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USE OF DRILL CUTTINGS ASH AS STABILISING AGENT FOR SELECTED NIGER DELTA SOILS FOR ROAD CONSTRUCTION

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ABSTRACT

This study investigated potential of the use of Drill Cuttings Ash (DCA) in the stabilisation of Niger Delta soils for road construction. Most of the in-situ soils encountered in the region are fine-grained and highly plastic that would require special treatment. Four soil samples were obtained and the following tests were carried out: classification, compaction, California Bearing Ratio (CBR), and Unconfined Compressive strength (UCS). Dry DCA quantities ranging 2 – 8 percentages by weight of the soil was added to the air-dried soils for the stabilisation process. They were classified as A-6 (clayey soil), A-2-6 (clayey sand), A-3 (silty fine sand), and A-4 (silty clay soil). Generically, the unstabilised soils were fine-grained having low to medium plasticity, with low shear strength. Other results showed that 6% DCA content caused improvement in the texture, plasticity, and dry density of the clayey soil, while its CBR and UCS parameters compared favourably well with the unstabilised soil values. Also, there was increase in CBR value of the clayey soil after soaking for 24 hours. DCA increased the plasticity of the clayey sand, silty fine sand, and silty clay soil, and there was no substantial improvement in their strength properties. These results showed that DCA would be useful in improving clayey soilswhich are known to be prone to excessive swelling and difficult to handle during construction especially after heavy rainfall.

Keywords: *Drill Cuttings Ash; Soil; Stabilisation; road construction; Niger Delta*

INTRODUCTION

Quest to effectively stabilise problematic soils (especially fine-grained and highly plastic soils) and at low cost has been ongoing for a long time, and it is one of the reasons for the various research into the use of waste and by-products of materials. The rationale behind this is that effective adaptation of the waste product especially for construction purposes will not only save cost but will also result in protection of land-use and the environment. Niger Delta in Nigeria is naturally endowed with crude oil and its exploration has been very huge business for many international and local companies. Drill Cuttings Ash (DCA) is the ashobtained from the thermal desorption of waste product of the crude oil drilling operations. The waste product is a mixture of drilling mud (type depends on the crude oil company), base fluid (water, oil, or synthetic-oil), crude oil, crushed rocks and soils. The waste is stock-piled according to source/company and treated accordingly by subjecting it to indirect heat at a very high temperature and the constituents are separated through grade-separation process. Some of the useful components are reclaimed and re-used in the drilling process while the solid residue flow out as the ash, and is either disposed-off in a designated landfill or stock-piled.It is generated in very large quantities on a daily basis and there is yet to be any useful adaptation of this material for construction purposes. Meanwhile, conventional construction materials are responsible for high cost of construction. Hence, using this ash for construction purposes will go a long way in mitigating this challenge. The DCA is fine grained, silty textured, and hydrophobic. The ash could either be dark brown or grey in colour (see Figure 1).

Figure 1: Drill Cuttings Ash

Drilling Waste - Soil Stabilisation

Soil stabilisation is a process of treating unstable soil to produce valuable construction soil. The process can either be mechanical, physical or chemical. Compactive force is used in mechanical stabilisation to condense the soil particles. Physical process involves the addition of another material or soil either to make up for the particle fraction deficiency or to bind the particles together without any chemical reaction taking place, while chemical stabilisation is the use of cementitious or pozzolanic binders to alter the chemical composition of the soil to form a monolith material.

Ifeadi (2004) investigated the use of Dispersion by Chemical Reaction (DCR) –treated drilling waste as an aggregate in the production of interlocking bricks. The study revealed that the use of the treated waste as a partial replacement for sand yielded a compressive strength (255 kPa) which compared adequately well with the interlocking brick (262 kPa) made with sand, gravel and cement. Al-Ansary and Al-Tabbaa (2007) also studied the effect of different binders at various compositions in the stabilisation/solidification of a synthesized drill cuttingsmud similar to that in use at the North Sea in Northern Europe. The binders were Portland cement, hydrated lime, pulverized fuel ash, blast furnace slag, MgO cements, zeolites, silica fume, and cement kiln dust. The study showed that the binders could effectively immobilize the toxic (chloride) in the drill cuttings and increase the shear strength of soils suitable for a wide range of applications.

STUDY AREA

The delta of the river Niger is the third largest delta in the world and is richly endowed with petroleum and natural gas. It is situated in the southern part of Nigeria, bordered by the Atlantic Ocean to the south and Cameroon to the east. It covers an approximate 112,110 km^2 surface area representing about 12% of Nigeria's total surface area. There are nine of the Nigeria's constituent states in the region namely: Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo, and Rivers. The terrain in the region is flat at the coastal and deltaic plains which are to the south, but the northern part has a gently rolling and undulating landscape. The Niger Delta has a tropical climate with two distinct wet and dry seasons. The mean annual rainfall usually exceeds 3500mm along the coast and gradually decreases inland to about 2000mm, and annual mean temperature is between 18^oC and 35^oC. This high rainfall usually results in widespread flooding, which may rise more than 5m in some area and hence the high insitu moisture content of foundation soils (Akpokodje, 1987). This causes large volume changes in the clayey soils and results in excessive swelling and shrinkage. The high plasticity and moisture contents that are peculiar to the soils imply that it will take longer time for the soils to dry out after heavy rainfall thus difficult to handle during construction (Akpokodje, 1987). There is therefore the need to stabilise these soils for them to be useful in pavement construction.

Soil samples were obtained from the subgrade level and the borrow-pit along East/West-Nyokuru link roads in Port-Harcourt, River State and designated as Samples 1 and 2 respectively; Kaa-Ataba link road in Ogoni land, River State (Sample 3), and also from Okaka road in Yenogoa, Bayelsa State (Sample 4). Samples1 and 2 locations were relatively flat and free draining, while Samples 3 and 4 locations were swampy with water table almost at the ground surface. Figure 2 shows these locations. There was no form of stabilisation of the subgrade soils at these locations, instead the problematic soils were excavated to some depth and massive filling to formation level were done using sands dredged from nearbyrivers or borrow-pit. Figure 3a & b shows the site condition in many locations in the Niger Delta and the usual practice of sand filling the soft subgrade.

Figure 2: Sample Collection Points at various locations in the Niger Delta, Nigeria

Figure 3: Site condition and construction practice in the Niger Delta - (a): Soft subgrade with puddle of water; (b): Sand filling to formation level

METHODOLOGY

The DCA used in this study was obtained from DEL Waste Management Company Limited in Onne Oil and Gas Free Zone, Rivers State, and the cement (PC grade 42.5R) was obtained from Dangote cement Plc, both in Nigeria.

Analytical Procedures for Polycyclic Aromatic Hydrocarbon, Aliphatics and Oxides in DCA

The Gas Chromatography test method (USEPA 8270) was adopted using GC-MS for the polycyclic aromatic hydrocarbons (PAHs) while the sample extraction was effected using sonication method. About 10g of wet soil sample was extracted with pyrene-d10 as surrogate. The extraction was carried out with 30ml of dichloromethane (DCM) in sonication water bath. The soil sample extract was subsequently filtered through glass wool containing anhydrous sodium sulphate in a glass funnel. This was followed by clean-up and separation into aliphatic and aromatic fractions in a 10mm chromatographic column. The aromatic fraction was then concentrated to 1ml, transferred into the vials and analysed using Agilent 6890N/5975C GC/MS previously calibrated with polycyclic aromatic hydrocarbon (PAH) standards under specific temperature programmed inlet, oven and detector conditions. The equipment turns out the concentration of the PAH in that the reciprocal of the volume of sample is entered as the multiplier in the sequence table.

Aliphatic content in the DCA was analysed using GC-FID following USEPA 8270B test method. About 10g of wet sample was extracted with 1- chlorooctadecane as surrogate. The extraction was carried out with 30ml of dichloromethane (DCM) in sonication water bath. This was followed by clean-up and separation into aliphatic and aromatic fractions in a 10mm chromatographic column. The aliphatic fraction was then concentrated to 1ml, transferred into the vials and analysed using Agilent 6890NGC/FID previously calibrated with Hydrocarbon Window Defining Standard, under specific temperature programmed inlet, oven and detector conditions. The equipment turns out the concentration of the aliphatics in that the reciprocal of the volume of sample was entered as the multiplier in the sequence table.

The oxides were determined using the X-ray fluorescence Spectro Xepos and USEPA 6200 test method.The spectrometer was first calibrated and the correlation coefficient for the standard curve was 0.990. About 5g of the milled soil sample (of 5µm grain size) was used for the analysis. These tests were done at thelaboratory of Fugro Nigeria Limited, Port Harcourt, Nigeria.

Soil Analysis

Comprehensive laboratory analysis was carried out on the representative disturbed soil samples, to identify their inherent engineering properties and the effect of DCA on these properties. The soil samples were properly sealed in polythene bags at the sites to prevent moisture loss and some quantities were immediately placed in the oven at about 105^{o}C on reaching the laboratory to obtain their natural moisture contents. The remaining bulk samples were air-dried at room temperature in preparation for other tests. The tests carried out on both the natural and stabilised soils were particle size distribution, Atterberg limits, compaction, California Bearing Ratio (CBR) and Unconfined Compression Strength (UCS). All the tests were conducted in accordance with BS 1377

(1990) and BS 1924 (1990). Wet sieving method was used to analyse the particle sizes of the samples with the percentage passing sieve 63µm completely washed out. The difference between the original soil quantity and the oven-dried washed quantity was taken as the silt and clay contents of the soils. The Casagrande apparatus was used to determine the liquid limit on soil passing sieve 425µm and it was taken at 25 blows on the semi-logarithm graphs. West African Compaction was performed to obtain the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). This was carried out using the CBR mould and 4.5kg rammer applied on 5 layers of the soil at 25 blows per layer. The CBR test was done both on the unsoaked and 24 hours soaked samples. Split mould of 100mm diameter x 200mm height was used for UCS test. The samples were compacted in 3 layers using 2.5kg rammer and applying 25 blows per layer. The UCS test was conducted after moist-curing the de-moulded samples for 7, 14 and 28 days. Moist-curing was carried out by wrapping the compacted samples with cellophane, and placed in a covered barrel filled with moist sawdust. 2%, 4%, 6% and 8% DCA contents by dry weight of the soil were added for the stabilisation of the soils.The DCA was dry-mixed with the air-dried soils before adding water for all the tests.

RESULTS AND DISCUSSION

Comparison of DCA and Cement

The physical properties and chemical compositions of DCA and cement are shown in Table 1. The specific gravity of 1.54 indicated that the DCA was less dense than cement, while the pH value of 12.0 indicated that DCA was an alkaline material like cement. The initial setting time of DCA wasbeyond the specified lower limit of 75 mins for pozzolanic cement according to BS EN 197 -1 (2000), and it showed that it would take a long time for the material to harden with exposure to natural air. This non-cementing attribute of DCA was revealed in its CaO and SiO_2 ratio which was about 1.3. This ratio value was less than the specified ratio of ≥ 2 for cementitious binders according to BS EN 197-1 (2000). However, the relatively high value of cementing compound CaO (25.6%) could be the possible explanation for the friable and workable effects this material had on the fine-grained and plastic Niger Delta soils. Little and Nair (2009) reported that high pH and calcium content were good indications of cementation potential of a material that could result in high strength. Although, DCA lacked the attributes to be labelled as cementitious material. Bin-Shafique, et al. (2004) classified such materials having the CaO/SiO_2 greater than 1 as 'off specification' pozzolanas.

Furthermore, the total PAH content of DCA was less than 5,000µg/m^3 (or 5mg/m^3) as specified by Federal Environmental Protection Agency of Nigeria (FEPA, 1991) while the total aliphatic content was 1396.58 mg/m^3. These values showed that the drilling waste was well treated by the thermal desorption method and the DCA does not pose any hazardous treat to human health and the environment if used for soil stabilisation both in the laboratory and in the field.

Table 1: Physico-chemical Properties of DCA and Cement

Properties	DCA	*Cement (42.5R)
Specific gravity	1.54	3.02
Initial setting time (min)	>300	105
Final setting time (min)	>375	240
pH @ 23.5^{o}C	12.00	12 – 13
SiO_2(%)	19.30	19.96
Fe_2O_3(%)	7.24	2.99
Al_2O_3(%)	5.52	6.05
CaO	25.60	64.86
MgO	0.72	1.26
SO_3	-	1.99
K_2O	-	1.09
Na_2O	-	-
P_2O_3	-	0.24
LOI	-	7.84
Not detected	41.62	-
Total PAH (mg/m3)	0.01	-
Total aliphatic (mg/m3)	1396.58	-

*Oxides content obtained from Ibrahim, et al. (2012)

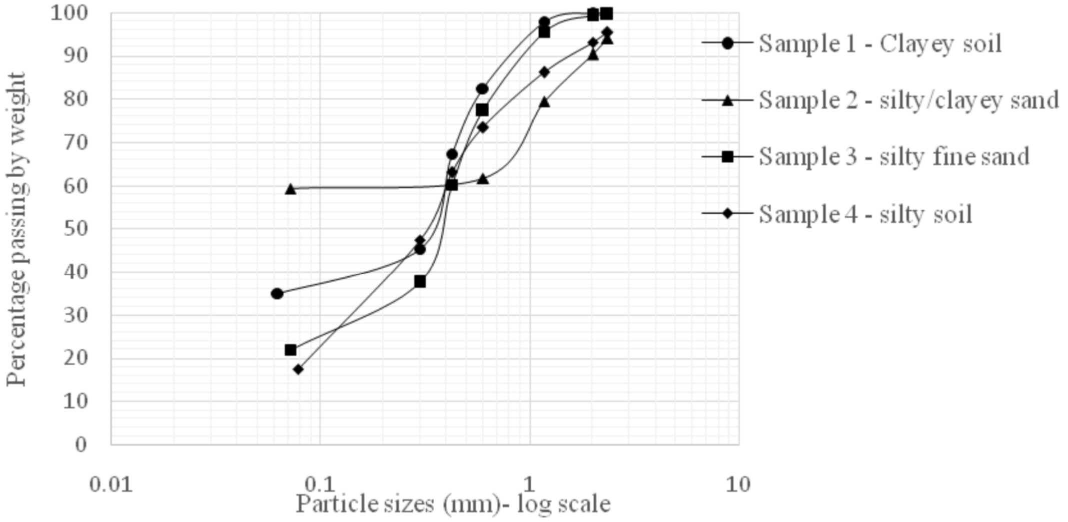
Soil Classification

The unstabilised Samples 1, 2, and 4 had liquid limit less than 50% and the plasticity index greater than 7, and were classified as inorganic clays of low to medium plasticity (CL soils) in the Unified Soil Classification System (USCS). Also, in AASHTO system the soils were classified as follow: Sample 1 – A-6 (clayey soil); Sample 2 – A-2-6 (silty/clayey sand) and Sample 4 was A-4 (silty soil). However, Sample 3 was non-plastic and had less than 35% passing 63µm sieve, thus could be classified as inorganic silt and fine sand of slight plasticity (ML soil) in USCS and A-3 soil (fine sand) in the AASHTO classification system (see Table 2 and the particle sizes distribution curves in figure 4).

Table 2: Summary of Soil Analysis

Engineering Properties	East/West-Nyokuru Link Road Subgrade Soil (1)					East/West-Nyokuru Link Road Borrow-pit Soil (2)				
	Nat Soil	Drill Cuttings Ash				Nat Soil	Drill Cuttings Ash			
	0%	2%	4%	6%	8%	0%	2%	4%	6%	8%
AASHTO class	A-6	A-4	A-6	A-6	A-6	A-2-6	A-2-6	A-2-6	A-2-7	A-2-6
USCS class	CL	CL	CL	CL	CL	CL	CL	CL	CL	CL
NMC (%)	12.44	-	-	-	-	0.80*	-	-	-	-
% Passing 63µm	40.00	-	-	-	-	23.14	-	-	-	-
Liquid Limit (%)	32.58	25.95	28.09	24.73	27.53	37.82	36.27	32.97	40.67	35.23
Plastic Limit (%)	6.88	16.75	14.82	11.13	14.60	17.48	14.57	12.01	13.07	12.44
Plasticity Index	25.70	9.20	13.27	13.60	12.93	20.34	21.70	20.96	27.60	22.79
LSL (%)	7.30	4.50	7.50	7.76	7.35	10.43	10.52	11.28	11.34	12.54
MDD (kg/m3)	2000	1920	2060	2220	1900	1880	1999	2150	1999	2038
OMC (%)	10.50	13.60	9.00	9.50	10.50	16.50	10.00	10.50	9.00	13.00
CBRu %	39.60	0.75	19.46	16.09	6.88	1.25	7.00	0.65	1.20	0.35
CBRs % – (24hrs)	39.13	1.24	28.66	35.82	11.52	2.29	9.32	1.20	1.72	0.67
UCS (MPa) - 7 days	0.69	0.04	0.12	0.55	0.11	0.05	0.36	0.33	0.31	0.09
UCS (MPa) -14 days	0.72	0.03	0.13	0.70	0.11	0.22	0.38	0.45	0.38	0.09
UCS (MPa) -28 days	0.62	0.03	0.18	0.53	0.11	0.20	0.26	0.45	0.37	0.09
Engineering Properties	Kaa-Ataba Link Road Subgrade Soil (3)					Okaka Road Subgrade Soil (4)				
	Nat Soil	Drill Cuttings Ash				Nat Soil	Drill Cuttings Ash			
	0%	2%	4%	6%	8%	0%	2%	4%	6%	
AASHTO class	A-3	A-4	A-6	A-4	A-6	A-4	A-4	A-4	A-4	
USCS class	ML	ML	CL	CL	CL	CL	CL	CL	CL	
NMC (%)	27.86	-	-	-	-	26.72	-	-	-	
% Passing 63µm	37	-	-	-	-	37.32	-	-	-	
Liquid Limit (%)	NP	14.23	22.95	22.92	25.63	26.27	27.54	28.10	27.36	
Plastic Limit (%)	NP	12.73	12.35	15.20	13.54	18.75	20.02	19.97	19.47	
Plasticity Index	NP	1.50	10.60	7.72	12.09	7.52	7.52	8.13	7.89	
LSL (%)	6.71	7.51	7.98	7.72	7.46	4.74	5.20	5.21	4.99	
MDD (kg/m3)	2030	1985	2010	1870	2110	2063	1867	1811	2060	
OMC (%)	9	8	7	14	14.5	9	11.5	13.5	14.5	
CBRu %	67.13	66.63	55.11	1.65	1.05	18.54	7.84	1.02	1.14	
CBRs % – (24hrs)	50.40	55.11	22.32	2.71	1.77	1.66	4.51	1.12	0.84	
UCS (MPa) - 7 days	0.28	0.02	0.19	0.17	0.14	0.21	0.26	0.31	0.21	
UCS (MPa) -14 days	0.27	0.01	0.22	0.20	0.17	0.38	0.25	0.35	0.15	
UCS (MPa) -28 days	0.28	0.01	0.15	0.41	0.39	0.37	0.34	0.56	0.46	

Nat Soil = Natural Soil; NMC = Natural Moisture Content; LSL = Linear Shrinkage Limit;
CBRu = CBR – Unsoaked sample; CBRs = CBR – Soaked sample; * Sample taken in dry season



Silt & Clay	Fine	Medium	Coarse	Fine	Medium
	Sand			Gravel	

Figure 4: Particle size Distribution curves of Samples 1, 2, 3, and 4

Effect of DCA on Texture and Consistency Limits

Adding 2% DCA to Sample 1 caused an improvement in its texture. This sample which was initially classified as A-6 was improved to A-4 with corresponding decrease in its plasticity. However, the texture increased in plasticity again when DCA content was increased. Sample 2 became more plastic when DCA was added, and similar effect of DCA was also observed on Sample 3. There was no significant impact on the texture of Sample 4.

Only the unstabilised Sample 4 had acceptable linear shrinkage with the specified limit of 6% (Dreyfus, 1952). The linear shrinkage of unstabilised Sample 3 was marginally acceptable, while those of unstabilised Samples 1 and 2 were unacceptable. Addition of 2% DCA to Sample 1 caused an initial decrease in its linear shrinkage, which thereafter increased as the DCA content was increased. Similar effects with the same quantity were observed in Samples 2 and 3; substantial shrinkage was noticed in Sample 2, while the marginally acceptable linear shrinkage in Sample 3 became unacceptable. There was no significant impact of DCA on the linear shrinkage of Sample 4.

The explanation that could be given to this phenomena observed in the samples was that the addition of DCA which was a fine-grained and silty textured material to clayey soil caused an improvement on texture and workability by reducing its plasticity. However, the material effected friability and increase in the plasticity indices of silty/clayey, silty, and fine sand soils. The overall effect on the soils is however dependent on the amount of silt and clay particles inherent in the soils.In summary, DCA quantity above 4% caused detrimental effect on the consistencies of the clayey soil, clayey sand, and silty fine sand (Samples 1, 2, and 3) while it had no useful effect on the consistency of the silty clay soil (Sample 4).

Effect of DCA on Compaction

(i) Effect on Maximum Dry Density (MDD)

The MDD of Sample 1(clayey soil) was reduced with the addition of 2% DCA, which subsequently increased as the DCA content increased and became maximum at 6% DCA content, after which the MDD decreased rapidly. Furthermore, the curve of MDD versus DCA content in Figure 5a showed that there would be continued decrease in the MDD of the sample with increase in DCA content. The Sample 2 (clayey sand) had the lowest MDD which increased as the DCA content increased. Maximum dry density for Sample 2 was obtained with 4% DCA content, after which the MDD decreased. The curveshowed that the MDD for Sample 2 would continue to decrease with increasing DCA content. Both Sample 3(silty fine sand) and Sample 4 (silty clay soil) had high MDDs which were decreased with the addition of DCA. The lowest MDD was obtained with 6% DCA content for Sample 3, while the lowest MDD was obtained with 4% DCA content for Sample 4. Thereafter, the MDD of both samples increased with increasing DCA content, as also shown by the curves.

(ii) Effect on OMC

This observed effect of DCA content on MDD could be related to their OMC as shown in Figure 5b. The curve drawn for Sample 1 (clayey soil) showed that there was gradual decrease in OMC as DCA content increased. The DCA (a silty material) contributed more silty particles to the clayey soil, which reduced the affinity of the soil for water, and the more the DCA content the lesser the water required for compaction. The initial high density observed in Sample 1 could then be based on the fact that a more uniform soil particles were developed up to 6% DCA content. Thus, high density was obtained with the 'just enough' water used to compact these mixtures. However, as the DCA content increased, the soil particle matrix had changed and more water was needed for lubrication and to effect adequate densification. This increase in water caused the decrease in densification. The curve for Sample 2 (clayey sand) showed an initial decrease in OMC as DCA content increased up to 4% DCA content, after which the OMC increased as DCA increased. The same effect as with Sample 1 was noticed, except that lesser amount of DCA (4%) was initially needed to change the soil matrix and made it less demanding for water. However, subsequent increase in DCA caused a corresponding increase in water. Samples 3 (silty fine sand) and Sample 4 (silty clay soil) had increasing OMC as the DCA content was increased.

In summary, DCA content up to 6% and 4% caused an increased MDD and lower OMC in the clayey soil and clayey sand respectively, after which the reverse effects occurred for both soil types. This indicated that these DCA contents effected reduction in the plasticity of these soils which resulted in better compaction. While DCA contents more than these values increased the silt content in the soils and more water was required for effective compaction, which subsequently caused the reduction of the MDDs.DCA content up to 6% and 4% caused decreased MDD and higher OMC in the silty fine sand and silty clay soil respectively, after which the reverse effectsoccurred for both soil types.This also indicated that DCA increased the silty content in the soils, and subsequently affected the water required for effective compaction. The initial lower MDD obtained depicted that not enough silt particles was present. While the high MDD signified that enough silt and water were present for maximum densification. These resultsare comparable to what Senol, et al. (2006) reported as well as Vukicevic, et al. (2013) who showed in their studies that low plastic soil stabilised with fly-ash had better response to compaction than the highly plastic soil.

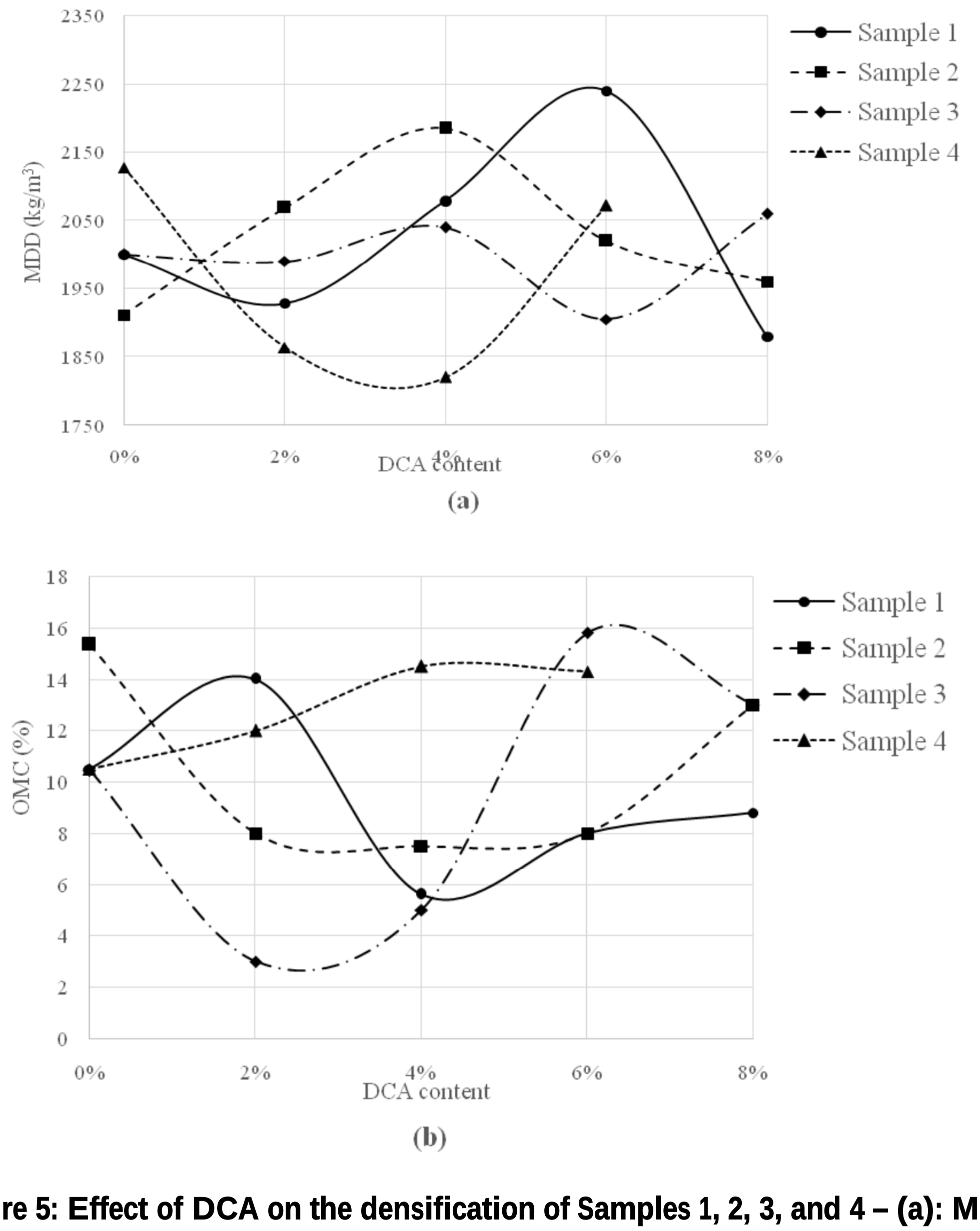


Figure 5: Effect of DCA on the densification of Samples 1, 2, 3, and 4 – (a): MDD vs DCA content; (b): OMC vs DCA content

Effect of DCA on CBR and UCS

i. *Effect on CBR*

Figure 6 showeda comparison between the natural Sample 1 and the DCA-stabilised sample revealed that there was substantial reduction in the CBR (both unsoaked and soaked), when the initial 2% DCA was added. Maximum unsoaked and soaked CBR values for DCA-stabilised Sample 1 were obtained with 4% and 6% DCA contents, but both values were lower than the values for the natural soil. Furthermore, the soaked CBR values were higher than the unsoaked. Slight increase over the unsoaked and soaked CBRvalues of natural soil were obtained with 2% DCA-stabilised Sample 2. These, however, decreased as the DCA content was increased. Natural Sample 3 and its 2% DCA-stabilised soil had the highest CBR (unsoaked and soaked) compared with other samples. These values however decreased as the DCA content increased in the soil, and the unsoaked CBR values were higher than the soaked values. There was a general decrease in the unsoaked CBR of DCA-stabilised Sampled 4 compared with the natural soil. However, there was a slight increase in the soaked CBR of the 2% DCA-stabilised Sample 4, which decreased as the DCA content increased.

In summary, small quantity of DCA could be said to have acted as substitute for the deficient silty particles in the clayey soil (Sample 1), thereby effecting an improvement in the particle grading of the soil, which was reflected in the engineering properties. With larger quantity (~ 6%) of the ash, its hydrophobic nature was more pronounced and reflected in the soaked CBR of the soil. However, DCA content above 6% would decrease the CBR of the soil. Furthermore, DCA content above 2% could not substantially improve the CBR of the clayey sand, silty fine sand, and silty clay soil (Samples 2, 3, and 4).

ii. *Effect on UCS*

Figure 7a showed that there was a general reduction in the UCS of stabilised Sample 1 compared with the natural soil. However, UCS value equal to the natural soil was obtained with 6% DCA content at 14 days, and this was the highest for the stabilised soil. Sezer, et al. (2006), Brooks, et al. (2011), and Bose (2012) also reported increase in the UCS of plastic clayey soils when stabilised with fly-ash.The increase in the compressive strength of DCA-stabilised Samples 2and 4 was maximum with 4% DCA content and obtained at both 14 and 28 curing days, after which there was a reduction. The curves showed that this reduction would continue with increasing DCA content (Figure 7 b&d). Similar increase in UCS observed in DCA-stabilised Sample 1 was seen in DCA-stabilised Sample 3 (Figure 7c), except that the maximum strength occurred at 28 curing days with 6% DCA content. The curve also revealed the possibility of increase in the shear strength with increasing DCA content and longer curing days. This effect agreed with the finding in Vukicevic, et al. (2013) who reported that gain in strength of low plastic soil (fine-grained) was time dependent.

In summary, DCA-stabilised Sample 1 (clayey soil) showed the best response to the stabilising effect of DCA, irrespective of its exposure to moisture. DCA-stabilised Sample 3 (silty fine sand) would response better if it does not have direct contact with water while the stability of DCA-stabilised Samples 2 (clayey fine sand) and 4 (silty clay soil) on exposure to water is doubtful.

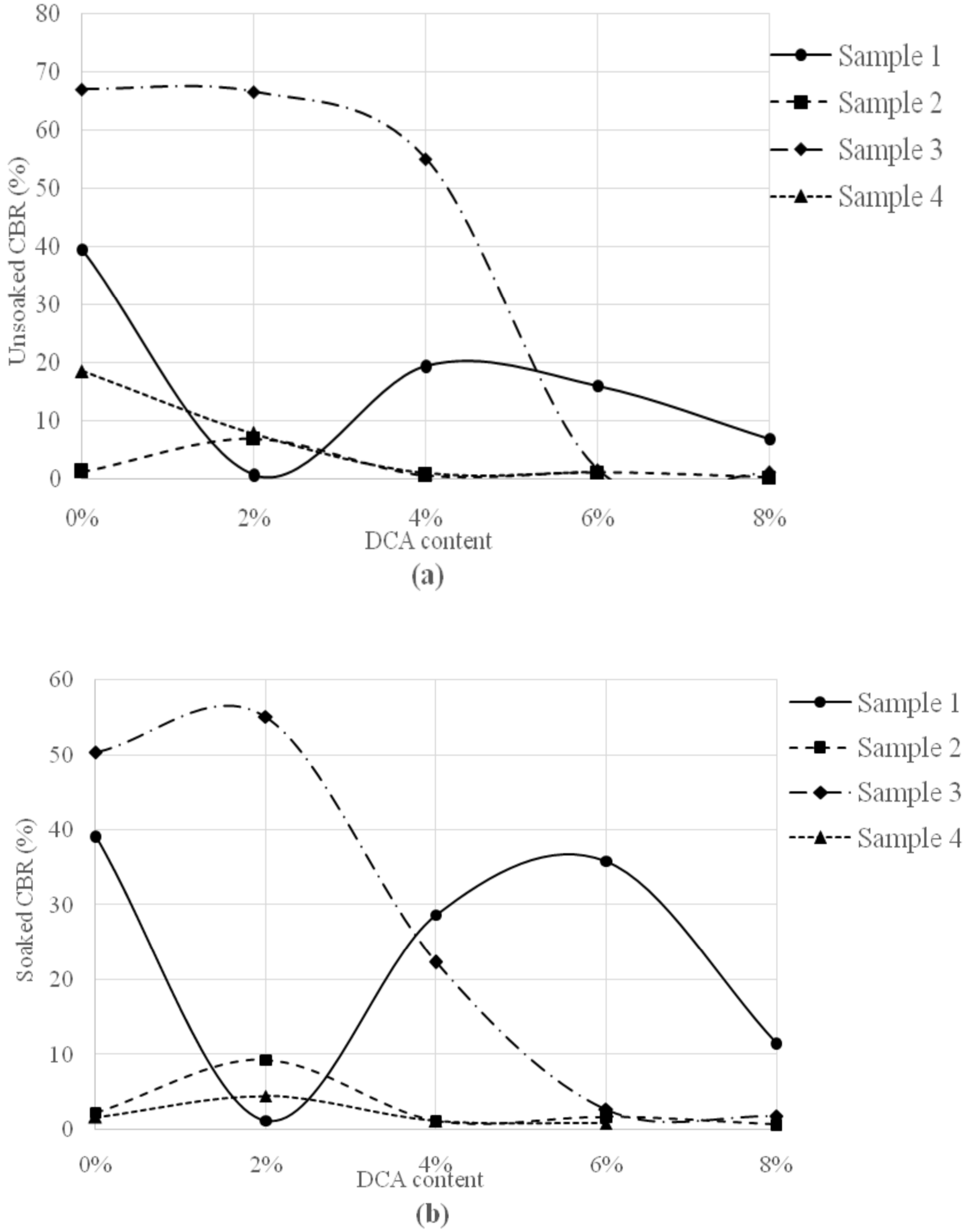


Figure 6: Effect of DCA on the CBR of samples 1, 2, 3, and 4 – (a): DCA content vs unsoaked CBR; (b): DCA content vs soaked CBR

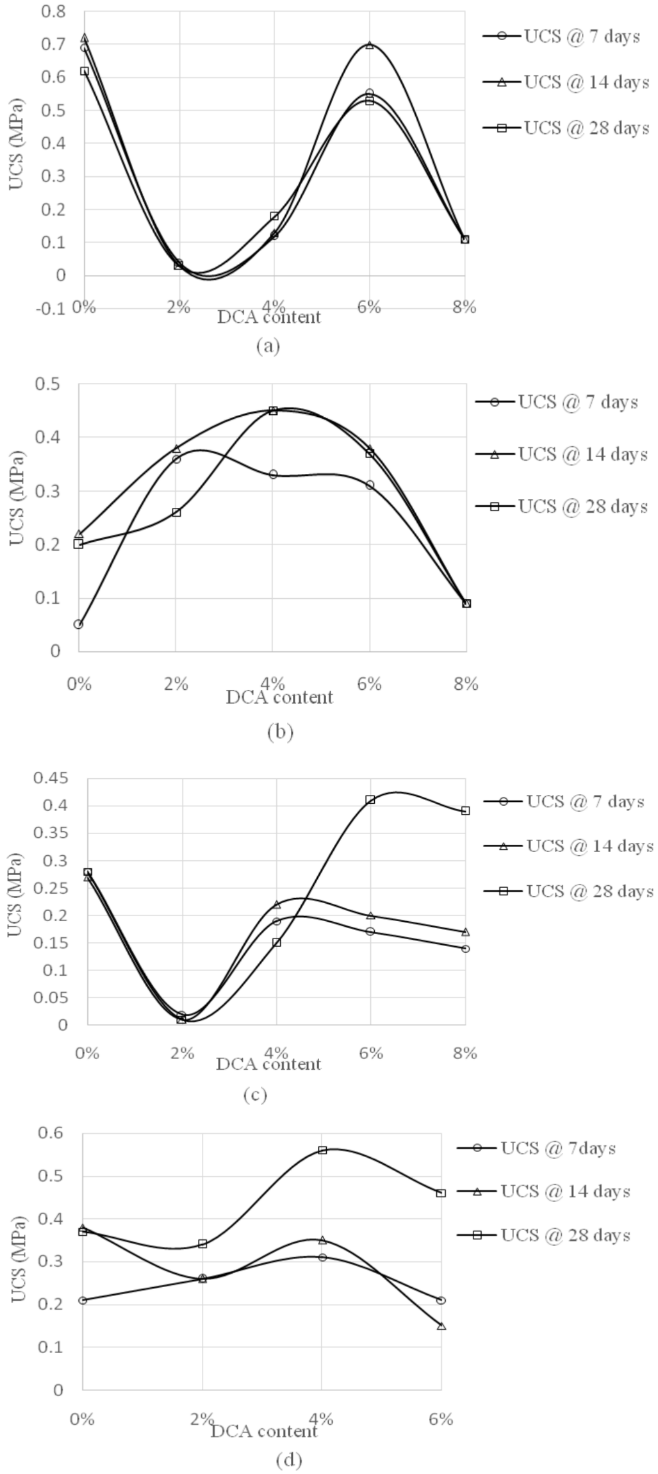


Figure 7: Effect of DCA on the UCS of samples 1 to 4 – (a, b, c, d): UCS vs DCA content for Samples 1, 2, 3, and 4 respectively.

CONCLUSIONS

The potential of the adaption of Drill Cuttings Ash in the modification of clayey soils in the Niger Delta is very high and the effect in increasing the dry density of other soils types investigated in this study had been shown. Also the potential of having increased strength was also revealed in the soaked CBR and UCS at a longer curing time. Also, there was an indication that increase strength might be gained, if sufficient DCA quantity was used and the pozzolanic reaction was given enough time to develop before compaction.This study thus revealed that DCA would be useful in the modification of the clayey soil and possibly stabilise the silty and fine-sand soils, especially for subgrade applications.

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