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# Index Properties and Compaction Characteristics of Vermiremediated Crude Oil-Contaminated Lateritic Soil Stabilized with Gum Arabic for Road Subgrade Application

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**ABSTRACT**

*Crude oil contamination progressively degrades the index and compaction properties of lateritic soils, undermining their suitability as pavement subgrade material. This study evaluates the index properties and compaction characteristics of vermiremediated crude oil-contaminated lateritic soil stabilized with Gum Arabic (GA), a natural biopolymer, as a sustainable alternative to conventional chemical stabilizers. Lateritic soil obtained from Shika, Zaria, Kaduna State, was contaminated with Bonny Light crude oil at 75 cl per 10 kg of soil, biologically treated using the earthworm species Eudrilus eugeniae, and thereafter stabilized with 0, 2, 4, 6 and 8% GA by dry weight. Natural moisture content, specific gravity, Atterberg limits, particle size distribution, linear shrinkage, and compaction characteristics (maximum dry density, MDD, and optimum moisture content, OMC) were determined for the British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH) compactive efforts, in accordance with BS 1377 (1990). Contamination increased the liquid limit from 47.0% to 51.8% and reduced the specific gravity from 2.66 to 2.40. Following vermiremediation and GA stabilization, the liquid limit and plastic limit generally decreased with increasing GA content, falling from 54.0% and 32.3% at 0% GA to minimum values of 44.0% and 15.0% at 6% GA, respectively, while the percentage fines passing the 0.075 mm sieve decreased markedly, indicating particle flocculation and agglomeration. The MDD values were most sensitive to GA addition under the BSH effort, decreasing from 1.79 g/cm³ at 0% GA to 1.70 g/cm³ at 6% GA, while OMC values generally increased with GA content before declining at 8% GA. The results demonstrate that GA measurably alters the index and compactive behaviour of remediated contaminated lateritic soil, with 2-4% GA offering the most favourable balance of reduced plasticity and workable compaction response for subgrade application.*

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## INTRODUCTION

Road infrastructure underpins socio-economic development, and lateritic soils remain the dominant subgrade material in Nigeria owing to their wide availability and relatively low cost (Preston, 2022; Ogunsanwo & Oyedele, 2022). However, crude oil contamination arising from pipeline failures, illegal bunkering and operational spillage progressively degrades the geotechnical properties of lateritic soils by coating soil particles, reducing inter-particle friction and altering their index and compaction behaviour (Ogundipe & Oyedele, 2023; Ogunbode & Adeyemi, 2022). Restoring such soils for engineering reuse requires both remediation of the hydrocarbon load

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and stabilization of the resulting mechanical deficiencies.

Vermiremediation, which uses earthworms to accelerate microbial degradation of petroleum hydrocarbons, offers an environmentally sustainable route to reducing contamination (Kumar & Singh, 2022; Mishra & Singh, 2023), but does not, on its own, restore the strength and workability required for subgrade application. Chemical stabilizers such as cement and lime are effective but carry cost and carbon-emission concerns, prompting growing interest in natural biopolymers. Gum Arabic (GA), derived from Acacia senegal and abundantly produced in northern Nigeria, forms a gel-like matrix on hydration that can bind soil particles, alter plasticity and modify compaction response (Hamidu et al., 2022; Soni, 2023).

While the strength and durability performance of GA-stabilized soils has received attention, the index properties and compaction characteristics that govern workability, moisture control and constructability are equally critical to subgrade design, yet are less frequently isolated for detailed reporting. This paper therefore presents the index properties (natural moisture content, specific gravity, Atterberg limits, particle size distribution and linear shrinkage) and compaction characteristics (maximum dry density and optimum moisture content across BSL, WAS and BSH compactive efforts) of vermiremediated crude oil-contaminated lateritic soil stabilized with 0-8% Gum Arabic, with a view to establishing the GA content that yields the most favourable index and compaction response for road subgrade use.

## MATERIALS AND METHODS

### Materials

The lateritic soil used for the study was collected by disturbed sampling from a borrow pit in Shika, Zaria, Kaduna State (Latitude 11°15' N, Longitude 7°45' E) at a depth of 1.5-2.0 m. The soil was air-dried and pulverized to pass BS No. 4 sieve (4.76 mm) prior to testing. Bonny Light crude oil, sourced from Port Harcourt, Rivers State, was selected for its low sulphur content and moderate viscosity, which allow it to readily penetrate and coat soil particles under laboratory conditions. Gum Arabic was procured locally in Kaduna, cleaned, mechanically ground, and sieved through BS Sieve No. 10 (2.00 mm) to obtain a uniform powder for admixing. The earthworm species Eudrilus eugeniae, obtained from the Kaduna River axis, was used for vermiremediation on account of its tolerance to organic contaminants and its epigeic habit, which favours interaction with near-surface contaminated soil.

### Sample Preparation

The air-dried and sieved soil was contaminated with Bonny Light crude oil at a rate of 75 cl per 10 kg of soil and cured undisturbed for one month to allow full contamination. The contaminated soil was then subjected to vermiremediation using earthworms at a combined rate of 300 worms per 200 kg of soil, held in an aerated perforated tank with daily moisture replenishment for one month. Total petroleum hydrocarbon (TPH) content reduced from 4500 mg/kg before remediation to 3300 mg/kg after remediation, representing a removal efficiency of approximately 27%. The vermiremediated soil was thereafter blended with Gum Arabic at 0, 2, 4, 6 and 8% by dry weight of soil for subsequent index and compaction testing.

### Determination of Index Properties

Natural moisture content was determined in accordance with BS 1377 (1990) Part 2 by oven-drying triplicate samples at 105-110°C for 24 hours. Specific gravity was determined using the density bottle method in accordance with BS 1377 (1990) Test B for fine-grained soils. Atterberg limits (liquid limit, plastic limit and plasticity index) were determined in accordance with BS 1377 (1990) Part 2 and ASTM D4318-21, with liquid limit obtained from the flow curve at 25 blows and plastic limit from the rolling thread method; linear shrinkage was determined from the shrinkage of a remoulded soil paste dried in a shrinkage trough. Particle size distribution was determined by wet sieving (to remove silt and clay fractions using the 0.075 mm sieve) followed by dry sieving of the retained oven-dried fraction, in accordance with BS 1377 (1990) Part 2.

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**Determination of Compaction Characteristics**

Compaction tests were carried out on the natural, vermiremediated and GA-stabilized soils in accordance with BS 1377 (1990) Part 4 and the Nigerian General Specifications (1997), using three compactive efforts: British Standard Light (BSL - 2.5 kg rammer, 27 blows per layer in three layers), West African Standard (WAS - 4.5 kg rammer, 10 blows per layer in five layers) and British Standard Heavy (BSH - 4.5 kg rammer, 27 blows per layer in five layers). Each 3 kg sample was compacted into a 1000 $cm^3$ mould at incremental moisture contents, and the bulk and dry densities were computed for each compaction point. The maximum dry density (MDD) was taken as the peak of the dry density-moisture content curve, with the corresponding moisture content recorded as the optimum moisture content (OMC).

## RESULTS AND DISCUSSION

**Index Properties of Natural, Contaminated and Vermiremediated Lateritic Soil**

Table 1 presents the index properties of the natural soil in comparison with the crude oil-contaminated soil (prior to vermiremediation and GA stabilization). The natural soil is a light brown, kaolinitic clay with a natural moisture content of 16.70%, liquid limit of 47.00%, plastic limit of 27.30%, plasticity index of 19.70%, specific gravity of 2.66 and 64.00% passing the 0.075 mm sieve, classifying as CL (USCS) or A-7-6(12) (AASHTO). Following crude oil contamination, the liquid limit rose to 51.80%, the fines content increased to 72.42%, and the specific gravity fell to 2.40, while the colour darkened, consistent with hydrocarbon coating of soil particles and disruption of the natural sesquioxide cementation that reduces effective particle contact and increases water demand (Ogundipe & Oyedele, 2023).

Table 1: Index properties of natural and vermiremediated crude oil-contaminated lateritic soil

| Property | Natural Soil | Vermiremediated Contaminated Soil |
|---|---|---|
| Natural moisture content (%) | 16.70 | — |
| Liquid limit, LL (%) | 47.00 | 51.80 |
| Plastic limit, PL (%) | 27.30 | 32.26 |
| Plasticity index, PI (%) | 19.70 | 19.50 |
| Linear shrinkage (%) | 11.43 | 11.00 |
| Specific gravity | 2.66 | 2.40 |
| Passing BS Sieve No. 200 (%) | 64.00 | 72.42 |
| AASHTO classification | A-7-6 (12) | A-7-6 (12) |
| USCS classification | CL | CL |
| Colour | Light brown | Dark brown |
| Dominant clay mineral | Kaolinite | Kaolinite |

**Effect of Gum Arabic on Particle Size Distribution**

The percentage of fines passing the 0.075 mm sieve decreased consistently with increasing GA content across all three compactive efforts. Under the BSL effort, fines decreased from 27.58% at 0% GA to 1.1%, 0.1%, 0.0% and 0.0% at 2, 4, 6 and 8% GA, respectively; a comparable trend was observed for the WAS (27.2% to 0.1-1.1%) and BSH (22.0% to 0.0-1.7%) efforts. This coarsening of gradation is attributed to flocculation and agglomeration of clay particles arising from

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cation exchange between the calcium ions ($Ca^{2+}$) contributed by GA and the weaker monovalent cations ($Na^{+}$, $K^{+}$) on the clay surfaces, which bond individual clay particles into larger aggregates unable to pass the finer sieves. This trend is consistent with observations reported for other biopolymer- and admixture-stabilized lateritic soils (Amu & Adetuberu, 2010; Eberemu et al., 2021; Edeh & Amadi, 2024).

**Effect of Gum Arabic on Atterberg Limits**

Figure 1 shows the variation of liquid limit, plastic limit and plasticity index with GA content. The liquid limit decreased from 54.0% at 0% GA to a minimum of 44.0% at 6% GA, before rising again to 54.0% at 8% GA; the plastic limit followed a similar pattern, decreasing from 32.3% to a minimum of 15.0% at 6% GA. The reduction in both limits with increasing GA (up to 6%) reflects flocculation of clay particles and ion exchange between the calcium in GA and the lower-valence metallic ions native to the clay structure, which reduces the water-holding capacity of the soil matrix (Amu & Adetuberu, 2010). The plasticity index, by contrast, increased from 21.7% at 0% GA to a peak of 35.0% at 4% GA before declining to 29.0% and 30.0% at 6% and 8% GA, respectively, reflecting the differential rates at which the liquid and plastic limits respond to GA addition at low dosages.

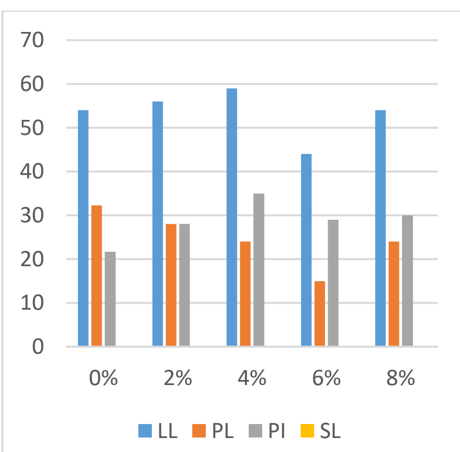


Figure 1. Variation of Atterberg limits with Gum Arabic content

**Effect of Gum Arabic on Linear Shrinkage and Specific Gravity**

The linear shrinkage increased steadily with GA content, from 11.10% at 0% GA to 11.57%, 11.86%, 12.43% and 13.29% at 2, 4, 6 and 8% GA, respectively (Figure 2), consistent with the trend reported by Edeh and Amadi (2024) for biopolymer-stabilized lateritic soils. Specific gravity decreased from 2.40 at 0% GA to 2.30, 2.40, 2.30 and 2.20 at 2, 4, 6 and 8% GA, respectively, reflecting the lower density and more porous nature of GA relative to the natural soil minerals, which reduces the composite unit weight of the soil-GA blend as GA content increases (Oyediran & Enya, 2021).

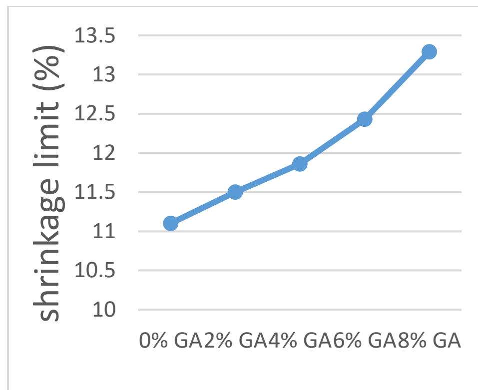


Figure 2. Variation of specific gravity and linear shrinkage with Gum Arabic content

**Effect of Gum Arabic on Compaction Characteristics**

Figure 3 summarise the effect of GA content on maximum dry density (MDD) across the three compactive efforts. Under the BSL effort, MDD decreased from 1.64 Mg/m³ at 0% GA to 1.62 Mg/m³ at 2% and 1.58 Mg/m³ at 4% GA, increased slightly to 1.60 Mg/m³ at 6% GA, and decreased again to 1.56 Mg/m³ at 8% GA. A generally decreasing trend was also observed for the WAS effort (1.68 Mg/m³ at 0% GA to 1.62 g/cm³ at 8% GA) and the BSH effort (1.79 Mg/m³ at 0% GA to 1.70 Mg/m³ at 6% GA, rising marginally to 1.71 Mg/m³ at 8% GA). The decline in MDD with GA addition is attributed to GA occupying pore space within the soil matrix and to

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flocculation and agglomeration of clay particles arising from cation exchange, both of which reduce the packing efficiency of the compacted soil (Etim et al., 2021).

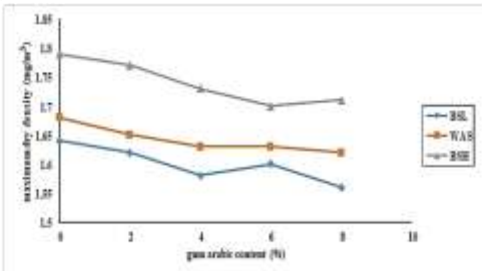


Figure 3. Variation of maximum dry density with Gum Arabic content for BSL, WAS and BSH compactive efforts

The corresponding optimum moisture content (OMC) values (Figure 4) generally increased with GA content before declining at the highest dosage. For the BSL effort, OMC increased from 18.85% at 0% GA to 22.4% at 6% GA before decreasing to 21.3% at 8% GA. A similar pattern was observed for the WAS effort (17.18% at 0% GA, rising to 19.8% at 6% GA, then falling to 15.8% at 8% GA) and the BSH effort (14.78% at 0% GA, rising to 18.2% at 4% GA, then falling to 12.2% at 8% GA). The initial rise in OMC reflects the water demand of the hydrating GA matrix and the finer effective pore structure created by particle flocculation, while the decline at higher GA content suggests a saturation effect beyond which additional GA no longer increases water retention during compaction.

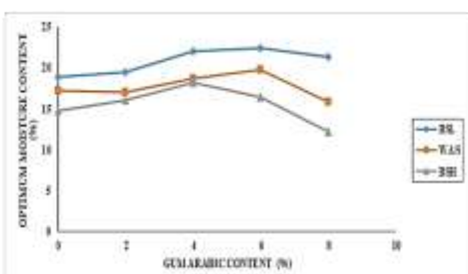


Figure 4. Variation of optimum moisture content with Gum Arabic content for BSL, WAS and BSH compactive efforts

Taken together, the index and compaction results indicate that GA addition measurably reduces soil plasticity and fines content while altering compactive behaviour, with the most favourable balance of reduced plasticity, moderate MDD and manageable OMC observed in the 2-4% GA range, broadly consistent with the recommendations of related studies on biopolymer-stabilized contaminated lateritic soils (Etim et al., 2021; Edeh & Amadi, 2024).

## CONCLUSION

This study evaluated the index properties and compaction characteristics of vermiremediated crude oil-contaminated lateritic soil stabilized with Gum Arabic. Crude oil contamination increased the liquid limit and fines content of the natural soil while reducing its specific gravity. Vermiremediation reduced the total petroleum hydrocarbon content by approximately 27%. Gum Arabic stabilization progressively reduced the liquid limit, plastic limit and fines content of the contaminated soil up to 6% GA, through flocculation and agglomeration mechanisms driven by cation exchange, while linear shrinkage increased steadily with GA content.

Compaction characteristics were sensitive to both GA content and compactive effort: maximum dry density generally decreased with increasing GA content, most markedly under the BSH effort, while optimum moisture content generally increased before declining at 8% GA. On the basis of the index and compaction response, 2-4% Gum Arabic content offers the most favourable combination of reduced plasticity and workable compaction behaviour for vermiremediated crude oil-contaminated lateritic soil intended for road subgrade application.

## REFERENCES

AASHTO. (1996). Standard specification for transport materials and methods of sampling and testing (14th ed.). American Association of State Highway and Transportation Officials.

ASTM D4318-21. (2021). Standard test methods for liquid limit, plastic limit, and

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plasticity index of soils. ASTM International.

ASTM D698-21. (2021). Standard test methods for laboratory compaction characteristics of soil using standard effort. ASTM International.

Amu, O. O., & Adetuberu, A. A. (2010). Characteristics of lateritic soil stabilized with eggshell powder. Journal of Engineering and Applied Sciences, 5(2), 143-147.

Areola, O. (1982). Soils. In K. M. Barbour, J. S. Oguntoyinbo, J. O. C. Onyemelukwe, & J. C. Nwafor (Eds.), Nigeria in maps. Hodder and Stoughton.

BS 1377. (1990). Methods of test for soils for civil engineering purposes. British Standards Institution.

Butcher, R., & Salie, K. (2020). Evaluation of the potential for vermiremediation of hydrocarbon-contaminated soil. Frontiers in Environmental Science.

Eberemu, A. O., Osinubi, K. J., & Amadi, A. A. (2021). Effect of Gum Arabic biopolymer on Atterberg limit and cation exchange capacity of contaminated lateritic soil. Journal of Engineering Research and Reports, 20(4), 1-12.

Edeh, J. E., & Amadi, A. A. (2024). Evaluation of vermi-remediated crude oil contaminated lateritic soil stabilized with Gum Arabic for road subgrade. Nigerian Journal of Technology, 43(2), 1-10.

Etim, M. A., Eberemu, A. O., & Osinubi, K. J. (2021). Stabilization of vermi-remediated crude oil contaminated lateritic soil with Gum Arabic for road sub grade. International Research Journal of Engineering and Technology, 8(6), 1120-1128.

Hamidu, A., Suleiman, I., & Yusuf, M. (2022). Characterization of Gum Arabic as a sustainable soil stabilizer in northern Nigeria. Journal of Sustainable Materials, 9(1), 45-53.

Nigerian General Specifications for Roads and Bridges. (1997). Federal Ministry of Works, Abuja.

Ogunbode, E. B., & Adeyemi, G. O. (2022). Geotechnical implications of crude oil spillage on lateritic subgrade soils. Journal of Environmental Geotechnics, 9(3), 210-219.

Ogundipe, O. M., & Oyedele, K. F. (2023). Effects of crude oil contamination on the geotechnical properties of lateritic soils. Journal of African Earth Sciences, 198, 104834.

Ogunsanwo, O., & Oyedele, K. F. (2022). Road failure and subgrade soil deficiencies in developing regions: A geotechnical review. Nigerian Journal of Civil Engineering, 18(1), 33-47.

Oyediran, I. A., & Enya, N. I. (2021). Crude oil effects on some engineering properties of sandy alluvial soil. International Journal of Mining and Geo-Engineering, 55(1), 7-10.

Preston, D. (2022). Road infrastructure and socio-economic development in sub-Saharan Africa. Transportation Research Record, 2676(4), 88-99.

Soni, A. (2023). Gum Arabic as a sustainable biopolymer for geotechnical soil improvement. Materials Today: Proceedings, 78, 112-119.

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