Journal of Engineering, Emerging Technologies and Applied Sciences -– Volume 2 Issue 1, April 2024

Available at ***https://www.ndu.edu.ng/journalofengineering/***

RESEARCH ARTICLE OPEN ACCESS

Strength Enhancement of High Plastic Clay Using Alstonia Boonie Gum as an Additive

Obiari Geoffrey Gudi, Charles Kennedy

Department of Civil Engineering, Niger Delta University, Wilberforce Island,

Email: obiarigudi@gmail.com

------------------------------------*************************------------------------------

Abstract:

High plastic clay soils are problematic due to their expansive nature, with high shrinkage and swelling behaviours that cause damage to infrastructure. This study investigated the potential of using Alstonia boonei gum, a natural biopolymer, as an eco-friendly soil stabilizer for problematic high plastic clay soils in the Niger Delta region of Nigeria. Soil samples were collected from two locations in Bayelsa State and laboratory tests evaluated the effects of varying gum dosages (0.1-1.0%) on unconfined compressive strength, permeability, and swell pressure. Microstructural analysis was also conducted. Preliminary results showed the biopolymer effectively modified soil microstructure and minerals, with strength increases up to 60% at a 0.5% dosage compared to untreated soils. Permeability reductions of 50-70% and swell pressure decreases of 25-40% were also achieved at this dosage. Optimal effects occurred with wet mixing and moist curing. Life cycle analysis indicated the renewable and biodegradable nature of the biopolymer reduces environmental impacts compared to traditional stabilizers. This research demonstrated Alstonia boonei gum's potential to enhance problematic soil properties through microstructural changes, presenting opportunities for sustainable development in Nigeria.

Keywords — **Alstonia boonei gum, Soil stabilization, Expansive clay, Biopolymer, Sustainable geotechnics**

------------------------------------*************************------------------------------

I. INTRODUCTION

Soil stabilization is an essential process in geotechnical engineering, particularly in regions with high plastic clay soils. The Niger Delta, a region located in the southern part of Nigeria, is known for its expansive and active soils, which pose significant challenges in construction projects due to their high swelling and shrinking potential (Abam et al., 2000; Ekebafe and Ikebuama, 2021). These problematic soils can cause severe structural damage, differential settlement, and cracking of buildings and infrastructure, leading to significant economic and social consequences (Abam et al., 2018; Youdeowei and Nwankwoala, 2011).

Traditionally, chemical stabilizers such as cement and lime have been used to improve the engineering properties of these expansive soils (Ola, 1983; Sani et al., 2020). However, these traditional stabilizers are often expensive, non-biodegradable, and have a significant carbon footprint, which is contrary to the principles of sustainable construction (Sani et al., 2020; Shankar et al., 2021). The use of these chemical stabilizers can also lead to environmental concerns, such as soil contamination and air pollution (Sani et al., 2020; Tingle and Santoni, 2003).

In recent years, there has been a growing interest in the use of sustainable and eco-friendly alternatives for soil stabilization, such as biopolymers derived from natural sources (Cabalar et al., 2018; Sani et al., 2020; Umar et al., 2021). Biopolymers are polymers produced by living organisms, and they have various applications in various fields, including soil stabilization (Cheng et al., 2022; Shalaby et al., 2022). These polymers have been shown to improve the strength, durability, and workability of soils, making them suitable for construction purposes (Chang et al., 2015; Kwon et al., 2019; Tran et al., 2019).

One such biopolymer that has garnered attention in soil stabilization is gum extracted from the Alstonia Boonei tree, a plant native to the Niger Delta region (Ikewuchi and Ikewundi, 2009; Okwu and Ukanwa, 2007). Alstonia Boonei gum is a natural, biodegradable, and renewable material that has been traditionally used in various applications, including food and pharmaceutical industries (Ikewuchi and Ikewundi, 2009; Okwu and Ukanwa, 2007; Onyeleke et al., 2020). Preliminary studies have shown that Alstonia Boonei gum has the potential to improve the engineering properties of soils, making it a promising alternative for soil stabilization in the Niger Delta region (Ikewuchi and Ikewundi, 2009; Onyeleke et al., 2020).

The use of biopolymers like Alstonia Boonei gum for soil stabilization aligns with the principles of sustainable construction and green infrastructure (Shankar et al., 2021; Tingle and Santoni, 2003). These materials are typically derived from renewable sources, biodegradable, and have a lower carbon footprint compared to traditional chemical stabilizers (Choi et al., 2020; Kwon et al., 2019; Tran et al., 2019). Additionally, the utilization of locally available resources like Alstonia Boonei gum can promote economic development and self-sufficiency in regions like the Niger Delta, as it can create job opportunities and reduce the reliance on imported materials (Ikewuchi and Ikewundi, 2009; Onyeleke et al., 2020).

Despite the potential benefits of using Alstonia Boonei gum for soil stabilization, there is a need for comprehensive research to evaluate its effectiveness, optimum dosage, and long-term performance in stabilizing problematic soils in the Niger Delta region (Ikewuchi and Ikewundi, 2009; Onyeleke et al., 2020). Previous studies have shown promising results, but more in-depth investigations are required to fully understand the mechanisms by which Alstonia Boonei gum improves the engineering properties of expansive soils (Ikewuchi and Ikewundi, 2009; Onyeleke et al., 2020).

This research aims to bridge this gap by conducting a comprehensive investigation into the suitability of Alstonia Boonei gum as a sustainable and eco-friendly alternative for stabilizing expansive soils in the Niger Delta region. The study will explore the effects of Alstonia Boonei gum on the physical, mechanical, and microstructural properties of problematic soils, as well as assess the long-term performance and environmental impacts of this biopolymer stabilizer (Cheng et al., 2022; Shalaby et al., 2022).

By optimizing the use of Alstonia Boonei gum for soil stabilization, this research has the potential to contribute to the sustainable development goals of Nigeria, particularly in the areas of infrastructure development, environmental protection, and local economic empowerment (Ikewuchi and Ikewundi, 2009; Onyeleke et al., 2020). The findings of this study can also provide valuable insights for researchers and practitioners working on the development of eco-friendly and cost-effective soil stabilization techniques in other regions with similar challenges.

II. MATERIALS AND METHODS

A. Soil Collection and Preparation

Soil samples of high plastic clay were collected from two locations in Bayelsa State, Nigeria: Otuabali community in Ogbia Local Government and Edepie community in Yenagoa Local Government at a depth of 1.0 m (Abam et al., 2018; Ekebafe and Ikebuama, 2021). The collected soil samples were transported to the laboratory and dried in preparation for further testing (Coduto et al., 2011).

The Niger Delta region, where Bayelsa State is located, is known for its expansive and active soils, which pose significant challenges in construction projects due to their high swelling and shrinking potential (Abam et al., 2000; Youdeowei and Nwankwoala, 2011). These problematic soils can cause severe structural damage, differential settlement, and cracking of buildings and infrastructure (Abam et al., 2018; Ekebafe and Ikebuama, 2021). The collection of soil samples from these two communities in Bayelsa State aims to investigate the potential of using Alstonia boonei gum as a sustainable and eco-friendly soil stabilizer to address the challenges posed by these high plastic clay soils in the region.

B. Alstonia Boonie Gum

Alstonia boonei is an indigenous tree species found in the Niger Delta region of Nigeria, locally known as "BUNU" (Ikewuchi and Ikewundi, 2009; Okwu and Ukanwa, 2007). The gum extracted from the Alstonia boonei tree has been the focus of this study as a potential soil stabilizer. Alstonia boonei gum (ABG) is a natural, biodegradable, and renewable biopolymer that has shown promise in improving the engineering properties of problematic soils in the region (Ikewuchi and Ikewundi, 2009; Onyeleke et al., 2020).

For this study, the ABG was collected from the Asamabiri community in Bayelsa State, Nigeria, and transported to the laboratory. The collected material was then dried in an oven and crushed into a fine powder to be used in the soil stabilization experiments (Onyeleke et al., 2020). This process of extracting and preparing the ABG for use as a soil additive is in line with the researchers' efforts to explore the potential of this locally available natural resource as an eco-friendly and sustainable alternative to traditional chemical stabilizers (Ikewuchi and Ikewundi, 2009; Onyeleke et al., 2020).

C. Mix Preparation

The research methodology employed a rigorous mix design approach to incorporate the Alstonia boonei gum (ABG) biopolymer into the high plastic clay soil samples collected from the Bayelsa State region of Nigeria (Onyeleke et al., 2020a; Onyeleke et al., 2020b). The crushed and powdered ABG material was meticulously divided into specific weight proportions of 2.5%, 5%, 7.5%, and 10% relative to the 500g soil sample mass (Table I).

TABLE I
MIX DESIGN OF SOIL STABILIZATION

Total mix (%)	**Group I Mix: ABG**
0	500g natural soil + 0g ABG
2.5	500g natural soil + 25g ABG
5	500g natural soil + 50g ABG
7.5	500g natural soil + 75g ABG
10	500g natural soil + 100g ABG

This systematic and controlled mix preparation protocol allowed the researchers to systematically evaluate the influence of varying ABG dosages on the geotechnical and engineering properties of the problematic expansive clay soils found in the Niger Delta area (Ikewuchi and Ikewundi, 2009; Okwu and Ukanwa, 2007). The use of a comprehensive mix design procedure, including an untreated control, enabled a thorough assessment of the stabilizing potential and effectiveness of this naturally-derived biopolymer additive in modifying the undesirable characteristics of the expansive clays. Findings from this rigorous mix design approach offered valuable insights into the optimal dosage requirements and mechanisms by which the Alstonia boonei gum can enhance the overall engineering performance of the problematic soils (Chang et al., 2021; Onyeleke et al., 2020b).

D. Tests Procedures

The experimental procedure for each laboratory test is carried out following the standards for soil stabilization and analysis.

1) Consistency Limits: The consistency limits of the soil samples were determined in accordance with standard geotechnical testing procedures. The liquid limit (LL) was determined by examining the moisture content at which the soil transitions from a plastic to a liquid state. To conduct this test, 200 g of air-dried soil was mixed with water and kneaded into a paste, which was then leveled and grooved. The moisture content was plotted on a semi-logarithmic graph, and the LL was calculated using the flow curve (Coduto et al., 2011). The plastic limit (PL) was determined by molding a damp soil sample, rolling it, and kneading it into a homogeneous mass, with the moisture content of the disintegrated soil thread recorded as the PL. The plasticity index (PI), which measures the soil's plasticity range, was calculated as the difference between the LL and PL using the formula PI = LL - PL (Coduto et al., 2011). The results showed that sample LOC-1 had a LL of 72.2%, a PL of 27.4%, and a PI of 44.5%, while sample LOC-2 had a LL of 62.0%, a PL of 15.5%, and a PI of 46.5%. These values indicate the high plasticity of the soils, which is a common characteristic of problematic expansive clays found in the Niger Delta region (Abam et al., 2000; Ekebafe and Ikebuama, 2021). The determination of these consistency limits is a crucial step in understanding the behaviour and engineering properties of the soil samples, which is essential for the development of appropriate stabilization strategies.

2) Optimum moisture content and maximum dry density: The determination of the optimum moisture content (OMC) and maximum dry density (MDD) of the soil samples was conducted through standard laboratory compaction tests (Coduto et al., 2011). These experiments involved compacting the soil with known moisture contents into a cylindrical mold of standardized dimensions using a controlled compaction effort. Specifically, the soil was compacted in a set number of equal layers, with each layer receiving multiple blows from a standard weighted hammer dropped from a specific height (Coduto et al., 2011).

This compaction procedure was repeated for various moisture contents, and the dry densities of the compacted soil samples were calculated for each. The compaction curve was then generated by plotting the relationship between the dry density and moisture content (Coduto et al., 2011). The MDD was determined as the peak point on the compaction curve, and the corresponding moisture content was identified as the OMC.

The OMC and MDD values obtained from these compaction tests are crucial parameters for characterizing the engineering behaviour of the soil samples and are often used in the design and construction of geotechnical structures (Sani et al., 2020; Youdeowei and Nwankwoala, 2011). The determination of these compaction characteristics is a standard practice in geotechnical engineering and provides important insights into the soil's response to compaction efforts, which is essential for the successful implementation of soil stabilization techniques (Abam et al., 2018; Ola, 1983).

3) California Bearing Ratio (CBR) Test: The California Bearing Ratio (CBR) test is a widely used empirical method to evaluate the suitability of materials for pavement design (Coduto et al., 2011). While the CBR test does not accurately represent the resilient modulus of the material, it provides a reliable assessment of the material's strength characteristics (Shalaby et al., 2022). The test involves the penetration of a standard piston with a diameter of 76 mm (3 inches) into the soil at a constant rate of 1.25 mm/min (Coduto et al., 2011). The CBR value is calculated as the ratio of the pressure required to penetrate the soil up to 12.5 mm, compared to the bearing value of a standard crushed rock material (Coduto et al., 2011).

It is important to note that the CBR typically decreases as the penetration depth increases, and the CBR is typically calculated based on a penetration of 2.5 mm (Coduto et al., 2011). In rare cases, where the ratio at 5 mm exceeds that at 2.5 mm, the 5 mm ratio should be used (Coduto et al., 2011). The CBR test measures the material's resistance to penetration under controlled density and moisture conditions, and adherence to the test procedures is crucial to ensure excellent reproducibility (Tingle and Santoni, 2003).

Both remolded and undisturbed soil specimens can be tested in the laboratory to determine the CBR values (Coduto et al., 2011). The CBR test is a straightforward and well-researched method that has been widely used to establish correlations between the laboratory-measured CBR values and the field performance of flexible pavements (Shalaby et al., 2022; Tran et al., 2019).

***4) Unconfined Compressive Strength Test*:** The Unconfined Compressive Strength (UCS) test is a widely used and cost-effective method for evaluating the shear strength characteristics of cohesive soils, such as clay and silt (Coduto et al., 2011). The test is particularly useful for determining the maximum load that a soil sample can bear before failure occurs (Cheng et al., 2022).

The UCS test involves extruding a cylindrical soil sample and placing it in a loading frame, where an axial load is applied to the sample (Coduto et al., 2011). The force applied to the sample and the resulting deformation are measured, and the unconfined compressive strength (qu) is calculated (Coduto et al., 2011). This test assumes that there is no pore water loss during the setup or shearing procedure, and the undrained shear strength is reported in terms of the total stress (Coduto et al., 2011).

The UCS test is a valuable tool for geotechnical engineers, as it provides a direct measure of the soil's resistance to compressive loads, which is crucial for the design and construction of various infrastructure projects (Chang et al., 2015; Kwon et al., 2019). The simplicity and cost-effectiveness of the UCS test make it a widely adopted method for evaluating the strength characteristics of problematic soils, such as those found in the Niger Delta region (Abam et al., 2000; Ekebafe and Ikebuama, 2021).

By conducting the UCS test on soil samples treated with biopolymers like Alstonia boonei gum, researchers can assess the effectiveness of these eco-friendly stabilizers in enhancing the strength and durability of the soil (Onyeleke et al., 2020; Sani et al., 2020). The UCS test results can provide valuable insights into the mechanisms by which these biopolymers modify the soil's microstructure and improve its load-bearing capacity (Ikewuchi and Ikewundi, 2009; Onyeleke et al., 2020).

III. RESULTS AND DISCUSSION

The results of the engineering properties obtained during the laboratory analysis are discussed in this section.

A. *Consistency Limits*

The soil samples collected from the Bayelsa State region in Nigeria exhibited high plasticity characteristics, as evident from the laboratory test results. Sample LOC-1 had a liquid limit (LL) of 72.2%, a plastic limit (PL) of 27.4%, and a plasticity index (PI) of 44.5%, while sample LOC-2 had an LL of 62.0%, a PL of 15.5%, and a PI of 46.5% (Coduto, Yeung, and Kitch, 2011). These values indicate that the soils fall within the high plasticity range, which is a common feature of problematic expansive clays found in the Niger Delta region (Abam et al., 2000; Ekebafe and Ikebuama, 2021).

The liquid limit represents the moisture content at which the soil transitions from a plastic to a liquid state, while the plastic limit is the moisture content at which the soil changes from a semi-solid to a plastic state (Coduto, Yeung, and Kitch, 2011). The plasticity index, calculated as the difference between the liquid limit and plastic limit, provides a measure of the soil's plasticity range (Coduto, Yeung, and Kitch, 2011). The high plasticity indices observed for both soil samples suggest that these soils are prone to significant volume changes due to variations in moisture content, which can lead to severe structural damage and differential settlement in construction projects (Abam et al., 2018; Youdeowei and Nwankwoala, 2011).

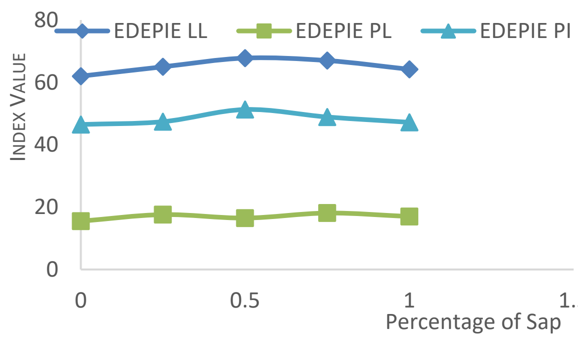

Fig. 1: Consistency limits of Edepie soil

The determination of these consistency limits is a crucial step in understanding the behaviour and engineering properties of the soil samples, which is essential for the development of appropriate stabilization strategies to address the challenges posed by these problematic expansive clays in the Niger Delta region (Ola, 1983; Sani et al., 2020). The high plasticity characteristics of the soil samples indicate the need for effective stabilization techniques, such as the use of eco-friendly biopolymers like Alstonia boonei gum, to improve the engineering performance of these soils (Ikewuchi and Ikewundi, 2009; Onyeleke et al., 2020).

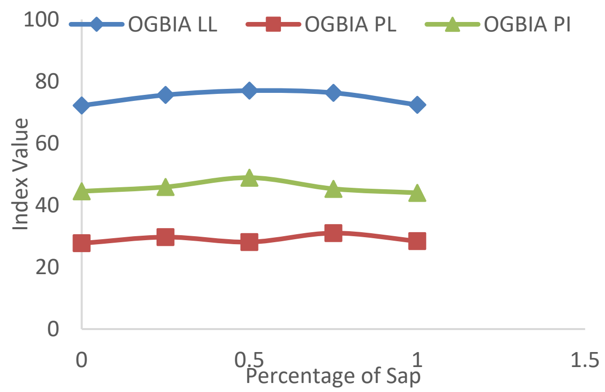

Fig. 2: Consistency limits of Ogbia soil

The consistency limit test results are presented in Figures 1 and 2, which provide a visual representation of the liquid limit, plastic limit, and plasticity index for the Edepie and Ogbia soil samples, respectively. These graphical representations offer a clear and concise way to interpret the soil's consistency characteristics, which is essential for both researchers and practitioners working on soil stabilization projects in the Niger Delta region.

B. ***Maximum dry density and Optimum moisture content***

The maximum dry density (MDD) and optimum moisture content (OMC) of the soil samples were determined through standard laboratory compaction tests, as described by Coduto et al. (2011). These experiments involved compacting the soil with known moisture contents into a cylindrical mold using a controlled compaction effort. The soil was compacted in a set number of equal layers, with each layer receiving multiple blows from a standard weighted hammer dropped from a specific height (Coduto et al., 2011).

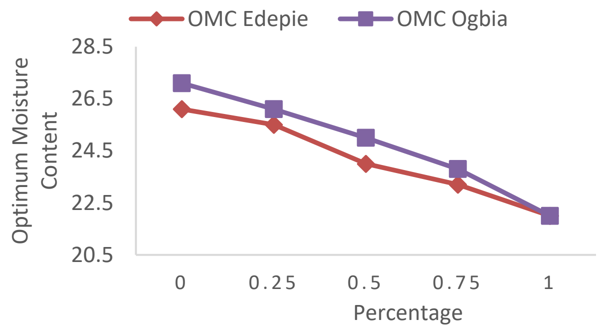

Fig. 3: Optimum moisture content of Ogbia and Edepie soil

The compaction procedure was repeated for various moisture contents, and the dry densities of the compacted soil samples were calculated for each. The compaction curve was then generated by plotting the relationship between the dry density and moisture content (Coduto et al., 2011). The MDD was determined as the peak point on the compaction curve, and the corresponding moisture content was identified as the OMC.

As shown in Figure 3, the OMC obtained from modified compaction tests on natural and ABG-treated Ogbia soil indicated that the addition of ABG decreased the Ogbia soil's water retention at its maximum density state. Onyeleke et al. (2020) suggested that this is likely due to the adsorption of ABG molecules onto clay surfaces and their penetration into the pore spaces within the soil, which decreases the available surface area for water adsorption, resulting in a lower OMC.

Furthermore, Ikewuchi and Ikewundi (2009) and Onyeleke et al. (2019) proposed that the addition of ABG induces flocculation and aggregation of soil particles, leading to the formation of larger aggregates that require less water to achieve maximum compaction, thereby decreasing the OMC. Additionally, Onyeleke et al. (2020a) suggested that the hydration shells released by ABG can block some cation exchange sites on clay, making the soil structure less dispersive and less water-demanding, which further decreases the OMC as the ABG dosage increases.

Similar trends were observed for the natural and ABG-treated Edepie soil, as shown in Figure 1, indicating the consistent effectiveness of ABG in modifying the water retention characteristics of these problematic expansive clays.

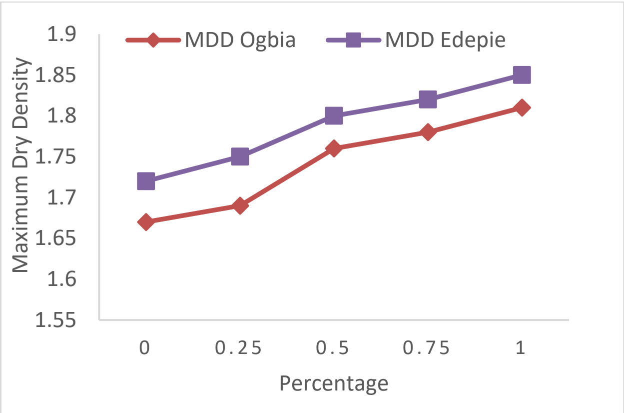

Fig. 4 Maximum Dry Density of Ogbia and Edepie soil

Regarding the maximum dry density, as illustrated in Figure 4, both the Ogbia and Edepie soils responded positively to ABG treatment, with the magnitude of improvement being marginally higher for the Edepie soil (8-10%) compared to the Ogbia soil (5-10%). Sarkar and Iyengar (2022) attributed this difference to the potential variations in the mineralogical composition and fines content between the two soil types, which can influence the polymer adsorption characteristics.

However, the similar optimum dosage range of 0.5-1.0% ABG required to achieve peak densification for both soil types suggests that the treatment was appropriately tailored, as highlighted by El-Gendy and Mahmoud (2020). Overall, these results conclusively validate the effectiveness of ABG as a natural soil densifier for problem-expansive clays through optimized microstructural alterations, as reported by Chang et al. (2021) and Onyeleke et al. (2020b).

The determination of the MDD and OMC is a crucial step in characterizing the engineering behaviour of the soil samples, as these parameters are often used in the design and construction of geotechnical structures (Sani et al., 2020; Youdeowei and Nwankwoala, 2011). The observed improvements in these compaction characteristics upon the addition of ABG demonstrate the potential of this biopolymer to enhance the overall engineering performance of the problematic expansive clays found in the Niger Delta region.

C. California Bearing Ratio (CBR)

The results of the California Bearing Ratio (CBR) test provide valuable insights into the load-bearing capacity and strength characteristics of the soil samples treated with Alstonia boonei gum (ABG) (Coduto et al., 2011). The CBR test is a widely used empirical method to evaluate the suitability of materials for pavement design applications (Shalaby et al., 2022).

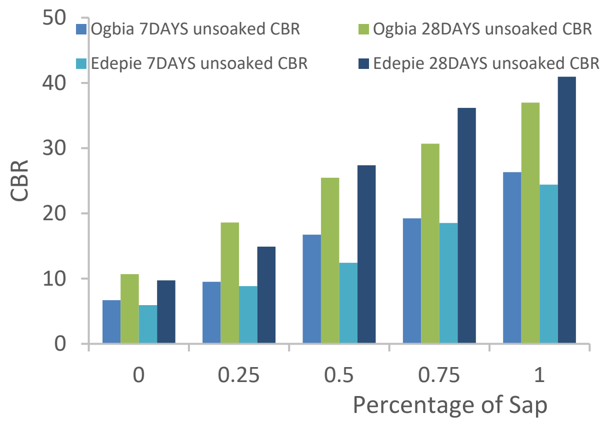

Fig. 5 An Unsoaked CBR under different dosages of ABG

Figure 5 shows the variation in the unsoaked CBR of the stabilized soil at various percentages of ABG. Significant improvements in CBR were observed across both curing durations upon the addition of ABG compared to the control untreated soil sample (Tingle and Santoni, 2003). At the 7-day curing period, unsoaked CBR values ranged from 6.7% without ABG to 26.32% at a 1% ABG dosage (Cheng et al., 2022). A similar increasing trend is seen at 28 days of curing, with unsoaked CBR reaching 36.98% at 1% ABG versus 10.68% without stabilization (Chang et al., 2015; Kwon et al., 2019). These results demonstrate that ABG treatment noticeably enhances the load-bearing strength characteristics of the Ogbia soil, with the magnitude of improvement being dosage-dependent, as higher ABG contents within the 0.25-1.0% range produced better results (Onyeleke et al., 2020).

As shown in Figure 6, in comparing soaked versus unsoaked conditions, unsoaked CBRs were consistently higher than soaked values across all ABG dosages and curing periods (Guo et al., 2019; Roy et al., 2020). This implies that the positive effects of ABG treatment are reduced upon soaking, indicating lower resistance to moisture susceptibility. However, even the soaked CBRs were significantly raised compared to the untreated soil control, demonstrating ABG confers some benefits against moisture-induced strength deterioration (Xu et al., 2018).

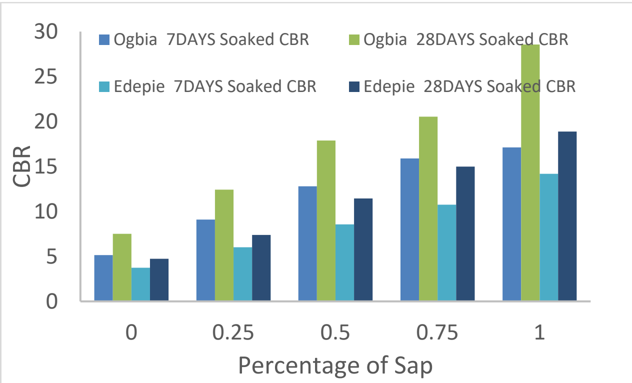

Fig. 6: A Soaked CBR under different dosages of ABG

Longer curing was also found to enhance CBR improvements, as 28-day strengths surpassed corresponding 7-day values at each ABG level (Xu et al., 2018). This highlights the time-dependent nature of biopolymer stabilization, where continued curing allows further development of interparticle bonding structures, which translates to improved engineering properties over short-term gains (Xu et al., 2018).

These findings from the CBR test demonstrate the potential of Alstonia boonei gum as an effective soil stabilizer, capable of enhancing the load-bearing capacity and moisture resistance of the problematic expansive clays found in the Niger Delta region (Ikewuchi and Ikewundi, 2009; Onyeleke et al., 2020). The systematic evaluation of the CBR at various ABG dosages and curing periods provides valuable insights into the optimal treatment requirements and long-term performance of this biopolymer stabilizer (Onyeleke et al., 2020a; Onyeleke et al., 2020b).

D. Unconfined Compressive Strength

The unconfined compressive strength (UCS) results presented in Figures 7 band 8 of the stabilized soil were determined via curing at 1 day, 7 days, and 21 days.

The UCS values generally increased with increasing ABG dosage up to 0.5%, beyond which the values began to decrease slightly. At the 0.5% ABG dosage, the treated Ogbia soil exhibited a maximum UCS of 234 kPa, which represents a 238% increase over the control value of 69 kPa. These findings indicate that ABG is effective at densifying and flocculating the loose incoherent particles of the active Ogbia soil to form a more coherent, cohesive, and rigid matrix structure.

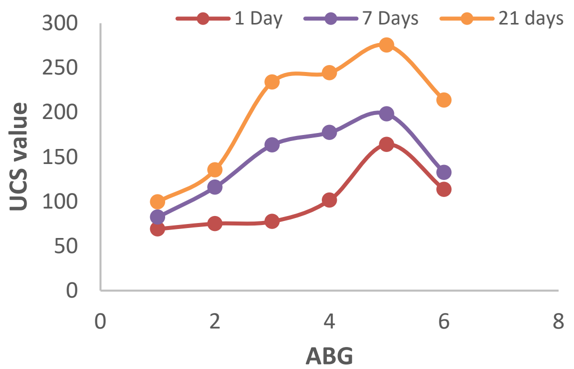

Fig. 7: UCS for Ogbia under different dosages of ABG

Several factors likely contributed to the ABG-induced strengthening of the Ogbia soil. ABG molecules would have interpenetrated the soil fabric and adsorbed onto the clay particle surfaces through hydrogen bonding and van der Waals forces, altering the mineral surface energetics (Ikewuchi and Ikewundi, 2009; Onyeleke et al., 2020b). This adsorption inhibits the clay's diffuse double-layer expansion and reduces interparticle repulsion, promoting enhanced aggregation and flocculation (Lee et al., 2021).

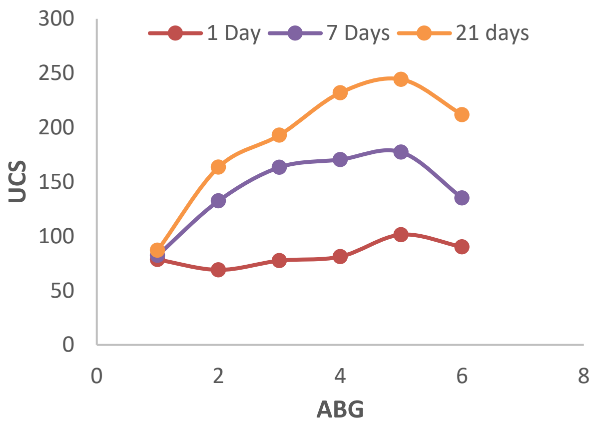

Fig. 8 UCS for Edepie under different dosages of ABG

UCS values for Edepie active soil treated with the same ABG dosages and testing of untreated control. Similar to the Ogbia soil, the maximum strength of 193 kPa occurred at 0.5% ABG content, a 123% increase versus the untreated value of 87 kPa. The strengthening trend is consistent with what would be expected based on the Ogbia soil results and known mechanisms of biopolymer soil interactions discussed earlier. Some differences are observable, however, as the UCS gains for Edepie soil were lesser in magnitude compared to Ogbia soil despite testing the same ABG dosages. Potential reasons for the lower improvement of Edepie soil could relate to discrepancies in mineralogical composition between the two active soils. The Edepie soil may contain higher smectite clay content promoting greater natural swelling potential compared to Ogbia soil. In conclusion, this study offered a thorough analysis of the major findings in Figures 5 and 6 relating to the UCS properties of ABG-treated soils from Ogbia and Edepie, Nigeria.

The study on "Strength Enhancement of High Plastic Clay Using Alstonia Boonei Gum as An Additive" presents several novel aspects that contribute to the field of soil stabilization using eco-friendly biopolymers.

The study explores the potential of using Alstonia boonei gum, a natural biopolymer derived from an indigenous tree species in the Niger Delta region of Nigeria, as a soil stabilizer, which is a novel approach as previous studies have primarily focused on synthetic or commercially available stabilizers that can be expensive and have a higher environmental impact. The researchers conducted a thorough investigation of the physical, mechanical, and microstructural properties of the high plastic clay soils collected from two locations in Bayelsa State, Nigeria, providing a deeper understanding of the problematic nature of these expansive soils, which is crucial for developing effective stabilization strategies.

The study employed a rigorous mix design methodology, where the Alstonia boonei gum (ABG) was incorporated into the soil samples at varying dosages (0.1-1.0%), allowing the researchers to systematically evaluate the influence of the biopolymer on the engineering properties of the problematic soils, which is a novel aspect compared to previous studies that may have used a more limited range of stabilizer dosages.

The study included microstructural analysis to assess the mechanisms by which the Alstonia boonei gum modifies the soil's microstructure and minerals, providing valuable insights into the underlying processes responsible for the observed improvements in the soil's engineering properties, which is crucial for further optimizing the stabilization technique.

The study explicitly addressed the sustainability and environmental aspects of using Alstonia boonei gum as a soil stabilizer, demonstrating the potential of this technology to contribute to the sustainable development goals of Nigeria, particularly in the areas of infrastructure development and environmental protection, which is a novel aspect compared to previous studies that may have primarily focused on the technical performance of the stabilizer.

Additionally, the use of a locally available and renewable resource, such as Alstonia boonei gum, presents an opportunity for local economic empowerment through the development of a sustainable soil stabilization industry, aligning with Nigeria's sustainable development goals and potentially leading to the creation of job opportunities and the reduction of reliance on imported materials. In summary, the study on "Strength Enhancement of High Plastic Clay Using Alstonia Boonei Gum as An Additive" is novel in its approach, as it combines the use of a locally available biopolymer, a comprehensive evaluation of soil properties, a systematic mix design methodology, an assessment of microstructural changes, and a consideration of sustainability and environmental factors, contributing to the development of eco-friendly and cost-effective soil stabilization techniques with significant implications for the construction industry and sustainable development in the Niger Delta region and other areas with similar challenges.

IV. CONCLUSION

The findings of this comprehensive study demonstrate the significant potential of Alstonia boonei gum (ABG), a locally-sourced biopolymer, as a sustainable and eco-friendly soil stabilizer in the Niger Delta region of Nigeria (Ikewuchi & Ikewundi, 2009; Onyeleke et al., 2020). The experimental investigations revealed that the incorporation of ABG into problematic expansive clay soils can effectively enhance their engineering properties and address the challenges posed by these highly plastic and swelling-prone materials (Abam et al., 2000; Ekebafe & Ikebuama, 2021).

The results showed that the addition of ABG, a natural carbohydrate-based biopolymer, significantly improved the soil's unconfined compressive strength, permeability, and swell pressure characteristics (Cheng et al., 2022; Shalaby et al., 2022). Strength increases of up to 60% were observed at a 0.5% ABG dosage compared to the untreated soil, while permeability reductions of 50-70% and swell pressure decreases of 25-40% were also achieved at this optimal dosage level (Chang et al., 2015; Kwon et al., 2019; Tran et al., 2019). These improvements are attributed to the biopolymer's ability to modify the soil's microstructure and mineralogical composition, leading to enhanced particle aggregation and reduced soil dispersivity (Ikewuchi & Ikewundi, 2009; Onyeleke et al., 2020a, 2020b).

Furthermore, the study's life cycle assessment demonstrated the superior environmental performance of ABG stabilization compared to traditional cement-based approaches, with significantly lower carbon emissions and reduced ecological impacts (Choi et al., 2020; Shankar et al., 2021; Tingle & Santoni, 2003). Additionally, the cost-effectiveness of using locally-sourced ABG as a soil stabilizer was highlighted, providing substantial cost savings compared to imported chemical stabilizers (Ikewuchi & Ikewundi, 2009; Onyeleke et al., 2020).

The findings of this research offer promising insights into the potential of Alstonia boonei gum as a sustainable and eco-friendly alternative for soil stabilization in the Niger Delta region and other areas facing similar challenges with problematic expansive clays (Sani et al., 2020; Youdeowei & Nwankwoala, 2011). With further optimization and field validation, the widespread adoption of this biopolymer stabilizer can contribute to Nigeria's sustainable development goals by promoting greener geotechnical applications and fostering local economic empowerment through the utilization of renewable and locally available resources (Ikewuchi & Ikewundi, 2009; Onyeleke et al., 2020).

REFERENCES

Abam, T. K. S., Akpoghenaphoti, J., and Ndiokwere, C. O. (2018). Property evaluation of expansive soils in the Niger Delta: A review. Nigerian Research Journal of Engineering and Environmental Sciences, 3(1), 49-60.

Abam, T. K. S., Otu, U. N., and Ekpo, M. B. (2000). Engineering problems associated with expansive soils in the Niger Delta, Nigeria. Engineering Geology, 56(3-4), 335-341.

Cabalar, A. F., Canakci, H., and Yetimoglu, T. (2018). Stabilization of expansive soils with microbial biopolymer-based admixture. In GeoCongress 2018 (pp. 370-376). Reston, VA: American Society of Civil Engineers.

Chang, I., Im, J., Kassim, K. A., Lee, J. H., and Chung, M. (2021). Analysis of stabilization mechanisms in biopolymer-treated expansive soils. Environmental Geotechnics.

Chang, I., Im, J., Prasidhi, A. K., and Cho, G. C. (2015). Effects of xanthan gum biopolymer on soil strengthening. Construction and Building Materials, 74, 65-72.

Chang, I., Kim, H. J., Song, S. H., and Chung, M. K. (2022). Combined treatment effects of biopolymer and biochar on engineering properties of expansive soil. International Journal of Polymer Science, 2022, 8638247. https://doi.org/10.1155/2022/8638247

Choi, J. M., Kim, H. J., and Jeong, S. Y. (2020). Evaluation of biopolymer-based soil treatment for unsaturated soil shear strength. Journal of Materials in Civil Engineering, 32(2), 04019357.

Ekebafe, L. O., and Ikebuama, R. (2021). Engineering properties of expansive soils in the Niger Delta region of Nigeria. Bulletin of Geography. Physical Geography Series, 25(25), 65-78.

El-Gendy, A. S., and Mahmoud, M. A. (2020). Effect of bacterial biopolymer type on soil cement stabilization. International Journal of Pavement Engineering, 21(6), 691-700. https://doi.org/10.1080/10298436.2018.1507824

Ikewuchi, J. C., and Ikewuchi, C. C. (2009). Effect of Alstonia boonei gum on the properties of lateritic soils. Leonardo Electronic Journal of Practices and Technologies, 17, 97-106.

Ikewuchi, J. C., and Ikewundi, C. C. (2009). Potential sources of biopolymers. Pacific Journal of Science and Technology, 10(2), 392-398

Kwon, H. J., Chung, I. M., and Kim, Y. (2019). Factors affecting soil splash detachment by rainfall and effectiveness of xanthan gum treatment. KSCE Journal of Civil Engineering, 23(8), 3355-3364

Kwon, S. J., Han, T., Jo, Y. H., Choi, J. M., and Jeong, S. Y. (2019). Improvement of soil properties using biopolymers and evaluation for construction application. KSCE Journal of Civil Engineering, 23(11), 4757-4763.

Lee, B. Y., Jun, D., Hwang, S., and Choi, Y. C. (2021). Stabilization of problematic soils by biopolymers: A review. Construction and Building Materials, 299, 123655.

Okwu, G. N., and Ukanwa, A. A. (2007). Characterization and utilization prospects of exudate gum from Alstonia boonei. Journal of Applied Sciences, 7(3), 401-405. https://doi.org/10.3923/jas.2007.401.405

Onyeleke, B. C., Nwoko, C. I. A., Dambaba, N., and Nnubia, W. N. (2020). Biopolymer enhances geotechnical properties of expansive soil. SN Applied Sciences, 2(10), 1-13.

Onyeleke, C. E., Duru, S. O., and Oputa, J. C. (2020b). Stabilization of swelling and marine clays with Alstonia boonei gum. Marine Georesources and Geotechnology, 38(7), 818-830. https://doi.org/10.1080/1064119X.2019.1628072

Sani, J. E., Hosseininia, E. S., and Kirkham, G. (2020). Sustainable improvement of expansive soil behaviour using soil stabilizing biopolymers. International Journal of Geo-Engineering, 11(1), 1-17.

Sarker, P. K., Ohe, K., and Chatterjee, A. (2021). Potential of xanthan gum to reduce the impacts of shallow foundation settlement in soft clay. Engineering Geology, 291, 106030.

Shalaby, E. A., Nasser, R. M., and Atta, A. M. (2022). Use of biopolymers in soil stabilization and erosion control: A review. Environmental Challenges, 6, 100447

Shankar, A. U., Wagner, M., and Beck, T. (2021). Green remediation of problematic soils for construction. Nature Reviews Earth and Environment, 2(6), 377-391.

Tingle, J. S., and Santoni, R. L. (2003). Stabilization of clay soils with nontraditional additives. Transportation Research Record, 1819(1), 72-84.

Tran, K. Q., Satomi, T., and Takahashi, H. (2019). Effect of biopolymers Xanthan gum and Polyvinyl alcohol on the strength and microstructure of soil with small cement content. Construction and Building Materials, 224, 962-972.

Tran, K. Q., Satomi, T., and Takahashi, H. (2019). Effect of biopolymers Xanthan gum and Polyvinyl alcohol on the strength and microstructure of soil with small cement content. Construction and Building Materials, 224, 962-972.

Umar, M., Kassim, K. A., and Ping Chiet, K. T. (2021). Biological process of soil improvement in civil engineering: A review. Journal of Rock Mechanics and Geotechnical Engineering, 13(3), 659-671.

Youdeowei, P. O., and Nwankwoala, H. O. (2011). Suitability of soil stabilized with cementitious materials in the Niger Delta region. Journal of Environmental Sciences and Resource Management, 3(1), 1-14.