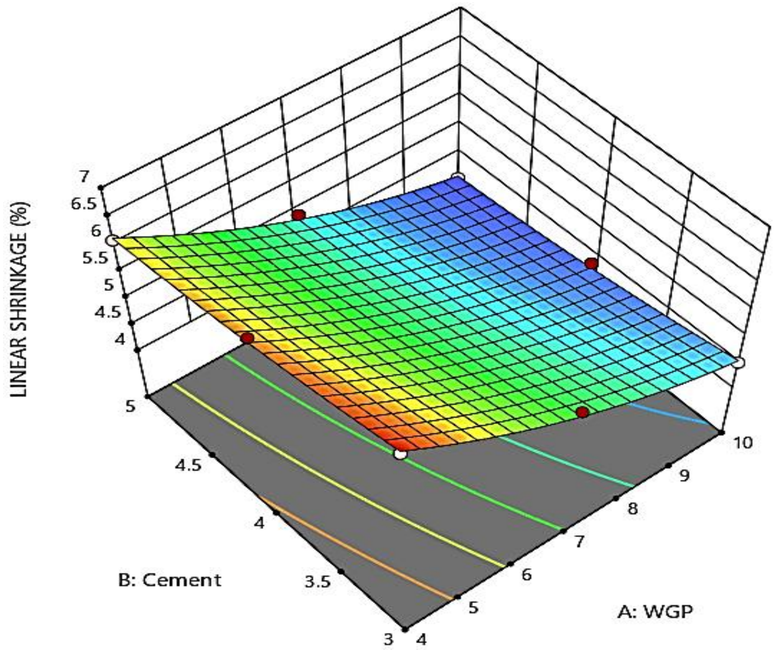


Figure 4: 3-D Response Graph of WGP and Cement on LS

Figure 4 shows 3D response surface graph of interaction between WGP, cement and the influence on linear shrinkage. The graph shows that increase in percentage of WGP causes a decrease in Linear shrinkage properties.

4.2.4 Result of UCS at 7 Days

The ANOVA result of UCS at 7 days is presented in Table 13 and the Fit statistics in Table 14.

Table 13: ANOVA for UCS at 7 Days

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	15457.02	5	3091.40	74.29	< 0.0001
A-WGP	14701.50	1	14701.50	353.29	< 0.0001
B-Cement	266.67	1	266.67	6.41	0.0391
AB	6.25	1	6.25	0.1502	0.7099
A^2	2.48	1	2.48	0.0597	0.8140
B^2	435.13	1	435.13	10.46	0.0144
Residual	291.29	7	41.61		
Lack of Fit	291.29	3	97.10		
Pure Error	0.0000	4	0.0000		
Cor Total	15748.31	12			

The Model F-value of 74.29 implies the model is significant. The P-values less than 0.05 indicate model terms are significant. In this case A, B, B^2 are significant model terms.

Table 14: Fit Statistics for UCS at 7 Days

Parameter	Value
R^2	0.9815
Adjusted R^2	0.9683
Predicted R^2	0.8272
Adeq Precision	26.6901

The Predicted R^2 of 0.8272 is in reasonable agreement with the Adjusted R^2 of 0.9683; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio of 26.69 indicates an adequate signal. The model equation for UCS at 7 days is shown in Equation 4.

$$UCS\ at\ 7\ days = -57.6 + 13.4\,wgp + 104.2\,cement + 0.42\,wgp\,(cement) + 0.105\,wgp^2 - 12.5\,cement^2 \quad \ldots (4)$$

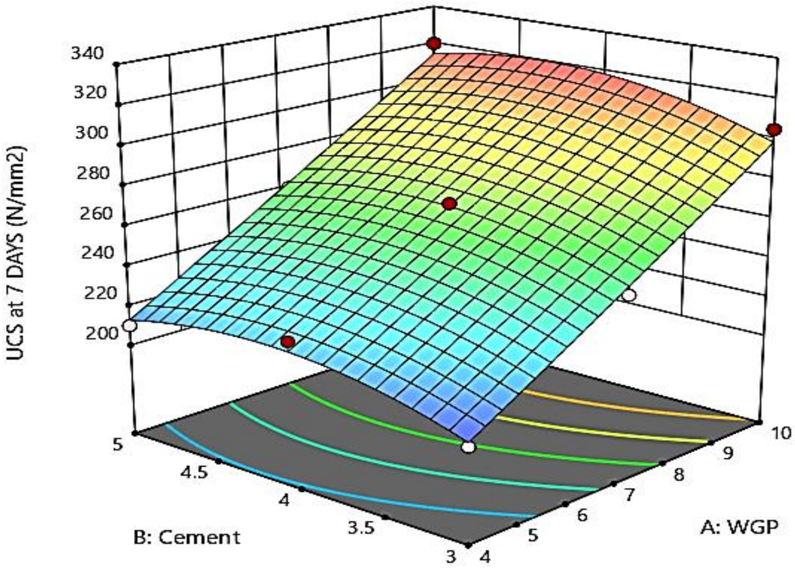


Figure 5: 3-D Response Graph of WGP and Cement on UCS at 7 Days

Figure 5 shows 3D response surface graph of interaction between WGP, Cement and the influence on UCS at 7 days. The graph shows that increase in percentage of cement causes a slight increase in UCS while an increase in WGP causes a significant increase in UCS. The high increase in UCS by WGP is connected to the its high pozzolanic properties.

4.2.5 Result of UCS at 28 days

The ANOVA result of unconfined compressive strength at 28 days is presented in Table 15 and the Fit statistics in Table 16.

Table 15: ANOVA for UCS at 28 Days

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	2.196E+05	5	43917.55	137.54	< 0.0001
A-WGP	1.922E+05	1	1.922E+05	602.07	< 0.0001
B-Cement	9841.50	1	9841.50	30.82	0.0009
AB	6400.00	1	6400.00	20.04	0.0029
A^2	1131.59	1	1131.59	3.54	0.1018
B^2	11052.18	1	11052.18	34.61	0.0006
Residual	2235.17	7	319.31		
Lack of Fit	2235.17	3	745.06		
Pure Error	0.0000	4	0.0000		
Cor Total	2.218E+05	12			

The Model F-value of 137.54 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.05 indicate model terms are significant. In this case A, B, AB, B^2 are significant model terms.

Table 16: Fit Statistics for UCS at 28 Days

Parameter	Value
R^2	0.9899
Adjusted R^2	0.9827
Predicted R^2	0.8974
Adeq Precision	36.1621

Table 21 shows that the Predicted R^2 of 0.8974 is in reasonable agreement with the Adjusted R^2 of 0.9827. Adeq Precision of 36.1621 indicates an adequate signal. Model equation for UCS at 28 days is shown in Equation 5.

$$UCS\ at\ 28\ days = -498 - 25.15\ wgp + 453\ cement + 13.3\ wgp(cement) + 2.24\ wgp^2 - 63.3\ cement^2 \quad \ldots (5)$$

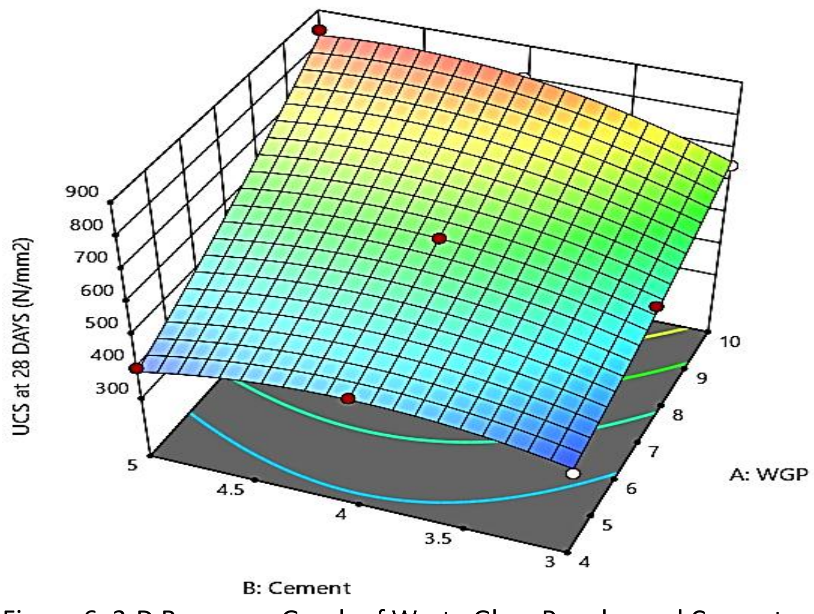


Figure 6: 3-D Response Graph of Waste Glass Powder and Cement on UCS at 28 Days

Figure 6 shows 3D response surface graph of interaction between WGP, Cement and the influence on UCS at 28 days. The 3-D surface elucidates the correlation between the dependent variables (responses) and the independent variables (factors). The graph shows that increase in percentage of cement causes a slight increase in UCS while an increase in WGP causes a significant increase in UCS at 28 days. The high increase by WGP is connected to the its high pozzolanic properties.

4.2.6 Result of soaked CBR (SCBR)

The result of CBR (Soaked) of the soil at different replacement is presented in Table 17 and the Fit statistics in Table 18.

Table 17: ANOVA of Quadratic Model for **S**CBR

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	1166.84	5	233.37	192.67	< 0.0001
A-WGP	895.48	1	895.48	739.31	< 0.0001
B-Cement	21.28	1	21.28	17.57	0.0041
AB	0.4900	1	0.4900	0.4045	0.5450
A^2	181.44	1	181.44	149.80	< 0.0001
B^2	6.26	1	6.26	5.17	0.0572
Residual	8.48	7	1.21		
Lack of Fit	8.48	3	2.83		
Pure Error	0.0000	4	0.0000		
Cor Total	1175.32	12			

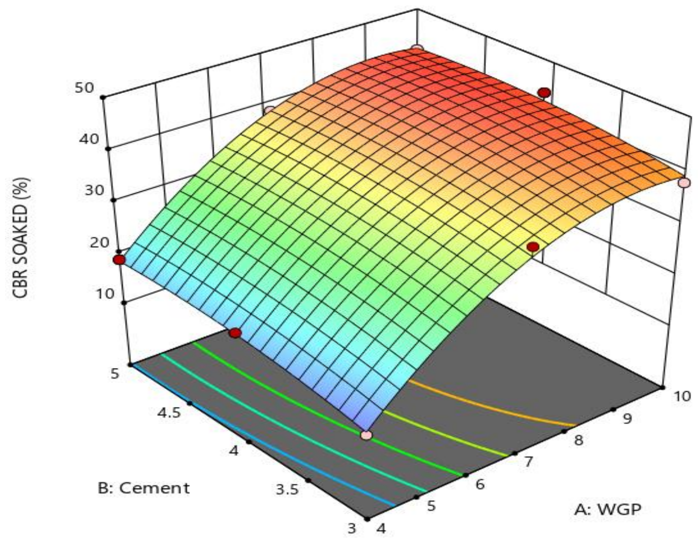
The Model F-value of 192.67 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case A, B, A^2 are significant model terms. Values greater than 0.1 indicate the model terms are not significant.

Table 18: Fit Statistics for SCBR

Parameters	Value
R^2	0.9928
Adjusted R^2	0.9876
Predicted R^2	0.9399
Adeq Precision	37.7163

The Predicted R^2 of 0.9399 is in reasonable agreement with the Adjusted R^2 of 0.9876; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 37.7163 indicates an adequate signal. The model equation for soaked CBR is shown in Equation 6.

$$SCBR = -69.4 + 17.2\,wgp + 14.7\,cement - 0.12\,wgp\,(cement) - 0.9\,wgp^2 - 1.5\,cement^2 \quad \ldots (6)$$



The Figure 7 shows 3D response surface graph of interaction between WGP, Cement and the influence on CBR (soaked). The graph shows that increase in WGP and Cement causes increase in CBR (soaked).

4.2.7 Result of Unsoaked CBR (UCBR)

The analysis of variance and Fit statistics for UCBR are presented in Table 19 and 20 respectively.

Table 19: ANOVA for Unsoaked CBR

Table 19: ANOVA for Unsoaked CBR

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	1416.84	7	202.41	2608.79	< 0.0001
A-WGP	24.50	1	24.50	315.78	< 0.0001
B-Cement	264.50	1	264.50	3409.11	< 0.0001
AB	90.25	1	90.25	1163.22	< 0.0001
A^2	0.0525	1	0.0525	0.6772	0.4480
B^2	140.72	1	140.72	1813.71	< 0.0001
A^2B	14.08	1	14.08	181.52	< 0.0001
AB^2	14.08	1	14.08	181.52	< 0.0001
A^3	0.0000	0	0.0776		
B^3	0.0000	0	0.3879		
Residual	0.3879	5	0.0000		
Lack of Fit	0.3879	1			
Pure Error	0.0000	4			
Cor Total	1417.23	12			

Table 20: Fit Statistics for

Parameters	Value
R^2	0.9997
Adjusted R^2	0.9993
Predicted R^2	0.9682
Adeq Precision	178.434

The Model F-value of 2608.79 implies the model is significant. P-values less than 0.05 indicate model terms A, B, AB, B^2, A^2B, AB^2 are significant model terms.

The Predicted R^2 of 0.9997 is in reasonable agreement with the Adjusted R^2 of 0.9993; i.e. the difference is less than 0.2. Adeq Precision ratio of 178.434 indicates an adequate signal. The model equation for UCBR is shown in Equation 7.

$$\text{UCBR} = 75 + 3.5\,\text{wgp} + 11.5\,\text{cement} - 4.75\,\text{wgp (cement)} - 0.14\,\text{wgp}^2 - 7.14\,\text{cement}^2 + 3.25\,\text{wgp}^{2B} - 3.25 * \text{wgp(cement)}^2$$

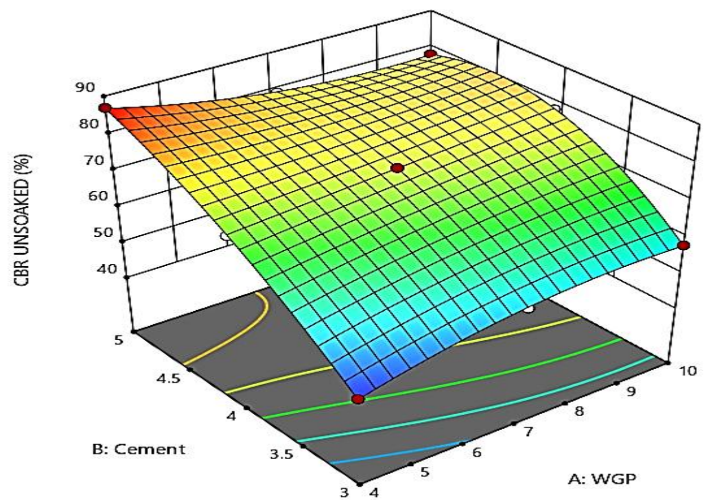


Figure 8: 3-D Response Graph of Effect of WGP and Cement on Unsoaked CBR

The Figure 8 shows 3D surface graph of interaction between WGP, Cement and the influence on Unsoaked CBR. The graph shows that increase in both WGP and Cement increase the value of unsoaked CBR of the black cotton soil.

4.3 Optimization of Mixtures by Numerical Method

The automatic optimization function is shown in Figure 9 with desirability of 0.804

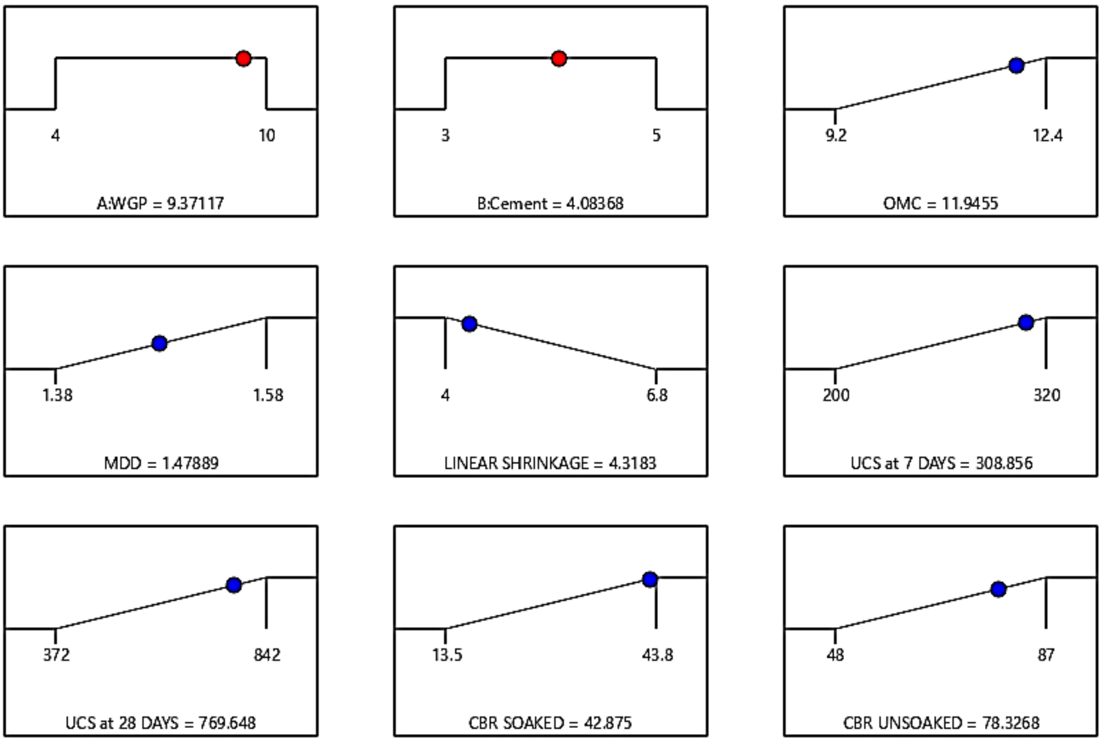


Figure 9: Ramp Plot Showing the Optimal Values for Factors and Responses

5.0 CONCLUSION

The natural black cotton soil (BCS) is highly plastic, with a liquid limit of 68 %, a plastic limit of 35 % and a plasticity index of 33 %, classifying it as A-7-6 (AASHTO) and CH (USCS); only 8.7 % passes the BS No 200 sieve, indicating montmorillonite dominance, and its strength is poor (UCS = 124 kN/m², soaked CBR = 18 %, unsoaked CBR = 34 %), failing Nigeria's 1997 general specification. When the soil is treated with waste glass powder (WGP) and cement, the UCS rises to 308.8 N/mm² after 7 days and 770 N/mm² after 28 days, while soaked CBR reaches 42.8 % and unsoaked CBR 78.3 %.

An optimized mix using rice husk ash (RHA) and granite tile powder (GTP) achieves an optimum moisture content of 11.9 %, a maximum dry density of 1.47 g/cm³, reduced linear shrinkage of 4.3 %, and the same high UCS and CBR values as the WGP-cement mix.

Reference

1) Abdulkarim I. I, Musa A., Adetoye O., (2025). Investigating the Effect of Waste Glass Powder on Properties of Cement-Stabilized Adobe Bricks. *Adeleke University Journal of Engineering and Technology (AUJET).* Vol. 8, No 1, 179 – 183.
2) Ahmad M. A. Y. (2020). Geotechnical Study of the Properties of Black Cotton Soil Treated with Cement and Bone Ash as Admixture. *Journal of Construction and Building Materials Engineering*, 5 (2).
3) Akanbi, D.O. (2010). Engineering properties of black cotton soil stabilized with industrial waste cement. An unpublished B.Eng. Project of Civil Eng. Dept. ATBU Bauchi State
4) Akinola J. O. and Rapheal R. A. (2022). California Bearing-Ratio Characteristics and Behaviors of Black Cotton Soil on Basement Complex of Part of South-Western Nigeria. *International Journal of Advanced Geotechnic and Impact Engineering* Vol. 2, Issue 1, Pp 55-63
5) Akinwande, J., and Aderinola O. R. (2020). Sub-Soil Investigation of a Proposed Construction Site at Ado-Ekiti, South Western, Nigeria. 7: 11471- 11476.
6) Aliyu A., Abdulkarim I. I. and Umar S. Y., (2022). effect of mining tailing waste on properties of cement stabilized black cotton soil. *Global Journal of Engineering and Technology Advances*, 2022, 11(03), 031–036. https://doi.org/10.30574/gjeta.2022.11.3.0090

7) Anigilaje B. Salahudeen, A. O. (2019). Microanalysis and Compactive Efforts Study of Black Cotton Soil Treated with Cement Kiln Dust. *FUOYE Journal of Engineering and Technology*, 2579-0617
8) Annafi Q., Babatunde, E. A. (2020). Effect of Elapsed Time after Mixing on the Strength Properties of Lime–Iron Ore Tailings Treated Black Cotton Soil as a Road Construction Material. *Infrastructure*, 5 (89)
9) Bhagwan S. L., Yadav R. K (2021). Stabilization of Black Cotton Soil using Quick Lime and Waste Glass Powder (WGP). *International Journal of Research Publication and Reviews* Vol (2) Issue (6) (2021) Page 114—120
10) Chethan B. A. and Ravi Shankar A. U. (2021). Effect of Flash Flood and Weather Changes on Unconfined Compressive Strength of Cement- and Fly Ash-Stabilized Black Cotton Soil Used as Road Materials, *International Journal of Pavement Research and Technology- Springer Science and Business Media*, https://doi.org/10.1007%2Fs42947-021-00125-y
11) Etim, R. K., Eberemu, A. O., & Osinubi, K. J. (2017). Stabilization of black cotton soil with lime and iron ore tailings admixture. *Transportation Geotechnics*, 10, 85-95.
12) Garg R., Biswas T., Kumar A., Siddharth A., and Singh D. R. (2021). Stabilization of expansive soil by using industrial waste, *Journal of Physics*: Conference Series- IOP publishing, (1) 2070: 012238, https://doi.org/10.1088%2F1742-6596%2F2070%2F1%2F012238
13) Ibrahim A. Ikara, (2019). Predicting CBR Values of Black Cotton Soil Stabilized with Cement and Waste Glass Admixture Using Regression Model. *American Journal of Traffic and Transportation Engineering*. Vol. 4, No. 1, 2019, pp. 31-36. doi: 10.11648/j.ajtte.20190401.15.
14) Jayaganesh M. K. (2020). Effect of Polymeric Resins on Geotechnical Properties of Black Cotton Soil. Jayaganesh Kuppusamy, Muthumani Krishnamurthy, 8 (5), 1781-1785
15) Kankia M. U, (2021). Optimization of Cement-Based Mortar Containing Oily Sludge Ash by Response Surface Methodology. 2021. 14(21): p. 6308.
16) KPrabin, A. B. (2020). Performance Study on Soil and Stabilization Using E-Waste. *European Journal of Molecular & Clinical Medicine*
17) Mai-Bade U.Y., Chinade A.U., Batari A., and Saeed S.M., (2021). Stabilization of Black Cotton Soil Using Various Admixtures: A Review, *Composite Materials*. (5) 2:37-45. doi: 10.11648/j.cm.20210502.12
18) Majeed M. and Tangri A.P. (2021). Stabilization of soil using industrial wastes, Conference Series: Earth and Environmental Science-IOP publishing, https://doi.org/10.1088%2F1755-1315%2F889%2F1%2F012018, (889)1:
19) Matawal, D. S. (2012). "Deformation of soils" Cephas and Clems publisher, Nigeria. Chandana G.S, Charan S.H, Sree Y.J, Reddy M.S, Reddy R.R, Sumanth J.V., (2025). Stabilization of Black Cotton Soil by Using Type-C Glass Fiber. *Building Materials and Engineering Structures*, Vol 3 (1) March 2025, 25-32. http://doi.org/10.46632/bmes/3/1/4
20) Matawal, D. S., Umar, S. Y and Bala, Y. U. (2006). "Effect of Oil Palm Ash (OPA) on cement Stabilized Soil". *Journal of civil Engineering. Nigerian Institute of civil Engineers*. Volume 5, No.3. pp.5-12.
21) Miao, S., Shen, Z., Wang, X., Luo, F., Huang, X., & Wei, C. (2017). Stabilization of highly expansive black cotton soils by means of geopolymerization. *Journal of Materials in Civil Engineering,* 29(10), 04017170.
22) Nanda P. (2021). Black Cotton Soil Stabilization by Using Fly Ash - Kota Stone Slurry Mix, *International Journal for Research in Applied Science and Engineering Technology*, (11) 9: 1699-1703.Dio.10.22214/ijraset.2021.39086
23) Navagire O. P, Sharma S. K., and Rambabu D. (2021). Stabilization of black cotton soil with coal bottom ash, Materials Today: Proceedings- Elsevier, 52: 979--985, https://doi.org/10.1016%2Fj.matpr.2021.10.447
24) Nilesh S. Pawar, Tejas N. Rasal, Sourabh B. Shinde, Supriya S. Gavade, Mrunali M. Kagwade, Neha A. Wadkar (2021). Stabilization of Black Cotton Soil Using Crushed Glass. *International Journal of Advances in Engineering and Management* (IJAEM) Volume 3, Issue 6 June 2021, pp: 367-372
25) Nooraien H., Priya G., Prajwal B., Shimna M., (2020): Utilization of Recycled Glass Powder for the Stabilization of Black Cotton soil by Alkali Activation, IOP Conference Series: *Materials Science and Engineering* 955 (2020) 012063
26) Omisande, L. A. (2020). Stabilization of Black Cotton Soil Using Fly Ash. *Ilaro Journal of Environmental Research & Development* (2020) (4), (1) 13 – 20
27) Premkumar R, Subha B, Sandhiya P. S., and Narayanan S. K., (2021). Stabilization of Black Cotton Soil with Groundnut Shell Ash, *Materials Research Proceedings*, 19: 44-50
28) Rizgar A. B., Aryan F. H., Hawkar H. I., Rabar H. F., Ako D. (2020), "Strength improvement of expansive soil by utilizing waste glass powder", *Case Studies in Construction Materials* 13 (2020) e00427
29) Shanmugavadivu P.M. (2021). Indian Journal of Research - Black cotton soil. Paripex-Indian Journal of Research. 8: 44-45. https://www.researchgate.net/publication/355170343_Indian_Journal_of_Research-_Black_cotton_soil
30) Umaru, I., Alhaji, M. M., Jagaba, A. H, Kutty, S. R. M., Lawal, I. M., Abubakar, S. & Soja, U. B. (2023), The effect of groundnut shell ash and metakaolin on geotechnical properties of black cotton soils. Sustainability Challenges and Delivering Practical Engineering Solutions: R*esources, Materials, Energy, and Buildings. Advances in Science, Technology and Innovation, Springer,* Cham, pp. 177-183. https://doi.org/10.1007/978-3-031-26580-8_27