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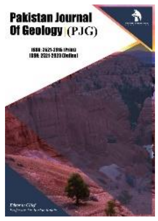

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*RESEARCH ARTICLE*

# ENHANCING THE ENGINEERING PROPERTIES OF LATERITIC SOILS USING ANTHILLS, SPECIFICALLY MOLD SOILS, IN CERTAIN PARTS OF THE BENIN METROPOLITAN CITY IN SOUTHERN NIGERIA

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**ABSTRACT**

The study was carried out in Ovia North-East local government area of Edo state. The study area is located between latitudes of 6°24'16.116''N and longitudes of 5°37'26.205″E to 5°36'16.8''E in Ovia North-East local government area. A total of three (3) soil samples were collected from an Anthill (Mold soil) mix with Lateritic soil at 0%, 3% and 6%. The following geotechnical analyses (the Particle size analysis, Specific Gravity, Atterberg Limits, Compaction Test and Triaxial Tests) was carried on the Mold soil samples mixed with lateritic soil to evaluate their suitability for road construction. The analyses revealed that approximately 10% of the soil composition consists of fine sand grains, while the majority, accounting for 90%, is characterized as medium to coarse grained. The particle size distribution analysis of the Mold soil indicated that the percentage of fines is below 35%, classifying it as coarse-grained according to the American Association of State and Highway Transport Officials (AASHTO). The Mold soil exhibited weight retention of 47.26 grams. The Specific Gravity ranged from 2.34 to 2.51, Liquid Limit varied from 51.80% to 63.05%, Plastic Limit ranged from 26.70% to 29.39%, Plasticity Index ranged from 25.10% to 33.52%, and Shear strength spanned from 26.748 to 50.066 kN/m$^2$. The results of the Compaction Test indicated that the Maximum Dry Density (MDD) ranged from 1.54 to 1.61 g/cm$^3$, and the Optimum Moisture Content ranged from 14.45% to 13.93% for Mold soils mixed with lateritic soil at 0%, 3%, and 6%, respectively. The study results demonstrate that the incorporation of Mold soil enhances the geotechnical properties of the soil, while the Anthill proves to be a beneficial additive for improving lateritic soil in road construction. Furthermore, the Mold soil sample, when mixed with lateritic soil, meets the specifications set by the Federal Ministry of Works and Housing, specifically maintaining a percentage of ≤ 18% for sub-base and base materials. This finding underscores the suitability of the soil for road construction purposes.

**KEYWORDS**

road construction, American Association, Mold soil, geotechnical

## 1. INTRODUCTION

Enhanced soil suitability for engineering applications is anticipated, particularly as any nation strives for heightened infrastructure development. The connection between various engineering infrastructures and their underlying foundation soils holds crucial significance for both designers and contractors. The persistent instances of road pavement deterioration and building collapses, largely attributed to inadequate geotechnical and mechanical properties, underscore the pressing need for a thorough comprehension of soil geotechnical properties (Garg, 2009). Laterites frequently occur and are utilized in tropical regions for constructing road layers, including road base and base courses. To ensure the longevity of such roads, lateritic soils are commonly subjected to stabilization. Soil stabilization, as a concept, involves any treatment – whether chemical or mechanical – applied to soil with the aim of enhancing its strength (geotechnical properties) and diminishing its susceptibility to water.

If the treated soil can withstand the stresses imposed by traffic loads under all weather conditions without deformation, it is generally deemed stable. The demand for the construction of sufficient transportation facilities and the upkeep of existing ones is significantly rising in tandem with population growth. Highway engineers frequently encounter challenges in sourcing suitable earth materials, particularly lateritic soils, for constructing subbase and sometimes base layers in road construction. Due to this, ongoing research efforts by individuals, firms, and institutions aim to enhance the engineering properties of soils. In certain instances, the available soils lack adequate engineering properties to withstand the anticipated wheel loads, necessitating improvisations to enhance their strength and suitability for the applied axle loads post-construction.

The economic recession and high inflation in the country prompted the Federal Government to task engineers with finding local materials for road construction and improving the strength of commonly used laterite soils for local roads. This circumstance has driven road authorities to optimize the utilization of naturally occurring materials that are typically overlooked by conventional specifications for the upper layers of road pavements. One such naturally occurring material is laterite. Laterite is a type of residual soil found extensively in the humid tropical and sub-tropical zones globally, including significant regions of central, southern,

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and western Africa. Fortunately, research conducted in the late 1960s in various countries, such as Angola, Mozambique, Brazil, Australia, and Nigeria, suggests that the performance of laterite often exceeds expectations based on traditional specifications (Adam and Agib, 2001).

In an effort to address road maintenance at a cost-effective level, extensive research has been conducted on alternative materials that can partially or entirely replace cement in construction purposes (Okoli and Zubairu, 2002; Adam and Agib, 2001). Termites often referred to as ecosystem engineers, construct mounds that enhance the content of organic carbon, clay, and nutrients (King, 2006). Predominantly found in savannah areas, termite soil in the savannah weighs more than the total weight of above-ground animals (King, 2006). A common termite species in Nigeria is the light brown termite (Isoptera: Termitidae). These termites are crucial agents of decomposition, contributing significantly to nutrient and carbon fluxes (Jouquent, 2004). They play a key role in redistributing organic matter, improving soil stability, and enhancing its physical and chemical properties (Manuwa, 2009). Additionally, termites improve water absorption and storage capacity (Holt and Lepage, 2000; Jude and Ayo, 2008).

Noteworthy characteristics of termite mounds include their remarkable strength, especially during the dry season, making them challenging to work with. The structure of termite mounds changes with climatic conditions, being dry during the dry season and wet or sticky during the rainy season, possessing a concrete-like material (Lavelle and Spain, 2001). Various applications of termite mounds have been highlighted by Lavelle and Spain and Frederic, including plastering and brick making, construction of brick stoves, repair of wood boats, soil amendment, construction of pit latrines, water-proof liners, footpaths and driveways, reducing crop losses, paint making, and stabilization as an additive to the soil (Lavelle and Spain, 2001; Frederic, 2003). The economic importance of adding termite mound material to the soil lies in preventing excessive settlement, enhancing soil stiffness, shear strength, and soil bearing capacity (Lavelle and Spain, 2001).

Researchers such as have reported that termite clay powder exhibits higher values of clay, liquid limit, plastic limit, and maximum dry density compared to laterite soil (Mijinyawa et al., 2007; Yohanna et al., 2003). It has proven to be a superior material for molding lateritic bricks, and this type of clay has demonstrated superior performance compared to ordinary clay in dam construction (Odumodu, 1999; Mijinyawa et al., 2007; Yohanna et al., 2003). According to various properties such as particle size distribution, liquid limit (LL), plastic limit (PL), compaction properties (optimum moisture content, OMC, and maximum dry density, MDD), California bearing ratio (CBR), and unconfined compressive strength (UCS) of soil samples were determined (Adekemi et al., 2021). There was a noticeable enhancement in the geotechnical properties, particularly for samples A and B, with around a 20% reduction in LL, a 38% increase in CBR, and a 120% increase in UCS. The study suggests that a combination of Cassava peel ash (CPA) and lime has the potential to improve the geotechnical properties of fine-grained lateritic soil.

According to soil samples were analyzed for geotechnical characteristics according to ASTM standards (Ojeaga Kenneth et al., 2020). The soil was mainly silty/clay with a small amount of fine sand. The liquid limits ranged from 31.94% to 21.03%, and the plasticity index varied from 11.95% to 17.67%. Specific gravity ranged from 2.48 to 2.51. Maximum dry density values (MDD) were 1.83g/cm$^3$, 1.84g/cm$^3$, and 1.81g/cm$^3$, while optimum moisture content values were 12.87%, 12.0%, and 11.19% for the three sampling points. The California Bearing Ratio (CBR) values indicated that none of the soil samples met the criteria for road sub-grade, as CBR values were above the required 10%.

According to termite mound samples were mixed with two soil samples (clayey soil and laterite soil) separately (Olorunwa et al., 2018). The findings revealed that termite mound had the highest maximum dry density and compressive strength compared to the other two soil samples. Termite mound as an additive proved to be more effective in laterite soil than in clay soil in terms of compressive strength and maximum dry density. The compressive strength of laterite was almost double that of clay soil at the same termite ratio. Termite is recommended as an additive for laterite soil in building construction.

According to geotechnical analyses, including particle size analysis, specific gravity, Atterberg limits, and compaction tests, were conducted on soil samples to evaluate their suitability for road construction (Andre-Obayanju, et al., 2017). The results indicated well-graded soils (GW) with percentage fines ranging from 28.06% to 57.8%. The termite soils showed varying properties. Both soils were deemed suitable for road construction as subgrade, but the termite hill of Igarra exhibited higher strength with a higher MDD to low moisture content, making it a better material according to the Federal Ministry of Works and Housing recommendations for road base, sub-base, and sub-grade. The geotechnical properties of soils serve as indicators of the soil's suitability as a construction material. A higher specific gravity value contributes to increased strength, making it advantageous for roads and foundations (Akpokodje, 2001). These properties, including grain size distribution, plasticity, compressibility, shear strength, permeability, soil compaction, California bearing ratio, and others, play a crucial role in predicting how soil behaves under different loads.

The engineering properties of soil are influenced by two main factors: compositional factors and environmental factors. Compositional factors encompass the size and shape of particles, the type and proportion of minerals, and the composition of pore water. On the other hand, environmental factors involve water content, density, confining pressure, temperature, and structure. Both sets of factors collectively impact the overall behaviour and performance of the soil in various engineering applications. Laterite soil, enriched in iron oxide, is formed through extensive weathering of various rocks under strongly oxidizing and leaching conditions. This type of soil is prevalent in humid tropical and subtropical regions (Olorunwa et al., 2018). Laterite is characterized by its development in hot and wet tropical areas, featuring high concentrations of iron and aluminum due to prolonged weathering of the parent rock (Wikipedia, 2020).

Soil stabilization is a treatment applied to soil to enhance its strength and reduce vulnerability to water. If the treated soil can withstand traffic-induced stresses under all weather conditions without deformation, it is considered stable. This definition applies regardless of whether the treatment is applied in situ or after the soil has been relocated for use in pavements or embankments (O'Flaherty, 2002). Soil stabilization methods are broadly categorized as mechanical or chemical. Anthills, mounds built by ants or termites, are composed of soil carried from underground as they construct their nests. Active anthills contain enriched soil organic matter and inorganic nutrient elements, such as Ca, K, Mg, and P, compared to adjacent surface soils. Anthill clay is a distinctive soil/clay type due to its unique accumulation method. Small particles are carried and assembled into an anthill by small creatures known as termites. Researchers suggest that anthill soils help retain moisture, similar to manure, which is often more readily available since many farmers also raise livestock (Grow further, 2022). The ant mound serves three main purposes: it acts as the entrance to the underground nest, regulates the internal temperature of the nest, and provides protection against predators or intruders that could damage or destroy the nest.

## 2. Review of the Study Area

The study area is situated within the coordinates of 6°24'16.116''N and longitudes 5°37'26.205″E to 5°36'16.8''E, falling under the jurisdiction of Ovia North-East local government area in Nigeria. This region is characterized by a Tropical Savannah Climate. Ovia North-East LGA covers a total area of 2,301 km$^2$, with a population of 153,849 residents (National Population Commission, 2006). The local government area comprises various tribal groups, including Okada, Uhen, Utese, Okokhuo, Uhiere, Isiuwa, Ekiadolor, Oluku, and others.

The climate in the study area exhibits two distinct seasons: rainy and dry. The average temperature hovers around 28 °C, with an estimated humidity level of 68 percent. The residents are predominantly engaged in farming activities. Benin City, which is part of the study area, experiences a hot and humid climate, with the rainy season spanning from April to November and the dry season lasting from December to March. Benin City has high average daily temperatures of approximately 28 °C in the dry season and 24 °C in the wet season. The temperature range in the study area is relatively low.

The region encounters heavy rainfall, particularly during the wet season, with an annual total ranging from 2000 to 2300 mm and a monthly average of about 180 mm (Ministry of Environment, Benin Report 2009). This significant rainfall is attributed to intense evapotranspiration caused by high temperatures in the urban area. Relative humidity is also noteworthy, reaching around 80% in the wet season and 70% in the dry season (Manpower Nigeria 2020). The primary objective of the study is to enhance the engineering properties of lateritic soils in the area using anthills (Mold soils). This initiative aims to improve the soil's suitability for construction and infrastructure development in this climatic context.

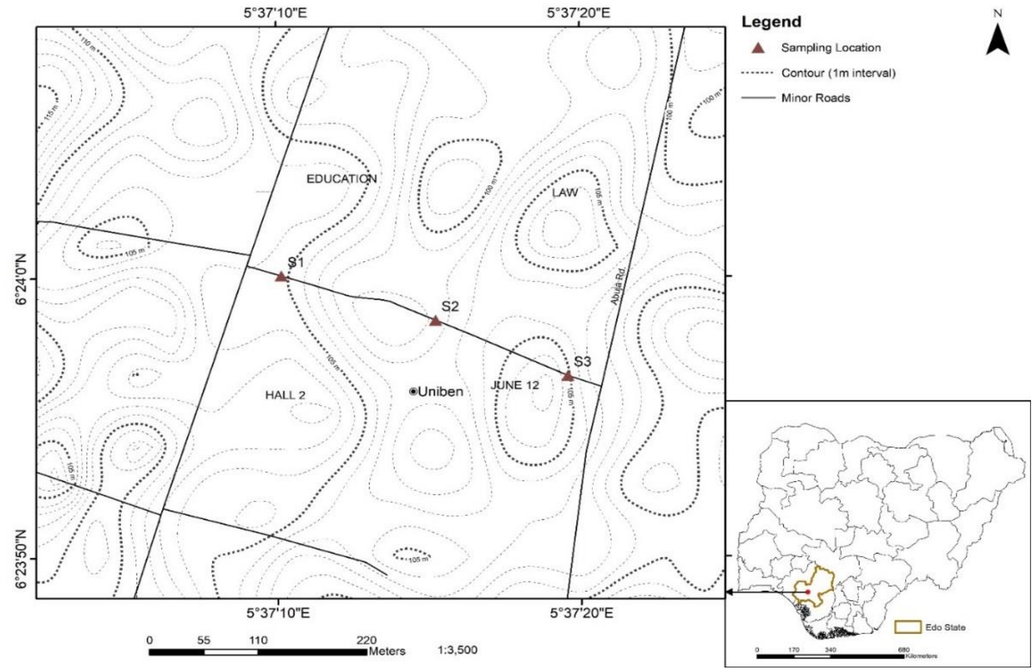


**Figure 1:** Location map of the study area

## 3. Geology of the Study Area

The Benin Region is situated above the sedimentary formation of the South Sedimentary Basin, characterized by a geological composition featuring a prominent reddish earth. This reddish earth is primarily composed of ferruginous or laterized Sandy Clay. The term "Benin sand" was initially coined to describe this reddish earth, which is underlain by sands, sandy clays, and ferruginous sandstone, signifying the Paleo-coastal Environment of the Paleocene-Pleistocene Age. These sedimentary deposits extend across the southern fringe of the Anambra Basin and mark the upper facies off-flaps of the Niger Delta Basin. Geologically, the Benin Region is comprised of distinct formations, including the Benin Formation, Alluvium, Drift/topsoil, and Azagba-Ogwashi Formation. The sedimentary rock prevalent in the study area is specifically attributed to the Benin Formation, which plays a crucial role as an essential groundwater reservoir.

### 3.1 Local Geology of The Study Area

The underlying geological structure in the study area consists of the Benin Formation, a significant reservoir of groundwater. This formation exhibits distinctive features, with its upper layers displaying reddish to reddish-brown-yellow lateritic massive clay and sand, as documented by Reyment in 1965. Overlying these layers are substantial sequences of poorly bedded friable, loose sand, gravelly, pebbly sand, and clay stringers in a pinkish-white hue, as detailed by Oomkens in 1974. The sedimentary sequence is characterized by poorly bedded layers with intermittent clay horizons at various depths, observable at erosion sites, sand quarries, and road cuttings. Encompassing a vast extent of 95% of the region, the Benin Formation holds geological prominence. The lithostratigraphy of this formation, spanning from the Miocene to the recent period, reveals a composition featuring 90% sand, conglomeratic gravels (including pebbles and cobbles), clays, and sporadic occurrences of peat and lignite in the form of beds or dispersed fragments. These sediments were deposited within a continental coastal plain with a fluvial depositional setting, as elucidated by Nwajide in 2013.

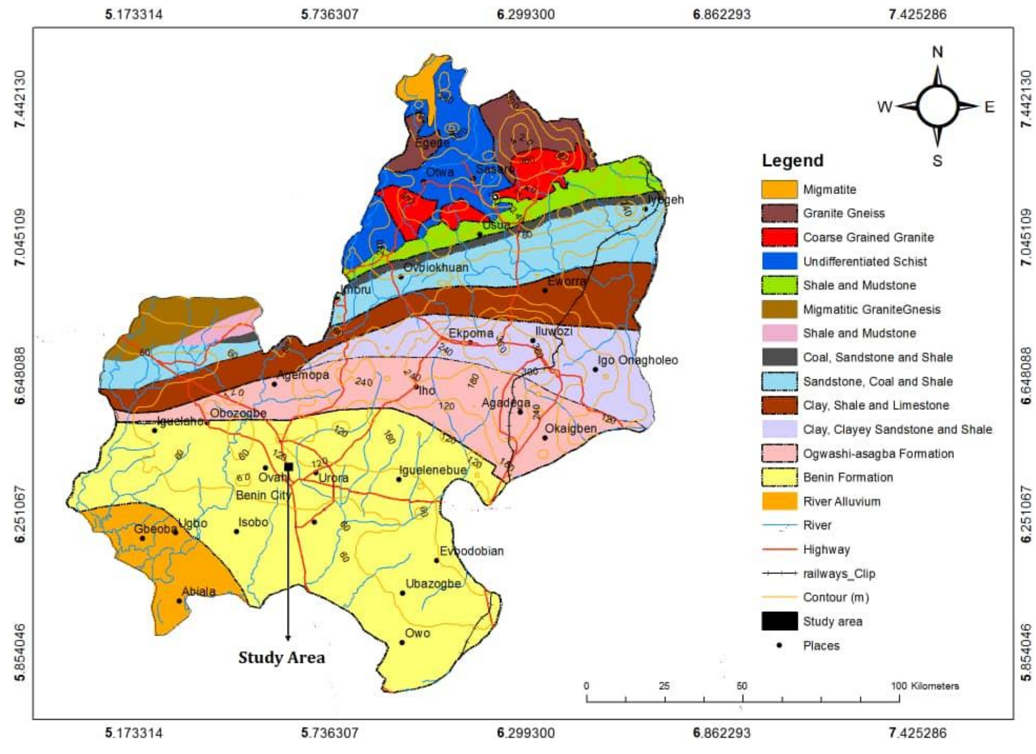


**Figure 2:** Geology Map of the Study.

## 4. MATERIALS AND SAMPLING METHOD.

A survey of the site was done. Three samples were obtained from three sampling point at depth range of 0m to 1m for each with the aid of a soil hand auger. Three undisturbed and six disturbed soil samples were gathered and subsequently transported to a laboratory for essential geotechnical assessments. These analyses encompassed particle size analyses, specific gravity tests, Atterberg tests, compaction tests, and triaxial tests. To preserve the integrity of the soil, the molded samples were swiftly placed into sample bags, a precautionary measure aimed at preventing moisture loss. Each bag was diligently labeled to ensure easy identification during the testing process. This meticulous handling of the soil samples is crucial for obtaining accurate and reliable geotechnical data in the laboratory. The coordinate was also collected with the aid of a GPS. Laboratory study of the soil was to determine its geotechnical index properties. The test carried out on mold soil include: Moisture content; Atterberg limit which include Plastic limit and Liquid limit; Particle Size Distribution, Triaxial and Compaction test. The testing procedures for the soil samples were carried out in accordance with the specifications outlined in BS 1377(1975).

### 4.1 Moisture Content Determination

The test conducted is aimed at determining the natural moisture content of the soil, representing the water content of the soil in its undisturbed, natural state. This moisture content is quantified as the ratio of the weight of water present to the weight of the dry soil. Additionally, it can be defined as the percentage ratio of the mass of water in the void spaces within the soil to the mass of the solid particles in the soil. Essentially, it provides a crucial measure of the amount of water naturally present in the soil, a fundamental parameter in understanding the soil's characteristics and behaviour.

$$Moisture\ content = \frac{Mw}{Ms} \times 100\%$$

Where: Mw is the Mass of Water and

Ms is the Mass of Solid

### 4.2 Atterberg's Limit Determination

The Atterberg's limit tests are commonly conducted on cohesive soils for both classification and correlation purposes. These tests are crucial as they represent the most important index properties in understanding the engineering behaviour of the soil. Atterberg's limit concept is based on the idea that cohesive soils can exist in any of four states, depending on the amount of water content. These limits were introduced to define the boundaries between these different states.

Among the Atterberg limits investigated on the soil samples, two key parameters are considered: plastic limit and liquid limit. The volume of soil at which water imparts the properties of a liquid, occurring at lower water content, is defined as the liquid limit. Conversely, the volume of soil at which it exhibits the properties of a semi-solid, occurring at lower water content, is known as the plastic limit. Understanding these limits is essential for classifying and interpreting the engineering characteristics of cohesive soils based on their water content states.

### 4.3 Plastic Limit

The plastic limit, measured as a percentage of clay in the moisture content, signifies the boundary between the plastic and brittle (semi-solid) state of a specific soil under defined conditions. This limit is influenced by the adhesive properties of cohesive forces, which are dependent on the strength and nature of the forces between soil particles. Specifically, the plastic limit can be defined as the capacity of cohesive soils to undergo continuous shape changes under pressure and to retain the new shape once the pressure is removed. In practical terms, it represents the moisture content at which the soil begins to exhibit cracking when rolled under the palm into 3mm diameter thin threads. Understanding the plastic limit is crucial for assessing the plasticity and moldability of cohesive soils under different moisture conditions.

**Table 1:** Classification of clays according to plasticity index (Akpokodje,2001)

| Qualifying term | Ranges of plasticity index |
|---|---|
| Non plastic | Under 1 |
| Slightly plastic | 1-7 |
| Moderately plastic | 7-17 |
| Highly plastic | 17-35 |
| Extremely plastic | Over 35 |

### 4.4 Liquid Limit

| Liquid Limit | Plasticity Index relative to A-line | Soil class and plasticity | Code |
|---|---|---|---|
| Liquid Limit <50% (L) | On or above | **Lean Clay** Inorganic clays, sandy clays, silty clays, lean clays. Low to medium plasticity, no or slow dilatancy. | CL |
| | Below | **Silt** Inorganic silts and very fine sands, rock flour, silty or clayey fine sands. Slight plasticity to non-plastic, slow to rapid dilatancy. | ML |
| Liquid Limit >50% (H) | On or above | **Fat Clay** Inorganic clays, fat clays. High plasticity, no dilatancy. | CH |
| | Below | **Elastic Silt** Micaceous or diatomaceous fine sandy and silty soils, elastic silts. Low to medium plasticity, no to slow dilatancy. | MH |
| Liquid Limit <30% (L) Plasticity Index 4 to 7% | Not applicable | **Silty Clay** Mixed zone where both CL and ML soils plot | CL-ML |

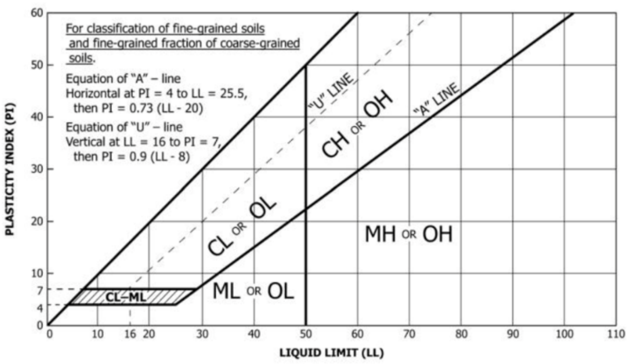


**Figure 3:** USCS-Inorganic fine-grained soil component, ASTM D2487, ASTM D2488 and Casagrande, 1967 (Rajkumar et.al, 2023).

The liquid limit of the soil is determined by the moisture content at which a 1cm groove is closed by 25 blows of the liquid limit device. The process involves taking a certain quantity of soil sample that has been over-dried, pulverizing it, and passing it through a sieve with a mesh size of 0.42mm. This finely pulverized soil is then thoroughly mixed with water until a uniform paste is formed.

A portion of this paste is placed in the liquid cup, and the surface is levelled parallel to the center of the soil using a grooving tool. The handle of the liquid limit machine is turned, and the number of blows required to close the groove is counted. This procedure is repeated until 25 blows are achieved. The moisture content is then plotted against the number of blows, allowing for the determination of the liquid limit. This method provides a standardized measure for assessing the plasticity and flow characteristics of the soil under specific moisture conditions.

**Table 2:** Classification of clays according to liquid limit (Akpokodje, 2001)

| Qualifying term | Ranges of Liquid limit |
|---|---|
| Low plasticity | Under 35 |
| Intermediate plasticity | 35-50 |
| High plasticity | 50-70 |
| Very High plasticity | 7-90 |
| Extremely high plasticity | Over 90 |

### 4.4 Particle Size Distribution

The Particle Size Distribution (Sieve Analysis Sieve test) was conducted to determine the diameter of soil particles constituting the soil mass. This involved sieving 0%, 3%, and 6% of the mold soil samples mixed with lateritic soil through a series of sieves with progressively smaller mesh openings, arranged from the top to the bottom of the stack. This method highlights why early soil classification systems were based on the distribution of particle sizes, classifying soils into basic types such as gravel, sand, silt, and clay (Helwany, 2007).

The particle size groups and their limits commonly utilized are adapted from the Massachusetts Institute of Technology (MIT) textural classification. For analysis of selected physical and chemical properties, the disturbed soil samples were air-dried and gently ground to pass through a 2 mm sieve. In a 500 mL conical flask, 100 grams of air-dried finely powdered mold soil were combined with 15 mL of 0.5 N sodium oxalate ($Na_2SiO_3$). To this mixture, 200 mL of distilled water was added and shaken for 20 minutes. The content was transferred to a one-liter measuring cylinder and made up to one liter by adding enough water. After thorough stirring, the suspension was left unstirred, and the hydrometer was dipped into the suspension after 5 minutes, providing a direct reading of the percentage of Clay + Silt. The percentage of sand was determined by subtracting the percentage of Clay + Silt from 100%. Similarly, the percentage of silt was determined by subtracting the hydrometer reading from Clay + Silt (APHA, 2005). The uniformity of the particle size of a soil is expressed by the uniformity coefficient (Cu) which is defined by

$$Cu = D_{60} / D_{10} \quad (1)$$

Where D60 is the diameter at which 60% of the soil is finer and D10 is the corresponding values at 10% finer.

### 4.5 Specific Gravity

Specific gravity is the ratio of the weight of a substance to that of an equal volume of water. The specific gravity is dimensionless.

#### *4.5.1 Procedure*

Weigh the Mold Soil Sample when it is completely dry. Carefully place Mold soil sample which was air-dry weighed 150g after which it was filled with distilled water. Ensure that the Mold soil sample is completely submerged. Record the new weight and measure the new weight of the conical flask, which now contains both the water and the immersed Mold soil sample. Compare with Water's Specific Gravity, since the specific gravity of water is 1, a specific gravity greater than 1 indicates that the soil is denser than water, while a specific gravity less than 1 suggests that the soil is less dense than water. Apparatus used are conical flask, distilled water and measuring scale. The specific gravity is the ratio of the unit weight of soil particles to the unit weight of water at some known temperature (usually 400C). The specific gravity of soil is generally between 2.50 and 2.90, for sand is 2.63; silt is 2.70 and 2.90 (Andre-Obayanju et al., 2017).

### 4.6 Compaction Tests

Compaction tests are carried out with the aim of determining the moisture density relationships and change in soils, increase unit weight, shear strength, reducing permeability. This makes the soil less susceptible to settlement under load, especially repeated loading. A number of methods have been developed for this purpose. These include the standard compaction method (also called proctor method), the modified (The American Association of State Highway and Transportation Officials) AASHTO method and the vibrating hammer methods.

Apparatus Used: 2.5kg Rammer: This is the device used to apply the compactive effort to the soil during the test; Mould with Removable Base: The mould is used to contain the soil sample during compaction, and the removable base allows easy extraction of the compacted sample; Detachable Collar: This collar is used to set the height of the mould during compaction.

#### *4.6.1 Test Procedure*

1. Soil Sample: Three kilograms of air-dried soil was used for each test. The moisture content ranged from 4% to 20% of the weight of the sample.
2. Mixing: The soil samples were thoroughly mixed before compaction to ensure uniformity.
3. Compaction: Three layers of compaction were performed for each trial, and each layer underwent 25 blows from the 2.5kg rammer. Repeat Tests: The test was repeated five times for each soil sample, providing a reliable set of data for analysis.

The moisture content for each test varied between 4% and 20% of the weight of the sample and the dry density values were determined for each combination of moisture content and trial. Dry density values were plotted against the average moisture content for each set of trials. These graphs are used to identify the point at which the dry density is maximized, indicating the optimum moisture content.

### 4.7 Triaxial Test

The purpose of this procedure is to assess the shear strength parameters and bearing capacity of cohesive soil. This test involves measuring the failure load on a solid sample, allowing the computation of deviator stresses. The resultant data enables the construction of Mohr circles, facilitating the calculation of shear strength parameters for the soil. Typically, the test conducted is the quick unconsolidated undrained triaxial shear stress, employing a 76mm-high solid sample. Confining cell pressures of 100, 200, and 300kN/m² are commonly utilized during the testing process. The procedures for triaxial test are as follows:

1. Prepare 3 set of soil samples of known length and diameter, using a sample extruder.
2. Measure the highest of sample using a vernier calipers
3. Enclose the samples appropriately into a thin rubber membrane using condom
4. Put porous plates above and below the sample, making sure they are held in place by a suitable rubber band.
5. Insert sample in the triaxial apparatus, then flood it with water
6. Apply a pre-determined lateral pressure (hand pump) starting from 100kN/m² for the test.
7. The dial readings were taken at each deflection of 30until the material fails. Failure occurs if the dial reading reaches a constant value thrice.
8. Remove the soil specimen from the apparatus, record the failure length and note the shape
9. Repeat step 5 to 8 with the remaining samples.

The most widely used relationship is the Mohr-Coulomb strength theory equation is

$$\tau = C + n \tan \emptyset \quad (2)$$

Where Ƭ stand for shear strength, C is cohesion, n is normal stress and Ø is frictional angle

| **Table 3:** Undrained Shear strength classification of Clays (Akpokodje, 2001) | |
|---|---|
| Consistency | Undrained shear strength (kN/m²) |
| Very stiff or hard | Over 150 |
| Stiff | 100 – 150 |
| Firm to Stiff | 75 - 100 |
| Soft to Firm | 40 – 50 |
| Soft | 20 – 40 |
| Very Soft | Below 20 |

## 5. Results and Interpretation

### 5.1 Particle Size Distribution

he analysis of the particle size distribution of the Mold samples is presented in Table 4. The distribution consistently falls within the sieve sizes of 2.0mm and 0.075mm, corresponding to fine, medium, and coarse sand fractions. Approximately 10% of the sand grains are classified as fine, while the majority, constituting 90%, are medium to coarse-grained. According to the American Association of State Highway and Transportation Officials (AASHTO), the particle size distribution results categorize the Mold soil as coarse-grained, with the percentage of fines being less than 35%. The weight retained for the Mold soil is measured at 47.26 grams.

| **Table 4:** Result of grain size analysis with the sieve sizes and weight retained for Mold soil samples | | | | |
|---|---|---|---|---|
| **WET SIEVE ANALYSIS** | | | | |
| **S/N** | BRITISH STANDARD SIEVE SIZES (mm) | WEIGHT RETAINED in gm | PASSING in gm | PASSING in (%) |
| 1 | 3.35 | - | 100 | - |
| 2 | 2.36 | - | 100 | 100 |
| 3 | 2 | 0.04 | 99.96 | 99.96 |
| 4 | 1.18 | 1.53 | 98.43 | 98.43 |
| 5 | 0.6 | 12.91 | 85.52 | 85.52 |
| 6 | 0.425 | 6.83 | 78.69 | 78.69 |
| 7 | 0.3 | 11.46 | 67.23 | 67.23 |
| 8 | 0.212 | 8.3 | 58.93 | 58.93 |
| 9 | 0.15 | 2.92 | 56.01 | 56.01 |
| 10 | 0.075 | 3.27 | 52.74 | 52.74 |
| **Total** | | **47.26** | | |

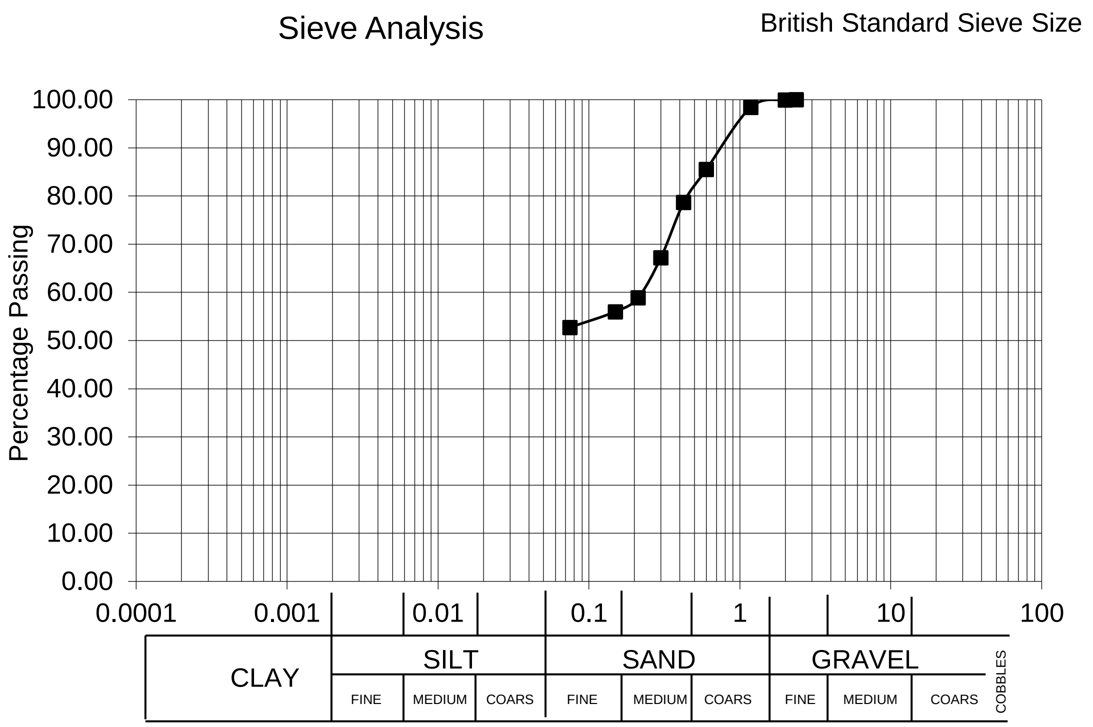


**Figure 4:** Particle Size Curve for Mold Soil sample.

### 5.2 Atterberg's Limits and Average Specific Gravity

The results for the Atterberg's limits and average specific gravity of the Mold soil samples at 0%, 3%, and 6% are presented in Table 5. The average values for liquid limits, plastic limit, and plasticity index are 58.48%, 28.39%, and 30.09%, respectively. These averages position the liquid limit and plasticity index within the ranges of 50 to 70% and 17 to 35%, respectively, according to standard clay classification. This categorization identifies the Mold soil samples at 1m depth as highly plastic. Given their clayey nature, plastic soils are generally considered less suitable for construction purposes. As a result, these soil samples are commonly excavated and replaced with more suitable materials, as highlighted (Okiotor et al., 2019). Casangrande's plasticity chart, depicted in Table 2 and Figure 3, classifies the Mold soil mixed with lateric soil as inorganic clay of high plasticity (CH) (Casangrande's, 1984). Gidigasu suggests that a soil is considered a good subgrade if its specific gravity (Gs) falls within the range of 2.50-4.60 (Gidigasu, 1976). In this study, the specific gravity values for the three samples at 0%, 3%, and 6% ranged from 2.34 to 2.51.

This indicates that the soil is a fine-grained soil, deemed suitable for subgrade purposes due to its fairly high specific gravity mineral. This observation also aligns with its mechanical strength as a subgrade material, as discussed (Mesida, 1981).

**Table 5:** Atterberg's Limits and Average Specific Gravity

| ATTERBERG LIMIT | | | | | | Specific Gravity |
|---|---|---|---|---|---|---|
| S/N | MOLD SOIL | DEPTH | LL | PL | PI | AGs |
| 1 | 0% | 1M | 60.60 | 29.08 | 31.52 | 2.51 |
| 2 | 3% | 1M | 51.80 | 26.70 | 25.10 | 2.34 |
| 3 | 6% | 1M | 63.05 | 29.39 | 33.66 | 2.35 |
| Average values | | | 58.48 | 28.39 | 30.09 | 2.4 |

### 5.3 Compaction Test of 0%, 3% and 6% of Mold soil samples

The compaction test results aimed to determine the optimum moisture contents (OMCs) and maximum dry density (MDD) of the Mold soil mixed with lateritic soil. The MDD and OMCs values were found to range from 1.54 to 1.61 g/cm$^3$ and 14.45 to 13.93%, respectively. Notably, an increase in MDD is observed with the addition of Mold soil from 0% to 6%, while OMCs values exhibit a fluctuating pattern of increase and decrease. This trend suggests that the incorporation of Mold soil has positively influenced the geotechnical properties of the lateritic soil. The resulting composite is deemed highly suitable for applications in sub-base and subgrade construction for roads, aligning with the findings of (Ogundipe, 2008). It is noteworthy that the MDD standard values for sub-base and subgrade materials typically range from 1.85 to 2.13 g/cm$^3$. Therefore, the observed MDD values in the range of 1.54 to 1.61 g/cm$^3$ further support the suitability of the Mold soil mixed with lateritic soil for road construction purposes. Soil samples with high amount of maximum dry density and low optimum moisture content have been considered more suitable as sub base and sub grade materials (Bello et al., 2007). The optimum moisture content of Mold soil sample mixed with lateritic soil met the Federal ministry of Works and Housing specification of ≤ 18% for sub-base and base materials.

**Table 6:** Compaction Test of 0%, 3% and 6% of Mold soil mixed with lateritic soil.

| SUMMARY OF COMPACTION TEST PARAMETERS | | | | |
|---|---|---|---|---|
| S/N | SOIL MOLD | MDD | OPT.MC | B.S/CBR |
| 1 | 0% | 1.54g/cm3 | 14.45% | 3224g |
| 2 | 3% | 1.55g/cm3 | 14.75% | 3224g |
| 3 | 6% | 1.61g/cm3 | 13.93% | 4653g |
| Average value | | 1.57 g/cm3 | 0.14% | 3224 |

### 5.4 Triaxial Test for 0%, 3% and 6% Mold soil mixed with Lateritic soil

The shear strength of the Mold soil mixed with lateritic soil demonstrates an increasing trend with the rise in percentage composition (Jean-Louis, 2023). Specifically, the shear strength values range from 26.748 kN/m$^2$ to 50.066 kN/m$^2$ as the mixture percentage increases, as outlined in Table 7. According to the undrained shear strength classification for clay provided by Akpokodje, the observed shear strength places the clay in the classification range of soft to firm (Akpokodje, 2001).

**Table 7:** Triaxial Test for 0%, 3% and 6% Mold soil mixed with Lateritic soil

| S/N | Mold soil % | cell pressure | Cohesion | Friction angles | Shear strength | Undrained shear strength classification of Clay (kN/m²) |
|---|---|---|---|---|---|---|
| 1 | 0% | 100,205,310kN/m² | 17.0kN/m² | 6.29° | 28.573 kN/m² | Soft |
| 2 | 3% | 100,205,310kN/m² | 11.0kN/m² | 8.53° | 26.748 kN/m² | soft |
| 3 | 6% | 100,205,310kN/m² | 36.0kN/m² | 7.63° | 50.066 kN/m² | Soft to firm |

## 6. Discussion

Particle Size Distribution: About 10% of sand grains are fine, while 90% are medium to coarse-grained. The percentage of fines is less than 35%, classifying it as coarse-grained according to AASHTO standards. Weight retained in the Mold soil is 47.26 grams.

Atterberg's Limits: Average liquid limit and plasticity index values fall within 50-70% and 17-35%, respectively. The soil is classified as highly plastic at a depth of 1m.

Plasticity Classification: According to Casagrande's plasticity chart, the Mold soil mixed with lateritic soil is classified as inorganic clay of high plasticity (CH) (Casagrande's, 1984).

Compaction Test Results: Maximum dry density (MDD) values range from 1.54 to 1.61 g/cm$^3$.

Optimum moisture content (OMC) values range from 14.45 to 13.93%. MDD increases with the addition of Mold soil (0% to 6%) while OMC values show a fluctuating pattern.

Shear Strength: Shear strength ranges from 26.748 kN/m$^2$ to 50.066 kN/m$^2$. Shear strength increases as the percentage of Mold soil in the mixture increases. The clay is classified as soft to firm based on undrained shear strength.

## 7. Conclusion

The Mold soil mixed with lateritic soil exhibits characteristics of a coarse-grained soil with high plasticity. Its compaction and shear strength properties make it potentially suitable for subgrade and sub-base applications in road construction, considering its plasticity and shear strength classifications.

## Recommendation

The results from this study indicated that the Mold soil have improve geotechnical properties of soil and the Anthill is a good additive to improve lateritic soil for road construction and the Mold soil sample mixed with lateritic soil met the Federal ministry of Works and Housing specification of ≤ 18% for sub-base and base materials. This indicates that the soil is suitable for construction of road.

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