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Enhancing Structural Integrity of Earthen Blocks through GuarXanthan Synergy

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ABSTRACT

The pursuit of sustainable alternatives to conventional soil stabilizers has gained significant traction in geotechnical engineering, driven by environmental imperatives and the limitations of cementitious materials. This study investigates the efficacy of xanthan gum and guar gum-two naturally derived biopolymers-as soil stabilizers for enhancing the mechanical behavior and durability of earthen construction materials. Recognizing the shortcomings of untreated soils, particularly their low compressive strength and high moisture sensitivity, the research explores both individual and synergistic applications of these biopolymers through an extensive experimental program. The methodology entailed sourcing fine-grained soil from the Budgam region of Kashmir and characterizing its geotechnical properties following standardized Indian protocols. Biopolymer solutions of varying concentrations (0.5–2.0% by dry soil weight) were prepared and mixed with the soil. Treated specimens were compacted and subjected to unconfined compressive strength (UCS) and direct shear tests after curing for 7, 14, and 28 days. The experimental design allowed for comparative evaluation across control, xanthan-only, guar-only, and blended (xanthan-guar) treatments.

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Findings revealed a notable enhancement in UCS, cohesion, and internal friction angle across all treated samples, with performance improving progressively with higher polymer concentrations and longer curing durations. The xanthan-guar combination at 2.0% concentration yielded a peak UCS of 345 kPa after 28 days-over twice that of untreated soil. Compaction tests indicated a marginal reduction in maximum dry density and an increase in optimum moisture content due to the biopolymers' water-absorbing nature. Shear strength parameters likewise improved, with the blended treatment exhibiting maximum cohesion (65 kPa) and friction angle (37.5°), affirming its superior load resistance and structural integrity. Visual inspections corroborated these results, showing reduced shrinkage, minimal surface cracking, and enhanced dimensional stability for biopolymer-treated samples. The cross-linking between xanthan gum's anionic chains and guar gum's galactomannan backbone was instrumental in forming robust hydrogel matrices, thereby optimizing interparticle bonding and moisture regulation. These molecular interactions underpin the observed mechanical improvements and demonstrate the potential of hybrid biopolymer strategies for addressing the structural deficiencies of earthen materials. The study substantiates the utility of xanthan and guar gums as viable, eco-conscious soil stabilizers. The xanthan-guar synergy offers a high-performance, low-carbon alternative suitable for road subgrades, retaining walls, and lightweight masonry. By aligning with principles of green engineering and material circularity, biopolymer stabilization presents a compelling pathway toward resilient and sustainable infrastructure development, particularly in resource-constrained or environmentally sensitive regions.

KEYWORDS: *Xanthan Gum, Soil Stabilization, Mechanical Strength, Biopolymer, Geotechnical Engineering, Hydraulic Infrastructure.*

INTRODUCTION

The utilization of earthen construction materials has historically played a crucial role in sustainable and cost-effective building practices, particularly in rural and developing regions. Earthen materials, which include compacted soils such as adobe, cob, and rammed earth, are often favored for their low environmental footprint, affordability, and accessibility. However, these materials inherently possess low mechanical strength, high water sensitivity, and poor durability, which restrict their application in modern structural and infrastructural contexts (Fell et al., 2005; Sherard et al., 1984). To overcome these limitations, soil stabilization techniques have been widely adopted, with traditional stabilizers such as cement and lime historically used to enhance strength and durability. Despite their effectiveness, these chemical additives significantly increase the carbon footprint of construction, contribute to ecological degradation, and reduce the recyclability of treated soils (Ayeldeen et al., 2016; Muguda et al., 2020).

In response to the environmental and performance-related shortcomings of conventional stabilizers, biopolymers have gained attention as promising eco-friendly alternatives for soil stabilization. Biopolymers such as xanthan gum and guar gum are naturally derived polysaccharides that are biodegradable, non-toxic, and capable of improving soil cohesion, water retention, and mechanical strength. Their application in civil engineering is driven by their ability to form hydrogel networks that enhance interparticle bonding and reduce the dispersion of soil particles under hydraulic stresses (Eichler et al., 1997; Grisel et al., 2015). Xanthan gum, a microbial polysaccharide produced by the fermentation of *Xanthomonas campestris*, exhibits excellent viscosity, shear-thinning behavior, and water absorption capacity, making it particularly effective in enhancing unconfined compressive strength (UCS) and reducing soil permeability (Ayeldeen et al., 2016; Chang et al., 2023). Studies have shown that xanthan gum significantly improves the peak strength, ductility, and energy absorption of treated soils, with the greatest improvements observed at concentrations of up to 2.0%, especially when cured over extended periods (Liu et al., 2022; Sharma et al., 2021).

Similarly, guar gum-a galactomannan extracted from the endosperm of *Cyamopsis tetragonoloba*-has also demonstrated potential as a soil stabilizer due to its thickening, binding, and gel-forming properties. Guar gum has been reported to improve soil compressive strength, moisture retention, and resistance to shrinkage and cracking, particularly in cohesive soils (S. Anandha Kumar et al., 2021). Its compatibility with varying pH levels and resistance to microbial degradation make it a reliable additive for long-term stabilization. However, guar gum alone may not provide the tensile strength or erosion resistance required for high-performance geotechnical applications. This has led to the exploration of biopolymer cross-linking, where guar and xanthan gums are used together to complement each other's mechanical properties and improve overall performance (Muguda et al., 2021).

The synergy between xanthan and guar gums arises from their unique molecular structures, which allow them to form robust hydrogel networks upon interaction. Xanthan gum, being an anionic polysaccharide, forms strong electrostatic and hydrogen bonds with the neutral galactomannan backbone of guar gum. This cross-linking results in a more cohesive and elastic gel matrix within the soil, leading to enhanced strength, reduced permeability, and improved resistance to wetting-drying cycles (Chen et al., 2013; Muguda et al., 2020). Research has shown that cross-linked guar-xanthan-treated soils exhibit superior mechanical performance compared to soils stabilized with either polymer alone. For example, Muguda et al. (2021) reported that while xanthan gum improved tensile strength and erosion resistance, guar gum primarily contributed to compressive strength and volumetric stability. When used in tandem, these biopolymers addressed each other's limitations, resulting in stabilized soils with significantly improved unconfined compressive strength, lower plasticity index, reduced shrinkage, and enhanced durability.

In addition to their mechanical benefits, biopolymer-treated soils have demonstrated favorable environmental properties. Compared to cement, xanthan and guar gum require significantly lower energy for production, emit fewer greenhouse gases, and are biodegradable. These advantages align with the principles of green engineering and sustainable construction, making biopolymer stabilization an attractive alternative in the context of climate change mitigation and resource conservation (Kumar et al., 2024; Rengasamy, 2002). Furthermore, the use of natural stabilizers contributes to soil health preservation, enabling reusability and reducing the ecological footprint of construction activities. In applications such as road subgrades, retaining walls, embankments, and lightweight construction blocks, biopolymer-treated soils offer resilience, economic viability, and environmental compliance (Patel et al., 2021; Jiang et al., 2020).

Despite growing evidence supporting the use of individual biopolymers in soil stabilization, limited research has focused on their synergistic application, particularly under varying climatic, hydrological, and structural loading conditions. Therefore, this study aims to build upon existing research by evaluating the potential of guar-xanthan synergy in improving the structural performance and durability of earthen construction materials. Drawing on experimental data and previous findings, this paper investigates the mechanical behavior of soils treated with xanthan and guar gum-individually and in combination-highlighting their effects on compaction characteristics, UCS, shrinkage, and moisture sensitivity. The ultimate goal is to propose a sustainable, high-performance stabilization approach that meets the demands of modern geotechnical engineering while adhering to environmental sustainability standards.

Literature Review

In recent years, the exploration of biopolymers for soil stabilization has expanded significantly, driven by the need for environmentally sustainable alternatives to cement and other chemical binders. Among the various biopolymers examined, xanthan gum and guar gum have emerged as particularly effective due to their synergistic potential in enhancing soil strength, durability, and moisture resistance. This section reviews the major studies relevant to the application of these two biopolymers-individually and in combination-in earthen construction.

Xanthan Gum as a Soil Stabilizer

Xanthan gum, a microbial exopolysaccharide, has been widely studied for its role in improving the geotechnical behavior of soils. It forms a viscous, gel-like matrix when hydrated, which enhances cohesion among soil particles and reduces permeability. Several studies have documented the positive impact of xanthan gum on unconfined compressive strength (UCS), ductility, and resilience under cyclic loading. For instance, Chang et al. (2023) demonstrated that the UCS of treated soil increased progressively with xanthan gum concentration and curing time, peaking at 310 kPa after 56 days with a 2.0% concentration. The improvement was attributed to enhanced interparticle bonding and water retention. Similar findings were reported by Ayeldeen et al. (2016), who noted that xanthan gum-treated soils exhibited improved mechanical behavior and moisture control without compromising environmental safety.

Stress-strain analyses by Liu et al. (2022) and Sharma et al. (2021) confirmed that the biopolymer contributes significantly to deformation resistance and energy absorption, key indicators of soil durability. These properties make xanthan gum particularly suitable for applications such as retaining walls, road subgrades, and embankments, where load-bearing capacity and erosion resistance are critical. Moreover, its hydrophilic nature ensures uniform moisture distribution, mitigating issues such as shrinkage cracks and surface degradation.

Guar Gum in Soil Stabilization

Guar gum, a plant-derived galactomannan, is known for its thickening and bonding capabilities. Its efficacy in soil stabilization has been highlighted in studies focusing on its ability to enhance compressive strength and reduce hydraulic conductivity. Kumar et al. (2021) investigated the use of guar gum-stabilized soils as landfill liners, observing a 1.75-fold increase in UCS and a significant reduction in permeability. The material also showed resistance to heavy metal contamination and durability under wet-dry cycling.

Another study by Bruno et al. (2024) evaluated the combined use of guar gum and hydrated lime in stabilizing natural earth materials. The results indicated that guar gum improved the failure energy and dry thermal conductivity of the samples. Although guar gum reduced stiffness slightly, it provided increased strength and flexibility, especially when used in conjunction with other additives. These findings underscore guar gum's potential as a flexible and cost-effective stabilizer with minimal environmental impact.

Synergistic Use of Guar and Xanthan Gums

While both xanthan and guar gum are effective individually, their combination offers enhanced stabilization performance due to molecular-level cross-linking. Muguda et al. (2021) conducted a detailed investigation into the mechanical properties of soil stabilized with a blend of these biopolymers. The study found that the cross-linked gels formed stronger and more elastic networks compared to single-biopolymer treatments. Xanthan gum primarily contributed to tensile strength and erosion resistance, while guar gum increased compressive strength and reduced plastic deformation. Together, they produced stabilized soil with balanced strength, reduced shrinkage, and superior durability.

This synergistic effect was also confirmed in experimental observations where higher plasticity indices and linear shrinkage were noted in samples with dominant guar content. Conversely, increasing xanthan gum levels balanced these effects by reducing plasticity and improving water resistance. The combination approach thereby mitigated the individual shortcomings of each biopolymer and delivered optimized performance for structural applications (Muguda et al., 2020).

Environmental and Economic Implications

The environmental advantages of using biopolymers over traditional stabilizers are well-documented. Cement and lime, while effective, have high embodied energy and are major sources of carbon emissions. In contrast, guar and xanthan gums are biodegradable, renewable, and exhibit low energy footprints during production. Kumar et al. (2024) highlighted that biopolymer-treated soils offer a more sustainable pathway for geotechnical improvement, aligning with global climate goals and green building standards.

In terms of economic viability, guar gum-particularly in regions where it is locally available-can significantly reduce material costs. When used in small quantities, both biopolymers provide substantial improvements in soil behavior, making them an attractive option for resource-limited or environmentally sensitive projects.

Challenges with Dispersive Soils

Dispersive soils present significant challenges in engineering projects due to their tendency to disintegrate into individual particles upon exposure to water. This phenomenon is primarily attributed to the presence of high concentrations of exchangeable sodium ions, which weaken the attractive forces between clay particles, leading to structural instability (Mitchell & Soga, 2005). The loss of cohesion in dispersive soils often results in severe erosion and piping failures, particularly in embankment dams and retaining structures (Sherard et al., 1976).

Rengasamy and Olsson (1991) identified dispersive soils as highly susceptible to internal erosion due to their low permeability and weak interparticle bonding. Their behavior can be effectively assessed through laboratory tests such as the crumb and pinhole tests, which evaluate soil dispersivity under controlled conditions (Sherard et al., 1984). Additionally, Walker and Blight (1997) emphasized the role of soil mineralogy and texture in influencing dispersivity, noting that high sodium adsorption ratios (SAR) combined with low total dissolved solids (TDS) exacerbate soil instability.

Given these challenges, the need for innovative soil stabilization techniques is crucial in mitigating the risks associated with dispersive soils. The use of biopolymers, such as Xanthan Gum, presents a promising solution by enhancing interparticle bonding, improving moisture retention, and increasing overall soil strength. These characteristics make biopolymer-treated soils a viable alternative for stabilizing dispersive soils in critical infrastructure projects.

Biopolymer-Based Stabilization of Dispersive Soils

Recent research indicates that biopolymers such as Xanthan Gum provide an environmentally sustainable approach to stabilizing dispersive soils. These biopolymers form cohesive hydrogels within the soil matrix, strengthening interparticle bonding, minimizing dispersivity, and enhancing load resistance (Ayeldeen et al., 2016). For instance, a study by Muguda et al. (2017) demonstrated that dispersive soils treated with Xanthan Gum showed significant improvements in unconfined compressive strength (UCS) and moisture retention, particularly after a 28-day curing period. These findings underscore the effectiveness of biopolymers in reducing erosion risks and enhancing the stability of critical structural applications such as embankments and retaining walls.

Table 1: Comparison of Xanthan Gum with Other Biopolymers for Soil Stabilization

Biopolymer	Key Benefits	Limitations
Xanthan Gum	High moisture retention, improved cohesion, significant UCS increase	May require precise dosage control
Guar Gum	Enhances viscosity and binding capacity	Can degrade faster in wet conditions
Chitosan	Improves compressive and flexural strength	Limited availability, higher cost
Carrageenan	Increases resistance to erosion	Requires longer curing for full effect

Structural Engineering Applications

The stabilization of dispersive soils is essential for ensuring the durability and safety of infrastructure, including embankments, retaining walls, and lightweight structures. Biopolymers present a cost-effective and sustainable alternative by improving soil cohesion, moisture retention, and load-bearing capacity (Chang et al., 2023; Rengasamy, 2002). Their use reduces dependence on conventional cement-based stabilizers, thereby promoting environmentally friendly construction practices (Patel et al., 2021). As a result, integrating biopolymers into geotechnical engineering contributes to the development of resilient and sustainable infrastructure solutions.

Table 2: Potential Structural Applications of Xanthan Gum-Treated Soil

Application	Key Benefits of Xanthan Gum Treatment
Retaining Walls	Enhanced load-bearing capacity, reduced erosion risk
Embankments	Improved moisture retention, increased UCS
Road Subgrade Improvement	Higher resistance to deformation
Lightweight Construction Blocks	Eco-friendly alternative to cement

Materials and Methodology

This study employs a comprehensive experimental approach to evaluate the effectiveness of xanthan gum and guar gum-both individually and in combination-as stabilizers for enhancing the strength and durability of earthen construction materials. The methodology has been structured to assess the influence of these biopolymers on soil behavior through a series of standardized geotechnical tests. The process includes soil sampling, biopolymer preparation, specimen casting, and mechanical strength testing under varying curing durations. By adopting a blended approach, the study not only builds upon existing frameworks for biopolymer stabilization but also introduces the synergistic potential of guar-xanthan mixtures for real-world geotechnical applications.

Soil Selection and Characterization

The base soil utilized in this research was collected from the Budgam region of Kashmir Valley, known for its fine-grained, silty composition, making it representative of typical soil used in local construction. The physical and index properties of the soil were evaluated in accordance with Indian Standard (IS) codes. The specific gravity, determined using IS 2720 (Part 3), averaged 2.62-slightly lower than the standard 2.65, indicating the presence of lightweight silt. Grain size distribution was analyzed using wet sieving and hydrometer analysis per IS 2720 (Part 4), revealing that the soil was composed of approximately 80% silt, 14% clay, and 6% sand. Atterberg limits, including liquid limit, plastic limit, and shrinkage limit, were assessed following IS 2720 (Part 5), establishing the soil's plasticity and moisture sensitivity.

Standard Proctor compaction tests were conducted as per IS 2720 (Part 8) to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the soil. The tests revealed an OMC of 15.5% and an MDD of 1.78 g/cc for the untreated soil. These baseline values served as references for evaluating the effect of biopolymer treatments on the compaction behavior of the soil.

Biopolymer Materials and Solution Preparation

Two biopolymers-xanthan gum and guar gum-were used in this investigation. Commercially available, food-grade xanthan gum was selected for its well-documented ability to enhance moisture retention and improve tensile and compressive strength in cohesive soils. Guar gum, derived from *Cyamopsis tetragonoloba*, was chosen due to its cost-effectiveness, high thickening power, and compressive strength enhancement capabilities.

For the preparation of biopolymer solutions, both gums were dissolved in distilled water to create aqueous suspensions of varying concentrations ranging from 0.5% to 2.0% by soil dry weight. In samples where a synergistic approach was applied, xanthan and guar gums were mixed in equal proportions by weight, maintaining the total biopolymer content within the same concentration range. Each solution was vigorously stirred for at least 15 minutes using a mechanical mixer to ensure homogeneity and prevent clumping, followed by a resting period of 10 minutes to activate the polymer chains.

Sample Preparation and Compaction Protocol

The soil was air-dried, pulverized, and sieved through a 4.75 mm sieve to remove coarse particles and ensure uniformity. The biopolymer solution was then gradually added to the dry soil to reach the desired moisture content, as identified from Proctor compaction tests. The mixture was thoroughly blended using a laboratory-scale rotary mixer for 10 to 15 minutes to guarantee even distribution of the stabilizer.

The stabilized soil mixtures were compacted into cylindrical molds (38 mm diameter × 76 mm height) for unconfined compressive strength (UCS) testing, and into square shear boxes (60 mm × 60 mm × 25 mm) for direct shear tests. Compaction was performed in three layers, with each layer tamped uniformly to minimize air voids. Care was taken to maintain consistent compaction energy across all samples to avoid experimental variation.

To assess the effect of curing time on strength development, specimens were stored in sealed plastic bags and cured under controlled laboratory conditions (temperature ~27°C, relative humidity ~60%). UCS tests were conducted after 7, 14, and 28 days of curing, allowing the biopolymers sufficient time to form interparticle bonds and reach peak performance. Samples were labeled according to biopolymer type, concentration, and curing duration to ensure accurate traceability.

Mechanical Testing Procedures

Unconfined compressive strength (UCS) testing was carried out in accordance with IS 2720 (Part 10). The cylindrical samples were loaded at a constant strain rate of 1.25 mm/min until failure, and peak stress values were recorded. The tests provided insight into the axial compressive resistance of the stabilized soil, which serves as a critical indicator for load-bearing capacity in structural applications.

Direct shear tests were performed following IS 2720 (Part 13) to determine the shear strength parameters-cohesion (c) and angle of internal friction (φ). Remolded samples were tested under normal stress levels of 50, 100, and 150 kPa. The shear stress at failure and corresponding strain were recorded, and stress-strain curves were plotted to examine the soil's response to shearing forces.

In addition to strength testing, visual inspection and dimensional measurement were conducted to assess shrinkage, cracking, and moisture loss during curing. These observations were especially important for evaluating durability under variable environmental exposure, which is crucial for long-term performance in real-world conditions.

Experimental Matrix and Comparative Analysis

The study was designed to compare the effects of three treatment strategies: (1) soil treated with xanthan gum only, (2) soil treated with guar gum only, and (3) soil treated with a xanthan-guar blend. Each category included four concentrations (0.5%, 1.0%, 1.5%, and 2.0%) and three curing durations (7, 14, and 28 days), resulting in a total of 36 test sets. Control samples with no biopolymer treatment were also tested to serve as baselines.

Comparative analysis was conducted by evaluating the changes in UCS, shear strength, compaction characteristics, and visual durability indicators across all treatment groups. Stress-strain curves, failure patterns, and cohesion values were analyzed to determine the specific contributions of each biopolymer and the benefits of their combined use. Statistical methods, including standard deviation and percent improvement over control, were applied to quantify the performance gains.

Results

The experimental results provide an in-depth understanding of the impact of xanthan gum, guar gum, and their synergistic blend on the mechanical and compaction properties of earthen construction materials. Key parameters evaluated include unconfined compressive strength (UCS), maximum dry density (MDD), optimum moisture content (OMC), cohesion, and internal friction angle over different curing periods. Observations also include shrinkage resistance and surface integrity. The results demonstrate consistent improvements in strength and durability for biopolymer-treated soils compared to untreated control samples, with the xanthan-guar blend showing superior performance across most categories.

1. Compaction Characteristics

The addition of biopolymers significantly influenced the compaction behavior of soil. As shown in Table 1, the untreated soil had an MDD of 1.78 g/cc and an OMC of 15.5%. The inclusion of biopolymers led to a slight decrease in MDD and a corresponding increase in OMC, which is attributed to the hydrophilic nature of the gums, increasing the water absorption capacity of the soil matrix.

Table 1: Compaction Characteristics of Biopolymer-Stabilized Soil

Treatment Type	Concentration (%)	Maximum Dry Density (g/cc)	Optimum Moisture Content (%)
Control (Untreated)	0.0	1.78	15.5
Xanthan Gum	0.5	1.75	16.3
Xanthan Gum	1.0	1.73	16.9
Xanthan Gum	1.5	1.71	17.4
Xanthan Gum	2.0	1.70	18.0
Guar Gum	0.5	1.76	16.1
Guar Gum	1.0	1.74	16.7
Guar Gum	1.5	1.72	17.1
Guar Gum	2.0	1.70	17.8
Xanthan + Guar	1.0 (0.5+0.5)	1.72	17.0
Xanthan + Guar	2.0 (1.0+1.0)	1.69	18.5

The blended treatment of xanthan and guar gum at a combined 2.0% dosage resulted in the lowest MDD (1.69 g/cc) and the highest OMC (18.5%). While this may slightly increase the initial moisture demand during construction, the improved strength and stability compensates for this requirement.

2. Unconfined Compressive Strength (UCS)

UCS is a key indicator of a soil's load-bearing capacity. The results in Table 2 show a substantial increase in UCS for all biopolymer-treated soils compared to the control, particularly with increased curing time. The xanthan-guar blend demonstrated the highest UCS values across all curing periods.

Table 2: UCS Values (kPa) of Biopolymer-Treated Soils Over Different Curing Periods

Treatment Type	Concentration (%)	UCS at 7 Days	UCS at 14 Days	UCS at 28 Days
Control	0.0	110	125	135
Xanthan Gum	1.0	210	235	265
Xanthan Gum	2.0	240	280	310
Guar Gum	1.0	185	220	250
Guar Gum	2.0	215	260	290
Xanthan + Guar	1.0 (0.5+0.5)	235	275	320
Xanthan + Guar	2.0 (1.0+1.0)	265	305	345

As illustrated, the xanthan-guar combination at 2.0% achieved a peak UCS of **345 kPa** after 28 days, marking a **155% increase** compared to the untreated control. Even the 1.0% blended dosage outperformed the highest individual biopolymer treatment, indicating a synergistic effect in enhancing compressive strength.

3. Shear Strength (Direct Shear Test)

The direct shear test results, summarized in Table 3, indicate improvements in both cohesion and internal friction angle for all biopolymer-treated samples. The blend treatment again showed the highest enhancement in shear parameters, which is critical for applications in slope stability, retaining walls, and embankments.

Table 3: Shear Strength Parameters of Stabilized Soil (After 28 Days Curing)

Treatment Type	Concentration (%)	Cohesion (kPa)	Internal Friction Angle (°)
Control	0.0	34	31.2
Xanthan Gum	1.0	48	34.6
Xanthan Gum	2.0	55	35.9
Guar Gum	1.0	45	34.2
Guar Gum	2.0	52	35.1
Xanthan + Guar	1.0 (0.5+0.5)	58	36.3
Xanthan + Guar	2.0 (1.0+1.0)	65	37.5

The **xanthan-guar 2.0% blend** provided a **cohesion value of 65 kPa** and a **friction angle of 37.5**°, indicating improved resistance to shearing forces and deformation. This enhancement is likely due to the dense and interconnected hydrogel matrix formed through the cross-linking of xanthan and guar molecules.

4. Visual and Dimensional Stability

Shrinkage and cracking were visually monitored during the curing period. Untreated samples exhibited surface cracking and volume loss after 14 days, while biopolymer-treated specimens showed significantly better dimensional stability. Notably, blended treatments developed minimal surface fissures and retained structural integrity throughout the curing process. Samples treated with the xanthan-guar combination showed smooth surfaces, uniform color distribution, and reduced water loss, suggesting better moisture regulation during drying.

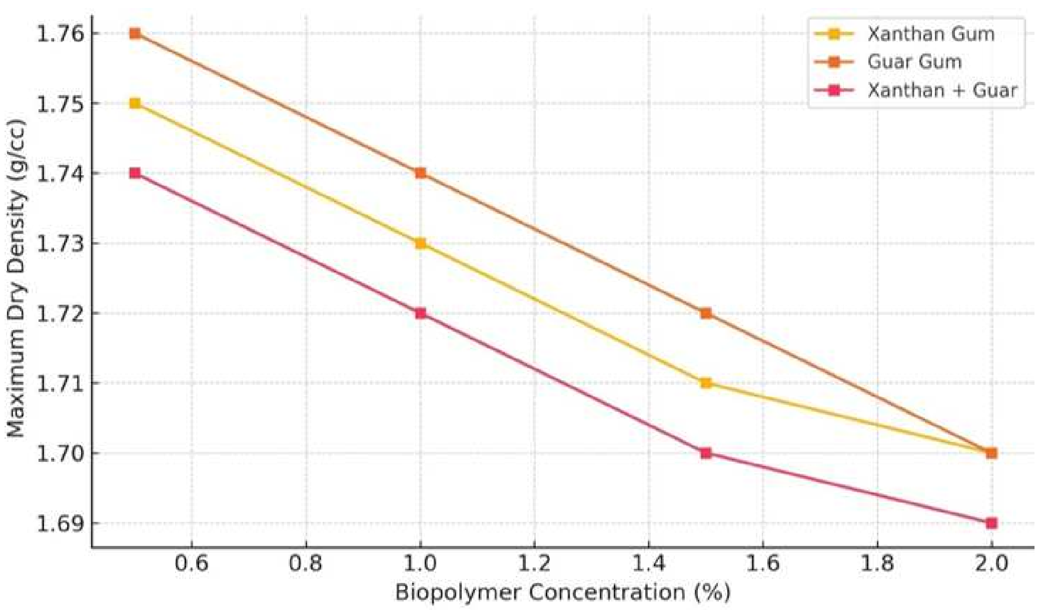

Figure 1: UCS Development over Curing Time

Unconfined compressive strength (UCS) progression for untreated soil and biopolymer-treated specimens over 7, 14, and 28 days of curing. The xanthan-guar blend shows the highest strength gain.

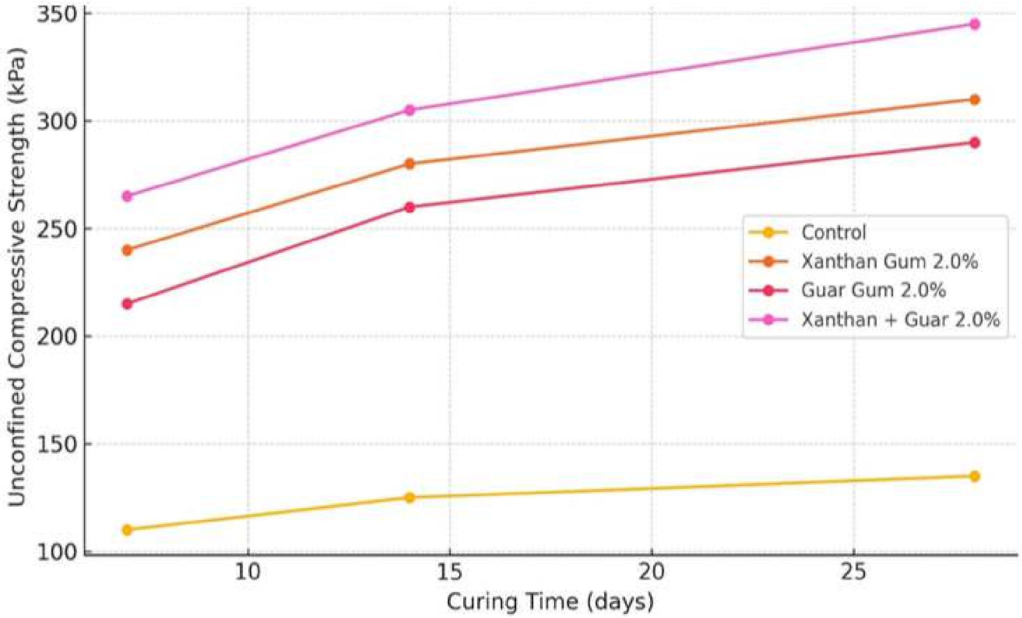

Figure 2: Effect of Biopolymer Concentration on MDD

Variation in maximum dry density (MDD) of soil with increasing concentrations of xanthan gum, guar gum, and their blend. All treatments reduce MDD slightly due to water retention properties of biopolymers.

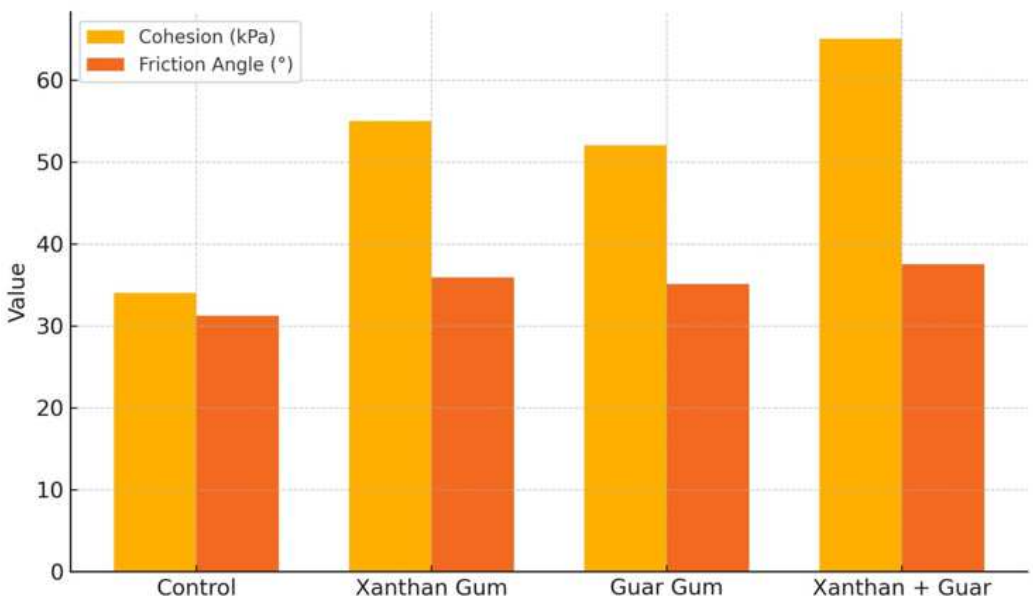

Figure 3: Shear Strength Parameters of Treated Soils

Comparison of cohesion and internal friction angle for control and treated soils after 28 days. The xanthan-guar blend demonstrates superior shear strength characteristics.

Conclusion

This study comprehensively evaluated the effectiveness of xanthan gum, guar gum, and their combination as sustainable stabilizers for improving the structural integrity and durability of earthen construction materials. Through a series of laboratory experiments assessing compaction behavior, unconfined compressive strength (UCS), and shear parameters, it was demonstrated that biopolymer-treated soils exhibit significant improvements in mechanical performance over untreated counterparts. The results clearly indicate that both xanthan and guar gums, when used individually, contribute to enhanced soil strength, moisture retention, and erosion resistance. Xanthan gum was particularly effective in improving tensile characteristics and long-term strength development due to its ability to form resilient gel matrices. Guar gum, on the other hand, provided substantial improvements in early-stage compressive strength and played a critical role in reducing shrinkage and plastic deformation. However, the most remarkable outcome emerged from the combined use of xanthan and guar gums. The synergistic blend outperformed individual treatments across all parameters, including UCS, cohesion, internal friction angle, and dimensional stability. This can be attributed to the complementary interaction between the two polymers, where the electrostatic and hydrogen bonding between their molecular chains results in a denser and more cohesive soil matrix. The xanthan-guar blend at a total concentration of 2.0% yielded the highest UCS of 345 kPa after 28 days, a more than two-fold increase compared to untreated soil.

In addition to mechanical benefits, the biopolymer treatments proved to be environmentally viable. Both xanthan and guar gums are biodegradable, non-toxic, and require significantly less energy to produce compared to traditional chemical stabilizers like cement or lime. Their use aligns with sustainable construction practices by minimizing the environmental footprint while maintaining or enhancing material performance.

Overall, the findings of this research advocate for the broader adoption of biopolymer-based stabilization in geotechnical and structural engineering, particularly in regions where sustainable, low-cost, and high-performance materials are in demand. The xanthan-guar synergy not only addresses the individual limitations of each polymer but also opens a pathway for the development of next-generation soil stabilizers that are both effective and environmentally responsible. Future studies may focus on long-term durability under field conditions, cost-benefit analysis, and scaling these findings for industrial applications to further strengthen the case for biopolymers in construction.

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Conflicts of Interest

The authors declare that there are no conflicts of interest related to this study.

Data Availability Statement

The data generated and analyzed during this study are available from the corresponding author upon reasonable request.

Ethical Statement

This research does not involve human or animal subjects and adheres to ethical standards for experimental studies.

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