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Bone Ash Impact on Soil Shear Strength

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***Abstract*—**Most failures of soil have been attributed to poor shear strength. Consequently, the present paper investigated the suitability of cattle bone ash as a possible additive to improve the shear strength of soils. Four soil samples were collected and stabilized with prepared bone ash in proportions of 3%, 5%, 7%, 10%, 15% and 20% by dry weight. Chemical analyses of the bone ash; followed by classification, compaction, and triaxial shear tests of the treated soil samples were conducted. Results obtained showed that bone ash contained high proportion of calcium oxide and phosphate. Addition of bone ash to soil samples led to increase in soil shear strengths within the range of 22.40% to 105.18% over the strengths of the respective control tests. Conversely, all samples attained maximum shear strengths at 7% bone ash stabilization. The use of bone ash as an additive will therefore improve the shear strength of soils; however, using bone ash quantities in excess of 7% may not yield ample results.

***Keywords*—**Bone ash, Shear strength, Stabilization, Soil.

I. Introduction

VIRTUALLY every structure is supported by soil or rock. Those not fly either float or fall over [1]. In civil engineering soil is an assemblage of discrete particles in the form of a deposit, usually of mineral composition but sometimes of organic origin, which can be separated by gentle mechanical means and which includes variables amounts of water and air, and sometimes other gases [2]. The engineering behavior of soil is very important because the foundations of all structures have to be placed on or in soil. It is therefore mandatory to understand different soil types and to develop various techniques to improve their properties.

Soil stabilizations are required when a given soil does not have suitable engineering properties to support structures, roads, and foundations. One possibility is to adapt the foundation to the geotechnical conditions at the site. Another possibility is to try to stabilize or improve the engineering properties of the soils at the site. Depending on the circumstances, the latter approach may be the most economical solution to the problem [3]. Therefore, soil stabilization is the physical and chemical alteration of soils to enhance their physical properties. Stabilization can substantially increase the shear strength of a material such that it can be incorporated into structural design calculations. As a matter of fact, the magnitude of soil stabilization is usually measured by the increase in strength [4].

The shear strength of a soil sample is generally defined as its maximum resistance to shearing forces [5]. In as much as most soils can withstand only small tensile stresses or even none at all, significant tension rarely develops in masses of soil. Consequently, most failures of soil take place in shear. Hence, knowledge of the shear strength characteristics of soils is a prerequisite to the solution of many problems in foundation engineering [6].

Over time, various stabilization techniques and materials have been applied to improve the shear strength of soils. The primary methods for improving shear strength today are either mechanical or chemical forms of stabilization. Mechanical stabilization refers to either compaction or the introduction of fibrous and other non-biodegradable reinforcement to the soil. Chemical stabilization, on the other hand, involves the addition of chemicals or other materials to improve the existing soil. 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. Studies have also shown the recent use of egg shells which are also rich in calcium, as soil stabilizers [7]. The present study focuses on the possibility of using bone ash - which is yet material containing calcium - as a stabilizer.

Bone ash is the white material produced by the calcination of bones. It is primarily composed of calcium phosphate. It is commonly used in fertilizers, polishing compounds and in making ceramics such as bone china. It also has historical uses in the manufacture of baking powders and assay cupels [8]. A review of literature revealed that bone ash calcined at a temperature of 1100°C contains the following oxides: CaO (55.25%), P_2O_5 (41.65%), MgO (1.40%), CO_2 (0.43%), SiO_2 (0.09%), FeO (0.08%) and AlO (0.06%). Any application of bone ash in sand and clay stabilization will be governed by the physical and chemical composition of the ash. Although other products of bone such as animal glues have been used for soil stabilization [9], but quantum works have not been published to analyze the use of bone ash as a soil stabilizer which may improve shear strength which is the main focus of this work.

II. Materials and Method

The present study involved soil sample collection from four different locations within the Ibadan metropolis: Akobo, peripherals of Botanical Gardens in the University of Ibadan, Gongola Road (near Awba dam) in the University of Ibadan, and Ojoo. The locations were selected as case-studies to establish the basic effect that bone ash would have on the properties of soil. At each of the four sites, a burrow pit was dug to collect soil samples from at least 1.0m below the ground surface downwards (Table I).

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The bone samples used were obtained in fresh state from the slaughter house at Bodija market in Ibadan. The first step in the preparation of the bone ash involved the burning of the bone samples in open air. The open-air burning was followed by the calcination of the bone samples in a closed furnace at a temperature of 1100°C over a period of about 4 hours. Upon cooling of the furnace-burnt samples, the resulting samples were then milled to fine particle size using a milling machine, and passed through a 75µm sieve aperture to obtain the bone ash required. A pure white mass of bone ash was obtained. The bone ash was then stored properly in sealed storage bags to avoid absorption of moisture prior to laboratory tests. The chemical properties of the bone ash were determined in laboratory using an atomic absorption spectrophotometer (AAS) to know the percentage composition of the elements and thereafter applying conversion factors to calculate the percentage of the oxide of each element.

For the purpose of determining the shear strength of the soil required for geotechnical design and assessing the behavior of soil properties as affected by bone ash, the following laboratory tests were conducted on the samples: particle size analysis, Atterberg limits test, compaction test and triaxial shear strength test. The first stage of the compaction and triaxial shear strength tests involved mixing bone ash with each of the four (4) soil samples in the following percentage proportions: 0% (control test), 3%, 5%, 7%, 10%, 15%, and 20%. This resulted to a total of twenty-eight samples that were tested. The procedures for the various tests were carried out in compliance with the specifications [2].

TABLE I
COORDINATES OF SOIL SAMPLE COLLECTION POINTS

Location	Sample	Coordinates	
		Northing	Easting
Akobo	A	7º27'46.14"	3º56'48.87"
Botanical garden	B	7º27'45.90"	3º53'43.78"
Gongola Road	C	7º26'22.87"	3º53'20.01"
Ojoo	D	7º28'45.79"	3º55'31.54"

III. RESULTS AND DISCUSSION

Results of the conducted chemical analysis are as summarized and presented (Table II). The results of the chemical analysis revealed that the major oxides present in the prepared bone ash samples were CaO (43.53%) and P_2O_5 (38.66%). The result justified the earlier works and gives authenticity to the methodology adopted in preparing the bone ash [10]. The CaO present in the bone ash is capable of reacting with the fine particles of soils to aid stabilization. The P_2O_5 has the potential to act as a binding agent to cement particles of soil together and increase its stability.

The results of the particle size analysis are summarized and presented (Fig. 1). The results of the particle size analysis suggested that soil Samples A and B were sandy in nature. The higher proportion of fines recorded in Samples C and D suggested that these soils were predominantly fine. The results of the Atterberg limits test and the natural moisture content (NMC) determination were summarized and presented (Table II). The soil classification was carried out according to the Unified Soil Classification System (USCS) (Table III).

The results obtained from the Atterberg limits test attested to the fact that Sample C and Sample D had more clay content than Samples A and B, as evidenced by their PI values. Also, the results of the natural moisture content determination revealed that Sample D had the highest natural moisture content and Sample A had the lowest value. The implication is that Sample A probably had the largest void ratio compared to others while Sample D retained water more readily. The compaction test was carried out to determine the optimum moisture content (OMC) and the maximum dry density (MDD) of the samples at both the unstabilized and stabilized states. The results of the compaction tests were recorded and e illustrated pictorially (Figs. 2 and 3) to show the effect of bone ash on OMC and MDD respectively. The optimum moisture contents of the samples decreased between 0% stabilization and the range of 3% - 7% stabilization with bone ash. The values began to increase thereafter.

TABLE II
CHEMICAL ANALYSIS OF BONE ASH

Oxide	Composition (%)
calcium oxide (CaO)	45.53
phosphate (P_2O_5)	38.66
magnesium oxide (MgO)	1.18
silicon oxide (SiO_2)	0.09
iron oxide (Fe_2O_3)	0.1
aluminum oxide (Al_2O_3)	0.06
moisture	0.11
loss on ignition	0.29

The initial decrease in OMC was attributable to the absorption capacity of the bone ash due to its porous properties. The subsequent increase was as a result of the pozzolanic action of bone ash and soil, which needs more water [11]. The lower the OMC, the better the workability of good soils [12]. Therefore, the behavior of the soils between 0% and 7% bone ash stabilization (based on OMC) indicates the improvement of soil properties with the application of an optimum of 7% of bone ash by dry weight. The behavior of the MDD curves for Samples A, B, C and D was quite consistent. It was observed that the MDD curves initially sloped upwards, indicating an increase in MDD with increase in bone ash content. After attaining maximum values at 7% bone ash stabilization, the maximum dry densities of the samples began to drop. The initial increase in the dry densities of the samples indicates improvements in the soil properties and further attested to the enhancement of soil properties with the application of an optimum of 7% of bone ash by dry weight [12].

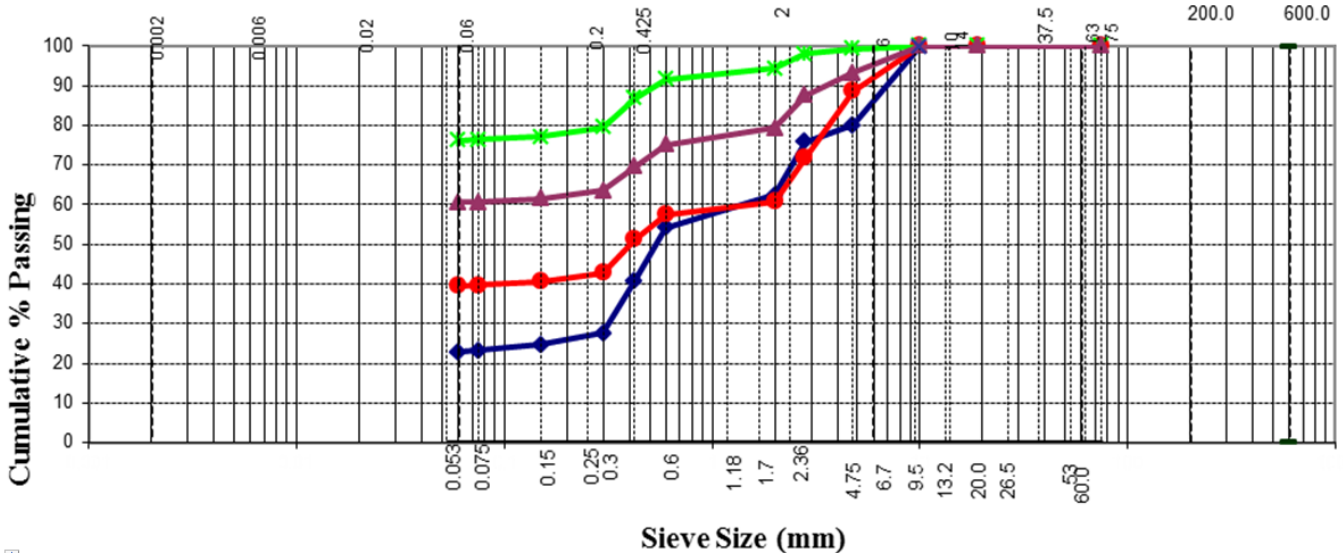
Soil shear strength is considered to be a unique function of cohesion and friction angle in using the Mohr-Coulomb failure criterion [13]. The values of cohesion and angle of friction were obtained from Mohr's circle plots. These values, which were used in computing shear stresses, are fully indicative of the influence of bone ash on shear strength. The cohesion (c) values for all samples were observed to increase from 0%

bone ash stabilization to a maximum at between 5% and 7% stabilization, followed by a decline until a minimum was attained at 20% stabilization (see Fig. 4). On the other hand, curves obtained for the angle of friction do not show any uniform trend as the percentage content of bone ash increases as shown in Fig. 5. However, the plot of computed shear stresses against varying bone ash proportions (Fig. 6) shows that the shear strength of the treated soil samples increased with increase in bone ash content until a peak at 7% was attained and an eventual drop thereafter.

The highest increase in shear strength was recorded with Sample D i.e. 105.18%. The soil classification tests also indicated that Sample D had the highest plasticity index (PI) of 21.46%. On the other hand, Sample B which had the lowest PI of 6.10% also had the lowest increase in shear strength of 22.40% between 0% and 7% stabilization. The relationship between increase in shear strength and PI of the soils is also similar for Samples A and C. This shows that for the present study, bone ash had a more pronounced effect on soils with higher proportion of fines. The behavior of soils with respect to shear stresses is also similar to the behavior of soils with respect to MDD (Fig. 3). As with the MDD behavior, the four samples recorded maximum shear strengths at 7% bone ash stabilization.

TABLE III
ATTERBERGE LIMIT VALUES

	Sample A	Sample B	Sample C	Sample D
Liquid limit (%)	36.42	17.00	44.45	53.59
Plastic limit (%)	20.69	10.90	25.97	32.13
Plasticity index (%)	15.73	6.10	18.48	21.46
Natural moisture content (%)	2.57	2.58	19.67	21.54
USCS Classification	SM-SC	SM-SC	MH	CL



Legend	Sample	Description	Soil Composition		
			Gravel %	Sand %	Fines %
	A	Well graded sand with Silt	24.77	35.59	39.64
	B	Sandy soil with little silt	31.42	45.44	23.14
	C	Very fine silty soil	15.19	24.13	60.68
	D	Very fine clayey soil	4.72	18.89	76.39

Fig. 1 Particle size distribution of soil samples

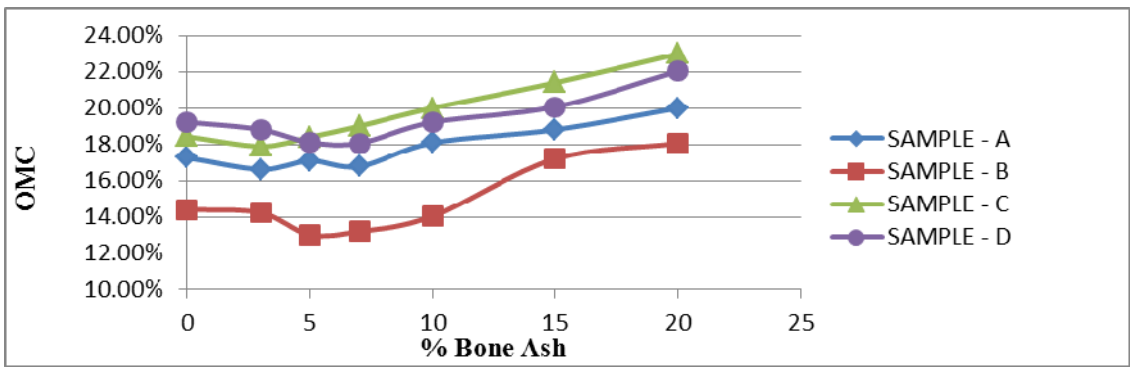


Fig. 2 Effect of bone ash on soil optimum moisture content

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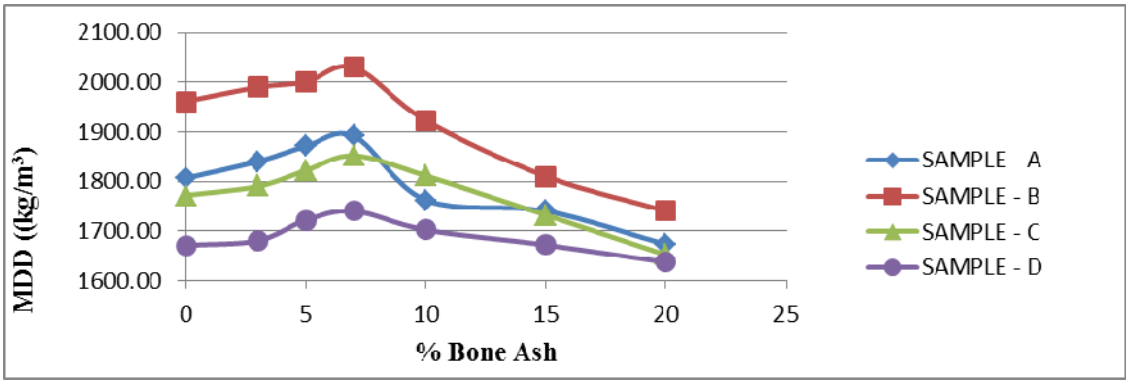


Fig. 3 Effect of bone ash on soil maximum dry density

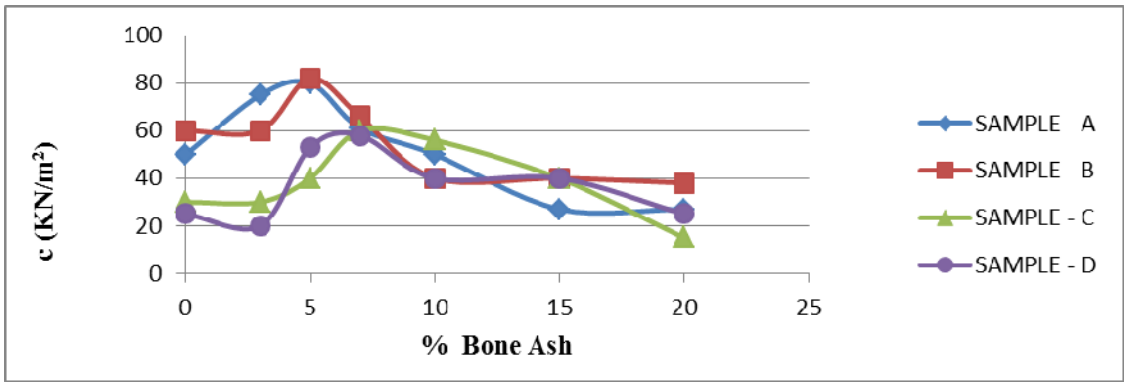


Fig. 4 Effect of bone ash on soil cohesion

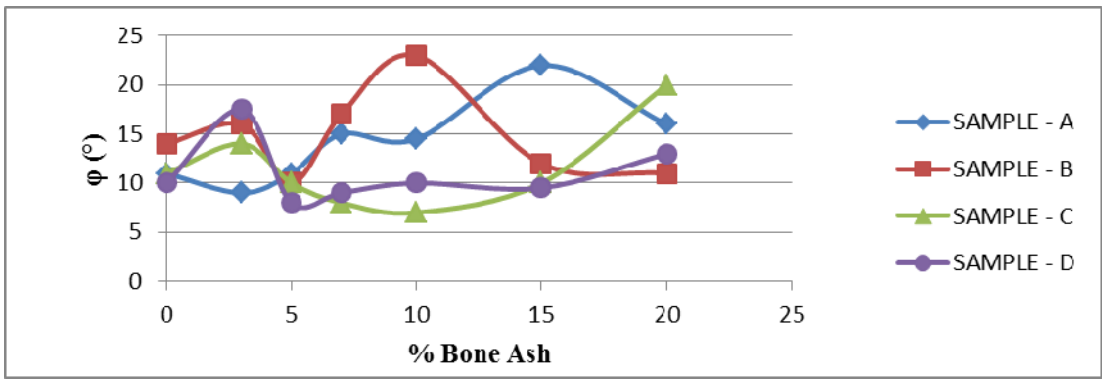


Fig. 5 Effect of bone ash on soil angle of friction

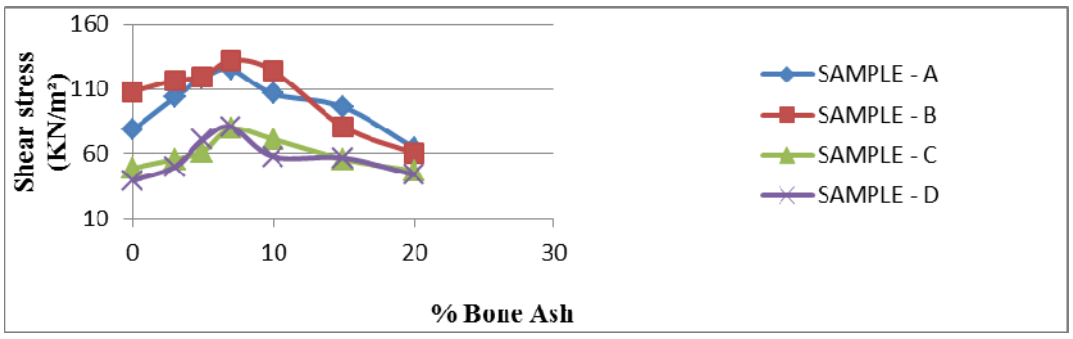


Fig. 6 Effect of bone ash on soil shear stress

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This attests to an overall optimum increase in the strength of the soil when stabilized with bone ash of 7% of soil dry weight. The initial increase in the shear strength is expected because of the gradual formation of cementitious compounds between the calcium hydroxide present in the soil and the pozzolan present in the bone ash [14]. The decrease in the shear strength values after the addition of 7% bone ash is attributable to excess bone ash that occupies spaces within the soil to form weak bonds between the soil and the cementitious compounds formed by reaction, thus having a negative effect on the cohesive nature of the soil.

IV. Conclusion

From the interpretation of results obtained from the implementation of the chemical analysis of bone ash, as well as the particle size analysis, Atterberg limits, compaction and triaxial shear tests on soils, the following facts emerged. Soil samples A and B were identified to be sands (SM-SC), Sample C was categorized as silt (MH) and Sample D was classified as clay (CL) according to the Unified Soil Classification System (USCS). Treatment with bone ash showed that lowest values of OMC were recorded within the range of 3% and 7% stabilization and that optimum MDD values were attained at 7% stabilization with bone ash for all soil samples.

The shear strengths of all the soil samples increased with addition of bone ash (within the range of 22.40% - 105.18% over the strengths of the respective control tests). Conversely, with all four samples, it was observed that the addition of bone ash in quantities above 7% of the soil dry-weight led to a decline in the shear strength values. For the present study, bone ash had a more pronounced effect on soils with higher proportion of fines.

References

[1] R. L. Handy, *The day the house fell*, New York: ASCE Press, 1995
[2] BS 1377, *Methods of test for Soils for civil engineering purposes*, UK: British Standards, 1998.
[3] R. Holtz and W. Kovacs, *An Introduction to geotechnical engineering*, New Jersey: Prentice Hall, 1981.
[4] J. P. Milburn and R. L. Parsons, *Performance of soil stabilization agents*, Report No. K-TRAN: KU-01-8 for Kansas Department of Transportation, 2004.
[5] G.P. Raymond and J. R. Davies, "Triaxial tests on dolomite railroad ballast", *Journal of Geotechnical Engineering*, ASCE, vol. 104, (GT6), pp. 737–751, 1978.
[6] R. B. Hanson and T. H. Thornburn, *Foundation engineering*, New York: John Wiley and sons, 1974.
[7] A.M. King'ori, "A review of the uses of poultry eggshells and shell membranes", *International Journal of Poultry Science*, vol. 10, pp. 908-912, 2011.
[8] Wikipedia, *Bone China*, http://en.wikipedia.org/wiki/Bone_china, 2012.
[9] R. Stulz and K. Mukerji, *Appropriate building materials: a catalogue of potential solution*, Fayetteville, Skat, 1988.
[10] T. Ifka, M. T. Palou and Z. Bazelova, Influence of CaO and P_2O_5 of bone ash upon the reactivity and the burnability of cement raw mixtures, Slovak University, 2011.
[11] G. Sarkar, R. Islam and M. Alamgir, "Interpretation of rice husk ash on geotechnical properties of cohesive soil," *Global Journal of Researches in Engineering, Civil and Structural Engineering*, vol. 12, Issue 2, pp. 1 – 8, 2012.
[12] O. O. Amu, N. T. Basiru and A. A. Coker, "Effects of forage ash as stabilizing agent in lateritic soil for road," *Innovations in Science and Engineering*, pp. 1-8., 2011.
[13] F. Sariosseiri, and B. Muhunthan, "Geotechnical properties of Palouse loess modified with cement kiln dust and Portland cement". *Geocongress*, 2008, pp. 92 – 99.
[14] M. Alhassan, "Potentials of rice husk ash for soil stabilization," *Australian Journal of Technology*, vol. 1, pp. 246-250, 2008.

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