**Investigation of Selected Geotechnical Properties of Excavated Subgrade Stabilized with Fly Ash for Reuse as Subbase**

**ABSTRACT**

Lateritic soil is among the most commonly used materials for road construction. However, constructing roads withpoor lateritic soil is one of the causes of road failures in Nigeria resulting in loss of lives and properties. Therefore, this study investigated fly ash as a stabilizing agent for excavated subgrade for reuse as subbase. Soil samples were obtained at depths of 1 m and distances of 10 m along Sango-Ota-Owode expressway at right hand and left hand sides of the road, while fly ash was purchased from Nigerian Building and Road Research Institute (NBRRI), Ota, Ogun State, Nigeria. Fly ash was characterized for its oxides in Central Research Laboratory, Bells University of Technology (BELLSTECH), Ota using the United States Environmental Protection Agency (2001) standards. Fly ash was added to excavated soil samples at 2%, 4% and 6% by dry weight of the soil respectively and selected geotechnical (particle size distribution, compaction, California bearing ratio and Atterberg’s limits) tests were conducted onboth natural and stabilized lateritic soil samples in accordance with BS 812-102:1984, BS 812-103.1:1985 and BS 1377 part 2-4 (1990) standards. Fly ash results revealed significant amounts of SiO2, Al2O3, Fe2O3 and K2O, with other oxides present in trace amounts. Soil analyses revealed that as percentage addition of fly ash increased, there was corresponding improvement in analyzed geotechnical parameters of soil samples at both sides of the road, thereby confirming the efficacy of the fly ash. Results also revealed that the percentage addition of fly ash that produced the optimal stabilization value was 4%. This study concludes that fly ash is a good stabilizing agent for excavated subgrade to be reused as sub-base. This study recommends futurereuse of fly ash in construction activities of related nature.

**KEYWORDS**- Lateritic soil, Soil stabilization, Fly ash, Geotechnical investigation, Subgrade, Subbase

**INTRODUCTION**

Soil is defined soil as a naturally occurring organic material that has unique mechanical properties which makes it agreeable and malleable to handling for various construction works such as construction of buildings, roads and bridges (Amanamba *et al*., 2021). Furthermore, soil is one of the most commonly used engineering materials for various building and construction purposes especially lateritic soils (Padalkar *et al.,* 2017). However, the properties of soil vary according to parent material, origin, formation, time, location and prevailing weather or environmental conditions. These factors to a large extent affect the engineering properties of soil. A common example of soil is laterite which is mostly used for filling during road construction (Padalkar *et al.,* 2017). Lateritic soils are formed from extensive weathering of pre-existing rocks in the tropical regions of the world with high temperatures and rainfall but have not been subjected to transportation (Okeke*et al*., 2011; Ehujuo *et al*., 2017; Ogbuchukwu *et al*., 2019). Lateritic soils are generally rich in secondary aluminium and iron oxides with red, reddish-brown or dark brown colour (Amadi, 2010; Nayak *et al*., 2019; Aderinlewo, 2020).

By virtue of its formationinitiated through intense temperature and rainfall over the years, as well as alternating the wet and dry seasons of the region, lateritic soilnaturally becomesweakhaving engineering properties such as high plasticity, poor workability, low strength, high permeability, high water retention, absorption capacity and high natural moisture content (Aderinlewo *et al*., 2020). In addition, lateritic soils contain less than 30% silt, liquid limit between 25 and 63% and plasticity index between 5 and 42% (American Association of State Highway and Transportation Officials) (AASHTO) (2013); Jaja *et al.,* (2023). This clearly shows that lateritic soils are naturally weak as engineering materials and are in need of enhancement or stabilization before use for various engineering or construction purposes. Due to the mechanical properties of lateritic soil coupled with the climatic and environmental conditions of the regions where these materials are naturally abundantly available and used for various construction purposes, they require modification or stabilization before application. The moisty and wet conditions of the soils in these tropical climatic regions makes handling difficult and are not easily amenable. Hence, the obvious need for stabilization, enhancement or modification (Aderinlewo *et al*., 2020).

Early studies on geotechnical properties and performance of lateritic soil as an engineering material reported it as a poor aggregate unfit for use for pavement (Terzaghi and Robertson, 1958; Nanda and Krishnamachari, 1958). However, recent studies showed that most engineers eliminate the poor or weak soil samples while utilizing the good ones as well as stabilizing the intermediate ones (Amanamba *et al*., 2022). Soil stabilization is referred to as the process of increasing the strength, reducing the permeability or improving the groundwater condition of poor lateritic soils (Elmashad and Hafez, 2017; Onyelowe *et al*., 2019 and Onyelowe *et al*., 2021). In a related study, soil stabilization was defined as the process of enhancing the performance and output of problematic soils as well as intermediate soils in order to transform them into better engineering materials (Marathe *et al.,* 2015). Also, lateritic soils that are difficult to handle in moist and wet conditions are referred to as problematic soils (Amadi, 2010). Furthermore, cement (Ordinary Portland Cement), lime, fly ash, coir fibres, gypsum, pulverised wood charcoal and quarry dust are common examples of chemicals, materials or admixtures that are used for stabilization in order to improve the engineering properties of the soil (Padalkar *et al.,* 2017; Nayak *et al*., 2019; Adeleke *et al.,* 2019; Aderinlewo *et al*., 2020; Rusdi and Daud, 2022; Amanamba *et al*., 2022; Jaja *et al.,* 2023).

Furthermore, lateritic soils are expansive soils having high shrinkage and swelling tendencies especially when exposed to high temperature. In order to reduce the shrinkage, swelling and plasticity indices of expansive lateritic soils, chemical admixtures are blended and added to the soils before use as subgrade or subbase during road construction. Civil engineers and project managers in the bid to reduce cost of construction often use locally sourced materials for soil stabilization because they are cheaper and readily available in large quantities. A large percentage of these materials are mostly derived from agricultural residues or industrial by-products that produce cementitious compounds on exposure to moisture. It is therefore important to conduct geotechnical investigation of construction materials, especially lateritic soils before they are applied for filling during road construction.Studies have reported that one of the major causes of road accidents in Nigeria is poorly constructed road; this has been attributed to wrong use of construction materials or use of substandard construction materials such as defective lateritic soil for subgrade or subbase (Oke *et al*., 2009a; Nwankwoala *et al*., 2014). Unfortunately, in order to reduce cost of construction, civil engineers and construction companies oftenengage in unprofessional practices and evenintentionally fail to conduct geotechnical investigation of construction materials that will reveal the mechanical properties of these materials before applying them.

Similarly, some construction companies tend to overlook the importance of geotechnical investigation and only conduct the investigation as a mere academic exercise. This has contributed immensely to high incidence of road accidents, building collapse and eventual loss of livesand property (Ayeni and Adedeji, 2015; Esonanjor *et al.,* 2022). A major attribute of materials used as base or subbase is its ability and strength to transfer axle load to the sub-soil or the subgrade; that is, the efficiency and durability of a construction material is determined by its ability and capacity to respond positively to the load or pressure it is subjected to (Oke *et al*., 2009b; Nwankwoala and Amadi, 2013). In a related study, it was reported that the mineralogical composition of a lateritic soilsample to a large extent influences the major geotechnical parameters of that soil such as specific gravity, shear strength, swelling potential, Atterberg limits, bearing capacity and petrographic properties (Amadi *et al*., 2012). Over the years, Nigeria has seen a gradual increase in the cases of newly constructed roads developing cracks and serious damage. A study conducted in Minna, Nigeria reported the worrisome state of many newly constructed roads in the city. The study through geotechnical investigation of samples taken attributed the cracks and serious damages seen on roads in Minna metropolis to use of weak lateritic soils during road construction (Amadi *et al*., 2015).

Consequently, this study embarked on the investigation of selected geotechnical properties of lateritic soil samples taken at different sections of Bells University/Covenant University/Idiroko road, along Sango-Ota-Owode expressway Ogun State, with the aim of determining the properties of the soil samples used as subgrade. This was done to provide baseline information of soils in this area and to determine the efficacy of fly ash as a stabilization agent. The lateritic soils were stabilized with fly ash generated from by-products of industrial wastes. This became imperative because of the reported deplorable conditions of the roads in Sango-Ota community, especially the Sango Ota-Owode Expressway (Akanbi *et al*., 2021). The study noted that the roads (flexible pavements) in the study area have become unserviceable with many deformations and deterioration seen across many sections of the roads. Consequently, this study area was selected because it is an industrial area and this particular section of the city is one of the busiest routes, due to the regular industrial activities and presence of two private universities (Bells University of Technology and Covenant University).

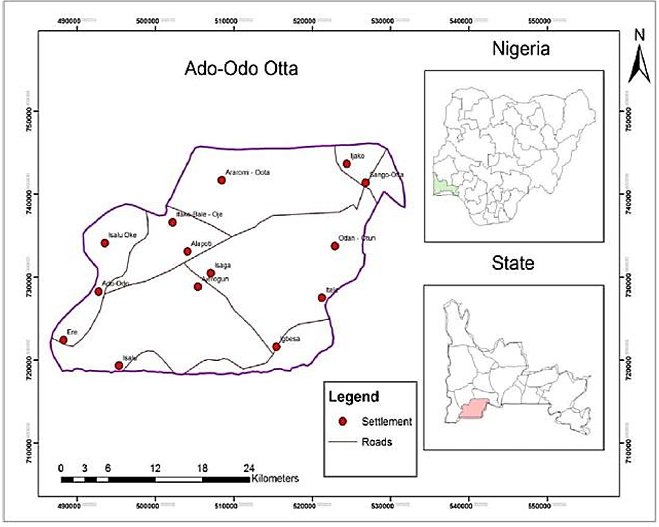
The presence of many articulated and other private vehiclesresulted inincreased trafficvolume experienced on the road, thereby contributing significantly to the deplorable conditions of the road.Therefore, this study investigated the possibility of improving the engineering properties of the excavated lateritic soil (subgrade) with fly ash by enhancing its geotechnical properties for reuse as subbase. The geotechnical properties of the subgrade soil samples taken were determined in their natural state. In addition, the properties/oxide composition of fly ash was determined. Furthermore, the strength and index properties of fly ash stabilized lateritic soil were evaluated at 2, 4 and 6 percentages by dry weight of the soil. Finally, the percentage replacement with fly ash that produced optimal engineering properties was determined.

**MATERIALS AND METHODS**

**Study Area**

The lateritic soil samples collected for this study were taken at depths of 1 m and distances of 10 m along Sango-Ota-Owode expressway. This is one of the busiest routes in Sango-Ota as it is the road that links Idiroko border; there is also the presence of two private universities and notable industrial firms along the road. Hence, the large number of vehicular activity as well as volume of traffic. Sango-Ota is located in Ado-Odo/Ota Local Government Area, Ogun State; it is the second largest local government in Ogun State with its headquarter in Ota (Idoko *et al*., 2020). The town is located within longitudes 6038’ and 6044’ north of the Greenwich Meridian and latitudes 3002’ and 3014’ east of the equator as shown in Figure 1 (Akanbi *et al*., 2021; Enyoh *et al.,* 2021). This road is equally important because it is the expressway linking Nigeria with Benin Republic notable for transportation of goods and services.

The road pavement is flexible in structure; the surface is made of asphalt, stone base material, subbase and subgrade courses (Akanbi *et al*., 2021). Ota is bounded in the North by Egbado and Ifon, Ipokia to the West, Ojo and Badagry to the South and Alimosho and Ifako-Ijaye to the East (Idoko *et al*., 2020). It has an elevation of 53m above sea level and it belongs to the tropical rain forest with two distinct seasons (rainy/wet and dry seasons) (Enyoh *et al.,* 2021). The rainy season lasts for about 7 to 8 months between April and October with a break in August, while the dry season lasts for about 5 months between November and February. The number of rain days exceeds 90 days and annual precipitation is about 250 cm with atmosphere well saturated with moisture. The mean annual rainfall in the Southern part of the town is 2,000mm which differs from that of the Northern part (1,500mm); annual relative humidity is between 80 and 85% (NiMET, 2016). The average monthly temperature is about 180C, while the average daily temperature ranges between 200C and 290C for most parts of the year(Ufoegbune *et al*., 2016).



**Figure 1**: Map of Ado-Odo/Ota Local Government Area, Ogun State

**Source**: (Ogunyemi *et al*., 2017)

The underlain geology of Ota is similar to that of Ogun State which is majorly composed of rocks from the pre-Cambrian age and younger rocks (Ufoegbune *et al*., 2016), with crystalline and gneiss as the rocks lying beneath the surface (Idoko *et al*., 2020).

**Fly Ash Sampling and Characterization**

The fly ash used for this study was purchased at the Nigerian Building and Road Research Institute (NBRRI), Ota, Ogun State, Nigeria. The fly ash was characterized in the laboratory using the United States Environmental Protection Agency (2001) standards to determine its constituent oxides and ultimately, its fitness for use as a soil stabilizing agent.

**Lateritic Soil Samples Collection**

Lateritic soil samples for this study were obtained at depths of 1 m and distances of 10 m along Sango Ota-Owode expressway, Ota, Ogun State respectively. The simple implements used for the digging and collection of the soil samples were hand auger, shovel and the wheel barrow which was used to transport the samples from one point to another on the site. Two soil samples each were obtained from the subgrade layer of the right-hand side and the left-hand side of the completed portions of the road to be stabilized with the fly ash. Thereafter, the soil samples were immediately transferred into improvised sacks and transported to the highway and geotechnical laboratory of the Department of Civil and Environmental Engineering, Bells University of Technology, Ota, Ogun State for the laboratory analyses of all the soil samples obtained. This immediate transfer of soil samples was done in order to appropriately preserve the natural properties of the soil samples and also carry out the laboratory analyses of some of their geotechnical parameters.

**Laboratory Analyses of the Stabilized Lateritic Soil Samples**

The lateritic soil samples were stabilized with the fly ash sample at 2, 4 and 6 % by dry weight of the soil samples respectively for both the right-hand side and left-hand side respectively, with the 0% being the control samples for both sides of the road respectively. Consequently, the stabilized soil samples were subjected to the analyses of their selected geotechnical parameters such as; particle size distribution analysis, compaction, California bearing ratio and Atterberg’s limits tests. The tests were carried out in accordance with the procedures outlined in BS 812-102:1984, BS 812-103.1:1985 and BS 1377 part 2-4 (1990) on both natural and stabilized lateritic soil samples respectively.

**RESULTS AND DISCUSSION**

The data obtained from the laboratory analysis of the fly ash and the lateritic soil samples from both the right hand and left hand sides along the Sango Ota-Owode expressway, Ota, Ogun State are hereby presented accordingly. The results of fly ash obtained revealed that Calcium Oxide, Silicon Dioxide, Aluminium Oxide, Iron (III) Oxide, Magnesium Oxide, Sulphur Trioxide, Sodium Oxide, Potassium Oxide and Loss of Ignition values were 0.9%, 57.65%, 19.28%, 10.11%, 0.8%, 0.03%, 0.39%, 1.55% and 11.29% respectively. These results which are in agreement with the findings of the American Society for Testing and Materials (1978) confirm the efficacy and fitness of the fly ash as a stabilization agent.

**California Bearing Ratio**

The results of California bearing ratio are as shown in Table 1. The results obtained for the 0% addition of fly ash of both the right and left hand sides of the road fell below the maximum of 10% and minimum of 3% for materials recommended by the British Standards. This is probably what accounted for some of the failures observed at this portion of the road. The recommended CBR value of >10% was not satisfied on both sides of the road. The results also fell below the Nigerian Specification for Road and Bridge Materials which stipulated that the recommended value of lateritic samples for CBR should be greater than 80 %. However, there was a noticeable increase in the CBR values of the second, third and fourth samples after the addition of 2%, 4% and 6% of fly ash to the soil samples. These results are in agreement with the findings of a related study where an appreciable increase in the analyzed values of stabilized lateritic soil using fly ash was recorded (Karthik *et al.,* 2014).

Therefore, the data obtained showed that the stabilized soil samples for both sides of the road satisfied the minimum requirements as prescribed by the British Standards (B.S), but not the maximum. These results also reinforce the significant roles that the bearing capacity of lateritic soils play in the eventual survival or collapse of the roads to be erected on the soil, because the higher the shear strength of any soil material, the better its bearing capacity. When the bearing capacity of the soil is high enough, the durability of the roads built on it is guaranteed. This also agrees with the findings of Adeonile (2017) where the study evaluated the failed sections of selected roads in Southwest Nigeria. The study established a strong connection between the poor bearing capacity values and the failure of the road sections investigated. The results also showed that for the soil samples to meet the maximum requirements for British Standards, a comprehensive stabilization effort which will significantly improve the CBR status of the road beyond the data obtained for this study is required. This will provide more certainty for all road users and more importantly, become a reference point for other roads with similar situations in the community.

**Compaction**

The results of the compaction tests which were carried out to determine the optimum moisture content (OMC) values and the maximum dry density (MDD) values of the soil samples as obtained are presented in Table 2. The soil samples from the natural and stabilized soil samples recorded MDD values that alternated between failure and pass when compared with the specifications of the B.S standards for MDD. Also, the results indicated that some of the soil samples met the specifications for OMC especially at 4% and 6% additions of fly ash for both sides, because some of the samples analyzed presented results that were below the 12.02 percent limit. Furthermore, these results agreed with the findings of an earlier study where a 25% significant increase in the analyzed values of stabilized lateritic soil using fly ash was recorded, when compared with the natural soil (Gyanen *et al.,* 2013).

The compaction value of a lateritic soil sample is significant because it reveals how well the pores and voids of the soil have been eliminated (Adama and Jimoh, 2012). Similarly, an acceptable compaction value (compaction value which falls within British Standards) also shows how well the granular materials of the soil sample have responded favorably to the repetitive mechanical blows of the compaction rammer. The study further mentioned that when a soil sample fails compaction analysis or is not thoroughly compacted, the soil material is prone to swelling under the influence of moisture. This will inevitably result in the failure of the lateritic soil and worse still, the eventual failure of the road. This is particularly true for flexible pavement roads which are the type of pavements prevalent in Ota community and Ogun State in general.

Consequently, well graded soils are often preferred to uniformly graded soils during road construction because they usually contain a wide range of soil particles making it easier for the soil particles to be interlocked after compaction. Uniformly graded soils usually contain soil particles of similar sizes having larger voids, which results in poor compaction and lower shear strength (Adama *et al.,* 2013). This is why pneumatic rollers have been recommended by relevant national (Federal Ministry of Works and Housing, 1997) and international regulatory agencies (American Society for Testing and Materials, 1992) for compaction activities during road construction, especially the subbase and surface courses.

**Atterberg’s Limits Tests**

This comprises the liquid limit, plastic limit and plasticity index properties of the soil with fly ash at 2, 4 and 6% respectively as shown in Table 3. The result shows that the value for the liquid limit for the natural soil is 35%, plastic limit is 20%, and plasticity index is 15%. Therefore there is decrease in the liquid limit throughout the stabilization and there is also a decrease in plasticity index throughout the stabilization. As such, when compared with the B.S specifications, soil samples from both the right hand and left hand sides were within the stipulated standards of 35% for subgrade, 35% for sub-base, and 30% for base, respectively. These results are also in agreement with the findings of an earlier study which reported that the liquid limit results of the study reduced to 55% (20% for fly ash stabilization and 25% for rice husk ash stabilization, while the plasticity index reduced to 86% (20% for fly ash stabilization and 25% for rice husk ash stabilization) (Anil and Sudhanshu, 2014).

Furthermore, the differential free swell of the analyzed soil samples reduced to 75% (15% for fly ash and 20% for rice husk ash). Atterberg’s limits tests help road design engineers determine the plasticity of a particular soil material and how it will behave under different soil conditions.

**Table 1**: California Bearing Ratio Values at 0, 2, 4, and 6% addition of fly ash at both right-hand side and left-hand side

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Penetration Loading | Load Reading at 0% addition (RHS) |  | Load Reading at 2% addition (RHS) | Load Reading at 4% addition (RHS) | Load Reading at 6% addition (RHS) | Load Reading at 0% addition (LHS) | Load Reading at 2% addition (LHS) | Load Reading at 4% addition (LHS) | Load Reading at 6% addition (LHS) |
| 0.5 | 11.3 |  | 12.7 | 12.8 | 11.8 | 2.1 | 12.9 | 12.1 | 13.7 |
| 1 | 13.5 |  | 13.9 | 14.9 | 13.3 | 3.0 | 14.4 | 13.9 | 15.5 |
| 1.5 | 15.2 |  | 14.8 | 16.8 | 15.8 | 4.1 | 15.8 | 15.1 | 16.7 |
| 2 | 16.0 |  | 16.7 | 18.1 | 16.4 | 5.8 | 19.9 | 15.9 | 18.1 |
| 2.5 | 17.9 |  | 17.2 | 20.5 | 18.1 | 6.9 | 22.8 | 17.6 | 19.2 |
| 3 | 18.3 |  | 19.3 | 18.2 | 20.2 | 8.5 | 24.8 | 18.4 | 22 |
| 3.5 | 20.1 |  | 21.4 | 20.7 | 21.4 | 9.1 | 25.4 | 20.3 | 24.6 |
| 4 | 22.3 |  | 23.6 | 22.3 | 22.6 | 11.5 | 26.9 | 22.2 | 25.9 |
| 4.5 | 23.6 |  | 25.9 | 25.6 | 24.1 | 12.3 | 27.6 | 23.7 | 27.4 |
| 5 | 24.9 |  | 27.2 | 28.2 | 25 | 14.2 | 29.9 | 25.9 | 28.9 |
| 5.5 | 27.8 |  | 28.4 | 29.7 | 26.1 | 15.1 | 32.4 | 27.5 | 30.9 |
| 6 | 29.4 |  | 30.2 | 31.6 | 27.2 | 16.8 | 33.8 | 28.2 | 32.4 |
| 6.5 | 30.3 |  | 33.8 | 33.2 | 29.1 | 17.5 | 36.6 | 30.9 | 34.1 |
| 7 | 32 |  | 34.2 | 36.9 | 32.3 | 18.9 | 37.3 | 32.8 | 35.8 |
| 7.5 | 34.4 |  | 36.5 | 38.1 | 34.4 | 20.3 | 38 | 36.4 | 36.4 |

**Table 2**: Compaction Results at 0, 2, 4, and 6% addition at both right-hand side and left-hand side

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Compaction Results At 0, 2, 4 and 6% Addition at Right-Hand Side | | | | | | | | Compaction Results at 0, 2, 4 and 6% Addition at Left-Hand Side | | | | | | | |
| OMC (%) at 0% | MDD (mg/m3) at 0% | OMC (%) at 2% | MDD (mg/m3) at 2% | OMC (%) at 4% | MDD (mg/m3) at 4% | OMC (%) at 6% | MDD (mg/m3) at 6% | OMC (%) at 0% | MDD (mg/m3) at 0% | OMC (%) at 2% | MDD (mg/m3) at 2% | OMC (%) at 4% | MDD (mg/m3) at 4% | OMC (%) at 6% | MDD (mg/m3) at 6% |
| 12.5 | 1.34 | 13.1 | 1.22 | 15.1 | 1.14 | 16.2 | 1.47 | 17.5 | 1.53 | 22.45 | 1.38 | 3.5 | 1.2 | 21.2 | 1.24 |
| 13.2 | 1.45 | 13.9 | 1.34 | 15.5 | 1.23 | 16.7 | 1.55 | 17.9 | 1.58 | 23.56 | 1.46 | 3.1 | 1.65 | 23.4 | 1.85 |
| 14.4 | 1.48 | 14.5 | 1.45 | 16.3 | 1.43 | 17.4 | 1.68 | 18.4 | 1.63 | 24.98 | 1.55 | 5.4 | 1.72 | 25.2 | 2.15 |
| 15.3 | 1.53 | 15.3 | 1.58 | 17.1 | 1.56 | 17.9 | 1.72 | 19.2 | 1.71 | 26.5 | 1.71 | 11.8 | 1.88 | 26.7 | 2.75 |
| 16.5 | 1.78 | 15.9 | 1.68 | 18.0 | 1.67 | 18.6 | 1.78 | 19.7 | 1.75 | 27.2 | 1.69 | 9.6 | 1.81 | 27.5 | 2.54 |
| 17.8 | 1.64 | 16.4 | 1.62 | 18.6 | 1.51 | 19.3 | 1.69 | 20.5 | 1.65 | 28.2 | 1.62 | 15.5 | 1.91 | 28.4 | 2.32 |
| 18.4 | 1.57 | 17.2 | 1.54 | 19.2 | 1.42 | 19.9 | 1.63 | 21.3 | 1.61 | 29.5 | 1.57 | 16.9 | 1.99 | 29.5 | 1.82 |
| 19.3 | 1.43 | 17.7 | 1.48 | 19.9 | 1.23 | 20.6 | 1.56 | 22.4 | 1.56 | 30.4 | 1.52 | 12.1 | 1.87 | 30.4 | 1.45 |

**NOTE**: OMC represents optimum moisture content while MDD represents maximum dry density

Therefore, having a right understanding of how the soil material will behave under liquid, plastic or shrinkage limit conditions can also reveal details such as whether the soil will be prone to volume changes, deformation or even cracking in the near future (Ankit *et al.,* 2013). As such, the high value obtained for the liquid and plastic limits of the soil before stabilization confirm that the soil is prone to volume changes, deformation or even cracking. Furthermore, the analysis of the stabilized soil showed that there was a marginal improvement in the liquid limits, plastic limits and plasticity indexes of both the right and left hand sides of the road.

**Table 3**: Summary of Liquid Limit, Plastic Limit and Plastic Index Properties

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Percentage of Fly Ash (%) | Liquid Limit RHS (%) | Plastic Limit RHS (%) | Plasticity Index RHS (%) | Liquid Limit LHS (%) | Plastic Limit LHS (%) | Plasticity Index RHS (%) |
| 0 | 35 | 20 | 15 | 34 | 20 | 14 |
| 2 | 35 | 22 | 13 | 35 | 21 | 14 |
| 4 | 32 | 23 | 9 | 33 | 22 | 11 |
| 6 | 33 | 20 | 13 | 33 | 20 | 13 |

**Particle Size Distribution Analyses**

The particle size distribution analysis results are presented in Table 4 showing that the mass lost for the right hand side was 2.81g, while that of the left hand side was 0.18g. Furthermore, according to British Standard, the percentage by weight that must pass the sieve No.200 must be lower than 35% for any lateritic soil that will be used as material for road construction. Therefore, the results obtained from the analysis satisfied the standard. Furthermore, when the results obtained for particle size distribution analysis are compared with the Nigerian Specification for Road and Bridge Materials, the results revealed that the soil sample largely satisfied the requirements. However, the results further revealed that the soils are already prone to swelling/expansion and mild shrinkage. Therefore, the soil samples according to the Nigerian Specification for Road and Bridge Materials are still suitable for use as materials in road construction. Similarly, the results obtained according to the AASHTO classification confirms that the soil samples fall within the A-7-C subgroup, with group indexes 0 and 2 respectively, indicating the presence of silty or clayey gravel and sand.

This is in agreement with an earlier study conducted using rice husk ash for stabilization of lateritic soil for reuse as sub-base in road construction (Alabi *et al.,* 2015). The particle size distribution analysis of a soil material can also be used to predict other geotechnical properties like compaction or bearing capacity. This is because a well graded soil material will most likely also satisfy the 35% minimum particle size distribution requirement for soil to be used as subbase. Furthermore, when a soil material is well graded, it also means it contains a variety of soil particles, which will ultimately guarantee even distribution of the particles on the sieve aperture sizes often used for particle size distribution analysis (Aparna, 2014). As such, the compaction results of a soil sample may be used to validate the results of the particle size distribution analysis of the same soil sample.

**Table 4**: Results of the Particle Size Distribution Analysis at Right Hand and Left Hand Sides

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Sieve Diameter (mm and µm) | Weight Retained (g) RHS | Percentage Retained (%) RHS | Percentage Passing (%) RHS | Weight Retained (g) LHS | Percentage Retained (%) LHS | Percentage Passing (%) RHS |
| 4.75 mm | 24.55 | 2.45 | 97.51 | 34.2 | 3.42 | 96.5 |
| 3.35 mm | 34.2 | 3.42 | 93.99 | 34.59 | 3.4 | 92.99 |
| 1.18 mm | 182.9 | 18.2 | 75.75 | 161 | 16.1 | 76.95 |
| 500 µm | 349.5 | 35 | 40.70 | 318.98 | 31 | 45.04 |
| 425 µm | 59.24 | 5.9 | 34.91 | 54.18 | 5.42 | 39.77 |
| 300 µm | 114.9 | 11.4 | 23.29 | 124.2 | 12.42 | 27.2 |
| 212 µm | 44.11 | 4.41 | 18.87 | 48.2 | 4.82 | 21.93 |
| 0.075 mm | 152.8 | 15.3 | 3.57 | 182.88 | 18.3 | 3.9 |
| Receiver | 34.8 | 3.4 | 0.10 | 40.93 | 4.93 | 0.8 |
| Total | 997 | 99.48 |  | 999.16 | 99.81 |  |

**CONCLUSIONS AND RECOMMENDATION**

Based on the findings from the study, the following conclusions are drawn:

1. Fly ash is a good stabilizing agent for excavated subgrade, classified as a class C stabilizing agent according to ASTM (1978) and characterized with adequate Silicon Dioxide, Aluminium Oxide, Iron (III) Oxide and Loss of Ignition values of 57.65%, 19.28%, 10.21% and 11.29% respectively.
2. As percentage addition of fly ash increased, there was noticeable improvement in the analyzed geotechnical parameters of the soil samples, indicating the efficacy of the fly ash
3. The percentage addition of fly ash that produced the optimum strength parameter was 4%

Consequent upon the results of this study, it is therefore recommended that adopting 4% addition of fly ash as a stabilizing agent for excavated subgrade to be reused as subbase material is effective.

**Disclaimer (Artificial intelligence)**

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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