Laboratory Investigation of Biological and Chemical Stabilization of Sandy Soil in the Presence of Fine-Grained Soil

Halimeh Namdari[1], Mohsen Keramati[2*], Fahime Rafiee[3]

[1] Faculty of Civil Engineering, Shahrood University of Technology, Semnan, Iran
[2] Faculty of Civil Engineering, Shahrood University of Technology, Semnan, Iran
[3] Department of Civil Engineering, School of Engineering, Damghan University, Semnan, Iran

ABSTRACT

Chemical stabilization is a conventional method for improving the geotechnical properties of problematic soils, such as by increasing bearing capacity and reducing permeability. However, due to environmental concerns associated with this method, researchers have been encouraged to investigate more eco-friendly alternatives. This study compares the effectiveness of biopolymers, guar gum and xanthan gum, as biological stabilizers with traditional chemical stabilizers including cement and lime. Unconfined compressive strength (UCS) tests were performed on sandy soil samples mixed with different proportions of kaolin clay (0, 10, 15, 20, and 25% by weight). The samples were stabilized with varying concentrations of guar gum and xanthan gum (0.5%, 1%, 1.5%, and 2% by weight), as well as cement 5%, 10%, and 15% by weight) and lime (4%, 6%, 8%, and 10% by weight). The influence of curing time (7, 14, and 28 days) on compressive strength was also examined. The results demonstrated that increasing the concentration of cement, guar gum, and xanthan gum led to improved compressive strength. However, for lime-treated samples, the maximum strength was achieved at 8% lime content. Furthermore, in biopolymer-stabilized samples, both increased biopolymer concentration and longer curing times resulted in higher strength, with guar gum outperforming xanthan gum. The biopolymers significantly enhanced the soil's unconfined compressive strength, indicating their potential as sustainable alternatives to chemical stabilizers. Nevertheless, although higher clay and additive contents improved strength in biological stabilization, the rate of strength gain decreased with increasing clay percentage.

KEYWORDS

Soil Stabilization, Clayey Sand, Guar Gum, Xanthan Gum, Unconfined Compressive Strength

* Corresponding Author: Email: keramati@shahroodut.ac.ir

1. Introduction

With the expansion of construction projects on problematic soils, the demand for soil improvement techniques has increased substantially [1]. Traditional chemical stabilization methods using cement and lime, although effective, are associated with environmental concerns, including greenhouse gas emissions [2, 3]. In recent years, bio-stabilization using biopolymers such as guar gum and xanthan gum has been introduced as an environmentally compatible alternative. These materials enhance the mechanical properties of soil by forming inter-particle bonds and developing a network-like structure.

Chang et al. (2015) investigated the role of xanthan gum in improving coarse- and fine-grained soils, reporting that its effectiveness in fine-grained soils is higher than in sandy soils. This behavior is attributed to hydrogen bonding between xanthan gum and the charged surfaces of clayey soils [4]. The effects of xanthan and guar gums on the shear behavior of granular soils were studied by Latifi et al., who reported that increasing the biopolymer content and curing time significantly enhances soil shear strength [5]. In addition, Bouziget et al. (2021) examined the influence of xanthan and guar gums on the mechanical behavior of kaolinite clay. They found that both biopolymers increase the liquid limit, dry density, and unconfined compressive strength of the soil while decreasing the optimum moisture content [6]. Oliveira and Cabral (2023) demonstrated that bio-stabilization of silty sand with xanthan gum improves compressive strength, stress–strain behavior, and one-dimensional compressibility, with such improvements intensifying at higher xanthan contents [7].

Yang et al. (2025) reported that the addition of xanthan gum to red clay increases shear strength almost linearly with increasing normal stress [8]. Baldobino et al. (2025) concluded that the incorporation of xanthan gum and polypropylene fibers significantly increases the strength and stiffness of clay, with curing time and specimen density playing key roles in these improvements [9].

Despite numerous studies on pure fine- or coarse-grained soils, limited attention has been devoted to simultaneous biological and chemical stabilization of sandy soils containing various clay contents. The objective of the present study is to systematically evaluate the performance of chemical and biological stabilizers and assess the combined effects of clay content, stabilizer concentration, and curing time on the unconfined compressive strength of sandy soils.

2. Methodology

In this study, siliceous sand from Babolsar was used as the granular material and kaolinite clay as the fine-grained fraction. Clay contents of 0, 10, 15, 20, and 25% (by dry weight) were added to the sand. The specimens were stabilized using chemical additives, including Type II Portland cement (5, 10, and 15% by weight) and lime (6, 8, and 10% by weight), as well as biopolymers of xanthan gum and guar gum at concentrations of 0.5, 1, 1.5, and 2% by weight.

After preparation, the specimens were molded into standard cylindrical samples for unconfined compressive strength (UCS) testing and cured for 7, 14, and 28 days. UCS tests were carried out according to ASTM D2166. In addition, scanning electron microscopy (SEM) was conducted to investigate the microstructural mechanisms associated with biopolymer stabilization.

3. Results and Discussion

In the chemical stabilization of sand–clay mixtures, increasing cement content enhances compressive strength. However, increasing the clay content beyond 20% results in strength reduction, indicating the presence of an optimal clay content for cement-stabilized soils. Among specimens with different clay contents, those stabilized with 8% lime exhibited the highest compressive strength. Increasing lime content beyond 8% reduced strength due to the saturation of soil reactivity. Conversely, increasing clay content up to 25% had a positive effect on strength. In addition to stabilizer content, longer curing periods (7 to 28 days) also significantly improved compressive strength.

The results also showed that increasing guar and xanthan gum contents up to 2% enhances the UCS of the mixtures. The network structure formed by the biopolymers reinforces inter-particle bonding [10]. Furthermore, increasing clay content leads to higher UCS values; however, this trend diminishes at higher biopolymer concentrations. In other words, although clay contributes to strength improvement, excessive biopolymer concentrations increase viscosity and restrict optimal compaction, thus preventing continuous strength gains [5]. For comparison purposes, the maximum UCS values of guar-stabilized specimens and their strength improvement ratios relative to the baseline soil (sand with 0% clay) are presented in Table 1.

Table 1. Rate of Change in Maximum UCS of Guar Gum–Stabilized Mixed Soil Relative to the Base Sample

Clay Content (%)	Biopolymer Content (%)	Growth Rate of Maximum UCS (%)
0	0.5	**Base Sample**
10		46.54
15		75.37
20		108.63
25		210.58
0	2	**Base Sample**
10		28.30
15		46.12
20		88.95
25		101.52

UCS test results further indicated that curing time, along with biopolymer concentration and clay content, plays an important role in strength development. For comparison, the UCS behavior of guar-stabilized sand containing 20% clay is illustrated in Figure 1. Increasing guar concentration in combination with extended curing time promotes stronger inter-particle bonding and consequently improves mechanical performance.

Results further demonstrated that in most clay–sand mixtures, guar gum performs more efficiently than xanthan gum, although xanthan gum forms denser network structures at higher concentrations. SEM images confirmed the formation of polymeric bonding networks and reduced pore spaces in biopolymer-stabilized specimens.

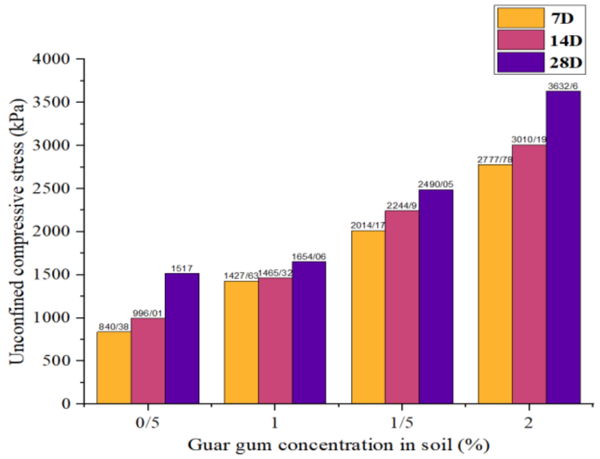

Figure 1. Effect of Curing Time on 20% Clay Sandy Soil Stabilized with Guar Gum

4. Conclusion

The findings of this study indicate that for projects with environmental considerations and in soils with low to moderate clay contents, bio-stabilization using guar and xanthan gums can serve as a suitable alternative to traditional chemical stabilizers. Although increasing clay content enhances compressive strength, optimal clay content and stabilizer concentration are required to achieve maximum performance. These results may guide engineers and researchers in selecting appropriate stabilization strategies considering soil conditions as well as economic and environmental constraints.

5. References

[1] R.H. Karol, Chemical grouting and soil stabilization, revised and expanded, Crc Press, 2003.

[2] I. Chang, M. Lee, G.-C. Cho, Global CO2 emission-related geotechnical engineering hazards and the mission for sustainable geotechnical engineering, Energies, 12(13) (2019) 2567.

[3] R. Etim, A.O. Eberemu, K. Osinubi, Stabilization of black cotton soil with lime and iron ore tailings admixture, Transportation Geotechnics, 10 (2017) 85-95.

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

[5] N. Latifi, S. Horpibulsuk, C.L. Meehan, M.Z. Abd Majid, M.M. Tahir, E.T. Mohamad, Improvement of problematic soils with biopolymer—an environmentally friendly soil stabilizer, Journal of Materials in Civil Engineering, 29(2) (2017) 04016204.

[6] I. Bozyigit, A. Javadi, S. Altun, Strength properties of xanthan gum and guar gum treated kaolin at different water contents, Journal of Rock Mechanics and Geotechnical Engineering, 13(5) (2021) 1160-1172.

[7] P.J. Venda Oliveira, D.J. Cabral, Behaviour of sand stabilised with xanthan gum under unconfined and confined conditions, Proceedings of the Institution of Civil Engineers-Ground Improvement, 176(1) (2023) 3-13.

[8] F. Yang, Z. Zhao, Z. Jia, W. Niu, Y. Liu, F. Song, H. Dong, H. Deng, Study on the mechanical properties and microscopic mechanism of xanthan gum improved red clay, Scientific Reports, 15(1) (2025) 31842.

[9] J.d.J.A. Baldovino, Y.E.N. de la Rosa, O.P. Calabokis, J.A.A. Vergara, L.C.S. López, Geotechnical Behavior of Xanthan Gum-Stabilized Clay Reinforced with Polypropylene Fibers, Polymers, 17(3) (2025) 363.

[10] X. Rong, S. Deng, B. Liang, J. Zhuang, Y. Yu, Z. Wu, Mechanical behavior and strengthening mechanism of loess stabilized with xanthan gum and guar gum biopolymers, Materials Research Express, 11(10) (2024) 105305.