Journal of Inventive Engineering and Technology (JIET)
ISSN: 2705-3865
Volume-2, Issue-3, pp-1-10
www.jiengtech.com
Research Paper Open Access

IMPROVEMENTS OF THE GEOTECHNICAL PROPERTIES OF SUBGRADE SOIL USING LIMESTONE DUST

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ABSTRACT :*The cost of improving the geotechnical properties of road subgrade in the Niger Delta using traditional chemical stabilizers such as Portland cement is partly responsible for the poor development of road network in the region. Lime stone dust (LSD), a by-product of the limestone crushing processes has not been fully utilized as a soil stabilizer in Nigeria. In this study, LSD was employed as a stabilizer to improve the geotechnical properties of Calabar South subgrade soil. The soil was stabilized by adding LSD at 0%, 5%, 10%, 15%, 25%, and 50% by weight of soil. Test conducted include, Atterberg Limits and indices, particle size distribution, specific gravity, compaction, California bearing ratio, unconfined compressive strength (UCS) and Shear strength. The subgrade was classified as inorganic clay with low plasticity under the Unified Soil Classification System and A-6 soil under the AASHTO classification. The specific gravity was 2.73 with a maximum dry density of 1.74 kg/m3 at an optimum moisture content of 24.5%. The soaked value of the California bearing ratio (CBR) was 6.92%. Atterberg Limits and indices were improved by a reduction in the plasticity of the soil. Compaction characteristics showed improvement by 11.5% as MDD increased from 1.74kg/m3 to 1.94kg/m3 at 10% optimal LSD level with a corresponding reduction in OMC. CBR increased by 75.86% from 6.92% to 12.12% while unconfined compressive strength (UCS) increased by 28.2% from 103.66KN/m2 to 132.89KN/m2. Shear strength increased by 24.1% from 58.83KN/m2 to 72.31KN/m2. The soil stiffness also improved with the addition of LSD as Secant modulus increased with stabilizer content. It was concluded that limestone dust is a good sustainable stabilizer to the soil.*

KEYWORDS *Soil stabilization, limestone dust, Atterberg Limits, Maximum Dry Density, California Bearing Ratio*

Date of Submission: 21-10-2022 Date of acceptance: 02-11-2022

I. INTRODUCTION

Soils are usually stabilized to improve their strength and durability, as well as to minimize erodibility of soil. The fundamental goal is to create a soil material or system that will stand up under design use conditions and during the engineering project's intended life (Arpan and Rishabh, 2012). Stabilization improves its index qualities and strength characteristics so that they can be used for building indefinitely and match engineering design specifications Salahudeen and Akiije (2014). Chemical stabilization entails combining industrial by-products, natural or agricultural additives to change the gradation, texture, or plasticity of the soil or function as a binder for cementation.

New research in geotechnical engineering and construction materials has focused on locally available agricultural and industrial wastes that pose a disposal challenge. The use of various industrial and agricultural wastes as soil stabilizers has become commonplace, (Yadu et al., 2011; Okagbue, 2007; Bethlehem, 2015; Patrick, 2016; Ewa et al., 2016; Fazal et al., 2020).

Stabilizers improve the load-bearing capability of a sub-grade to support pavements and foundations by increasing the shear strength of the soil and/or controlling the shrink-swell qualities of the soil. From expansive clays to granular materials, stabilization can be utilized to treat a wide range of sub-grade materials. Higher resistance (R) values, less plasticity, lower permeability, and reduced pavement thickness are some of the benefits of adding these components to the stabilizing process, (Rimal et al., 2019)

Cement kiln dust (CKD) as a chemical stabilizer has been reported by many authors. The engineering properties of soils as well as their performance as foundation and construction materials showed improvements as a result of using CKD in soil stabilization, (Hesham, 2013; Vivek and Rajesh, 2015; Miller and Azad, 2000; Mohamed, 2002). According to a recent study by Nishantha et al. (2020), for long-term purposes, soil stabilization using cement kiln dust or a combination of Fly Ash and Lime Kiln Dust could be adopted, whereas fly ash and cement kiln dust can be used as a short-term soil stabilizer in certain soil types for construction facilitation.

Sugarcane Bagasse Ash (SCBA) has received a lot of research as a soil stabilizer. Athira and Sini (2019) noted that when soil containing kaolinite clay was stabilized with bagasse ash, the strength and index values improved to some degree, this agreed with Kharade et al., (2014). However, Osinubi et al. (2009) noted that Bagasse ash was ineffective as a "stand-alone" stabilizer and should instead be used in admixture stabilization.

Limestone is available in considerable quantities in several parts of Nigeria. Limestone is abundant in Nigerian states such as Cross River, Ebonyi, Abia, Imo, Enugu, Benue, Edo, Ogun, Sokoto, Bauchi, and Gombe. Fig. 1 shows the areas in Nigeria where limestone and marble can be found. In Cross River State, limestone is abundant with local mining operations as seen in Fig. 2a.

Limestone dust (LSD) is a by-product of the cutting and polishing of limestone. LSD is a by-product of the limestone crushing process for use as a by-product in the aggregates manufacturing process. Hassan et al. (2021) investigated the effects of gravel dust and limestone dust on clayey soil geotechnical parameters. The findings revealed that as the number of dust increases, the Atterberg limits of clay dropped. The compaction qualities of clay were reduced as the gravel dust content increased. However, as the amount of limestone dust increased, the MDD improved while the OMC decreased. Limestone dust is richer in calcium oxide compared to gravel dust. A combination of limestone dust and sugarcane bagasse ash can be used to stabilize soil Desmond et al., (2022), contributing in the beneficial conversion of wastes and helping the global advocacy for sustainable development in terms of economic resource utilization.

The subgrade soils in Nigeria's Niger Delta are typically a soft deposit of clay with high plasticity, and because of their hydromorphic character, they tend to alter volume owing to wetting and drying, resulting in foundation failure beneath the pavement structure Ewa et al., (2016).

This present study investigates the influence of using limestone dust as a stabilizing agent to subgrade soil, located in Calabar south in the Niger Delta region of Nigeria. The focus is to improve the index and engineering properties of the soil for construction purposes.

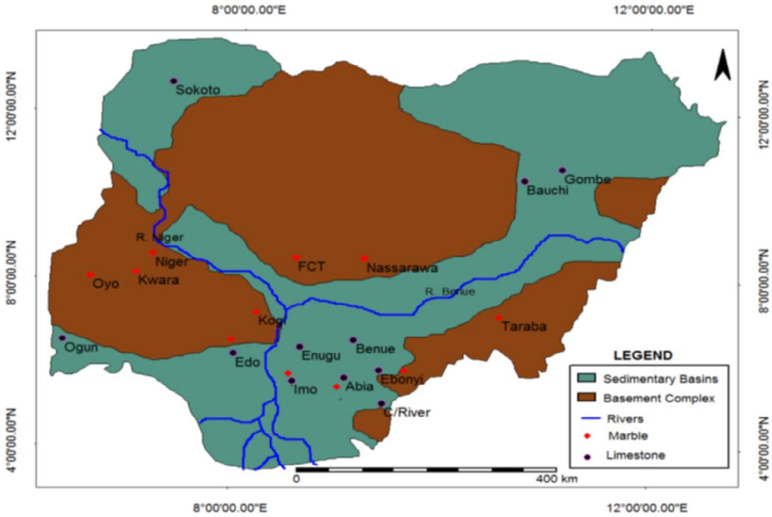

Fig. 1: Geology map showing Limestone and Marble Occurrences in Nigeria (Fatoye and Yomi (2013).

II. MATERIALS AND METHODS

A. UNMODIFIED SUBGRADE SOIL

The unmodified subgrade soil was collected around CRUTECH area where an internal road has been proposed on GPS coordinates of 425512.955E and 544220.535N 32N, in Calabar South Local Government Area. The soil was collected at a depth of 0.5 - 1m and then air-dried (see Fig. 2b) and stored in sag bags in the laboratory. The properties of the natural soil were determined following the BS1377 (1990) standard.

a b

Fig. 2: (a) Local limestone site (b) Sampling of soil

B. STABILIZER

Limestone Dust (LSD) was used as stabilizer to improve the geotechnical properties of the subgrade. The Limestone Dust was locally sourced from a small Limestone quarry/mining site located in Mfamosing, Akamkpa Local Government Area of Cross River State on GPS coordinates of 5°4′56.892″ N | 8°31′31.415″ E. Table 1 shows the chemical composition of the stabilizers used for the study.

Table 1: Chemical Composition of Stabilizers

Mineral	% In Limestone Dust
Al_2O_3	0.35
SiO_2	1.10
CaO	54.6
Fe_2O_3	0.04
K_2O	-
MgO	0.06
Na_2O	-
P_2O_5	-
$CaCO_3$	96.69
TiO_2	0.02
LOI	43.55

C. METHODOLOGY

The unmodified lateritic subgrade was stabilized by adding LSD at 0%, 5%, 10%, 15%, 25%, and 50% by weight of soil. Tests conducted on the matrix include Atterberg's, particle size distribution, dry density, the California Bearing Ratio (CBR), secant Modulus, and unconfined compressive test.

For each mixture matrix, the modified-proctor compaction test was carried out using a 4.5 kg rammer, the soil was compacted in the mold in five layers. The maximum dry density (MDD) and the corresponding moisture content (OMC) were obtained.
Each sample was subjected to a 48-hour soak in CBR for the CBR test. A 4.5 kg mechanical hammer was used to compact each mixed matrix into the CBR mould. Compaction was done in three layers, each with 56 blows.

Applying axial stress to a cylindrical soil specimen with no confining pressure and measuring the axial strains corresponding to various stress levels yields the unconfined compression strength. This test is carried out in compliance with the AASHTO T 208 standard (2015), see Figure 3 for experimental set-up. The secant modulus was also determined from the axial stress and strain of the UCS test.

Fig. 3: (a) USC set up.

III. RESULTS AND DISCUSSION

A. INDEX PROPERTIES UNMODIFIED SOIL

The index properties of the unmodified soil are presented in Table 2 while the particle size distribution of the soil is shown in Fig. 4. The soil is described as silty clayey soil. The soil had liquid limits of 38.44% with a plasticity index of 15.2% and was classified as clay with low plasticity from the Unified Soil Classification System and A-6 soil under the AASHTO classification. The specific gravity was 2.73 with an MDD of 1.74 kg/m3 at an OMC of 24.5%. The 24 hours-soaked value of the California bearing ratio (CBR) was 6.92%.

Table 2: Index properties of unmodified subgrade soil

Description	Results
Liquid limit (%)	38.44
Plastic limit (%)	23.24
Plasticity index (%)	15.20
Linear shrinkage (%)	12.33
Specific gravity	2.73
Percentage Passing BS Sieve 200 (0.075mm)	65
AASHTO classification	A- 6
Unified Soil Classification System	CL
Maximum dry density (kg/m3)	1.74
Optimum moisture content (%)	24.5
Unconfined Compressive strength (KN/m3)	103.66
California bearing ratio (soaked) %	6.92

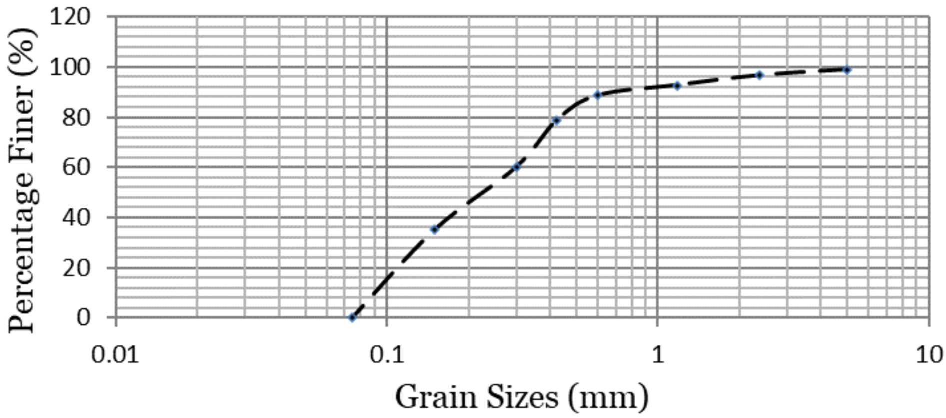

Fig. 4: Particle size distribution of soil

B. ATTERBERG LIMITS

The addition of limestone dust decreased the liquid limit, plastic limit, and plasticity index, as shown in Fig. 5a. Linear shrinkage was observed to also decreased as indicated in Fig. 5b. Improvements in the Atterberg Limits imply a reduction in the swelling and expansive potential of the subgrade soil. The calcium cations in the limestone dust take the place of soil cations as the limestone dust is added to the soil until the soil is full of calcium cations. This resulted in a significant reduction in the thickness of the diffuse double layer, lowering the liquid and plastic limit Brooks, (2011). The mixing of soil and limestone dust causes a pozzolanic reaction, which produces cementitious compounds, fills soil spaces, and lowers the soil's plasticity index Okagbue, (2007).

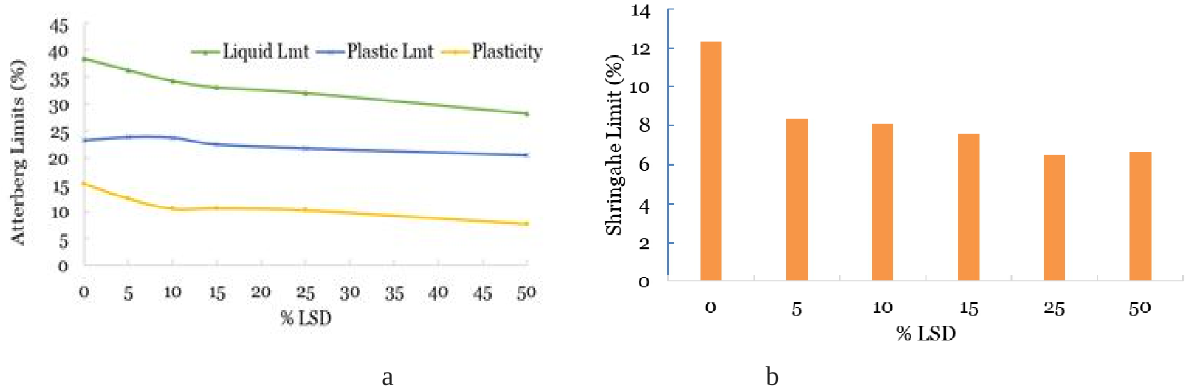

Fig. 5: (a) Influence of LSD on Atterberg Indices, (b) Influence of LSD on linear shrinkage.

C. COMPACTION CHARACTERISTICS

Increased shear strength, decreased compressibility, decreased permeability, and control of soil swelling and shrinkage are the main aim of soil compaction. Fig. 6a indicates that the MDD increases with an increase in the percentage of limestone dust up to 10% optimal stabilizer content, before declining, whereas the OMC decreases as the LDS content increases as shown in Fig. 6b. The addition of limestone dust coarsened the soil, resulting in a greater MDD. Mixing limestone dust with clay makes it easier to compact clay at low moisture levels, resulting in a densification structure with a reduced void ratio and higher density Ahmed et al., (2020). The OMC decreases as the limestone dust content increases. This can be attributed to the substitution of clay in the mixture by dust, which has a lower water attraction Hassan et al., (2021).

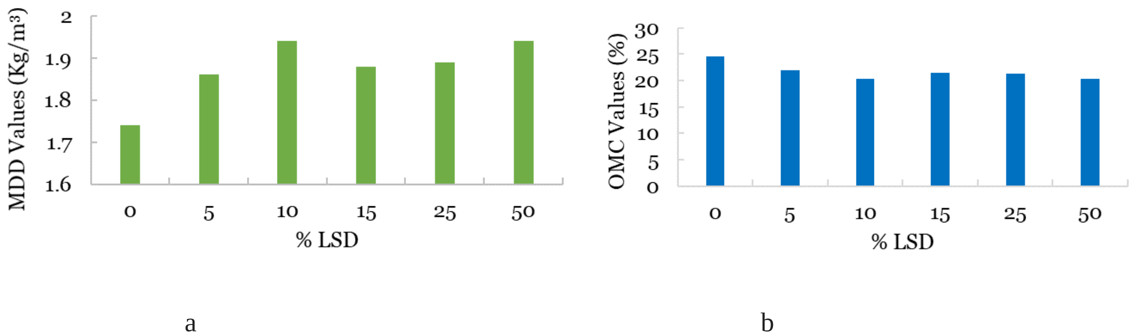

Fig. 6: (a) influence of LSD on MDD, (b) influence of LSD on OMC

D. CALIFORNIA BEARING RATIO

LSD improves soil CBR, as shown in Fig. 7. When calcium oxide is present in limestone dust, cation exchange, flocculation-agglomeration, carbonation, and pozzolanic reaction all contribute to stabilize soil. The flocculation-agglomeration response, according to (Fazal et al., 2020) enhances the geotechnical qualities of high plasticity clay soils.

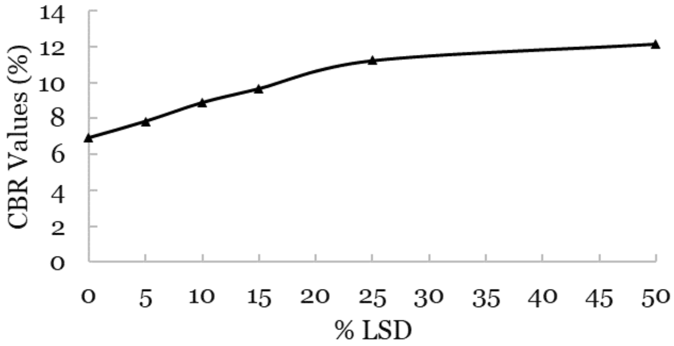

Fig.7: Influence of LSD on CBR

E. UNCONFINED COMPRESSIVE STRENGTH (UCS)

As seen in Fig. 8 the subgrade's unconfined Compressive Strength increased as the LSD content. The formation of calcium silicates after the reaction of calcium from LSD with silica from soil could explain the rise in UCS. The grain size effect and specific gravity of both materials may also contribute to increased strength. Sabat and Muni (2015) reported a similar trend when limestone dust was used to stabilize expansive soil.

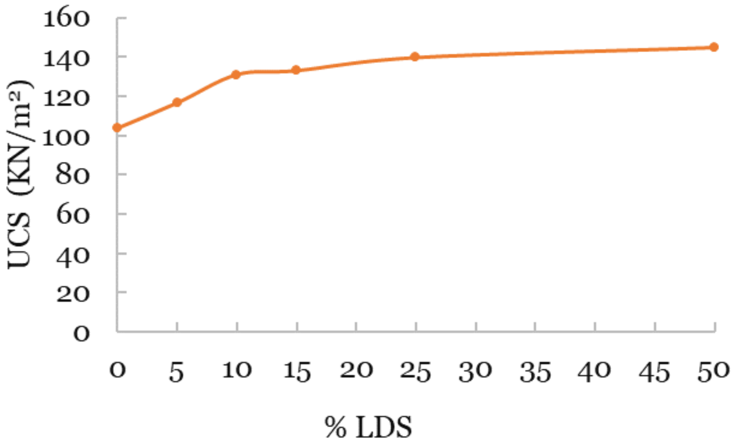

Fig. 8: Influence of LSD on UCS

F. SHEAR STRENGTH

From Fig. 9, the shear strength improved as the LSD content increased. The bond between the binder components in the soil (in this case, the CaO) and the aggregates could explain this improvement. Increased cohesion with increased limestone dust may also be attributed to the self-hardening effect of limestone dust, or to the bonding of particles to form bigger aggregates, resulting in a coarse-grained, strengthened soil.

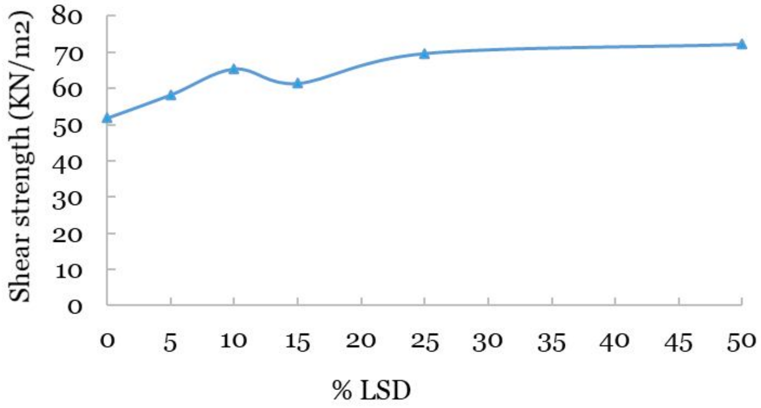

Fig. 9: Influence of LSD on Shear Strength

G. SECANT MODULUS

The secant modulus describes a material's stiffness in the inelastic zone of the stress-strain curve. Fig. 10 presents the effect of LSD on the Secant Modulus of the soil. Secant Modulus increased to an optimal value of 25% LSD content, thereafter, it declined. The self-hardening impact of limestone dust or the bonding of particles to form bigger aggregates, resulting in a coarse-grained, highly bony soil, could explain the improvement in Secant Modulus with increased limestone dust.

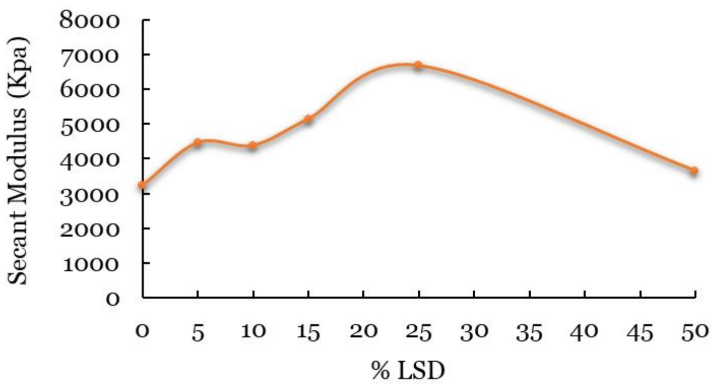

Fig. 10: Influence of LSD on Secant Modulus

IV. CONCLUSION

Limestone is abundant in many parts of Cross River State and the utilization of limestone dust from local mining sites for soil stabilization has not been given adequate entrepreneurial attention. The utilization of limestone dust in soil stabilization is very beneficial in the following ways:

Improvement in the index properties of the soil **-** The incorporation of limestone dust improves the engineering properties of road subgrade by reducing the Atterberg limits indices, resulting in reduction in swelling potential of the soil.

Improvement in geotechnical properties - the compaction behaviour of the soil, CBR, USCS, shear strength and stiffness of the modified subgrade showed improvement. There is a general increased strength property, decreased compressibility, decreased permeability, and controlled swelling and shrinkage of modified soil.

Economic benefit – compared to the use of Portland cement, the utilization of road subgrade using limestone dust is cheaper. This will result in overall cost reduction in pavement construction.

Entrepreneurial opportunities – entrepreneurial and employment opportunities around these local mining sites will reduce both poverty and youth restiveness in the area.

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