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Cement StabilizationPotential of Saw Dust Ash Pre-Treated Makurdi Shale for Pavement Construction Material

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ABSTRACT:*Due to increasing cost of industrial stabilizer such as cement and lime in the improvement of weak soil, the use of waste alone or jointly with industrial stabilizer for soil stabilization is encouraged. This study looks at the cement stabilization potential ofsaw dust ash (SDA) pre-treated weak soil such as an A-7-6 Makurdi shale. The index properties, unconfined compressive strength (UCS), California bearing ratio (CBR), durability and scanning electron microscopy (SEM)/energy dispersion x-ray spectrometer (EDX)of untreated and cement treated SDA pre-treated Makurdi shale were determined. The 7 dayUCS value of untreated Makudi shale of 273kN/m^2 increased to a value of 1412$kN/m^2$and 1511 $kN/m^2$for 8%C+20 %SDA and 10%C + 20%SDA treated Makurdi shale respectively. Similarly, the CBRvalue of untreated Makurdi shale which is 2% increased to a value of 78% and 82% for 8%C+20%SDA and 10%C+20%SDA treated Makurdi shale respectively.The resistance to the effect of water on strengthfor the untreated Makurdi shale which is 0% increased to 81% and 83% for 8%C+20 %SDA and 10%C+20%SDA treated Makurdi shale respectively. SEM/EDX results showed the presence of calcium, silicon and aluminium as a cementitious compound in the 20%SDA+10%C treated Makurdi shale.Based on the combined UCS, CBR and durability requirements, Makurdi shaletreated with 8%C+20%SDA is suitable for use as sub-base material, while Makurdi shale treated with10%C+20%SDA is suitable for use as base course material for a lightly trafficked road.*

KEYWORDS:*Shale, cement, saw dust ash, California bearing ratio, unconfined compressive strength, scanning electron microscopy.*

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I. INTRODUCTION

Buildings and roads overlain or constructed with expansive soil usually fail with varying degrees of cracks and defects. Shale is one of the expansive soils which is deposited in different parts of the world including some parts of Makurdi, the capital of Benue state, Nigeria [1,2]. Some buildings constructed on shale in the College of Engineering, Joseph Sarwuan Tarka University, Makurdi have failed with varying degrees of cracks, while roads pavements constructed within the University have suffered defects such as cracks, rutting, potholes and edge failure. The defects are attributed to the presence of some expansive clay minerals such as smectite and illite which are constituents of Makurdi shale [1].Shale is one of the soils that contain expansive clayey material which usually breakdown in the presence of moisture and frost [3].In the rainy season, shale absorbs water and swells while in the dry season, it releases the water due to evaporation and shrinks [4, 5].

Several researches have been conducted on the improvement of shale with industrial stabilizers alone or a combination of industrial stabilizersand waste materials.Researchers [6-11] treated shale with industrial stabilizers (lime and cement), or combination of industrial stabilizers and sand, or combination of industrial stabilizers and waste (Table 1). Such waste include bamboo leaf ash (BLA), palmyra palm leaf ash (PPLA). In all the studies, the unconfined compressive strength (UCS) and California bearing ratio (CBR) values of the treated shale increased to values sufficient for use as either sub-base or base materials in road pavement. A study on the modification of Makurdi shale with saw dust ash (SDA) only have been conducted [12]. The study showed reduction in swelling potential and volume change, but increase in CBR which was sufficient for application in capping layer of road pavements (Table 1).

Gana and Tabat [13] conducted study on stabilization of clay soil with cement only, and partial replacement of cement with SDA (Table 1).For the partial replacement, both cement and SDA were mixed at the same time for the clay treatment. The study showed that the UCS achieved by treatment of clay with cement only was higher than that achieved by the corresponding 50% replacement of cement with SDA.In their study,the highest combination of 3.5%SDA+3.5%cement was used for treatment of the clay. BS 1924-1 [14] recommends that forthe treatment of soil with combination of lime andcement, the soil should be pre-treated with lime and cured in airtight condition for either 24hrs or 48hrs prior to cement treatment. SDA is a lime-based waste and when it is to be mixed with cement for soil stabilization, pre-treatment with SDA prior to cement treatment would produce better stabilization.

Studies on cement stabilization ofSDA pre-treated clayfor use in road pavement material is scarce, thus prompted this research. The aim of this study is to determine whetherMakurdi shale could be pre-treated with SDA then stabilized with cement for application in road pavement. The specific objectives are to determine the UCS, CBR and durability of untreated and cement stabilized SDA pre-treated Makurdi shale. Also, to examine the microstructural changes in untreated and cement stabilized SDA pre-treated Makurdi shale.

TRL [15] and Sherwood [16]established a minimum compressive strength for stabilized layers in road pavement as 0.75 MPa, 1.5 MPa and 3.0 MPafor stabilized sub-base (SSB), cemented base course in lightly trafficked roads and cemented base course in heavily trafficked roads respectively. For CBR, the recommended values are to be greater than 15%, greater than 70% and a minimumof 80% for SSB, stabilized capping layers (SCL) and base course materials respectively.

Table 1: Previous studies on the improvement of shale/clay using industrial stabilizer alone or with waste or with waste alone

Author	Topic	Stabilizer/ waste	Properties improved
Joel and Agbede [6]	Effect of lime on some geotechnical properties of Igumale shale	Lime (L)	The 7 day UCS and CBR value of untreated Igumale shale increased from 360 kN/m² and 0.68% to a value of 1263 kN/m² and 37 % respectively at 8%L treated shale. Igumale shale treated with 8%L was not suitable for use as sub-base or base in road construction, based on UCS, CBR and durability consideration. But it was recommended for use as a modifier.
Joel and Agbede [7]	Cement stabilization of Igumale shale lime admixture for use as flexible pavement construction material	Combination of cement (C) and lime (L)	The 7 day UCS and CBR value of untreated Igumale shale increased from 360 kN/m² and 0.68% to 2377 kN/m² and 160 % respectively at 8%L+12%C treated shale. Igumale shale treated with 8%L+12%C was recommended for application in base course materials of road pavement. Similarly, The 7 day UCS and CBR value of untreated Igumale shale increased from 360 kN/m² and 0.68% to a value of 1820 kN/m² and 100% respectively at 6%L+8%C treated shale. Igumale shale treated with 6%L+8%C was recommended for application in sub-base course materials of road pavement.
Eze-Uzomaka and Joel [8]	Treatment of shale-sand mixture with cement for use as pavement material.	Combination of sand and cement	The treatment of Igumale shale with 50% sand and 12% cement resulted in 7 day UCS and CBR values of 1906kN/m^2 and 168% respectively. Based on strength requirements, 50% sand+12% cement treated Igumale shale using the plant-mix method was recommended for use as base material.
Joel and Otse [9]	Effect of lime pre-treatment mellowing duration on some geotechnical properties of shale treated with cement	Combination of cement and lime	The 7 day UCS value of untreated Makurdi shale increased from 400 kN/m^2 to peak value of 2006 kN/m^{2}when pre-treated with 9% lime and allowed to mellow for 48 hours before treatment with 6 % cement. However, when shale pre-treated with 9% lime and allowed to mellow for 0 hours before treatment with 6 % cement, the 7 day UCS was 1858 kN/m^2. Similarly the CBR value of untreated Makurdi shale increased from 2.4 % to 107 % when the shale was pre-treated with 9 % lime and allowed to mellow for 48 hours before treatment with 6 % cement. However, when the shale was pre-treated with 9 % lime and allowed to mellow for 0 hours before treatment with 6 % cement the CBR value was 96%. Based on UCS and CBR consideration, pre-treatment of Makurdi shale with 9 % lime and allowed to mellow for 48 hours before treatment with 6 % cement was recommended for use as road base material in lightly trafficked road and sub-base material of a heavily trafficked road.
Iorliam *et al.* [10]	Effect of bamboo leaf ash on cement stabilization of Makurdi shale for use as flexible pavement construction material	Combination of cement (C) and bamboo leaf ash (BLA)	The maximum 7 day UCS and soaked CBR values of 1784 kN/m^2 and 80 % was obtained at 14%C + 20%BLA. Makurdi shale treated with 14%C+20%BLA was recommended for use as sub-base materials in flexible pavement.

Iorliam *et al.* [11]	Effect of palmyra palm leaf ash on cement stabilization of Makurdi shale	Palmyra palm leaf ash (PPLA) and cement (C)	The maximum values of 7 day UCS and soaked CBR of 1041 kN/m^2 and 92% respectively were achieved at 10%C+14 % PPLA treated Makurdi shale. Makurdi shale treated with a combination of 10%C+14%PPFA was recommended for use as sub-base materials in flexible pavement.
Iorliam *et al.* [12]	Modification potential of saw dust ash on Makurdi clay shale as capping material	saw dust ash (SDA)	The swelling potential of untreated Makurdi shale with medium swelling potential (with 19% PI value) improved to low swelling potential (with 10% PI value) when treated with 20% SDA. The untreated shale with medium volume change (57% free swell value) was improved to low volume change (19% free swell value) when treated with 28% SDA. The CBR value of 2% for untreated Makurdi shale increased to 18% when the shale was treated with 20% SDA. Based on strength requirement, 20% SDA-treated A-7-6 Makurdi shale was recommended for use as a stabilized capping layer.
Gana and Tabat [13]	Stabilization of clay soil with cement and sawdust ash	Cement only and partial replacement of cement with saw dust ash (SDA)	The maximum values of 7 day UCS for 0%, 1.5%, 3%, 4% and 7% cement treated clay soil were 185.1 kPa, 320 kPa, 586 KPa, 925.5 kPa and 1140.4 kPa respectively. Additionally, the partial replacement of cement by 50% with SDA such as 0.75%cement+0.75SDA, 1.5%cement+1.5%SDA, 2%cement+2%SDA and 3.5%cement+3.5%SDA resulted in 7 day UCS of 216 kPa, 348.8 kPa, 402.2 kPa and 719 kPa respectively.

II. MATERIALS AND METHODS

2.1 Materials

To examine whether cement treatment of SDA pre-mixed shale would be adequate for use in road pavement, the following materials were used. Shale sample was obtained from a pit at the College of Engineering, Joseph Sarwuan Tarka University, Makurdi (formerly, Federal University of Agriculture Makurdi), Benue State Nigeria. The pit was located near a building which failed in cracks and being suggested to be consequence of shale. Disturbed shalesample was obtained inthe pit at a depth of 2.0 meters. Makurdi town is located on 7º43’50’’N and 8º32’10’’E on the geographical map of Nigeria [17].

Portland limestone cement(PLC) was obtained from a supplier in Makurdi, Benue state.To produce SDA, saw dust was obtained from a saw mill yard in Wurukum, Makurdi, Nigeria and was incinerated into ash at the temperature of 800^{o}C in an oven. SDA passing through sieve No. 200 with a 0.075 mm aperture was used for the study in accordance with BS 3892 [18].The combination of SDA and PLC was selected based on previous reports that the treatment of shale with cement alone, or SDA alone would not achieve stabilization [7, 12].

2.2 Methods

To prepare cement treated SDA pre-mixed Makurdi shale, the shale was firstly mixed with SDA at 0%, 10%, 20%, 30%, 40% and 50% each (by weight) as presented in Table 2. Required water content (as achieved from compaction test) was added to the SDA pre-mixed shale, thoroughly mixed to bring the material to a uniform consistency in accordance with BS 1924-1 [14]. The mixture was cured in airtight heavy duty polyethylene bags for 24 hours to allow for initial reaction between the shale and$Ca_2(OH)_2$, and/or water in accordance with BS 1924-2 [19]. Thereafter, cement content at 6%, 8%, 10%, and 12% each (by weight) was added to the SDA pre-mixed shale, thoroughly mixed in accordance with BS 1924-2 [19].This was immediately followed by either specimen manufacturing or testing. The manufacturing or testing was completed within 2 hours following cement addition. Any cement treated material remaining after 2 hours was discarded in accordance with BS 1924-1 [14].

Table 2. Mix ratios of cement treated saw dust ash pre-mixed Makurdi shale

Cement / SDA		0%C	6%C	8%C	10%C	12%C
SDA (%)	0%SDA	✓	✓	✓	✓	✓
	10%SDA	✓	✓	✓	✓	✓
	20%SDA	✓	✓	✓	✓	✓
	30%SDA	✓	✓	✓	✓	✓
	40%SDA	✓	✓	✓	✓	✓
	50%SDA	✓	✓	✓	✓	✓

C=Portland limestone cement, SDA=sawdust ash ✓ represents mix ratio used

The choice of SDA percentages was based on previous studies on SDA treated shale by Iorliam *et al*.[12], which showed modification of the shale within the selected SDA range. Similarly, cement content from 6% was selected due to previous studies on the shale which showed that stabilization of the shale is achieved above 6% cement content [9-11].

Laboratory tests such as particle size distribution (PSD) using the wet sieving method, specific gravity,liquid limit (LL), plastic limit (PL), linear shrinkage (LS)and compactionon untreated and cement treated SDA pre-mixed Makurdi shalewere conducted in accordance with BS 1924-1 [14] and BS 1924-2 [19]respectively.

To determine the optimum moisture contents (OMC) and maximum dry densities (MDD), compaction was carried out at the energy level of the British Standard (BS) light compaction effort only, using a 2.5kg rammer falling freely through 30 cm on three layers in the compaction mould of 1L. It also involves the application of 27 blows for each of the layers. The compaction method was selected due to the ease of achieving it in the field. Untreated and cement treated SDA pre-mixed Makurdi shale was manually mixed with deionised water at minimum water content of 13 % below the PL, and further at increments of 3 % [14, 19].

The preparation of specimens for UCS and CBR were conducted at the OMC and MDD based on BS light compaction. To determine the development of strength with time, untreated and cement treated SDA pre-mixed Makurdi shale were cured for 7, 14 and 28 days respectively prior to UCS testing. To achieve curing, specimens were wrapped in cellophane,followed byaluminium foil to retain their water content and kept in the laboratory at room temperature of 27^{o}C±1. The UCS testing was conducted at a strain rate of 1 mm/min (1.3%/mm) in accordance with BS 1924-2 [19].

The resistance to the effect of water (R) on strengthwas determined as the ratio of UCS of specimens cured for 7 days underunsoaked moisture condition, which were subsequently immersed in water for another 7 days to the UCS of specimens cured for 14 days under unsoaked moisture condition[19]. The minimum value of R as 80% was considered adequatefor use as pavement material in accordance with BS 1924-2 [19].

CBR test was carried out in accordance with BS 1377 [20] with slight modification to comply with theNigerian General specification [21], which specified that specimens be cured unsoaked for six days and later immersed in water for 24 hours before test.

The chemical composition of Makurdi shale, PLC and SDA were carried out usingthe compact energy dispersive x-ray spectrometer method (mini Pal) at the Centre for Energy Research and Training, ABU Zaria, Nigeria.

To determine the morphological properties of samples, polished sections of untreated shale and cement treated SDA pre-mixed shale wereanalyzed using scanning electron microscopy **(**SEM). The SEM was performed using JOEL-JSM 7600F model. This was fitted with an energy dispersion x-ray spectrometer (EDX). A point elemental analysis was performed on the crystal grains within the same sample using EDX to monitor the changes in the chemical composition due to the treatment.Untreated shalesample was selected to represent the control sample, while10%C+20%SDA treated shale was selected to represent the specimen with a remarkable compressive strength.

III. RESULTS AND DISCUSSION

3.1 Index Properties

The results showing the index properties of Makurdi shale is presented in Table 3. The results show that untreated Makurdi shale is an A–7– 6 soil and has fair to poor subgrade rating based on AASHTO classification [22]. The shale is a CH soil based on Unified Soil Classification systems (USCS) [23].The CBR of untreated Makurdi shale is found to be 2%, which is less than 15% and unsuitable for use as a road pavement material [16].Therefore the shale requires stabilizationto make it suitable for use as a road pavement material.

Table 3: Index properties of Makurdi shale

Properties	Quantity
Percentage passing BS sieve No.200 (%)	87
Liquid limit, LL (%)	52
Plastic limit, PL (%)	29
Plastic Index, PI (%)	23
Shrinkage limit, LS (%)	5.7
Free Swell (%)	57
Specific gravity G_s	2.68
AASHTO classification	A-7-6
USCS classification	CH
Maximum Dry Density MDD (Mg/$\mathbf{m^3}$)	1.61
Optimum Moisture Content, OMC (%)	14.4
Unconfined Compressive strength (kPa) 7days	273

California bearing ration, % (after 24 hrs soaking)	2
pH	6.80

The oxide composition of Makurdi shale, PLC and SDA is presented in Table 4. The results show that some cementious oxides content are found in both SDA and PLC stabilizers. The major content isCaO with 34.10% in SDA and 67.8% in PLC. Other oxide responsible for cementation is SiO_2with16.5% in SDA and 17.51% in PLC. Additionally, Al_2O_3composition in SDA is 2.3% while that in PLC is 5.40%. Therefore SDA is composed of some oxide responsible for cementation similar to that in PLC and could be combined for the stabilization of weak soil.

Table 4: Oxide composition of cement, saw dust ash and Makurdi shale

Element Oxide	Percentage Composition (%)		
	*PLC	Saw Dust Ash	Makurdi Shale
CaO	67.8	34.10	0.26
MgO	1.62	6.7	-
SiO_2	17.51	16.5	49.02
Al_2O_3	5.40	2.3	25.24
TiO_2	0.34	0.12	1.98
MnO	0.12	0.41	0.03
Fe_2O_3	2.54	3.41	8.37
P_2O_5	-	2.67	3.80
K_2O	0.46	26.45	1.85
Na_2O	0.57	1.57	2.57
SO_3	2.52	0.7	-
ZnO	-	0.07	-
LOI	1.10	5.0	-

*PLC=Portland limestone cement Grade 42.5R. LOI= Loss on ignition.

3.2. Effect of Cement andSDA Treatment on Compaction Characteristics of Makurdi Shale

The variation of MDD and OMC with cement treated SDA pre-mixed Makurdi shale is shown in Figs. 1 and 2. From Fig. 1, whereas the MDD of Makurdi shale decreased with all SDA additions, it increased with all cement contents. Generally, the MDD of SDA treated shale increased with cement additions for all percentages of SDA. The increase in MDD is due to the combined effect of SDA and cement, whereas SDA resulted in the flocculation and agglomeration of the shale, cement filled the voids between the particles as well as bound them together.

From Fig. 2, the results show that the OMC increased with SDA and cement additions to the shale. The increase in OMC could be due to additional water needed for hydration of cement and SDA (lime-based waste). This pattern of increase in OMC of shale with cement and SDA additionsis similar to the increase of OMC in the previous study[7] on treatment of Igumale shale with cement and lime.

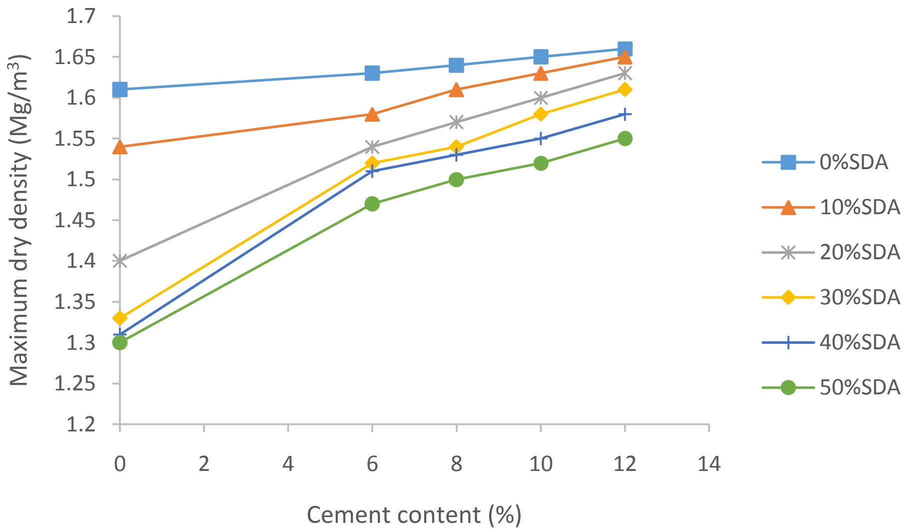


Fig. 1.Variation of maximum dry density with cement treated SDA pre-mixed Makurdi shale.

SDA=Saw dust ash.

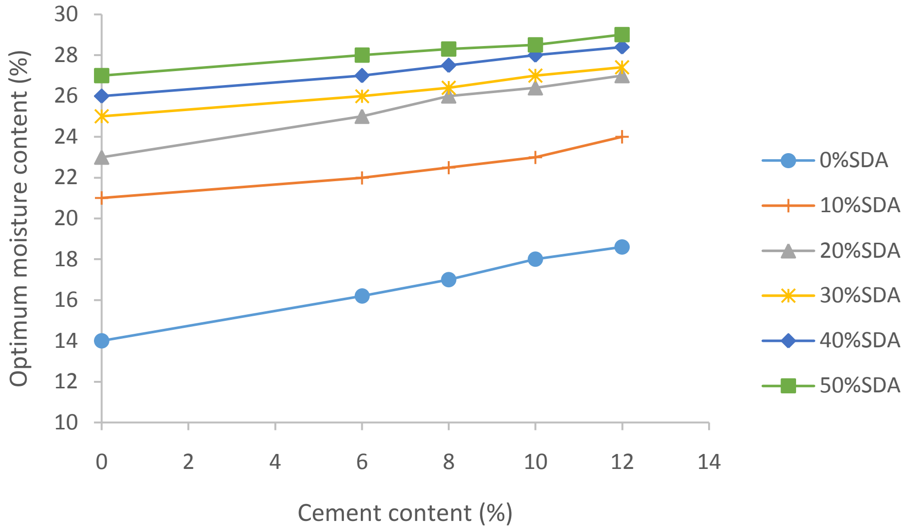


Fig. 2.Variation of optimum moisture content with cement treated SDA pre-mixed Makurdi shale. SDA=Saw dust ash.

3.3. StrengthDevelopment in Cement Treated SDA Pre-Mixed Makurdi Shale.

The results showing the variation of 7 day UCS with cement treated SDA pre-mixed Makurdi shale is presented in Fig. 3. Also the summary of 14 day and 28 day UCS values are presented in Table 5.In all cases, the 7 day UCS values increased with increasing cement content, while for SDA additions the peak strength was achieved at 20% SDA contents. Further additions of SDA resulted in UCS decrease (Figure 3). TheUCS value of 273 kN/m^2 for the untreated shale increased tomaximum values of 1613 kN/m^2, 1635 kN/m^2 and 1654 kN/m^{2}for 7 days, 14 days and 28 days curing respectivelyat 12%C+20%SDA content.Similarly, at 10%C+20%SDA content, the UCS values of 273 kN/m^2 for the untreated shale increasedto 1511 kN/m^2, 1540 kN/m^2 and 1540 kN/m^{2}for 7 days, 14 days and 28 days curing respectively (Table 5).Thestrength increase from the observations of 7, 14 and 28 day UCS resultsshow progressive strengthdevelopment with longer curing periods.

The increase in UCS for all cement additions and peak strength at a particular SDA (20% SDA in this case) is similar to the study by Joel and Agbede [7] which showed increases in UCS for all cement additions and peak strength at 8% lime content, when shale was treated with combinations of lime up to 14% content. Considering that SDA is a lime based waste (with 34.1% CaO), a peak strength of shale at combination of 20% SDA additions when the shale was treated with up to 50%SDA is expected.

For road pavement materials, there exist a compressive strength required for a stabilized pavement layer [15]. In the current study, the 7 day UCS value of 1511 kN/m^2 achieved at 10%C+20%SDA content is greater than 1500 kN/m^2, thus adequate for base course material in lightly trafficked roads based on Revised Road Note 31 [15].Similarly, the 7 day UCS value of 1412 kN/m^2 achieved at 8%C+20%SDA content (Table 5) is greater than 750 kN/m^2, thus adequate for sub-base material in road pavementbased on Revised Road Note 31 [15].

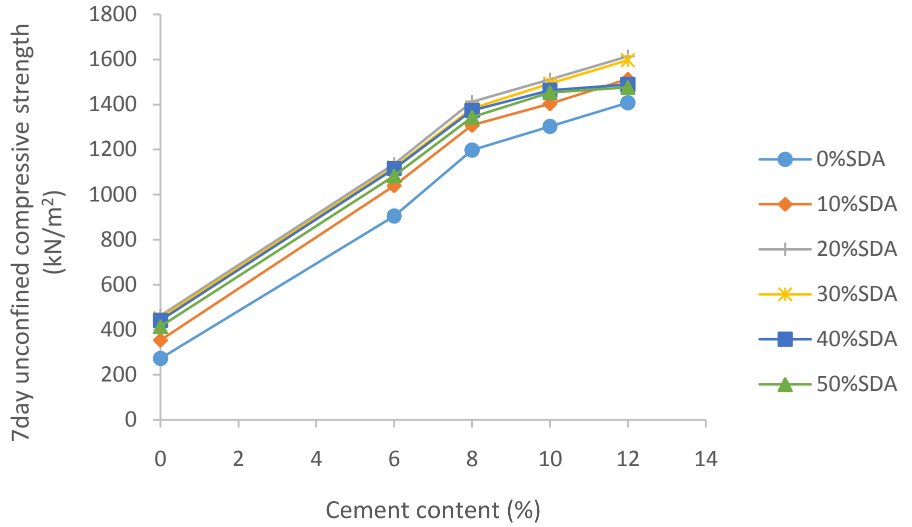


Fig. 3. Variation of cement and sawdust ash (SDA) treatment on 7 day UCS of Makurdi shale UCS=unconfined compressive strength.

3.4 California Bearing Ratio

The results showing the CBR of cement treated SDA pre-mixed Makurdi shale is shown in Fig.4.The CBR value of 2% for untreated shale increased to a maximum value of 85% at 12%C+20%SDA treated shale, followed by a value of 82% at 10%C+20%SDA treated shale.The maximum CBR value at a combination of 12%C+20% treated shale is in agreement with the maximum 7 day UCS value (1613 kN/m^2) which was also achieved at thesame combination (Table 5).

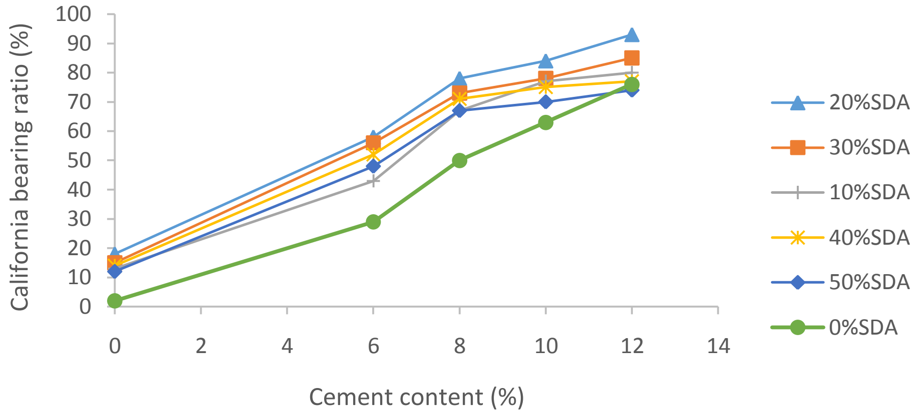


Fig. 4. Variation of CBR in Makurdi shale with various cement treated SDA pre-mixed Makurdi shale. CBR=California bearing ratio, SDA=Saw dust ash.

Based on the Revised Road Note 31 [15], the CBR value of 82% (at 10%C+20%SDA treated shale) is greater than the CBR value of 80% which is the minimum value for cemented base material in road pavement. Similarly, the CBR value of 78% (at 8%C+20%SDA treated shale) is greater than the CBR value of 70% which is the minimum value for cemented sub-base material in road pavement. Therefore the treatment of Makurdi shale with 10%C+20%SDA is adequate for use as cemented base material, while the treatment of the shale with 8%C+20%SDA is adequate for use as sub-base material in road pavement.

Table 5: Results of 7day, 14 day and 28 day UCS for cement treated SDA pre-mixed Makurdi shale.

SDA (%) \ Cement (%)		0	6	8	10	12
0% SDA	7dUCS (kN/m^2)	273	905	1198	1303	1408
	14dUCS (kN/m^2)	273	971	1275	1399	1524

	28dUCS (kN/m^2)	273	1041	1286	1407	1528
10% SDA	7dUCS (kN/m^2)	353	1039	1307	1403	1512
	14dUCS (kN/m^2)	372	1061	1325	1428	1534
	28dUCS (kN/m^2)	379	1072	1338	1444	1552
20% SDA	7dUCS (kN/m^2)	463	1136	1412	1511	1613
	14dUCS (kN/m^2)	488	1155	1425	1540	1635
	28dUCS (kN/m^2)	495	1166	1442	1553	1654
30% SDA	7dUCS (kN/m^2)	451	1122	1382	1492	1596
	14dUCS (kN/m^2)	465	1140	1394	1505	1608
	28dUCS (kN/m^2)	476	1158	1406	1521	1619
40% SDA	7dUCS (kN/m^2)	441	1115	1373	1462	1488
	14dUCS (kN/m^2)	456	1134	1393	1476	1501
	28dUCS (kN/m^2)	465	1145	1406	1488	1533
50% SDA	7dUCS (kN/m^2)	415	1084	1344	1453	1476
	14dUCS (kN/m^2)	423	1096	1351	1464	1487
	28dUCS (kN/m^2)	456	1114	1363	1472	1498

Note: 7d UCS =Seven day unconfined compressive Strength,14d UCS= Fourteen day unconfined compressive strength, 28d UCS= Twenty eight day unconfined compressive strength.

3.5 Durability

The results of Rfor cement treated SDA pre-mixed Makurdi shale is presented in Table 6. The R values of 81% and 83% were achieved at 8%C+20%SDA and 10%C+20%SDA treated Makurdi shalerespectively.

The durability of a stabilized material is important to determine whether a material has the ability to withstand adverseenvironmental condition (a critical wetting condition in the current study). In this study, the R values of 81% and 83% for 8%C+20%SDA and 10%C+20%SDA treated Makurdi shale respectively are greater than 80% which is the minimum R value recommended for stabilized material in road pavement [19].Based on durability requirement, Makurdi shale treated with 8%C+20%SDA and 10%C+20%SDA are adequate for use as road pavement materials.

Table 6: The plasticity index, CBR, 7day UCS and resistance to the effect of water on strength (R) for cement treated SDA pre-mixed Makurdi shale.

Cement (%) / SDA (%)		0	6	8	10	12
0% SDA	PI	23	21	19	18	16
	CBR (%)	2	24	50	63	76
	7dUCS (kN/m^2)	273	905	1198	1303	1408
	R(%)	0	52	56	67	71
10% SDA	PI	18	16	15	14	13
	CBR (%)	13	43	67	77	80
	7dUCS (kN/m^2)	353	1039	1307	1403	1512
	R(%)	25	64	74	78	79
20% SDA	PI	15	14	13	12	11
	CBR(%)	18	58	78	82	85
	7dUCS (kN/m^2)	463	1136	1412	1511	1613
	R (%)	46	68	81	82	83
30% SDA	PI	14	13	12	11	10
	CBR (%)	15	56	73	78	81

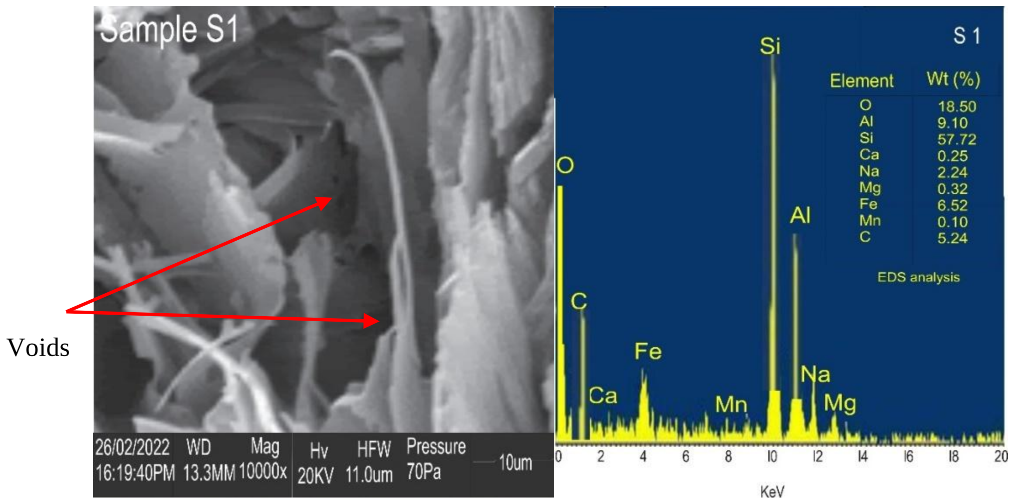
	7dUCS (kN/m^2)	451	1122	1382	1492	1596
	R(%)	37	69	82	82.4	84.4
40% SDA	PI	13	11	10	9	9
	CBR (%)	14	52	71	75	77
	7dUCS (kN/m^2)	441	1115	1373	1462	1488
	R(%)	39	71	82	83	85
50% SDA	PI	12	10	9	9	8
	CBR (%)	12	48	67	70	74
	7dUCS (kN/m^2)	415	1084	1344	1453	1476
	R(%)	39	72	83	84	86.6

PI = Plasticity Index, CBR = California bearing ratio   7d UCS =Seven day unconfined compressive strength (kN/m^2), R = resistance to the effect of water on strength

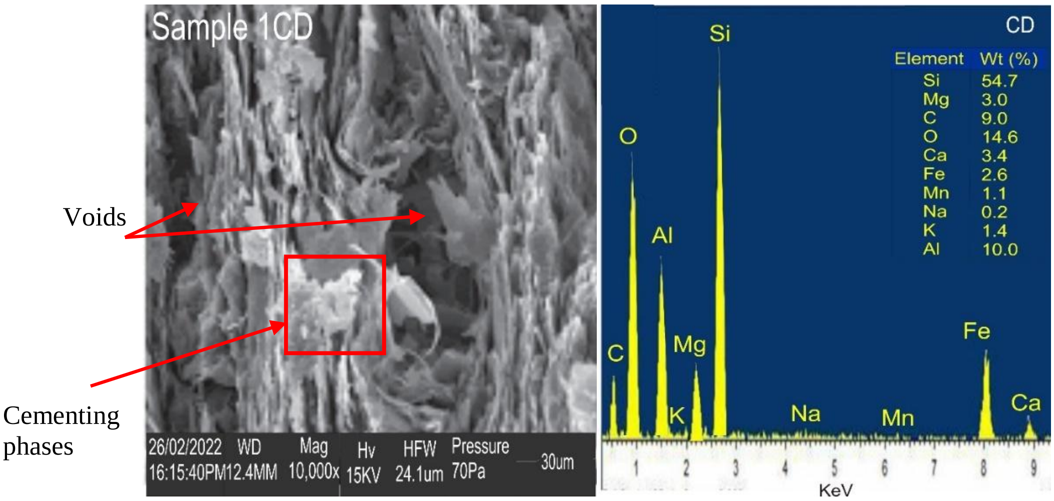
3.6Microstructure of Cement Treated SDA Pre-Mixed Makurdi Shale

The SEM-EDX results of the untreated and 10%C+20%SDA treated Makurdi shale is presented in Figs. 5a and 5b respectively. From the SEM images of untreated shale (Fig. 5a), there is a discontinuous structure, because the voids are more visible suggesting the absence of hydration products. The SEM image of 10%C+20%SDA treated shale (Fig. 5b) shows a more integrated composition suggesting cementitious reactions.

The point elemental analysis of the untreated shale (Figure 5a) shows high composition of Si (57.72%) and Al (9.10%), with low composition of Ca (0.25%). The composition of Si and Al suggests the characteristic of the clay shale. For the point elemental analysis of 10%C+20%SDA treated shale (Figure 5b), there was also high composition of Si (54.7%), other contents wereAl (10.0%), then Ca (3.4%). Again the high composition of Si and Al depicts the characteristic of clay shale. Ca was seen to have remarkably increased from 0.25% (for untreated shale) to 3.4% (for 10%C +20%SDA treated shale). The increase in Ca content at 10%C +20%SDA treated shale compared with that of the untreated shale might be responsible for the increase in compressive strength of 1511kN/m^2 compared with the compressive strength of 273 kN/m^2 for the untreated shale. Overall, the presence of Ca, Si and Al suggest the presence of cementious compounds CSH and CAH [24]. The formation of cementitious products in a stabilized soil are responsible for increase in the internal friction and shear strength of the stabilized soil [25].



(a)



(b)

Fig. 5. SEM-EDX of (a) Untreated Makurdi shale (b) 10%C+20%SDA treated Makurdi shale Note:SEM = Scanning electron microscopy, EDX= Energy dispersion X-ray spectrometer,C=Portland limestone cement, SDA=Saw dust ash.

IV. CONCLUSION

The current study looked at the potential of cement stabilization of SDA pre-treated Makurdi shale. Based on the results, the following conclusions can be drawn.

- Makurdi shale is an A-7-6 soil based on AASHTO [27] and CH soil according to USCS classification[28]. The CBR of untreated Makurdi shale is found to be 2%, which is less than 15% and unsuitable for use as a road pavement material [16]. The shale requires stabilization to make it suitable for use as a road pavement material.
- The PI value of 23% for untreated Makurdi shale reduced to a value of 8% at 12% C+50% SDA treated shale.
- The 7 day UCS value of 273kN/m^2 for untreated Makurdi shale increased to values of 1412kN/m^{2}and 1513 kN/m^2 at 8%C+20%SDA and 10%C+20%SDA treated Makurdi shale respectively. Based on Revised Road Note 31 [15], these UCS values are greater than 750kN/m^{2}and1500 kN/m^2 which are the minimum UCS values for sub-base and base materialsrespectively in lightly trafficked roads.
- The CBR value of 2% for untreated Makurdi shale increased to CBR values of 78% and82% at 8%C+20%SDA and 10%C+20%SDA treated Makurdi shale respectively. Based on Revised Road Note 31 [15], these CBR values are greater than the values of70% and 80% which are the minimum CBR values for sub-base and basecoursestabilized materials respectively.
- The values of resistance to the effect of water on strengthof 81% and 83% for 8%C+20%SDA and 10%C+20%SDA treated Makurdi shale respectively were achieved, compared with the value of 0% for the untreated Makurdi shale. These values of 81% and 83% are greater than 80%, which is the minimum R value recommended for stabilized material in road pavement [19].
- Based on SEM/EDX results, negligible Ca (0.25%) content was found in untreated Makurdi shale, while remarkable content of Ca (3.4%), Si and Al was found in 10%C+20%SDA treated Makurdi shale. This suggest the presence of cementious compound such as CSH and CAH [24]. The formation of cementitious products in a stabilized soil can cause the increase in shear strength of the soil.
- Based on the combined UCS, CBR and durability requirements, an A-7-6 Makurdi shale treated with 8%C+20%SDA is recommended for use as a sub-base material, while that treated with 10%C+20%SDA is recommended for use as a base course material in a lightly trafficked road.

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