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PHYSICO-CHEMICAL PROPERTIES OF LATERITIC SOIL TREATED WITH LIMESTONE POWDER AND FLY-ASH

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ABSTRACT

The quality of embankment construction directly influences the performance of the supported infrastructure. This research examined the quality of lateritic soil stabilized with limestone powder (LS) and fly ash (FA) through changes in the physico-chemical properties of mixtures. The representative lateritic soil was treated with a predetermined optimum LS content of 6% and varying proportions of FA (3, 6, 9, 12 and 15% by dry weight of soil). Physico-chemical test such as Atterberg limits (Liquid and plastic limit), linear shrinkage, specific gravity, cation exchange capacity (CEC), electrical conductivity (EC) and pH were conducted on soil mixtures. The result of the tests revealed that the natural soil was classified as A-7-5 and MH (inorganic silts) under ASSHTO and USCS classification systems respectively. The study also found that the addition 6%LS to the natural soil increased the plasticity index to 24.4% from 17.2% for the natural soil, while the combined effect of 15%FA +6%LS decreased the value to 15.9%. Similarly, both specific gravity and linear shrinkage of mixtures containing LS and FA were found to be lower compared to that of the natural soil. On the contrary, pH of soil increased on introduction of 6%LS which increased further when FA was added due to their neutralizing and alkaline properties. Likewise, the combined treatment yielded higher CEC, indicating more exchangeable cations, while the EC increased with fly ash, suggesting increased dissolved ion concentration from fly ash's soluble salts.

Key Words: Fly ash, Limestone, Lateritic soil, Physicochemical properties, Stabilization.

1.0 Introduction

The geochemical properties of soil are integral to the success of civil engineering construction projects, with particular significance in endeavors such as road construction, foundation laying, embankments, and dam development, among others. The quality of embankment construction, in particular, holds considerable sway over the performance and longevity of the infrastructure it supports (Chukwuka, *et al.*, 2022). Understanding and appropriately managing the geochemical characteristics of soil is therefore paramount in ensuring the durability, stability, and overall success of such projects. Lateritic soils, characterized by their prevalence in tropical

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regions are utilized in many engineering applications but some grades pose challenges due to their inherent geotechnical limitations, necessitating stabilization for various construction applications, particularly in the case of lateritic soils (Sharma *et al.,* 2023). These soils are commonly found in areas with warm and humid climates, typically undergoing weathering processes that result in the formation of a distinct soil profile. These grades of lateritic soils, often expansive and prone to erosion, are widely utilized in construction activities, especially in regions with limited alternatives. However, their instability can result in significant volume changes, notably when exposed to moisture, leading to challenges such as swelling, shrinkage, and diminished load-bearing capacity. Lateritic soils contribute to the general economy of the region where they are found (Akinmusuru, *et al*., 2021). They are primarily composed of iron and aluminium oxides, silicate minerals, and residual materials resulting from the weathering of parent rocks, usually rich in basalt or granite. These soils are recognized for their reddish-brown colour, high iron content, and a relatively high percentage of fines. Due to the weathering process, lateritic soils exhibit variable engineering properties, often leading to challenges in construction and infrastructure development.

However, utilization of these problematic soils has been hampered by workability issues, in the presence of montmorillonite and illite that undermine their strength and introduces swelling tendencies or potential. In order to utilize these soils, modification should be conducted through stabilization to improve its quality for desired purpose. In addition to the geotechnical properties, the physiochemical properties (such as pH, cation exchange and electrical conductivity) of soil are indicators of the quality of mixture as well as the concentration and composition of relevant minerals in the soil. It is essential to test soil for both its geotechnical and physicochemical properties to ensure sufficient information about the material's quality and adherence to standard specifications. Therefore, this work aimed to examined the quality of lateritic soil stabilized with limestone powder (LS) and fly ash (FA) through changes in the physico-chemical properties of mixtures. Treatment with limestone powder and fly ash introduces key physicochemical changes to lateritic soils. The addition of powdered limestone aids in neutralizing soil acidity, enhancing pH levels, and promoting cation exchange capacity (Sylvia *et al.,* 2022). Fly ash, a by-product of coal combustion, contributes to the pozzolanic reactions, resulting in improved cohesion, reduced plasticity, and increased strength (Arpita *et al.,* 2019). Additionally, these additives can modify the electrical conductivity of the soil which is a measure of how easily electrical charges can move through the soil, impacting its overall behaviour and stability. The physicochemical changes induced by the treatment alter the classification of lateritic soils. Stabilization becomes imperative to enhance the engineering properties of these soils, making them suitable for construction projects. It is common practice to use chemical additives to stabilize soft and/or wet fine-grained soils before they are built upon or used for embankment (Amadi *et al.,* 2021). The stabilization process improves the soils properties depending on the type of stabilizer and the soil property it was aimed to improve. The improvement was as a result of the chemical processes that occurred due to the stabilizer's effect. The stabilizer alters the physicochemical properties of soil which also ensure the preservation of macro structural integrity with minimal degradation under the combined effect of extreme climatic conditions and loading over the designed service period (Mehravar *et al.*, 2020). Soil stabilization is the treatment or improvement of soil though mechanical or chemical method thereby making it useful for the desired purpose. Soil stabilization techniques may involve the mixing or blending of soils with the available additives or agents that may affect the texture, gradation, or plasticity of soil (Kumar *et al.*, 2023). Recent study on lateritic soil stabilization with various methods has been widely practiced, especially in countries with varieties of these soils' types, such as in Asia and Africa. Some of these researches include research carried out by Zubair *et al.* (2017) which indicated that increase in lime content and increase in curing time has led to the increase in compressive strength of soil by 300% (three times higher than the untreated soil) in which the maximum strength was obtained at 10% CaO content. Lime stabilization is one of the oldest process of improving the engineering properties of soils and can be used for stabilizing both base and sub base materials (Garber *et al.*, 2000). The addition of lime to reactive fine-grained soils has beneficial effects on their engineering properties, including reduction in plasticity and swells potential, improved workability, increased strength and stiffness, and enhanced durability (Olugbenga, 2011). In addition, lime has been used to improve the strength and stiffness properties of unbound base and sub base materials.

Limestone addition alone might not be sufficient for achieving optimal soil modification. The incorporation of supplementary pozzolanic materials, such as fly ash, can be a more effective strategy. Villamizar *et al.* (2012) investigated and found that the addition of coal ash and cassava peels improved the water contact resistance of compressed earth blocks. The utilization of Fly ash will not only enhance the effectiveness of limestone stabilization but also offers a sustainable solution by mitigating environmental concerns associated with fly ash disposal. Fly ash, also known as pulverized fuel ash, is a byproduct generated during coal combustion. It consists of fine particles carried away from coal-fired boilers along with flue gases. Jina and Aswathy (2015) identified fly ash as one of the most abundant industrial waste products. This readily available material is a solid residue from coal combustion, typically appearing as a light to dark grey powder. The fly ash exhibits pozzolanic properties, which can contribute positively to laterite soil stabilization. Despite the potential benefits, research on combined limestone and fly ash treatment for lateritic soils remains limited. This brought the sole aim of this research, which is to investigate the Physico-Chemical Properties of Lateritic Soil Treated with Limestone Powder and Fly-Ash.

2.0 Materials and Methods

2.1 Materials

For this research purpose, lateritic soil was collected by disturb sampling method at depth 1m below surface. It was obtained from a borrow pit with the aid of hand tools (backhoe and auger) in Federal University of Technology, Minna main campus Gidan kwano (009°32.06N, 006°26.55E). The limestone (LS) was obtained from a site in Obajana, Kogi state (7°54.382N, 6°26.23.4E), it was grounded to powered form and sieved with a standard sieve, while fly ash (FA) utilized in this study is class F grade acquired from a thermal power-plant in Lokoja (7°33.21N, 6°39.18E), Nigeria. Both LS and FA were sieved through No. 200 sieve (75 µm) before being used in this work.

2.2 Testing Methods

In the present study, optimum limestone content of 6% determined by Eades and Grim method (Eades and Grim, 1966) was added to the soil while the fly ash was added in varying percentage of 3, 6, 9, 12 and 15% to constitute the mixture specimens namely Soil+6%LS; Soil+6%LS+3%FA; Soil+6%LS+6%FA, Soil+6%LS+9%FA, Soil+6%LS+12%FA, Soil+6%LS+15%FA. Physical properties of soil mixtures following the provision of BS1377 and BS1924 (1990) such as moisture content and particle size distribution of the natural soil, Atterberg limits (liquid and plastic limits), linear shrinkage and specific gravity were determined. The physicochemical properties such as the Electrical Conductivity (EC) and pH were measured using an Orion conductivity cell (product Orion 013005MD, thermo fisher scientific, Waltham, MA) and Orion Ross ultra PH/ATC Triod (product Orion 8157BNUMD, thermo fisher scientific Waltham, MA) respectively while Cation Exchange Capacity (CEC) of the samples was measured at pH 7 with ammonium acetate.

3.0 Results and Discussion

3.1 Lateritic soil characterization

The lateritic soil used in the study comprises of 16.52% sand particles and 81.57% fine-grained particles with approximately 0.45% gravel (Figure 1). The specific gravity of solid particles is 2.63 whereas liquid limit and plastic limit are 51.5% and 33.86%, respectively with a resultant Plasticity Index of 17.64%. The lateritic soil was classified as inorganic silts (MH) according to the Unified Soil Classification System (USCS). The mineralogical analysis of the lateritic soil sample by X-ray diffraction revealed the presence of kaolinite mineral in addition to quartz and calcite. Similarly, the chemical composition of the soil measured with x-ray fluorescence (XRF) is reported in Table 1.

Table 1: Index properties of Natural soil

Properties	Value
Natural Moisture content (%)	23.8
Specific gravity	2.58
Percentage passing sieve No. 200 (%)	81.57
Liquid limit (%)	51.5
Plastic Limit (%)	33.86
Plasticity Index (%)	17.64
ASSHTO Classification	A-7-5
USCS Classification	MH
Shrinkage limit (%)	10.6
Color	Reddish Brown

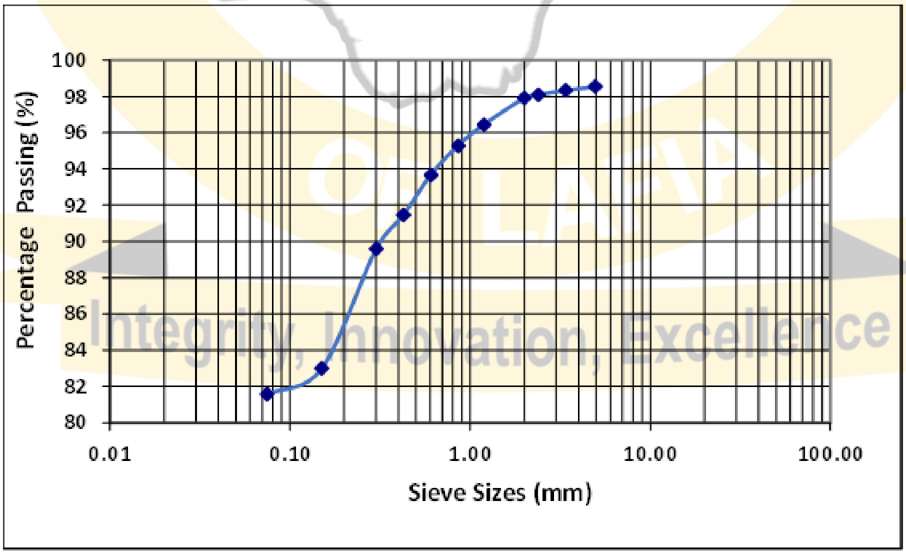

Figure 1: Particle size distribution curve of laterite.

3.2 Limestone characterization

The chemical analysis of limestone indicates that it has 2.25% SiO_2, 1.44% Al_2O_3, 0.24% Fe_2O_3 and 55.08% CaO as reported in Table 2. The mineral composition of the limestone powder obtained by analysis of the x-ray diffraction results indicate that the additive contains 98.80% calcium carbonate ($CaCO_3$). The limestone is composed predominantly of lime (CaO) based on XRD analysis.

Table 2: Oxide compositions for lateritic soil, limestone and fly ash.

Elements	Fly ash	Limestone	Lateritic soil
SiO_2	61.35	2.25	52.60
Al_2O_3	29.61	1.44	30.70
Fe_2O_3	4.58	0.24	2.40
CaO	1.16	55.08	0.28
T_1O_2	1.44	T	T
MgO	0.82	1.25	0.22
K_2O	T	0.08	0.5
SO_3	0.11	0.02	T
Na_2O	T	0.06	T
LOI	0.91	39.56	13.28

Note: T=Trace quantity

3.3 Fly ash characterization

The particle size distributions test established the fly ash (FA) utilized in the study to be 92.4% finer than 0.075mm diameter. The fly ash is classified as low plasticity silt (ML) according to the Unified Soil Classification System. The chemical analysis indicates that it has 61.35% SiO_2, 29.61% Al_2O_3 and 4.58% Fe_2O_3, while lime (CaO) which is a primary component responsible for cementitious reactions, accounted for only 1.16% as reported in Table 2. The fly ash is composed predominantly of Quartz (SiO_2) based on x-ray diffraction (XRD) analysis. Table 2 presents the chemical oxides composition of the lateritic soil, limestone powder and the fly ash.

3.4 Effect of Limestone and Fly Ash on Atterberg limits and linear shrinkage of Lateritic soil

The effect of liquid limit, plastic limit, plasticity index and linear shrinkage on lateritic soil treated with Limestone powder and fly ash is presented in Figure 2. The liquid limit, plastic limit and plasticity index for the natural soil are 51.5%, 33.86% and 17.64% respectively. The addition of 6% limestone elevated the liquid limit to 53%, whereas a 15% addition of fly ash resulted in a decrease to 50%. The decrease can be attributed to the characteristics of the additives: limestone typically contains calcium carbonate, which enhances soil cohesion through cementation, whereas fly ash, a non-plastic material, acting as a pozzolanic material, diminishes soil plasticity by filling voids and reducing water-retention capacity. Changes in plastic limit (PL) with the introduction of limestone and fly ash signify alterations in soil plasticity. Limestone functions as a filler, reducing inter-particle void spaces, while fly ash improves soil structure. Plasticity index (PI) exhibits a similar trend to liquid limit (LL), with limestone addition generally increasing it to 24.40%, and fly ash addition decreasing it to 15.9%. This can be attributed to limestone's enhancement of cohesion and plasticity through calcium carbonate binding, whereas fly ash diminishes PI by reducing plasticity and cohesion,

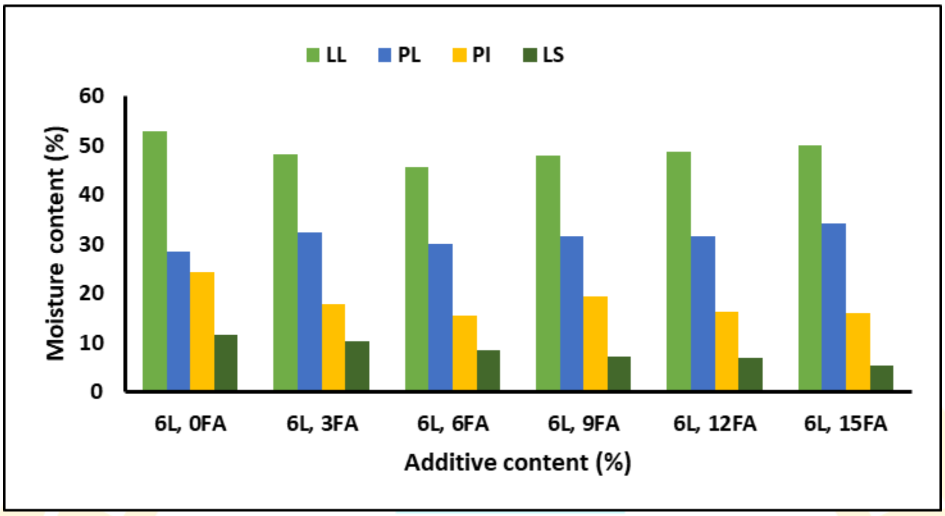

Figure 2: Relationship between LL, PL, PI, LS with 6% Limestone and variation of fly ash.

thereby limiting moisture retention and plastic deformation. Linear shrinkage decreases from 11.52% to 5.33% with 6% limestone addition and increasing proportions of fly ash, indicating reduced soil shrinkage potential upon drying. Limestone augments cohesion and diminishes void spaces, resulting in decreased linear shrinkage and improved soil structure. Conversely, fly ash further reduces linear shrinkage by enhancing soil structure and decreasing voids, thereby mitigating soil shrinkage upon drying. Umar *et al.* (2020), also reported similar decreasing trend in liquid limit and plasticity index of the clayey soil with increase in fly ash content.

3.5 Effect of Limestone and Fly ash on specific gravity of lateritic soil

The results of the specific gravity of lateritic soil determined with 6% limestone and varying percentages of fly ash are presented in Figure 3. From the result, decrease in the soil specific

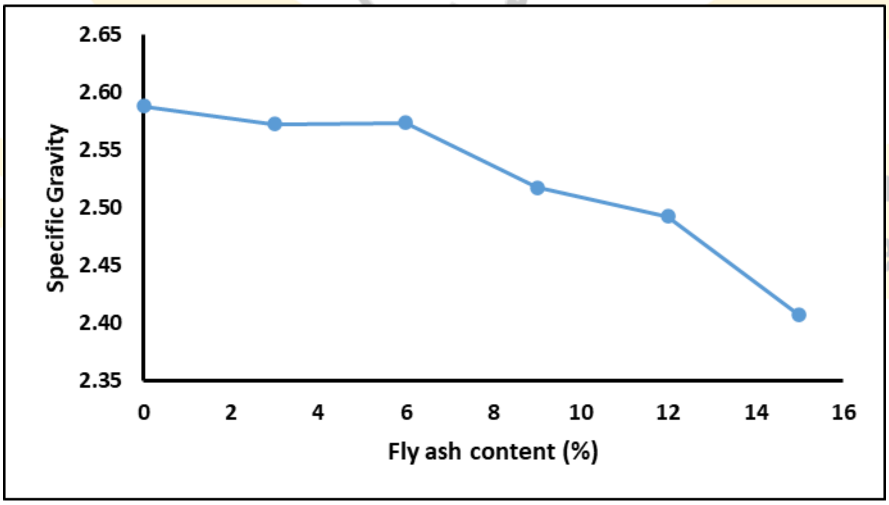

Figure 3: Relationship between specific gravity with 6% limestone and variation of fly ash.

gravity was recorded from 2.59 to 2.41 with increase in fly ash percentage at constant 6% limestone content. This was as a result of the introduction of FA with light dry density (2.17) compared to the soil. The result is similar to the findings reported by Karim *et al.* (2020).

3.6 Physico-Chemical Characteristics of Soil Mixtures (pH, CEC, EC)

Figure 4 shows that the pH of the soil increases gradually from 6.7 to 7.0 with the addition of 6% limestone powder alone as well as when varying proportions of fly ash were added to the mixture. At 15%FA the PH increase to 7.68. This is because limestone acts as a neutralizing agent, raising the pH of acidic soils while Fly ash, being alkaline in nature, further contributes to the increase in pH. As the proportion of fly ash increases, the pH tends to rise more rapidly due to its higher alkalinity compared to limestone.

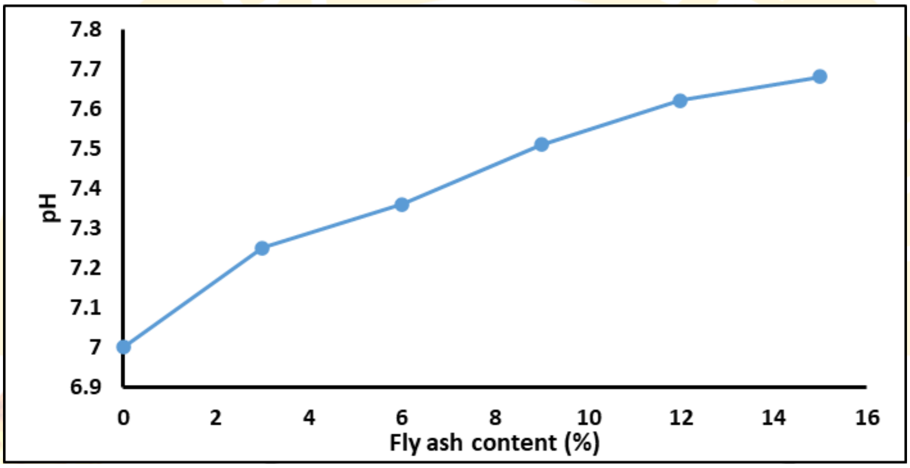

Figure 4: Relationship between pH with 6% limestone and variation of fly ash content.

Figure 5 shows that the CEC of the soil increases from 25.70 cmol(+)/kg to 30.62 cmol(+)/kg with the addition of 6% limestone content alone and also increases when varying proportions of fly ash were incorporated into the soil mixture because limestone and fly ash contain exchangeable cations that increase the soil's CEC. The higher proportion of fly ash leads to a

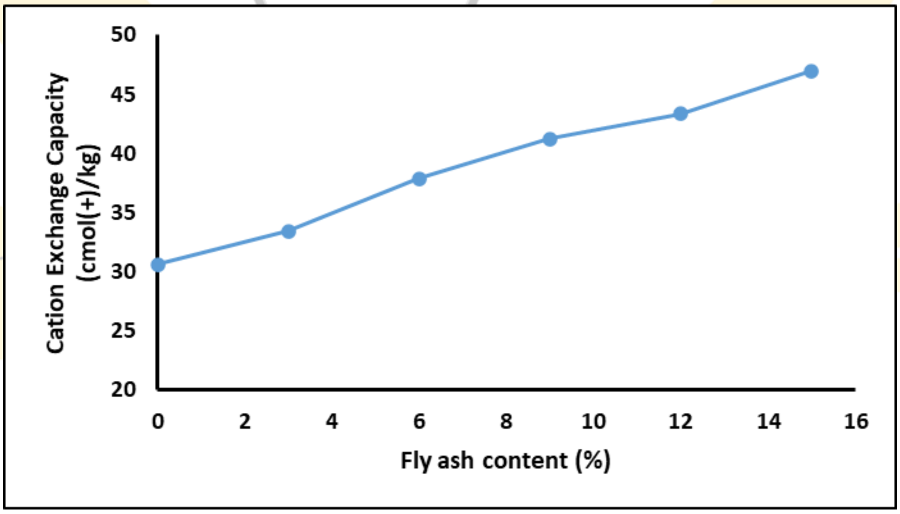

Figure 5: Relationship between CEC with 6% limestone and variation of fly ash content.

more significant increase in CEC due to its greater contribution of exchangeable cations (Matha *et al.*, 2017). This result agrees with the outcome of research carried out by Matha *et al.* (2017) which reported an increase in cation exchange capacity with increase in fly ash content.

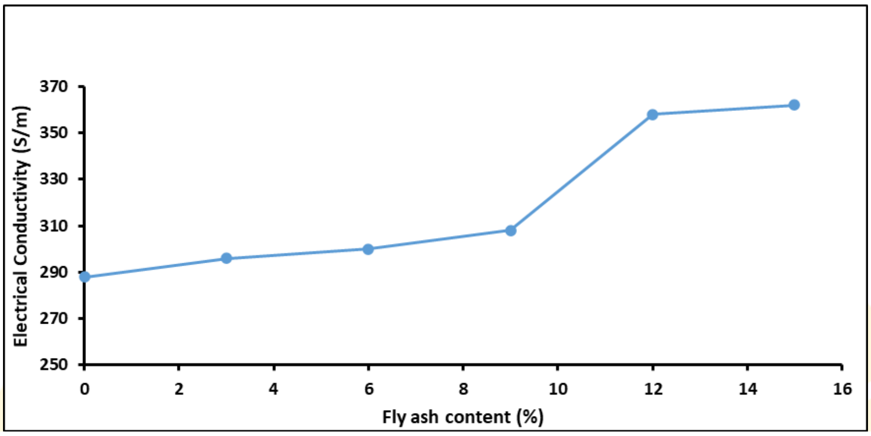

Figure 6: Relationship between EC with 6% limestone and variation of fly ash content.

Similarly, Figure 6 shows that the EC increases from 288 S/m to 362 S/m with the addition of varying proportions of fly ash with constant 6% limestone content, indicating an increase in the concentration of dissolved ions in the soil solution. Fly ash contains soluble salts, contributing to the rise in electrical conductivity. As the proportion of fly ash increases, the concentration of soluble salts also increases, leading to higher EC values.

4.0 Conclusion

The A-7-5 grade of lateritic soil used in this study was stabilized with 6% optimum limestone and fly ash (0-15%) content. Based on this study, the following conclusion were deduced;

- The lateritic soil used was determine to be A-7-5 and MH under ASSHTO and USCS classification respectively with a specific gravity of 2.63.
- The addition of predetermined optimum 6% limestone increased the liquid limit to 53% from 51.50%, whereas a 15% addition of fly ash resulted in a decrease to 50%. Plasticity index (PI) exhibited a similar trend. The Linear shrinkage decreased with increase in FA and constant 6%LS
- The soil specific gravity recorded decrease with increase in FA content, having the minimal value recorded at 15% FA.
- The experimental findings also demonstrated notable trends in respect of soil properties such as PH, CEC and EC upon the addition of limestone and fly ash. For example, the pH of the soil gradually increases with the inclusion of 6% limestone alone, and further rises with the addition of varying proportions of fly ash, owing to their neutralizing and alkaline properties, respectively.
- Similarly, the cation exchange capacity (CEC) shows an increasing trend with both limestone and fly ash additions, indicating a higher exchangeable cation content in the soil.
- The electrical conductivity (EC) rises proportionally with the addition of fly ash, suggesting an increase in dissolved ion concentration, attributable to the soluble salts present in fly ash.

Based on data obtained, more elaborate investigation should be conducted on the use of limestone and fly ash for lateritic soil stabilization. Also, consideration should be given on other important properties of soil such as strength, durability, swelling potential, hydraulic conductivity and other valuable characteristics of soil.

Conflict of Interest

The Authors declares no conflict of interest.

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