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Effects of quarry-dust and cement on the hydraulic conductivity of black cotton soil for sustainable landfill liner applications.

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Abstract
This study investigates the effect quarry-dust and cement on hydraulic conductivity of Black cotton soil for sustainable landfill liner applications. Most of construction works involve the use of soil materials. Some of these soil materials include Black cotton soil (BCS) and when encountered may not be suitable for use due to their poor strength. The replacement of black cotton soil with other materials of superior qualities may not be feasible and economical; hence, a suitable stabilization using quarry dust and cement can be employed at optimal percentages to modify the soil in order to upgrade their engineering properties. The silica sesquioxide molar ratio of iron and aluminium was 1.52 which indicates that the soil is lateritic. The MSW Leachate has a pH value of 8.0 which indicates the leachate was collected from old Landfill, and yielded a BOD_5/COD ratio of 0.1 which indicate the presence of high concentration of non-biodegradable organic compounds in the leachate. The tastes carried out include compaction test (OMC, MDD), Volumetric Shrinkage Strain (VSS), Unconfined Compressive strength (UCS), and Hydraulic Conductivity (K). The optimization and models for estimation of responses were done by the design expert. The result shows that the BCS was classified as A-7-6 and CH according to AASHTO and USCS respectively. The soil has a specific gravity of 2.19, moisture content of 0.71%, LL of 44.9% and PL of 28.5%. At natural state of the soil; The OMC was 18.2%, MDD was 1.53Mg/m^3, the Hydraulic conductivity (K) was 8.835x10^{-10}, Unconfined Compressive Strength (UCS) were; 7days 164kN/m^2, 14days 400kN/m^2, 28days 499kN/m^{2}and Volumetric Shrinkage Strain was 19.3%. The replacement of Black Cotton soil with Quarry-dust and cement was best recorded at 30% quarry dust and 6% cement which increase the UCS 7days to 487kN/m^2, 14days to 546kN/m^{2}and 28days to 625kN/m^2, MDD to 1.93% . While decreases the OMC to 8.4%, VSS to 3.43% and Hydraulic Conductivity permeated with leachate to 1.22851x10^{-10}. The optimization has carried out and models were developed for the estimation of Optimum Moisture Content (OMC), Maximum Dry Density (MDD), Hydraulic Conductivity (K), Unconfined Compressive Strength (UCS) and Volumetric Shrinkage Strain (VSS). Finally 30% Quarry-Dust and 6% Cement were best recommended for replacement of BCS in sustainable landfill liner applications.

Key words: black cotton soil (BCS), quarry dust (QD), municipal solid waste (MSW), hydraulic conductivity (K), volumetric shrinkage strain (VSS), unconfined compressive strength (UCS), unified soil classification system (USCS), American association of state highway officials (AASHTO), Portland cement

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I. Introduction

Leachate is a hazardous liquid which percolates through the landfills and extracts dissolved and suspended hazardous matter from it. Large quantities of municipal solid waste which consists of chemical, industrial and biomedical wastes are received in solid dump yards, which create environmental problems such as pollution of soil and groundwater. In this study, laboratory tests are conducted on both leachate-contaminated and uncontaminated prepared soil samples to determine the effects of leachate on the performance of engineering properties of the samples.

Municipal solid waste management is one of the greatest challenges facing the environmental protection agencies in Nigeria (Ityona, 2012). Further, solid waste management in Nigeria is characterized by insufficient collection methods, insufficient coverage of the collection system and improper disposal of solid waste. The consequence is such that most Nigerian towns and cities dispose of their trash in open dumps situated all over the environment.

Municipal solid waste accumulates in landfills and decomposes by the combination of physical, chemical and biological processes (Afshin *et al.,* 2011). This process produces a contaminated hazardous liquid called leachate. Liners are affected by leachate produced due to the decomposition of waste materials (Das & Sudha, 2016) Leachate is produced when water percolates through the waste in the landfill (Afshin *et al.,* 2011). Leachate is a great and major concern in municipal waste disposal landfills (I. N. Umar & Hassan, 2015). The main concern is to prevent the contamination of soil and groundwater by the leachate that is generated from the decomposition of the municipal solid waste inside disposal landfill (Kjeldsen & Bedding, 2011). Black cotton soils are soils which swell and shrink excessively due to changes in moisture content. When structures are built on expansive soils, they experience either settlement or heave depending on the swelling pressure of the soil. The design and construction of civil engineering structures on expansive soils pose a serious challenge to civil engineers

Black cotton soils (BCS) are clays or very fine silts that exhibit large volume changes, to swell, shrink and dry-crack, depending on the increase or decrease in moisture content. Black cotton soils (BCS) are found predominantly in the Northeastern part of Nigeria, lying within the Chad Basin and partly within the Benue trough (Osinubi *et al.,* 2022) The swell-shrink movements in expansive soils have historically caused frequent problems because of the unpredicted upward movements of structures or cracks in pavements resting on them. In addition, they also affect the serviceability performance of lightweight structures supported on them.

Black cotton soils are expensive clays with the potential for shrinking or swelling under changing moisture conditions. These cause damage to structures, particularly light buildings and pavements. They are produced from the breakdown of basic igneous rocks where the seasonal variation of weather is extreme (Osinubi *et al.,* 2023). They are known as Vertisols, Chernozems, Gilgais, seif-touching soils, self-swallowing soils, black cotton soils, cracking clays, vleis and wadi soils (Denison *et al.,* 2011)

Perhaps one of the most documented cases in soil improvement studies was recorded by (Heck *et al.,* 2017) He stated that it was possible to stop the differential settlement of multi-storey buildings by freezing the subsoil.

In stabilization, alteration of soil structure is evident. Therefore, in altering the properties of soil to obtain different characteristics, the choice of a particular method of stabilization depends on the nature of the soil application and the cost of the stabilizing agent. However, the most commonly used methods of soil stabilization are broadly classified into: -

i. Mechanical stabilization
ii. Thermal stabilization
iii. Chemical stabilization
iv. Electrical stabilization

(M. Ibrahim *et al.,* 1976) found that stabilization with cement alone in black cotton is not suitable because of the percentage of montmorillonite in the clay which retards hydration and a high percentage of Portland cement would be required to achieve adequate stabilization since the effect of cement on the Atterberg limit was minimum, workability was not improved.

The conventional improvement of the soil with lime and ordinary Portland cement has been confirmed in its requirement for construction works (Randhawa *et al.,* 2022); (Olarewaju & Falola, 2022); (Salahudeen *et al.,* 2023).

In conclusion, all the writers and contributors to stabilization processes tend to achieve one or more of the following:

i. Increase in strength and durability of the soil
ii. Improvement in the workability of soil
iii. Waterproofing of the soil to inhibit the ingress of water
iv. Decrease in the potential for volume change in the soil due to shrinkage and swelling
v. Increase the plasticity index of highly plastic soils.

In view of the nature of black cotton soil, attempts have been made by researchers to stabilize the black soil using various materials, evidenced by the volume of the available literature on the topic, but on the subject; there are limited literatures available on investigating the hydraulic conductivity of black cotton soil stabilized with quarry-dust and cement permeated with resulting leachate.

II. Materials and Methods

A. Materials

Black Cotton soil

Black Cotton soil used in the study is obtained from a borrow pit is in Yamaltu-Deba, Deba LGA of Gombe State Nigeria. The sample was obtained using the method of disturbed sampling at a depth of 1.0 - 1.5 m below the ground level. The soil samples were preserved in polythene bags to prevent moisture loss, and transported to the laboratory for analyzing the engineering properties of the Black Cotton soil. The oxide compositions and the mineralogy of the soil was determined by the X-ray fluorescence (XRP) spectroscopy and ray diffraction (XRD) respectively, at the National Steel Raw Material Exploration Agency (NSRMEA), Malali, Kaduna state.

Quarry dust
The quarry dusts used in the study research is obtained from Triacta quarry site in Gombe state.

Cement
Cement is a building material with a factory finish of fines and is highly pozzolanic.

Municipal Solid Waste Leachate
Municipal solid waste leachate used for this study is collected from an active refuse dump along Tudun Sunnah, Deba Local government area, Gombe state, Nigeria. The chemical compositions of the leachate were determined using an Atomic Absorption Spectrophotometer (AAS) at the Public Health Engineering Laboratory in Abubakar Tafawa Balewa University, Bauchi. The leachate sample was then analyzed for pH and metals such as Calcium (Ca), Copper (Cu), Lead (Pb), Zinc (Zn), Manganese (Mn), Nickel (Ni), Chromium (Cr), Sodium (Na), Magnesium (Mg), Potassium (K), Iron (Fe) and Cadmiurn (Ca). The organic content of the leachate sample was estimated by measuring the biochemical oxygen demand (BOD:) and the Chemical oxygen demand (COD).

B. Method
The following laboratory tests were conducted on the soil sample in accordance to BS 1377: part 2 (1990) at Soil laboratory, Abubakar Tafawa Balewa University. These tests include:

2. Natural moisture content
3. Particle size distribution
4. Atterberg limit
5. Specific gravity
6. Compaction
7. Volumetric Shrinkage strain (VSS)
8. Unconfined Compressive Strength (UCS)
9. Hydraulic conductivity (K)

III. Results and Discussion

3.1 Soil Properties
The results are presented in Table 1 to 4 and Figure 1 to 4, which are discussed below.

Table 1: Properties of the Natural Soil.

S/N	PROPERTY	VALUE
A. Basic Properties		
1.	Natural Moisture Content (%)	0.71
2.	Liquid Limit (%)	44.9
3.	Plastic Limit (%)	25.8
4.	Plasticity Index (%)	19.1
5.	Linear Shrinkage (%)	8.98
6.	Activity	1.4
7.	Specific Gravity	2.19
8.	AASHTO Classification	A - 7 – 6
9.	Clay Soil (AASHTO)	Fair to Poor
10.	USCS Classification	CH
11.	Colour	Dark Grey
B. Particle Size Distribution		
12.	% Passing No. 200 Sieve	82.7

S/N	PROPERTY	VALUE
13.	% Sand (0.075 - 4.76 mm) (%)	17.3
14.	% Gravel (> 4.76 mm) (%)	0
C. Compaction Properties		
15.	Maximum Dry Densities (MDD) (Mg/m^3)	1.53
16.	Optimum Moisture Contents (OMC) (%)	18.2
D. Strength Properties		
17.	7 Days UCS (kN/m^2)	164
18.	14 Days UCS (kN/m^2)	400
19.	28 Days UCS (kN/m^2)	499
E. Volumetric Shrinkage Strain (VSS)		
21.	VSS (%)	19.3
F. Hydraulic Conductivity		
22.	Permeability (m/s)	$8.8385x10^{-10}$

Chemical Properties of the Soil

The oxide composition of the soil determined using the XRF spectroscopy is summarized in Table 2. The major oxides present in the soil are silicon oxide (SiO_2) 51.41%, aluminium oxide (Al_2O_3) 20.29%, iron oxide (Fe_2O_3) 13.20% and calcium oxide (CaO) 3.38%. The silica sesquioxide molar ratio of iron and aluminium obtained by dividing the percentage of silicon oxide (SiO_2) by the summation of the percentages of iron oxide (Fe_2O_3) and aluminium oxide (Al_2O_3) is 1.52 which indicates that the soil is classified as lateritic soil, lateritic soils can be distinguished by other soil type based on the ratio of silicon oxide (SiO_2) to sesquioxide (Fe_2O_3, Al_2O_3). In laterite, the ratio is less than 1.33. Those between 1.33 and 2.0 are termed lateritic soils, and the ratio greater than 2.0 indicates other types of tropical soils (Blight, 1997).

Table 2. Oxide Composition of the Soil

SN.	Oxide		Concentration
1	SiO_2		51.41
2	$A1_2O_3$		20.29
3	MgO		1.22
4	K_2O	0.55	
5	CaO	3.38	
6	Ti_2O		2.73
7	P_2O_5		0.05
8	SO_3	0.06	
9	V_2O_5		0.15
10	Fe_2O_3		13.02
11	MnO		1.08
12	NiO	0.07	
13	CrO_3		0.02
14	Na_2O		0.06
15	ZnO	0.05	

Characteristics of Municipal Solid Waste Leachate

The chemical and biological characteristics of the municipal solid waste leachate are presented in Table 3. The leachate sample has a pH value of 8.0, chemical oxygen demand (COD) of 769.78 mg/l, biological oxygen demand (BOD_5) of 60.5 mg/l and the BOD_5 to COD ratio of 0.10. According to Christensen *et al*. (2001), leachate is generally found to have pH value between 4.5 to 9, but the pH of young leachate is less than 6.5 while old landfill leachate has pH value greater than 7.5. Therefore, a pH of 8.0 indicates that the leachate is from an old landfill. Bhalla *et al*. (2013), reported that the degree of biodegradation of leachate is described by the BOD_5 to COD ratio which also gives information on the age of the landfill. BOD_5 to COD ratio in the range of 0.1 to 0.3 indicate the presence of high concentration of non-biodegradable organic compounds in the leachate.

Table 3: Characteristics of the Municipal Solid Waste Leachate

SN.	Parameters	Results
1	pH	8.0
2	EC (μs/cm)	4442
3	TDS (mg/l)	2633
4	Turbidity (NTU)	75
5	Magnesium Mg^{2+} (mg/l)	0.1345
6	Iron Fe^{2+} (mg/l)	0.2958
7	Manganese Mn^{2+} (mg/l)	0.76221
8	Lead Pb^{2+} (mg/l)	0.06844
9	Nickel Ni^{2+} (mg/l)	1.07913
10	Chromium Cr^{2+} (mg/l)	0.16372
11	Calcium Ca^{2+} (mg/l)	10.9681
12	Sodium Na^{2+} (mg/l)	16662
13	Copper, Cu^{2+} (mg/l)	0.16974
14	Zinc Zn^{2+} (mg/l)	0.18633
15	Cadmium, Cd^{2+} (mg/l)	0.02190
16	Cobal Co^{2+} (mg/l)	0.00449
17	Potassium K^{2+} (mg/l)	4997.10
18	COD (mg/l)	769.78
19	BOD_S (mg/l)	60.5

Table 4: Summary of Experimental Design Results

Run	**Factors**		**Responses**				
	Cem (%)	QD (%)	MDD (Mg/m³)	OMC (%)	UCS 28 days (kN/m²)	K (LEACHATE) (m/s)	VSS (%)
1	3	5	1.75	11.8	541.00	3.9786310^{-10}	5.22
2	4.5	5	1.80	9.9	556.00	3.6514510^{-10}	5.00
3	6	5	1.88	8.4	593.00	3.0447910^{-10}	4.88
4	3	17.5	1.77	11.5	545.00	2.7478110^{-10}	4.17
5	4.5	17.5	1.92	9.4	575.00	2.2318810^{-10}	3.92
6	6	17.5	1.99	7.9	604.00	1.7555710^{-10}	3.85
7	3	30	1.93	10.0	563.00	1.4493210^{-10}	3.63
8	4.5	30	1.99	7.6	592.00	1.3542410^{-10}	3.59
9	6	30	2.03	7.1	625.00	1.2285110^{-10}	3.43

Note: QD=Quarry-dust, BCS=Black cotton soil, OMC=Optimum Moisture Content, MDD=Maximum Dry Density, MSW=Unconfined Municipal solid waste, VSS=Volumetric Shrinkage Strain, K=Hydraulic Conductivity.

3.2 Performance Evaluation Test Results

3.2.1 Optimum Moisture Content (OMC)

The ANOVA result of OMC is presented in Table 5 and the Fit to statistics in Table 6.

Table 5: ANOVA for OMC

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	22.18	5	4.44	101.08	< 0.0001	significant
A-Quarry Dust	4.86	1	4.86	110.76	< 0.0001	
B-Cement	16.34	1	16.34	372.27	< 0.0001	
AB	0.0625	1	0.0625	1.42	0.2716	
A²	0.7389	1	0.7389	16.84	0.0046	
B²	0.5172	1	0.5172	11.79	0.0109	
Residual	0.3072	7	0.0439			
Lack of Fit	0.3072	3	0.1024			
Pure Error	0.0000	4	0.0000			

Cor Total	22.48	12

Table 5 shows the ANOVA for OMC. The model F-value of 101.08 implies the model is significant. P-value less than 0.05 indicate model term is significant. In this case, A is a significant model term. Values greater than 0.1 indicate the model terms are not significant.

Table 6: Fit Statistics for OMC

Parameters	Values
R^2	0.9940
Adjusted R^2	0.9920
Predicted R^2	0.9755
Adeq Precision	77.2974

The **Predicted R^2** of 0.9755 is in reasonable agreement with the **Adjusted R^2** of 0.9920; i.e. the difference is less than 0.2.

Adeq Precision measures the signal to noise ratio. A ratio 77.297 is greater than 4 is desirable. Your ratio of 77.297 indicates an adequate signal. The model equation for OMC is shown in equation 1 and the 3-D response surface is shown in Figure 1.

$$OMC = 9.36207 + -0.9 * A + -1.65 * B + 0.125 * AB + -0.517241 * A^2 + 0.432759 * B^2 \quad \ldots(1)$$

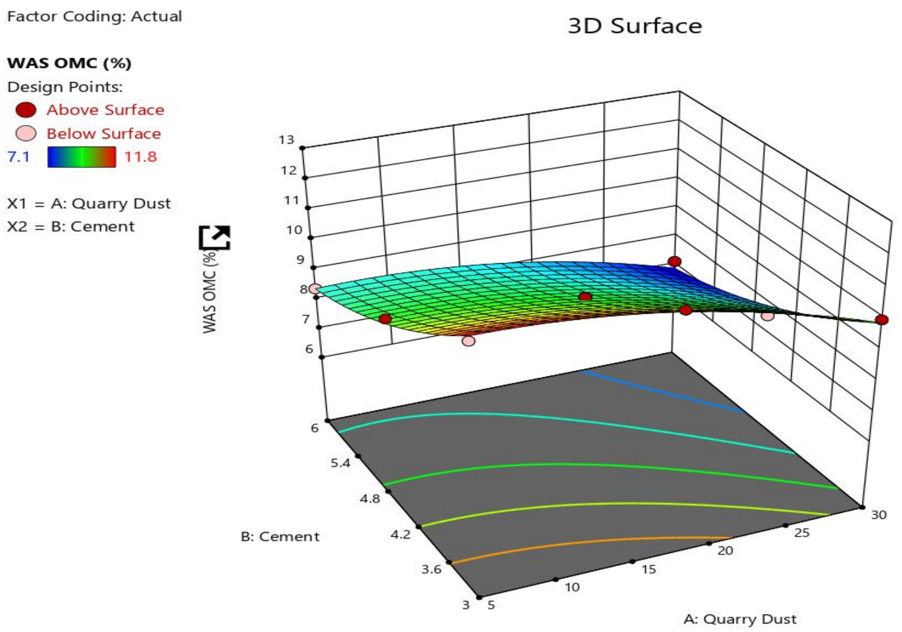

Figure 1: 3-D Response Graph of Effect on Quarry-dust and Cement on OMC

Figure 5 showing 3-D surface graph of the interaction between quarry-dust and cement, and the influence on optimum moisture content. The 3-D surface indicates the correlation between the dependent variable (K) and the independent variables (quarry-dust and cement). The graph shows that an increase in quarry-dust and cement causes a decrease in OMC.

3.2.2 Maximum Dry Density (MDD)

The ANOVA result of MDD is presented in Table 7 and the Fit to statistics in Table 8.

Table 7: ANOVA for MDD

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.0788	2	0.0394	57.44	< 0.0001	significant
A-Quarry Dust	0.0451	1	0.0451	65.69	< 0.0001	
B-Cement	0.0337	1	0.0337	49.20	< 0.0001	
Residual	0.0069	10	0.0007			
Lack of Fit	0.0069	6	0.0011			

Pure Error	0.0000	4	0.0000		
Cor Total	0.0857	12			

Table 7 shows the ANOVA for MDD. The model F-value of 57.44 implies the model is significant. P-value less than 0.05 indicate model term is significant. In this case, B is a significant model term. Values greater than 0.1 indicate the model terms are not significant.

Table 8: Fit Statistics for MDD

Parameters	Values
R^2	0.9199
Adjusted R^2	0.9039
Predicted R^2	0.8480
Adeq Precision	25.6975

The **Predicted R^2** of 0.8480 is in reasonable agreement with the **Adjusted R^2** of 0.9039; i.e. the difference is less than 0.2.

Adeq Precision measures the signal to noise ratio. A ratio of 25.6975 is greater than 4 is desirable. Your ratio of 25.698 indicates an adequate signal. The model equation for MDD is shown in equation 1 and the 3-D response surface is shown in Figure 2.

$$MDD = 1.90308 + 0.0866667 * A + 0.075 * B \quad \ldots(4)$$

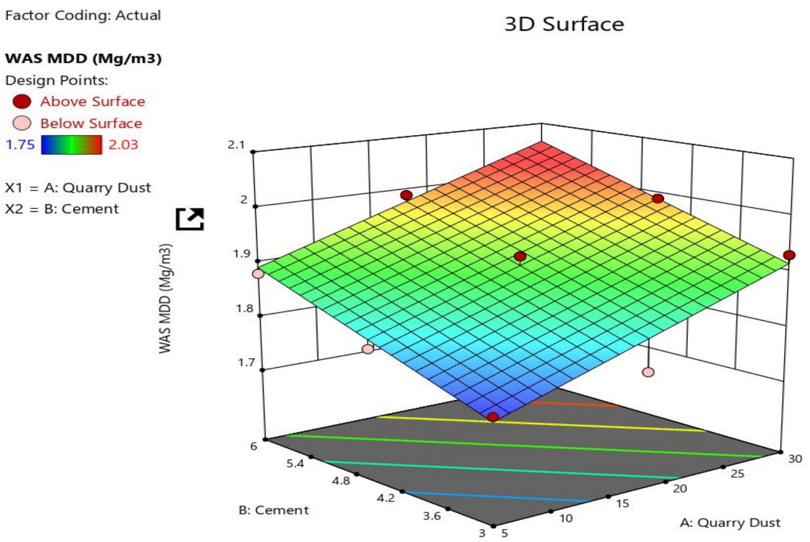

Figure 2: 3-D Response Graph of Effect on Quarry-dust and Cement on MDD

Figure 5 showing 3-D surface graph of the interaction between quarry-dust and cement, and the influence on maximum dry density. The 3-D surface indicates the correlation between the dependent variable (response) and the independent variables (factors). The graph shows the increase in quarry-dust and cement has influence in the increase of UCS.

3.2.3 Unconfined Compressive Strength (UCS)

The ANOVA result of UCS is presented in Table 9 and the Fit to statistics in Table 10.

Table 9: ANOVA for UCS

Source	Sum of Squares	Df Mean	Square	F-value	p-value	
Model	9020.42	3	3006.81	495.08	< 0.0001	Significant
A-Quarry Dust	2281.50	1	2281.50	375.66	< 0.0001	
B-Cement	6666.67	1	6666.67	1097.69	< 0.0001	

AB	72.25	1	72.25	11.90	0.0073
Residual	54.66	9	6.07		
Lack of Fit	54.66	5	10.93		
Pure Error	0.0000	4	0.0000		
Cor Total	9075.08	12			

Table 9 shows the ANOVA for UCS. The model F-value of 495.08 implies the model is significant. P-value less than 0.05 indicate model term is significant. In this case, B is a significant model term. Values greater than 0.1 indicate the model terms are not significant.

Table 10: Fit Statistics for UCS

Parameters	**Values**
R^2	0.9940
Adjusted R^2	0.9920
Predicted R^2	0.9755
Adeq Precision	77.2974

The **Predicted R^2** of 0.9755 is in reasonable agreement with the **Adjusted R^2** of 0.9920; i.e. the difference is less than 0.2.

Adeq Precision measures the signal to noise ratio. A ratio is 77.297 greater than 4 is desirable. Your ratio of 77.297 indicates an adequate signal. The model equation for MDD is shown in equation 1 and the 3-D response surface is shown in Figure 3.

$$UCS = 574.385 + 19.5 * A + 33.3333 * B + -4.25 * AB \quad \ldots(3)$$

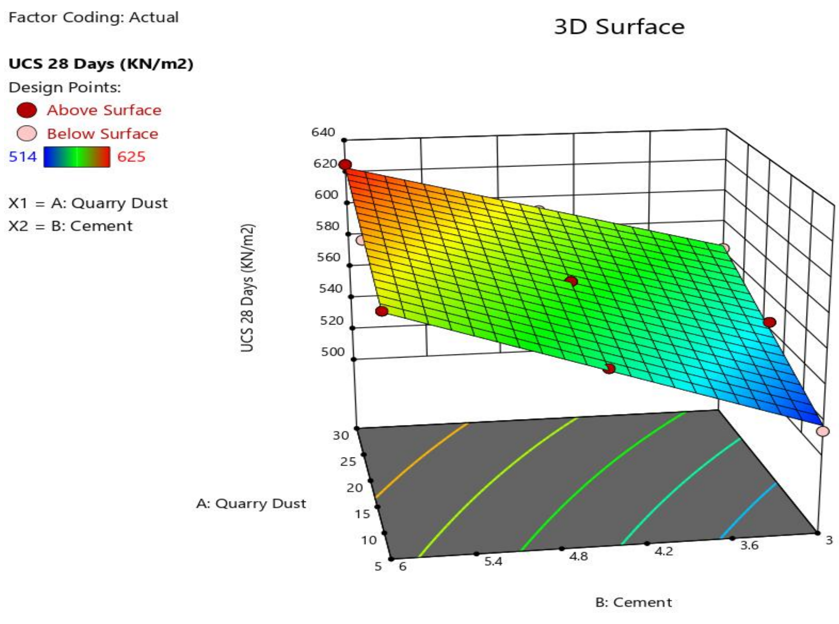

Figure 3: 3-D Response Graph of Effect on Quarry-dust and Cement on UCS

Figure 5 showing 3-D surface graph of the interaction between quarry-dust and cement, and the influence on UCS. The 3-D surface indicates the correlation between the dependent variable (UCS) and the independent variables (quarry-dust and cement). The graph shows that an increase in the percentage quarry-dust and cement causes a significant increase in UCS.

3.2.4 Volumetric Shrinkage Strength (VSS)

The ANOVA result of UCS is presented in Table 11 and the Fit to statistics in Table 12.

Table 11: ANOVA for UCS

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	3.82	5	0.7641	482.28	< 0.0001	significant
A-Quarry Dust	3.30	1	3.30	2083.07	< 0.0001	
B-Cement	0.1233	1	0.1233	77.80	< 0.0001	
AB	0.0049	1	0.0049	3.09	0.1221	
A^2	0.2992	1	0.2992	188.84	< 0.0001	
B^2	0.0054	1	0.0054	3.40	0.1079	
Residual	0.0111	7	0.0016			
Lack of Fit	0.0111	3	0.0037			
Pure Error	0.0000	4	0.0000			
Cor Total	3.83	12				

Table 11 shows the ANOVA for VSS. The model F-value of 482.28 implies the model is significant. P-value less than 0.05 indicate model term is significant. In this case, A, B and A^2 are significant model term. Values greater than 0.1 indicate the model terms are not significant.

Table 12: Fit Statistics for MDD

Parameters	Values
R^2	0.9971
Adjusted R^2	0.9950
Predicted R^2	0.9760
Adeq Precision	65.4541

The **Predicted R^2** of 0.9760 is in reasonable agreement with the **Adjusted R^2** of 0.9950; i.e. the difference is less than 0.2.

Adeq Precision measures the signal to noise ratio. A ratio 65.454 is greater than 4 is desirable. Your ratio of 65.454 indicates an adequate signal. The model equation for VSS is shown in equation 1 and the 3-D response surface is shown in Figure 4.

$$VSS = 3.9331+-0.741667*A+-0.143333*B+0.035*AB+0.329138*A^2+0.0441379*B^2 \quad \ldots(4)$$

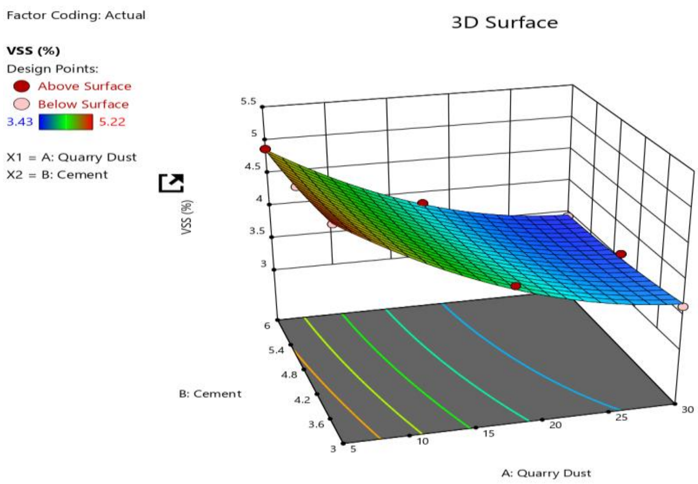

Figure 4: 3-D Response Graph of Effect on Quarry-dust and Cement on VSS

Figure 5 showing 3-D surface graph of the interaction between quarry-dust and cement, and the influence on volumetric shrinkage strain. The 3-D surface indicates the correlation between the dependent variable (VSS) and the independent variables (quarry-dust and cement). The graph shows that an increase in quarry-dust and cement reduces the VSS.

3.2.5 Hydraulic Conductivity (K)

The ANOVA result of K is presented in Table 13 and the Fit to statistics in Table 14.

Table 13: ANOVA for K

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	8.40	5	1.68	170.22	< 0.0001	significant
A-Quarry Dust	7.35	1	7.35	745.25	< 0.0001	
B-Cement	0.7682	1	0.7682	77.84	< 0.0001	
AB	0.1271	1	0.1271	12.88	0.0089	
A^2	0.1385	1	0.1385	14.04	0.0072	
B^2	0.0020	1	0.0020	0.2068	0.6631	
Residual	0.0691	7	0.0099			

Table 13 shows the ANOVA for VSS. The model F-value of 170.22 implies the model is significant. P-value less than 0.05 indicate model term is significant. In this case, A and B are significant model term. Values greater than 0.1 indicate the model terms are not significant.

Table 14: Fit Statistics for MDD

Parameters	Values
R^2	0.9918
Adjusted R^2	0.9860
Predicted R^2	0.9195
Adeq Precision	43.4133

The **Predicted** R^2 of 0.9195 is in reasonable agreement with the **Adjusted** R^2 of 0.9860; i.e. the difference is less than 0.2.

Adeq Precision measures the signal to noise ratio. A ratio 43.413 is greater than 4 is desirable. Your ratio of 43.413 indicates an adequate signal. T The model equation for K is shown in equation 1 and the 3-D response surface is shown in Figure 5.

$$K = 2.24531+-1.10713*A+-0.357815*B+0.178258*AB+0.223972*A^2+-0.0271829*B^2 \quad \ldots(5)$$

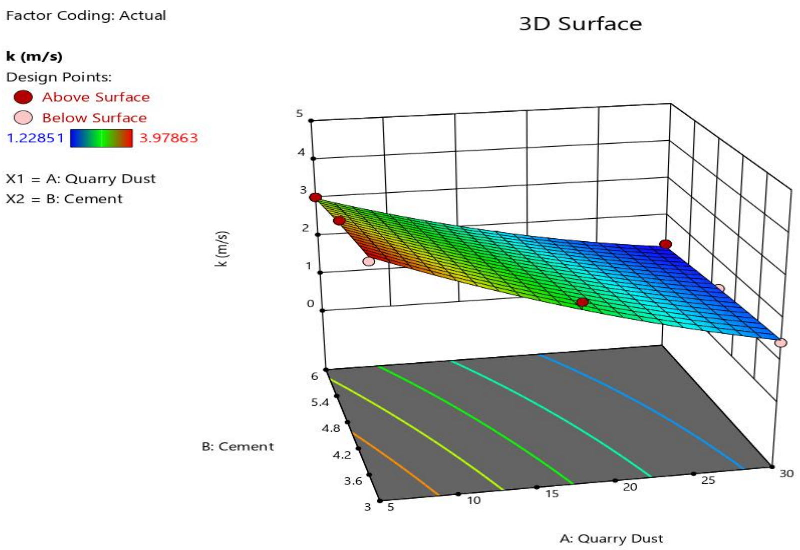

Figure 5: 3-D Response Graph of Effect on Quarry-dust and Cement on K

Figure 5 showing 3-D surface graph of the interaction between quarry-dust and cement, and the influence on hydraulic conductivity. The 3-D surface indicates the correlation between the dependent variable (K) and the independent variables (quarry-dust and cement). The graph shows that an increase in quarry-dust and cement reduces the K.

IV. Conclusions

After the experimental work, the following conclusions were made:

i. The Black Cotton soil used in this study was classified as A-7-6 and CH soil in accordance with the American Association of State Highway Transportation Officials and Unified Soil Classification System. The soil is Lateritic with Silica sesquioxide ratio of 1.52, OMC was 18.2%, and MDD was 1.53 Mg /m3. The soil has specific gravity of 2.19, natural moisture content of 0.71%, LL of 44.9%, PL of 25.8%.

ii. The leachate is old and is slightly Alkaline with pH value of 8.0 and indicate the presence of high concentration of non-biodegradable organic compound with BOD_5 to COD ratio of 0.10

iii. The Maximum Dry Density (MDD) increased with the addition of quarry fines and cement percentage while the Optimum Moisture Content (OMC) decreased with higher quarry fines content and cement for all the compaction energies, the best results were recorded when 30% quarry-dust and 6% cement were use.

iv. The replacement of black cotton soil with quarry-dust and cement improves the hydraulic conductivity, UCS and VSS of the soil. The hydraulic conductivity of the soil was $8.8385\text{x}10^{-10}$ m/s, UCS (28 days) was 499 kN/m^2 and VSS was 19.3%. The best result was recorded at 30% quarry-dust and 6% cement with hydraulic conductivity, UCS (28 days) and VSS of $1.22851\text{x}10^{-10}$ m/s, 625 kN/m^2 and 3.43% respectively.

v. Optimization was carried out and models were developed for the estimation of OMC, MDD, UCS, VSS and hydraulic conductivity of admixed black cotton soil. The numerical optimization was done using central composite design and the minimum acceptable quantities and values are 26% QD, 6% cement, 11.5% OMC, 1.84% MDD, 454 kN/m^2 for UCS 28 days, VSS at 4.0% and 1.2285110^{-10} m/s for hydraulic conductivity.

4.1 Recommendations

i This study recommends the use of quarry-dust at 22% and cement at 6% as a replacement for black cotton soil for effective utilisation for waste containment systems, such as liners and barriers in landfills, to prevent leachate migration and environmental contamination.

ii Further research should be carried out to evaluate the effects of more locally available materials that can be further used to improve black cotton soil.

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