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Mechanical and Chemical Stabilization of Black Cotton Soil for Subgrade Pavement

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ABSTRACT
Black cotton soil (BCS) is a localized weak soil with unusual swell-shrinkage potential which leads to differential settlement of foundation of many infrastructural facilities, severe crack and adverse damage of structures erected on it. BCS has a swelling-shrinkage potential phenomenon which is greatly influenced by the clay mineralogy constituent, environmental stress condition and soil properties factors which describe the functional relationship of the swell-shrinkage potential of the study area. This research investigates the mechanical and chemical stabilization of BCS obtained from Eket senatorial district which possessed a swell-shrinkage potential. The method of mechanical and chemical stabilization was adopted in this study. Results show that the optimum moisture content (OMC) of stabilized BCS increases with simultaneous increase in partial percentage replacement of Bagasse ash (BA) from 0% to 12% for all BCS obtained from Etet, Ikot Abasi, and Eastern Obolo. Increase in percentage of partially replaced lime from 0% to 12% stabilized BCS obtained from the three locations at Eket senatorial district gave simultaneous increase in the MDD, while an increase in percentage of partially replaced BA from 0% to 12% stabilized BCS simultaneous decreases the MDD. Conclusively, lime and BA respectively increases and decreases the MDD of stabilized BCS. Combining the two admixtures will optimally reduce the MDD, compaction operation effort and cost without compromising on the maximum strength of stabilized BCS. Federal ministry of works should support the use of BA and lime for mechanical stabilization of BCS since it will help to optimally reduce operation cost and increase soil bearing capacity as per 9001:2018 requirements.

Keyword: Mechanical stabilization, chemical stabilization, black cotton soil, and subgrade pavement

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I. INTRODUCTION

According to the thought of Shanmugavadivu (2021), BCS is clayish in nature characterized with enormous volume changes, swell-shrinking potential, and uncertainty to large shear stress failure as soon as water comes in contact with it. In the field of civil engineering construction, road subgrade pavement construction on BCS is challenging. The works of Fulzele, Ghane, and Parkhe (2016), showed that, an attempt to construct on weak soil resulted in possible severe damage of structures due to its differential settlement such as foundation of buildings, pavement and retaining structures. Considerable distress to lightweight civil engineering structures is caused by excessive heaves linked with swelling and shrinking of expansive soil Bhujbal, and Gaikwad, 2022; Akaha, and syveslter,2016). In view of this phenomenon, maintenance and economic life of highway posses so many problems (Kshatriya and Sathe and Kankarej, 2022).

Civil engineering works require soil investigation before commencement (Patel, 2019). Effective utilization of localized weak soil in rural and urban areas has been a challenge for decades to civil engineers (Akinwande, and Aderinola, 2020). Improving the properties of BCS requires soil stabilization technique (Rehman, 2020; Agunwamba, Okonkwo, and Iro, 2016). Several types of stabilization materials have been used for BCS stabilization. BCS can be stabilized using fly ash (FA) - kota stone slurry mix (Nanda, 2021;

Chethan, and Ravi Shankar, 2021). Prudhvi , and Chellaiah, (2022) utilizes the use of salts for stabilization. Majeed, and Tangri (2021) and Garg, Biswas, Kumar, Siddharth, and Singh (2021). utilizes industrial waste for BCS stabilization. BCS can also be stabilized with coal bottom ash (Navagire, Sharma, and Rambabu.2021). Mai-Bade, Chinade, Batari, and Saeed, (2021) and Premkumar, Subha, Sandhiya, and Narayanan, (2021), utilizes lime, cement, E-waste, groundnut shell ash, BA and plantain peel powder, reclaimed asphalt pavement, E-waste, and still mill ore for BCS stabilization.

BCS can be stabilized using mechanical (Kiran, Muhamed, and Jaya, 2019) and chemical (Kumar, Gadekari, Vani., and Mini, 2022) method. This research seeks to carry out mechanical and chemical stabilization on Eket's BCS for subgrade pavement using BA and lime. The specific objectives of this research are to classify the soil, carry out test and check if liquid limit, plastic limit, and compressive strength of the stabilized BCS will increase with increase in bagasse ash and lime.

II. MATERIAL AND METHODS

The materials used in carrying this research include BCS obtained from Ikot abasi, Eastern Obolo, and Eket, disturbed soil collector, and all laboratory equipments required for Atterberg limit, moisture content and compressive test. The soil samples (BCS) were collected from three different locations namely Obok-idem in Eket, Ikot Abasi and Eastern Obolo at Eket senatorial district of Akwa Ibom state, Nigeria, having coordinates of $4^o27'57''$N $7^o37'45''$E. The BCS was collected at a depth not less than 150mm from 8 different trial pits of about 4m apart, each using the method of disturbed sampling technique.

The reach of this research study cover stabilization of black cotton soil with inclusion of BA and lime to ascertain the consistency limit, Atterberg limit, strength characteristic such as confined compressive strength(CCS), as well as it suitability as sub-grade pavement in area with seldom socio-economic development of road network.

Atterberg's limit, unconfined compressive strength (UCS) of original soil, and direct shear Test of a black cotton soil with varying percentage of lime and BA were carried out based on the work of Kollu, Nagarajan, Rajarajachozhan,.Sriaadith, and Saravanan, (2021). Sample preparation of BCS, BA, sieve analysis, Atterberg limit, BCS compaction, and BCS chemical content test were carried out based on the thoughts of Kollu, Nagarajan, Rajarajachozhan, Sriaadith, and Saravanan (2021), and Premkumar, Subha, Sandhiya, and Narayanan, (2021). The test results of sieve analysis, liquid and plastic limits are presented in table 2.1 to 2.11 and figure 2.1 to 2.6 below. Photos of sample preparation are presented in appendix A.

2.1 Sieve analysis

The test results obtained for sieve analysis of BCS and LS for Eket, Ikot Abasi and Eastern and Obolo are presented in table 2.1 to 2.4 and Figure 2.1 and 2.2 below.

Table 2.1. Particle Size Distribution for Ikot Abasi Black Cotton Soil.

Sieve size (mm)	Sieve sizes (mm)	Mass retained (mm)	%mass retained	Cum% mass retained	Percentage finer 100-col
	1	2	3	4	5
3.36	2.36	36.90	7.38	7.38	92.62
2.00	2.00	29.10	5.82	13.20	86.80
1.180	1.18	73.00	14.60	27.80	72.20
850	0.850	36.20	7.24	35.04	64.96
300	0.300	87.20	17.40	52.44	47.56
212	0.212	40.20	8.04	60.48	39.52
150	0.150	20.10	4.02	64.50	35.50
75	0.75	89.50	17.90	82.18	17.60
Receiver	Pan	87.80	17.56	82.4	0
Total		500	-	-	-

Table 2.2. Particle Size Distribution for Eket Black Cotton Soil.

Sieve size (mm)	Sieve sizes (mm)	Mass retained (mm)	% mass retained	Cum % mass retained	Percentage finer 100-col
	1	2	3	4	5
3.36	2.36	36.90	7.38	7.38	92.62

2.00	2.00	29.10	5.82	13.20	86.80
1.180	1.18	73.00	14.60	27.80	72.20
850	0.850	36.20	7.24	35.04	64.96
300	0.300	87.20	17.40	52.44	47.56
212	0.212	40.20	8.04	60.48	39.52
150	0.150	20.10	4.02	64.50	35.50
75	0.75	89.50	17.90	82.18	17.60
Receiver	Pan	87.80	17.56	82.4	0
Total		**500**	-	-	-

Table 2.2: Particle Size Distribution for Eastern Obolo Black Cotton Soil.

Sieve size (mm)	**Sieve sizes (mm)**	**Mass retained (mm)**	**% mass retained**	**Cum % mass retained**	**Percentage finer 100-col**
	1	**2**	**3**	**4**	**5**
3.36	2.36	36.90	7.38	7.38	92.62
2.00	2.00	29.10	5.82	13.20	86.80
1.180	1.18	73.00	14.60	27.80	72.20
850	0.850	36.20	7.24	35.04	64.96
300	0.300	87.20	17.40	52.44	47.56
212	0.212	40.20	8.04	60.48	39.52
150	0.150	20.10	4.02	64.50	35.50
75	0.75	89.50	17.90	82.18	17.60
Receiver	Pan	87.80	17.56	82.4	0
Total		500	-	-	-

Table2.4. Particle Size Distribution for lateritic soil

Sieve size (mm)	**Sieve sizes (mm)**	**Mass retained (mm)**	**% mass retained**	**Cum % mass retained**	**Percentage finer**
1	Col 2	Col 3	Col 4	Col 5	Col 6
2.36	2.36	0.90	0.18	0.18	99.82
2.00	2.00	0.20	0.04	0.22	99.79
1.180	1.180	2.70	0.54	0.76	99.24
850	0.850	4.00	0.80	1.56	98.44
300	0.300	99.00	19.80	21.36	79.64
212µm	0.121	242.00	48.40	69.76	30.24
150	0.150	62.10	12.42	82.18	17.82
75	0.075	81.70	16.28	98.46	1.54
Receiver	Pan	19.70	1.72	100.0	0
		500			

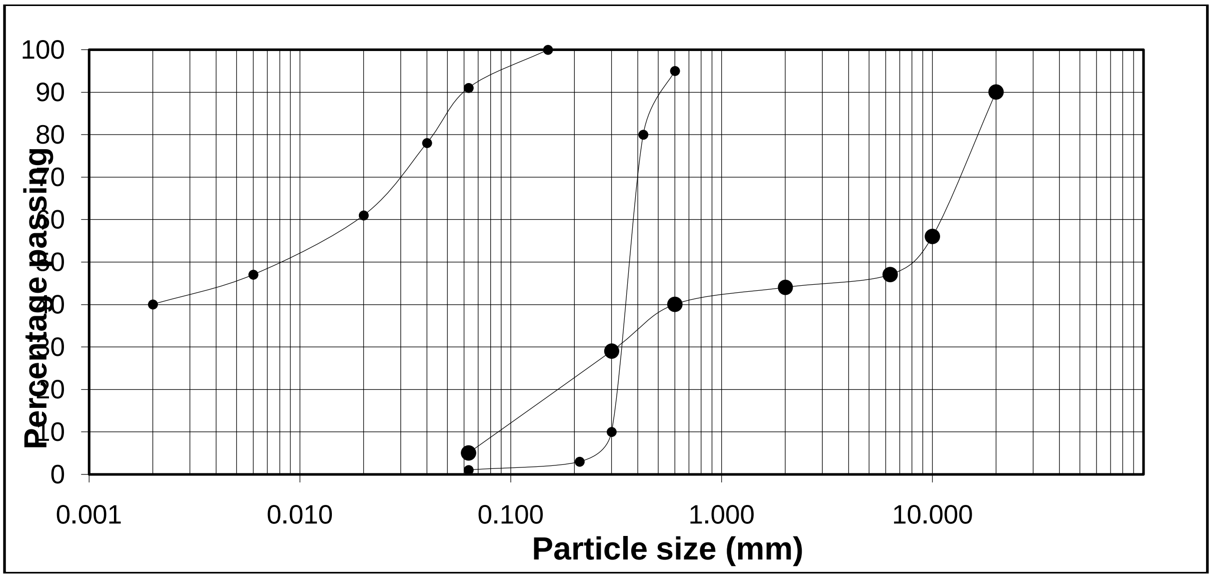

Figure 2.1: showing the percentage passing versus particle size of black cotton soil from three locations selected in Eket senatorial district of Akwa Ibom State.

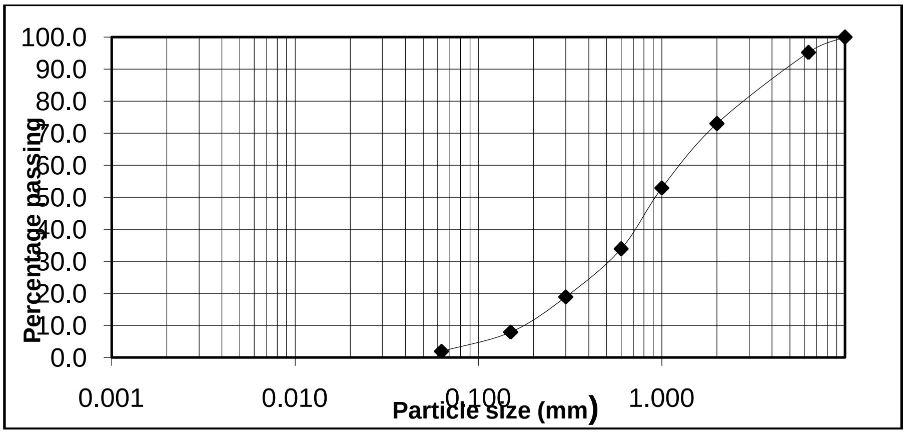

Figure 2.2: showing the percentage passing versus particle size of lateritic soil

2.2 Liquid and plastic limit

The test results of the liquid limit (LL) and plastic limit (PL) of BCS and LS for Eket, Ikot Abasi and Eastern Oblolo are presented in table 2.5 to 2.10 and Figure 2.3 and 2.5 below

Table 2.5. Test result of LL of BCS from Ikot Abasi location

Can No	**Empty can weight (m1)**	**Type**	**Empty can + wet soil (m3)**	**Empty can +dry soil (m2) (m2)**	**Blows**	**Water content fraction**	**%**
0	2	3	4	5	6	7	8
1	16.80g	MW2	24.78g	21.40g	25	0.734	73.4
2	16.60g	E7	21.20g	19.50	30	0.586	58.6
3	16.50g	RHA	21.70g	21.20g	35	0.581	58.1
Average							63.36

Table 2.6: Test result of PL for BCS from Ikot Abasi Location

CAN N0	**WEIGHT EMPTY CAN**	**WEIGHT OF EMPTY CAN + WET SOIL**	**WEIGHT OF EMPTY CAN + DRY SOIL**	**MOISTURE CONTENT FRACTION**	**MOISTURE CONTENT %**
1	2	3	4	5	6
R_4	16.6	31.6	27.6	0.4158	41.6
M_{w2}	16.8	30.0	26.6	0.251	25.1
AVERAGE					**33.35**

Table 2.6: Test Result of LL for BCS from Eket location

Can No	**Empty can weight (m1)**	**Type**	**Empty can + wet soil (m3)**	**Empty can +dry soil (m2) (m2)**	**Blows**	**Water content fraction**	**%**
0	2	3	4	5	6	7	8
1	16.80g	MW2	24.78g	21.40g	25	0.724	72.4
2	16.60g	E7	21.20g	19.50	30	0.586	59.6
3	16.50g	RHA	21.70g	21.20g	35	0.581	57.2
Average							63.06

Table 2.7: Test Result of PL for BCS from Eket location

CAN N0	**WEIGHT EMPTY CAN**	**WEIGHT OF EMPTY CAN + WET SOIL**	**WEIGHT OF EMPTY CAN + DRY SOIL**	**MOISTURE CONTENT FRACTION**	**MOISTURE CONTENT %**
1	2	3	4	5	6
R_4	16.6	31.6	27.6	0.4158	42.6
M_{w2}	16.8	30.0	26.6	0.251	24.1
AVERAGE					**32.35**

Table 2.8: Test Result of LL for BCS from Eastern Obolo location

Can No	**Empty can weight (m1)**	**Type**	**Empty can + wet soil (m3)**	**Empty can +dry soil (m2) (m2)**	**Blows**	**Water content fraction**	**%**
0	2	3	4	5	6	7	8
1	16.80g	MW2	24.78g	21.40g	25	0.714	71.4
2	16.60g	E7	21.20g	19.50	30	0.566	56.6
3	16.50g	RHA	21.70g	21.20g	35	0.571	57.1
Average							61.7

Table 2.9: Test Result of PL for BCS from Eastern Obolo location

CAN N0	**WEIGHT EMPTY CAN**	**WEIGHT OF EMPTY CAN + WET SOIL**	**WEIGHT OF EMPTY CAN + DRY SOIL**	**MOISTURE CONTENT FRACTION**	**MOISTURE CONTENT %**
1	2	3	4	5	6
R_4	16.6	31.6	27.6	0.4158	42.6
M_{w2}	16.8	30.0	26.6	0.251	26.1
AVERAGE					**34.35**

Table 2.10. Liquid Limit of lateritic Soil for comparison

Can NO	Empty can weight (m1)	Types	Empty can+ wet soil (m3)	Empty can dry +soil (m2)	Blows	Water content fraction	%
1	2	3	4	5	6	7	8
1	16.90g	Db	31.80g	27.70g	25	0.379	37.96
2	16.8g	RA_2	34.0g	34.0	30	0.344	34.38
3	16.7g	RH_4	43.0g	43.0g	35	0.321	32.16
Average							31.3

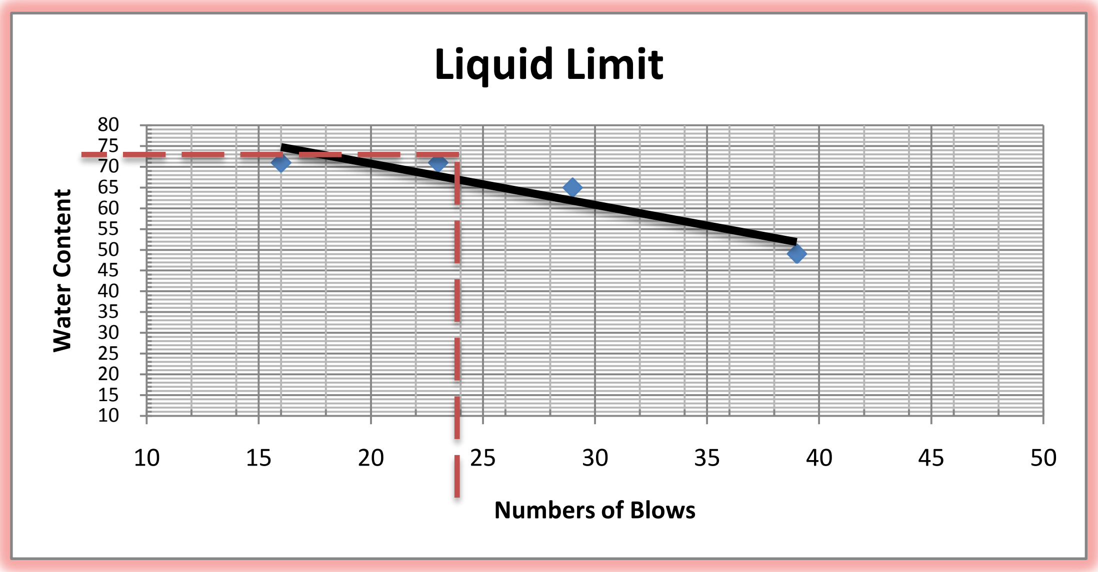

Figure 2.3. LL of Ikot Abasi BCS

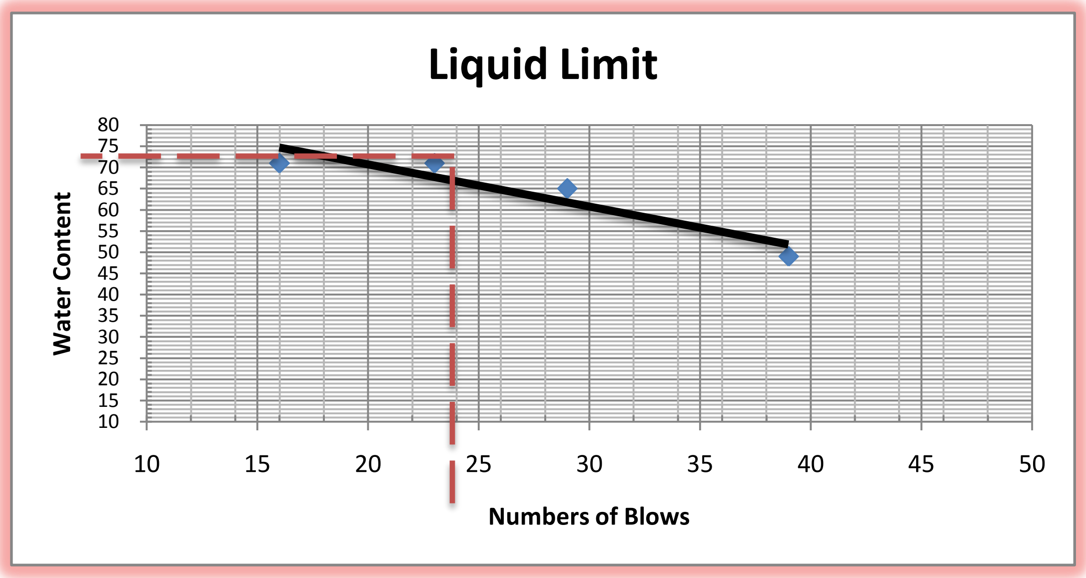

Figure 2.4. LL of Eket local government area BCS

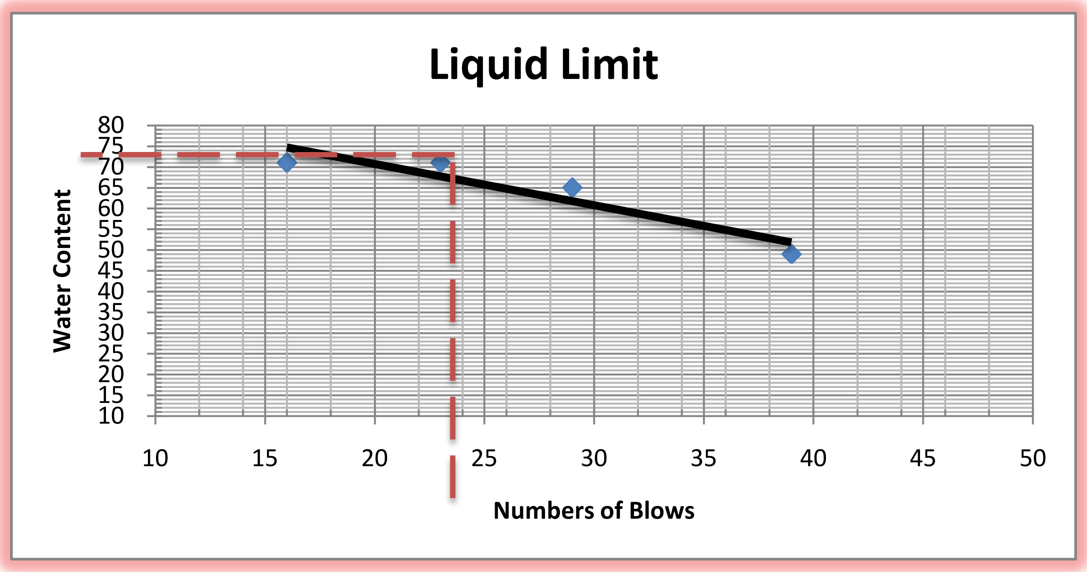

Figure 2.5: LL of Eastern Obolo BCS

III. RESULTS AND DISCUSSION

The results of the compressive strength and Atterberg limit test are presented and discussed bellow

3.2 Compressive strength

The test results of the OMC and MDD of BCS obtained from Eket, Ikot Abasi and Eastern Oblolo are presented in table 2.1 to 2.5below

Table 3.1. Variations of OMC with increase in BA and lime content in BCS obtained from Ikot Abasi location

BAGASSE ASH % CONTENT	OPTIMUM MOISTURE CONTENT %					
	2%Lime	4%Lime	6%Lime	8%Lime	10%Lime	12%Lime
0	16.50	17.90	18.24	20.39	21.32	22.01
2	16.80	17.97	18.41	20.56	22.71	24.16
4	17.71	18.30	18.91	21.24	25.04	27.96
6	18.14	19.69	20.85	21.63	25.82	28.74
8	19.58	20. 48	21.66	22.08	26.24	29.22
10	20.23	21. 29	22.39	22.63	26.48	29.46
12	20.81	21.71	22.71	23.05	26.82	29.80

Discussion of Table 3.1

i. Table 3.1 is a tabulated result of the OMC of varying percentages of BA and lime stabilized BCS obtained from Ikot Abasi location.
ii. The result showed that an increase in percentage of BA and lime from 0% to 12% results in simultaneous increase in OMC of the stabilized BCS obtained from Ikot Abasi

Table 3.2: Variations of MDD with increase in BA content in BCS obtained from Ikot Abasi location

BAGASSE ASH % CONTENT	MAXIMUM DRY DENSITY (KG/M^3)					
	2%Lime	4%Lime	6%Lime	8%Lime	10%Lime	12%Lime
0	1661	1777	1891	2199	2351	2429
2	1634	1771	1875	2132	2362	2489
4	1612	1759	1805	2084	2262	2324
6	1584	1742	1783	2022	2301	2409
8	1551	1708	1724	1996	2153	2208

10	1533	1691	1702	1971	2099	2199
12	1503	1671	1689	1954	2049	2189

Discussion of Table 3.2

i. Table 3.2 is a tabulated result of the MDD of varying percentages of BA and lime stabilized BCS obtained from Ikot Abasi location.
ii. The result showed that increase in percentage of lime from 0% to 12% partial replacement of stabilized BCS will result in simultaneous increase in MDD.
iii. The result also showed that increase in percentage of BA from 0% to 12% partial replacement of stabilized BCS will result in simultaneous decrease in MDD.

Table 3.3. Variations of OMC with increase in BA and lime content in BCS obtained from Eket location

BAGASSE ASH % CONTENT	OPTIMUM MOISTURE CONTENT %					
	2%Lime	4%Lime	6%Lime	8%Lime	10%Lime	12%Lime
0	10.50	20.65	23.24	26.44	29.32	32.01
2	13.80	21.97	23.41	26.56	29.71	32.16
4	17.71	22.30	24.91	27.24	30.04	32.96
6	18.14	23.69	25.85	27.63	30.82	33.14
8	19.58	24.48	26.66	28.08	31.24	33.22
10	20.23	25. 29	26.39	28.63	31.48	32.46
12	20.81	21.71	26.71	29.05	31.82	33.8

Discussion of Table 3.3

i. Table 3.3 is a tabulated result of the OMC of varying percentages of BA and Lime stabilized BCS obtained from Eket location.
ii. table 3.3 showed that an increase in percentage of BA and lime from 0% to 12% results in simultaneous increase in OMC of the stabilized BCS obtained from Eket

Table 3.4. Variations of MDD with increase in BA content in BCS obtained from Eket location

BAGASSE ASH % CONTENT	MAXIMUM DRY DENSITY (KG/M^3)					
	2%Lime	4%Lime	6%Lime	8%Lime	10%Lime	12%Lime
0	1671	1767	1881	2179	2361	2459
2	1634	1771	1875	2132	2362	2489
4	1612	1759	1805	2084	2262	2324
6	1584	1742	1783	2022	2301	2409
8	1551	1708	1724	1996	2153	2208
10	1533	1691	1702	1971	2099	2199
12	1503	1671	1689	1954	2049	2189

Discussion of Table 3.4

i. Table 3.4 is a tabulated result of the MDD of varying percentages of BA and Lime stabilized BCS obtained from Eket location.
ii. The result showed that an increase in partial percentage replacement of lime from 0% to 12% results in simultaneous increase in MDD of the stabilized BCS obtained from Eket location.
iii. The result equally showed that an increase in partial percentage replacement of BA from 0% to 12% results in simultaneous decrease in MDD of the stabilized BCS obtained from Eket location.

Table 3.5. Variations of OMC with increase in BA and lime content in BCS obtained from Eastern Obolo location

BAGASSE ASH % CONTENT	OPTIMUM MOISTURE CONTENT %					
	2%Lime	4%Lime	6%Lime	8%Lime	10%Lime	12%Lime
0	10.50	20.65	23.24	26.44	29.32	32.01
2	13.80	21.97	23.41	26.56	29.71	32.16

4	17.71	22.30	24.91	27.24	30.04	32.96
6	18.14	23.69	25.85	27.63	30.82	33.14
8	19.58	24.48	26.66	28.08	31.24	33.22
10	20.23	25. 29	26.39	28.63	31.48	32.46
12	20.81	21.71	26.71	29.05	31.82	33.8

Discussion of Table 3.5

i. Table 3.5 is a tabulated result of the OMC of varying percentages of BA and Lime stabilized BCS obtained from Eastern Obolo location.
ii. The result showed that an increase in partial percentage replacement of BA and lime from 0% to 12% results in simultaneous increase in OMC of the stabilized BCS obtained from Eastern Obolo

Table 3.6: Variations of MDD with increase in BA content in BCS obtained from Eastern Oblolo location

BAGASSE ASH % CONTENT	MAXIMUM DRY DENSITY (KG/M^3)					
	2%Lime	4%Lime	6%Lime	8%Lime	10%Lime	12%Lime
0	16.71	17.67	18.81	21.79	23.61	24.59
2	16.34	17.71	18.75	21.32	23.62	24.89
4	16.12	17.59	18.05	20.84	22.62	23.24
6	15.84	17.42	17.83	20.22	23.01	24.09
8	15.51	17.08	17.24	19.96	21.53	22.08
10	15.33	16.91	17.02	19.71	20.99	21.99
12	15.03	16.71	16.89	19.54	20.49	21.89

Discussion of Table 3.6

i. Table 3.6 is a tabulated result of the MDD of varying percentages of BA and Lime stabilized BCS obtained from Eastern Obolo location.
ii. table 3.6 showed that an increase in partial percentage replacement of BA from 0% to 12% results in simultaneous decrease in MDD of the stabilized BCS obtained from Eastern Obolo.
iii. The result also showed that an increase in partial percentage replacement of lime from 0% to 12% results in a simultaneous increase MDD of the stabilized BCS obtained from Eastern Obolo.

Table 3.7: plasticity index of Ikot Abasi, Eket and Eastern Obolo BCS in Eket senatorial district

S/No	Ikot Abasi	Eket	Eastern Obolo
Liquid limit	63.36	63.06	61.7
Plastic limit	33.35	**32.35**	34.35
Plasticity index	30.01	30.71	27.35

Discussion of Table 3.7

i. BCS from Eeasten Obolo has the least LL of BCS while BCS form Ikot Abasi has the highest LL
ii. The PL of Eket and Eastern Obolo is the least and highest of all.
iii. Eket and ikot Abasi has the highest and least PI.
iv. The result also showed that the swelling potential of BCS obtained from Eket, Ikot Abasi and Eastern Obolo are relatively high since their PI falls between 20 and 35
v. Table 2.1 to 2.4, 3.7 and figure 2.1 to 2.2 showed the particle size distribution for the Ikot Abasi, Eket and Eastern Obolo locations, and according to AASTHO Classification, the soil is A-2-7 soil which has some percentages of silt, sand and clay(AASHTO Classification chart*)*

IV. CONCLUSION

The soil is classified as an A-2-7 soil which has some percentages of silt, sand and clay (AASHTO classification). The swelling potential of BCS obtained from Eket, Ikot Abasi and Eastern Obolo are relatively high since their PI falls between 20 and 35. The application of varying partial percentages replacement of BA and lime on stabilized BCS obtained from Ikot Abasi, Eket and Eastern Obolo location influences its OMC and MDD.

The OMC result of stabilized BCS obtained from Ikot Abasi showed that an increase in partial percentage replacement of BA and lime from 0% to 12% mechanical stabilization would results in simultaneous increase in OMC of the stabilized

BCS. The MDD result of lime stabilization also showed that increase in percentage of lime from 0% to 12% partial replacement of stabilized BCS result in simultaneous increase in MDD. However, BA stabilization gave a reverse result that showed that increase in percentage of BA from 0% to 12% partial replacement of stabilized BCS result in simultaneous decrease in MDD.

The result of stabilized BCS from Eket location showed that an increase in percentage of BA and lime from 0% to 12% results in simultaneous increase in OMC of the stabilized BCS. The MDD result also showed that an increase in partial percentage replacement of lime from 0% to 12% would result in simultaneous increase in MDD of the stabilized BCS. The MDD of BA stabilization gave a reverse trend unlike lime stabilization. The result showed that an increase in partial percentage replacement of BA from 0% to 12% results in simultaneous decrease in MDD of the stabilized BCS.

The result of stabilized BCS from Eastern Obolo location showed that an increase in partial percentage replacement of BA and lime from 0% to 12% results in simultaneous increase in OMC of the stabilized BCS obtained from Eastern Obolo. The result of BCS stabilization with BA showed that an increase in partial percentage replacement of BA from 0% to 12% results in simultaneous decrease in MDD of the stabilized BCS. Stabilization of BCS with lime result showed that an increase in partial percentage replacement of lime from 0% to 12% would results in simultaneous increase in MDD of the stabilized BCS.

Conclusively, the mechanical and chemical stabilization of BCS obtained from the three locations produced similar characteristics in OMC and MDD when BA and lime admixtures are used.

V. RECOMMENDATION

Federal ministry of works should support the use of BA and lime for mechanical stabilization of road pavement, since it will help fulfill the requirements ISO 9001:2018 standards.

CONTRIBUTION TO KNOWLEDGE

The use of BA and lime will help engineers to properly analyze and design subgrades road pavements in locations where black cotton soil exist.

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APPENDIX A

Plate 1. 1 Processing stage of bagasse fibrous

Plate 1.2. bagasse refining

Plate 1.3 Raw sugar cane plant processed to bagasse

Plate 1.4 refined bagasse fibrous

Plate1.5 Incinerated bagasse fibrous

Plate 1.6.liquid limit testing of black cotton soil

Plate 1.7 stacked arranged sieve