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# Lateritic Soil Stabilized with Fly Ash as a Sustainable Structural Material for Flexible Pavement Construction

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**ABSTRACT**
This paper describes a laboratory study conducted to evaluate the improvement in engineering properties relevant to highway design and construction that can be obtained when fine grained lateritic soil is stabilized with fly ash obtained from coal fired electric power plants. The experimental program included sieve analysis of soil sample; Atterberg limits tests, compaction, Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) tests on soil mixtures prepared with fine-grained lateritic soils at 0, 5, 10, 15 and 20% fly ash content. Specimens for UCS and CBR tests were prepared at optimum moisture content and cured for 28 days. The Nigerian General specification for Roads and Bridges and U.S Army Corps of Engineers unconfined compressive strength criteria were used for judging the performance of the soil mixtures. Test data showed that the addition of fly ash led to substantial enhancement of the soil, satisfying the Atterberg limits criteria used by regulatory agencies to assess performance of stabilized pavement materials. While all the lateritic soil - fly ash mixtures met the CBR and UCS criteria for subgrade construction, only mixture containing 10% fly ash satisfied the requirement for sub base layer. The CBR and UCS requirement for use as base course was not met in any soil mixture.

**Keywords:** *Fly ash, Lateritic soil, Pavement layers*

## 1. INTRODUCTION

As a consequence of economic growth, road traffic is increasing in vehicle numbers and in axle loads in all parts of the world. This requires extension of the road network which invariably demands large amounts of materials with good structural performance and a long service life below the asphalt or concrete. Each year, tons of these materials which require mining, quarrying, and transportation are consumed in this country for construction.

Quite often, most of the areas where these projects are executed are covered with fine grained lateritic soils that exhibits insufficient engineering properties needed to provide structural support for the imposed loads during usage and loads from construction equipments (Amadi, 2011).

Lateritic soils, a highly weathered soil type rich in iron and aluminum are distributed in many parts of the world. Some low grade lateritic soils with high percentage of fines content present many problems in road construction and maintenance (Gidigasu, 1976). Nevertheless, the use of the soil in pavement construction offer numerous benefits such as reducing the need for quarrying and transportation of natural aggregate, which saves construction costs and energy consumption.

The properties of these soils can be improved by addition of a stabilizing agent. Among the various stabilizing agents available, lime, fly ash and cement are most widely and commonly used to accomplish this need. Many of these treatments can significantly improve the strength, stiffness, durability, permeability and stability of host materials to allow them to support the load from the structure above them (Amadi, 2013). To reduce the cost of soil improvement and for sustainable development, the replacement of cement by fly ash is one of the best alternative ways (Nicholson and Kashyap, 1993; Arora and Aydilek, 2005; Amadi, 2013).

Fly ash is the by-product produced by coal-burning electricity generating power plants. It contains siliceous and aluminous materials (pozzolans) and also certain amount of lime. Depending on the source and composition of the coal being burned, the components of the resulting fly ash vary considerably, but all fly ash contains substantial amounts of silica ($SiO_2$) and free lime ($CaO$).

When mixed with soils, it reacts chemically and forms cementitious compounds. As pozzolans, fly ash can provide an array of divalent and trivalent cations ($Ca^{2+}$,$Al^{3+}$,$Fe^{3+}$etc) under ionized conditions that can promote flocculation of dispersed clay particles. Several chemical reactions that occur when fly ash is mixed with clay namely cation exchange, flocculation/agglomeration of the soil particles and pozzolanic reaction are responsible for stabilization.

A number of researchers have investigated the use of fly ash in stabilizing weak soils. While Cokca (2001) studied the effect of fly ash on expansive soils, concluded that fly ash can be recommended as an effective stabilizing agent for the improvement of expansive soils, Ferguson (1993) has shown that the addition of 16% self-cementing fly ash increases the soaked CBR values of heavy clay soils into the mid 30s, which is comparable to gravelly sands (Rollings and Rollings 1996). Also Zia and Fox (2000) found that the CBR of loess increased five times with the addition of 10% fly ash, but an ash addition rate of 15% showed lower CBR than the 10% mixtures. On the other hand, unconfined compressive strengths of soils stabilized with self-cementing fly ash according to Ferguson (1993) as well as Ferguson and Leverson (1999) are typically on the order of 100 psi, but can be as high as 500 psi at seven days, depending on ash content and ash properties.

## 2. MATERIALS AND METHODS

### 2.1 Lateritic Soil Characterization

Fine grained lateritic soil sample obtained from a borrow pit in Shika – Zaria, (Latitude 11°15' N and Longitude 7°45' E) Nigeria at about 1.2m depth was used for this study. The soil is a reddish brown sandy clayey silt. The properties of the soil sample obtained in accordance with standard procedures outlined in BS 1377 (1990) and its oxide composition determined by Atomic Absorption Spectrometer (AAS) are presented in Tables 1 and 2, respectively. Analysis by X – ray diffraction (XRD) method indicate that the clay fraction is dominated by koalinite clay mineral. The particle size distribution curve of the studied soil, presented in Fig. 1 indicate that the soil contains 57% fines (i.e., percentage passing BS No. 200 sieve) as determined by mechanical sieve analysis.

**Table 1:** Properties of the studied lateritic soil

| Property | Value |
|---|---|
| Natural moisture content (%) | 5.80 |
| Liquid Limit (%) | 42.22 |
| Plasticity Index (%) | 22.22 |
| Linear shrinkage (%) | 9.5 |
| USCS Classification | CL |
| Specific gravity | 2.76 |
| pH | 6.67 |
| Color | Reddish brown |
| Dominant Clay Mineral | Kaolinite |

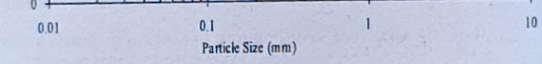


Fig. 1 Particle size distribution of lateritic soil used in the study

Typically, specifications for pavement construction limit maximum fines content (No. 200 sieve) to 35% (Nigeria General Specifications, 1997). The studied soil therefore, had fines fraction greater than the maximum suggested for pavement layers.

### 2.2 Properties of Fly Ash used in the study

The fly ash used in this study is a Class F fly ash following ASTM C 618, from Oji River thermal station in Enugu state, Nigeria. The fly ash has low calcium oxide (CaO) content (9.8%), and high silicon dioxide ($SiO_2$) content (46.02%). The specific gravity of this ash is 2.06 and as in most fly ashes is a non-plastic material. The Oxide composition of soil sample analyzed by Atomic Adsorption spectrometer (AAS) is summarized in Table 2. Only fraction passing BS sieve No. 200 was used throughout the test without additional treatment at 0, 5, 10, 15 and 20%.

**Table 2:** Oxide composition of study soil and Fly Ash

| Oxide | (%) | |
|---|---|---|
| | Lateritic soil | Fly Ash |
| CaO | 0.28 | 1.78 |
| $SiO_2$ | 35.60 | 46.02 |
| $Al_2O_3$ | 27.40 | 24.16 |
| $Fe_2O_3$ | 2.40 | 13.68 |
| MgO | 0.22 | 1.91 |
| $SO_3$ | 0.85 | ND |
| $Mn_2O_3$ | 2.00 | 0.56 |
| $K_2O$ | ND | 5.58 |
| $TiO_2$ | ND | 1.86 |
| $Na_2O$ | ND | 5.31 |
| Loss on ignition | 14.60 | 1.3 |

ND – Not determined

### 2.3 Atterberg limits and Compaction tests

The plasticity characteristics namely, liquid limit (LL), plastic limit (PL) and plasticity index (PI) and linear shrinkage (LS) as well as specific gravity of the various soil – fly ash mixtures were determined in accordance with procedures outlined in BS 1377 (1990) and 1924 (1990). For the compaction test, specimens with the relevant quantities of dry soil and fly ash (0, 5, 10, 15 and 20%) prepared at optimum were compacted with British Standard Heavy, (BSH) compactive effort in accordance with the relevant sections of BS 1377 (1990) as well as 1924 (1990).

### 2.4 CBR test

Specimens of the soils and soil–fly ash mixtures prepared at optimum moisture content were subjected to CBR testing in soaked condition following the methods described in the relevant sections of BS 1377 (1990) and BS 1924 (1990). Prior to CBR testing, soil–fly ash specimens were left in the mould after compaction, sealed using plastic wrap, and cured at about 25°C and 100% relative humidity for 28 days. A 28-day curing period was adopted to allow sufficient pozzolanic reaction. The CBR tests on soil mixtures were conducted after the 28-day curing period and 96 hours soaking.

### 2.5 Shear strength test

The unconfined compression test was carried out in accordance with the procedures outlined in BS 1377 (1990) and 1924 (1990). The test was conducted on specimens prepared at optimum moisture content using BSH compactive effort. The compacted specimens were stored in cellophane bags and kept in a humid environment for 28 days before testing. The test was performed on cylindrical specimens with diameters of 38 mm and lengths of 76 mm, which were trimmed from the larger compacted cylinders. The samples were tested in triaxial compression test machine without applying cell pressure.

## 3.0 RESULTS AND DISCUSSION

### 3.1 General Effects of Fly Ash Treatment

#### 3.1.1 Plasticity Characteristics

One common and simple way of measuring the improvement of a granular material containing clay is by the reduction in its plasticity characteristics as measured by the plasticity index (PI). This index is a significant indicator of soil behaviour; the higher the PI, the more plastic the soil will be and the more unsuitable it will be for use in road construction. Treatment with fly ash makes such soils more granular in nature and suitable for use in engineering applications.

Test data indicate that the liquid limit (LL) of the untreated soil was 42.2% (Table 1) which increased to 29.53% for specimen containing 20% fly ash content. On the other hand, the PI decreased gradually with higher fly ash content from 22.22 for 0% fly ash content to 15.87, 12.06, 7.78 and 3.54% in the same sequence of fly ash treatment (Fig. 2). Soil mixtures containing 0-15% fly ash were classified as CL and mixture treated with 20% fly ash as ML according to USCS classification system.

To be considered effective for pavement construction, the soil mixtures must exhibit LL not greater than 35%; PI not greater than 12% (Nigerian General Specification, 1997) which indicate that only mixtures containing 10, 15 and 20% fly ash satisfied the Atterberg limits criteria.

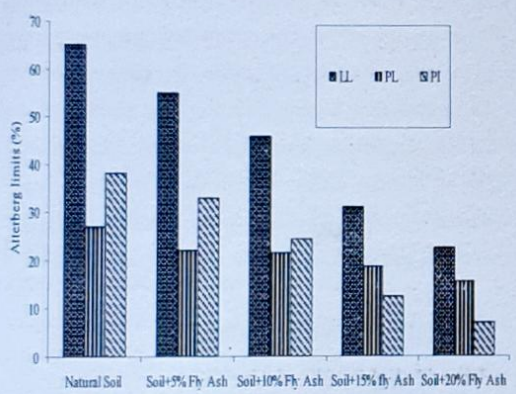


Fig. 2: Changes in Atterberg limits of studied soil with fly ash content

### 3.1.2 Compaction Parameters - Maximum Dry Unit Weight and Optimum Moisture Content (OMC)

The effect of fly ash addition on the maximum dry unit weight and optimum water content is presented in Fig. 3. The maximum dry unit weight of soil mixtures decreased slightly with corresponding increase in optimum water content as the amount of fly ash in the mixtures increased from 0 to 20%. The decrease in dry unit weight with increasing fly ash content is primarily due to the lower specific gravity of fly as which resulted in mixtures with lower specific gravity. On the other hand, the increase in OMC with higher fly ash content could be as a result of the additional water requirement for the hydration of cementitious products of soil - fly ash reaction. The optimum moisture content (OMC) ranged from 11.88% to 13% yielding dry unit weight mostly in the range 17.26 $kN/m^3$ to 18.78 $kN/m^3$.

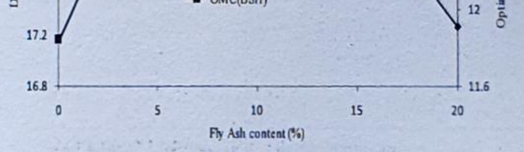


Fig. 3: Variation of maximum dry unit weight and OMC with fly ash content

### 3.1.3 California Bearing Ratio (CBR)

The CBR of the soil increased gradually with the addition of fly ash up to 10% beyond which further increase in fly ash resulted in decreasing trend in the CBR values. The value of the soaked CBR varied from 8% for unstabilized soil to 30% for stabilized soil. Improvement of the soil was provided by the matrix formed with fly ash acting as a filler and as a cementing agent.

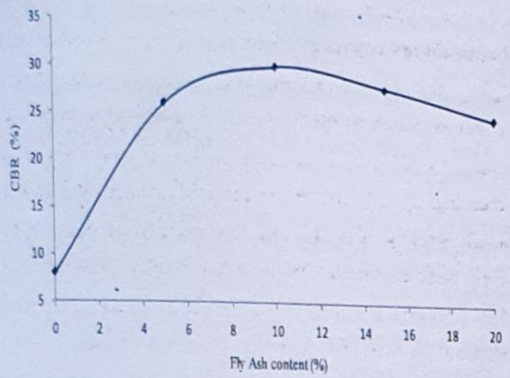


Fig. 4: Variation of CBR with fly ash content

In pavement design and construction, CBR values of 10%, 30% and 80% (standard Proctor compaction) have been adopted as criteria to be met for subgrade, sub-base and base courses, respectively (Nigeria General Specifications, 1997). The CBR requirement for subgrade was met in all the soil mixtures while the requirement for sub-base layers was only met at 10% fly ash content. All soil mixtures had CBR lower than the minimum suggested for pavement base layers.

### 3.1.4 Unconfined Compressive Strength (UCS)

The effect of addition of fly ash to the unconfined compressive strength of lateritic soil samples is shown in Fig. 5.

UCS of fly ash treated lateritic soil attained a compressive strength 2 – 3 times greater than that of the natural soil. The highest strength value of 1921.62 kn/m$^2$ was recorded on application of 10% fly ash.

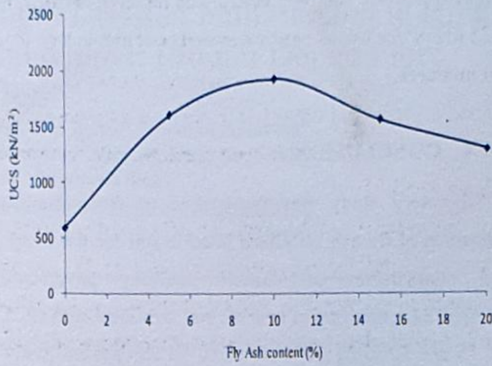


Fig. 5: Variation of UCS with fly ash content

Subsequent increase in ash content did not yield higher strength values, rather, reductions in strength values were observed. Excessive fly ash content (> 10%) behaved as low strength filler, effectively weakening the soil - fly ash mixture that led to reduction in UCS. This finding is in conformity with the results reported by zia and fox (2000). It is also important to note that strength gain was however comparatively low, probably due to the low cementing potential of the ash utilized and therefore does not possess adequate pozzolanic reactivity to fully mobilize the compressive strength of the mixtures.

Explanation for the increase in strength values with fly ash application is probably due to the coupled effects of flocculation and agglomeration of fly ash together with the neo-formations such as calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) that coats and binds the soil particles to produce strong matrices (Edil etal., 2006).

In terms of regulatory specifications, the typical minimum UCS requirement varies from around 345 kN/m$^2$ for subgrades, 1340 kN/m$^2$ for sub base layers and 5175 kN/m$^2$ for base layers (United Facilities Criteria, 2004). All soil mixtures exceeded the specification requirement for subgrade course while only specimen with 10% fly ash achieved the requisite UCS for sub base layers. The requirement of 5175 kN/m$^2$ for use as base course was not met in any soil mixtures.

## 4 CONCLUSION

A laboratory study was undertaken to determine the properties of fly ash stabilized lateritic soil for the design and construction of durable roadway pavements. Compacted specimens of lateritic soil stabilized with (0, 5, 10, 15 and 20%) fly ash were cured for 28 days and tested for unconfined compressive strength (UCS) and CBR.

In terms of plasticity, all mixtures containing fly ash were effectively improved satisfying the specification limits i.e., LL ≤ 50%, PI ≤ 35%. Moderate increases in the CBR and UCS of soil mixtures were recorded up to 10% fly ash content. The UCS requirement for a sub-base layer was met only at 10% fly ash content. However, all the lateritic soil - fly ash mixtures fall below the minimum suggested CBR and UCS for chemically stabilized base layers.

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