

# Biopolymer-Based Soil Stabilization for Enhanced Mechanical Integrity and Erosion Control in Soft Marine Clays

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**Abstract.** Tillage disrupts the structure of the soil, which speeds up surface runoff and soil erosion. But tillage has consistently resulted in a decrease in soil quality. Soil splashing is another effect of ploughing, where particles splash and obstruct the soil's pores, thereby sealing off the soil's surface and causing inadequate water absorption. The low-lying Kuttanad region includes Vembanad Lake and the marshy land around it. Flood damage is a big problem here since it makes the soil lose its mechanical properties. The movement of microscopic particles from the original ground lowers soil cohesiveness and water retention, hastening soil erosion. Restoring soil internal cohesion is vital for successful and reliable anti-desertification operations. The Kuttanad region is observed for its soft black or grey marine clay soil, with natural water content nearly at the liquid limit. The soil employed in this study was taken from the Pulinkunnu region of Kuttanad, Alappuzha district, Kerala, India, which is characterized by soft marine clay. In this study, we propose treating soil with biopolymers as a way to successfully limit soil erosion and accelerate regeneration, considering engineering and environmental aspects. Biopolymers have the ability to dramatically decrease soil erodibility by enhancing inter-particle bonding, even at low concentrations (i.e., 0.5% to 1.5%). Biopolymers like Xanthan Gum and Guar Gum, with their hydrophilic qualities, improve water absorption in soil, resulting in a continuous soil structure with more dense packing. Biopolymer treatment can also improve soil structure and stimulate vegetation development, ultimately recovering deteriorated soil qualities.

Key words: Tillage, Soil Splashing, Biopolymer, Xanthan Gum, Guar Gum.

## 1 Introduction

Land degradation has happened due to the rise in global temperatures and human population development. This degradation lowers the soil's nutrient content and mechanical strength, rendering it less fertile and unsuitable for construction purposes. Additionally, land deterioration enhances soil erosion by weakening the cohesiveness between soil particles [1]. When the cohesiveness is insufficient to tie the particles together, the top layer of soil becomes prone to erosion. In a broader perspective, soil stabilization covers several procedures targeted at changing soil characteristics to improve its engineering performance. Stabilization improves essential soil features such as volume stability, hardness, compressible properties, permeability, resilience, and particle management, hence rendering the soil more suited for diverse purposes [2]. Organic clay soil was gathered from the Pulinkunnu region of Kuttanad, Alappuzha district, Kerala, India for this study. This soil, being sedimentary in origin, occurs in a loose state in the

Kuttanad region. It exhibits strong compressibility due to its enhanced void ratio and organic content. There are several portions of the earth are unusually soft, providing obstacles for construction activities.

Soil stabilization procedures attempt to modify the physical features in the soil, accordingly boosting its stability as well as durability. It is vital that soil stabilising processes be both inexpensive and environmentally benign, delivering best benefits. Strengthening the soil is strongly suggested for any building project to enhance

the lifespan of the structure. Various stabilising strategies exist, including physical, chemical, and polymer methods. Physical treatments consist of strengthening the soil's characteristics through processes that involve absorption and compaction, which contribute to enhanced soil water resistance. Several traditional measures to address land deterioration pose risks to the environment. Therefore, every action we make must emphasise environmental benefit to ensure the conservation of our surroundings.

In the current study, the efficiency of biopolymer stabilization is being assessed for expansive soils. Biological methods such as microbe insertion and byproduct precipitation are being extensively researched as alternatives traditional soil treatment and enhancement technologies in geotechnical engineering research.

Biopolymers are organic polymers generated from the monomeric components of microorganism cells. It have the power to enhance several properties, including tensile strength and flexibility, making them sustainable materials [3]. With their binding capabilities, biopolymers can function as soil stabilizers and contribute to lowering fertilizer consumption [4]. Agriculture can effectively employ biopolymers without causing harm to biodiversity. This review presents strengthening strategies based on tiny inter-particle interactions between common biopolymers and soils [5].

## 2 Materials

### 2.1 Biopolymers

Biopolymers are extensively employed in culinary and pharmaceutical applications due to their environmental friendliness. Recent research has demonstrated that biopolymers have the potential to reinforce soil, control permeability, manage erosion, minimise dust, and even treat water. Biopolymer-driven soil treatment is faster and more efficient than other biological soil treatment approaches. Utilizing biopolymers manufactured in growing facilities, where both quantity and quality control are achievable, is the essential notion of Bio-Polymer Soil Treatment (BPST). Also, the electrostatic biopolymer-soil matrix created by continuous bio polymer combined with soils leads in homogeneous biopolymer treated soil mixes that are rapidly enhanced [6]. Biopolymers are frequently exploited in industry due to their unique features. They are coupled with a range of materials to boost the features of these biopolymers and increase their utility. PHA, polylactic acid, and starch are extensively utilised in packaging due to their accessibility and affordability. Also they possess barrier properties not found in other polymers, including resistance to water [7]. Biopolymers are used in the automobile industry to make interior and exterior components, as well as electrical components, engines, exhaust, and steering wheels. Biopolymers are used in concrete to improve its needed properties. They are also used to decorate buildings.

Biopolymers are frequently used in the biomedical industry because they are biocompatible, non-toxic, and degradable. They find applications in medication delivery, medicine, and tissue engineering. In our project investigation, we employed guar gum and xanthan gum as biopolymers.

#### 2.1.1 Xanthan Gum

**3** The microbe known as *Xanthomonas campestris* generates xanthan gum, a polysaccharide biopolymer comprised of two glucose, two mannose, and one glucuronic acid unit. The shape of the solution formed by xanthan gum depends on the temperature at which it dissolves and the amount of salt present, with possibilities including a helix or a random coil. The linear relationship observed between the flow rate of xanthan gum solutions and their xanthan gum content indicates exceptionally stable behaviour across a varied spectrum of temperature ranges, pH levels, and electrolyte concentrations [8]. A biopolymer called xanthan gum alters a sand's permeability, mechanical properties without harming the environment.

It was discovered that the amount of xanthan gum and the curing period had a clear correlation with the enhancement within permeability and unconfined compression properties of sand modified with xanthan gum. Adding xanthan gum was found to increase stiffness and greatly reduce compressibility. Sand with a 1.5 percent xanthan gum content has permeability and strength that are more than twice as high, while compressibility is reduced by around 50%. The study came to the conclusion that biopolymer treatment holds potential as a method for modifying soil properties such as permeability, stability and deformation characteristics such as ductility or stiffness. The outcomes of this method could pave the approach for a microorganism-mediated technique to enhance some subsurface soil formations' technological features. In cohesion-less soils, grouting using these substances create polymeric soil columns in the field offers a flexible enhancement.

#### 3.1.1 Guar Gum

There have been experiments of using viscosity-controlled gum as injected grout (with additives like acrylamide, formaldehyde (H<sub>2</sub>), and ammonium persulfate ((NH<sub>4</sub>)<sub>2</sub>S<sub>2</sub>O<sub>8</sub>)) to support construction operations in arid environments. To reduce cracking at shallow depths, guar gum can be used to stabilise expansive soils on slopes and desert soils. Furthermore, it has been reported that upward boundary walls, like cut-off walls, can be built with a gum slurry. On the other hand, gum slurry might spontaneously break down into water and simple sugars due to the action of bacteria or enzymes, which wouldn't harm the environment. Therefore, while employing guar gum biopolymer in geotechnical engineering procedures, durability becomes an important factor to take into account.

## 2.2 Soil sampling

The term "soil sampling" often refers to the process of collecting and analysing the soil samples to determine their chemical and engineering characteristics.

Soil samples were collected from the Pulinkunnuregion of Kuttanad, Alappuzha district, Kerala, India for this investigation. Marine clay soils from the Kuttanad region are mainly made of clay minerals such as kaolinite and smectite, coupled with modest quantities of quartz and organic matter. Previous investigations on Kuttanad coastal clays have indicated that the presence of these clay minerals adds to the high plasticity, compressibility, as well as the water accumulation features of the soil. These mineralogical features influence the relationship within ground particles and stabilizing agents such as biopolymers. It is usually insufficient to collect dirt at a single spot because soil changes across short distances. Rather, a composite sample was collected. Composite samples consist of multiple separate samples gathered from different parts of the same area, which are then blended collectively to create one composite sample. By integrating several subsamples into a single composite sample, we may reduce the effects of soil variability by averaging the soil's attributes over greater areas. Estimate how many soil samples there will be and where they will be before you go into the field. In order to avoid contamination, samples must be stored correctly after a composite sample has been collected. If the soil is very wet or you can't keep samples in a freezer or refrigerator, spread the dirt thinly on a level surface, like a table. The samples will be able to air dry considerably as a result. You can use old newsprint or other paper to cover the surface and keep it clean. A sample should never be dried in a microwave or oven as this can harm the material and alter the findings of the experiment.

### 2.3 Preliminary Examinations

#### 2.3.1 Sieve Analysis

The gradation and particle size distribution of a soil sample are assessed in civil engineering through the use of a sieve analysis technique or procedure. The hydrometer method detects finer particles, while sieve analysis identifies larger, coarser particles. The distribution of different grain sizes affects the soil's engineering characteristics. The soil is gap-graded, and the particle size distribution graph shows that some particles are missing in the middle tabulated in Table 1. Figure 1 shown curve of Particle Size Distribution

Table 1. Particle Size Distribution observation

Sieve Size (mm)	Soil retention weight (g)	Weight retention percentage	Cumulative retention percentage	Finer percentage, N
4.75	24	2.4	2.4	97.6
2.36	46	4.6	7	93

1.18	70	7	14	84
0.6	56	5.6	19.6	80.4
0.3	91	9.1	28.7	71.3
0.15	117	11.7	40.4	59.6
0.075	103	10.3	50.7	49.3
Pan	493	49.3	100	0

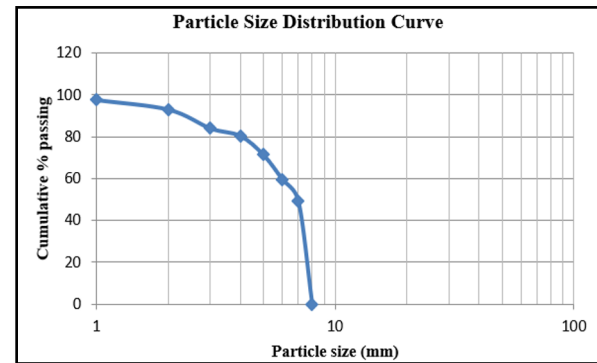


Fig. 1. Curve of Particle Size Distribution

#### 2.3.2 Atterberg Limit

All soil samples must pass the Atterberg limits a 425  $\mu\text{m}$  test sieve and be prepared using wet or dry techniques specified in the standards. Water is added to the samples, mixed with a spatula, and conditioned for at least 16 hours to adjust moisture content. To compute the liquid limit, a portion of the soil is placed in a liquid limit machine and divided with a grooving tool; the liquid limit was the moisture value at which the groove closes to half an inch after 25 drops. The plastic limit is found by repeatedly rolling a moist soil ball into a 1/8-inch thread until it crumbles. A plastic limit roller mechanism may also be employed. To determine the shrinkage limit, a wet soil sample is molded into a shrinkage dish, oven-dried, weighed, and the specimen's volume is measured by water distribution.

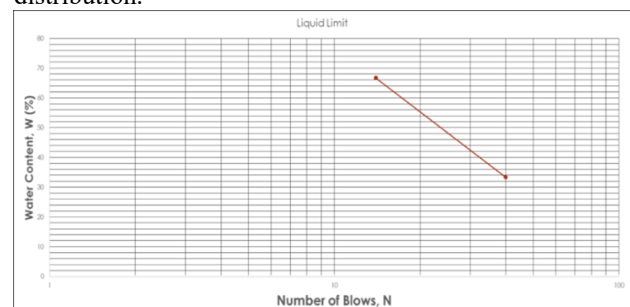


Fig. 2. Graph of Atterberg Limits

These experiments measure the moisture levels at which fine-grained clay and silt soils transition from solid to partially solid, plastics, or liquid phases. The Atterberg Limits refer to the water contents that define the transitions between a soil material's solid, plastics, and liquid forms. The tests are limited to cohesive soils that contain significant levels of sand or silt as shown in Figure 2. The addition of biopolymers such as xanthan gum and guar gum changes the Atterberg

limits of the soil. With increased biopolymer content, a modest drop in the liquid limit and plasticity index is seen due to better inter-particle bonding and creation of a polymer–soil matrix. The reduction in plasticity means that the treated soil becomes more solid and workable. This behavior indicates the usefulness of biopolymers in altering the consistency characteristics of coastal clay soils.

### 2.3.3 Unconfined Compressive Strength Test on Untreated Soil

Collect 300g of soil that has passed through a 300-micron filter. Mix the soil to the desired moisture level and shape it into a cylinder using a cylindrical mold. Place the specimen in a compression testing apparatus, centering the lower plate, and adjust the upper plate so it just touches the specimen. Record the load and deformation values while applying the load to create axial strain, ensuring the strain rate keeps the test time within 10 minutes. Table 2 shows continue the test until the axial strain reaches 20% or the load decreases as strain increases. After testing, determine the sample moisture content by examining the complete specimen or representative cuttings. If quantifiable, include the slope angle of the failure surface in a schematic of the test specimen at failure as shown in Figure 3 and Figure 4.

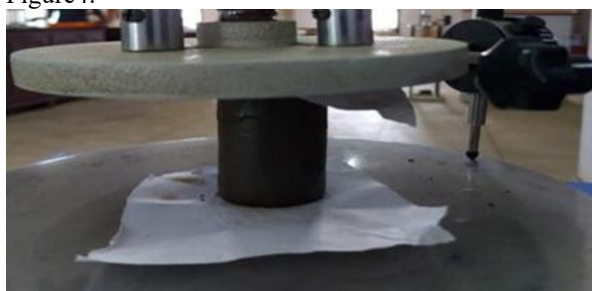


Fig. 3. Unconfined Compressive strength Test

Table 2 Unconfined compressive strength of untreated soil

S . N o	DG R	PR R	Def orm atio n	Loa d X 10-3	Strain	Corr ected Area mm2 x10-3	Compr ressive Stress (kPa)
1	50	3.6	0.5	8.3	0.065	1.212	1.9
2	100	3.8	1	8.76	0.1315	1.304	4.94
3	150	5	1.5	11.53	0.195	1.412	8.168
4	200	6.3	2	14.53	0.203	1.538	10.494
5	250	7.4	2.5	17.07	0.328	1.687	11.44
6	300	8.7	3	20.06	0.394	1.878	12.04
7	350	10.6	3.5	24.45	0.46	2.1	12.22

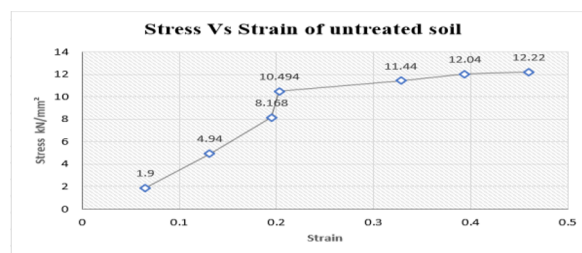


Fig. 4. Stress Vs Strain graph of untreated soil

### 2.3.4 Unconfined Compressive Strength Test on treated Soil

The removed soil was air dried to make it ready for treatment. After that, 4 trays with 5 kg each of soil were filled. For each biopolymer dosage and curing duration (7, 14, and 28 days), three replicate specimens were made and examined to confirm reliability of the results.

The stated unconfined compressive strength values indicate the average value of the three specimens. Each of these four trays received the same amount of the Xanthan and Guar gum mixture—0.25%, 0.5%, 1%, and 2%, respectively. The required quantities of xanthan gum and guar gum were measured according to the desired biopolymer percentage and combined with the air-dried soil. Water was gradually added to the soil–biopolymer mixture to obtain homogeneous moisture content. The mixture was physically mixed for approximately 10–15 minutes to ensure homogenous distribution of the biopolymers throughout the soil. The produced mixture was then placed in molds for specimen preparation and curing. To maximise the effects of the biopolymer mixture, water is sporadically applied to the air-dried soil sample. Without adding any additional biopolymer mix, this process is repeated after each day of the laboratory testing (7th, 14th, and 28th days after mixing). Accurate measurements should be taken when weighing each biopolymer and the soil sample. To ensure that the mixture of Xanthan gum and guar gum delivers the necessary amount of biopolymer corresponding to the soil sample, the weights of the two substances are divided by the required percentage of the biopolymer.

## 3 Methodology

### 3.1 Production of Xanthan Gum

The microorganism *Xanthomonas campestris*, which is naturally found on luggage, is used to produce xanthan gum through aerobic submerged fermentation. There is a multi-stage inoculum that ranges from an initial plate to shake flasks, small seed fermenting vessels, to giant final fermenting vessels. Fermentation equipment is utilised with stringent aseptic techniques and is cleaned and sterilised at every stage of production to guarantee a pure and uncontaminated culture [9]. Protein, an organic nitrogen source, ammonium or nitrate salt, glucose syrup derived from maize or wheat, and trace components comprise the fermentation media. After

the last fermentation is complete, the container's contents are pasteurised to maximise the composition of polymers and get rid of all the bacteria from the original culture. By adding alcohol (often isopropyl alcohol) to the fermentation broth, the gums are eliminated and xanthan fibres precipitate [10]. Subsequently, the fibres undergo treatment to eliminate surplus alcohol and are dried under careful circumstances. Figure 5 shows that the flow diagram for the manufacturing process of Xanthan gum.

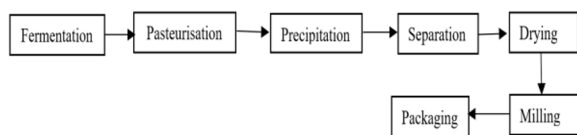


Fig. 5. Xanthan gum manufacturing process

### 3.2 Production of Guar Gum

Guar gum processing differs amongst plants. The seeds of guar are spherical, brownish, and smaller than pea seeds when they are extracted from their pods. Commercial gum extraction from seeds mostly involves a mechanical roasting, distinguishing, sifting, and polishing process. The germ and endosperm are separated, and the seeds are shattered. Unhusked guar seeds are the two portions of endosperm that are produced by each seed. The thin layer of fibrous substance that make the outer layer of the husk is scraped and polished away from the endosperm halves to get refined guar splits [10]. As a considerable byproduct of the manufacturing of guar gum powder, the hull (husk) and germ section of guar seeds are known as "guar meal," and they are fed to cattle. Depending on the intended outcome, the processed gum is then further processed utilising a range of paths and methods to turn it into powders, commonly referred to as guar gum [11]. Guar splits that have been pre-hydrated are first ground in a flaker mill and then evenly moved to an ultra-fine grinder, which grinds the splits without using too much heat. After being dried, the ground material is sent through screens to be ground in accordance with particle size [12]. Depending on the colour, mesh size, viscosity potential, and hydration rate, different grades are available (Chudzikowski 1971). The commercial manufacture of gum also involves extrusion prior to hydration and flaking. These procedures finish the grinding and drying processes. When extrusion is used, the hydration rate of guar gum powder is improved (Chowdhary 2002). Figure 6 displays the Guar Gum manufacture process.

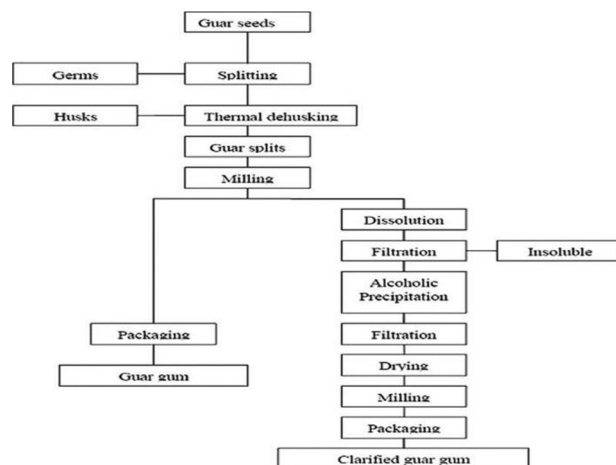


Fig. 6. Manufacturing of Guar Gum

## 4 Results and Discussion

### 4.1 Treated soil unconfined Compressive Strength tested on 7th day

Compared strength values of 12.73 kPa, 13.83 kPa, 14.297 kPa, and 15.038 kPa were obtained for soil sample blended with 0.25%, 0.5%, 1%, and 2% of respectively. The results shown in Figure 7 suggest that biopolymer concentration greatly impacts compressive strength. The variation in compressive strength will increase with the biopolymer content.

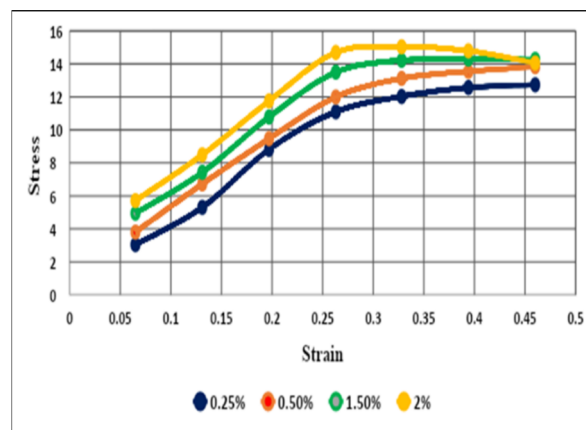


Fig. 7. Unconfined Compressive Strength tested on 7th day

The unconfined compressive strength values when assessed on the seventh day following mixing for each fraction of the biopolymer with the soil demonstrated an increase in strength with time and biopolymer content.

### 4.2 Unconfined Compressive Strength tested on 14th day

On the fourteenth day, the soil sample's unconfined compressive strength test value was 14.297 kPa,

14.548 kPa, 14.765 kPa, and 18.246 kPa, respectively as shown in Figure 8.

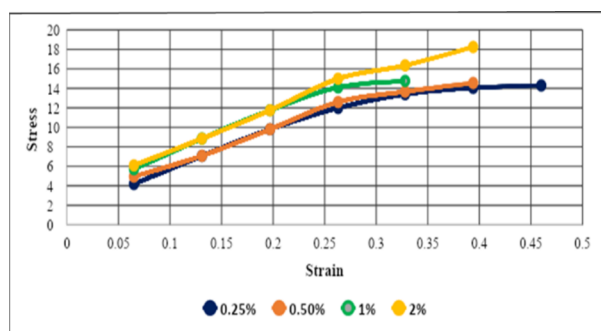


Fig. 8. Unconfined Compressive Strength tested on 14th day

### 4.3 Unconfined Compressive Strength tested on 28th day

On day 28, the soil sample mixed with 0.25%, 0.5%, 1%, and 2% yielded unconfined compressive strength test values of 15.53 kPa, 15.59 kPa, 17.01 kPa, and 18.89 kPa, respectively. The biggest percentage of increase in compressive strength, or 54.58%, is seen in the soil sample blended with 2% as shown in Figure 9.

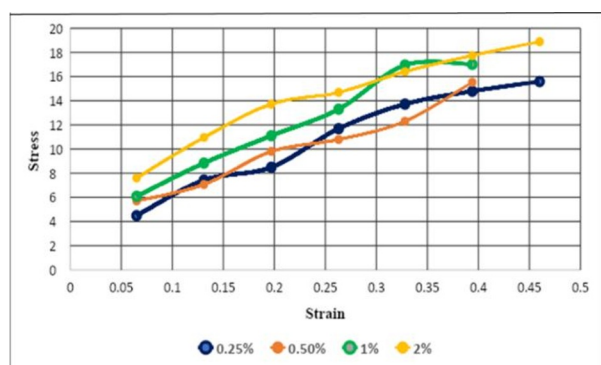


Fig. 9. Unconfined Compressive Strength tested on 28th day

The unconfined compressive strength value of soil samples that have been combined with guar gum and xanthan gum increases with a rise in percentages up to 1.5%, and it is discovered that an excess of these biopolymers greater than 2% results in a loss in strength value. When combined with the appropriate amount of water, the biopolymer will form lumps due to its basic composition and interactions. As a result, adding too much Xanthan Gum and Guar Gum causes the unconfined compressive strength value to drop. Based on the experimental data, the ideal biopolymer dose for soil stabilization was found to be roughly 1–1.5% of the soil weight. At this concentration, the treated soil displayed considerable improvement in compressive strength due to the establishment of a stable polymer–soil matrix. The combination of xanthan gum and guar gum increases the interaction between soil particles, resulting in enhanced bonding and higher mechanical strength. Higher biopolymer levels may lead to challenges in

mixing and workability. Comparable improvements in unconfined compressive strength have been found in prior research when xanthan gum or guar gum was used independently for soil stabilization. The results of the present investigation demonstrate comparable strength augmentation, supporting the efficiency of biopolymers in enhancing the mechanical properties of clay soils

### 4.4 Mechanism of Soil-Biopolymer Interaction

#### 4.4.1 Strengthening Soil using Biopolymers

Biopolymer in soil can significantly strengthen even in little concentrations (0.5–1% of the soil weight). Generally speaking, polymers can directly interact with fine soil particles to form hard, highly strong polymer–soil matrix composites due to their high specific surfaces and electrical charge points. Structural details of the sand-clay-biopolymer combination reveal that biopolymers create direct bonds with kaolinite particles, resulting in the accumulation of face-to-face layer layers, whereas sandy beaches either stay clear of particles or just build film-like coverings around them. As a result of the hydrogen and ionic bonding between the biopolymers and the electrically charged particles, the strength is greatest when cement-like particles are present. In order to determine the appropriate amounts of biopolymers to use and the best utilisation strategies for geotechnical engineering purposes, it is imperative to perform specific in-situ characterization prior to using biopolymers in order to understand the unique characteristics of the selected soil, as its texture and clay ratio. Biopolymers, for instance, can be utilized in dry or semi-arid deserts to promote the growth of plants and reduce aeolian erosion. Given that most desert soil is composed of coarse grains, biopolymers should exhibit suitable workability with respect to material rheology and soil structure. Sandy soils can also be treated with additional clay-like materials or ionic ions (such as  $Mg^{2+}$  and  $Ca^{2+}$ ) to boost the soil-fortifying power of the biopolymers. Previous investigations using scanning electron microscopy (SEM) have displayed that bio polymers such as xanthan gum and guar gum form thin gel-like coats surrounding soil particles and produce inter-particle bridges between adjacent particles. These polymer bridges connect soil grains and generate a continuous polymer–soil matrix that promotes particle bonding and increases soil strength. The creation of this network structure also minimises pore gaps and promotes the overall stability of the soil. While SEM analysis was not performed in the present work, similar soil–biopolymer interaction processes are expected in the treated soil samples.

#### 4.4.2 Effects of Biopolymer on Soil

Biopolymer-based soil treatment (BST) provides advantages over other biological soil treatment technologies in terms of quantity/quality control and speed. To provide sufficient salt precipitation for fortifying the soil, endo cultivating MI specifically

requires a significant investment of time and materials and the precise amount of saline precipitation required is very variable and case-dependent. But the core idea behind BST is that biopolymers made in an exocultivation facility—where quality and quantity control are feasible—are used. Homogeneous polymer-treated soil (BTS) mixes produced by direct polymer mixing with soil show ongoing strengthening due to the development of an electrostatic polymer-soil matrix.

The purpose of this study is to evaluate of BPST's present formation and potential future directions. Various types of biopolymers that have been developed and evaluated in lab-based studies are presented, along with attempts at site application. The application and practice of bio-geotechnical engineering are examined in connection to the influence of biopolymers on soil behavior.

The UCS value fluctuates between increases and decreases with Xanthan gum and guar gum contents of 0.25%, 0.5%, 1%, and 2%. The UCS value rises when air dries out between 0 and 7 days. Continuous Xanthan gum gel deterioration brought on by the dehydration of leftover moisture in the gels resulted in an increase in the UCS value for the dry side water content. Guar gum reacts with damp soils, changing the nature of the adhesive layer as ions replace sodium or iodine ions. The double layer often compresses due to an increase in the concentration of the capillary. Hence, the liquid and solid limits of the soil decrease with the stabilization of guar gum. As a result, the soil's plasticity index decreases, making it easier to work with. A 0.5–1% concentration of Xanthan gum and guar gum is the most cost-effective and effective amount for treating soil. The addition of biopolymers such as xanthan gum and guar gum normally does not create major changes in the pH of the soil. These biopolymers often display near-neutral pH properties and stabilize soil primarily through physical mechanisms such as gel formation and particle binding rather than chemical reactions. The polymer chains engage with clay particles by hydrogen bonding and electrostatic interactions, which may produce mild flocculation of clay particles and increase soil stability.

The inclusion of biopolymers also helps to enhance resilience against soil erosion. The gel-like structures generated by xanthan gum and guar gum bind soil particles together and lower the risk of particle separation under flowing water conditions. This polymer-soil matrix helps minimise soil erodibility and promotes the stability of the soil surface. Due to their hydrophilic nature, biopolymers such as xanthan gum and guar gum can absorb and retain water within the soil matrix, thereby enhancing moisture retention and contributing to better soil stability. Although erosion resistance tests such as pinhole or rainstorm simulation tests were not performed in the present study, the observed increase in compressive strength indicated better resistance to erosion.

Durability is an essential factor in soil stabilization, particularly under environmental situations such as dry-wet cycles or chronic moisture exposure. From various research has demonstrated that biopolymers

such as xanthan gum and guar gum can improve the durability of treated soils by producing gel-like structures that bind soil particles and prevent erosion. These polymer networks assist preserve soil strength even under variable moisture conditions. Still, wide durability testing such as wet-dry cycles and freeze-thaw resistance were rather undertaken in the present study and may be considered for future investigations. Biopolymers reduce soil permeability by filling pore spaces and forming gel-like structures between soil particles.

Biopolymers such as xanthan gum and guar gum are biodegradable and may progressively deteriorate due to microbial activity over long durations. But the polymer-soil matrix created during stabilization can maintain soil strength for some period under stable environmental circumstances.

## 5 Conclusion

On the 28th day, a soil sample mixed with 0.25%, 0.5%, 1%, and 2% showed an increase in compressive strength of 27.08%, 27.57%, 39.19%, and 54.58%, respectively. In soil samples combined with 2% biopolymer, the rate of strength development increased significantly within the first 28 days. Biopolymer concentrations of 1.5% are considered to be the ideal level; concentrations over this showed handling difficulties. The 28-day unconfined strength was 18.88 kN/m<sup>2</sup>, which is 54.58% more than that of untreated soil, at 1.5% biopolymer content. Strength and other properties of the soil have improved as a result of changes in the fabric and intercellular forces of the soil. It may be concluded that employing biopolymers to treat soil offers an environmentally acceptable alternative to conventional chemical soil treatments.

The concentration of xanthan gum and guar gum was found to be directly responsible for the improvement in soil characteristics. However, larger concentrations of polymers, such as 2% and above, affect the consistency and texture of the soil, making it challenging to work with. Due to water loss during the curing process, the xanthan gum structure shrinks and takes on characteristics of a hard plastic, strengthening the soil through increased interparticle interactions and increasing its stiffness and strength. The effectiveness of the biopolymer additive will be affected by natural cycles of wet and dry climates. Dehydration of polymers produces the creation of a gel within soil gaps, which improves critical properties. Although the present study primarily focused on analysing soil strength using the unconfined compressive strength test, additional tests such as California Bearing Ratio (CBR) and triaxial shear strength tests might provide greater insight into the engineering behavior of biopolymer-treated soils. These tests are particularly relevant for pavement design and geotechnical applications and may be addressed in future studies to further understand the shear strength parameters of stabilized marine clay.

From an economic standpoint, the usage of biopolymers may have a somewhat higher material cost compared with typical soil stabilizers such as lime or cement. But biopolymers offer various advantages like environmental sustainability, biodegradability, and decreased carbon footprint. These properties make biopolymer-based stabilization an interesting alternative for environmentally friendly geotechnical applications despite the greater initial cost. In practical applications, biopolymers such as xanthan gum and guar gum can be applied in the field by mixing the biopolymer solution with soil using mechanical mixers or by spraying the solution into the soil surface followed by compaction. The present study mainly focused on laboratory evaluation of compressive strength. Additional investigations involving permeability, durability, and large-scale field applications are recommended.

## References

1. Garcia-Ochoa, F., V. E. Santos, J. A. Casas, and E. Gómez. "Xanthan gum: production, recovery, and properties." *Biotechnology advances* 18, no. 7 (2000): 549-579.
2. Chang, Ilhan, and Gye-Chun Cho. "Strengthening of Korean residual soil with  $\beta$ -1, 3/1, 6-glucan biopolymer." *Construction and Building Materials* 30 (2012): 30-35.
3. Khatami, Hamid Reza, and Brendan C. O'Kelly. "Improving mechanical properties of sand using biopolymers." *Journal of Geotechnical and Geoenvironmental Engineering* 139, no. 8 (2013): 1402-1406.
4. Chang, Ilhan, Jooyoung Im, Awlia Khari Prasidhi, and Gye-Chun Cho. "Effects of Xanthan gum biopolymer on soil strengthening." *Construction and Building Materials* 74 (2015): 65-72.
5. Jose, Babu T., A. Sridharan, and Benny Mathews Abraham. "A study of geotechnical properties of Cochin marine clays." *Marine Georesources & Geotechnology* 7, no. 3 (1988): 189-209.
6. Chang, Ilhan, Awlia Khari Prasidhi, Jooyoung Im, Hyun-Dong Shin, and Gye-Chun Cho. "Soil treatment using microbial biopolymers for anti-desertification purposes." *Geoderma* 253 (2015): 39-47.
7. Latifi, Nima, SuksunHorpibulsuk, Christopher L. Meehan, Muhd Zaimi Abd Majid, and Ahmad Safuan A. Rashid. "Xanthan gum biopolymer: an eco-friendly additive for stabilization of tropical organic peat." *Environmental Earth Sciences* 75 (2016): 1-10.
8. Cabalar, Ali Firat, Mateusz Wiszniewski, and Zdzisław Skutnik. "Effects of xanthan gum biopolymer on the permeability, odometer, unconfined compressive and triaxial shear behavior of a sand." *Soil mechanics and foundation engineering* 54 (2017): 356-361.
9. Cabalar, A.F., Awraheem, M.H. and Khalaf, M.M., 2018. Geotechnical properties of a low-plasticity clay with biopolymer. *Journal of materials in civil engineering*, 30(8), p.04018170.
10. Rashid, Ahmad Safuan A., SeyedAli Tabatabaei, Suksun Horpibulsuk, Nor Zurairahetty Mohd Yunus, and Wan Hasmida Wan Hassan. "Shear strength improvement of lateritic soil stabilized by biopolymer based stabilizer." *Geotechnical and Geological Engineering* 37 (2019): 5533-5541.
11. Nair, Lekshmi P., and K. Kannan. "Assessment of kuttanad soil stabilized with biopolymers." *International Journal of Research in Engineering, Science and Management* 2, no. 2 (2019): 547-549.
12. Tasuji, MohammadReza Amiri, Pooria Ghadir, Amin Hosseini, Akbar A. Javadi, Asghar Habibnejad Korayem, and Navid Ranjbar. "Experimental investigation of sandy soil stabilization using chitosan biopolymer." *Transportation Geotechnics* 46 (2024): 101266.