Materials Today: Proceedings 65 (2022) 2228–2235

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Effects of *Gliricidia sepium* ash for stabilization of abattoir polluted soils

Elemile Olugbenga Oluwaseun, Ibitogbe Enoch Mayowa *, Aladegboye Oluwasegun James, Ejigboye Praise Oladapo, Olajide Sunday Opeyemi

Department of Civil Engineering, College of Engineering, Landmark University, Omu-Aran, Nigeria

A R T I C L E I N F O

Article history:
Available online 5 July 2022

Keywords:
Abattoir effluent
Gliricidia sepium ash
Hydration
Soil stabilization

A B S T R A C T

Abattoir effluents, improperly disposed of, can contaminate and cause adverse effects on nearby soils thereby altering their physical and engineering properties. This necessitates the stabilization of these soils. This study aims to determine the effect of *Gliricidia sepium* ash (GSA) on contaminated lateritic soils as a stabilization agent. The GSA was mixed with the soil specimen in different ratios (0%, 2.5%, 5%, 7.5%, and 10%), by the dry weight of the soil sample. Characterization tests were also carried out on the GSA while the test specimens were subjected to various laboratory analyses including particle size distribution, compaction characteristics, California bearing ratio (CBR), unconfined compressive strength (UCS), direct shear and permeability test to determine the soil response to the addition of GSA. The results show there was an overall improvement in the strength properties of the soil specimen. This was achieved at 10% GSA addition, there was also an increase in UCS and CBR by 61.5% and 19.7% respectively. In contrast, the permeability showed a steady decrease with a simultaneous increase in GSA content. This property response to GSA could be attributed to the void filling action of the ash, hydration/cation exchange reaction, and micro-fabric changes. Findings reveal that the strength properties of the GSA-soil mixture (CBR-33%; UCS-837.7KNm2 @ GSA-10%) make it suitable as a sub-base material for lightly trafficked rural roads having met requirements given by the Federal Ministry of Works. X-ray Fluorescence Spectroscopy test carried out shows GSA as pozzolanic material containing proportions of SiO_2, Fe_2O_3, and Al_2O_3 (>70.0 mg/cm^2) which governs its cementitious behavior. A 10% by soil weight of *Gliricidia sepium* ash in ratio 1:1 stabilized lateritic soil could be used as a potential subbase material for highway construction.

1. Introduction

Abattoirs are potential sources of pollution to the environment and ecosystem [1,2]. This form of pollution exists in urban and rural settlements in Nigeria. [3,4] have stressed that anthropogenic activities negatively affect the environment. Preliminary investigation on soil in abattoir impacted environment shows a reduction in the geotechnical properties of the soil [4]. Low-quality soils can have unfavorable structural properties, such as low bearing capacity, swell potential, and high moisture susceptibility. The continuous requirement to expand beef supply to satisfy the protein needs of the population is generally correlated with some pollution consequences [5].

Abattoir acts [6] have defined an abattoir as any place that is dedicated to the slaughter of animals, the meat of which is intended for human consumption comprising a slaughterhouse. And excludes a field location. Abattoir effluent is the waste material left over after slaughtering animals like cattle, sheep, and goats. The effluent contains materials such as the blood, urine, feces, water, and other bodily fluids of slaughtered animals. As a consequence of such emissions, soil fertility and geotechnical properties may suffer as a result of the deposition of such nutrients and heavy metals, which could lead to poor yields in the local agriculture, in addition to the destruction and loss of marine life [7,8]. Many researchers have been interested in studies on the adverse changes in soil properties caused by contamination and the associated soil remediation techniques. The need to stabilize the abattoir effluent infected soil for construction may arise later in the future, and this will give rise to the need to improve the geotechnical property of

* Corresponding author.
E-mail address: ibitogbe.enoch@lmu.edu.ng (E.M. Ibitogbe).

https://doi.org/10.1016/j.matpr.2022.06.264
2214-7853/

the soil. Soil stabilization consists of changing the soil property, if undesired by adopting physical or chemical means tailored to meet its engineering purpose [9,10]. Soil improvement is done either by alteration or stabilization, or both.

Soil modification refers to the addition of modification (cement, lime, etc.) to the soil to change its index properties, whereas soil stabilization refers to the treatment of soils to increase their strength and resilience to the point where they are fully suitable for building beyond their original nature. Cement and lime are the most used soil stabilizing agents for strengthening soils and improving their geotechnical properties. This is because cementitious materials such as C-S-H (calcium silicate hydrate) and C-A-S-H (calcium aluminate-silicate-hydrate) which contains excess $Ca(OH)_2$ are formed when cement undergoes hydration reaction i.e. silicates and aluminates of calcium are react with water [11]. As a result of the effectiveness of Portland cement in treating granular and fine-grained soils, some lateritic soils stabilized with cement have been used as highway pavement layers, earth building materials, and backfill materials. However, this material has risen dramatically in price due to a sharp rise in the cost of energy. The over-dependence on the use of industrially developed soil-improving additives (cement, lime, etc) has kept the cost of constructing stabilized roads economically high [11].

Nonetheless, lime treatment has several drawbacks, including carbonation, sulfate attack, and environmental impact [12]. This has necessitated the search for alternative solutions, such as phytoremediation. Phytoremediation is a bioremediation technique that uses different species of plants to extract, pass, stabilize and/or destroy soil and groundwater pollutants [13,14]. An example of such a plant is Rice Husk Ash (RHA). It has several benefits, including increased strength and toughness, lower manufacturing costs due to cement savings, and environmental benefits [16].

[15] looked into the use of ceramic waste dust (CWD) for laterite soil stabilization. Their findings show that moisture content decreased consistently as ceramic dust was added incrementally up to 30%, whereas maximum dry density and California bearing ratio increased from 59.62% to 35.61%. [18] examined treating lateritic soil with cement and oil palm fruit bunch ash (OPFBA) blend in a stepwise level of 0, 2, 4, 6, and 8% cement and OPFBA, simultaneously. The results demonstrate that the CBR values met the 80% minimum for basic course materials, with the added benefit of using palm oil mill waste, which is good for the environment.

Gliricidia sepium also known as '***Agumaniye***' is a fast-growing tree with the ability to distribute seeds 40 m away from the parent tree. It is commonly used as wood for fuel, shade construction, green manure, and live fencing. Nonetheless, it is an aggressive and rapidly growing plant that is characteristic of an invasive species and capable of colonizing secondary forests as well as outgrowing other crops [19]. Hence, it may be beneficial to find alternative uses for instance as a stabilizer. Little has been documented about incorporating the use of *Gliricidia sepium* ash as a binder agent for soil stabilization. In this study, the use of *gliricidia sepium*, a locally available plant was investigated as a stabilizing agent for laterite soils affected by abattoir effluent.

2. Materials and methods

2.1. Sample preparation

Clay soil samples used in this study were located in Ilorin, Kwara (latitude 8°08′N and longitude 5°06′E). These samples were obtained from three different locations surrounding a major abattoir popularly known as "Dr. Saraki Abattoir" and transported to the laboratory where they were air-dried and kept for quantitative and qualitative analysis. The soils were collected on a market day when the abattoir was active. The soil can be classified as Clay-Silt according to the Unified Soil Classification System (USCS). A summary of the geotechnical properties of the samples is given in Table 1.

2.2. Gliricidia sepium ash

Gliricidia sepium also known locally as "*Agumaniye*" was obtained locally from Omu-Aran. It was collected, air-dried, and ashed in the furnace situated in the Chemical Engineering Laboratory, Landmark University. The *Gliricidia sepium* ash (GSA) is the residue obtained that served as the modifier for the proposed research. The GSA was sieved through a BS sieve (63 µm) to obtain the fraction needed for ash–clay reaction. Characterization tests were done on GSA.

3. Experimental procedure

GSA, a soil modifier, was added to the soil sample in various proportions (0, 2.5, 5, 7.5, and 10) % of the entire mass of the soil sample. The GSA-soil mixture was then mixed manually in a large tray using a hand trowel at dry state conditions with proper care to allow for a uniform mix as described in Table 2. After which a series of laboratory tests were conducted on the soil sample in natural and modified (mixed with GSA). Particle size distribution, compaction, California bearing ratio (CBR), unconfined compressive strength (UCS), direct shear test, and permeability test on unmodified and GSA-modified soils. These procedures are outlined below.

3.1. Compaction test

Compaction tests were done for soil samples (untreated and GSA-modified) at varying percentages to assess the moisture–density relationship of the soil using the British Standard Light (BSL). In a standard mould (1000 cm^3), the soil samples were compacted in three layers while the water content was varied with standard compaction energy by ASTM D698 (2003) [17]. This was repeated sufficiently until a relationship (compaction curve) is established for density and moisture content. The curve shows the optimum moisture content at maximum dry density. Compaction testing is significant in the design of engineering landfills and is required before CBR, permeability, and shear strength tests.

3.2. Strength test

3.2.1. California bearing ratio, CBR

The test was performed according to BS 1924 [20] modified to suit the Nigerian tropical conditions. The preparation of samples was according to the OMC and MDD that were determined from the compaction experiment. Specimens were cured for 6 days and subsequently soaked for 24 h before testing.

3.2.2. Unconfined compressive strength, UCS

Most experimental programs used unconfined compressive strength tests to verify the effectiveness of the treated soil. The dry density and moisture content obtained were used to prepare UCS test samples. These samples were made in a split mould with a constant volume of dimensions 38.1 mm × 76.2 mm according to ASTM D-2166 [21].

3.2.3. Direct shear strength

Shear strength is the maximum resistance to shearing stresses. Its parameters (c and φ) were determined by the direct shear test (ASTM D 3080) [22]. The shear strength is expressed as.

Table 1
Characteristics of Soil Samples.

Property	Sample A	Sample B	Sample C	Standard soil
Specific gravity	2.54	2.53	2.59	2.65–2.80
Maximum dry density kg/m^3	2024.6	1832.0	1707.1	1380
Optimum moisture content (%)	9.6	20.4	18.8	16
California bearing ratio	18.16	9.64	12.05	10
Cohesion KN/m^2	25	32	46	20
The angle of friction (^{0})	19	15	17	30

Table 2
Combination Matrix of Soil Samples.

Sample	Soil (grams)	GSA (grams)	GSA (%)
Untreated	3000	–	0
T1	3000	75	2.5
T2	3000	150	5
T3	3000	225	7.5
T4	3000	300	10

$$S = c + \sigma \tan \Phi \quad (1)$$

where S is the shear strength; σ depicts effective stress; c is the cohesion parameter of the specimen, and Φ is the angle of internal friction.

3.2.4. Permeability test (Falling head)

Permeability was carried out using a falling head apparatus setup.

$$K = \frac{aL}{At} In \frac{h_1}{h_2} \quad (2)$$

where a = area of the stand pipe's cross-section; A = cross-sectional area of the soil sample; h_1 = Hydraulic head across the sample at the beginning of the test; h_2 = Hydraulic head across the sample at the end of the test; L = Length of the soil sample.

4. Results and discussion

4.1. Characterization test for Gliricidia sepium

4.1.1. Scanning Electron Microscope (SEM)

Morphology of *Gliricidia sepium ash* was carried out using scanning electron microscopy as shown in Fig. 1. The high affinity to water was seen in the clustering of the ash.

4.1.2. Energy Dispersive X-Ray Analysis (EDX) analysis of the soil

The mineral constituent of the *Gliricidia* sepium ash obtained from the EDX analysis (Table 3) shows potassium as the highest elemental composition of 49.12% by weight of the ash. The oxygen content in it was seen to be less than half of the potassium content.

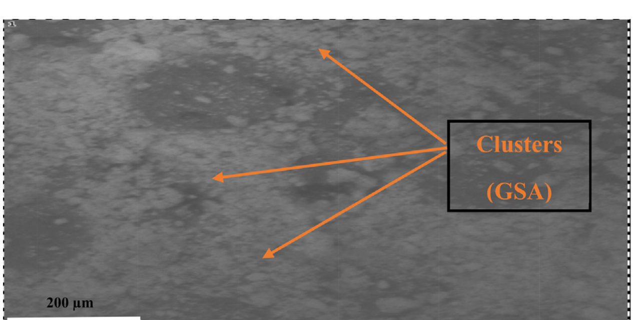

Fig. 1. Image of GSA.

4.1.3. X-Ray Diffractometer (XRD) analysis of the soil

The mineralogy composition of the *Gliricidia* sepium ash (GSA) shown in a pie chart in Fig. 2, revealed the prominence of hydroxylherdite and gphirgeyite at 32% and 36% respectively. A very small fraction of limenite was noticed which was 4.3%.

4.1.4. X-ray Spectroscopy (XRF) analysis of the soil

As shown in Fig. 3, the elemental composition analysis of *Gliricidia sepium* ash (GSA) using the XRF analysis highlights the major and trace elements. Findings reveal that the concentration of silica (SiO_2) iron (Fe_2O_3) and alumina (Al_2O_3) was 24.62, 23.63, and 26.50 mg/cm^2 respectively. Thus, it can be considered a material possessing pozzolanic properties (74.76 mg/cm^2). According to [23], materials are considered pozzolanic when they contain as much as 70 % of silicates, aluminates, and oxides of certain metals.

4.1.5. Sieve analysis

Grain size distribution analysis was investigated on the original soil sample collected following BS1377: Part 2 [24] procedures and summarized in Fig. 4. The percentage retained from the highest sieve to the lowest is 22.2% and 2.6% for sample A, 20.0% and 3.8% for B, and 18.9% and 5.2% for C. According to the Unified Soil Classification System (USCS), the soil is classified as Silt-Clay (CL-ML).

4.1.6. Compaction

The influence of varying amounts of GSA content on the maximum dry density (MDD) and optimum moisture content (OMC) of the abattoir lateritic soil was studied as displayed in Fig. 5. MDD shows a decreasing trend and vice versa for OMC which increased upon the addition of GSA to the soil. As the stabilizing agent increased from 0% to 10%, MDD values decreased from 1854.6 kN/m^3 to 1721.3 kN//m^3. This finding is consistent with [25]. The behavior is attributable to the void-filling action of the GSA particles. Since it is relatively lighter compared to the soil, there is a corresponding difference in the overall density of the mixture [25,26]. The OMC values increased from 16.2% to 18.5% at 7.5% GSA addition and only decreased slightly at 10% GSA addition.

The increase in optimum moisture content (OMC) could be due to a higher demand for water due to the higher amount of GSA required for the cation exchange reaction which involves hydration (formation of the lime-like product $Ca(OH)_2$) and dissolution (product is split into Ca^{2+} and OH^- ions giving rise to more Ca^{2+}) [27]. Another reason for the surge in water demand is an increase in the surface area of the mixture. The benefit of having a soil with increased OMC and a decrease in MDD with corresponding addition of modifier (GSA), is the ease of compaction of such soil on the field even in moist conditions [28]. At 7.5 % GSA, the MDD was found to be at its lowest and OMC, at its highest for that same percentage addition.

4.1.7. Direct shear

Fig. 6 shows the results of the direct shear strength tests. The addition of GSA increases the cohesion and internal friction angle

Table 3
Results of the EDX.

Element number	Element Symbol	Elements Name	Atomic Conc.	Weight Conc.
19	K	Potassium	37.77	49.12
8	O	Oxygen	29.97	15.95
20	Ca	Calcium	6.58	8.78
17	Cl	Chlorine	2.99	3.53
6	C	Carbon	7.03	2.81
12	Mg	Magnesium	3.25	2.63
15	P	Phosphorus	2.50	2.58
16	S	Sulfur	1.65	1.76
39	Y	Yttrium	0.56	1.66
41	Nb	Niobium	0.53	1.63
46	Pd	Palladium	0.44	1.54
14	Si	Silicon	1.43	1.34
13	Al	Aluminum	1.46	1.31
22	Ti	Titanium	0.75	1.19
47	Ag	Silver	0.28	0.99
26	Fe	Iron	0.51	0.94
25	Mn	Manganese	0.50	0.91
23	V	Vanadium	0.28	0.48
7	N	Nitrogen	0.99	0.46
11	Na	Sodium	0.52	0.39

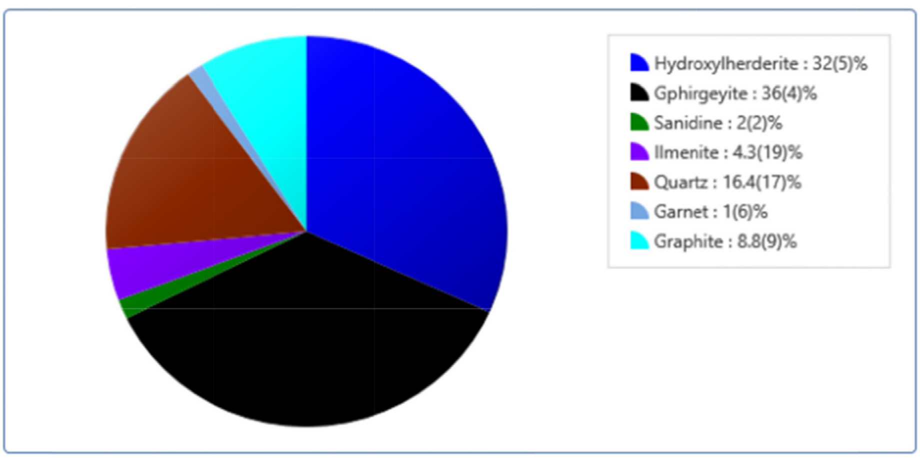

Fig. 2. X-ray diffractometer of GSA.

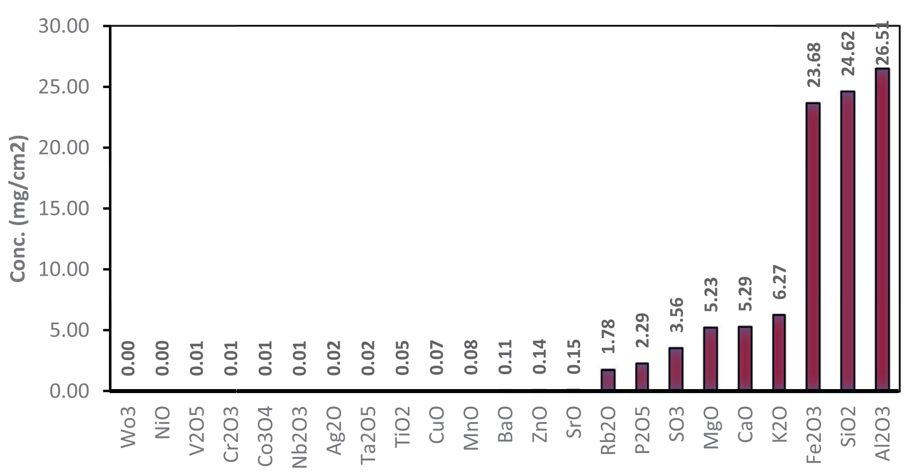

Fig. 3. Concentration of elements in GSA.

parameters of the soil. This is evidence of the cementation process (resulting from the pozzolanic reaction) that takes place in the soil. Firstly, an initial increase in cohesion for GSA addition (2.5%) is observed before decreasing. The internal friction angle also followed a similar pattern peaking at 2.5 % GSA before a decline. This result is in agreement with [29]. Although both parameters are

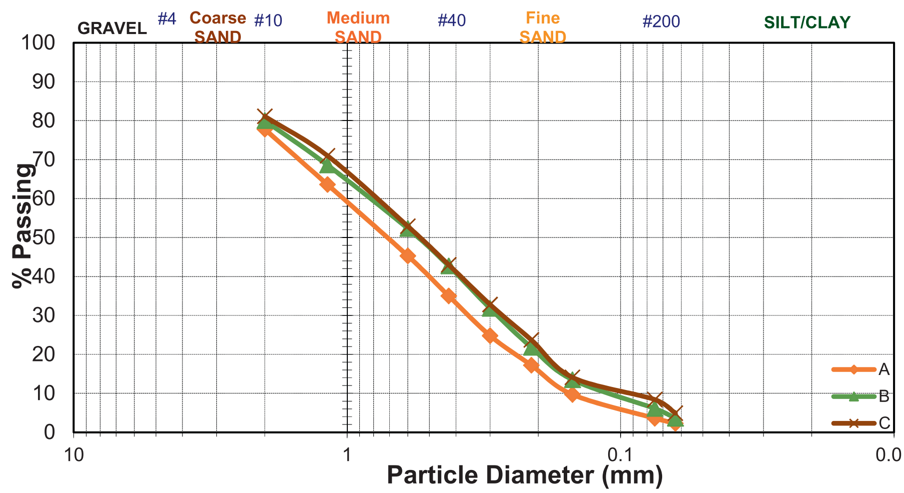

Fig. 4. Comparison of particle size distribution of soil samples A, B and C.

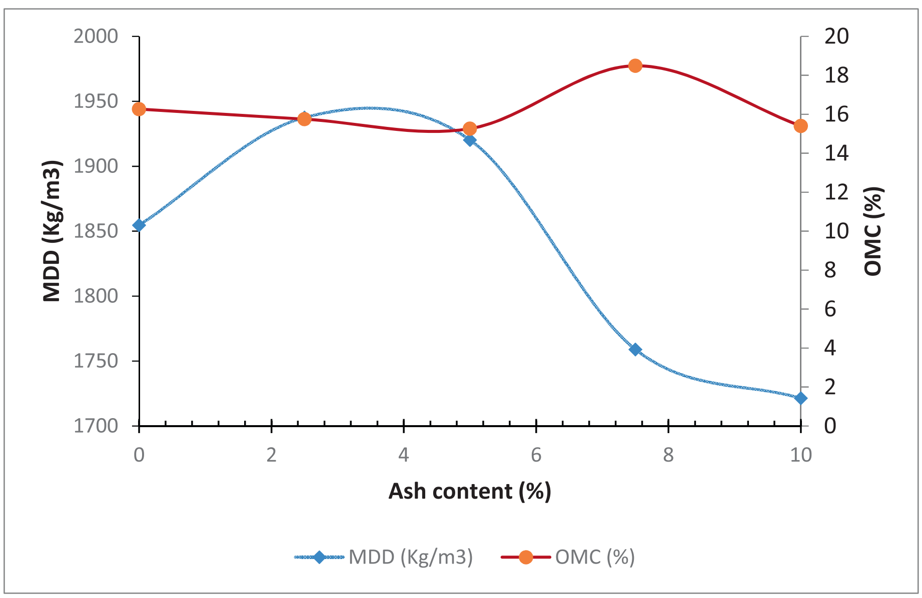

Fig. 5. Maximum dry density (MDD) and optimum moisture content (OMC) variations with modifier content.

very significant, under a large confining load, internal friction becomes the most important determining factor of shear strength, while cohesion becomes less important according to Coulomb's law. This finding infers that GSA can be a useful component to prevent soil shear failure [21].

4.1.8. Unconfined compressive strength test

The unconfined compressive strength (UCS) test was used as a more accurate indicator to measure the effect of the additives on the improvement of the soil. Thus, the influence of GSA on the strength behavior of abattoir soil was determined via UCS. Fig. 7 represents the variation of UCS with the inclusion GSA modifier. The results show that the natural soil sample has a relatively high UCS of 518.7 KPa. Our findings reveal that a gradual increase in the mixture's strength corresponded simultaneously to an increase in stabilizing agent content. Therefore, a 61.5% increase in the UCS was achieved at 10% GSA content up to 837.7 KPa. Significant improvement was also reported for UCS concerning the ash content [21]. The reaction between active pozzolana present in GSA and SiO_2 with Al_2O_3 present in the soil might be responsible for the strength increase. [30] also suggested the growth in strength could be attributed to the optimal moisture content and maximum unit weight variation of the sample. The peak UCS value (837.7 kN/m^2) meets requirements given by the Federal Ministry of Works (750–1500 kN/m^2), being suitable as a sub-base material for lightly trafficked rural roads. The authors observed a different interaction between MDD and UCS values in relation to the inclusion of the GSA. The behaviour of the former could be a result of substituting the soil sample with a material of lower specific gravity (ash) which inevitably decreases the density of the mixture. In the case of UCS, the mixture had undergone a hydration reaction resulting from the pozzolanic materials after curing which aided the solidification of the matrix. Moreover, [33] reported a reduction in MDD values (from 1.85 mg/m^3 to 1.55 mg/m^3) with a respective increase in rice husk ash (RHA) content while an increase in UCS was equally noted (from 100.57kN/m^2 to 696.63kN/m^2) for the same

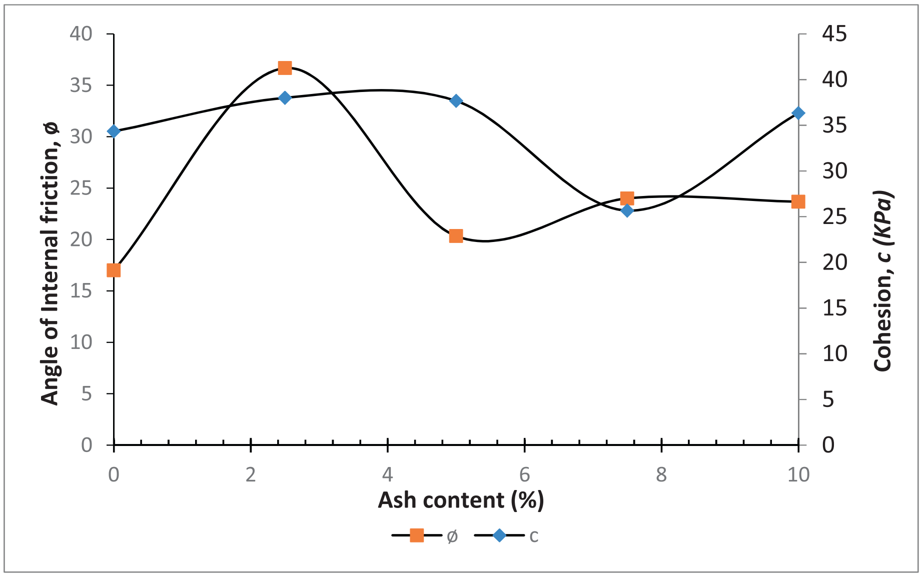

Fig. 6. Relationship between direct shear parameters and modifier content.

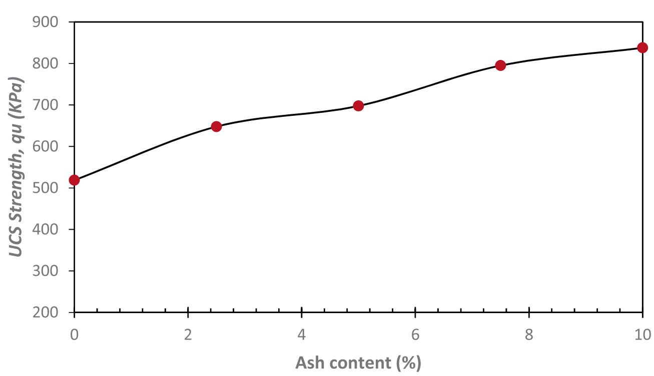

Fig. 7. UCS values (q_u) with respect to the increase in modifier.

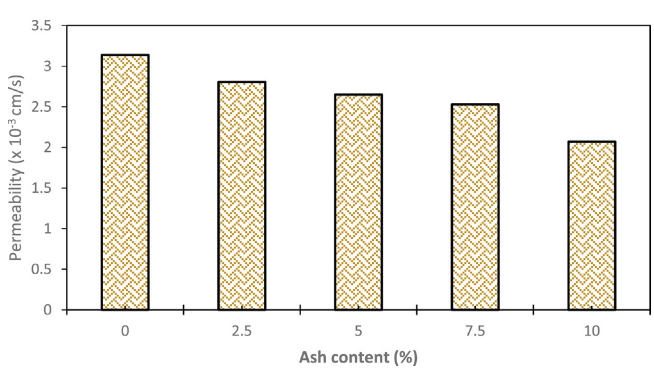

Fig. 8. Relationship between CBR and the increase in modifier.

increase in RHA. Similarly, [32] also observed a reduction in MDD values (from 17.5 mg/m^3 to 12.8 mg/m^3) with a respective increase in milled egg shell (MES) content while an increase in UCS was equally noted (from 227.8 kN/m^2 to 345.3 kN/m^2 @ 7 days and 1011.9 kN/m^2 @ 28 days) for the same increase in MES.

4.2. California bearing ratios

The CBR test is seen as reliable and as such is used to determine the strength of sub-grade materials and the required thickness of pavement to satisfy a specific load capacity. The results of the CBR test on the various soil-GSA mix are shown in Fig. 8. It shows an appreciable increase in the CBR values with the addition of ash content. This upward trend can be a result of the pozzolanic nature which is an inherent property that GSA possesses (SiO_2 – 24.62%, Fe_2O_3 – 23.68%, and Al_2O_3 – 26.50%). [31] credited this behaviour to the presence of cementitious compounds (CSH and CAH), which are major compounds responsible for strength gain. The highest CBR value of all samples tested was 33% obtained at 10% GSA. This value meets the requirements for subbase (soaked; 30% minimum) and subgrade (soaked; 10% minimum) materials as specified by the Nigerian General Specifications for highways.

4.2.1. Permeability

Permeability is an important soil parameter in any project that involves the flow of water through the soil. The test result (Fig. 9) shows the relationship between the soil grains and voids volume concerning the percentage of GSA content added progressively. It can be observed that an increase in the percentage of GSA content will lower the permeability with the highest value of permeability gotten at 3.21×10^{-3} cm/s at 0% GSA to the lowest value of 2.07×10^{-3} cm/s at 10% GSA. The reduction in the permeability coefficient can be caused by the stabilizing binder's effect on reducing the void ratio of the sample [30]. Calcium ions are released in alkaline conditions which react with silica or alumina or both causing flow restrictions through the soil voids [26].

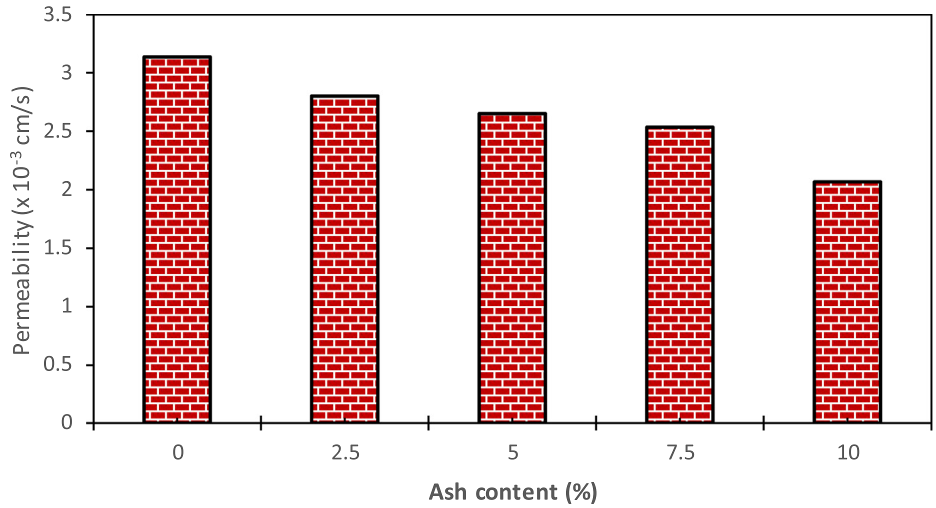

Fig. 9. Relationship between permeability and the increase in modifier.

5. Conclusions

This study showed the effect of *Gliricidia sepium ash* on the fundamental geotechnical properties of abattoir polluted soils including soil classification, compaction, and strength test. The following conclusion was made based on the above-mentioned analysis. The lateritic soil can be classified as Silt-Clay according to the Unified Soil Classification System (USCS). Characterization test reveals GSA ash consists of compounds (SiO_2 + Al_2O_3 + Fe_2O_3 > 70.0 mg/cm^2) sufficient to meet the requirement of ASTM C 618 as a natural pozzolanic material. The compaction test results showed that with an increase in the quantity of the stabilizing binder there is a subsequent decrease in the maximum dry density of the soil and an increase in the optimum moisture content of the soil. As per the strength test, we observed a gradual increase in the strength of the matrix corresponding to a simultaneous increase in stabilizing agent content. An overall 61.5% increase was achieved for UCS at 10% GSA content up to 837.7 KPa. The reaction between active pozzolana present in GSA and SiO_2 with Al_2O_3 present in the soil might be responsible for the strength increase. This improvement makes it useful as a suitable sub-base material as it meets requirements given by the Federal Ministry of Works for lightly trafficked rural roads.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors are immensely thankful for the community's support and collaborative effort in carrying out this research, as well as the management of Landmark University for providing a platform for doing research.

References

[1] M.K. Simon, O.C. Jegede, W.D. Nafarnda, Seasonal influence on Haemonchus contortus infection and response to treatment with albendazole in Yankasa lambs, Adv. Appl. Sci. Res. 3 (4) (2012) 2243–2246.
[2] O.O. Elemile, D.O. Raphael, D.O. Omole, E.O. Oloruntoba, E.O. Ajayi, N.A. Ohwavborua, Assessment of the impact of abattoir effluent on the quality of groundwater in a residential area of Omu-Aran, Nigeria, Environ. Sci. Eur. 31 (1) (2019) 1–10.
[3] O.O. Elemile, E.M. Ibitogbe, O.P. Folorunso, P.O. Ejiboye, J.R. Adewumi, Principal component analysis of groundwater sources pollution in Omu-Aran Community, Nigeria, Environ. Earth Sci. 80 (20) (2021) 1–16.
[4] O.O. Elemile, O.D. Raphael, D.O. Omole, O.E. Oluwatuyi, E.O. Ajayi, O. Umukoro, M.G. Elemile, Assessment of the impact of abattoir activities on the physicochemical properties of soils within a residential area of Omu-Aran, Nigeria, IOP Conference Series: Materials Science and Engineering, Vol. 640, No. 1, IOP Publishing, 2019, p. 012083.
[5] M. Henchion, M. Hayes, A.M. Mullen, M. Fenelon, B. Tiwari, Future protein supply and demand: strategies and factors influencing a sustainable equilibrium, Foods 6 (7) (2017) 53.
[6] Act, A. Local Government (Ireland) Water Pollution Act. Statutory Instrument, (258), 1988.
[7] A.B. Rabah, S.B. Oyeleke, S.B. Manga, L.G. Hassan, U.J.J. Ijah, Microbiological And Physico-chemical Assessment Of Soil Contaminated With Abattoir Effluents In Sokoto Metropolis, Nigeria, Sci. World J. 5 (3) (2010).
[8] J.Y. Magaji, C.D. Chup, The effects of abattoir waste on water quality in Gwagwalada-Abuja, Nigeria, Ethiopian J. Environ. Stud. Manage. 5 (4) (2012) 542–549.
[9] B.M. Bolker, M.E. Brooks, C.J. Clark, S.W. Geange, J.R. Poulsen, M.H.H. Stevens, J.-S. White, Generalized linear mixed models: a practical guide for ecology and evolution, Trends Ecol. Evol. 24 (3) (2009) 127–135.
[10] D. Toksöz Hozatlıoğlu, I. Yılmaz, Shallow mixing and column performances of lime, fly ash, and gypsum on the stabilization of swelling soils, Eng. Geol. 280 (2021) 105931, https://doi.org/10.1016/j.enggeo.2020.105931.
[11] R.K. Etim, D.U. Ekpo, Attah, I.C. Mik, K.C. Onyelowe, Effect of micro sized quarry dust particle on the compaction and strength properties of cement stabilized lateritic soil, Cleaner Mater. 2 (2021) 100023.
[12] B.S. Kumar, T.V. Preethi, Behavior of clayey soil stabilized with rice husk ash & lime, Int. J. Eng. Trends Technol. 11 (1) (2014) 44–48.
[13] I.T. Jawad, M.R. Taha, Z.H. Majeed, T.A. Khan, Soil stabilization using lime: Advantages, disadvantages, and proposing a potential alternative, Res. J. Appl. Sci. Eng. Technol. 8 (4) (2014) 510–520.
[14] P. Agamuthu, O.P. Abioye, A.A. Aziz, Phytoremediation of soil contaminated with used lubricating oil using Jatropha curcas, J. Hazard. Mater. 179 (1-3) (2010) 891–894.
[15] O. Onakunle, D.O. Omole, A.S. Ogbiye, A.K. Choudhary, Stabilization of lateritic soil from Agbara Nigeria with ceramic waste dust, Cogent Eng. 6 (1) (2019), https://doi.org/10.1080/23311916.2019.1710087.
[16] H. Chao-Lung, B.L. Anh-Tuan, C. Chun-Tsun, Effect of rice husk ash on the strength and durability characteristics of concrete, Constr. Build. Mater. 25 (9) (2011) 3768–3772.
[17] ASTM D698, Standard practice for laboratory compaction characteristics of soil using standard effort (12 400 ft-lbf/ft3 (600 kN-m/m3)). Book of Standards 04.08, 2003.
[18] O.O. Komolafe, K.J. Osinubi, Stabilization of lateritic soil with cement–oil palm empty fruit bunch ash blend for California bearing ratio base course requirement, IOP Conference Series: Materials Science and Engineering, Vol. 640, No. 1, IOP Publishing, 2019, p. 012085.
[19] J.M. Suttie, Gliricidia sepium (Jacq.). SKERMAN, PJ, CAMERON, DG; RIVEROS, F. Tropical forage legumes, 2, 2015.
[20] BSI, BS 1924: 1990: Methods of test for stabilized soils, 1990.
[21] ASTM D2166, A, Standard test method for unconfined compressive strength of cohesive soil, 2016.
[22] OAK, S. DIRECT SHEAR TEST (ASTM D3080).
[23] B.D. Nath, G. Sarkar, S. Siddiqua, M.d. Rokunuzzaman, M.R. Islam, Geotechnical Properties of Wood Ash-Based Composite Fine-Grained Soil, Adv. Civ. Eng. 2018 (2018) 1–7.

[24] British Standards Institution. BSI, BS 1377: Part 2: 1990: Methods of Test for Soils for Civil Engineering Purposes. British Standards Institution, 1990.
[25] H.M. Nadir, A. Ahmed, Comparative Evaluation of Potential Impacts of Agricultural and Industrial Waste Pozzolanic Binders on Strengths of Concrete, SRC/JMSMR-123. J. Mater. Sci. Manuf. Res. (2021) 1–8, https://doi.org/10.47363/JMSMR/10.47363/JMSMR/2021(2)119.
[26] M. Alhassan, Permeability of lateritic soil treated with lime and rice husk ash, Assumption Univ. J. Thailand 12 (2) (2008) 115–120.
[27] J.A. Sadeeq, J. Ochepo, A.B. Salahudeen, S.T. Tijjani, Effect of bagasse ash on lime stabilized lateritic soil, Jordan J. Civ. Eng. 9 (2) (2015).
[28] K.J. Osinubi, V. Bafyau, A.O. Eberemu, Bagasse ash stabilization of lateritic soil, in: Appropriate technologies for environmental protection in the developing world, Springer, Dordrecht, 2009, pp. 271–280.
[29] A.J. Choobbasti, H. Ghodrat, M.J. Vahdatirad, S. Firouzian, A. Barari, M. Torabi, A. Bagherian, Influence of using rice husk ash in soil stabilization method with lime, Front Earth Sci. China 4 (4) (2010) 471–480.
[30] O.E. Oluwatuyi, O.O. Ojuri, A. Khoshghalb, Cement-lime stabilization of crude oil contaminated kaolin clay, J. Rock Mech. Geotech. Eng. 12 (1) (2020) 160–167.
[31] A.A. Amadi, A. Okeiyi, Use of quick and hydrated lime in the stabilization of lateritic soil: a comparative analysis of laboratory data, Int. J. Geo-Eng. 8 (1) (2017) 1–13.
[32] O.E. Oluwatuyi, B.O. Adeola, E.A. Alhassan, E.S. Nnochiri, A.E. Modupe, O.O. Elemile, T. Obayanju, G. Akerele, Ameliorating effect of milled eggshell on cement stabilized lateritic soil for highway construction, Case Stud. Constr. Mater. 9 (2018) e00191, https://doi.org/10.1016/j.cscm.2018.e00191.
[33] J.E. Sani, P. Yohanna, I.A. Chukwujama, Effect of rice husk ash admixed with treated sisal fibre on properties of lateritic soil as a road construction material, J. King Saud Univ. Eng. Sci. 32 (1) (2020) 11–18.