STABILISATION OF NIGER DELTA FAT CLAY WITH BLEND OF BINDERS FOR SUBGRADE APPLICATION (PART 2) – ASSESSMENT OF DURABILITY

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ABSTRACT

In this study, the durability of fat clay stabilised with blends of additives and cement (PC) as subgrade materials was determined. The blends and compositions used were as follow: Drill Cuttings Ash (DCA)-PC (1:1), sand-PC (4:1), and lateralite-PC (2:1). The durability test using CBR procedure yielded values in the range of 24 – 41% after 5 cycles of wetting and drying. This procedure caused instability and radial cracks on the compacted surface of soil-DCA-PC and soil-sand-PC blends respectively after 3 cycles while the compacted surface of soil-lateralite-PC was relatively stable after 5 cycles. The soil-blends were subjected to different curing procedures namely: wrapped and dry; wrapped and moist; not wrapped and moist for 28 days before the Unconfined Compressive Strength (UCS) test. Soil-sand-PC and soil-lateralite-PC developed optimal UCS values of 0.38 MPa and 0.36 MPa respectively after wrapped and dry curing, while soil-DCA-PC had an optimal UCS value of 0.39 MPa after wrapped and moist curing. All the soil-blends responded poorly when exposed to water directly. The durability test using UCS procedure yielded values in the range of 0.11 – 0.18 MPa after 1 cycle. The results showed that stabilised fat clay could be adopted as subgrade material.

Keywords: *Fat clay; Stabilisation; Durability; Subgrade*

1.0 Introduction

Stabilisation of marginal soils with pozzolanic materials and/or cement effect improvement of texture and immediate strength. Durability test then becomes necessary because fulfilment of these criteria is not a guarantee of long-term performance. The ability of stabilised soils to resist likely detrimental environmental conditions such as cyclic wetting-drying or freezing-thawing when subjected to use must be ascertained. Thus durability tests are used as quality assurance entity. Several reports are available on both short and long-term performance including the test employed in the assessment of stabilised soils. Common engineering properties checked for are changes in strength, variations in weight, variations in chemical compositions, and shrinkage as reported by Thomas (1986); Al-Tabbaa and Evans (1998); Janoo, et al (2012); Al-Tabbaa and Evans (2000); Al-Tabbaa and Boes (2002); Bin-Shafique, et al (2004); Parsons and Kneebone (2005); Rajasekaran and Rao (2002); George (2006); Kumar, et al (2007); Bin-Shafique, et al (2010). Thomas (1986) used coring method to obtain PC-stabilised samples from distressed roads in Northeast England and Kent. The soils were reported to be coarsely graded, and the clay content (% passing sieve 63µm) was about 44%, and contained expansive clay minerals. It was also noted that 8% PC gave a laboratory UCS of 5.75 MPa at 7 days, which was more than the specified minimum of 3.0 MPa. One of the sources of the distresses was linked to pyritic sulphate in the soil, which led to the formation of ettringite in the PC-stabilised soils. This revealed that inherent property of soil (expansive clay minerals in this case) could compromise the durability of a stabilised soil when in use or exposed to environmental conditions.

George (2006) also reported the performance of six stabilised sections on a highway in Marshall County, Mississippi. The sections were stabilised with various blends of binders, out of which the PC-fly ash is reported here. The author noted increase in strength for the first 28 days for the laboratory tested cored soil-blend having 3.5% PC and 8% fly ash (1:2), thereafter the strength remained unchanged. The cored samples were poorly cemented, and this was attributed to poor site mixing. However, the structural index was on target, and the long-term performance was rated as very good. It could be inferred from this study that adequate site mixing was essential for proper cementation between the soil and the stabiliser. However, overall strength developed was depended on the type and amount of stabilisers used.

Al-Tabbaa and Evans (1998, 2000) gave details of time-related performance analysis of in-situ soil, which was treated with blends of cement (PC), PC-PFA-lime, and PC-bentonite in Drayton, Middlesex. The cored samples were subjected to wet-dry and freeze-thaw cycles in the laboratory, and long-term weathering condition was stimulated using elevated temperature to accelerate ageing. Minimal deterioration was observed in the samples subjected to the cyclic weathering conditions while significant decrease in UCS was noted in the samples subjected to the high temperature. However, continuous increase in UCS up to 3.5 MPa was obtained throughout the test period for samples containing adequate PC content, and low permeability ranging between 0.1 x 10^{-9} - 0.8 x 10^{-9} m/s was obtained at the 28 months. This was attributed to the continued hydration of the cementitious compounds in the soil. This study revealed that high temperature could negatively impact the durability of stabilised soils while soils stabilised with adequate PC content could thrive in adverse conditions.

Al-Tabbaa and Boes (2002) performed further laboratory on the aforementioned site after 5 years and discovered that coring of sample using water as lubricant was difficult because the soil had become brittle, therefore polymer was used. Comparative laboratory analyses with pervious work revealed that the mixes with adequate PC continued to increase in strength and the UCS was 3 – 6 times greater than previous results while the strength of mixes with inadequate PC had decreased substantially. It could be inferred from this study that the amount of PC used affected the long term performance of the stabilised material. Also, higher permeability, lower pH, and ettringite formation were observed with the mixes treated with PC-PFA-lime.

This study is sequential to an earlier investigation (Alayaki et al, 2017) on stabilisation of Niger Delta fat clay with blend of binders, hence durability tests of the stabilised samples in the laboratory were conducted and the performance evaluated.

2.0 Materials and Methods

The blends: DCA-PC (1:1); sand-PC (4:1); and lateralite-PC (2:1) were mix with the fat clay obtained from the subgrade level of Odoni-Agbere road, Sampou, Bayelsa State. The durability of these soil-blends was evaluated by adopting both the CBR and UCS basic procedures specified in B.S 1924 – 2 (1990) with some additions. The soil-blends were prepared at their optimum moisture contents for both tests. For the CBR test, the soil-blends were compacted in 5 layers in a CBR mould (2305cm^3) using 4.5kg rammer with 62 blows applied on each layer. Five cycles of wetting and drying procedures as suggested by Netterberg (2007) were apply on the compacted samples in the CBR mould, and the bearing capacity (CBR) was tested after the fifth soaking period. Complete soaking was performed using tap-water and the swell of the sample was monitored throughout the soaking period with the swell gauge (Plate 1a), while the oven-drying was done at a temperature of about 105^{o}C.

The split mould of 115.5mm height by 105mm diameter and 2.5kg rammer were used to compact the samples for the UCS test. 25 blows per layer were applied on the 3 layers of soils. The samples were prepared in triplicate/mix/test day. Three types of curing processes were used to cure the samples before the UCS test was done at 28 days. These curing procedures were moist curing, dry curing, and wet curing. These were done to determine the effects of moisture on the stabilised blends under curing procedure. These procedures are explained as follow;

i. Moist curing: The samples were wrapped with cellophane wrapper, placed in a covered barrel filled with moist sawdust;
ii. Dry curing: The samples were wrapped with cellophane wrapper and placed in a sealed empty container;
iii. Wet curing: Unwrapped samples were placed on a raised wire-mesh in a container with water at the bottom, there was no direct contact of the samples with water.

The durability of the UCS samples was tested after the 28 days curing, using site-mixed soil blends. The soil-blends were oven dried for 24 hours and then soaked for four hours and allowed the water to dissipate for 15mins before testing. This procedure was a trial and error method based on the observed behaviour of the soil in the laboratory especially its affinity for water. Plate 1b shows the wrapped samples.

(a)

(b)

Plate 1: - (a): Complete soaking of compacted samples in CBR moulds with the mounted swell gauges; (b): Split mould, 2.5 kg rammer, and wrapped compacted samples

3.0 Results

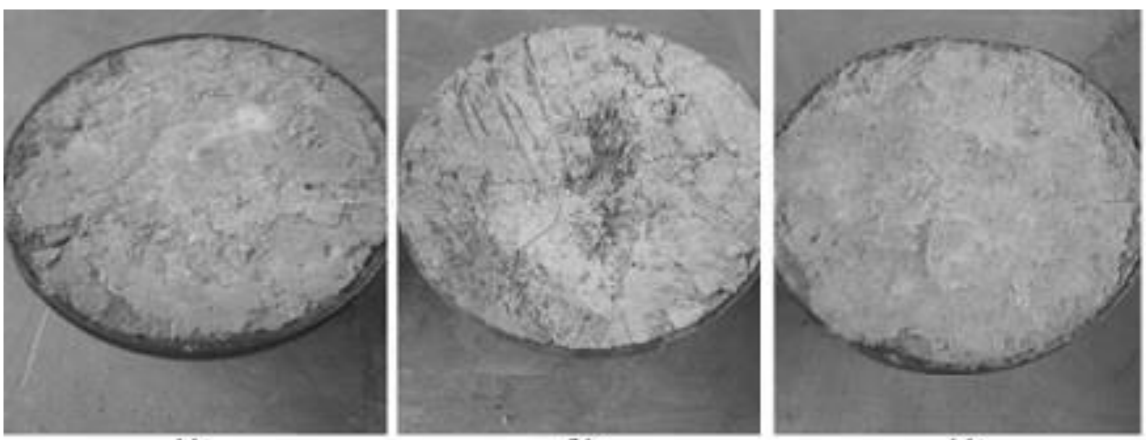
(i) Assessment of Durability Using CBR Test

The CBR values presented in Table 1 are for lab-mixed samples. Percentage increase or decrease in weight is used to measure the swelling potential. The cycle period used is given as a footnote.

Table 1: Percentage increase between 24 hrs soaked and 5 cycles CBR and Swell

	CBR (%)			% increase / decrease in weight			
	24 hrs soaked	5 cycles	% increase	24 hrs soaked	5 cycles	% difference	Average % swell
Soil-DCA-PC	20	41	105	1.12	-0.19	117	0.002
Soil-sand-PC	16	24	50	-0.20	-1.86	-830	0.200
Soil-lateralite-PC	27	36	33	1.00	0.67	33	0.004

Swelling % was taken as the ratio of swell reading from dial gauge to the height of the CBR mould
5 cycles of wetting and drying (one cycle = ± 16 hrs soaking and ± 16 hrs oven-drying at 110ºC)
*Negative sign indicated % decrease in weight



(a) (b) (c)

a) Soil-DCA-PC
b) Soil-sand-PC
c) Soil-lateralite-PC

Plate 2: Assessment of the stability of compacted soil-blends in CBR mould – (a): Compacted surface of soil-DCA-PC showing sign of instability; (b): Eroded surface and radial crack developed on soil-sand-PC; (c): Soil-lateralite-PC showing stable compacted surface

The wetting and drying procedure on soil-DCA-PC blend yielded a CBR value of 41% which was an increase of 105% above the value obtained after 24hrs soaking period. This value could upgrade this soil-blend from a subgrade to a sub-base material. FMWH (1997) specifies a minimum CBR value of 30% for a sub-base material. However, there was loss in weight of 0.19% by the fifth cycle, which suggested that the cyclic process had caused some loosening effect on the compacted blend. The average swell throughout the test period was 0.002% (see Table 1). The compacted surface of the soil-blend shown in Plate 2a had signs of instability after the third cycle of wetting and drying.

The cycled CBR obtained after the durability test for the soil-sand-PC blend was not as high as the other soil-blends, but the value was an increase of 50% above the 24hrs soaked CBR. However, massive reduction in weight was observed throughout the test, and a difference in weight of 830% was obtained after the whole process. Plate 2b showed the loosened compacted surface with radial cracks after the third cycle of wetting and drying. Infiltration of water through the cracks had effected the loosening of the compacted stabilised soil.

Similar improvement in the CBR value after the durability test was also noticed with soil- lateralite-PC blend. The five cycles of wetting and drying yielded a CBR value of 36%, which was 33% higher than the 24hrs soaked CBR value. This value also upgraded the stabilised soil to a sub-base material. There was an initial increase in weight of 1% at the start of the cycle which reduced to 0.67% by the fifth cycle, and the percentage difference in weight gain was 33%, with an average swell of 0.004%. The compacted surface in the CBR mould which was relatively stable after the third cycle is shown in Plate 2c.

(ii) Effect of Curing Methods on UCS

Table 2 shows the summary of the UCS test results using different curing procedures. The uncured samples were tested almost immediately after compaction (i.e. no curing). All other samples: the wrapped and moist cured, wrapped and dry cured, and unwrapped and moist cured tested after 28 days. A comparative analysis of the strength development at 0 and 28 days of curing was carried out.

Table 2: Summary of UCS results of lab-mixed stabilised composites

	Soil-DCA-PC	Soil-Sand-PC	Soil-Lateralite-PC
UCS (MPa) – No curing	0.10	0.20	0.09
<u>*WM samples*</u>			
UCS (MPa) – 28 days curing	0.39	0.08	0.25
<u>*NWM samples*</u>			
UCS (MPa) – 28 days curing	0.04	0.03	0.04
<u>*WD samples*</u>			
UCS (MPa) – 28 days curing	0.16	0.38	0.36

WM = Samples wrapped and moist cured; NWM = Samples not wrapped and moist cured; WD = Samples wrapped and dry cured (Dry curing = wrapped samples were placed in sealed containers without moisture)

The results showed that there was an increase in UCS of uncured soil-DCA-PC blend from 0.10 MPa to 0.39 MPa at 28 days when wrapped and moist cured. The uncured soil-sand-PC had a UCS value of 0.20 MPa which reduced drastically to 0.08 MPa on the 28th day. The uncured soil-lateralite-PC had a UCS value of 0.09 MPa, which increased to 0.25 MPa at 28 days.

Figure 1 shows the effect of the different curing processes on the soil-blends. The low UCS values for all the unwrapped and moist cured soil-blends revealed the adverse effect on the shear strength when the compacted samples had direct exposure to moisture. However, when the soil-blends were wrapped and dry cured, soil-sand-PC and soil-lateralite-PC developed optimal UCS values of 0.38 MPa and 0.36 MPa at 28 days respectively. Thus, it could be inferred that adequate water was present for hydration and reactions of these soil blends to generate optimal strength and that additional water or moisture condition was not required. However, soil-DCA-PC had an optimal UCS value of 0.39 MPa at 28 days when wrapped and moist cured. This inferred that excess water and/or moisture condition was needed.

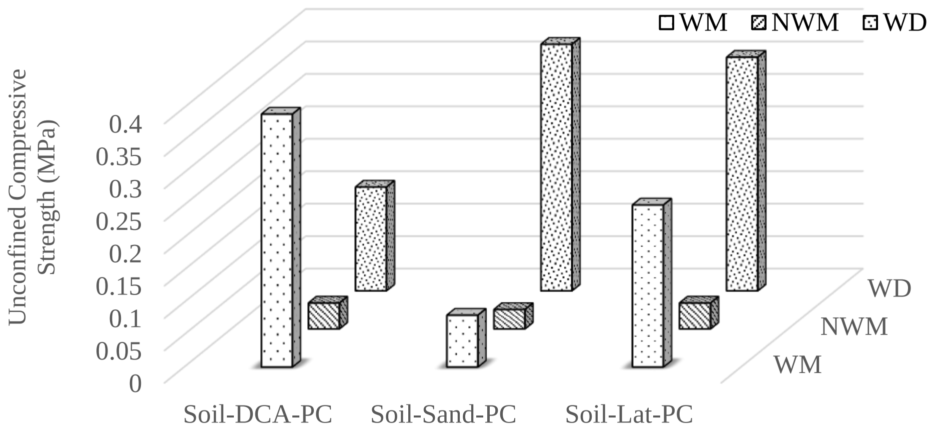


Figure 1: Effect of curing methods on the UCS of samples; WD = Wrapped-dry cured samples; NWM = Not wrapped-moist cured samples; WM = Wrapped-moist cured samples

(iii) Assessment of Durability Using UCS Test

The summary of UCS results of soil blends before and after durability procedure are presented in Table 3. Plate 3 shows the resultant stress effects on the shape of the stabilised soil during the test.

Table 3: Summary of UCS results of soil blends before and after durability procedure

Blends	Ordinary UCS (MPa)	Durable UCS (MPa)	% decrease in UCS
Soil-DCA-PC	0.24	0.18	25
Soil-sand-PC	0.32	0.11	66
Soil-lateralite-PC	0.23	0.16	30

Ordinary UCS = soil-blends were tested without subjecting them to any special treatment after curing period
Durable UCS = soil-blends were subjected to durability process after curing as reported in section 2.0.

There was a general decrease in the UCS values after the durability test. However all the soil-blends had acceptable UCS values ranging 0.11 – 0.18 MPa. Based on the recommended values of 0.103 MPa (Madedor, 1983) and 0.115 MPa (Jones, et al., 2012), the soil-blends could be adopted as subgrade materials. Furthermore, soil-DCA-PC and soil-lateralite-PC had higher values than soil-sand-PC, and this could be attributed to the susceptibility of the soil-blend to water. The almost sheared failure patterns of soil-DCA-PC and soil-lateralite-PC blends showed that there was some resistance to the applied stress while soil-sand-PC had sheared failure pattern under the test (Plate 3a - c).

(a) Soil-DCA-PC (b) Soil-sand-PC (c) Soil-lateralite-PC

(Images taken with the loading plate removed)

Plate 3: Assessment of the stability of soil-blends during UCS test –
(a): Bulging shape at failure; (b): Sheared shape; (c): Bulged and almost sheared shape

4.0 Conclusion

The conclusions drawn from this study are as follow:

1. The stabilised blends had the potential to be durable in the foundation, provided that they are not exposed beyond five cycles of wetting and drying as tested in this study. There is the possibility that the procedures could negatively impart both soil-DCA-PC and soil-sand-PC blends after 3 cycles while soil-lateralite-PC could be negatively imparted after 5 or more cycles. Furthermore, it cannot be ascertained for now if the cycle of ± 16 hrs of wetting and drying used in this study could be equated to seasonal wetting and drying which occurs over a long period of time.
2. Curing of all the soil-blends without direct exposure to moisture resulted in adequate UCS values, and they could be adopted as subgrade materials while curing with exposure to water resulted in reduced shear strength that made them non-applicable as subgrade materials. These results confirmed the opinion in Akpokodje (1986, 1987) that PC-stabilised Niger Delta soils should be protected from water.
3. The durability quality based on the CBR and UCS tests established that the soil-blends were suitable for subgrade application. It is therefore recommended that adequate protection or sealing should be provided for the compacted surface if these soil-blends are used as subgrade material in pavement construction.

References

Akpokodje, E. G. (1986): A Method of Reducing the Cement Content of Two Stabilized Niger Delta Soils. *Quarterly Journal of Engineering Geology, London.* Vol. 19, pp. 359 – 363.

Akpokodje, E. G. (1987): The Engineering – Geological Characteristics and Classification of the Major Superficial Soils of the Niger Delta. *Eng. Geol., 23:* pp. 193 – 211.

Alayaki, F. M., Al-Tabbaa, A. and Ayotamuno, M. J (2017): Stabilisation of Niger Delta Fat Clay with Blend of Binders for Subgrade Application – Part 1. *Nigerian Journal of Technology (NIJOTECH)*, Vol. 36, No. 3, pp. 740 -748.

Al-Tabbaa, A. and Boes, N. (2002): Pilot in-situ auger mixing treatment of a contaminated site Part 4: Performance at 5 year. *Proc. Instn. Civ. Engrs. Geotech. Egrng*. 155: pp 187 – 202.

Al-Tabbaa, A. and Evans, C. W. (1998): Pilot in-situ auger mixing treatment of a contaminated site Part 1: Treatability Study". *Proc. Instn. Civ. Engrs. Geotech. Egrng*. 131: pp 52 - 59.

Al-Tabbaa, A. and Evans, C. W. (2000): Pilot in-situ auger mixing treatment of a contaminated site Part 3: Time-related performance. *Proc. Instn. Civ. Engrs. Geotech. Egrng*. 143: pp 103 - 114.

Bin-Shafique, M. S, Edil, T. B, Benson, C. H, and Senol, A. (2004): Incorporating a fly ash stabilised layer into pavement design – case study. *Geotechnical engineering,* Institution of Civil Engineers, London, Vol. 157 No. GE4, 239 – 249. In: Edil, T. B., Acosta, H. A. and Benson, C. H. (2006): Stabilising Soft Fine-grained Soils with Fly Ash" *Journal of Materials in Civil Engineering*, pp 283 – 294.

Bin-Shafique, S., Rahmanb, K., Yaykirana, M., and Azfara, I. (2010): The Long-term Performance of Two Fly Ash Stabilized Fine-grained Soil Sub-bases. *Resources, Conservation and Recycling*, 54, pp 666–672.

British Standards Institution (1990): British Standards 1924 - *Stabilized Materials for Civil Engineering Purposes Part 2:* Methods of test for cement-stabilized and lime-stabilized materials". ISBN 0 580 18498 6.

Federal Ministry of Works and Housing (1997): *General Specification- Roads and Bridges.* Vol. 2, Director of Federal Highways, FMWH, Abuja, Nigeria, 280p.

George, K. P. (2006): *Soil Stabilisation Field Trials: Final Report*. Mississippi Department of Transportation, Research Division. 77pp.

Janoo, V. C., Firicano, A. J., Barna, L. A. and Orchino, S. A. (2012): Field Testing of Stabilised Soil. *Journal of Cold Regions Engineering,* 13(1), 1999 pp 37 – 53.

Jones, D., Rahim, A., Saadeh, S. and Harvey, J. T. (2012):

Guidelines for the Stabilisation of Subgrade Soils in California. Guideline: UCPRC-GL-2010-01. Prepared for California Dept. of Transportation. Division of Research and Innovation - Office of Roadway Research.

Kumar A, Singh B, Asheet B. (2007): Influence of fly ash, lime, and polyester fibers on compaction and strength properties of expansive soil. *Journal of Materials in Civil Engineering*; 19 (3): pp 242–248.

Madedor, A. C. (1983): Pavement Design Guidelines and Practice for Different Geological Areas in Nigeria. In: Ola, S. A. (ed) Tropical Soils of Nigeria in Engineering Practices. AA Balkema, Rotterdam, 1983, pp. 291 – 297.

Netterberg, F. (2007): Wet-Dry Cycled CBR Test for Identification of Potentially self-stabilizing Soils (unpublished).

Parsons, R. L. and Kneebone, E. (2005): Field Performance of Fly Ash Stabilised Subgrades. *Ground Improvement,* 9(1), pp 33–38.

Rajasekaran, G. and Rao, S. N. (2002): Permeability Characteristics of Lime Treated Marine Clay. *Ocean Engrng* 29: pp 113 – 127.

Thomas, M. D. A. (1986): *The performance of cement stabilised minestone*. Published PhD thesis. The University of Aston, Birmingham, United Kingdom.