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PERFORMANCE EVALUATION OF FORAGE ASH STABILIZED SHALE SOIL FOR EFFECTIVE USE IN FLEXIBLE PAVEMENT

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Abstract

For most developing countries, infrastructural development, especially in the road sector, plays a key role in its development, however geotechnical engineers encounter lots of problem during the construction of most roads especially when the subgrades consists of expansive soils due to their swelling and shrinkage problems which are responsible for potholes, cracking and undulations in the pavement leading to discomfort and lessening the life of vehicle, hence the engineering properties of these soils needs to be improved. Preliminary tests which include specific gravity, atterberg's limits test, grain size analysis, compaction tests, California bearing ratio test and unconfined compressive tests were carried out the shale samples, after which 2 to 20% by weight of forage ash was added to the shale sample and subjected to Atterberg's limits test and some strength tests (Compaction, California Bearing Ratio, and Unconfined Compressive Test). The results show that the addition of forage ash increased the plasticity index of the shale sample, however, the California bearing ratio (CBR) values (soaked and unsoaked) were significantly increased both at the West African level and Modified AASHTO level. The maximum dry density (MDD) of the sample was increased as well as a reduction of the Optimum Moisture Content (OMC) of the sample was found. The values of the unconfined compressive strength show that there was also an increase in the strength of the sample. In conclusion, forage ash was found to be an effective additive for shale soil stabilization and improves the strength of the soil.

Keywords: Forage Ash; Shale; Soil Stabilization; Unconfined Compressive Strength; Pavement Designs.

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1. Introduction

In developing nations, road construction plays a very important role in its development due to increase in population and urban development, there has been more demand for road and housing facilities. Since the main objective of road construction material selection is aimed at ensuring overall economy and stability of pavements, a thorough knowledge of the soil and aggregate properties which affect pavement stability and durability is required as well as the properties of the binding materials which may be added to improve these pavement features (Amu et al, 2012). When these materials consist of expansive soils and do meet up with the necessary requirements, it is imperative to find an economic and environmental friendly way to improve the materials. Removing of these unsuitable materials and replacing them with the suitable ones is not cost effective results in an increase in the cost of the road construction. One of such ways is the use of agricultural waste to improve the geotechnical properties of the materials. In recent years there has been an intensified research towards the use of these by-products and waste materials in construction, because the safe disposal of these wastes is increasingly becoming a major concern around the world (Engineering Technical Letter 1999; Gardner 2011; Gomes et al. 2011; Hossain et al. 2011; Wen and Wu 2011; Osinubi and Edeh 2011). The use of these materials as alternatives results in two-fold advantages - conservation of natural resources and disposal or reduction in size of waste heaps.

Shale is an expansive soil and it's regarded as a problematic soil owing to its cyclic nature and it also undergoes volumetric changes when subjected to changes in moisture content as a result of the annual rainy and dry season and also perhaps as a result of its clayey nature (Joel and Agbede, 2008). It's also regarded as a fine-grained sedimentary rock covering a vast area of the earth's surface formed from clays compacted together by pressure and were deposited in very slow moving water which is often found in the lake and lagoonal deposits, in river deltas, on floodplains and offshore of beach sands. Shale problems could be as a result of its mineralogical framework as the swelling and shrinking of soils are usually affected by mineralogical constituents and surroundings (Akawwi and Al-Kharabsheh, 2002). Shale is also noted to be intensely fractured and weathered resulting in variable geotechnical characteristics which cause significant construction problems and damage to civil structures (Nandi et al, 2009). Pavement designed over a shale subgrade results in distress like potholes, cracking and undulations in the pavement leading to discomfort and lessening the life of vehicle

Forage (*Pennisetum purpureum) also known as elephant grass* is a major tropical grass. It is one of the highest yielding tropical grasses, it grows vigorously and can reach 4 m in 3 months (Skerman et al., 1990). It is a very versatile species that can be grown under a wide range of conditions and systems. It is a very important forage in the tropics due to its high productivity. It is particularly suited to feed cattle and buffaloes and it's mainly used in cut-and-carry systems ("zero grazing") and fed in stalls, or made into silage or hay. It yields ranges from 20 to 80 tons/year under high fertilizer inputs (Francis, 2004; Skerman et al., 1990). The total land area devoted to these kinds of crops is greater than the land area for all other kinds of crops combined, hence forage is readily available. As the seasons changes and the weather become dry, forage tend to lose their moisture and dry up during dry seasons, hence becoming useless for grazing animals, which later becomes a huge waste and makes disposal a problem. (Amu et al, 2012).

Researchers have used agricultural waste all over the world to improve soils used in construction (Nottidge et al. 2009; Ramezanianpour et al. 2009; Amu et al, 2012; Fattah et al. 2013; Edeh et al, 2014; Oyedrian and Fadamoro, 2015; Nnochiri and Aderinlewo, 2016).

While there has been research works carried out on the improvement of geotechnical properties of soils like laterite soils and black cotton soils using agricultural waste (Okafor et al. 2009; Amu et al. 2011a, b, 2012; Olarewaju et al. 2011). There has been little work done on improving geotechnical properties of shales. Hence, the focus of this research work includes finding suitable means of waste re-use to solve problems relating to waste disposal, seeks ways to modify and improve the geotechnical properties of shale to make it suitable for use in construction works, with a view to help lower construction costs associated with haulage and use of other well-known chemical additives like cement.

2. Materials and Methods

Bulk disturbed shale sample were obtained from a pit at a depth of 1.5m at Ibese town, Ogun State, Nigeria (latitudes N 06^0 59′ 28″ and longitudes of E 03^0 02′ 10″) which geologically falls within the Ewekoro formation of the Dahomey sedimentary basin. The shale was grey in colour, relatively dense and hard and do not crumble easily under finger pressure. The shale sample was collected in a closed bag and transported to the lab for analysis. Forage ash was obtained from open-air burning of *elephant grass* which was readily available. Its ash was then collected and sieved through BS sieve no. 200, and the fraction that passed through the sieve size was then collected and kept in air tight containers to prevent pre-hydration during storage.

The shale samples were first air-dried for 3 weeks to reduce the effect of clods on hydraulic conductivity as well as to prevent some irreversible changes if oven dried because certain clay materials undergo changes when subjected to a temperature between 100 °C to 110 °C. Preliminary geotechnical tests including grain size analysis, specific gravity, consistency limits, compaction, California bearing ratio (CBR) and unconfined compressive strength (UCS) were carried out on the samples in accordance with BSI 1377 (1990) standard test procedures. Compaction was carried out at the Modified AASHTO level of compaction because it is usually achievable with conventional field equipment and shale can, as well, withstand higher energy level without mechanical instability (Mohamedzein et al. 2005). Five different dosages of forage ash (i.e. 2%, 6%, 10%, 14% and 20% by weight of soil) was added to the shale sample. Three specimens were casted per each dosage of forage ash, consistency limits, compaction, California bearing ratio (CBR) and unconfined compressive strength (UCS) was then carried out on the samples In addition, the chemical composition of the forage ash, as well as shale, were determined through chemical analysis at the Agronomy Department of the University of Ibadan, while its Mineralogical composition was determined using X-Ray Diffraction (XRD) at the Acme Laboratories, Vancouver, Canada. Powdered samples of the soil were pelletized and sieved to 0.074 mm. These were later mixed with acetone to produce a thin slurry and each sample mixture was applied to a glass was scanned through the Siemens D500 Diffractometer (using MDI Data Scan and JADE 8 software) for the determination of XRD.

3. Results and Discussion

3.1 Oxide Composition of Forage Ash (FA)

The oxide composition of forage ash is given in Table 1. From the table, the combined proportion of Silicon Dioxide (SiO_2), Aluminium Oxide (Al_2O_3) and Iron Oxide (Fe_2O_3) is given as 53.95%, while its Loss of Ignition (LOI) which is an indication of the amount of unburned coal in the ash is 6.89%, following the description in ASTM C618 (ASTM 2015). FA used in this study is a class C fly ash.

Table 1: Oxide Composition of Forage Ash and Shale

Oxides	Forage Ash Composition (%)	Shale Sample (%)
MnO	0.017	-
CaO	0.023	0.34
$CaCO_3$	-	0.60
K_2O	0.78	0.71
FeO	-	4.21
Fe_2O_3	0.33	4.68
MgO	0.017	5.24
$MgCO_3$	-	10.96
Na_2O	-	0.05
SiO_2	52.38	56.87
TiO_2	1.65	0.74
Al_2O_3	1.24	14.55
P_2O_5	0.12	0.05
LOI	6.89	-

3.2 Mineralogical Composition

The Mineralogy of the Ibese shale (Fig 1) shows the presence of Quartz (3.99%), Kaolinite (7.61%), Palygorskite (33.66%), and Montmorillonite (54.74%). The high Magnesium oxides (16.2%) present in the shale could be attributed to the presence of palygorskite. Also, the high presence of montmorillonite clay mineral which is an expansive clay mineral due to it expanding when it comes in contact with water further explains the plastic nature of the soil as well as the high OMC.

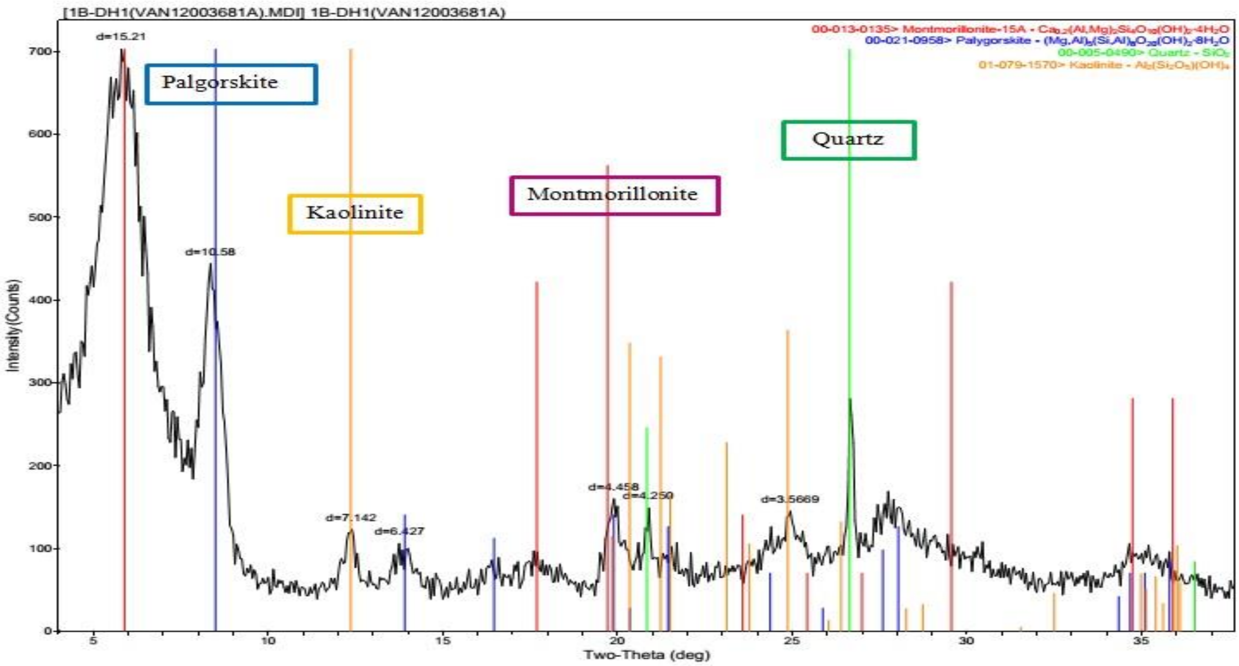

Fig 1: X-Ray Diffractogram of Ibese Shale.

3.3 Preliminary Results

Preliminary results of the tests carried out on the soil sample as shown in table 2 indicates that the shale soil is an organic soil with high compressibility with a liquid limit of 95%, plastic limit of 46% and plasticity index of 49%. The high compressibility of the soil could be attributed to the high amount of fines (89%) present in the shale. Based on the high amount of fines plus the high plasticity properties, the soil was classified as an A-7-5 "fair to poor soil" (AASHTO). The result of the compaction tests carried at modified AASHTO level of compaction shows that the maximum dry density (MDD) has a value of 1244 kg/m^3 with corresponding optimum moisture content (OMC) of 33.60%, while it's California bearing ratio (CBR) and Unconfined compressive strength (UCS) were 36% (unsoaked); 30% (soaked) and 56.43 kN/m^2 respectively. These values show that it's unsuitable as base course materials for road pavements without treatment, hence needs for improvement.

Table 2: Geotechnical Properties of Ibese Shale

Geotechnical Properties		Values
Amount of Fines (%)		89.00
Specific Gravity		1.82
Liquid Limit (%)		95.00
Plastic Limit (%)		46.00
Plasticity Index (%)		49.00
AASHTO Classification		A-7-5
Maximum Dry Density (kg/m^3)		1244
Optimum Moisture Content (%)		33.60
Unconfined Compressive Strength (kN/m^2)		56.43
California Bearing Ratio (%)	(unsoaked)	36.00
	(soaked)	30.00

3.4 Effect of Forage Ash on Consistency Limits

The addition of forage ash on the consistency limits of shale as shown in fig 2 shows that there was continuous increase in the Liquid Limit (LL) and Plasticity Index (PI) from 121% at 2% to 163% at 20% and 43% at 2% to 75% at 20% respectively.

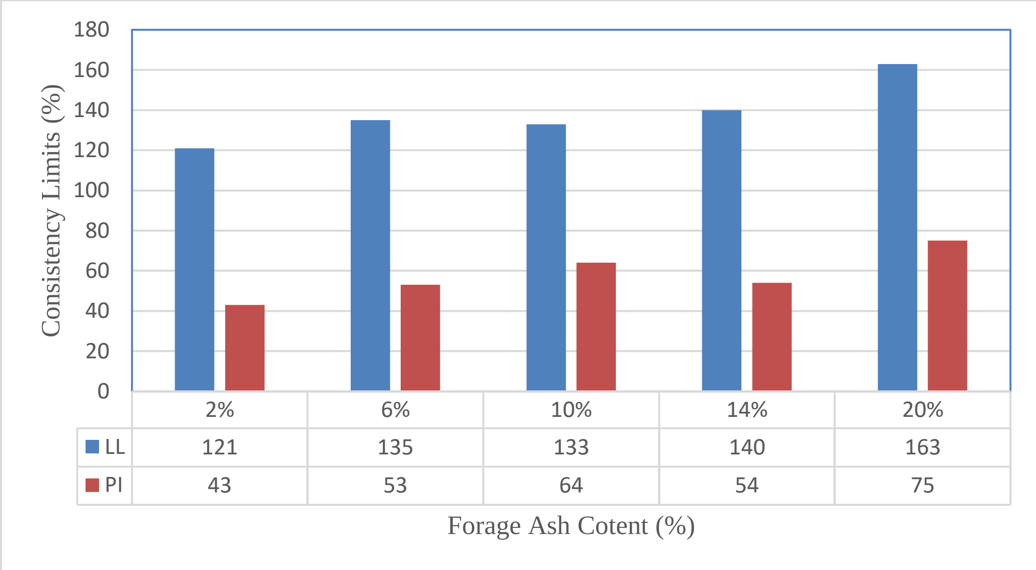

Fig 2: Effect of Forage Ash on Consistency Limits

3.5 Effect of Forage Ash on Compaction Parameters

Fig 3 and fig 4, shows the compaction properties of the shale with varying percentages of forage ash. The MDD generally increases as the OMC decreases from 1370kg/m3 at 2% to 1445kg/m3 at 10% and 30.5% at 2% to 22.5% at 10% respectively. There was a decrease in the MDD to 1360kg/m3 at 20% and subsequent increase in the OMC to 29.6% at 20% respectively. The initial increase observed in the MDD may be attributed to the reduction in particle-particle frictional forces, while further decrease might be attributed to the specific gravity has been lowered as well as decrease in the surface area of the shale as a result of further addition of forage ash. The corresponding increase in OMC may be due to the increased surface area of particles caused by increased forage ash content in the mix that required more water to lubricate the entire mix matrix.

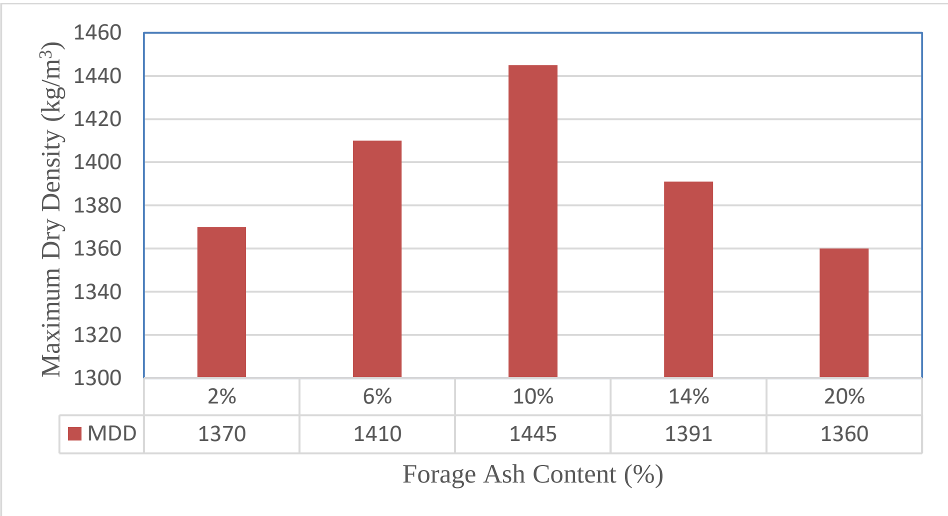

Fig 3: Effect of Forage Ash on MDD

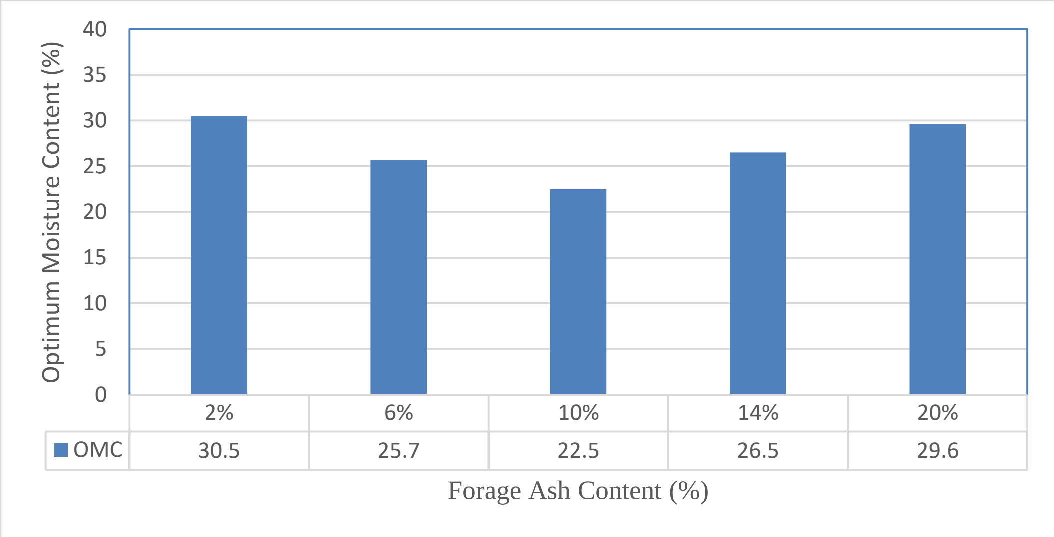

Fig 4: Effect of Forage Ash on OMC

3.6 Effect of Forage Ash on Unconfined Compressive Strength (UCS)

Fig 5 shows the UCS of the shale containing varying percentages of forage ash. It was noted that there was continuous increase of the shale strength from 46.88kN/m2 at 2% to 155.59kN/m2 at 20%. Forage ash fulfils the requirement of a pozzolanic materials which thus explains the continuous increase in the strength of the shale due to the fact that pozzolanic materials would react in the presence of moisture to yield cementatious products (Malhotra and Mehta 2004).

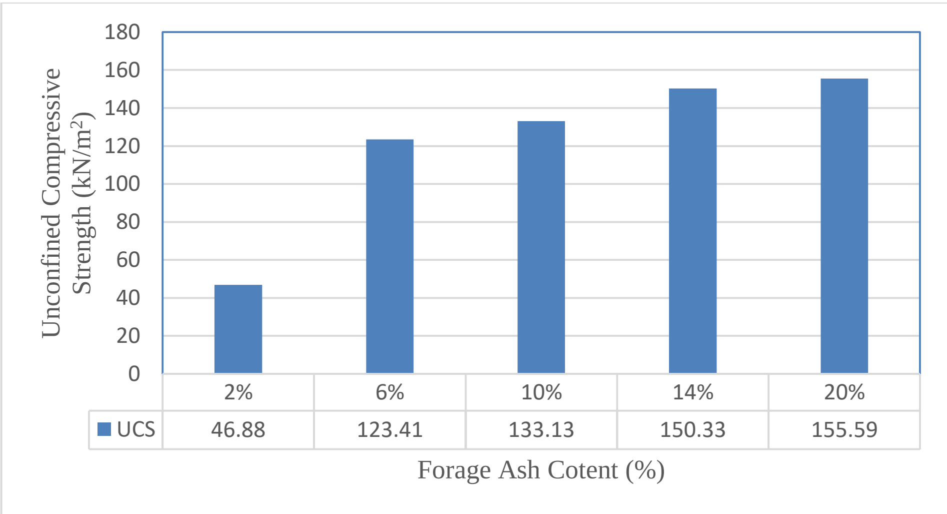

Fig 5: Effect of Forage Ash on Unconfined Compressive Strength

3.7 Effect of Forage Ash on California Bearing Ratio (CBR)

CBR test was carried out both in soaked and unsoaked conditions, the results has seen in fig 6 shows that there was continuous increase in the CBR values from 57% and 48% at 2% to 195% and 187% at 10% for unsoaked and soaked conditions respectively. CBR increment may due to the gradual formation of cementitious compounds in the shale by the reaction between the additives and the shale resulting in a well bonded mixture.

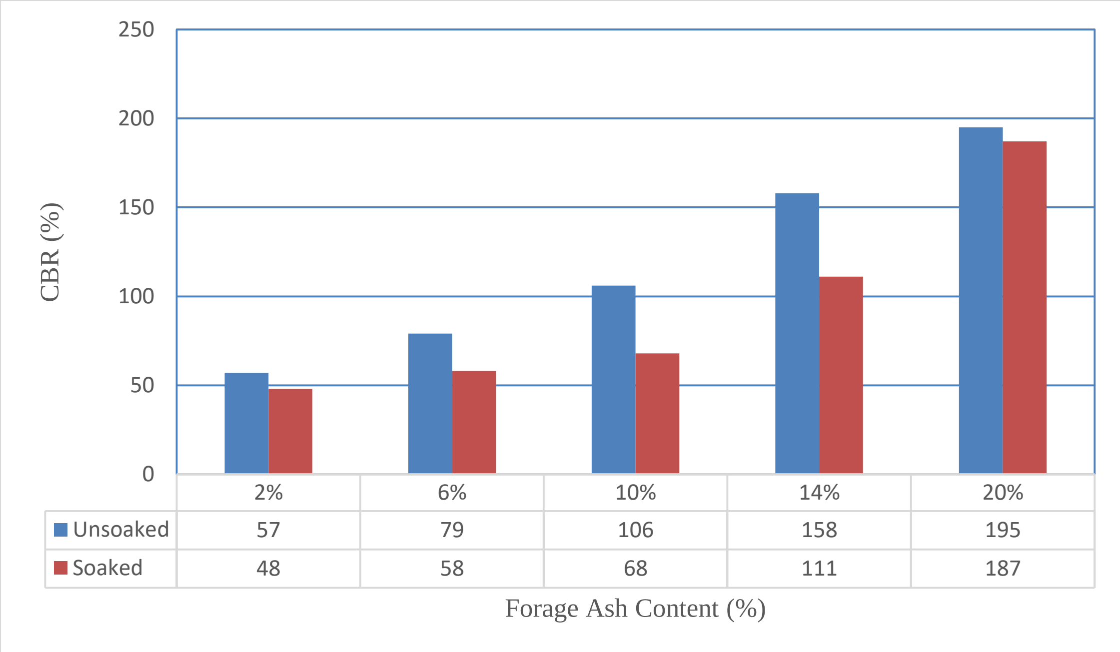

Fig 6: Effect of Forage Ash on California Bearing Ratio

4. Conclusion

Based on the investigation carried out the effect of forage ash on shale, it could be seen that forage ash can be classified as a pozzolanic material because the percentage sum of its SiO_2, Al_2O_3 and Fe_2O_3 components (53.95%) exceeds the minimum requirement of 50%. It could also be seen that the forage ash didn't improve the plasticity of the shale sample owing to the high plasticity index values, however it increases its MDD and subsequently decreases its OMC with peak values recorded at 10% addition, which could be taken as the optimum value during the design and construction of pavements. There was considerable increase in the strength of the shale as seen from results of the CBR and UCS, which can be concluded that forage ash can be used to significantly improve the strength of shale soils.

5. Acknowledgement

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