

Characterization of Lateralite: An Environment Friendly Chemical Additive for Soil Stabilization

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ORIGINAL RESEARCH

Abstract— The objective of this paper is to determine the chemical composition of Lateralite stabilizer and to characterize Lateralite, stabilizer as a solution for improving the engineering properties of fined grained lateritic and clayey soil for road construction. Oxides and metallic compositions of Lateralite was determined by Atomic Absorption Spectroscopy, AAS, composition of chemical elements of Lateralite stabilizer was determined by X-ray Photoelectron Spectroscopy (XPS) and a quantitative analysis by Scanning Electron Microscopy (SEM) associated with Energy Dispersive X-ray spectroscopy (EDX). The oxide composition of Lateralite as determined by AAS is: Calcium Oxide (63.89%), Silicon Oxide (18.31%), Aluminium Oxide (5.89%), Ferrous oxide (1.67%), Magnesium oxide (1.56%), Sulphur oxide (1.22%), Potassium oxide (0.78%), Sodium oxide (0.41%) and L.O.I 6.27%. The elemental composition analysis by XPS revealed ten (10) elements with Percentage Atomic Concentration, PAC, as: Oxygen (54.33%), Carbon (18.26%), Silicon (9.38%), Calcium (7.56%), Magnesium (4.08%), Aluminium (2.90%), Sodium (2.47%), Ferrous (0.44%), Sulphur (0.31%) and Nitrogen (0.27%) while SEM revealed eleven (11) elements: Oxygen (57.9%), Calcium (21.13%), Silicon (11.08%), Aluminium (4.23%), Ferrous (1.89%), Sulphur (1.07%), Magnesium (1.02%), Sodium (0.99%), Potassium (0.35%), Tin (0.18%) and Barium (0.17%). The three (3) characterization techniques used, (AAS, XPS and SEM) revealed the exchangeable cations in Lateralite are Calcium (7.56%), Magnesium (4.08%), Aluminium (2.90%) and Sodium (2.47%) which are in the ratio 3: 1.65:1.17:1, (Ca²⁺: Mg²⁺: Al³⁺: Na⁺). This shows a high concentration and quantity of exchangeable calcium cations over other cations. This will enable the formation of Calcium compounds with very strong and stable inter-particle bonds and a stable Lateralite-stabilized soil mixture.

Keywords—Elemental Composition, Exchangeable Cations, Lateralite, Lateritic Soil, Oxide and Metallic Composition, Quantitative Analysis

1 INTRODUCTION

There is a frequent deformation of flexible road pavement on Lateritic-clayey soil in Nigeria and in many parts of the world, Jegede (2000); Igboama *et al.*, (2021). The main reasons for the frequent deformation of flexible road pavements on lateritic soil are low shear strength of soaked lateritic soil, inadequate pavement thickness and excessive axle-loads. Adeyemi and Oyeyemi (2000), Meshida (2006) and Ogunribido (2012b) explained that frequent excessive road distresses and deformations are due to inadequate and poor geotechnical characteristics of the underlying lateritic clay soil used for the base and subbase layers. Majority of roads in Nigeria are flexible pavement built on laterite. These have very low and weak tensile strength. Therefore, distresses and deformations in the subgrade, subbase and base layers appear simultaneously on the flexible road pavement surface thereby affecting a smooth ride.

Laterite and clayey soils soaked with water have poor geotechnical engineering characteristics including high amount of swelling, medium-high plasticity, and low strength due to water percolation, Frempong and Yanful, (2006), Osinubi and Kundirin (2007).

Meshida (2006) stated that the road distresses, deformations, and instability of flexible pavements on lateritic foundations is due to the presence of large quantities of clay in the lateritic soil.

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During wet seasons, rainfall water percolates, dissolve and break down compacted laterite used for flexible pavement foundations thereby causing various road distresses and deformations on the asphaltic surface.

This common, world-wide occurrence and appearance of road distresses, deformations, and failures of flexible pavements on laterite and clayey soil has led to the creation of various products and chemicals to stabilize and strengthen the poor geotechnical properties.

Cement, calcium hydroxide, lime, admixtures, bentonite and waste products are some of the product fos that are being investigated to improve the engineering characteristics of laterite and clayey soil for road construction (Osinubi *et al.*, (2006a). These have given limited results. Soil stabilization with cement has resulted in some improvements but requires foreign currency which is often scarce. Therefore, research efforts to improve the geotechnical characteristics of soil is centred on local product development and material such as fly ash and rice husk ash, (Osinubi 2006b; Sabat 2012; Sabat and Nanda 2011; Ogundalu *et al.* 2013; Ogunsanya *et al.*, 2022). The addition of bentonite to improve the strength of compacted lateritic soil resulted in increase in plasticity index and optimum moisture content but the maximum dry density and unconfined compressive strength of the compacted mixture reduced, Osinubi and Amadi (2010). Ogunribido (2012a) reported that adding rock floor to soil improves linear shrinkage, Atterberg limits, optimum moisture content and un-soaked CBR of the soil to an extent while Al Rawas and Goosen (2006) noted that lime and other additives also improve the engineering characteristics of clay soils to an extent.

The addition of lime is to clay soils causes a reaction

between ions of calcium in the lime and minerals in the clay minerals. Ramadas *et al.*, (2011) however believes that lime only improves soil workability and not the soil strength. The strength of the stabilized mixture depends on the strength of the exchange and bonding between the clay soil ions and the ions in the stabilizer. Replacement of a cation by another, cation, cation exchange, depends on the different types of cations present, the size, valency, and relative concentration, Bing So *et al.*, (2004).

Lateralite is a stabilizer for improving the engineering characteristics of laterite and clayey soils for flexible road pavements, Meshida, (2005).

1.1 LATERALITE

A soil is made up of solid particles, liquid and gas. The solid particles vary in shape and size (boulders to microscopic size) and from long spheres to granules and plate like structures. A soil contains chemical elements including oxygen, hydrogen, silicon (that are usually abundant) and other elements, depending on its mode of geological formation and exposure to weather conditions. Mitchell and Soga, (2005) observed that the engineering characteristics of the stabilized soil mixture is related to the strength of the reactions that take place between the particles of the soil and the particles of the stabilizer added to it, the soil surface characteristics, the type and strength of new compounds formed in the stabilized soil mixture and the strength of the bond formed.

Meshida (2005) and Meshida *et al.* (2011) reported that Lateralite's reaction with the sesquioxide is pozzolanic and reacts with the sesquioxide to form new chemical substances that fills up the pores of the lateritic clay soil. The cementation is very solid and almost insoluble and that the strength and geotechnical characteristics of the soil are significantly improved. The actual geochemical processes are being investigated. The aim of this research work is to investigate the physio-chemical characteristics of Lateralite and its potential for stabilizing lateritic-clay soil.

2 MATERIALS AND METHODS

2.1 LATERALITE

The sample of Lateralite stabilizer was analyzed in powder form. Lateralite is dark grey in color. The sample was analyzed by Atomic Absorption Spectroscopy for oxide and metallic composition; mineralogy and chemical composition was determined with X-Ray Photoelectron Spectroscopy (XPS) and a detailed image and physical features of the lateralite stabilizer using Scanning Electron Spectroscopy (SEM).

2.2 OXIDE AND METALLIC COMPOSITION USING ATOMIC ABSORPTION SPECTROSCOPY (AAS)

The oxide and metallic composition of the Lateralite was investigated with Atomic Absorption Spectroscopy at the Chemistry Department, University of Lagos, Nigeria. This is a quantitative determination of chemical elements by the absorption of light radiation of atoms that are free in the vaporous state. The oxide and metallic composition of the Lateralite is presented in Tables 1 and 2.

2.3 ELEMENTAL COMPOSITION OF LATERALITE

The surface of Lateralite was analyzed with an X-ray Photoelectron Spectroscopy, XPS, equipped with X-ray kV and mA emission; a 180-degree hemispherical analyzer; resistive anode and Position Sensitive Detector. The survey scans were done with a 150V pass-energy. The X-ray incidence and emission angle was 55 degrees from sample normal. An angle of 710 was used between x-rays and analyzer. The collection of Photoelectrons was done at an emission angle $\beta = 55^\circ$, with respect to the sample normal.

2.4 QUANTITATIVE ANALYSIS OF LATERALITE

Quantitative analysis was performed using a Scanning Electron Microscopy (SEM) associated with Energy Dispersive X-ray spectroscopy (EDX) to determine the chemical content of Lateralite. The equipment has a high-resolution, high accuracy and a micro-analyzer that gives an accurate and efficient analysis. The SEM-EDX analyze and) and the backscattered electron image gives 15 elements (5 WDS, 8 EDS, 2 backscattered signals). SEM-EDX analysis of chemical composition of both x-ray spectrometer is presented.

3.0 RESULTS AND DISCUSSION

3.1 OXIDE AND METALLIC COMPOSITION

The result of the oxides and metallic analysis are shown in Tables 1 and 2. The Atomic Absorption Spectroscopy showed that the main oxides present in Lateralite are Calcium Oxide (63.89%), Silicon Oxide (18.31%) and Aluminum Oxide (5.89%). The three oxides constitute 88.09% of the total oxide composition and a Loss on Ignition (L.O.I) of 6.27%, (Table 1). There is a low percentage of Ferrous Oxide (1.67%), Magnesium Oxide (1.56%), Sodium Oxide (0.41%), Potassium Oxide (0.78%) and Sulphur Oxide (1.22%). AAS detected the presence of five (5) main metals (copper, manganese, nickel, iron and zinc) n the sample.

TABLE 1: OXIDE COMPOSITION OF LATERALITE

Mineral (%)	Lateralite
S ₁ O ₂	18.31
Al ₂ O ₃	5.89
Fe ₂ O ₃	1.67
CaO	63.89
MgO	1.56
Na ₂ O	0.41
K ₂ O	0.78
SO ₃	1.22
L.O.I	6.27

There is a net negative charge on the surfaces of particles of clay minerals. This negative charge reacts with positively charged ions (cations) from molecules of water and other substances to form various compounds. Table 1

shows that Calcium (Ca²⁺), Magnesium (Mg²⁺), Potassium (K⁺) and Aluminum (Al³⁺) cations are present in Lateralite as the exchangeable cations that will react and bond with the soil elements. The excess calcium cations is responsible for pozzolanic activities and may react with the alumina and silica clay minerals to form cemented chemical compounds like calcium silicate hydrates (CaSiH), calcium sulphate (CaSO₄) and calcium aluminum hydrates (CaAl₂H) which contribute to strength.

Table 2: Metals Identified in the Lateralite (mg/kg)

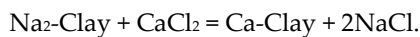
Metals (mg/kg)	Lateralite
Cadmium	Not detected
Copper	2.30 x 10 ⁻⁶
Manganese	0.77 x 10 ⁻⁶
Nickel, Ni	0.01 x 10 ⁻⁶
Lead, Pb	Not detected
Iron, Fe	4.16 x 10 ⁻⁶
Zinc, Zn	3.27 x 10 ⁻⁶

3.2 ELEMENTAL COMPOSITION OF LATERALITE

Figure 1 represents the constituent elements of Lateralite. The Percentage Atomic Concentration (PAC) of the elements detected by XPS. are Oxygen (54.33%), Carbon (18.26%), Silicon (9.38%), Calcium (7.56%), Magnesium (4.08%), Aluminium (2.90%), Sodium (2.47%), Ferrous (0.44%), Sulphur (0.31%) and Nitrogen (0.27%), Table 3.

The ions of Clay minerals in lateritic soils reacts with and absorb positively charged ions from water and other substances like Lateralite (cation exchange) to neutralize their negative charge to become more stable. The absorption capacity of clays depends on the net negative charge on the structure of the minerals present in the clay particles, the surface area and the porosity.

The higher the quantity and types of exchangeable cations present, the more the chemical compound that can be formed with different degree and kinds of bonds. Singh (1992) reported that when clay containing sodium cation is mixed with a solution of calcium chloride, a reaction takes place where a calcium-clay is formed with sodium chloride:



In this reaction one ion of calcium (Ca²⁺) replaces two ions of sodium (Na⁺) and the sodium ion is washed out in the solution. This process is called ‘cation exchange’. The exchange of ions and replacement capacity depend on the sizes, valency, quantity and strength of the various positively charged ions present and reactivity. A stabilizer must have a high concentration quality and quantity of exchangeable cations, especially calcium ions to be able to stabilize the soil. Ions of calcium forms very strong ionic compounds which stronger than bonds with compounds of magnesium, sodium and potassium.

Table 3 shows the exchangeable cations in Lateralite as: Calcium (7.56%), Magnesium (4.08%), Aluminium (2.90%) and Sodium (2.47%). The Calcium (7.56%),

Magnesium (4.08%), Aluminium (2.90%) and Sodium (2.47%) ratio is 3: 1.65:1.17:1, (Ca²⁺: Mg²⁺ : Al³⁺ :Na⁺) showing a higher concentration and quantity of exchangeable calcium cations over other cations present. Calcium cations will form calcium compounds with very strong and stable inter-particle bonds. Compounds of Magnesium are less strong and stable.

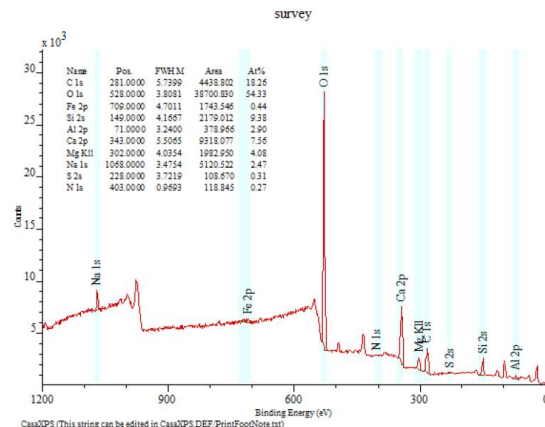


Fig. 1. XPS Elemental composition of Lateralite

Table 3: Percentage Atomic Composition of Lateralite

Name	Percentage (%)
Carbon (C 1s)	18.26
Oxygen (O 1s)	54.33
Ferrous (Fe 2p)	0.44
Silicon (Si 2s)	9.38
Aluminium (Al 2p)	2.9
Calcium (Ca 2p)	7.56
Mg K11	4.08
Sodium (Na 1s)	2.47
Sulphur (S 2s)	0.31
Nitrogen (N 1s)	0.27
Total (%)	100

3.3 QUANTITATIVE ANALYSIS OF LATERALITE

Table 4 gives the details of the quantitative analysis of Lateralite as consisting of Sodium, Magnesium, Aluminium, Silicon, Sulphur, Potassium, Calcium, Tin, Ferrous, Oxygen and Barium, eleven (11) elements. The result compares favourably with the elemental composition by XPS except Oxygen. The SEM-EDS analysis data is given in Figure 2 showing the peaks of chemical elements detected while Figure 3 is the SEM-EDS image of Lateralite showing the physical characteristics.

The quantitative analysis by SEM-EDS gave higher percentages of oxygen, silicon, calcium and aluminium than the percentages given by XPS. Very reactive ions of elements are found on the surface while less reactive and heavy metals are not on the surface and are more difficult to detect except by more sensitive microbes.

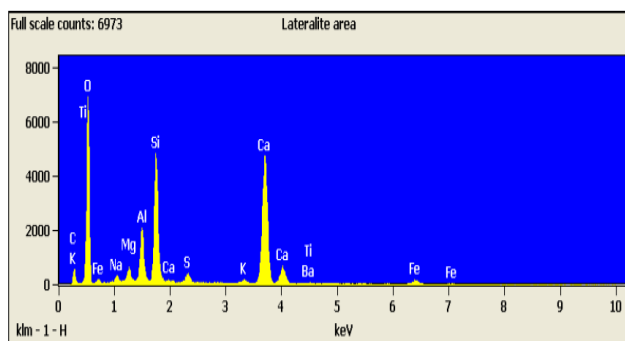
The percentage distribution of elements by atom given by SEM for sodium and magnesium are lower than that

given by XPS. But the SEM also confirms the presence of exchangeable cations in descending order as: Calcium (21.13%), Aluminium (4.23%), Magnesium (1.02%), Sodium (0.99%) and Potassium (0.33%).

Table 4: Quantitative Analysis of Lateralite

Element Line	Weight (%)	Atom (%)	Compound (%)
C K	0	0	0
O K	38.11S	57.9	---
Na K	0.93	0.99	1.26
Mg K	1.02	1.02	1.69
Al K	4.7	4.23	8.88
Si K	12.8	11.08	27.39
Si L	---	---	---
P K	1.41	1.07	3.53
P L	---	---	---
K K	0.56	0.35	0.68
K L	---	---	---
Ca K	34.84	21.13	48.74
Ca L	---	---	---
Ti K	0.35	0.18	0.58
Ti L	---	---	---
Fe K	4.34	1.89	6.2
Fe L	---	---	---
Ba L	0.94	0.17	1.05
Ba M	---	---	---
Total	100	100	100

Project: Wale samples



Live Time: 30.0 sec.

Acc.Voltage: 15.0 kV Take Off Angle: 40.0 deg.

Quantitative Results Lateralite area

Fig. 2. SEM-EDS analysis data of Lateralite

These are in the ratio 21: 4.2:1:1, (Ca²⁺ : Al³⁺: Mg²⁺ : Na⁺) excluding potassium. This also shows that there is an abundance of exchangeable calcium cations over magnesium and sodium to form calcium compounds with stronger inter-particle bonds. The presence of more positively charged ions of Calcium causes calcium

compounds to be formed with very strong and stable inter-particle bonds. Compounds of Magnesium are less strong and stable.

Sodium and Potassium are group 1 elements. They have only one electron in their outermost shells. They are very electropositive and ionize to form univalent positive ions. But the metallic bonding in the crystal lattices of Group 1 metals is weak because each atom in the crystal can only contribute one valence electron for the electron cloud that forms the metallic bond. As a result, Group 1 metals tend to be soft and light with low melting points. The low melting point encourages the reaction and formation of Group 2 elements.

Magnesium and Calcium are group 2 elements. They are less reactive than Sodium and Potassium which are Group 1 elements. The atoms have two valence electrons and ionize to form divalent positive ions. In this case, the metallic bonds are stronger than those in Group 1. As we go down Group 2, the atomic radius increases and the ionization energy decrease. Therefore, the reactivity of the metals in Group 2 increases down the table. Calcium is therefore more reactive than Magnesium. Group 2 elements form mainly electrovalent compounds which are strong as they have strong inter-particle bonds.

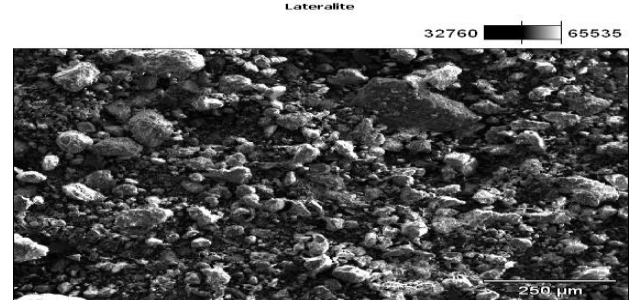


Fig. 3. SEM image of the Lateralite particles

4.0 CONCLUSION

- i. Atomic Absorption Spectroscopy, AAS gave the oxide composition of Lateralite as: Calcium Oxide (63.89%), Silicon Oxide (18.31%), Aluminium Oxide (5.89%), Ferrous oxide (1.67%), Magnesium oxide (1.56%), Sulphur oxide (1.22%), Potassium oxide (0.78%) and Sodium oxide (0.41%). This indicates the presence of Calcium (Ca²⁺), Magnesium (Mg²⁺), Potassium (K⁺) and Aluminium (Al³⁺) cations as exchangeable cations for soil reaction. The excess calcium cations are responsible for pozzolanic reactions with ions of clay to form cemented, stable and strong bond molecules with calcium and other elements.
- ii. Elemental Composition of Lateralite detected ten (10) elements. The Percentage Atomic Concentration (PAC) of the elements are Oxygen (54.33%), Carbon (18.26%), Silicon (9.38%), Calcium (7.56%), Magnesium (4.08%), Aluminium (2.90%), Sodium (2.47%), Ferrous (0.44%), Sulphur (0.31%) and Nitrogen (0.27%). XPS gave the exchangeable cations in Lateralite in descending order as: Calcium (7.56%), Magnesium (4.08%), Aluminium (2.90%) and Sodium (2.47%) in the ratio 3: 1.65:1.17:1, (Ca²⁺ : Mg²⁺ : Al³⁺ : Na⁺) which also shows that there is an abundance of

- exchangeable calcium cations over magnesium and sodium to form calcium compounds.
- iii. Quantitative analysis revealed eleven (11) elements, Oxygen (57.9%), Calcium (21.13%), Silicon (11.08%), Aluminium (4.23%), Ferrous (1.89%), Sulphur (1.07%), Magnesium (1.02%), Sodium (0.99%), Potassium (0.35%), Tin (0.18%) and Barium (0.17%). The positively charged ions are Calcium (Ca^{2+}), Aluminium (Al^{3+}), Magnesium (Mg^{2+}), Sodium (Na^+) and Potassium (K^+) in the ratio 21: 4.2:1:1, ($\text{Ca}^{2+} : \text{Al}^{3+} : \text{Mg}^{2+} : \text{Na}^+$). There is an overabundance of calcium ions relative to other reactive positive ions.
- iv. The AAS, XPS and SEM confirmed the presence of four main exchangeable cations in Lateralite which are Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Aluminium (Al^{3+}) and Sodium. All the three investigations confirm the abundance of exchangeable calcium cations over magnesium, aluminium, sodium and potassium. The excess calcium cations are responsible for pozzolanic activities and may react with clay minerals to form cemented calcium compounds which are ionic and divalent with strong and stable inter-particle bonds.

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