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EFFECT OF GUM ARABIC BIOPOLYMER ON ATTERBERG LIMIT AND CATION EXCHANGE CAPACITY OF LEAD-CONTAMINATED LATERITIC SOIL

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ABSTRACT

Laboratory tests and regression analysis were used to assess the liquid limit, plastic limit, and plasticity index, as well as cation-exchange capacity (CEC) of the contaminated lateritic soil treated with up to 25% Gum Arabic biopolymer (GAB). Tests conducted on the soil sample include specific gravity, Atterberg limit, particle size distribution, and cation exchange capacity (CEC). The findings indicate a rise in cation-exchange capacity up to 25% GAB content, while the liquid limit, plastic limit, and plasticity of the lead-contaminated soil decreased with an increase of up to 10% GAB content. However, regression analysis of test results shows a strong correlation between the experimental and predicted values. The consistency indices for use as a subgrade material on lightly traveled roads were improved by a 10% GAB content blend with contaminated lateritic soil.

Keywords: *Contaminated lateritic soil, Plasticity, Cation exchange capacity, Gum arabic biopolymer.*

INTRODUCTION

Contaminated soil, characterized by poor geotechnical features, requires improvement before it can be considered suitable for engineering applications (Oluremi et al 2015). Laterites and lateritic soils are examples of such soil and are mostly found in the tropical and equatorial regions of countries (Osinubi *et al.*, 2019). The characteristics of this soil, including low strength, high compression, and high plasticity, render it unsuitable for engineering works (Osinubi et al., 2019; Oluremi *et al.*, 2017; Ishola *et al.*, 2019; ishola et al., 2023). However, for more than a century, chemical additives have been employed conventionally to stabilize and modify soil. The environmental concerns associated with the use of chemical additives have resulted in a significant shift in the last ten years toward "green" and sustainable technologies.

A novel and innovative material called biopolymer has been evaluated by researchers (Arasan *et al.*, 2017, Prashant et al., 2019). Biopolymers are synthetic materials made by living things and are also referred to as polymeric biomolecules. Commercially available biopolymers include gelatin made from animal skin or bones, gum arabic made from plant sources, guar gum, and locust bean gum, starches made from corn or tapioca, and xanthan gum made from bacteria (Van de Velde and Kiekens, 2002; Chang and Cho, 2012). Geotechnical engineering and geo-environmental engineering use biopolymers to improve soil (Khatami and O'Kelly, 2013; and Arasan and Nasirpur, 2015); to lessen soil permeability (Bouazza et al., 2009; Wiszniewski et al., 2013); and as soil drilling mud (Mitchell and Santamarina, 2005). Several researchers (Sari Ahmad et al., 2018, Eyo et al., 2022, Amiri and Hatami, 2022) have examined the effect of fly ash on the behavior of high-plasticity clay soils. As a result, the research aims to examine the impact of GAB content when used as an admixture to enhance the workability of lateritic soil and to provide engineers and contractors with the necessary recommendations.

MATERIALS AND METHODS

Materials

Lateritic soil sample

The lateritic soil sample used for this study was collected from a borrow pit at Olokuta, Osogbo, Osun State (Latitude 7° 46’ 37’’ N and Longitude 4° 36’ 3¨ E) Nigeria, at a depth between 1·0 and 1.2 m, corresponding to the B-horizon, which is characterized by accumulation of material leached from the overlying horizon. The obtained pulverized lateritic soil was contaminated with lead nitrate until the concentration of lead reached 963.4 mg/kg using an atomic absorption spectrophotometer.

Gum Arabic Biopolymer (GAB)

The GAB used was obtained from the Nigeria Rubber Research Institute in Gashua, Yobe State, and ground into powder, to allow its passage through British Standard (BS) sieve 200 before being stored and later mixed with proper ratios with lateritic soil. According to an X-ray fluorescence analyzer, Table 1 displays the oxide compositions of GAB.

Methods

Cation Exchange Capacity

The cation exchange capacity test conducted was in line with the guidelines provided by the International Soil and Reference Information (Isric, 1998) at Adeleke University Ede, Osun State, and the results were calculated using equation (1)

$$C_{EC}\ (\text{cmol/kg}) = \frac{(\,titre - B)x\,N_A\,x\,100}{weight\ of\ soil} \qquad (1)$$

where B is blank and NA is the normality of acid.

Table: Chemical composition of GAB and Lead contaminated lateritic soil

Parameters	GAB (%)	Lead-Contaminated Soil (%)
SiO_2	10.68	56.46
Al_2O_3	7.96	29.09
Fe_2O_3	0.87	4.72
TiO_2	0.01	1.79
CaO	51.79	1.25
K_2O	18.86	1.2
MnO	0.11	0.06
MgO	2.54	0.01
Na_2O	0.05	0.03
ZnO	0.08	0.12
PbO	0.02	4.46
LOI	11.47	13.72

Atterberg limit

Atterberg limits, which include plasticity index, liquid limits, plastic limit and linear shrinkage, were investigated following test BS 1377-2:1990 for unstabilized soils and BS 1924 for treated soils.

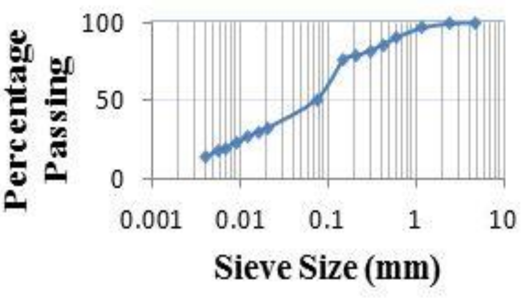

Figure 1: Particle size distribution curve of the contaminated laterite

RESULTS AND DISCUSSIONS

Index properties

The initial test conducted on the contaminated lateritic soil revealed that is fine-grained soil in reddish-brown colour with a natural moisture content of 162%. Table 2 provides a summary of the index features, and Figure 1 displays the natural soil's particle size distribution curve.

Table 2: Properties of contaminated lateritic soil

Properties	Values
Natural Moisture Content (%)	14.48
Specific Gravity	2.58
Liquid Limit (%)	60.48
Plastic Limit (%)	37.34
Plasticity Index (%)	23.14
Linear shrinkage (%)	14.42
USCS Classification	ML
Colour	Reddish-brown
AASHTO Classification	A-7-5 (17)
Percentage Passing BS No 200 Sieve	52.79

Cation exchange Capacity

Figure 2: depicts the changes in the lateritic soil's cation-exchange capacity (CEC) with the presence of GAB. The trends in the graph demonstrated that the cation-exchange capacity improved from 3.34 cmol/kg for the natural lateritic soil to the peak value of 4.42 cmol/kg with 25% GAB treatment of the soil. The increase in CEC of lateritic soil to the peak value was attributed to the pH increase of the soil and growing capacity for isomorphous substitution of its base cation with GAB concentration. This resulted in the soil's high capacity for flocculation and agglomeration of the GAB content that introduced calcium hydroxide content to the contaminated lateritic soil mixture, which supplied calcium ions (Ca^{2+}) required to displace lead ion (Pb^{2+}) for the cation exchange between the clay mineral particles (Oluremi et al 2017). This is consistent with the findings reported by Adeyemo et al. (2022) that electrostatic pull between the charged ion of clay particles and the cation concentration of the CPA content.

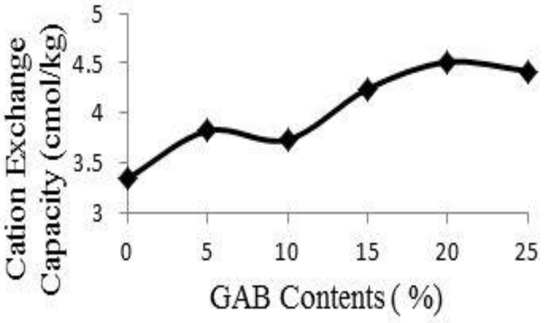

Figure 2: Variation in cation exchange capacity of contaminated lateritic soil–GAB mixtures

Plasticity Characteristic

Atterberg limits

Liquid limit

Figure 3 illustrates the variation in liquid limits with GAB concentrations for the treated contaminated lateritic soil. According to the graph, the liquid limit dropped from 60.48% for the contaminated lateritic soil to a minimum value of 48.43% at 10% GAB content, then rose as the GAB content increased. The cation-exchange processes in which calcium ions from the GAB reacted with ions of lower valence in the clay structure may have caused the drop in the liquid limit with an increase in the GAB content up to 10%. The increase in liquid limit linked to the moisture needed for the contaminated lateritic soil and GAB combination to react with the increasing of GAB content. When a soil reaches its liquid limit, a change in the system causes the repulsive forces and more water is required to bring the soil up to its dynamic shear strength (Oluremi et al 2017).

Plastic limit

Figure 3 depicts the fluctuation in the plastic limit with the GAB concentrations. The plastic limit value dropped from 37.34% for the contaminated lateritic soil to a minimum value of 31.86% with 10% GAB treatment and then rose with higher GAB concentration. The cation-exchange process, which released adsorbed water particles in the soil caused the soil to aggregate and flocculate and was responsible for the fall in the plastic limit value (Ramesh et al., 2013). Lead ions in the clay structure were replaced by the more active and higher valence cations in the GAB (i.e., calcium ions), which caused flocculation and the release of water bound to the outer layers. However, dispersion of the contaminated soil by cation exchange at the surface of the clay particles may be the reason for the increase in the plastic limit with the addition of GAB content. This supports the conclusions made by Oluremi et al. (2017) for lateritic soil treated with iron ore tailings.

Plasticity Index

The effects of GAB content on the plasticity index of contaminated lateritic soil–GAB mixtures are shown in Figure 3. From the graphs, generally, the plasticity index decreased with an increase in GAB contents. It was observed that the plasticity index decreased from 0 to 10% GAB content for GAB-treated contaminated lateritic soil.

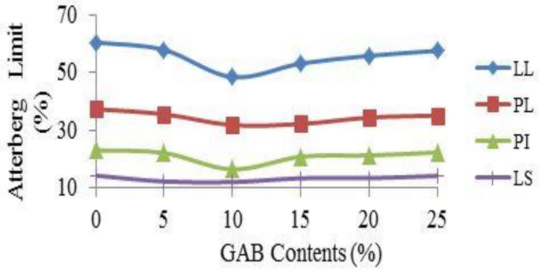

Figure 3: Variation in Atterberg limit of contaminated lateritic soil–GAB mixtures

Regression Equation of the Test Results

Using the GAB contents as independent variables, linear regression equations were produced. The produced equations were employed in computational analysis to predict the relationship between the GAB and the laboratory-measured variables. Summaries of computed linear regression equations are shown in Table 3. while the measured and predicted values of the plasticity characteristics (liquid limit, plastic limit, plasticity index), and cation-exchange capacity as a function of GAB are shown in Table 4. It can be seen from Table 4. that experimental values for the lateritic soil treated with GAB range between 48.43 and 60.48% (liquid limit), 16.57 and 37.34% (plastic limit), 16.57 and 23.14% (plasticity index), and 3.34 and 4.42 cmol/kg (cation-exchange capacity) while the predicted values range between 56.69 and 58.60%, 35.45 and 37.45, 21.24 and 21.51, 3.44 and 4.58 cmol/kg respectively.

Table 3: Linear regression equation for the tests

Property	**Description**	**Linear regression**	**Correlation coefficient**
Liquid limit	GAB against L_L	Y = 0.0908x + 56.69	0.004
Plastic limit (PL)	GAB against P_L	Y = 0.0882x + 35.45	0.1289
Plasticity Index (PI	GAB against P_I	Y = 0.0106x + 21.24	0.0018
Cation exchange capacity	GAB against C_{EC}	Y = 0.0456x + 3.44	0.8795

Table 4: Experimental and predicted results of Atterberg limits and Cation exchange capacity of GAB treated lateritic soil

Additive	Soil properties	GAB content %	Experimental results	Predicted result	Absolute error
GAB	LL	0	60.48	56.69	3.79
		5	57.85	57.14	0.71
		10	48.43	57.6	9.17
		15	53.15	58.05	4.9
		20	55.83	58.5	2.67
		25	57.57	58.6	1.03
	PL	0	37.34	35.45	1.89
		5	35.62	35.85	0.23
		10	31.86	36.25	4.39
		15	32.24	36.65	4.41
		20	34.45	37.05	2.6
		25	35.16	37.45	2.29
	PI	0	23.14	21.24	1.9
		5	22.23	21.29	0.94
		10	16.57	21.35	4.78
		15	20.91	21.4	0.49
		20	21.38	21.45	0.07
		25	22.41	21.51	0.9
	CE	0	3.34	3.44	0.1
		5	3.82	3.67	0.15
		10	3.73	3.9	0.17
		15	4.24	4.12	0.12
		20	4.51	4.35	0.16
		25	4.42	4.58	0.16

Tables 4 and 5, respectively, display the conceptual regression models created for cation-exchange capacity and plasticity characteristics (liquid limit, plastic limit, and plasticity index) between the measured values obtained in the laboratory and the predicted values. GAB shows no significant correlation for the liquid limit, plastic limit, or plasticity index, but it does for cation exchange capacity (see Table 5). The increase or decrease in admixture content will therefore not affect the mixture when admixtures have little or no impact on the liquid limit, plastic limit, or plasticity of the stabilizing soil. This could make it difficult to predict the liquid limit using these stabilizing materials (Oluremi et al., 2017). Since there is a strong correlation between clay minerals and cation exchange capacity, it is obvious that these minerals, particularly in the lateritic soil-GAB mix, have a big impact on the soil's plasticity behaviour and should be monitored when applying the soil in the field. This emphasizes how important it is to determine the cation-exchange capacity of soil admixtures before using them.

CONCLUSIONS

A study of contaminated lateritic soil treated with up to 25% GAB by dry weight of soil reveals a rise in cation exchange capacity from 0 to 25% GAB content. The liquid limit, plastic limit, and plasticity index decreased up to 10% GAB. According to the findings of the regression analysis, GAB has little potential for improving plasticity but is more effective at increasing the cation-exchange capacity

(CEC) of treated lateritic soils. The properties of the lateritic soil were improved by an ideal mixture of 10% GAB, and each of the mixtures is advised for use as a subgrade material for the construction of lightly traveled roads.

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