Strength Characteristics of Lead and Hydrocarbon Contaminated Lateritic Soils Stabilized with Lime-Rice Husk Ash

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ABSTRACT

This study investigates the strength characteristics of the lead and hydrocarbon contaminated lateritic soil stabilized with lime-rice husk ash, a binder additive combined at a ratio of 1:2 Lime: Rice husk ash. The artificially contaminated Akure lateritic soil was stabilized with varied degrees of 5 and 10% of the binder by weight of the contaminated soil samples. Strength characteristics tests which include unconfined compressive strength and direct shear tests were then conducted on the soil-contaminant-binder mixes. The 10% binder addition produced the highest percentage increase in the strength characteristics which were in the range of 31.1%-47.7% and 41.4%-70.0% for the unconfined compressive strength on lead and naphthalene contaminated samples respectively. The influence of the contaminants and binder additives on the allowable bearing capacity (q_a) of the lateritic soil was inferred from the trend observed in the unconfined compressive strength (q_u).

KEYWORDS: Lateritic soil; Contamination; Binder; Stabilization

INTRODUCTION

Soil contamination is caused by the presence of man-made chemical alterations in virgin soil. This type of contamination typically results from the rupture of underground storage tanks, application of pesticides, percolation of contaminated surface water, oil and fuel dumping, leaching of wastes from landfills or direct discharge of industrial wastes to the soil. The most common chemicals involved are petroleum hydrocarbons, solvents, pesticides, lead and other heavy metals. Contamination of soil can alter its strength characteristics. It is pertinent therefore to explore methods of remediation and reclamation for the contaminated areas. In connection with cleanup initiatives, and for any possible applications of contaminated soils, knowledge of the geotechnical properties and behavior of contaminated soils is required (Khamehchiyan *et al*, 2006). Experiments analyzing contamination in soil shows that the strength characteristics of various types of soils all seem to be compromised due to the effects of contamination on soils (Khamehchiyan *et al*, 2006; Ojuri and Omotayo, 2012. Thus, there is need to protect the environment from the hazardous wastes and improve the mechanical properties of contaminated soils. Various technologies have been developed which reduce the potential release of these toxic wastes into the environment. One such promising technology is stabilization/solidification (S/S) of solid wastes by means of adding cementitious binders, like lime, cement, fly ash, phosphates, blast furnace slag cement and organic polymer (Conner, 1990; Dermatas *et al*, 2006; Korac *et al*, 2007). Although stabilization/solidification (S/S) technology was originally developed for treatment of nuclear waste in 1950s and later on different types of hazardous wastes. From around 1980s the technology was also applied for treatment of contaminated soil and sediments (Laugesen, 2007). Stabilization/Solidification technology has become a promising alternative to solve this problems because it provides an economically viable means of treating contaminated sites close to the areas where the problem exist and thereby reducing the need for landfills.

Laterite is a soil group, which is commonly found in the leached soils of the humid tropics and is formed under weathering systems that cause the process of laterization (Gidigasu, 1976). (Blight, 1997) describes laterites as highly weathered and altered residual soils formed by the in-situ weathering and decomposition of rocks under tropical condition. Laterites are rich in sesquioxides (secondary oxides of iron, aluminum or both) and low in bases and primary silicates but may contain appreciable amounts of quartz and kaolinite. Due to the presence of iron oxides, lateritic soils are red in colour ranging from light through bright to brown shades (Syafalni et al, 2012). It is a common construction material available in almost all the countries of the humid tropics of the world. Its formation is favoured by the factors encouraging laterization processes such as high intensity rainfall, high vegetation cover, permeable soil profile, alternating ground water movement, etc. From an engineering point of view, laterite or lateritic soil is a product of tropical weathering with red, reddish brown and dark brown colour, with or without nodules or concretions and generally (but not exclusively) found below hardened ferruginous crusts or hard plan (Ola, 1983). Generally, the degree of laterization is estimated by the silica to sesquioxides (S-S) ratio {SiO2/ (Fe2O3 + Al2O3)}. Silica-Sesquioxide (S-S) ratio less than 1.33 are indicative of laterites, those between 1.33 and 2.00 are lateritic soils and those greater than 2.00 are non-lateritic types

Many metals may occur in firing range soils due to the composition of shells, casings and penetrators. In recent years lead (Pb) contamination in firing range soils has received much attention as an environmental concern (Cao et al, 2003). Upon impact with the berm surface, bullet fragments and lead particulates build up significantly with continued range operations. Previous lead leachability studies showed that if proper management was not implemented, the lead leachability may not satisfy the Toxicity Characteristic Leaching Procedure (TCLP) regulatory limit of 5 mg/l (Cao et al, 2003; Dermatas et al, 2006; Chrysochoou et al, 2007). Leakage of petroleum products from improperly assembled and poorly maintained underground storage tanks (USTs) and pipelines has been considered as the major source of introduction of petroleum contamination into the subsurface. Petroleum products contain significant quantities of naphthalene, pyrene, benzene, toluene, and xylenes, which are among hazardous waste compounds listed by the United States Environmental Protection Agency (USEPA). Accordingly, remediation of petroleum-contaminated soils has increasingly been dealt with over the past several years. As a result, ex-situ treatment methods such as land spreading, thermal treatment and bioremediation, as well as in-situ methods such as bioventing and soil vapor excavation are now being implemented (Kamnikar, 2001). The difficulty encountered in remediating the petroleum contaminated soils (PCSs) led researchers to look for alternative approaches, such as soil stabilization by addition of a binder to absorb the pollutant(s) while maintaining the good engineering properties of the soil.

Materials stabilized in such a manner could be reused in highway construction, and the most common application is their use as a borrow fill material.

Stabilization aims to either bind or complex the compounds of a hazardous waste stream into a stable insoluble form (Wiles, 1987). It can be applied as an in-situ or ex-situ technology for contaminated soil remediation with advantages of relatively low cost, well known material and technology, good long-term physical and chemical stability, good mechanical and structural characteristics (Conner,1990). Lime stabilization will only be effective with materials which contain enough clay for a positive reaction to take place. Lime reacts to produce decreased plasticity, increased workability, and increased strength (Little, 1995). Strength gain is primarily due to the chemical reactions that occur between the lime and soil particles. These chemical reactions occur in two phases, with both immediate and long-term benefits. The first phase of the chemical reaction is subdivided into cation exchange and particle aggregation, the second phase of the chemical reaction which is also subdivided into pozzolanic reactions and lime carbonation (Eades and Grim, 1960). Strength gain also largely depends on the amount of silica and alumina available from the clay itself; thus, it has been found that lime stabilization is more effective and less expensive with the addition of Rice husk ash (RHA) because of the silica content in the ash (Chmeisse, 1992). Moreover, the stabilized wastes by Lime-Rice husk ash attain adequate stress-strain properties and it could achieve an end product with higher strength, which can be reused as construction materials, such as engineering fill, highway construction or pavement subgrade, backfill, and base material. Therefore, the study of the effect of lead (a heavy metal) and naphthalene (a hydrocarbon) on the strength properties for the stabilized contaminated soils is required for engineering purposes.

MATERIALS AND METHODS

Site Description

The uncontaminated Lateritic soil sample used in this study was taken from a site located along Oda road in Akure South local government area of Akure, Ondo State, which lies within the geographical coordinates of latitude 07.22426ºN and 07.22450ºN and between longitude 005.21067 ºE and 005.21193ºE. The elevation of the area was between 332 and 336m. The area where the sample was taken lies within the Pre – Cambrian crystalline rocks of the Basement complex of Southwestern Nigeria. The lateritic soils in this area are derived from migmatite-gneiss, medium to coarse grained biotite granite, porphyritic granite, charnockitic intrusives, and coarse porphyritic biotite and biotite-hornblende granites (Ademeso et al, 2012).

Soil Sampling and Sample Preparation

Soil Sampling

The method used in the sample collection of the lateritic soil is the trial pit method. A trial pit is simply a hole dug in the ground that is large enough for a ladder to be inserted, thus permitting a close examination of the sides. With this method, relatively undisturbed samples of soils were collected. The depth of the trial pit was about 1.0m and about (1.2m) x (1.2m) wide i.e. 1.2m x 1.2m x 1.0m pit. The pit was sunk by hand excavation with the aid of spade and digger.

Contaminants

Two forms of contaminants were used to artificially contaminate the lateritic soils. They are Lead nitrate salt and Naphthalene. Both contaminant chemicals were purchased from Pascal chemicals, a scientific chemicals retailer in Akure.

Binder

The binder selected was lime-Rice husk ash. A combination of hydrated lime (purchased from Pascal chemicals in Akure) and Rice husk ash (RHA). RHA was prepared by drying and burning rice husk, collected from a locally available mill in Ibadan and burnt in a controlled temperature environment until it completely turns to ashes. The lime and rice husk ash were mixed together in a ratio of 1:2, which is the optimum ratio of lime to RHA (Chmeisse, 1992).

Sample Preparation

Lead nitrate ($Pb(NO_3)_2$) salt was used to spike the lateritic soil measuring 500g at four different levels of 500; 1,000; 1500 and 2,000 parts per million (ppm) lead spike solution. These levels were in the range of those used in previous study (Tardy et al, 2003). Lateritic soil was also spiked with naphthalene at levels of 0.5%, 1.0%, 1.5%, 2.0%, 2.5% and 3.0% by weight of soil. These percentages were selected because soils exhibiting higher concentrations, i.e. soil contaminated with greater than 3% by weight of soil are accepted as hazardous waste and are generally disposed of in hazardous waste landfills (Kamnikar, 2001), after hours of agitation and shaking; the spiked soils were dried and stored. The contaminants were introduced into the lateritic soil following the “spiking” procedure of (Doick et al, 2003), in order to prepare homogenous and reproducible soil-contaminant mixtures.

Experimental Program

Soil index property and classification tests namely, natural moisture content, specific gravity, particle size analysis and atterberg limits tests were performed on the soil. Strength tests (unconfined compressive test and direct shear test) were then performed on the uncontaminated soil, all the lead and hydrocarbon contaminated soil samples and all the lead and hydrocarbon contaminated soil samples with their binder additive.

These tests were conducted at the Geotechnical Engineering laboratory, Federal University of Technology, Akure according to BS 1377:1990 as follows; moisture content (BS1377:1990 Part 2:3), atterberg limit tests (BS1377:1990 Part 2:4 & 2:5), specific gravity (BS1377:1990 Part 2:8), density tests (BS1377:1990 Part 2:7), particle Size Distribution (BS1377:1990 Part 2:9), Unconfined compressive test (BS1377:1990 Part 7:7) and direct shear test (BS1377:1990 Part 7:4).

RESULTS AND DISCUSSION

Soil Characterization Results (Uncontaminated Soil)

For this lateritic soil, the percentage passing sieve No. 200(0.075 mm), No. 40 (0.425 mm) and No. 10 (2.00 mm) were 23.65%, 45.9% and 77%, respectively. Summary of the basic geotechnical and elemental composition tests conducted on the lateritic soil is presented in Table 1.

Table 1: Summary of the preliminary analysis on lateritic soil sample

Engineering & Physical Properties	VALUES	Chemical/Elemental composition	VALUES (%)
CEC (meq/100g)	13.24	Aluminum Oxide, Al_2O_3	91.20
pH	6.5	Titanium Oxide, TiO_2	0.89
Specific Gravity	2.72	Silica, SiO_2	2.10
Liquid Limit, LL (%)	52.2	Ferric Oxide, Fe_2O_3	5.55
Plastic Limit, PL (%)	24.4	Zinc, ZnO	0.01
Plasticity Index, PI	27.8	Zirconium Oxide, ZrO_2	0.05
Natural Moisture content (%)	28.8	Molybdenum, MoO_2	0.04
Linear Shrinkage (%)	11.5	Magnesium Oxide, MgO	0.13
Bulk Density (g/cm^3)	1.64		
AASHTO Classification	A-2-7		

*CEC: cation-exchange capacity; AASHTO: American Association of State Highway and Transportation.
The elemental composition of the binder used which are lime and rice husk ash were shown in Table 2.

Table 2: Chemical Composition of Rice Husk Ash and Lime

Chemical Composition of Rice Husk Ash	VALUES (%)	Chemical Composition of LIME	VALUES (%)
Silica, SiO_2	82.10	Calcium Oxide, CaO	85.35
Aluminum Oxide, Al_2O_3	4.40	Phosphorus Oxide, P_2O_5	0.89
Ferric Oxide, Fe_2O_3	0.93	Magnesium Oxide, MgO	0.74
Calcium Oxide, CaO	1.00	Ferric Oxide, Fe_2O_3	0.55
Potassium Oxide, K_2O	3.80	Aluminum Oxide, Al_2O_3	0.21
Magnesium Oxide, MgO	1.47	Silica, SiO_2	0.04
Sodium Oxide, Na_2O	0.45		

Results for Strength Tests

Unconfined Compressive Strength (UCS) Tests

The values of the unconfined compressive strength (qu) of the uncontaminated soil for the variably contaminated lateritic soils and the variably contaminated lateritic soils with binder (Lime-Rice Husk Ash [LRHA]) additions were plotted in Figure 1 and 2 for the lead and naphthalene contaminated samples respectively. Figure 1 and 2 also displays the correlation relationship between the unconfined compressive strength (UCS) and the varied degrees of lead and naphthalene concentration in the lateritic soil respectively.

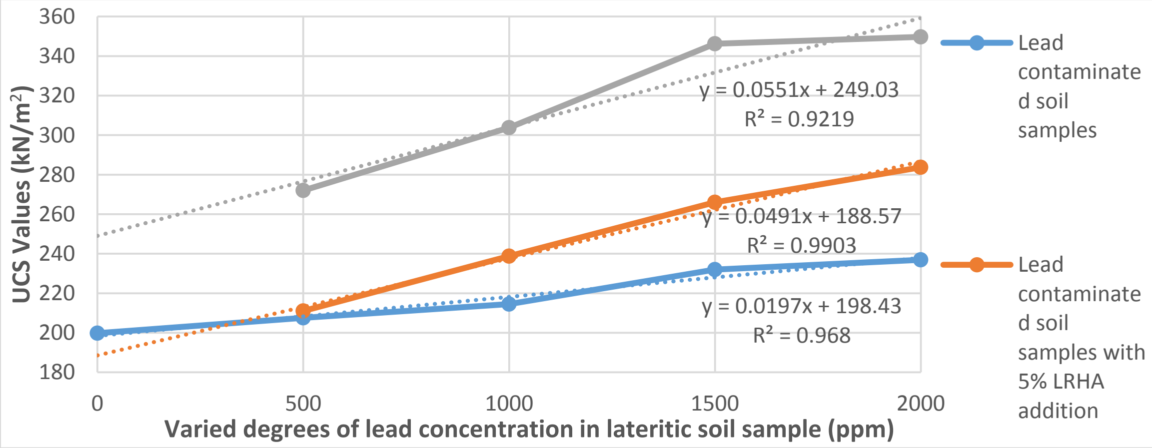

Figure 1: Unconfined compressive strength (UCS) values of uncontaminated, lead contaminated and lead contaminated lateritic soil sample with binder (Lime-Rice Husk Ash [LRHA]) addition

Figure 1 shows that with the contamination of the lateritic soil sample, there was an increase in the strength of the contaminated sample. The increase in strength was gradual as there was increase in the lead contaminant, from 199.81 kN/m^2 at uncontaminated lead content of 0 ppm to 236 kN/ m^2 at contaminated lead content of 2000 ppm. This may be due to the fact that the particle size of the lead contaminant salt which was in granular form may have added to the strength of the soil sample. The strength values for lead contaminated samples with binder additions of 5% and 10% showed a gradual increase like the contaminated samples with 0% binder addition as the contaminants were increased. The compressive strengths were 211.04 kN/ m^2 and 272.03 kN/ m^2 at 5 and 10% binder additions respectively for 500 ppm of lead, they increased to 283.72 kN/ m^2 and 349 kN/ m^2 at 5 and 10% binder additions respectively for 2000 ppm of lead. Figure 1 also showed the effect of the 5% and 10% by weight of sample binder additions to the strength of lead contaminated samples. On adding the 5% binder to the varied degrees of lead contaminated soil, its strength increased by 1.7%, 11.3%, 14.7% and 19.8% for the 500, 1000, 1500 and 2000ppm degrees of lead concentration respectively. On adding of the 10% binder to the varied lead contaminated samples, the percentage increase in the strength were 31.1%, 41.6%, 49.3% and 47.7% for the 500, 1000, 1500 and 2000ppm degrees of lead concentration respectively. This was due to the binder (Lime-Rice husk ash) added which has cementitious properties solidifying the soil matrix, thereby increasing the strength of the samples.

From Figure 1, the linear correlation for the unconfined compressive strength (UCS) versus the varied degrees of Lead concentration (Pb) showed that:

Lead contaminated samples with no binder addition had a coefficient of correlation which was ($R^2 = 0.97$) with a linear equation of

$$UCS\ (kN/m^2) = 0.0197Pb + 198.43 \tag{1}$$

Lead contaminated samples with 5% binder addition had a coefficient of correlation which was ($R^2 = 0.99$) with a linear equation of

$$UCS\ (kN/m^2) = 0.0491Pb + 188.57 \tag{2}$$

Lead contaminated samples with 10% binder addition had a coefficient of correlation which was ($R^2 = 0.92$) with a linear equation of

$$UCS\ (kN/m^2) = 0.0551Pb + 249.03 \qquad (3)$$

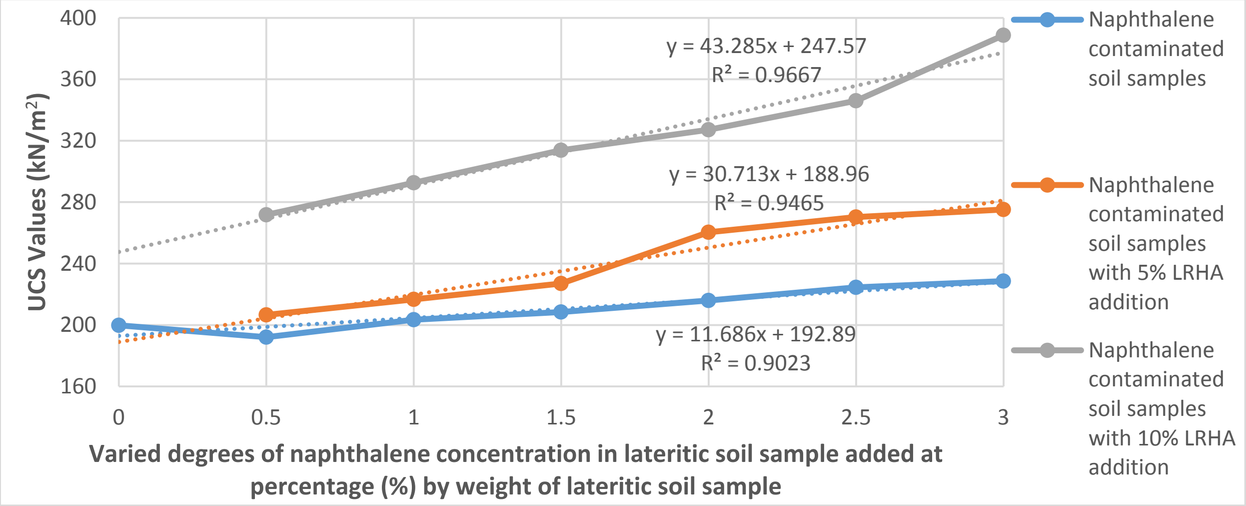

Figure 2: Unconfined compressive strength (UCS) values of uncontaminated, naphthalene contaminated and naphthalene contaminated lateritic soil sample with binder (Lime-Rice Husk Ash [LRHA]) addition

Figure 2, showed that with the contamination of the lateritic soil sample, there was a slight initial decrease and a gradual increase in the strength of the contaminated sample. From 199.81 kN/m^2 at uncontaminated naphthalene content of 0%, it decreased to 192 kN/m^2 at naphthalene content of 0.5% and increased gradually to 228 kN/m^2 at contaminated naphthalene content of 3% by weight of the lateritic soil sample. This may be due to the fact that the particle size of the naphthalene contaminant just like the lead salt, which was in granular form may have added to the strength of the soil sample. The strength values for naphthalene contaminated samples with binder additions of 5% and 10% showed a gradual increase as the contaminants were increased. The compressive strengths were 206.58 kN/m^2 and 271.76 kN/m^2 at 5 and 10% binder additions respectively for naphthalene content of 0.5% by weight of lateritic soil sample, they increased to 275.24 kN/m^2 and 388.61 kN/m^2 at 5 and 10% binder additions respectively for naphthalene content of 3% by weight of soil sample. Figure 2 also showed the effect of the 5% and 10% by weight of sample binder additions to the strength of naphthalene contaminated samples. On adding the 5% binder to the varied degrees of naphthalene contaminated soil, its strength increased by 7.5%, 6.5%, 8.9%, 20.5%, 20.4% and 20.4% for the 0.5%, 1.0%, 1.5%, 2.0%, 2.5% and 3.0% by weight of the soil degrees of naphthalene concentration respectively. On adding of the 10% binder to the varied naphthalene contaminated samples, the percentage increase in the strength were 41.4%, 43.8%, 50.5%, 51.4%, 54.1% and 70% for the 0.5%, 1.0%, 1.5%, 2.0%, 2.5% and 3.0% by weight of the soil degrees of naphthalene concentration respectively.

From Figure 2, the linear correlation for the unconfined compressive strength (UCS) versus the varied degrees of Naphthalene concentration (N) showed that:

Naphthalene contaminated samples with no binder addition had a coefficient of correlation which was ($R^2 = 0.90$) with a linear equation of

$$UCS\ (kN/m^2) = 11.686N + 192.89 \qquad (4)$$

Naphthalene contaminated samples with 5% binder addition had a coefficient of correlation which was ($R^2 = 0.95$) with a linear equation of

$$UCS\ (kN/m^2) = 30.713N + 188.96 \qquad (5)$$

Naphthalene contaminated samples with 10% binder addition had a coefficient of correlation which was ($R^2 = 0.97$) with a linear equation of

$$UCS\ (kN/m^2) = 43.285N + 247.57 \qquad (6)$$

Allowable Bearing Capacity

The allowable bearing capacity (q_a) is the maximum bearing stress that can be applied to the soil such that it is safe against instability due to shear failure and the maximum tolerable settlement is not exceeded. It was calculated from the ultimate bearing capacity (q_{ult}) using a factor of safety (F_S) as shown in equation 7.

$$q_a = \frac{q_{ult}}{F_S} \qquad (7)$$

$$q_{ult} = 1.3C^I N_c \qquad (8)$$

$$C^I = \frac{q_u}{2} \qquad (9)$$

where: q_u is the unconfined compressive strength of the soil sample

C^I is the effective cohesion

$N_C = 5.14$ (for $\phi = 0$)

The allowable bearing capacity (q_a) was inferred from the unconfined compressive strength (q_u) and plotted against the varying degrees of lead concentration in the lateritic soil sample was shown in Figure 3, the graph followed the same trend as that of the UCS in Figure 1. The allowable bearing capacity were 235.0 kN/m^2 and 316.0 kN/m^2 at 5 and 10% binder additions respectively for 500 ppm of lead, they increased to 302.9 kN/m^2 and 389.5 kN/m^2 at 5 and 10% binder additions respectively for 2000 ppm of lead.

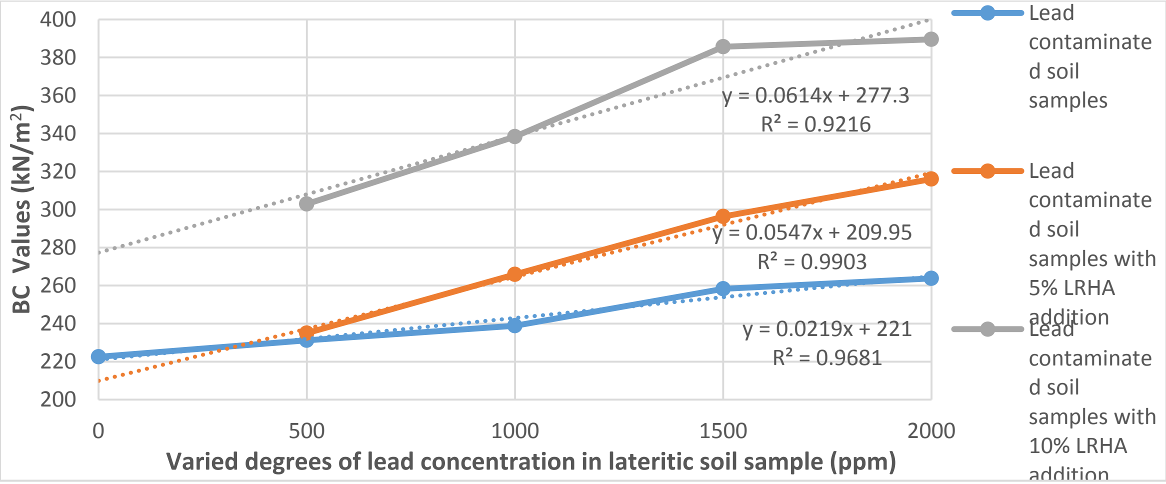

Figure 3: Allowable Bearing Capacity (BC) values of uncontaminated, lead contaminated and lead contaminated lateritic soil sample with binder (Lime-Rice Husk Ash [LRHA]) addition

The linear correlation for the allowable bearing capacity (BC) versus the varied degrees of Lead concentration (Pb) showed that:

Lead contaminated samples with no binder addition had a coefficient of correlation which was ($R^2 = 0.97$) with a linear equation of

$$BC\ (kN/m^2) = 0.0614Pb + 277.3 \tag{10}$$

Lead contaminated samples with 5% binder addition had a coefficient of correlation which was ($R^2 = 0.99$) with a linear equation of

$$BC\ (kN/m^2) = 0.0547Pb + 209.95 \tag{11}$$

Lead contaminated samples with 10% binder addition had a coefficient of correlation which was ($R^2 = 0.92$) with a linear equation of

$$BC\ (kN/m^2) = 0.0219Pb + 221 \tag{12}$$

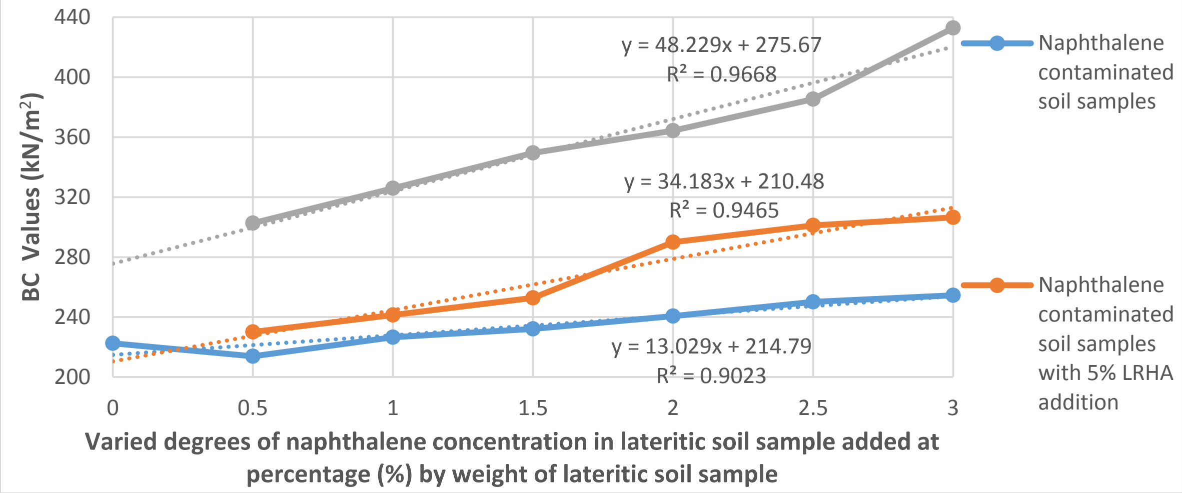

Figure 4: Allowable bearing capacity (BC) values of uncontaminated, naphthalene contaminated and naphthalene contaminated lateritic soil sample with binder (Lime-Rice Husk Ash [LRHA]) addition

The allowable bearing capacity calculated from the unconfined compressive strength (UCS) values and plotted against the varying degrees of naphthalene concentration in the lateritic soil sample was shown in Figure 4, the graph followed the same trend as that of the UCS in Figure 2. The allowable bearing capacity were 230.1 kN/m^2 and 306.5 kN/m^2 at 5 and 10% binder additions respectively for naphthalene content of 0.5% by weight of lateritic soil sample, they increased to 302.6 kN/m^2 and 432.8 kN/m^2 at 5 and 10% binder additions respectively for naphthalene content of 3% by weight of soil sample.

The linear correlation for the allowable bearing capacity (BC) versus the varied degrees of Naphthalene concentration (N) showed that:

Naphthalene contaminated samples with no binder addition had a coefficient of correlation which was ($R^2 = 0.90$) with a linear equation of

$$\mathrm{BC\ (kN/m^2) = 13.029N + 214.79} \tag{13}$$

Naphthalene contaminated samples with 5% binder addition had a coefficient of correlation which was ($R^2 = 0.95$) with a linear equation of

$$BC\ (kN/m^2) = 34.183N + 210.48 \tag{14}$$

Naphthalene contaminated samples with 10% binder addition had a coefficient of correlation which was ($R^2 = 0.97$) with a linear equation of

$$BC\ (kN/m^2) = 48.229N + 275.67 \tag{15}$$

Direct Shear (DS) Tests

The cohesion and angle of internal friction values during the direct shear test of the lead contaminated soil samples were shown in Figure 5 and 6 respectively. Figure 5 and 6 also shows the correlation relationship between the cohesion and angle of internal friction values during the direct shear (DS) respectively.

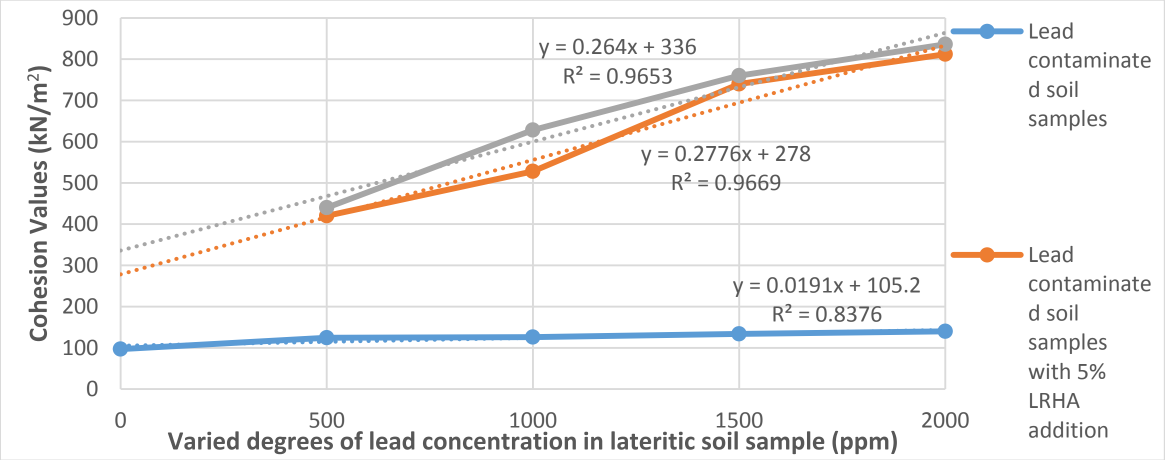

Figure 5: Cohesion (C) values of uncontaminated, lead contaminated and lead contaminated lateritic soil with binder (Lime-Rice Husk Ash [LRHA]) addition samples during direct shear test

Figure 5 shows that with the contamination of the lateritic soil sample, there was an increase in the cohesion value of the lead contaminated sample. The increase in cohesion value was gradual as there was increase in the lead contaminant, from 97 kN/m^2 at uncontaminated lead content of 0 ppm to 140 kN/m^2 at contaminated lead content of 2000 ppm. The cohesion values for lead contaminated samples with binder additions of 5% and 10% showed a gradual increase like the contaminated samples with 0% binder addition as the lead concentration was increased. The cohesion values were 420 kN/m^2 and 440 kN/m^2 at 5 and 10% binder additions respectively for 500 ppm of lead, they increased to 812 kN/m^2 and 836 kN/m^2 at 5 and 10% binder additions respectively for 2000 ppm of lead. Figure 5 also showed the effect of the 5% and 10% by weight of sample binder additions to the cohesion values of lead contaminated samples. On adding the 5% binder to the varied lead contaminated soil, its cohesion values increased by 237.3%, 319%, 452.2% and 480% for the 500, 1000, 1500 and 2000ppm degrees of lead concentration respectively. With the addition of the 10% binder to the varied lead contaminated soil its cohesion values increased by 253.4%, 398.4%, 467.1% and 497.1% for the 500, 1000, 1500 and 2000ppm degrees of lead concentration respectively.

From Figure 5, the linear correlation for the cohesion values versus the varied degrees of Lead concentration (Pb) showed that:

Lead contaminated samples with no binder addition had a coefficient of correlation which was ($R^2 = 0.84$) with a linear equation of

$$C\ (kN/m^2) = 0.0191Pb + 105.2 \tag{16}$$

Lead contaminated samples with 5% binder addition had a coefficient of correlation which was ($R^2 = 0.97$) with a linear equation of

$$C\ (kN/m^2) = 0.2776Pb + 278 \tag{17}$$

Lead contaminated samples with 10% binder addition had a coefficient of correlation which was ($R^2 = 0.96$) with a linear equation of

$$C\ (kN/m^2) = 0.264Pb + 336 \tag{18}$$

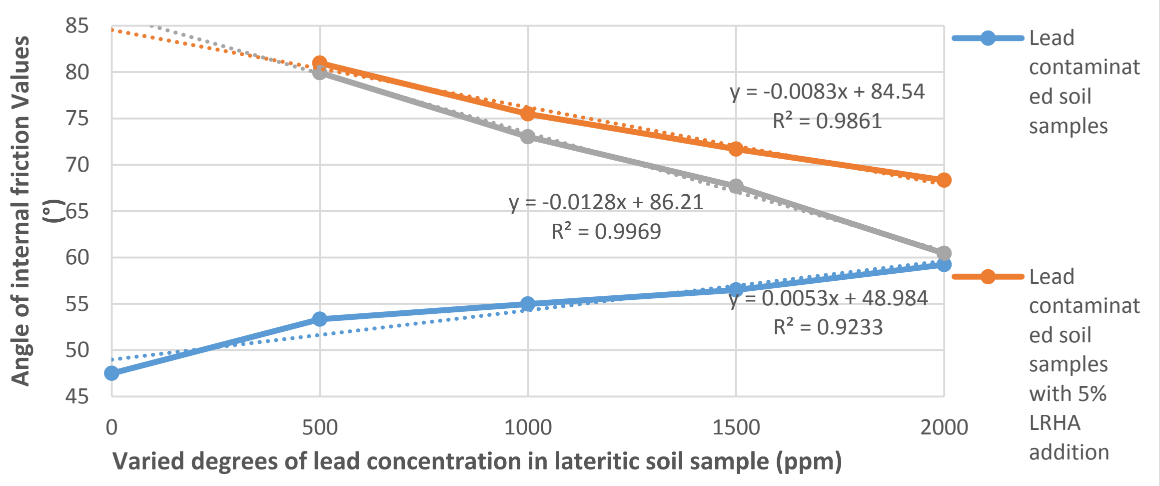

Figure 6: Angle of internal friction (ϕ) values of uncontaminated, lead contaminated and lead contaminated lateritic soil with binder (Lime-Rice Husk Ash [LRHA]) addition samples during direct shear test

Figure 6, showed the angle of internal friction values during the direct shear test on the lateritic soil sample, lateritic soil sample contaminated with varied degree of lead and their binder additions. There was an increase in the angle of internal friction value of the lead contaminated sample as there was increase in the lead contaminant, from 47.5° at uncontaminated lead content of 0 ppm to 59.22° at contaminated lead content of 2000 ppm. The angle of internal friction values for lead contaminated samples with binder additions of 5% and 10% showed a gradual decrease unlike the contaminated samples with 0% binder addition as the lead concentration was increased. The values were 80.97° and 79.92° at 5 and 10% binder additions respectively for 500 ppm of lead, they decreased to 68.34° and 60.43° at 5 and 10% binder additions respectively for 2000 ppm of lead. Figure 6 also showed the effect of the 5% and 10% by weight of sample binder additions to the angle of internal friction values of lead contaminated samples. On adding the 5% binder to the varied lead contaminated soil, its angle of internal friction values increased by 51.7%, 37.3%, 26.9% and 15.4% for the 500, 1000, 1500 and 2000ppm degrees of lead concentration respectively. With the addition of the 10% binder to the varied lead contaminated soil its cohesion values increased by 49.8%, 32.8%, 19.7% and 2.0% for the 500, 1000, 1500 and 2000ppm degrees of lead concentration respectively.

From Figure 6, the linear correlation for the angle of internal friction values versus the varied degrees of Lead concentration (Pb) showed that:

Lead contaminated samples with no binder addition had a coefficient of correlation which was ($R^2 = 0.92$) with a linear equation of

$$\phi\ (°) = 0.0053Pb + 48.984 \tag{19}$$

Lead contaminated samples with 5% binder addition had a coefficient of correlation which was ($R^2 = 0.99$) with a linear equation of

$$\phi\ (°) = -0.0083Pb + 84.54 \qquad (20)$$

Lead contaminated samples with 10% binder addition had a coefficient of correlation which was ($R^2 = 0.99$) with a linear equation of

$$\phi\ (°) = -0.0128Pb + 86.21 \qquad (21)$$

The cohesion and angle of internal friction values during the direct shear test of the naphthalene contaminated soil samples were shown in Figure 7 and 8 respectively. Figure 7 and 8 also shows the correlation relationship between the cohesion and angle of internal friction values during the direct shear (DS) respectively.

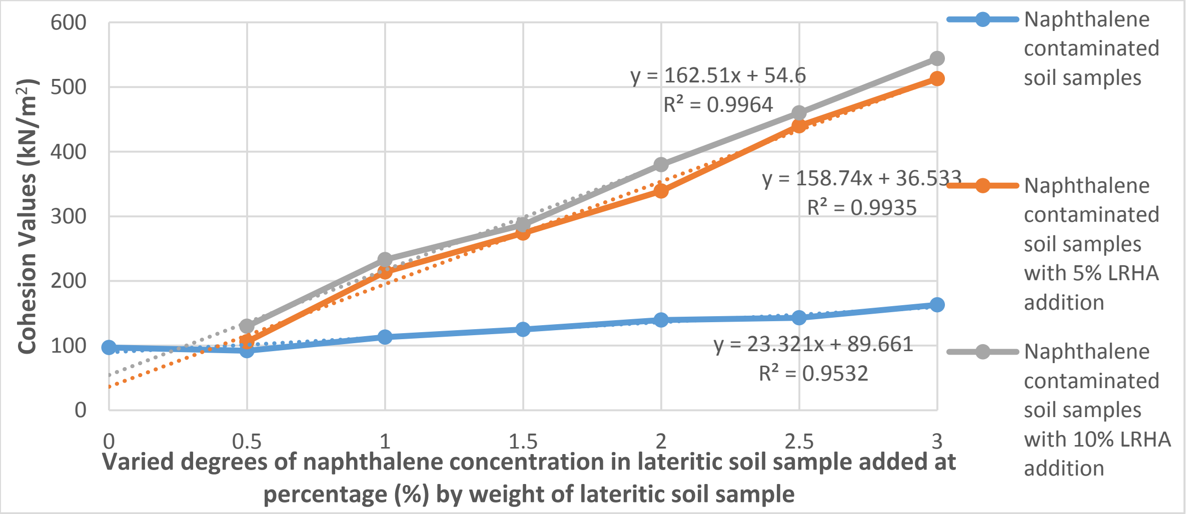

Figure 7: Cohesion (C) values of uncontaminated, naphthalene contaminated and naphthalene contaminated lateritic soil with binder (Lime-Rice Husk Ash [LRHA]) addition samples during direct shear test

Figure 7 shows that with the contamination of the lateritic soil sample, there was a slight initial decrease and a gradual increase in the cohesion values of the contaminated sample. From 97 kN/m^2 at uncontaminated naphthalene content of 0%, the cohesion value decreased to 92 kN/m^2 at naphthalene content of 0.5% and increased gradually to 163 kN/m^2 at contaminated naphthalene content of 3% by weight of the lateritic soil sample. The cohesion values for naphthalene contaminated samples with binder additions of 5% and 10% showed a gradual increase as the naphthalene concentration was increased. The cohesion values were 106 kN/m^2 and 130 kN/m^2 at 5 and 10% binder additions respectively for naphthalene content of 0.5% by weight of lateritic soil sample, they increased to 513 kN/m^2 and 544 kN/m^2 at 5 and 10% binder additions respectively for naphthalene content of 3% by weight of soil sample. Figure 7 also showed the effect of the 5% and 10% by weight of sample binder additions to the cohesion values of naphthalene contaminated samples. On adding the binder to the varied naphthalene contaminated soil, its cohesion values increased when compared to the values of naphthalene contaminated and the uncontaminated lateritic soil sample. The cohesion values increased by 15.2%, 89.4%, 119.2%, 143%, 207.7% and 214.7% for the 0.5%, 1.0%, 1.5%, 2.0%, 2.5% and 3.0% by weight of the soil degrees of naphthalene concentration respectively as the 5% binder was added was added to the naphthalene contaminated soil samples. The cohesion values also increased by 41.3%, 106.2%, 129.6%, 172.4%, 221.6% and 233.7% for the 0.5%, 1.0%, 1.5%, 2.0%, 2.5% and 3.0% by weight of the soil degrees of naphthalene concentration respectively as the 10% binder was added was added to the naphthalene contaminated soil samples.

From Figure 7, the linear correlation for the cohesion values versus the varied degrees of Naphthalene concentration (N) showed that:

Naphthalene contaminated samples with no binder addition had a coefficient of correlation which was ($R^2 = 0.95$) with a linear equation of

$$C\ (kN/m^2) = 23.321N + 89.661 \qquad (22)$$

Naphthalene contaminated samples with 5% binder addition had a coefficient of correlation which was ($R^2 = 0.99$) with a linear equation of

$$C\ (kN/m^2) = 158.74N + 36.533 \qquad (23)$$

Naphthalene contaminated samples with 10% binder addition had a coefficient of correlation which was ($R^2 = 0.99$) with a linear equation of

$$C\ (kN/m^2) = 162.51N + 54.6 \qquad (24)$$

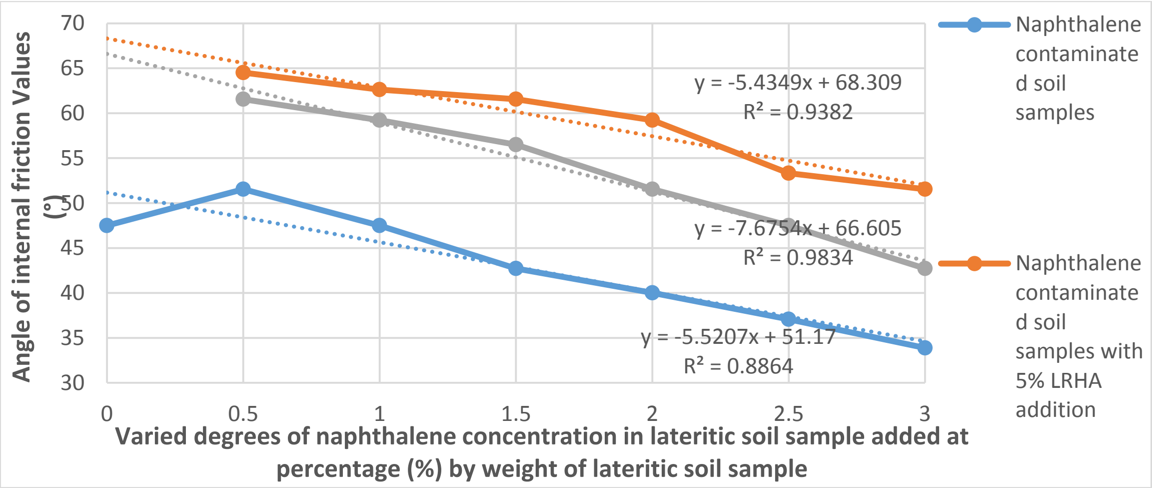

Figure 8: Angle of internal friction (ϕ) values of uncontaminated, naphthalene contaminated and naphthalene contaminated lateritic soil with binder (Lime-Rice Husk Ash [LRHA]) addition samples during direct shear test

Figure 8, showed the angle of internal friction values during the direct shear test on the lateritic soil sample, lateritic soil sample contaminated with varied degree of naphthalene and their binder additions. There was an initial increase and gradual decrease in the angle of internal friction value of the naphthalene contaminated sample as there was increase in the naphthalene concentration, from 47.5° at uncontaminated lead content of 0% the value increased to 51.54° at contaminated naphthalene content of 0.5% and decreased gradually to 33.88° at contaminated naphthalene content of 3%. The angle of internal friction values for naphthalene contaminated samples with binder additions of 5% and 10% showed a gradual decrease as the naphthalene concentration was increased. The values were 64.52° and 61.56° at 5 and 10% binder additions respectively for naphthalene 0.5% by weight of lateritic soil sample, they decreased to 51.54° and 42.72° at 5 and 10% binder additions respectively for naphthalene 3% by weight of lateritic soil sample. Figure 8 also showed the effect of the 5% and 10% by weight of sample binder additions to the angle of internal friction values of naphthalene contaminated samples. On adding the 5% binder to the varied naphthalene contaminated soil, its angle of internal friction values increased by 25.2%, 31.8%, 44.3%, 48%, 43.9% and 52.1% for the 0.5%, 1.0%, 1.5%, 2.0%, 2.5% and 3.0% by weight of the soil degrees of naphthalene concentration respectively. On adding the 10% binder to the varied naphthalene contaminated soil, its angle of internal friction values increased by 19.4%, 24.7%, 32.2%, 28.8%, 28.1% and 26.1% for the 0.5%, 1.0%, 1.5%, 2.0%, 2.5% and 3.0% by weight of the soil degrees of naphthalene concentration respectively.

From Figure 8, the linear correlation for the angle of internal friction values versus the varied degrees of naphthalene concentration (N) showed that:

Naphthalene contaminated samples with no binder addition had a coefficient of correlation which was ($R^2 = 0.89$) with a linear equation of

$$\phi\ (°) = -5.5207N + 51.17 \tag{25}$$

Naphthalene contaminated samples with 5% binder addition had a coefficient of correlation which was ($R^2 = 0.94$) with a linear equation of

$$\phi\ (°) = -5.4349N + 68.309 \tag{26}$$

Naphthalene contaminated samples with 10% binder addition had a coefficient of correlation which was ($R^2 = 0.98$) with a linear equation of

$$\phi\ (°) = -7.6754N + 66.605 \tag{27}$$

CONCLUSIONS

The study was conducted to stabilize lead and naphthalene contaminants in lateritic soil using lime-rice husk ash. A series of laboratory tests that included basic geotechnical tests on the collected lateritic soil sample and strength tests. Based on these laboratory tests, the following conclusions were drawn:

- The lateritic soil sample collected was an A-2-7 according to AASHTO classification with a natural moisture content of 28.8% and specific gravity of 2.72 with a bulk density of 1.64 g/cm^3. Atterberg limits were 52.2 % and 24.4% respectively for the liquid limit and plastic limit, the linear shrinkage was 11.5%
- The strength of the contaminated lateritic soil sample increased with an increase in the binder content, with the 10% binder addition producing the highest percentage increase in strength characteristics which were in the range of 272.03-349.75 kN/m^2 and 271.76-388.61 kN/m^2 for the unconfined compressive strength on lead and naphthalene contaminated samples respectively. While the cohesion (c) and angle of internal friction (ϕ) values from the direct shear test were in the range of 440-836 kN/m^2 and 79.92-60.43° for the lead and 130-544 kN/m^2 and 61.56-42.72° for naphthalene contaminated samples respectively.
- The bearing capacity of the varying soil-contaminant-binder mix samples were calculated from their respective unconfined compressive strength, they were in the range of 302.9 and 389.5 kN/m^2 for the 500 and 2000 ppm of lead contaminated soil samples and 302.6 and 432.8 kN/m^2 for the 0.5% and 3% by weight of the lateritic soil naphthalene contaminated soil samples.

- The high indices of coefficient of correlation (R^2) for the established relationships between strength characteristics and the lead and hydrocarbon content, suggest that these linear expressions are suitable for the determination of the strength characteristics for similar lateritic soils at different degrees of lead and hydrocarbon contamination stabilized with 0%, 5% and 10% Lime-rice husk ash.

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