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Characteristics Of Lateritic Soil Stabilized With Biopolymers

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Abstract- Lateritic soils are widely used in construction, particularly in subgrade applications, but their engineering performance is often limited due to low strength, poor gradation, and susceptibility to environmental conditions. To overcome these limitations, this study investigates the stabilization of lateritic soil using eco-friendly biopolymers, namely chitosan and sodium alginate. Soil samples collected from Kalluvathukkal, Kollam, Kerala were subjected to various laboratory tests including index properties, compaction, and unconfined compressive strength (UCS) tests to establish baseline characteristics. Biopolymer solutions of different concentrations were prepared and mixed with soil in varying ratios, followed by curing periods of 7, 14, 21, and 28 days. The experimental results revealed a significant improvement in the engineering behavior of the soil after stabilization. The UCS value of natural soil was relatively low, but the addition of biopolymers, especially in combined form, resulted in a substantial increase in strength, with the highest improvement observed at early curing stages. Durability tests also indicate enhanced resistance to environmental degradation. The study concludes that cross-linked biopolymers are effective in improving both strength and durability of lateritic soil and can serve as a sustainable and environmentally friendly alternative to conventional stabilizing agents such as cement and lime.

Keywords-Lateritic Soil, Biopolymers, Chitosan, Sodium Alginate, Soil Stabilization, UCS

1. INTRODUCTION

Soil stabilization is a fundamental aspect of geotechnical engineering aimed at improving the physical and mechanical properties of weak soils to make them suitable for construction purposes. With rapid infrastructure development, the availability of high-quality construction land has become limited, forcing engineers to utilize marginal soils such as lateritic soils. Although lateritic soils are abundantly available in tropical regions like Kerala, their engineering performance is often constrained by low strength, high plasticity, and susceptibility to environmental variations such as moisture fluctuations.

Traditionally, soil stabilization has been carried out using additives such as cement, lime, and fly ash. These materials enhance soil strength and durability by forming cementitious compounds through chemical reactions. However, their use is associated with several drawbacks including high carbon emissions, increased cost, long curing time, and potential environmental hazards due to the presence of toxic elements. In recent years, there has been a growing emphasis on sustainable and eco-friendly alternatives for soil improvement.

Biopolymers have emerged as a promising solution in this context due to their biodegradable nature, renewability, and ability to improve soil properties without causing environmental harm. Biopolymers such as chitosan and sodium alginate are naturally derived materials that can form strong binding networks within soil particles, thereby enhancing cohesion, reducing permeability, and increasing strength. Moreover, the use of cross-linked biopolymers further improves the stability and durability of treated soils by creating a more rigid and interconnected polymer matrix.

This study focuses on evaluating the effectiveness of biopolymers in stabilizing lateritic soil. The research investigates the influence of chitosan and sodium alginate, both individually and in combination, on the strength and durability characteristics of soil. Laboratory tests such as particle size distribution, compaction, and unconfined compressive strength (UCS) are conducted to assess the performance of treated soil under different curing periods.

The primary objective of this study is to explore the potential of cross-linked biopolymers as a sustainable alternative to conventional soil stabilizers and to provide a practical solution for improving the engineering properties of lateritic soils used in construction.

2. LITERATURE REVIEW

Biopolymers are naturally derived organic materials obtained from plants, animals, or microorganisms, and have gained increasing attention in geotechnical engineering due to their sustainable and eco-friendly characteristics. Their ability to form gel-like structures and bind soil particles makes them suitable for improving soil strength, durability, and resistance to environmental degradation. In recent years, extensive research has been conducted to evaluate the effectiveness of both individual and cross-linked biopolymers in soil stabilization applications.

Studies on individual biopolymers such as xanthan gum, guar gum, chitosan, and sodium alginate have demonstrated notable improvements in soil properties. For instance, xanthan gum has been widely recognized for its ability to increase soil cohesion and compressive strength, although its performance tends to decrease under wet conditions due to its water sensitivity. Similarly, chitosan has been reported to enhance compressive strength significantly, while sodium alginate improves durability and binding characteristics. However, the performance of these individual biopolymers is often influenced by factors such as soil type, pH conditions, and moisture content.

To overcome these limitations, recent research has focused on cross-linking techniques, which involve chemically bonding polymer chains to form a more stable and rigid network. Lee et al. (2023) demonstrated that cross-linking xanthan gum with trivalent chromium ions significantly improved soil strength and resistance to water-induced degradation. The study showed that cross-linked biopolymers exhibited higher yield stress and maintained structural integrity even under prolonged wet conditions. Similarly, Kumar et al. (2023) reported that cross-linked guar and xanthan gum improved Atterberg limits, compaction characteristics, and unconfined compressive strength of soils with varying plasticity.

Further advancements in biopolymer stabilization include the use of alkaline cross-linking agents such as calcium hydroxide and sodium hydroxide. These agents enhance the bonding mechanism within the soil matrix, resulting in improved compressive strength and reduced water absorption. Kim et al. (2022) introduced hydrophilic–hydrophobic biopolymer crosslinking (HHBC), which showed significant improvements in compressive strength, shear strength, and water resistance. Similarly, Im et al. (2021) investigated malonic acid cross-linked starch and reported notable increases in strength and durability along with reduced permeability.

Research has also highlighted the importance of curing conditions and biopolymer concentration. The strength development of biopolymer-treated soils is highly dependent on curing time, with significant improvements observed during early curing stages. Additionally, the combination of different biopolymers has been found to produce synergistic effects, resulting in better performance compared to individual usage. Cross-linked biopolymers not only enhance compressive strength but also improve resistance to cyclic wetting and drying, making them suitable for real-world environmental conditions.

Despite these promising findings, challenges such as cost, availability, and long-term durability still need to be addressed. However, the overall trend in research indicates that biopolymers, particularly in cross-linked form, offer a viable and sustainable alternative to conventional soil stabilizers. This study builds upon previous research by evaluating the combined effect of chitosan and sodium alginate on lateritic soil, aiming to optimize their performance for practical engineering applications.

3. MATERIALS AND METHODOLOGY

3.1 Materials

3.1.1 Lateritic Soil

The soil used in this study was lateritic soil collected from Kalluvathukkal, Kollam, Kerala. The collected samples were air-dried and prepared for laboratory testing. The index and engineering properties of the natural soil were determined in accordance with relevant Indian Standard (IS) codes.

The soil exhibited a natural moisture content of approximately 14.16% and a specific gravity of 2.49. Particle size distribution analysis indicated that the soil consists of 73.4% coarse fraction and 26.6% fine fraction. The compaction characteristics revealed a maximum dry density (MDD) of 1.83 g/cc and an optimum moisture content (OMC) of 19.5%. The initial unconfined compressive strength (UCS) of untreated soil was found to be 256 kPa, indicating relatively low strength suitable for stabilization.

3.1.2 Biopolymers

Two eco-friendly biopolymers were used as stabilizing agents:

- Chitosan (Ch): Obtained from Swakit Biotech Pvt. Ltd., Bengaluru. It appeared as cream-colored flaky particles with a moisture content of 6–8% and a degree of acetylation greater than 88%.
- Sodium Alginate (Ag): Procured from Marine Hydrocolloids, Cochin. It was in powder form with particle size less than 75 microns and a pH of approximately 6.5.

These biopolymers were selected due to their biodegradable nature and ability to form strong binding networks within soil particles.

3.1.3 Chemicals Used

- Citric Acid Monohydrate was used as a dissolving agent for chitosan.

- The acid solution (approximately 3%) facilitated proper dissolution and uniform mixing of the biopolymer solutions.

3.2 Methodology

The methodology adopted in this study involves systematic laboratory investigation to evaluate the effect of biopolymers on lateritic soil stabilization.

3.2.1 Determination of Soil Properties

The collected soil samples were tested to determine their index and engineering properties using standard laboratory procedures:

- Particle size distribution (wet and dry sieve analysis)
- Specific gravity test
- Moisture content determination
- Atterberg limits (liquid limit)

- Compaction test (Proctor test)
- Unconfined Compressive Strength (UCS) test

These tests established the baseline characteristics of untreated soil for comparison with treated samples.

3.2.2 Preparation of Biopolymer Solutions

Biopolymer solutions were prepared using concentrations of 1% and 2%. Chitosan was dissolved in a 3% acidic medium using a magnetic stirrer at approximately 400 rpm until a homogeneous solution was obtained. Sodium alginate was then added to the solution in varying proportions.

Different mix ratios of chitosan and sodium alginate were prepared, ranging from 0% to 100%, to evaluate both individual and combined effects.

3.2.3 Sample Preparation and Mixing

The prepared biopolymer solutions were mixed with dry soil using the wet mixing method to ensure uniform distribution. The treated soil was then compacted into standard molds to prepare test specimens.

The samples were subjected to curing for different durations of:

- 7 days
- 14 days
- 21 days
- 28 days

This was done to study the effect of curing time on strength development.

3.2.4 Unconfined Compressive Strength (UCS) Test

The UCS test was conducted on both untreated and treated soil samples in accordance with IS 2720 (Part X). The test evaluates the maximum axial stress the soil can withstand without lateral confinement.

The UCS values were recorded after each curing period to analyze the improvement in strength due to biopolymer stabilization. Additionally, the effect of environmental conditions such as wetting and drying cycles was considered to assess durability.

3.3 Experimental Variables

The key variables considered in this study include:

- Biopolymer concentration (1% and 2%)
- Ratio of chitosan to sodium alginate
- Curing period (7, 14, 21, and 28 days)

These variables were analyzed to determine the optimum combination for maximum strength and durability.

4. Results and Discussion

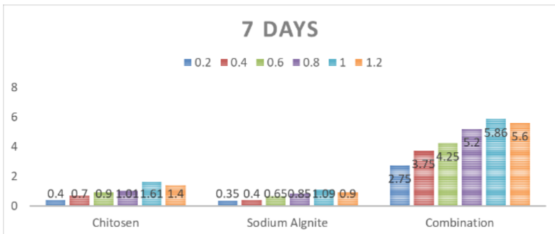
4.1 General Observations

The experimental investigation was carried out to evaluate the improvement in strength characteristics of lateritic soil stabilized with biopolymers (chitosan and sodium alginate). The results obtained from Unconfined Compressive Strength (UCS) tests at different curing periods (7, 14, 21, and 28 days) indicate a significant enhancement in soil performance compared to untreated soil.

The untreated soil exhibited relatively low strength, confirming the necessity for stabilization. Upon addition of biopolymers, both individual and combined treatments showed noticeable improvement, with the combined (cross-linked) biopolymer mix yielding superior results.

4.2 Effect of Biopolymers on Strength

4.2.1 7-Day Curing



At the early curing stage, a rapid increase in strength was observed. The UCS values indicate that:

- Combination of chitosan and sodium alginate showed the highest strength gain (~5.8 kg/cm² equivalent)

Dial Reading	Axial Compression	Axial Load	Axial Stress
50	0.1	2.57	0.26
100	0.2	5.14	0.523
150	0.3	7.71	0.78
200	0.8	20.56	2.09
250	1.2	30.84	3.14
300	2	51.4	5.23
350	2.4	61.68	6.28
400	2.8	71.96	7.33
450	3.2	82.24	8.38
500	3.4	87.38	8.90
550	3.6	92.52	9.43
600	3.7	95.07	4.69
650	3.8	97.66	9.95

- Chitosan alone showed moderate improvement

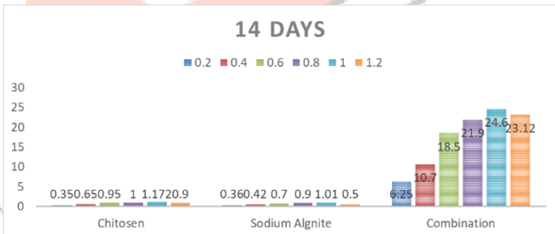
Dial Reading	Axial Compression	Axial Load	Axial Stress
50	2	5.14	0.29
100	3.2	8.22	0.49
150	4.6	11.82	0.66
200	6	15.42	0.86
250	7.4	19.02	1.07
300	8.6	22.10	1.24
350	9.2	23.04	1.32
400	10.2	26.21	1.47
450	10.6	27.24	1.56
500	10.9	27.96	1.57
550	11	28.27	1.58
600	11.2	28.75	1.61

- Sodium alginate showed relatively lower strength compared to chitosan

Dial Reading	Axial Compression	Axial Load	Axial Stress
50	1.2	3.08	0.16
100	1.6	4.11	0.21
150	2	5.14	0.26
200	2.4	6.16	0.32
250	2.6	6.68	0.34
300	2.8	7.19	0.37
350	3	7.71	0.4
400	3.6	9.25	0.48
450	3.8	9.76	0.50
500	4	10.28	0.53
550	4.4	11.30	0.58
600	4.8	12.33	0.64
650	5	12.85	0.66
700	5.6	14.39	0.74
750	6	15.42	0.8
800	6.2	15.93	0.86
850	6.8	17.47	0.90
900	7.2	18.50	0.96
950	7.6	19.53	1.01
1000	8.2	21.07	1.09

This behavior is attributed to the initial formation of biopolymer bonds that enhance inter-particle cohesion.

4.2.2 14-Day Curing



At 14 days, the strength further increased due to continued curing:

- Combined biopolymer mix exhibited significant strength enhancement (~24.6 units in given data)

Dial Reading	Axial Compression	Axial Load	Axial Stress
50	2.4	6.16	0.032
100	2.9	7.45	0.038
150	3.8	9.76	0.050
200	4.2	10.79	0.056
250	4.9	12.59	0.065
300	5.2	13.36	0.069
350	5.8	14.90	0.077
400	6.2	16.06	0.086

450	6.9	17.73	0.092
500	7.5	19.27	0.1
550	8	20.56	0.10
600	8.6	22.10	0.11
650	9.3	23.90	0.124

- Sodium alginate individually showed gradual improvement

Dial Reading	Axial Compression	Axial Load	Axial Stress
50	0.8	2.05	0.0107
100	2	5.14	0.0267
150	3	7.71	0.0400
200	3.8	9.76	0.0507
250	4.4	11.30	0.0587
300	5.2	13.36	0.0693
350	5.6	14.39	0.0747

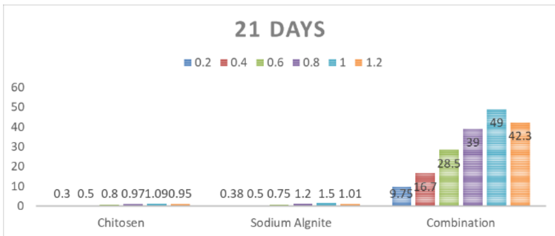
- Chitosen demonstrated a steady increase in strength with moderate effectiveness.

Dial Reading	Axial Compression	Axial Load	Axial Stress
50	1.2	3.08	0.016
100	1.6	4.11	0.021
150	2	5.14	0.026
200	2.4	6.16	0.032
250	2.6	6.68	0.034
300	2.8	7.19	0.037
350	3	7.71	0.04
400	3.6	9.25	0.048
450	3.8	9.76	0.050
500	4	10.28	0.053
550	4.4	11.30	0.058
600	4.8	12.33	0.064
650	5	12.85	0.066
700	5.6	14.39	0.0744
750	6	15.42	0.08
800	6.2	15.93	0.082
850	6.8	17.47	0.090
900	7.2	18.50	0.096
950	7.6	19.53	0.101

- Strength development became more stable compared to 7 days

This indicates improved bonding and gradual development of a stronger soil matrix.

4.2.3 21-Day Curing



The 21-day results show peak strength development:

- Combined mix achieved the maximum strength (~49 units)

Dial Reading	Axial Compression	Axial Load	Axial Stress
50	2.5	5.911	0.315
100	2.3	6.425	0.342
150	3.6	9.252	0.493
2200	4.1	10.537	0.561
250	4.9	12.593	0.671
300	5.3	13.621	0.726
350	5.9	15.163	0.808
400	6.4	16.448	0.877
450	6.9	17.733	0.945
500	7.3	18.761	1.000
550	8.1	20.817	1.110
600	8.7	22.359	1.192
650	9.8	24.5	1.306

- Sodium alginate showed considerable improvement due to better gel formation

Dial Reading	Axial Compression	Axial Load	Axial Stress
50	2.2	12.45	0.70
100	3.4	17.99	1.01
150	4.8	23.19	1.30
200	7.9	28.27	1.58
250	8.6	33.41	1.87
300	9.4	38.55	2.16
350	10.3	43.69	2.45
400	10.9	46.26	2.59

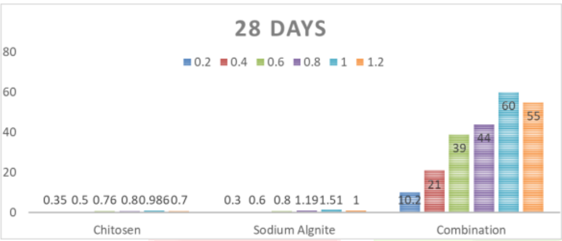
450	11.2	51.40	2.88
500	11.4	53.79	3.01

- Chitosan also contributed to increased stiffness and cohesion

Dial Reading	Axial Compression	Axial Load	Axial Stress
50	0	0	0
100	0.6	1.54	0.08
150	1.8	4.62	0.24
200	3	7.71	0.4
250	4.4	11.30	0.58
300	5.4	13.87	0.72
350	6	15.42	0.8
400	6.4	16.44	0.85

The enhanced performance at this stage is due to the formation of a well-developed cross-linked polymer network that binds soil particles effectively.

4.2.4 28-Day Curing



At 28 days:

- Strength values showed stabilization or slight reduction in some cases
- Combined biopolymer still maintained higher strength compared to individual mixes

Dial Reading	Axial Compression	Axial Load	Axial Stress
50	0.2	0.54	0.020
100	0.6	1.542	0.082
150	2	5.14	0.27
200	2.2	5.65	0.30
250	2.4	6.16	0.328
300	2.6	6.682	0.35

- Sodium alginate showed improved durability but slightly reduced peak strength

Dial Reading	Axial Compression	Axial Load	Axial Stress
50	0.8	0.8	0.71
100	1.4	1.4	1.23
150	2.4	2.4	2.12
200	3	3.0	2.64
250	3.2	3.2	2.82
300	3.4	3.4	3.00

- Chitosen exhibited stable strength with minor reduction over time, indicating consistent but moderate performance

Dial Reading	Axial Compression	Axial Load	Axial Stress
50	2.2	5.65	0.301
100	2.4	6.168	0.328
150	2.8	7.196	0.383
200	3.2	8.22	0.438
250	3.6	9.252	0.493
300	3.9	10.02	0.539
350	4.2	10.794	0.575
400	4.4	11.308	0.603
450	4.8	12.336	0.657
500	5.2	13.364	0.712
550	5.9	15.163	0.808
600	6.3	16.191	0.863
650	6.7	17.219	0.918
700	7.2	18.504	0.986

This slight reduction can be attributed to environmental exposure and possible microstructural changes such as moisture redistribution.

4.3 Comparison of Individual and Combined Biopolymers

The results clearly demonstrate that:

- Combined (cross-linked) biopolymers outperform individual biopolymers
- Cross-linking enhances:
  - Soil cohesion

- Load-bearing capacity
- Resistance to deformation

The synergistic interaction between chitosan and sodium alginate results in a stronger and more stable soil structure compared to single biopolymer treatment.

4.4 Effect of Curing Period

Curing time plays a crucial role in strength development:

- Rapid strength gain observed during early curing (7–14 days)
- Maximum strength achieved at 21 days
- Stabilization or slight decline observed at 28 days

This trend indicates that biopolymer reactions and bonding mechanisms are most effective during intermediate curing periods.

4.5 Engineering Implications

From an engineering perspective:

- Biopolymer stabilization significantly improves UCS and shear strength
- Cross-linked biopolymers can be used for:
  - Road subgrades
  - Embankments
  - Foundation support in weak soils

Additionally, the use of biopolymers provides a sustainable alternative to conventional stabilizers, reducing environmental impact.

5. Conclusion

This study investigated the effectiveness of biopolymers, namely chitosan and sodium alginate, in improving the engineering properties of lateritic soil. Based on the experimental results and analysis, the following conclusions can be drawn:

- The untreated lateritic soil exhibited low strength and required stabilization for use in engineering applications. The addition of biopolymers significantly enhanced the soil's strength characteristics, particularly the unconfined compressive strength (UCS).
- Both chitosan and sodium alginate individually improved soil performance; however, the combined (cross-linked) biopolymer system showed superior results due to the formation of a stronger and more stable bonding network within the soil matrix.
- The strength of stabilized soil increased with curing time, with maximum strength observed around 21 days of curing. Beyond this period, strength values tended to stabilize, indicating completion of major bonding reactions.
- The use of biopolymers also improved the durability and resistance of soil to environmental conditions, such as wetting and drying cycles, by reducing pore spaces and enhancing particle interlocking.
- The study confirms that cross-linked biopolymers can serve as an effective and sustainable alternative to traditional stabilizers like cement and lime, which are associated with high carbon emissions and environmental concerns.
- From a practical perspective, biopolymer stabilization can be effectively applied in road construction, subgrade improvement, and foundation works, especially in regions where lateritic soils are prevalent.

In conclusion, the incorporation of eco-friendly biopolymers offers a promising solution for sustainable soil stabilization, contributing to both improved engineering performance and environmental protection.

6. References

[1] I. Chang, J. Im, and G.-C. Cho, "Introduction of Microbial Biopolymers in Soil Treatment for Future Environmentally-Friendly and Sustainable Geotechnical Engineering," Sustainability, vol. 8, no. 3, pp. 1–20, 2016.

[2] A. Azimi, M. Haddad, and H. Ghaffari, "Effect of Biopolymers on Soil Stabilization: A

Review," Construction and Building Materials, vol. 350, pp. 1–15, 2023.

[3] S. Soldo, M. Miletić, and I. Auad, "Biopolymer-Based Soil Treatment under Wetting–Drying Cycles," Geotechnical Engineering Journal, vol. 53, no. 2, pp. 245–258, 2022.

[4] K. H. Head, Manual of Soil Laboratory Testing, Vol. 2, 3rd ed., London: Whittles Publishing, 2018.

[5] R. Singh, P. Sharma, and A. Kumar, "Performance of Sodium Alginate in Soil Stabilization," International Journal of Geotechnical Engineering, vol. 14, no. 5, pp. 456–463, 2020.

[6] Y. Liu, X. Zhang, and H. Wang, "Effect of Gellan Gum on Soil Strength and Durability," Soils and Foundations, vol. 59, no. 4, pp. 1120–1130, 2019.

[7] X. Zhang, Y. Liu, and J. Chen, "Improvement of Soil Strength Using Xanthan Gum Biopolymer," Journal of Materials in Civil Engineering, vol. 33, no. 6, pp. 1–10, 2021.

[8] T. Nguyen, H. Tran, and D. Le, "Starch-Based Biopolymer for Soil Stabilization," Construction Materials Journal, vol. 36, no. 2, pp. 210–218, 2022.

[9] H. Wang, Y. Li, and X. Zhao, "Cellulose Biopolymer in Soil Improvement," Journal of Cleaner Production, vol. 256, pp. 1–12, 2020.

[10] S. Jha, R. Kumar, and P. Singh, "Protein-Based Biopolymers in Geotechnical Engineering," Materials Today: Proceedings, vol. 45, pp. 567–572, 2021.