

Effect of Bio-Polymer on the Properties of Expansive Soil

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ABSTRACT: The process of modifying soil's properties by adding various admixture and additives is one of the most widely practiced ground improvement methods. The stabilization of expansive soils has been examined both from the aspect of removing their potential for swelling and shrinking, as well as from the standpoint of increasing those mechanical properties of relevance in civil engineering. This study evaluated the performance of biopolymer i.e Guar Gum in enhancing Free swell index, Unconfined compressive strength, Atterberg limit, Consolidation, pH and Conductivity of expansive soils. The varied Guar Gum dosages were maintained by dry soil mass weight. According to the results, when the amount of Guar Gum was raised, the strength of the expansive soil after treatment increased swelling characteristics decreased, Atterberg limit increased, coefficient consolidation decreases, pH increased and conductivity decreased. One of the main advantages of using biopolymers such as guar gum as soil stabilizers is that relatively low amounts of Guar Gum percentage i.e. 0.5% - 1.00% are needed to achieve maximum modification of the geotechnical properties comparable to those obtained with conventional soil stabilizers like cement and lime. This is a significant advantage in terms of cost, resource efficiency, and environmental impact. The practical engineering significance of Guar Gum on the properties of expansive soils lies in its ability to effectively stabilize these soils, enhance their strength, improve their workability, and provide a more sustainable and cost-effective solution for construction projects compared to treatment using traditional materials such chemicals such as cement and lime. Guar gum reduces swelling, mitigates plasticity, making it a valuable tool in addressing the challenges posed by expansive soils. Its environmentally friendly nature and cost-effectiveness further enhance its appeal, particularly in projects that prioritize sustainability. By using guar gum to stabilize expansive soils, engineers can ensure more reliable, durable, and cost-efficient infrastructure and improving the safety and performance of structures. Geo-environmental engineering has given a lot of attention to biopolymers because they offer a carbon neutral substitute and stabilize the soil.

KEYWORDS: Expansive Soil, Biopolymer, Guar Gum, Unconfined Compressive Strength, and Coefficient of Consolidation

1. INTRODUCTION

Soil is regarded as a three-phase system in geotechnical engineering, consisting of solid, liquid and gas. The water and air are contained in the voids of a soil, which are the spaces between mineral particles. Soil is classified into four types: sand, silt, clay, and loam. Each soil has unique characteristics and needs when it comes to soil stabilization. When working on soil stabilization, one of the most crucial elements to examine is the soil's organic content. The soil's organic matter is frequently measured by the Plasticity Index, which is determined by an Atterberg test. The process of boosting a soil's strength or bearing capacity through proportioning, adding appropriate admixtures, controlled compaction or stabilizers is referred to as "soil stabilization." Enhancing a soil's shear strength parameters will increase its bearing capacity, and controlling a soil's shrink-swell characteristics will improve the ability of a subgrade to support loads, which will support foundations and pavements. The process of modifying soil's properties by adding various admixture and additives is widely used in ground improvement methods. Biological methods provide a strong and durable solution in addition to being environmentally friendly. A long-term, effective, and sustainable alternative to traditional procedures is soil stabilization by biological means. Geo-environmental engineering has given a lot of attention to biopolymers because they offer a carbon-neutral substitute in order to remove heavy metals and stabilize the soil. Biopolymers are unique because of the polymeric molecules and sugars they contain. Various biopolymers, including Xanthan Gum, Guar Gum, Cellulose, Starch and Chitosan are available. This study examines the application of soil stabilization with Guar Gum. The following are the main objectives of this research.

- a) Evaluation of plasticity characteristics of Guar Gum treated soil.
- b) Detailed investigation on swelling characteristics of Guar Gum treated soil.
- c) Strength behaviour of Guar Gum treated soil.
- d) Evaluation of pH and conductivity of Guar Gum treated soil.
- e) To determine the coefficient of consolidation behaviour of Guar Gum treated soil.

2. LITERATURE REVIEW

In this part, we offer a concise analysis of the literature on the stabilization of clayey soil using Guar Gum.

Sujatha and Saisree (2019) conducted an experimental study to thoroughly investigate the engineering properties of soil treated with Guar Gum. The results showed that the MDD of the treated soil increased slightly, while the OMC also rose at higher concentrations of Guar Gum. It was observed that both the biopolymer concentration and the curing duration had a significant effect on the strength of the soil-Guar Gum matrix. Specifically, the soil's unconfined compressive strength increased significantly after treatment. The addition of Guar Gum led to the development of hydrogels, which thickened the soil matrix and clogged pore spaces, effectively reducing the soil's compressibility. Since Guar Gum is prone to deterioration, durability testing was performed over a 90-day period. The findings revealed that there was no noticeable degradation of the soil sample throughout the investigation, indicating the stability of the treated soil during the study period. The study highlights the significant advantages of using Guar Gum, for soil stabilization, which offers an environmentally friendly alternative to traditional methods. Guar Gum improves soil's geotechnical properties by enhancing bonding through hydrogen bonding, without altering the

soil's mineral composition. Guar gum significantly enhances soil strength, stability, and durability, making it a promising sustainable option for soil stabilization.

Dehghan et al. (2019) conducted a series of tests to evaluate the engineering properties of soil treated with varying concentrations of biopolymers and under different curing durations. The tests included compaction, permeability, consolidation, and unconsolidated-undrained triaxial tests. In addition, scanning electron microscopy (SEM) was utilized to investigate the changes in the morphological features of the stabilized soil. The results indicated that biopolymer treatment reduced MDD and permeability in the collapsible soil, while increasing OMC. The findings also showed that both the biopolymer concentration and curing duration significantly influenced the strain-stress behavior of the soil. Overall, the study highlighted the effectiveness of Guar Gum and Xanthan Gum in stabilizing expansive soil, offering an environmentally friendly and durable alternative to traditional stabilizing agents. The addition of biopolymers was found to dramatically reduce the permeability at different densities, as the biopolymer molecules bound the soil particles together and filled the pore spaces. This reduction in permeability is crucial for enhancing the stability of collapsible soils. The greatest improvement in soil strength was observed at a 1% biopolymer concentration, with further increases in strength maintained even when the biopolymer concentration was raised to 2%. Despite a decrease in soil density, the addition of biopolymers was shown to improve soil stability. Furthermore, extending the treatment duration to 28 days resulted in increased soil resistance, with cohesion continuing to improve over time. Additionally, increasing confining pressure was found to further enhance the soil's resistance. The study concluded that the addition of biopolymers effectively reduces the collapsible potential of the soil, establishing it as a feasible method for improving the stability and durability of collapsible soils. Biopolymers can improve collapsible soils, though further research is needed on their durability in different environmental conditions. The biopolymer industry is encouraged to make biopolymers more economically competitive with materials like cement and lime.

Anandha et al. (2021) investigated whether it is possible to use Guar Gum stabilized soil as a liner for a landfill by enhancing the hydro-mechanical behavior and ability to attenuate heavy metals of the inadequately graded clay-sand combination. In contrast to traditional bentonite liners for landfills, the study looked at the use of GGSS as an alternative liner material. Biopolymers, such as Xanthan Gum, Guar Gum, and biopolymer blends, have significant potential in geoenvironmental applications, offering a carbon-neutral substitute to traditional stabilizing agents. This study evaluated their long-term effectiveness in stabilizing soil, specifically for use as landfill base liners and contaminant barriers. The results showed that biopolymer-amended soils (BAS) exhibited a 3-5 order reduction in permeability and a 2-5 times rise in unconfined strength with just 2% biopolymer addition. The study also highlighted that the effectiveness of BAS as a liner material was influenced by the type, dosage, and age of the biopolymer. XG and GG demonstrated strong heavy metal attenuation capabilities due to their tendency to form viscous gels. While permeability increased slightly after extreme drying, the biopolymer-treated soil remains suitable as a baseliner in landfills, where extreme drying is unlikely due to the presence of trash and leachate. The study suggests that biopolymers can be effectively used to stabilize in-situ soils, enabling their use as base liners, barriers against contaminants, or for controlling seepage. Further research is recommended to develop a large-scale mixing method and to explore biopolymer stabilization to improve the strength and heavy-metal attenuation capacity of geosynthetic clay liners. Additionally, GGSS has a much higher capacity to attenuate the effects of heavy metals than traditional liners and is more cost-effective. These positive outcomes support the use of GG as a healthy, profitable, and environmentally friendly liner material.

Sujatha et al. (2020) conducted an in-depth investigation into the effects of Guar Gum on soil properties and strength enhancement.

Their study revealed that Guar Gum significantly alters soil characteristics. Guar Gum's capacity to form gel plugs and biofilms enables it to fill the soil's pore spaces, creating a uniform distribution throughout the soil matrix via hydration-induced hydrogelation. This process leads to a dramatic decrease in soil permeability, as gel formation reduces the size of pore spaces. The study also observed a slight change in the pH of the soil-guar mixture, with the viscosity of the Guar Gum varying significantly with concentration. This demonstrates that the pH compatibility at different Guar Gum concentrations makes it suitable for use in applications such as landfill liners. The modification of the soil's matrix properties is largely attributed to the dissolution of Guar Gum in water, which creates high-viscosity gels. During hydration, strong hydrogen bonds form, binding the soil particles together and thus enhancing the soil's structure. Over time, as the soil-Guar Gum matrix undergoes the aging process, it becomes increasingly rigid and durable, resulting in improved resilience, strength, and a reduction in compressibility.

Ayeldeen et al. (2016) carried out a study examining how poorly graded sand and high-plasticity silt respond when combined with different types of biopolymers. The results showed that the effects of biopolymers on soil characteristics vary with several factors, including the biopolymer type and concentration, curing duration, and soil type. The conclusion drawn from the experiment is that Guar Gum was more effective than Xanthan Gum at reducing permeability and enhancing shear strength. The accumulation of biopolymers within the soil pores results in a transition from a gel-like state to a glassy state as a result of dehydration. This transformation strengthens the soil and improves its permeability. A key area that requires further investigation is the durability of biopolymers, particularly under different wetting and drying cycles and varying environmental conditions. The wide range of biopolymer types and compositions enables the selection of the appropriate biopolymer for specific applications and environmental conditions. While biopolymers are more environmentally friendly and sustainable than materials like cement, they are currently less cost-effective. However, as biopolymer production increases, their prices are expected to decrease, potentially making them economically viable for soil improvement applications.

Latifi et al. (2017) conducted a range of laboratory macro- and microstructural investigations to evaluate the strength of bentonite and kaolinite soils treated with xanthan gum and to determine the stabilization mechanisms at the atomic scale of the treated sample. The results from the UCS test showed that Xanthan Gum at 1% for bentonite and 1.5% for kaolinite produced the most effective stabilization. Generally, higher concentrations of Xanthan Gum and longer curing times led to higher shear strength, measured by UCS and direct shear tests, as well as higher yield stress and stiffness in 1-D consolidation tests for the stabilized specimens. The greatest enhancements in the mechanical properties of the stabilized samples were observed during the initial 28 days of curing, with only minor changes observed between 28 and 90 days. These findings indicate that Xanthan Gum can be an efficient stabilizer for clayey soils. Additionally, the study found that the development of cementitious compounds led to the bonding of soil particles, filling of pore spaces, and a reduction in the total surface area of the particles. These results provide important insight into the stabilization processes that occur when xanthan gum is used to treat fine-grained soils. Based on the results, xanthan gum is recommended as an environmentally friendly alternative to conventional soil stabilization methods for problematic clayey soils.

Ramachandran et al. (2021) studied stabilizing sand and clay mixtures using Xanthan Gum biopolymer and explored the underlying mechanisms of stabilization through various microscopic techniques. The research reveals that adding clay significantly enhances the compressive strength of biopolymer-stabilized sands, as evidenced by unconfined compressive strength (UCS) testing. Key findings include: The optimal biopolymer dosage depends on the desired strength, curing temperature, and duration. A 0.5% biopolymer dosage provides the best performance at 30°C for 7 days.

Digital Image Correlation was utilized to identify localized stress concentrations in specimens subjected to compressive loading, which ultimately result in failure. The water absorption test showed that sand samples stabilized with biopolymer experienced local failure caused by pore blockage, while the addition of clay helped distribute moisture more evenly, reducing absorption and preventing failure. Microstructural analysis using scanning electron microscopy revealed that the biopolymer and clay particles form a stable network, enhancing the stiffness of the soil. PeakForce-QNM mapping showed that moisture exposure weakened the biopolymer network, leading to a reduction in strength. The work emphasizes the promise of bacterial polymerization as a sustainable method of soil stabilization, though further research is needed to explore the effects of moisture content and biopolymer dissolution, and to conduct additional strength tests, such as triaxial testing. The investigation of failure modes is crucial for accurately interpreting UCS results.

Jang (2020) examined five commonly used biopolymers, exploring their production processes, physical and chemical characteristics, potential applications, and market value. Research has demonstrated that biopolymers, such as Xanthan Gum, Gellan Gum, Agar, Polyacrylamide (PAM), and Guar Gum, improve soil strength. For example, xanthan gum enhances cohesion and friction angle in sand, while gellan gum increases cohesion in sand-clay mixtures, particularly when mixed properly. Agar improves unconfined compressive strength (UCS) in clayey soils due to its long molecular structure. Guar gum is particularly effective in increasing UCS and cohesion in silt compared to other biopolymers like modified starch and xanthan gum. However, the effectiveness of each biopolymer varies depending on soil type, biopolymer ratios, temperature, and moisture conditions. The study emphasizes the need to comprehend the physical and chemical properties of biopolymers for their optimal application in soil stabilization, ensuring that the right biopolymer is chosen for specific geographic and soil conditions.

Soldo et al. (2020) conducted an experimental study to develop a biopolymer-based, environmentally friendly method for soil improvement and to investigate how different biopolymers affect the mechanical behavior of soils. The study aimed to explore the impact of different biopolymer concentrations and curing times on soil performance, as well as the impact of different types of biopolymer. The biopolymers examined in the study included Xanthan Gum, Burdock Gum, Guar Gum, Chitosan, and Alginate. Three biopolymer concentrations (1%, 2%, and 4%) were tested, with curing times ranging from 4 to 30 days. To assess the mechanical characteristics of biopolymer-treated soils, several laboratory tests were conducted, including Unconfined Compression, Splitting Tensile, Unconsolidated Undrained Triaxial, and Direct Shear tests. The results indicated that as curing time increased, the strength values in the UC, ST, and UU tests improved significantly. The greatest enhancement in mechanical properties was observed during the first four days of curing, with relatively minor changes occurring during the following 4 to 30 days. Notably, the mechanical characteristics in the UU test continued to evolve throughout the curing period, showing significant changes from day 0 to day 30. Furthermore, the study found that larger specimens required extended drying and curing times to achieve optimal strength. Incorporating biopolymers increased the tensile strength of the soil, particularly in the UC and ST tests, as biopolymers contributed to the cohesion of the treated soil. However, the results from the Direct Shear test revealed an interesting finding: while biopolymers enhanced the soil's cohesiveness, they reduced the friction angle over time. This observation suggests that the beneficial effects of biopolymers on soil cohesion may not be accompanied by an increase in shear strength, which may require careful consideration when designing soil stabilization treatments. Additionally, the relationship between the biopolymer concentration and the mechanical characteristics of the soil was found to be complex. The increase in biopolymer percentage did not always result in a linear improvement in soil strength, indicating that there is an optimal biopolymer concentration for each soil type, depending on the specific biopolymer and water content.

Higher biopolymer concentrations were not always associated with better soil performance, indicating that excessive amounts of biopolymers may not enhance soil strength. Among the different biopolymers tested, XG-treated specimens demonstrated the most promising results, particularly in terms of wetting-drying resistance to atmospheric conditions. This finding suggests that biopolymers, particularly Xanthan Gum, have significant potential to improve soil stability under varying environmental conditions. However, further investigation is required to optimize biopolymer concentration and curing times for specific soil types and applications. The study highlights the need for more in-depth research to refine the use of biopolymers in soil stabilization, particularly regarding their long-term performance and sustainability in practical engineering applications.

Ni et al. (2020) carried out an experimental study on the use of Xanthan Gum to treat Shanghai clay, focusing on its impact on soil compaction, strength, and resistance to fatigue. Standard Proctor compaction, Atterberg limit tests, unconfined compression strength tests, and fatigue loading tests (both constant-amplitude and stepping-amplitude) were conducted. The findings showed that the initial moisture content significantly influenced the effectiveness of XG treatment. The unconfined compression strength increased as the initial moisture content reached 1.1 to 1.2 times the OMC, resulting in maximum strengthening efficiency for XG concentrations ranging from 1.0% to 5.0%. Additionally, fatigue loading tests demonstrated that XG improved both the soil's bearing capacity and its fatigue life under repeated loading, highlighting its potential as an eco-friendly soil stabilizer.

Singh et al. (2019) experiments have been conducted to measure the enhancement of expansive soil treated with Xanthan Gum. The plasticity index increases with the addition of 0.5% XG, but thereafter it declines rapidly. Conversely, the diffuse double layer and higher pore fluid viscosity when soil is treated with XG cause the shrinkage limit to rise, while an increase in biopolymer concentration leads to a noticeable decline in the linear shrinkage value. Tests of severe and light compaction demonstrate that the OMC and MDD values of the soil mass after treatment do not clearly correlate with the biopolymer content. Moreover, a longer curing time and greater additive amount resulted in an improvement in compressive strength, whereas a higher stiffness value causes a dramatic reduction in swelling pressure. When 1% XG is added to expansive soil, its compressive strength increases by roughly 93% while its swelling pressure is found to be lowered by roughly 54%. The compressibility of the treated soil somewhat rises, whereas hydraulic conductivity significantly reduces. The production of the gel-like cementitious substance and particle agglomeration result in an improvement in the strength and durability of the soil after treatment, which is supported by microscopic analysis.

Kumar et al. (2024) explored the use of biopolymers as a substitute for conventional soil stabilization techniques, highlighting concerns about their effects on the environment and their contribution to global warming. As a result, there has been growing interest in sustainable alternatives, such as biopolymers derived from plants, animals, or microbes. Biopolymers such as Xanthan Gum, Agar Gum, and Guar Gum have shown promising results in improving soil properties. Based on experiments, XG enhances permeability and water retention, AG boosts shear strength and speeds up cementation, and GG enhances soil strength and imperviousness. These treatments offer various applications, including erosion control, soil remediation, and stabilization of slopes and mine tailings. Biopolymers present an eco-friendly alternative to conventional soil stabilization techniques, offering potential solutions for sustainable geotechnical engineering. However, further research is required to enhance their effectiveness, evaluate their long-term performance, determine their compatibility with various soil types, and analyze their cost-effectiveness. This review focuses on Xanthan Gum, Guar Gum, and Agar Gum and suggests that future studies could compare these biopolymers with traditional materials such as concrete and

alternative methods, such as Microbial-Induced Calcite Precipitation, to better evaluate their potential for soil stabilization.

3. MATERIALS AND METHOD

3.1 Soil

The expansive soil was collected from Guwahati, Assam, 176 km from Tezpur, Assam. The soil is greyish black in colour. These soils are known as expansive soils, sometimes called shrink-swell soils, because of their tendency to swell and shrink in response to changes in moisture content. Soils prone to considerable volume variations (swelling and contraction) caused by water content. Soils that contain smectite clay minerals like montmorillonite and bentonite have the greatest shrink-swell capability.

3.2 Guar gum

Guar Gum (GG) is a naturally occurring biopolymer extracted from the endosperm of guar seeds (*Cyamopsis tetragonoloba*). Guar Gum is a non-polar hydrocolloid in nature. The 1,4-linked mannose residues in the linear GG chain are linked with 1,6-linked galactose residues every other mannose to form short side branches Figure 1. Guar Gum is more affordable than other biopolymers. The Guar Gum's higher viscosity is a key factor in its widespread use as a thickening agent in a variety of sectors. Almost 80% of the Guar Gum produced worldwide is produced in India. It can interact easily with soil due to the hydroxyl groups in its chemical structure. It changes different soils' hydraulic conductivity and unconfined compressive strength. Guar Gum was chosen in this study to alter the in situ soil properties. This was added to soil at different percentages. Guar Gum was collected from the IndiaMART online marketplace.

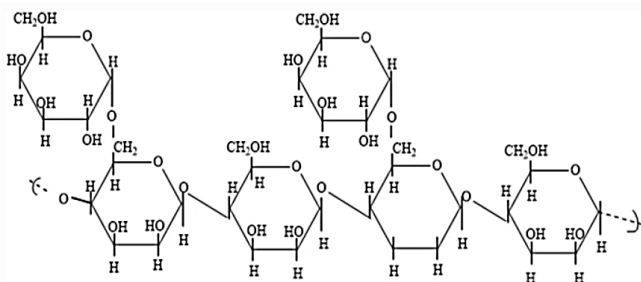


Figure 1 Guar Gum's molecular structure (Chudzikowski, 1971)

3.3 Sample preparation

The expansive soil was dried in an oven for 24 hours. Soil samples treated with Guar Gum were prepared through the dry mixing method. According to this procedure, the weight of the biopolymer required for a specific concentration is calculated and thoroughly mixed with the dried soil until homogeneity is achieved. The soil's compaction characteristics were evaluated by conducting the IS Light Compaction Test in accordance with IS: 2720 (Part 7) – 1980. The test was performed using a 2.6 kg hammer with a free-fall height of 310 mm. The soil was compacted in three layers, with each layer receiving 25 blows. The test utilized a cylindrical mould of 1000 cc volume. This method corresponds to the Standard Proctor Test used internationally, delivering a compaction energy of 594 kJ/m³ (Saikia et al., 2017), which is equivalent to that of the standard Proctor compaction effort. Based on the experimental results, the Optimum Moisture Content (OMC) was determined to be 28%, and the Maximum Dry Density (MDD) was found to be 1.51 gm/cc.

3.4 Experimental investigation

In this research, the impact of untreated and Guar Gum-treated soil on consistency limits, Unconfined Compressive Strength, Free Swell Index, Consolidation, pH, and conductivity tests was examined. The

experimental inquiry followed the steps specified in the IS Code 2720 and the norms and specifications of the different parts. In this research, Guar Gum was added to expansive soil in different percentages (0.5%, 1%, 1.5%, and 2%). After air-curing for 7 and 14 days, the strength of soil guar gum combination was assessed by its relative unconfined compressive strength.

Guar gum can form gel plugs and biofilms. The ability of gel-plug formation to build a continuous coating over the soil matrix, forming a network of hydrogen bonds, reflects the hydrogen-bonding activity of Guar Gum. This leads to the development of hydrogel and biofilm, which form a continuous layer over the soil matrix, creating a network of hydrogen bonds. These mechanisms are essential for modifying soil characteristics. In addition, once the hydrogels dry, they become rubbery and tend to adhere to soil particles. The chemical composition of guar gum contains hydroxyl groups, which make it possible for it to interact with soil with ease.

4. RESULT

At the beginning, the Consistency Limits, Unconfined Compressive Strength, Free Swell Index, Consolidated test, pH, and conductivity tests for the untreated soil were carried out as per the procedures specified in the Indian Standard Codes. The test results for the expansive soil are given in Table 1. The particle size distribution curve for the soil sample is shown in Figure 2. Since more than 50% of the soil sample passes through the 75-micron IS Sieve, the soil is classified as fine-grained. From the test results of liquid limit and plastic limit and from the IS Plasticity Chart, the fine-grained soil is finally classified as CH (High plasticity Clay).

Table 1 Test result for expansive soil

Parameter	Value
Specific Gravity	2.74
Liquid Limit	77%
Plastic Limit	32.8%
Plasticity Index	44.2%
Shrinkage Limit	17.57%
Maximum Dry Density (MDD)	1.51 gm/cc
Optimum Moisture Content (OMC)	28%
Classification of the soil	CH
Free Swell Index (FSI)	190%
pH	5.96 pH/mv
Conductivity	4.05 ms/ppt
Coefficient of Consolidations	0-100 kPa 0.91 100-200 kPa 0.74
Unconfined Compressive Strength (UCS)	
(a) 0 day	111.82 kN/m ²
(b) 7days	111.82 kN/m ²
(c) 14days	111.82 kN/m ²

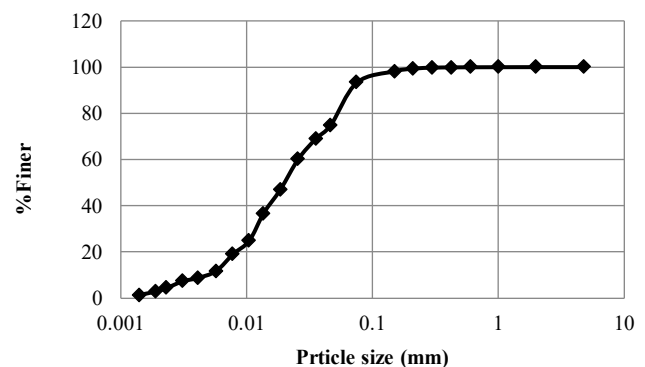


Figure 2 Grain size distribution for untreated soil

4.1 IS light compaction test

Figure 3 shows the test result for IS Light Compaction test. From the experimental results, the OMC has been obtained as 28%, and the MDD is obtained as 1.51 gm/cc.

4.2 Atterberg Limits (Consistency Limits)

Figure 4 illustrates the variation of test results obtained for the Consistency Limits for Guar Gum treated and untreated soil. The liquid limit experiment was conducted using cone penetrometer equipment as per IS-2720: Part 5 (1985). The research was carried out on oven-dried soil, with a portion of the soil finer than 425 μm , then rolled onto the glass plate until it crumbled into 3mm-diameter threads. It has been found that as the GG proportion increases, the liquid, plastic, and shrinkage limits increase.

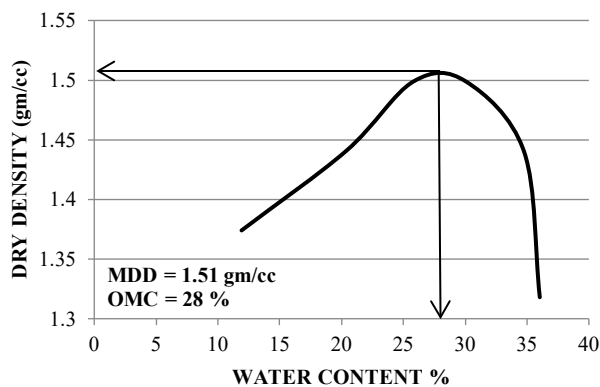


Figure 3 IS light compaction test graph

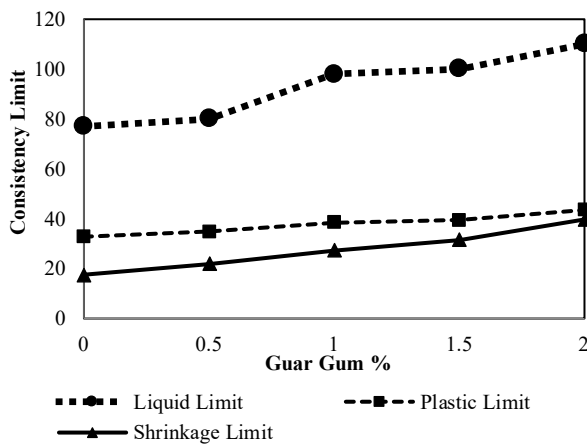


Figure 4 Variation of consistency limit with guar gum content

4.3 Unconfined compressive strength(UCS)

Unconfined compressive strength tests were performed on untreated and treated clay samples as per IS-2720: Part 10 (1991). The effect of curing on guar gum-treated and untreated soil is also investigated. The curing process is carried out by wrapping the mould with aluminum foil. The comparison of test results for the curing effect of guar gum-treated and untreated soil for 0 day, 7 days, and 14 days is shown in Figures 5-7. As GG content increases, the UCS value of the soil increases. UCS value increases with aging.

4.3.1 For 0 day curing

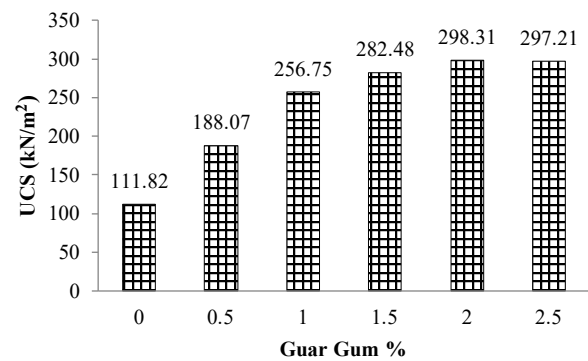


Figure 5 Variation between guar gum content and UCS

4.3.2 For 7 days curing

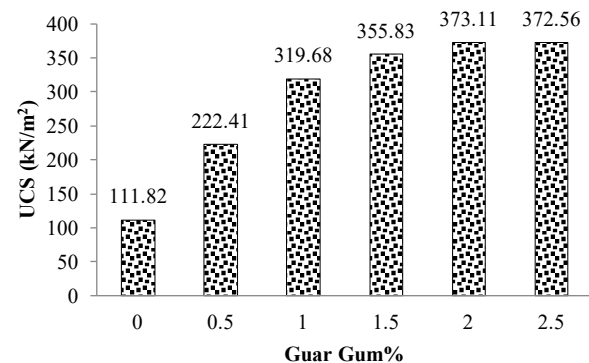


Figure 6 Variation between guar gum content and UCS

4.3.3 For 14 days curing

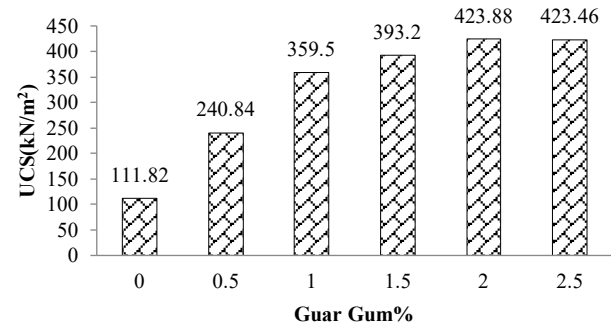


Figure 7 Variation between guar gum content and UCS

4.4 Free swell index(FSI)

Free swell index test was performed on both untreated and Guar Gum treated soil with various percentages (0.5%, 1%, 1.5% and 2%) as per IS-2720: Part 40 (1977). With addition of 0.5%, 1%, 1.5% and 2% of GG on soil FSI value decreases with an extended curing period from 7 to 14 days. The comparison test result for FSI is shown in Figure 8.

4.5 pH and conductivity

The pH and conductivity test results for soil treated with Guar Gum and untreated soil are shown in Figures 9 and 10. As per IS- 2720: Part 26 (1987), the pH test was carried out. According to IS-4767 (2000), the conductivity test was performed; 20 g of the soil sample was placed in a 100 mL beaker. The pH and conductivity of the sample increase with increasing GG proportion.

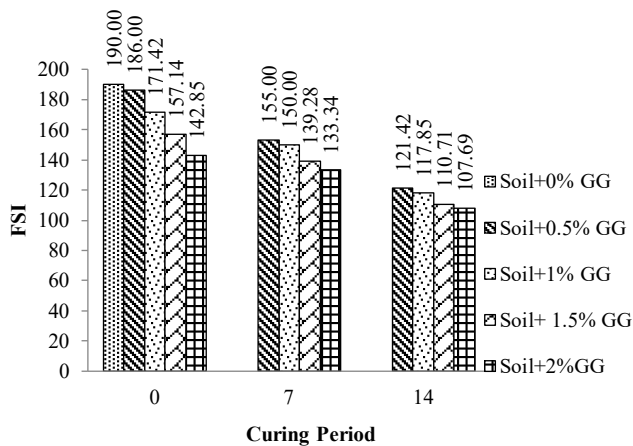


Figure 8 Variation of FSI between guar gum & curing period

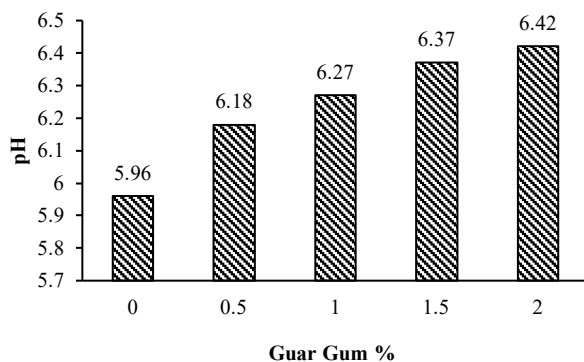


Figure 9 Test result for pH

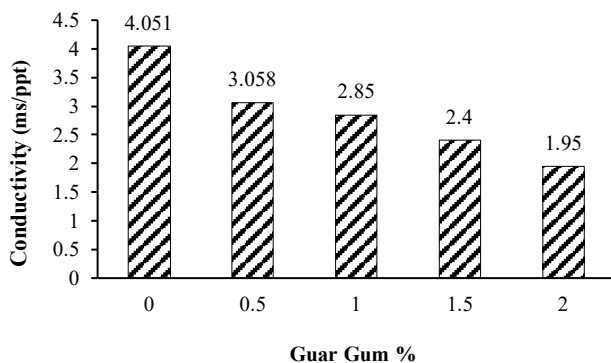


Figure 10 Test result for conductivity

4.6 One dimensional (1-D) consolidation test

The consolidation characteristics of untreated and Guar Gum treated soil samples at (0.5%, 1%, 1.5% and 2%) were determined in an oedometer according to IS-2720: Part 15 (1986). The sample was prepared by taking the MDD and OMC obtained from the IS light compaction test, and the prepared sample was then compacted in a metal ring with a diameter of 60mm and a height of 20mm. Two porous stones are set on the bottom and top of the sample to ensure effective drainage of excess pore pressure generated during loading. We place the assembly on the loading frame and center it so that the load exerted is axial. The compressive load is applied using a hanger, which, in turn, is transferred as normal stress on the specimen, and the corresponding deformations are measured by dial gauges. The dial gauge is positioned to record the vertical compression of the

specimen. The sample is always kept submerged throughout the test. Consolidation is the result of compression under prolonged static load and the subsequent release of pore water. Initially, a setting load of 5 kN/m² is applied to the sample. The subsequent load increments are 100 and 200 kN/m². Each load increment is given a 24-hour period to stand, after which the final settlement is noted. To generate deformation vs. time curves, deformation dial readings are taken at intervals of 0.1, 0.25, 1, 2, 4, 8, 16, 40, 60, 120, 240, 480, and 1440 minutes. This procedure was performed for two pressure ranges: 0-100 and 100-200 kN/m². From the deformation vs. time curves, the coefficient of consolidation (C_v) values were determined using the logarithmic-time fitting method.

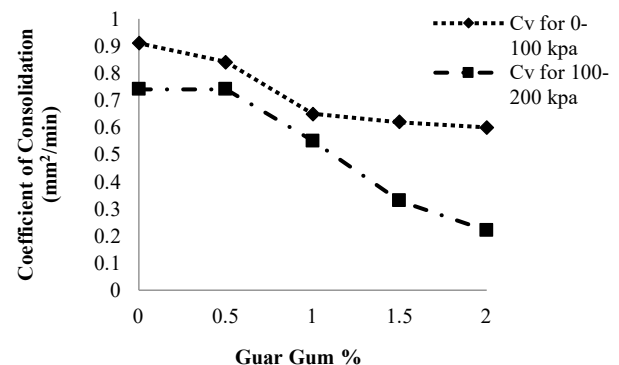


Figure 11 Comparison graph between C_v and various biopolymer content

5. DISCUSSION

5.1 Effect of Guar Gum on the Atterberg's limits

The liquid limit of treated soil increases with increasing Guar Gum content (Figure 4) because Guar Gum has a tendency to hydrate and produce a solid hydrogel through hydrogen bonding. As the GG content increases, hydrogen-bond activity increases, resulting in the formation of hydrogels.

Because of monomeric molecules, soil rigidity increases, resulting in a slight increase in the plastic limit. The plastic limit of soil increases when treated with Guar Gum at increasing percentages because Guar gum has a tendency to hydrate and produce a solid hydrogel through hydrogen bonding. As the percentage of Guar Gum increases, hydrogen-bond activity increases, resulting in the formation of a hydrogel.

The plasticity index does not change considerably as Guar gum content is raised because Guar gum increases pore fluid viscosity, which enhances the sticking property in the soil Guar Gum mixture. Furthermore, numerous molecules with many branches accelerate hydration and hydrogen-bond formation, which only slightly alters the plasticity index.

The increased Guar Gum concentration causes the hydrogels to shrink rapidly upon drying, pulling the soil particles along; as a result, the shrinkage limit increases.

A similar result for the Atterberg limits was reported by Sujatha et al. (2019).

It has been observed that adding Guar Gum to expansive soil results in an increase in the Liquid Limit and Plastic Limit. This enhancement is primarily due to the increased cohesion among soil particles, which makes the soil more susceptible to plastic flow. Guar gum's presence improves the soil's cohesiveness, making it more resistant to deformation at lower moisture contents. Consequently, the soil exhibits a firmer texture, requiring a higher moisture content to transition from the plastic to semi-solid state. The increase in the Plasticity Index suggests that the soil becomes more moldable, which may be beneficial for certain construction applications, such as producing clay bricks or other moldable materials. Additionally, guar gum increases the Shrinkage Limit, thus reducing the risk of cracking

and improving the soil's volume stability. These modifications result in improved workability, reduced cracking, and enhanced foundation stability. The increased plasticity can potentially reduce the stability of the soil in certain applications, particularly in environments subject to fluctuating moisture conditions. A high plasticity index (PI) may make the soil more prone to swelling or shrinkage, resulting in undesirable volume changes when exposed to moisture content variations. These factors could compromise the long-term stability and performance of structures built on or with such soils. The addition of Guar Gum to soil can lead to excessive moisture retention, which may adversely affect the soil's drainage characteristics. In applications such as agriculture, this reduced permeability can increase the risk of waterlogging, particularly in poorly drained soils or regions experiencing high rainfall. Impeded drainage may reduce oxygen availability in the root zone, thereby negatively impacting root respiration and overall plant health. Crops that require well-drained soil conditions for optimal growth may be especially vulnerable to these effects, potentially reducing agricultural productivity.

5.2 Effect of Guar Gum on the unconfined compressive strength (UCS)

With an increasing proportion of Guar Gum, the strength of soil samples that had been blended with it increased immediately. The UCS value of soil samples mixed with GG increases with increasing GG content, peaking at 2.0%. With an increasing proportion of GG, the compressive strength of soil samples blended with it increased immediately. It has been observed that when GG exceeds 2.0%, strength decreases. A similar trend was also observed by Kullayappa et al. (2018) and Anandha et al. (2021). Because of the reactions and the basic nature of the biopolymer, it transforms into lumps when mixed with the appropriate water concentration. As demonstrated in the instance of 0 days of curing, the strength from the UCS test of the soil improves with an increase in GG concentration. The soil treated with 2% GG, after 14 days of curing, shows a compressive strength that rises from 111.82 kPa before curing to 423.89 kPa. This implies that increasing the GG concentration significantly increases soil strength. The soil specimens treated with 2.5% GG were evaluated for unconfined compressive strength (UCS) at different curing periods: 0 days, 7 days, and 14 days. The results indicate a marginal reduction in strength values across all curing durations. At 0 days of curing, the UCS decreased slightly from 298.31 kPa (untreated) to 297.21 kPa after treatment. Similarly, after 7 days of curing, the UCS decreased from 373.12 kPa to 372.56 kPa, and after 14 days of curing, the strength declined marginally from 423.89 kPa to 423.46 kPa. These findings indicate that adding 2.5% GG has a minimal impact on the compressive strength of the soil. Numerous hydroxyl groups joining together to form hydrogen bonds caused the rise in strength. Due to guar gum's chemical structure, the hydrocolloids formed through hydrogen bonding exert an effect. Both hydrated mineral surfaces and organic surfaces develop hydrogen bonding. It functions as a coagulant in clayey soil with inorganic surfaces. Additionally, the hydrogels change into a rigid or transparent state upon drying, which is prone to connect with soil particles. The age of the treated soil affects this occurrence. The rubbery linkages have a significant water-holding capacity after drying. Initial coating of the soil particles by the GG buildup in the gaps initiates the formation of linkages or hydrogels. The consistency and density of the soil-GG mixture are determined by the links found in the pore spaces. As the GG percentage rises, the links become thicker and stronger with age. These connections allow for the support of heavier loads. The behavior of treated and untreated soil is similar at lower GG concentrations, but as GG content increases, the magnitude and rate of strength change with aging differ significantly.

Previous research conducted by Chudzikowski (1971), Sujatha et al. (2019), and Ayeldeen et al. (2016) reported similar observations, trends and outcomes.

The increase in strength observed in guar gum-treated soils highlights their potential for use in various geotechnical and

construction applications that demand enhanced mechanical performance. The improved unconfined compressive strength indicates that Guar Gum-treated soils can offer greater load-bearing capacity and structural stability. This makes them particularly suitable for use in critical infrastructure projects such as foundations, road subgrades, and embankments, where high strength and durability are essential. The ability of GG to improve soil strength, even at relatively low dosages, further emphasizes its practicality and cost-effectiveness as a sustainable soil stabilizer. In soils with high organic content, the effect of GG on UCS may be less pronounced, as organic matter can interfere with GG's binding properties. Additionally, excessive GG application can result in an excessively high UCS, which may make the soil too rigid, making it difficult to manipulate or work with in construction applications.

5.3 Effect of Guar Gum on the free swell index (FSI)

With increasing amount of GG in the soil sample, the FSI value of the soil decreases and as the curing time increases, the FSI value decreases. These are indications of the progressive development of hydration compounds in the soil, resulting from the interaction between Guar Gum and soil components.

A reduction in the Free Swell Index lowers the soil's susceptibility to swelling when exposed to water. This property is particularly advantageous for managing expansive soils, which, if not properly controlled, can cause substantial damage to infrastructure. The primary benefits of this reduction include enhanced stability, minimized swelling, and environmentally sustainable characteristics. These qualities make the treatment highly suitable for construction projects involving clayey or silty soils, where soil behavior management is critical for ensuring the longevity and safety of infrastructure. Over-reduction of soil swelling may impair its ability to adapt to moisture fluctuations, which could be detrimental in certain agricultural applications where moisture variability is essential for plant growth. Furthermore, excessive addition of guar gum to agricultural land may result in reduced soil fertility, as it could interfere with the natural microbial activity and nutrient cycling within the soil, potentially affecting plant health and crop yields.

5.4 Effect of Guar Gum on the pH and conductivity

The result from the pH test for untreated and treated soil with Guar Gum added at 0%, 0.5%, 1%, 1.5%, and 2% increases from 5.96 to 6.42. The result from the conductivity test for untreated and treated soil with GG added at 0%, 0.5%, 1%, 1.5%, and 2% decreases from 4.051 to 1.950. This is due to the fact that the reaction of GG with water leads to the release of calcium ions (Ca^{2+}), increasing the pH value. A comparable result was observed by Sujatha et al. (2019), indicating consistency with the findings of the present research. It is observed that as pH increases, conductivity decreases. Since pH reflects the concentration of hydrogen [and the hydroxyl] ions, in a basic solution, a higher pH corresponds to lower ion concentration, resulting in reduced conductivity. The negatively charged clay particles mix with the macromolecules to show minute pH changes. The pH of the soil-Guar Gum solutions slightly increases toward alkalinity. Additionally, at alkaline pH, the hydrogen bonds cross-link.

Acidic soils can contribute to the corrosion of metal reinforcements and other construction materials and negatively affect soil performance. Increasing the pH of acidic soils effectively neutralizes acidity, fostering more neutral or slightly alkaline conditions. This adjustment improves the compatibility of the soil with construction materials and reduces the risk of corrosion. For projects involving metal structures such as bridges, pipes, and underground foundations, neutralizing acidic soils by raising the pH helps mitigate corrosion risks, thereby extending material lifespans and reducing long-term maintenance costs. The addition of guar gum to soil typically has minimal direct impact on soil pH, as it does not significantly alter acidity or alkalinity. Its neutral behaviour makes it an ideal choice for pH-sensitive environments, where maintaining the

soil's natural pH is crucial for plant growth or ensuring soil stability in construction applications. Although guar gum itself does not directly alter the pH of soil, its impact on soil moisture retention and composition may indirectly influence microbial activity over time. In certain soils, changes in moisture levels and soil texture resulting from the addition of GG could affect the soil's microbial ecosystem, potentially altering nutrient availability and biological processes essential for soil health.

5.5 Effect of Guar Gum on the coefficient of consolidation

This coefficient of consolidation (C_v) is a parameter governing the time – rate of consolidation. The time required to reach a given degree of consolidation varies inversely with the coefficient of consolidation. The higher the C_v value, the less time is required to reach the desired degree of consolidation. It is observed that the C_v values decrease with increasing Guar Gum percentage when combined with the soil sample. The findings of the investigation show that adding GG improved the soil's compression capacity. The thick, viscous GG solution and the development of hydrogels contribute to soil hardening, effectively reducing its compressibility. The ongoing development of hydrogels induces soil dehydration, thereby increasing its stiffness and minimizing its potential for volumetric deformation. The gradual decrease in the coefficient of consolidation makes this evident. As a result, the soil-gum matrix resists volumetric changes, promotes particle rearrangement to generate a denser medium during compression, and exhibits reduced swelling once the load is removed. The water retained in the soil is consistently used to hydrate GG, giving the soil a rigid firmness. Hydrogels filling the pore spaces bind soil particles, creating a robust and cohesive GG–soil matrix that enhances resistance to compression and improves load-bearing capacity. It is evident that the C_v value is not a unique soil parameter. It depends on the pressure range. When the imposed pressure is high, the C_v value decreases, indicating that the soil sample will take longer to attain a given degree of consolidation. This is because higher stress leads to lower permeability, and so the drainage of excess pore pressure takes longer.

An analogous result was observed in the study by Sujatha et al. (2019).

For structures such as embankments, foundations, or roads, where uniform and gradual settlement is desirable, a reduced coefficient of consolidation can facilitate more controlled settlement over time. In foundation applications, particularly in areas where soil stability is critical—such as beneath buildings or large infrastructure projects—guar gum may provide additional resistance to excessive settlement or failure during consolidation. In regions with expansive clays, incorporating guar gum can enhance soil stabilization by reducing susceptibility to rapid consolidation, thereby improving soil performance under load. This modification contributes to the long-term stability and reliability of the foundation throughout the settlement process. In some instances, excessive reduction in consolidation may result in over-consolidation, which can make the soil less adaptable to load-bearing conditions over time. Additionally, modifying consolidation properties could delay the natural consolidation process in certain soils, requiring extended periods for the soil to achieve the desired stability under applied loads.

6. SUMMARY AND CONCLUSIONS

The improvement in strength and collapsibility of guar gum-treated soil was measured in this study through various laboratory experiments. In this study, expansive soil was chosen because of the great variety of problematic soils and the importance of environmental problems. Abundantly and naturally occurring biopolymers play a significant role in environmentally friendly soil stabilization. The usage of Guar Gum has been shown to significantly increase soil stabilization.

- a. With an increasing proportion of Guar Gum, with varied percentages (0.5%, 1%, 1.5% and 2%), liquid limit values

increase from 80% to 110%, the plastic limit values rise from 34.90% to 43.52%, and shrinkage limit values increase from 21.86% to 39.73%.

- b. When the percentage of Guar Gum increases in soil samples, the strength of the soil samples rises. As the GG percentage and curing time increase, it is found that treated samples' strengths have significantly increased.
- c. When the proportion of Guar Gum is raised from 0 to 0.5%, the percentage increase of UCS is 68.2. With further increases in the proportion of GG from 0.5% to 1%, 1% to 1.5%, and 1.5% to 2%, the rate of increase in UCS decreases. After curing for 7 and 14 days, the percentage increases in UCS are 98.9% and 115.22%, respectively, for a 0% to 0.5% increase in Guar Gum. For other percentages (0.5% to 1%, 1% to 1.5%, and 1.5% to 2%), the rate of strength gain decreases.
- d. After 14 days of curing, the strength from the UCS test was found to be 423.89% kN/m² of soil that has been treated with 2.0% Guar Gum.
- e. The compressive strength of the soil mixed with 2% biopolymer, after a 14-day curing period, is four times greater than that of the untreated natural soil.
- f. With increasing proportion of GG in soil sample, the FSI value decreases.
- g. As the curing time increases, the FSI value of soil treated with GG also decreases.
- h. When the proportion of GG is increased from 0 to 0.5%, the percentage decrease of FSI is 2.1. With further increases in the Guar Gum proportion from 0.5% to 1%, 1% to 1.5%, and 1.5% to 2%, the rate of decrease in the FSI value remains nearly the same. After curing for 7 and 14 days, the percentage decreases in FSI are 22.58% and 56.48%, respectively, for a 0% to 0.5% increase in Guar Gum. For other percentages (0.5% to 1%, 1 to 1.5%, and 1.5% to 2%), the rate of decrease of the FSI value decreases.
- i. From the results obtained from the pH test of soil-guar mixtures, only slight changes were observed as the Guar Gum percentage changed. As the Guar Gum content increases, the pH slightly increases, and conductivity decreases.
- j. The coefficient of consolidation (C_v) values are found to decrease with a rise in Guar Gum content in soil.
- k. The optimum range of percentage for Guar Gum addition to the soil is between 0.5%-1%.

When the proportion of Guar Gum is increased from 0% to 0.5% and 0.5% to 1.00%, the percentage increase/decrease in various parameters (such as LL, PL, SL, UCS, FSI, pH, conductivity and consolidation) is the maximum. This means that adding 0.5%- 1.00% GG significantly enhances soil properties. This observation suggests that GG significantly influences soil parameters even at low concentrations, and that 0.5%-1.00% GG is highly responsive to initial increases or decreases. However, as the GG proportion continues to increase beyond 0.5%, the rate of increase/decrease in the various parameters decreases. Specifically: From 0.5% to 1%, the increase/decrease in the parameters is less significant than the first increase. From 1% to 1.5%, the rate of change continues to slow. From 1.5% to 2%, the rate of change is even less pronounced. The use of GG in soil stabilization represents a promising alternative to traditional techniques, particularly for expansive soils that pose significant challenges in construction. Its ability to achieve maximum modification of geotechnical properties at low dosages makes it both a cost-effective and resource-efficient solution. Additionally, guar gum's environmentally friendly nature, carbon-neutral properties, and ability to improve soil strength, workability, and stability provide a more sustainable option for civil engineering projects. Guar gum stabilizes soils by reducing swelling, plasticity, and shrinkage, making it a reliable tool for addressing the challenges posed by expansive soils and ensuring long-term infrastructure reliability. As

interest in sustainable construction practices continues to grow, the role of biopolymers like guar gum in geo-environmental engineering will likely expand, offering significant benefits for future construction projects. In summary, the use of biopolymers for soil stabilization, particularly in expansive soils, offers numerous benefits. However, one of their limitations is long-term durability, a key concern in the use of biopolymers for soil stabilization. Although biopolymers are effective in the short term, their long-term stability can be affected by environmental factors such as biodegradation, moisture fluctuations, and temperature variations. Over time, the polymer may degrade, losing its effectiveness and requiring re-treatment of the soil. Secondly, effectiveness in highly expansive soils is one of the limitations. While biopolymers are effective in stabilizing moderately expansive soils, their effectiveness may be limited in highly expansive soils with extreme shrink-swell behavior. Although biopolymers are cost-effective when used in small quantities, the overall cost for large-scale projects can still be significant, especially if the project requires large quantities of the biopolymer. Therefore, when selecting biopolymers for soil stabilization, it is crucial to consider soil conditions, the percentage of biopolymer use, environmental factors, and project requirements to ensure the most effective and sustainable solution for stabilizing expansive soils.

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