Using biopolymers to improve stabilization operations in soft clay substrates

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ABSTRACT

Problematic soils often exhibit low strength and unfavorable engineering behavior, making stabilization necessary for safe and economical construction. This study experimentally compared hydrated lime, xanthan gum (XG), and sodium alginate (SA) in improving the unconfined compressive strength (UCS) of kaolinite (K), sodium bentonite (B), and a sand–clay mixture (SC) composed of 80% standard sand and 20% local clay. Lime was added at 2.5%, 5%, and 7.5% by dry soil mass, whereas XG and SA contents were 0.5%, 1%, 1.5%, and 2%. Specimens were cured for 7 and 28 days and tested in unconfined compression. Four replicate specimens were prepared for each soil–additive–curing combination. The results showed that stabilizer performance depended strongly on soil type, dosage, and curing time. At 28 days, the maximum UCS values for lime-treated soils were 2.08 MPa for K with 7.5% lime, 1.67 MPa for B with 5% lime, and 0.95 MPa for SC with 7.5% lime. XG produced a non-linear response, with the highest 28-day strengths within the tested ranges at 2% for K and 1% for both B and SC. SA was most effective at 0.5% in K and B, while it reduced the UCS of SC at all tested contents. Overall, lime provided the most consistent long-term strength improvement, whereas the effectiveness of the biopolymers varied with soil characteristics. The findings demonstrate that stabilizer selection and dosage should be tailored to the soil rather than applied uniformly.

KEYWORDS

Soil stabilization, Soft clay, lime, biopolymer, xanthan gum.

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1. Introduction

Soft and problematic soils can cause excessive deformation, low bearing capacity, and instability in infrastructure foundations and pavement subgrades. Soil stabilization improves engineering performance by modifying the soil fabric and/or creating bonds between particles. Lime is a widely used chemical stabilizer for clayey soils. In the presence of water, lime promotes cation exchange and flocculation; under suitable conditions, longer-term pozzolanic reactions may also form cementitious products that contribute to strength gain **[1, 2]**. Nevertheless, lime performance depends on mineralogy and dosage, and conventional chemical stabilization can have environmental and durability limitations.

Biopolymers have been investigated as alternative soil-improvement agents because their polymer networks can bind particles, alter water retention, and reduce particle movement. Xanthan gum (XG) is a polysaccharide that can form a viscous gel, while sodium alginate (SA) is a polysaccharide capable of forming gel-like structures under appropriate chemical conditions. Previous research has documented the potential of biopolymers in geotechnical engineering, while also emphasizing that their effects depend on soil type, polymer content, moisture, and curing conditions **[3-6]**. A dosage that improves one soil may provide limited or even adverse results in another.

A direct comparison of a conventional stabilizer and two biopolymers across soils with contrasting mineralogy and gradation can help clarify this soil-specific response. The present study therefore evaluates hydrated lime, XG, and SA in kaolinite, sodium bentonite, and a sand–clay mixture. Its main contribution is the consistent experimental comparison of three stabilizers at multiple dosages and two curing periods using the same principal strength indicator, unconfined compressive strength (UCS).

2. Methodology

Three soil materials were investigated: kaolinite (K), sodium bentonite (B), and a sand–clay mixture (SC) containing 80% standard sand and 20% local clay by mass. The soils represented contrasting fine-grained and granular–cohesive characteristics. The reported liquid limit (LL) and plasticity index (PI) were 47% and 24% for kaolinite, 257% and 198% for bentonite, and 37% and 18% for the local clay component, respectively. The bentonite was classified as CH, whereas kaolinite and the local clay were classified as CL under the Unified Soil Classification System.

The stabilizers were hydrated lime, xanthan gum (XG), and sodium alginate (SA). Lime was incorporated at 2.5%, 5%, and 7.5% of dry soil mass. XG and SA were each incorporated at 0.5%, 1%, 1.5%, and 2%. The required mixing water was determined from the optimum moisture content (OMC) obtained from compaction testing. XG and SA powders were first dry-mixed with the soil for approximately 10 min. For lime-treated mixtures, the required lime was initially mixed with water to form a slurry before being added to the soil. All mixtures were then blended using a laboratory mixer for approximately 15 min.

Cylindrical specimens were prepared and compacted in three layers, with 25 blows applied to each layer. Specimens were wrapped to limit moisture loss and cured for 7 or 28 days under consistent conditions. Unconfined compression tests were conducted in accordance with ASTM D2166 at a loading rate of 1 mm/min. The maximum recorded axial stress was taken as the UCS. Four replicate specimens were tested for each soil–stabilizer–dosage–curing combination, and the reported trends were assessed by comparing the measured UCS values at the two curing ages.

3. Results and Discussion

The untreated UCS values were 0.3716 MPa for kaolinite, 0.4550 MPa for bentonite, and 0.2030 MPa for the sand–clay mixture (SC).

Lime stabilization. Lime provided the highest 28-day UCS values overall. Kaolinite and SC reached 2.08 and 0.95 MPa at 7.5% lime, respectively, while bentonite achieved 1.67 MPa at 5%. These differences highlight the influence of soil properties on optimum lime content.

Xanthan gum. XG showed a non-linear dosage response. The maximum 28-day UCS values were approximately 1.12 MPa for kaolinite at 2% XG and 0.75 MPa for bentonite at 1%. SC also showed a dosage-dependent response. These trends indicate that increasing XG content does not necessarily improve strength.

Sodium alginate. SA was generally less effective than lime and XG. The best 28-day results for kaolinite and bentonite occurred at 0.5% SA, while SA reduced UCS in SC at all tested dosages.

Comparison and implications. Lime was the most effective stabilizer overall, although its optimum content varied by soil. XG improved strength at selected dosages, whereas SA performed poorly in SC. These findings demonstrate that stabilization effectiveness depends on soil type and additive content. Further

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testing is needed to assess durability, field performance, and the mechanisms underlying the observed strength changes.



Figure ١٠: Preparation of specimens for the main uniaxial compressive strength tests, up to the point of failure

4. Conclusions

This study compared hydrated lime, XG, and SA for the stabilization of kaolinite, sodium bentonite, and an 80:20 sand–clay mixture using UCS tests after 7 and 28 days of curing. The main conclusions are as follows:

(1) Stabilizer performance was strongly soil-dependent. At 28 days, the maximum lime-treated UCS values were 2.08 MPa for kaolinite with 7.5% lime, 1.67 MPa for bentonite with 5% lime, and 0.95 MPa for SC with 7.5% lime.

(2) XG showed a non-linear response, with optimum tested contents of 2% for kaolinite and 1% for both bentonite and SC. Higher XG content did not consistently yield higher strength.

(3) SA performed best at 0.5% in kaolinite and bentonite, but its addition reduced SC strength at all tested contents.

(4) Lime was the most consistent long-term strength enhancer in this experimental program. The selection of stabilizer and dosage should therefore account for soil mineralogy, gradation, and curing time. Further work involving durability cycles and microstructural analysis is recommended to verify the mechanisms inferred from UCS trends.

5. References

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