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SUSTAINABLE SOIL STABILIZATION USING GUAR GUM BIOPOLYMER

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ABSTRACT

Enhancing the geotechnical properties of soils is essential for improving ground performance in engineering applications. Traditional methods have been widely used, such as chemical stabilization, dewatering, natural and synthetic reinforcements, and drainage systems. Among these, chemical stabilization with cementitious additives like cement and lime is particularly effective. However, this approach raises significant environmental concerns, including permanently altering soil ecosystems and high carbon dioxide emissions during production. In response to these challenges, biopolymers such as guar gum have emerged as promising alternatives due to their biodegradability, non-toxicity, and low environmental impact. This study investigates the stabilization of sandy soils from Hungary using varying ratios of guar gum. The research aims to assess the potential of biopolymers as sustainable soil stabilizers by examining their impact on key geotechnical properties. Shear box tests were conducted to determine shear strength parameters to evaluate the performance of biopolymer-treated soils, while oedometer tests were used to measure compressibility. This study contributes to the growing body of knowledge on sustainable soil stabilization methods and highlights the potential of biopolymers to reduce the environmental footprint of geotechnical engineering practices.

Keywords: soil stabilization, biopolymers, shear strength, environmental-friendly.

INTRODUCTION

Soil stabilization is a critical aspect of geotechnical engineering, particularly in addressing the challenges posed by weak or problematic soils. Sandy soils, characterized by low coefficient of uniformity and high permeability, often require stabilization to enhance their mechanical and hydraulic properties. Traditional stabilization methods, such as the use of cement or lime, have been widely employed due to their effectiveness in improving soil strength and stability. However, these methods are often associated with significant environmental drawbacks, including high carbon emissions during production and long-term alterations to soil ecosystems (Chang et al., 2016). In recent years, there has been a growing interest in the use of biopolymers as sustainable alternatives for soil stabilization. Among these, guar gum (GG), a natural biopolymer derived from the endosperm of guar seeds, has emerged as a promising candidate due to its eco-friendly, biodegradable, and non-toxic properties (Aminpour and O'Kelly, 2015).

Guar gum is a polysaccharide composed of galactose and mannose units, which, upon hydration, forms a viscous, thixotropic gel. This gel-like structure can coat soil particles, creating bonds that enhance soil cohesion and stability. The use of guar gum in soil stabilization has been

explored in various studies, demonstrating its potential to improve soil mechanical properties such as shear

strength, compressibility, and erosion resistance. For instance, Chang et al. (2015) observed that the addition of guar gum significantly enhanced soil aggregate stability and reduced soil erosion, making it particularly effective in arid and semi-arid regions where soil degradation is a pressing issue. Similarly, Sujatha and Saisree (2019) investigated the geotechnical behavior of guar gum-treated soil and reported improvements in unconfined compressive strength (UCS) and reduced permeability, highlighting its potential for use in embankments and slope stabilization.

MATERIALS

Soil

The soil was obtained from a construction site in Göd, Hungary, originating from a mine of Düne Szektor Kft. It is yellowish-brown in color and does not contain any organic content. The grain size distribution curve of the soil, as measured by hydrometer and sieve tests following the Hungarian standard MSZ EN ISO 17892-4:2017, indicates that the soil is a uniformly graded sand

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as shown in Figure 1. The composition and grading characteristics are presented in the following tables: table 1 and table 2.

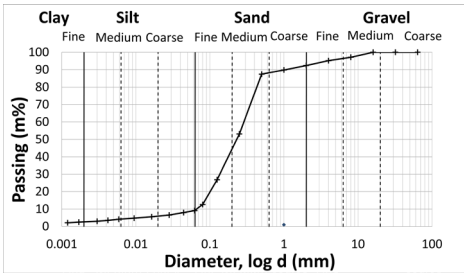


Figure 1 Grain size distribution curve of sand

Table 1 Soil Composition

Soil characteristics	Value
C_u	4.50
C_c	0.98
w	1.3 %
γ_s	2.65 kN/m ³

Table 2 Grading Characteristics of the Soil

Soil fractions	Percentage [%]
Gravel (Gr)	7.57
Sand (Sa)	83.17
Silt (Si)	6.63
Clay (Cl)	2.63

GUAR GUM (GG)

Guar gum, obtained from the seeds of *Cyamopsis tetragonoloba* in the Fabaceae family, is a natural polymer. The endosperm polysaccharide, upon complete hydration, transforms into a thixotropic, viscous, colloidal dispersion. The borate ions inherent in guar gum serve as cross-linking agents, facilitating the formation of cohesive and thick gels (Sujatha and Saisree, 2019)

METHODOLOGY

Sample preparation

The soil samples were oven-dried at 100 °C to 110 °C for 24 hours. The guar gum-treated soil samples were prepared using the dry mixing procedure. Initially, the biopolymer in powder form was mixed with the required amount of soil at percentages of 1% and 2% by weight of the soil. The biopolymer powder was thoroughly mixed with the soil sample in a plastic bag to prevent fine particles from being lost in the air. The required water amount was then added. The optimum water content for mixing was 6.5% of the total dry mass. Upon initial contact

with water, the galactose and mannose present in the biopolymer hydrated rapidly, coating the soil particles.

EXPERIMENTAL INVESTIGATION

SEM observations

The interaction between sand and guar gum was investigated using a scanning electron microscope (SEM) to examine the microstructure of the soil and the guar gum powder. In Figure 2, the top image presents the microstructure of the sandy soil, while the bottom image depicts the microstructure of raw guar gum, both images are at 200X magnification, with a scale bar of 300 μ m.

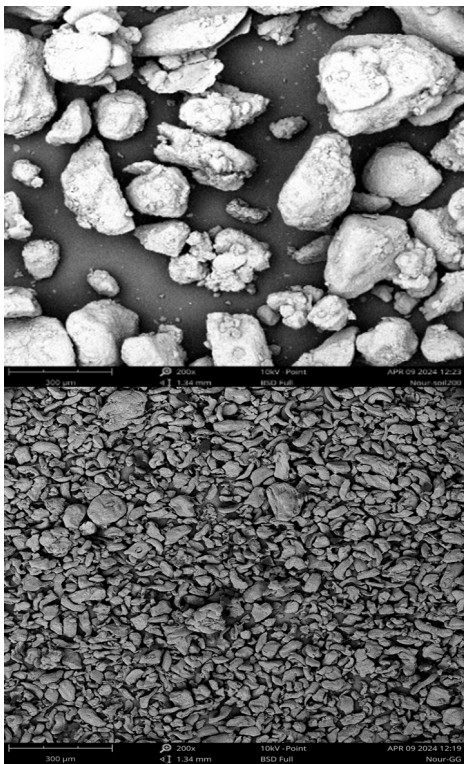


Figure 2 SEM observations of the sand (top) and Guar gum biopolymer powder (bottom) at 200X magnification

Shear box test

After sample preparation and ensuring homogeneity, direct shear tests were conducted to determine shear strength parameters. The tests were performed under loads of 50 kPa, 100 kPa, and 150 kPa, and the results were analyzed. the direct shear test was conducted using the apparatus in Figure 3.

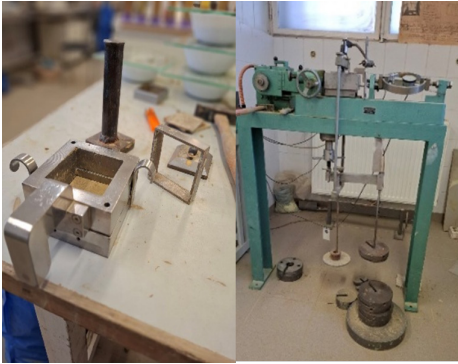


Figure 3 Direct shear apparatus (The Laboratory of Geotechnics and Engineering Geology at BME University, Hungary).

OEDOMETER TEST

The Oedometric test is essential in geotechnical engineering for assessing soil compressibility and consolidation under vertical stress, which helps in the design of foundations and earth structures. The test was initially performed on the original soil at seven loading points (0, 50, 100, 200, 400, 600, 800 kPa). It was then repeated with 1% guar gum treatment, followed by another set with 2% guar gum, at the same loading points. The initial settings of the apparatus are described in Table 3 below.

Table 3 Experimental initial data

Parameter	Value
Original Sample Height H_0	20.0 mm
Sample Diameter D	75.0 mm
Particle Density ρ_s	2.65 g/cm ³

RESULTS AND DISCUSSION

Shear test

Shear strength parameters play a crucial role in understanding the mechanical behavior of soils under different conditions. Table 4 presents the summary of the shear strength parameters derived from direct shear tests performed on untreated sand and sand treated with 1% and 2% guar gum. Each treatment condition was subjected to 10 shear tests to ensure statistical reliability.

Table 4 Shear Parameters summary

Soil sample	Peak		Residual	
	c' [kPa]	ϕ [°]	c' [kPa]	ϕ [°]
Untreated	0	33	0	31.5
1% GG	5.5	28	1	27.5
2% GG	6.4	28	5.6	26.5

Table 5 Shear Stress Results

Normal Load (kPa)	Sand	1% GG Treated	2% GG Treated
	Peak / Residual	Peak / Residual	Peak / Residual
50	27.83 / 22.44	32.62 / 30.15	28.90 / 27.13
100	60.39 / 57.58	55.79 / 52.62	57.55 / 55.09
150	100.75 / 97.06	87.61 / 85.79	85.17 / 83.08

Table 5 presents the shear stress values for untreated sand and sand treated with 1% and 2% guar gum (GG) under different applied normal loads (50 kPa, 100 kPa, and 150 kPa). Each set of values represents the average of ten direct shear tests performed for each treatment condition.

Figure 4 illustrates the variation in peak and residual shear stress of untreated and guar gum-treated sand under different normal loads.

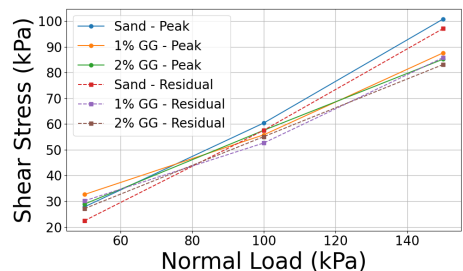


Figure 4 Variation of Peak and Residual Shear Stress with Normal Load for Treated and Untreated Sand

The results indicate that guar gum enhances residual shear strength at lower loads, improving post-peak behavior, but reduces peak shear strength at higher stresses due to its ductile nature.

OEDOMETER TEST RESULTS

Compression index and oedometer modulus

The oedometer test results in Table 6 demonstrate a clear threshold effect of guar gum (GG) on soil compressibility. At

This nonlinear relationship suggests that GG's stabilizing mechanism is dosage-dependent, with 1% representing an optimal balance between pore-filling efficiency and structural cohesion.

Table 6 Oedometer Test Results

Sample	C _c	E _{oed} (MPa)
1%GG	0.032	10.5
1%GG	0.010	33.3
1%GG	0.017	20.0
Mean ± SD	0.020 ± 0.011	21.3 ± 11.6
2%GG	0.040	8.3
2%GG	0.033	10.0
2%GG	0.032	10.5
Mean ± SD	0.035 ± 0.004	9.6 ± 1.1
Untreated	0.015	22.2

VOID RATIOS AT INCREMENTAL LOADS

The void ratio (*e*), a critical indicator of soil compressibility and porosity, varied significantly across guar gum (GG) mixtures under incremental loading. At 1% GG, the soil exhibited lower initial void ratios (*e*₀) and smaller reductions in (*e*) under load compared to 2% GG three mixtures, suggesting improved pore structure stability. In contrast, 2% GG three mixtures showed higher initial porosity and greater void ratio reduction, aligning with their degraded stiffness (lower *E*_{oed}) and higher compressibility (*C*_c). Table 7 summarizes and compares initial/final void ratios across mixes.

Table 7 Initial vs. Final Void Ratios

Sample	Initial <i>e</i> ₀	Final <i>e</i> (800 kPa)	Δ <i>e</i>
1%GG	0.63	0.58	0.05
1%GG	0.62	0.60	0.02
1%GG	0.58	0.54	0.04
Mean ± SD	0.61 ± 0.03	0.57 ± 0.03	0.04 ± 0.02
2%GG	0.68	0.62	0.06
2%GG	0.61	0.56	0.05
2%GG	0.56	0.51	0.05
Mean ± SD	0.62 ± 0.06	0.56 ± 0.05	0.05 ± 0.01
Untreated	0.62	0.58	0.04

CONCLUSION

- Guar gum use significantly enhances soil cohesion while maintaining favorable frictional characteristics, as evidenced by improved shear resistance at low-to-moderate stress levels.
- Void ratio analysis confirms superior pore structure stability with 1% GG, showing reduced compressibility compared to both untreated and 2% GG-treated specimens.
- Excessive GG content (2%) induces structural weakening, manifested through increased compressibility, reduced stiffness, and diminished shear strength under higher loads.

These results establish 1% guar gum as an effective bio-based stabilizer that improves both cohesive and frictional soil properties while maintaining optimal void structure characteristics for geotechnical applications.

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