Geotechnical Properties of Makurdi Shale Treated with Bamboo Leaf Ash

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Abstract

The study investigated the geotechnical properties of Makurdi shale treated with bamboo leaf ash (BLA). Different percentages of BLA in incremental order of 4% up to 20% by dry weight of soil were added to shale sample. Particle size distribution, Atterberg limits, compaction, unconfined compressive strength (UCS), California bearing ratio (CBR) and durability tests were performed on each combination. X-ray diffraction test was conducted on the natural shale and BLA. The results showed improvement in the plasticity index (PI), UCS and CBR values of the treated soil. The PI decreased from 39.4% to 24%, while 7 day UCS and CBR values increased from 53.52 kN/m^2 and 6% to 154.6 kN/m^2 and 18%, respectively. Improvements observed in the strength properties of BLA treated shale were below the minimum values specified for road building materials. Hence, it is recommended for use as a modifier, in the stabilization of shale with either cement, lime or other additives for road work.

Keywords*: Soil improvement, compaction, unconfined compressive strength, Atterberg limits, California bearing ratio, durability tests.*

Introduction

Shale is the product of highly consolidated clays, silts and sands or a mixture of all the three fractions of soil derived from the weathering of rocks. These fractions of soil were deposited in sea or riverbeds in layers and subjected to high overburden pressures, which lead to consolidation and diagenesis (de Graft - Johnson *et al*. 1973). According to O'Flaherty (1974), shale is essentially a clayey material, which is very likely to break down in the presence of moisture and frost. Since shale is highly clayey in nature, it is subjected to swelling during the rainy season and shrinkage during the dry season. Shale is a notorious unpredictable material, in which a number of failures have been reported involving cracks on buildings, settlement and shear failure of compacted shale embank-ments (Abeyesekera *et al.* 1978; El-Sohby *et al.* 1987; Williams 1980). Makurdi town, the headquarters of Benue State is extensively underlain with shale as confirmed by Agbede and Smart (2007). Buildings and roads constructed in Makurdi town suffer distress in form of cracks ranging from fraction of millimeters to about 10 mm, thereby reducing the lifespan of these structures and posing threat to lives and properties (See Figs. 1 and 2) (Iorliam *et al*. 2012b). Due to the challenge posed by shale and other expansive soils, many researchers have utilized agricultural or industrial waste to improve the geotechnical properties of these soils. The focus on utilization of waste in soil improvement have received much attention in the recent times due to rising cost of industrial stabilizers such as cement and lime as well as increased cost of waste disposal and environmental constraints caused by waste. The need for economic soil stabilizer is necessary, especially in localities where problem soils are encountered; with shortage of suitable construction materials, avoiding or by-passing them is difficult, thus, prompting engineers to improve the unsuitable natural soils for use in engineering work at economic cost.

Researchers (Hughes and Glendinning 2004; Iorliam *et al*. 2012a; Agbede and Joel 2011; Okafor and Okonkwo 2009; Oriola and Moses 2010; Medjo Eko and Riskowski 2004) have utilized wastes, such as blast furnace slag, cement kiln dust, carbide waste, rice husk ash, groundnut shell ash and sugar cane bagasse to treat problem soils and recorded improvement in their geotechnical properties; including PI, UCS, and CBR. According to Dwivedi *et al*. (2006), bamboo leaf ash (BLA) is a good pozzolanic material, which reacts with calcium hydroxide forming calcium silicate hydrate. Amu and Adetuberu (2010) reported the effective used of BLA to stabilize lateritic soils for highway construction with significant improvement in its strength properties, as the unsoaked CBR values of two samples A and B increased from 5.44 and 11.42 to 38.21% and 34.99%, respectively, while the shear strength of samples A and B also increased from 181.31 and 144.81 to 199.00 kN/m^2 and 155.90 kN/m^2, respectively.

Fig. 1. Cracks on building founded on shale deposits located at the College of Engineering, University of Agriculture, Makurdi, Benue State, Nigeria (Iorliam *et al*. 2012b).

However, research on shale treated with BLA is scarce. This has prompted the study on treatment of Makurdi shale with BLA. The aim of the study is to improve geotechnical properties of Makurdi shale with BLA; a cheap and locally available waste.

Geology of the Study Area

"Makurdi formation is comprised of three zones; the lower Makurdi sandstone, the upper Makurdi sandstone and the Wadata limestone (Nwajide 1982). The lower Makurdi sandstone, which could be found around the Makurdi Airport, consists of sandstones and mudrocks. They are micaceous throughout with mudrocks predominating. The upper Makurdi sandstone is similar to the lower sandstone but with mudsrocks being relatively less common, as found around the North Bank area of Makurdi. Sandstones and shales outcrop prominently and the sandstone range from very fine to medium in grain size. In this zone, there are shale units of mainly fissile siltstone, usually brownish grey in colour and often abundantly micaceous." (Iorliam *et al*. 2012b)

"Wadata limestone also consists of several limestone occurrences; most outcrops are shelly limestone often closely associated with mudrocks which is the most extensive component of the Makurdi formation (Agbede and Smart 2007). The sandstones in this zone are generally fine to medium grained, moderately sorted, micaceous and feldsphatic. In some parts, they are calcareous, micaceous and shelly. Various types of cement like iron oxides, silica, carbonates and clay were shown to be present in the Makurdi sandstone." (Iorliam *et al*. 2012b)

Materials and Methods

Bamboo leaf ash was obtained from Otukpo, Benue State, Nigeria, where the leaves are much available as waste. The leaves were sun dried, burnt in an open air and then heated in furnace at 600°C for two hours at the Metallurgy Laboratory, Department of Mechanical Engineering, University of Agriculture, Makurdi, Benue State, Nigeria. (Iorliam *et al*. 2012b)

Materials

Shale sample was obtained at 1.5 m depth from shale outcrop located in college of Engineering, University of Agriculture Makurdi, Benue state, Nigeria. Makurdi town s located on 7º43'50''N and 8º32'10''E, on the geographical map of Nigeria (Iorliam *et al*. 2012b; Wikipedia 2013). The disturbed sample was transported in sacks to the soil mechanic laboratory of the Department of Civil Engineering, University of Agriculture, Makurdi.

Fig. 2. Failed portion of the intra campus Road, University of Agriculture, Makurdi, Benue State, Nigeria (Iorliam *et al*. 2012c).

Methods

The following laboratory tests were performed on the natural soil and the soil treated with BLA; Atterberg limits, Grain size analysis, Compaction, UCS and CBR tests. The tests were conducted in accordance with BS 1377 (1990) and BS 1924 (1975), for untreated shale and BLA treated shale, respectively. The CBR test was conducted in accordance with the Nigerian General Specifications (Roads and Bridges) (Federal Ministry of Works and Housing 1997), which stipulates that specimens be cured in the dry for six days and then soaked for 24 hours before testing. Compaction was carried out at the energy level of the British Standard (BS) light compact effort only; hence this is easily achieved in the field. The resistance to loss in strength was determined as a ratio of the UCS value of specimens cured for seven days under controlled condition, which were subsequently immersed in water for another seven days to the UCS value of specimens cured for 14 days. The conventional criterion of a maximum allowable loss in strength of 20%, which translates to 80% resistance to loss in strength (Ola 1974) was adopted. X-ray fluorescence analysis was carried out on the BLA and shale samples, using Philips PW 1450/20 spectrometer to aid in the determination of their oxide composition. Different percentages of BLA in incremental order of 4% up to 20% of dry weight of soil samples were used.

Results and Discussion

Index Properties

The index properties of natural Makurdi shale are summarized in Table 1. The soil was found to be A-7-6, high plasticity (CH) and high swell potential soil by the American Association of State Highway and Transportation Officials (AASHTO), Unified Soil Classification System (USCS) and Nigerian Building and Road Research Institute (NBRRI) classification system (Madedor 1983), respectively. The test results showed that the natural soil was not suitable for use as sub-base or base course materials and even requires a modified layer above it as a sub-grade soil. Table 2 shows the oxide compositions of BLA and Makurdi shale. The results showed predominant presence of silicon (SiO_2), followed by calcium oxide (CaO) in BLA, while SiO_2 was predominant in Makurdi shale (Iorliam *et al*. 2012b).

Table 1. Index properties of Makurdi shale (Iorliam *et al*. 2012b).

Properties	Quantity
Percentage passing BS sieve No. 200 (%)	87
Natural moisture content (%)	30.43
Liquid limit (%)	46.90
Plastic limit (%)	31.0
Plasticity index (%)	14.68
Linear shrinkage (%)	12.10
Free swell (%)	30
Specific gravity	2.42
AASHTO classification	A-7-6
USCS classification	CH
Maximum dry density (Mg/m^3)	1.49
Optimum moisture content (%)	23.50
Unconfined compressive strength (kN/m^2)	53.52
California bearing ratio (after 24 hrs soaking)	6

Table 2. Chemical composition of Makurdi shale (Iorliam *et al*. 2012b,c) and BLA used.

Chemical Composition	Concentration (% by weight)	
	Makurdi shale	BLA
SiO_2	49.02	44.50
P_2O_5	0.50	3.80
SO_3	-	1.00
K_2O	1.85	10.10
CaO	0.26	9.89
TiO_2	1.98	1.29
V_2O_5	-	0.0049
Cr_2O_3	-	0.02
MnO	0.03	0.44
Fe_2O_3	8.37	3.26
Al_2O_3	25.24	-
MgO	1.16	-
Na_2O	2.57	-
LOI	-	25.00

Effect of Bamboo Leaf Ash (BLA) on Consistency Limits of the Shale

The variation of Atterberg limits of Makurdi shale treated with BLA is as shown in Fig. 3. Liquid limit and plastic limit decreased with BLA content. Similarly, plasticity index (PI) and linear shrinkage (SL) decreased with BLA content from 39.4% and 13% to 24% and 12.1% representing improvement of 39% and 7%, respectively. The proportional reduction in PI and SL of BLA treated shale is associated with the corresponding presence of Ca^{2+} cation in BLA; which aids flocculation, and aggregation of the clay particles. The agglomeration of clay particles due to BLA addition turns a clayey soil to a silty soil and this by itself will decrease the liquid limit of the soil because of the lower surface area. This trend is similar to Osinubi (1995). The trend of improvement in PI and SL is in agreement with Amu and Adetuberu (2010) and indicated that the addition of BLA have an improved effect on the swelling potential of expansive soil.

Effect of Bamboo Leaf Ash (BLA) on Compaction Characteristics

The variation of maximum dry density and optimum moisture content with BLA is as shown in Fig. 4. The maximum dry density (MDD) of Makurdi shale decreased with BLA content for all percentages. The MDD decreased from 1.49 Mg/m^3 at 0% BLA content to 1.37 Mg/m^3 at 20% BLA.

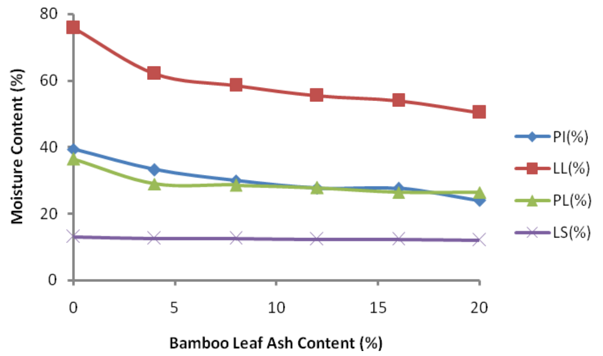

Fig. 3. Variation of Atterberg limits indices with bamboo leaf ash content.

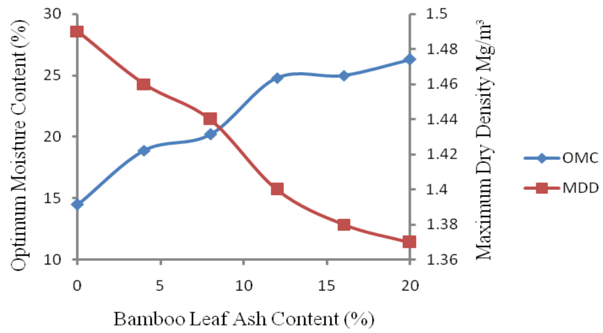

Fig. 4. Variation of maximum dry density and optimum moisture content with bamboo leaf ash content.

However, the optimum moisture content (OMC) increased with higher BLA treatment from 14.5 to 26.3%. The decrease in density according to Ola (1978) and Lees *et al*. (1982) is as a result of the flocculated and agglomerated clay particles occupying larger spaces leading to a corresponding decrease in dry density. The increased OMC with increased BLA content is as a result of the extra water required for the pozzolanic reactions.

Effect of Bamboo Leaf Ash (BLA) on the California Bearing Ratio (CBR), Unconfined Compressive Strength Indices and Durability.

The variation of CBR, UCS and durability of shale treated with BLA content is as shown in Figs. 5, 6 and 7.

The results showed an increase in CBR of shale with addition of BLA content. The soaked CBR increased from 6% to a peak value of 18% at 20% BLA content. The peak value is lower than the minimum CBR value of 40% prescribes for sub-base material of lightly trafficked roads by the Nigerian General

Specifications (Roads and Bridges) (Federal Ministry of Works and Housing 1997).

A similar trend was observed with the UCS results, as the UCS value of untreated shale increased from 53.52 kN/m^2 to peak values of 154.6 kN/m^2, 172 kN/m^2 and 182 kN/m^2 at 7, 14 and 28 days, respectively. The peak UCS values were obtained at 20% BLA content. However, the peak 7 day UCS value of 154.6 kN/m^2, fell short of 1710 kN/m^2 specified by TRRL (1977) as criterion for adequate stabilization using ordinary Portland cement. Nevertheless, BLA shows progressive strength development with longer curing periods from the observations of the 7, 14 and 28 day unconfined compressive strength results.

Durability test results showed that a maximum resistance to loss in strength value of 43% was attained when Makurdi shale was treated with BLA, this value fell short of the 80% used as evaluation criterion (Ola 1974).

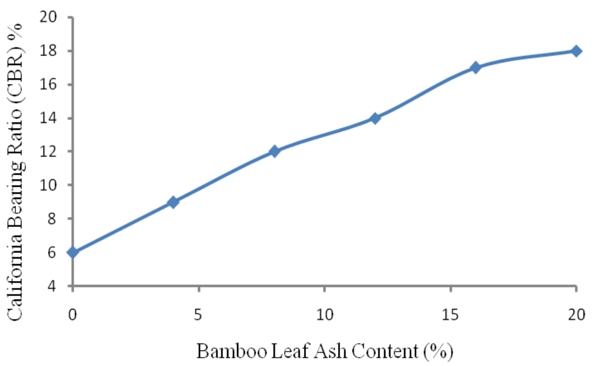

Fig. 5. Variation of California bearing ratio (CBR) of Makurdi shale with bamboo leaf ash content.

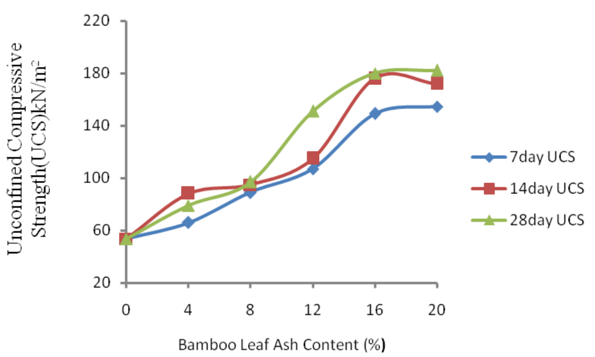

Fig. 6. Variation of unconfined compressive strength (UCS) of Makurdi shale with bamboo leaf ash content.

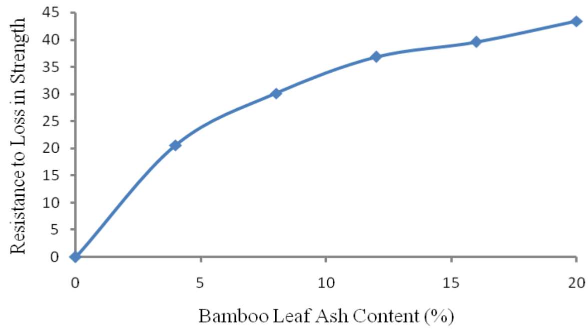

Fig. 7. Variation of resistance to loss in strength of Makurdi shale with bamboo leaf ash.

Conclusion

From the results of this study, the soil is classified as A-7-6 and CH by AASHTO and USCS classification systems, respectively (Iorliam *et al*. 2012b). In summary:

- Makurdi shale treated with BLA showed improvement in swelling properties as plasticity index and linear shrinkage of Makurdi shale reduced by 39% and 7%, respectively.
- The treatment of Makurdi shale with BLA yielded improvement in CBR and UCS. The peak CBR and 7 day UCS values of 18% and 154.6 kN/m^2, at 20% BLA content were observed, while the resistance to loss in strength value of 43% was achieved.
- The improved geotechnical properties of Makurdi shale treated with BLA did not satisfy the combined strength indices evaluation criteria (i.e. CBR, 7 day UCS and durability) specified for sub-base and base materials in road construction.
- The use of BLA combination with stabilizing agents like cement or lime for stabilization of high plasticity soil in road work use has also been studied in a separate work (Iorliam *et al*. 2012b).

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