CIVIL ENGINEERING

Application of Gum Arabic as Stabilizer on the Geotechnical Properties of Lateritic Soil

Olowookere Oluwaseyi Ezekiel, Folake O. Akintayo

Department of Civil Engineering, Faculty of Technology, University of Ibadan, Ibadan, Nigeria

Published November 2026

Abstract

Weak lateritic subgrade soils contribute to early pavement failure in Nigeria, and the cement and lime normally used to stabilize them are costly and carbon-intensive. This study evaluated Gum Arabic, a biodegradable biopolymer, as an eco-friendly stabilizer for a low-plasticity silty lateritic soil (A-7-5 AASHTO; ML USCS) and determined its optimum content. The soil was mixed with 0, 2, 4, 6 and 8% Gum Arabic by dry weight and tested for Atterberg limits, standard Proctor compaction, soaked and unsoaked California Bearing Ratio (CBR), and unconfined compressive strength (UCS) after 7 and 28 days of sealed curing, with specimens tested as-cured or after 4 hours of air exposure. At 2% content, maximum dry density rose from 1.623 to 1.798 g/cm^3, unsoaked CBR from 3.89% to 8.84%, and 28-day UCS from 10.8 to 28.5 kPa (+164%). The plasticity index rose from 10% to between 18.54% and 29.59%, and soaking removed 55–85% of the unsoaked CBR of the treated soil, leaving soaked CBR very low (1.37–2.10%). A content of 4% by dry weight gave the best overall balance, and Gum Arabic suits soils that will remain relatively dry unless combined with a water-resistant binder.

Keywords: biopolymer; California bearing ratio; gum arabic; lateritic soil; soil stabilization; unconfined compressive strength

1 Introduction

Weak subgrade soils, particularly the lateritic and fine-grained residual soils common in tropical regions, often fail to meet the strength and plasticity requirements for pavement and foundation construction [1]. Conventional chemical stabilizers such as Portland cement and lime improve soil strength, but they are costly and cause substantial carbon dioxide emissions [2], [3], and they are often hard to obtain in rural areas. These concerns have raised interest in biodegradable, locally sourced biopolymers as sustainable alternatives.

Gum Arabic, a natural polysaccharide exudate of Acacia senegal, is biodegradable, widely available in Sahelian and sub-Saharan regions, and has shown binding and strength-enhancing properties in a range of soils [4]–[6]. Earlier studies report higher maximum dry density and unsoaked California Bearing Ratio (CBR) with increasing Gum Arabic content [4], and gains in strength and stiffness of treated sand that continue with curing time [5]. Performance is not uniform across soil types, however. Changes in Atterberg limits vary with soil type and dosage [6], [7], and biopolymer-treated soils generally show a rise-then-fall strength response as additive content increases [8]. Because Gum Arabic is water-soluble, its strength gains are also sensitive to moisture and are reduced under soaked conditions [9].

Few data exist on the optimum Gum Arabic dosage and on the soaked-versus-unsoaked performance of low-plasticity silty lateritic soils, which are common along Nigerian road alignments. This study

therefore evaluates the effect of Gum Arabic at 0, 2, 4, 6 and 8% by dry weight on the Atterberg limits, compaction characteristics, soaked and unsoaked CBR, and unconfined compressive strength (UCS) of such a soil, and identifies a practical optimum dosage.

2 Materials and methods

2.1 Materials

The soil was a weak lateritic soil taken from a borrow pit below the topsoil to avoid organic contamination and transported to the laboratory in sealed bags. It classifies as a low-plasticity silt, A-7-5 under AASHTO [10] and ML under the Unified Soil Classification System [11], with a specific gravity of 2.50. Commercially supplied Gum Arabic lumps were ground to powder before use, and potable water was used throughout.

2.2 Specimen preparation and testing

The soil was air-dried, gently pulverized and passed through a 4.75 mm sieve. Gum Arabic powder was blended with the dry soil at 0% (control), 2%, 4%, 6% and 8% by dry weight, water was added gradually with continuous mixing, and the mixtures were sealed in moisture-tight containers for equilibration before testing.

Tests followed BS 1377 [12] and the corresponding ASTM procedures. The natural soil was characterized by moisture content, specific gravity, particle size distribution and Atterberg limits. All five mixes were tested for Atterberg limits, standard Proctor compaction, soaked and unsoaked CBR, and UCS. The maximum dry density (MDD) and optimum moisture content (OMC) of each treated mix were taken from the peak of a second-order curve fitted through three compaction points. CBR was computed from the loads at 2.5 mm and 5.0 mm penetration, recorded on the top and bottom faces of each specimen, and the mean of the two faces is reported. UCS specimens, 50 mm in diameter and 95 mm high, were compacted at OMC, sealed in airtight nylon and cured for 7 and 28 days. At each age one set was tested immediately after removal from the nylon (as-cured) and another after 4 hours of exposure to laboratory air (air-exposed).

3 Results and discussion

3.1 Properties of the natural soil

Table 1 gives the baseline properties of the untreated soil, a silt of low plasticity that serves as the control.

Table 1. Baseline geotechnical properties of the natural soil.

Parameter	Value
AASHTO classification	A-7-5
USCS classification	ML
Liquid limit (%)	43.00
Plastic limit (%)	33.00
Plasticity index (%)	10.00

Parameter	Value
Specific gravity	2.50
Optimum moisture content (%)	15.00
Maximum dry density (g/cm^3)	1.623

3.2 Atterberg limits

Gum Arabic raised the liquid limit from 43% to between 49.5% and 57% and lowered the plastic limit from 33% to between 27.41% and 30.96%, so the plasticity index widened from 10% to between 18.54% and 29.59% (Table 2). The rise in liquid limit is consistent with the hydrophilic, hydroxyl-rich polysaccharide chains of Gum Arabic, which hold water and swell into a viscous gel [5], [6]. The response was not linear: the 4% mix had the smallest increase in plasticity index and was the only treated mix to keep the A-7-5/ML classification of the natural soil, whereas the 2%, 6% and 8% mixes moved to A-7-6 with high-plasticity symbols. These classifications are indicative only, since they rest on the Atterberg limits alone. A wider plastic range is generally unfavorable for a subgrade because it increases sensitivity to moisture and volume change, so it must be weighed against the strength gains below.

Table 2. Atterberg limits of the natural and Gum Arabic-treated soil.

GA (%)	LL (%)	PL (%)	PI (%)
0	43.00	33.00	10.00
2	52.00	29.04	22.96
4	49.50	30.96	18.54
6	53.00	29.72	23.28
8	57.00	27.41	29.59

GA = Gum Arabic content; LL = liquid limit; PL = plastic limit; PI = plasticity index.

3.3 Compaction characteristics

Every treated mix had a higher MDD than the natural soil (1.623 g/cm^3), with gains of 10.8% at 2%, 9.9% at 4%, 7.8% at 6% and 2.9% at 8% (Table 3, Figure 1). The OMC of the 2–6% mixes was 1.6 to 2.4 percentage points below that of the natural soil. The higher density agrees with Ajagbe et al. [4] and with the void-filling and binding action of the hydrated gum, and the lower OMC suggests that the gum film lubricates the grains. The smaller gain at 6% and 8% is probably due to the growing volume of light, water-retaining gel displacing denser soil solids. Each curve rests on only three points, so the fitted values are approximate.

Table 3. Compaction parameters of the natural and treated soil.

GA (%)	OMC (%)	MDD (g/cm^3)	ΔMDD (%)
0	15.00	1.623	–
2	12.6	1.798	+10.8
4	13.4	1.784	+9.9
6	12.9	1.750	+7.8

GA (%)	OMC (%)	MDD (g/cm³)	ΔMDD (%)
8*	15.4*	1.670*	+2.9*

*Highest measured point for the 8% mix; its curve peak was not bracketed. OMC = optimum moisture content; MDD = maximum dry density.

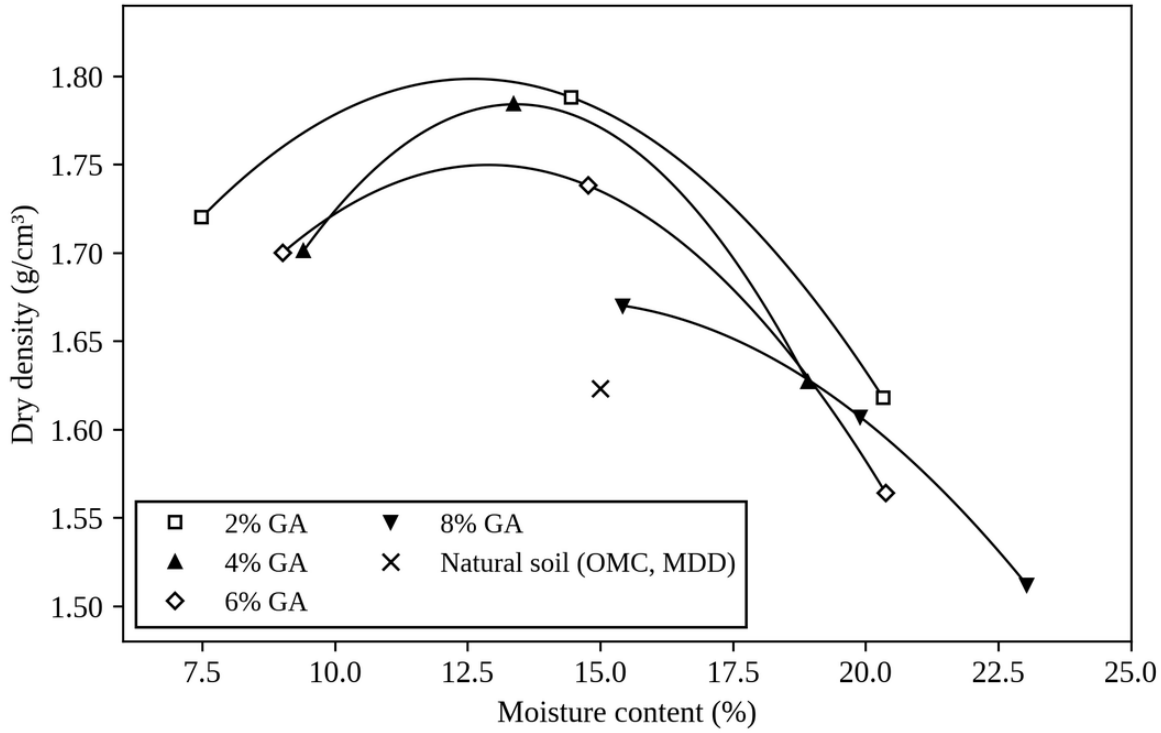


Figure 1. Compaction curves of the natural and Gum Arabic-treated soil.

3.4 California bearing ratio

Gum Arabic raised the unsoaked CBR at every dosage, from 3.89% for the natural soil to 8.84% (+127%) at 2%, then 8.01%, 6.50% and 4.65% at 4%, 6% and 8% (Table 4, Figure 2). The gain was largest at the lowest dosage tested, so the optimum for unsoaked CBR may lie at or below 2%. Soaked CBR was very low for every mix: it rose from 1.32% to between 1.37% and 2.10%, with clear improvement only at 6% and 8%, since the gains at 2% and 4% are within the uncertainty of single tests. Soaking removed 55–85% of the unsoaked CBR of the treated mixes, and the mixes that gained most when dry (2% and 4%) retained the least. This reflects the water-soluble nature of Gum Arabic, whose dry bonding film re-hydrates and softens on immersion [9]. No treated mix approaches the soaked CBR normally required of highway subgrade or sub-base material, so Gum Arabic alone does not make this soil suitable for pavement layers that will be saturated.

Table 4. Mean unsoaked and soaked CBR of the natural and treated soil.

GA (%)	Unsoaked CBR (%)	Soaked CBR (%)	Soaked / unsoaked (%)
0	3.89	1.32	34
2	8.84	1.37	15
4	8.01	1.48	19
6	6.50	2.10	32

GA (%)	Unsoaked CBR (%)	Soaked CBR (%)	Soaked / unsoaked (%)
8	4.65	2.08	45

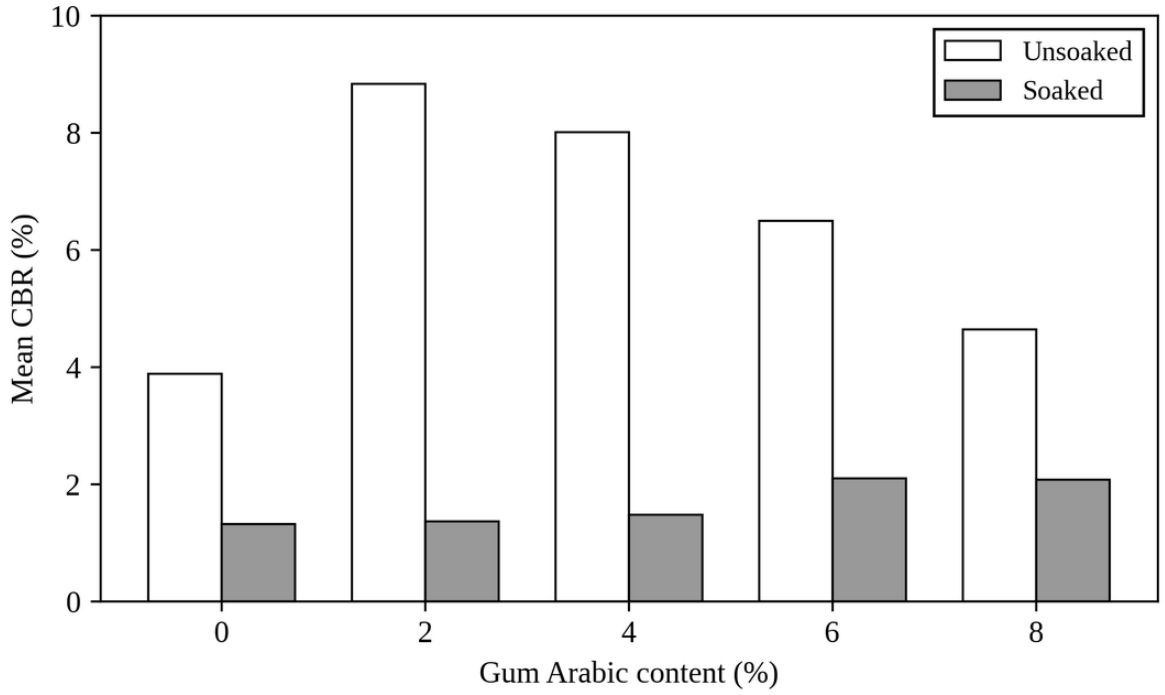


Figure 2. Mean unsoaked and soaked CBR against Gum Arabic content.

3.5 Unconfined compressive strength

Gum Arabic increased UCS at every age and test condition except 8% in the 7-day as-cured set, which matched the natural soil (Table 5, Figure 3). The 28-day as-cured strength rose from 10.8 kPa to 28.5 kPa (+164%) at 2%, and the 28-day air-exposed strength rose from 13.9 kPa to 28.1 kPa (+102%) at 4%. Strength then fell at 6% and 8%, a rise-then-fall pattern reported for other biopolymers [8], [13]. The secant modulus E50 followed the same trend and roughly doubled, from 0.81 MPa to 1.65 MPa at 2% (28 days, as-cured). The treated specimens also failed at larger strains (2.4–3.5%) than the natural soil (1.6–2.2%), so they were stiffer without becoming more brittle. The absolute strengths stay below 30 kPa because the soil is a weakly cohesive silt, so Gum Arabic improves the soil but does not turn it into a structural material.

Between 7 and 28 days the as-cured strength of the treated mixes increased by 36–59%, against 6% for the natural soil, which indicates that bonding by the gum keeps developing with time, as reported for gum-treated sand [5]. Four hours of air exposure raised the 7-day strength of every mix, by 32–73% for the treated soil and 21% for the natural soil, so part of the effect comes from drying and suction rather than from the gum alone. By 28 days the sealed specimens had largely caught up. Strength therefore depends on the moisture state at testing, and because the gum is water-soluble, the gains may not survive saturation.

Table 5. Unconfined compressive strength (kPa) of the natural and treated soil.

GA (%)	As-cured 7 d	As-cured 28 d	Air-exp. 7 d	Air-exp. 28 d
0	10.2*	10.8	12.3	13.9

GA (%)	As-cured 7 d	As-cured 28 d	Air-exp. 7 d	Air-exp. 28 d
2	20.1	28.5	26.6	27.3
4	17.1	26.0	27.5	28.1
6	12.8	20.3	22.1	24.1
8	10.1	13.7	15.6	17.3

*Specimen had not reached a peak; highest recorded value.

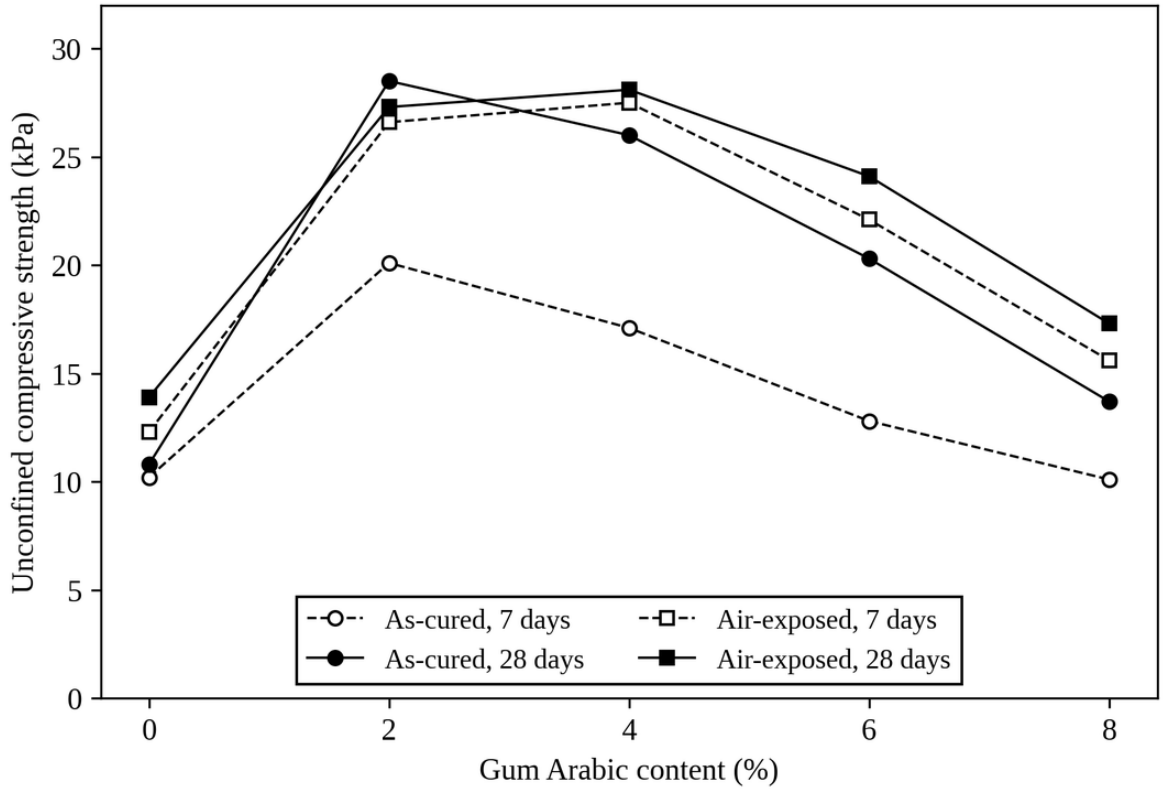


Figure 3. Unconfined compressive strength against Gum Arabic content.

3.6 Optimum Gum Arabic content

No single dosage was best for every property (Table 6). MDD, unsoaked CBR and as-cured strength peaked at 2%, air-exposed strength peaked at 4%, and soaked CBR, though uniformly low, peaked at 6%. The 2% and 4% mixes differ by only 0.9% in MDD, 9% in unsoaked CBR and 9% in as-cured 28-day strength. The 4% mix, however, was the only treated mix to keep the natural soil's classification, had the smallest rise in plasticity and gave the highest air-exposed strength. Contents of 6% and 8% are not justified, since they gave lower density, strength and unsoaked CBR and much higher plasticity. The optimum is therefore taken as 4% by dry weight, with 2–4% as the effective range. Because 2% was the lowest dosage tested, dosages below 2% should also be examined.

Table 6. Gum Arabic content giving the best result for each property.

Property	Natural soil	Best GA (%)	Value at best GA
Plasticity index (lowest, treated)	10.00%	4	18.54%
Maximum dry density	1.623 g/cm^3	2	1.798 g/cm^3

Property	Natural soil	Best GA (%)	Value at best GA
Unsoaked CBR (mean)	3.89%	2	8.84%
Soaked CBR (mean)	1.32%	6	2.10%
UCS, 28 d, as-cured	10.8 kPa	2	28.5 kPa
UCS, 28 d, air-exposed	13.9 kPa	4	28.1 kPa

4 Conclusion

Gum Arabic is a promising eco-friendly biopolymer for improving a low-plasticity silty lateritic soil. At 2–4% by dry weight it raised maximum dry density by up to 10.8%, unsoaked CBR by up to 127% and 28-day UCS by up to 164%, and 4% is recommended as the best overall balance. It also raised the plasticity index substantially, and because the biopolymer film is water-soluble it gave only marginal gains in soaked CBR, so it should not be used alone where the treated soil will be saturated. Where flooding or a high water table is expected, Gum Arabic should be combined with a small amount of a water-resistant binder, whose effect should first be tested. These findings come from laboratory tests on a single soil with single test series per mix, and replicate testing, field trials and durability tests under wetting and drying are needed before field use.

Acknowledgement

The authors thank the staff of the Geotechnical Engineering Laboratory, Department of Civil Engineering, University of Ibadan, for their assistance with the laboratory testing.

References

[1] Gidigasu MD. *Laterite soil engineering: pedogenesis and engineering principles*. Amsterdam: Elsevier; 1976.

[2] Firoozi AA, Guney Olgun C, Firoozi AA, Baghini MS. Fundamentals of soil stabilization. *Int J Geo-Eng*. 2017;8:26.

[3] Worrell E, Price L, Martin N, Hendriks C, Meida LO. Carbon dioxide emissions from the global cement industry. *Annu Rev Energy Environ*. 2001;26:303–329.

[4] Ajagbe WO, Akolade AS, Ogunlade OD, Olaomotito PA, Odunewu ID, Alabi OO. Application of gum arabic on the geotechnical properties of subgrade materials. *Acta Tech Jaurinensis*. 2024;17(4):152–162.

[5] Babatunde QO, Byun YH. Soil stabilization using gum arabic biopolymer. *Biopolymers*. 2026;117(1):e70077.

[6] Vishweshwaran M, Sujatha ER, Rehman AU, Moghal AAB. Efficacy of acacia gum biopolymer in strength improvement of silty and clay soils under varying curing conditions. *Polymers*. 2024;16(19):2831.

[7] Oluremi JR, Ishola K. Effect of gum arabic biopolymer on Atterberg limit and cation exchange capacity of lead-contaminated lateritic soil. *LAUTECH J Eng Technol*. 2024;18(1):57–63.

[8] Azimi M, Soltani A, Mirzababaei M, Jaksa MB, Ashwath N. Biopolymer stabilization of clayey soil. *J Rock Mech Geotech Eng*. 2024;16(7):2801–2812.

[9] Abdelaziz O, Song L, Bunu AW, Adamu GA, Shimky SA. Improving the engineering properties of black cotton soil using gum arabic: a comparative study with granite powder. *Open J Civ Eng*. 2025;15(4):633–650.

[10] American Association of State Highway and Transportation Officials. *AASHTO M 145-91: standard specification for classification of soils and soil-aggregate mixtures for highway construction purposes*. Washington, DC: AASHTO; 1991.

[11] ASTM International. *ASTM D2487-17: standard practice for classification of soils for engineering purposes (Unified Soil Classification System)*. West Conshohocken, PA: ASTM International; 2017.

[12] British Standards Institution. *BS 1377: methods of test for soils for civil engineering purposes*. London: BSI; 1990.

[13] Chang I, Im J, Cho GC. Introduction of microbial biopolymers in soil treatment for future eco-friendly geotechnical engineering. *Sustainability*. 2016;8(3):251.