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Evaluation of Cow Bone Ash (CBA) as Additives in Stabilization of Lateritic and Termitaria Soil

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Abstract

Continual pavement distresses on Nigerian highways, as well as environmental contamination from abattoir solid wastes such cow-bones have been a major concern. This study examined the usage of additives in stabilizing weak soils and enhancing their geotechnical properties utilizing Cow Bone Ash (CBA) on lateritic and termitaria soils. The following engineering confirmatory tests were carried out on the samples: compaction test, unconfined compressive strength (UCS) and California bearing ratio (CBR) test. CBA at 2%, 4%, 6%, 8%, and 10% were added to the soil samples. The study revealed that for lateritic and termitaria soils, the maximum amount of CBA that would allow for an increase in soaked CBR value was at 6% and 8%, respectively, while for the unsoaked CBR, the peak values was obtained at 8%. Also, the addition of CBA increased the UCS of both soil samples. The addition of CBA resulted in decreasing optimum moisture content (OMC) for termitaria soils as its pore spaces are filled up by the CBA while for the lateritic soils, increase in CBA resulted in increased OMC values. Also, the addition of CBA to both soil samples resulted in an increase in maximum dry density (MDD) values. The study revealed that termitaria soils have higher strength than the lateritic soils due to higher cohesiveness within its pore structure, lower OMC, higher MDD, UCS, and CBR values. The study concludes that the use of CBA to a maximum of 8% as an additive in stabilization of lateritic and termitaria soils is effective and therefore recommends its use in light and medium trafficked roads.

Keywords: Cow Bone Ash; Termitaria Soils; Lateritic soils; unconfined compressive strength; California bearing ratio.

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1. Introduction

The use of stabilizing agents (binder materials) in poor soils to improve geotechnical properties such as compressibility, strength, permeability, and durability is known as soil stabilization [1]. Soils and or soil minerals, as well as stabilizing agents or binders, are components of stabilization technology (cementitious materials). Soil stabilization, in order words, is the physical and chemical modification of soils to improve their physical properties [2]. Soil or rock supports almost every civil engineering structure such as roads and buildings. In civil engineering, soil is defined as an assemblage of discrete particles in the form of a deposit, typically of mineral composition but occasionally of organic origin, that can be separated by gentle mechanical means and that contains variable amounts of water, air, and other gases [3]. Because the foundations of all structures must be placed on or in soil, the engineering behaviour of soil is critical. Understanding different soil types and developing various techniques to improve their properties is therefore essential [4]. When a given soil lacks the engineering properties to support structures, roads, and foundations, soil stabilization is required [5]. One option is to modify the foundation to accommodate the site's geotechnical conditions. Another option is to attempt to stabilize or improve the engineering properties of the site's soils. Depending on the circumstances, the latter approach may be the most cost-effective solution [6]. Lateritic soils are known to be environmentally friendly and constructions made of earth-based materials are the most cost-effective because they are readily available and less expensive. Nigeria is rich in these and other natural construction material [7]. In Nigeria, lateritic soil is used for structures, roads, and foundations, brick moulding and plastering. It's a group of heavily weathered soils made up of hydrated iron and aluminium oxides [3]. Except for a few issues, lateritic soil as a locally accessible material appears to be a promising alternative to conventional construction materials. It has a lot of plastic clay [8]. Construction projects can crack due to the high plasticity [9]. Lateritic soil stabilization is needed to resolve this. The American Society for Testing and Materials (ASTM) lists many reasons for soil stabilization, including increasing the strength of existing soil to increase its load-bearing capability, improving permeability, and improving soil resistance to weathering and traffic [9]. Lateritic soil stabilization avoids potential issues such as swelling and damping, which could lead to the collapse of a structure constructed, road damages with untreated lateritic soil [10]. It also extends the life of roads and buildings constructed with lateritic soil and reducing maintenance costs [11]. Understanding the mechanical behavior of lateritic soil and, as a result, determining techniques for its stabilization is important. To increase the shear strength of soils, different stabilization methods and materials have been used over time. Mechanical or chemical ways of stabilization are the most common methods for increasing shear strength today. Compaction or the addition of fibrous and other non-biodegradable reinforcement to the soil are also examples of mechanical stabilization. Chemical stabilization, on the other hand, requires applying chemicals or other materials to the natural soil to strengthen it. Some of these chemicals or materials used in present day include Portland cement, lime, fly ash, calcium chloride, bitumen, enzymes, cement kiln dust (CKD) and other naturally available materials. Majority of the commonly used soil stabilizing materials contain varying levels of calcium e.g., Portland cement, lime and coal fly ash [12; 13]. Since the invention of soil stabilization technology in the 1960s, cement has been the oldest binding agent. It is used as a primary stabilizing agent or hydraulic binder because it provides the required stabilizing action on its own [14]. Ordinary Portland cement, blast furnace cement, sulfate resistant cement, and high alumina cement are among the many forms of cement available on the market. The type of cement used is generally determined by the type of soil to be handled and the desired final strength [4]. According to analysis, as at year 2020, cement costs a significant portion of the total construction cost in Nigeria, with an annual consumption of 77 million tons. To meet her cement needs alone for concrete production, Nigeria requires N142.92 trillion at the current rate of 3,500 naira. In developing countries where there is an abundance of agricultural and industrial waste, most of these wastes can be used as stabilizing material, potential or replacement material in the construction industry because of the level of calcium present in them. This will have the dual benefit of lowering the cost of construction materials while also serving as a means of waste disposal. At this point, the preceding approach is logical, worthy, and attributable [15]. Recycling or utilizing solid waste generated by most Agro-based and manufacturing industries is extremely rewarding. Concerns about massive waste generation, resource preservation, and material costs have heightened interest in solid waste reuse [16]. Material recovery from the conversion of agricultural and industrial wastes into useful materials not only benefits the environment, but it may also help to preserve natural resources. As a result, it is not surprising that research into the effective utilization of various types of solid waste has received increased attention in recent decades. Studies have also shown the recent use of egg shells which are also rich in calcium, as soil stabilizers [4]. Reference [8] investigated how to decide the best percentage of geopolymer to use to boost the compaction parameter of lateritic soil. They discovered that a lateritic soil mix with 15% geopolymer provided the best value of dry density and moisture content of soil with heavy and regular effort. Bone ash is the white, powdery ash that results from the calcination (burning) of bones. Calcium phosphate is the main component. Tricalcium phosphate in the form of hydroxyapatite $Ca_5(OH)(PO_4)_3$ is contained in bone ash. The special cellular structure of bones, which is preserved by calcination, is one of the most significant properties of bone ash. Bone ash is non-wetting, chemically inert, free of organic matter, and has a high heat transfer resistance. Reference [11] investigated the effects of bone ash on soil shear ability. The findings revealed that bone ash played a fascinating role in improving the soil's shear strength. Reference [17] worked on the chemical stabilization of lateritic soils for road construction by looking at a case study of the lateritic soil and the result showed that only 6% lime addition was the most suitable for stabilizing the soil. Previous works done on the use of bone ash for stabilization of lateritic soils were focused on shear strength and consolidation [2]. In view of these, this study looks into the possibility of using cow bone ash (CBA), a calcium-rich material, as a stabilizer by concentrating on the mix proportions of stabilized lateritic and Termitaria soil using cow bone ash (CBA) as a stabilization agent.

2. Materials and Methods

2.1 Materials

The materials used for this research work were lateritic soil, termitaria soil, and cow bone ash. The soil samples used for this research were disturbed samples. The lateritic and termitaria soil samples were collected from within the Campus of the Elizade University Ilara-mokin, Ondo state, Nigeria. The lateritic soil was collected at a depth of about 1.5m below the natural ground level while the termitaria soil taken from the surface. The Cow Bone Ash (CBA) used for this research was obtained from abattoirs and were sun dried in open air and burnt to ash in an electric furnace (Carbolite GPC 12/65) at 750°C for 90 minutes. The clinker was grinded to fine powder and passed through the 150µm sieve.

2.2 Methods

The following tests were carried out on both termitaria and lateritic soil differently and marked as control samples before the addition of cow bone ash at 2%, 4%, 6%, 8%, and 10% respectively to both soil samples. The tests are: moisture content test, particle size distribution, Atterberg limit tests, specific gravity test, compaction test, unconfined compressive strength (UCS) and California bearing ratio (CBR) test. These tests were carried out in accordance with ASTM Standard Methods [18; 19, 20] of testing soil for Civil Engineering purposes.

3. Results and Discussion

3.1 Preliminary test on the soil samples

Engineering properties of the soil samples were determined as summarized in Table 1. The natural moisture content of the soil samples is 13.90% and 22.8%. The specific gravity values are 2.47 and 2.70 for both termitaria and lateritic soil. These values fall within the range of value for clay (2.44 – 2.92) or Kaolin (2.47 – 2.92).

Table 1: Result of tests on termitaria and lateritic Soil (Control Samples)

Result of Tests on Termitaria and Lateritic Soil		
Description of Test	**Termitaria Soil**	**Lateritic Soil**
Natural Moisture Content (%)	13.9	22.8
Specific Gravity	2.47	2.70
Liquid Limit (%)	38.00	30.4
Plastic Limit (%)	22.50	24.2
Plasticity Index (%)	15.50	6.2
Liquidity Index (%)	-55.48	-22.6
Consistency Index (%)	155.48	122.6
Maximum Dry Density (Kg/M^3)	1767.60	1464
Optimum Moisture Content (%)	17.80	25.70
CBR (%) – Unsoaked	18	17
CBR (%) – Soaked	5	5
UCS	133.12	122.90
AASHTO Classification	A-1-b	
UCSC	SW	
Soil Type	Clayey	
Colour	Light Brown	

The Atterberg limit state revealed that the liquid limit (LL) values are 38% and 30.4% respectively for termitaria and lateritic soil while 22.50% and 24.2% were got for plastic limit (PL). The plasticity index (PI) was also determined to be 15.50% and 6.2% for termitaria and lateritic soil. According to the [21], sub-grade or fill material is expected to have a liquid limit value of less than 50% and plasticity index should be equal or less than 30%, while for sub base, liquid limit is expected to be equal or less than 30% and plasticity index should be equal or less than 12%. The two soil samples can be used effectively as sub-grade materials.

3.2 Chemical Analysis of Cow bone Ash (CBA)

The oxides composition of the CBA is given below in Table 2. The addition of percentage of SiO_2 + Fe_2O_3 + Al_2O_3 = 77.42% which is more than 70%. This shows that the CBA met the ASTM standard for a good pozzolan therefore, it can help in the stabilization of lateritic soils as it will act as a cementitious material and ensure hydration reaction with cement.

Table 2: Geochemical analysis result of selected Cow Bone Ash sample

Elemental Oxide	Weight Detected (%)
	Cow Bone Ash sample
SiO_2	49.86
Fe_2O_3	16.14
Al_2O_3	11.42
CaO	9.30
MgO	4.74
SO_3	1.00
K_2O	3.56
Na_2O	2.18
SiO_2 + Fe_2O_3 + Al_2O_3	77.42

3.3 Tests on Termitaria and Lateritic Soils

Results of the soaked and unsoaked California bearing ratio (CBR) for the termitaria and lateritic soils at varying percentages of CBA addition are as shown in Figures 1 and 2. Figure 1 shows that increasing addition of CBA leads to increasing CBR for the soils. The study reveals that the CBR value which is an indication of the strength of the soil use as a subgrade or base course material was higher for the termitaria soil when compared with the lateritic soil. The termitaria soil has peak CBR value of 24.2 at 8% CBA addition while the lateritic soil had peak CBR value of 20.6 at 6% CBA addition. Figure 2 reveals that increasing addition of CBA leads to increasing strength (CBA) of the unsoaked lateritic and termitaria soils. However, the termitaria soils indicate a higher CBR value when compared with the lateritic soils. Peak CBR values for the unsoaked soils was obtained at 8% CBA addition. The termitaria soil had a peak value of 40.2 while the lateritic soil had a peak value of 26.3. The result of this study is in consonance with the findings of [22] that stated that stabilization with industrial wastes could lead to increasing strength of soil due to the addition of Corn Cob Ash (CCA) reducing the plasticity, swell potential and permeability of the soil. These properties of CCA can also be likened to the properties of CBA which then leads to increasing strength and CBR of both the termitaria and lateritic soils. The study of [23] using chicken bone ash states that increasing CBR value could be attributed to the reaction between the high calcium content present in CBA and the fine particles of the soil thereby aiding stabilization. The increasing CBR values of the soil on addition of CBA could also be because of the formation of cementitious compounds between the CBA and calcium compounds present in the soil samples while the decrease may be associated with excess CBA addition beyond the peak CBR values [24]. The increased strength of the termitaria soil when compared with the lateritic soil could be as a result of the termite reworked soils (termitaria soils) having higher dry density, cohesiveness, compatibility, densification, reduced porosity, being a potential stabilizing agent and all these subsequently leads to their increased CBR [25].

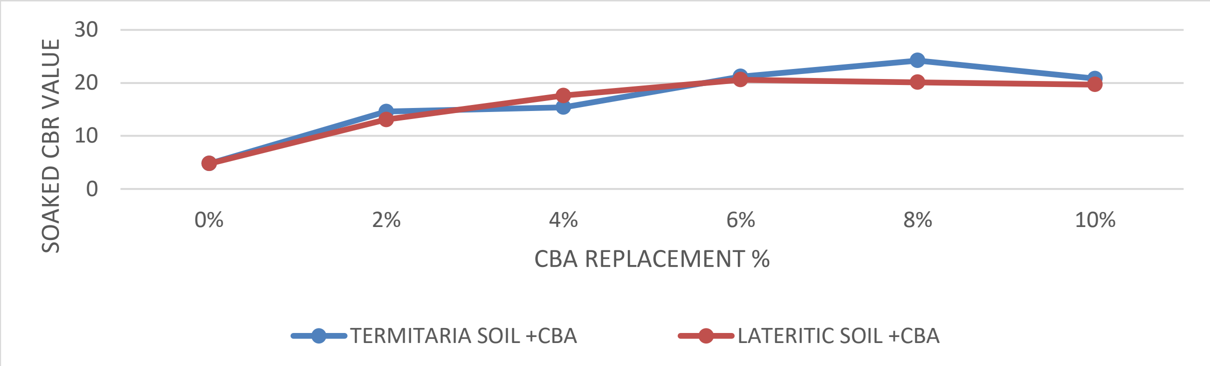

Figure 1: Result of Soaked CBR values for both soils at varying CBA percentage

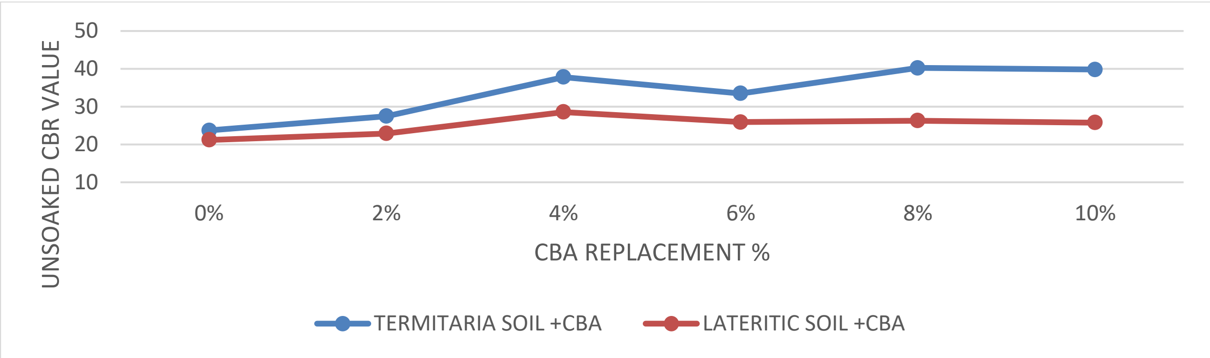

Figure 2: Result of Unsoaked CBR values for both soils at varying CBA percentage

Figure 3 presents the unconfined compressive strength result (UCS). The study reveal that increase in CBA addition leads to increasing UCS values for both the termitaria and lateritic soils. UCS values of 200.7 KN/m^2 and 160.7 KN/m^2 was obtained at 10% CBA addition for the termitaria and lateritic soils respectively. Increase in UCS values of the soils was probably due to the coupled effects of flocculation and agglomeration of CBA together with the neo-formations such as calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) that coat and bind the soil particles to produce strong matrices [26]. According to [27], the increase in the UCS may attributed to the formation of cementitious compounds between the CaOH present in the soil and the pozzolans present in Coconut shell ash (CSA) which is also similar to CBA which is also pozzolanic in nature.

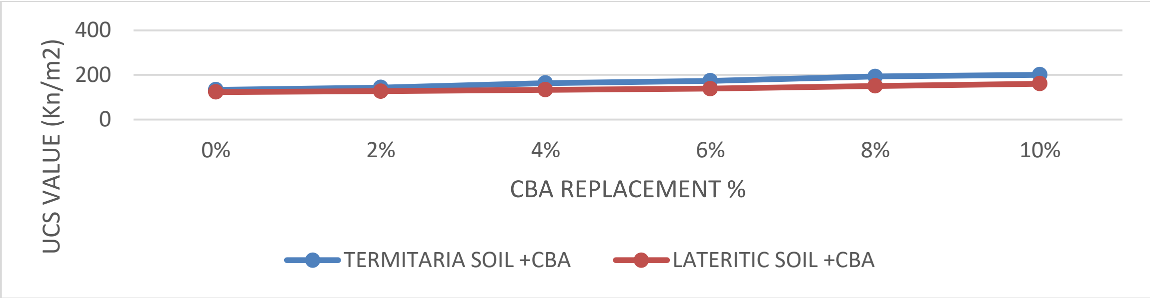

Figure 3: Result of UCS test for both soils at varying CBA percentage

The summary of compaction test results is shown in Table 3. The values for Optimum Moisture Content (OMC) of the termitaria and lateritic samples were got to be 17.80% and 25.70% with Maximum Dry Density (MDD) values of 1767.60kg/m³ and 1464.30 kg/m³ respectively. In termitaria Soil sample, the addition of CBA at 2%, 4%, 6%, 8%, 10% caused a corresponding decrease in the OMC of the soil. The values of the OMC are 16.90%, 15.80%, 15.10%, 14.30% and 14.25% respectively. On the other hand, the addition of CBA in proportion of 2%, 4%, 6%, 8%, 10% to lateritic soil, caused a perpetual increase in the values of the OMC. These values range from 26.20% to 27.60%. The addition of CBA (2%-10%) to both soil samples caused an increase in the values of maximum dry Density (MDD) as follow; 1803.80kg/m³,1845.70 kg/m³, 1870.80 kg/m³, 1904.90 and 1923.20 kg/m³ for termitaria soil while 1470.00 kg/m³, 1600.00 kg/m³, 1633.00 kg/m³, 1727.90 kg/m³ and 1742.50 kg/m³ were recorded for lateritic soil.

Table 3: Summary of OMC with variation of CBA on both termitaria and lateritic soil

	OMC		**MDD**	
CBA Variation (%)	**Termitaria Soil + CBA (%)**	**Lateritic Soil + CBA (%)**	**Termitaria Soil + CBA (kg/m³)**	**Lateritic Soil + CBA (kg/m³)**
0	17.80	25.70	1767.60	1464.30
2	16.90	26.20	1803.80	1470.00
4	15.80	26.60	1845.70	1600.00
6	15.10	26.90	1873.80	1633.00
8	14.30	27.50	1904.90	1727.90
10	14.25	27.60	1923.20	1742.50

The increase in OMC for the lateritic soil is probably due to the additional water held within the flocculent soil structure due to excess water absorbed as a result of the porous property of CBA. The increase in OMC may also be attributed to the addition of CBA reducing the free silt, clay fractions and coarse particle contents which have larger surface area within the soils as revealed in a similar study by [28]. The study agrees with the findings of [25] for the increasing MDD value of the termitaria soil which posit that termitaria soils have increased MDD due to increased cohesiveness within the soil pore structure.

4. Conclusion and Recommendations

The following evidence arose from the interpretation of findings obtained from the implementation of chemical analysis of Cow Bone Ash (CBA), as well as particle size analysis, and Atterberg limits of soils and unconfined compressive strength (UCS). According to the Unified Soil Classification System, soil samples from lateritic and termitaria soils were graded as clay (CL) (USCS). The geotechnical properties of the lateritic and termitaria soils used in this study enabled us to determine the effect of CBA on the California bearing ratio of the soils. For lateritic and termitaria soils, the maximum amount of CBA that would allow for an increase in soaked CBR value was revealed to be 20.6 at 6% and 24.2 at 8%, respectively, whereas unsoaked CBR value was 26.3 and 40.2 both at 8%. The addition of cow bone ash increased the unconfined compressive strength (UCS) of all soil samples. At 10% CBA, UCS values of 200.7 KN/m2 and 160.7 KN/m2 were obtained for termitaria and lateritic soils respectively. Cow bone ash addition at 2%, 4%, 6%, 8%, and 10% with the soil samples, showed that the OMC of termitaria soil was correspondingly reduced while the OMC values of the lateritic soil were constantly increasing. These variations range respectively from 17.80% to 14.25% and from 26.20% to 27.60%. Also, addition of CBA (2%-10%) to both soil samples resulted in an improvement in maximum dry density values (MDD). The study concludes that cow bone ash (CBA) is a good additive in Stabilization of Lateritic and Termitaria soils provided that the 8% additive threshold of CBA is not exceeded.

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