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Efficacy of Class-C Fly Ash as a Stabilizer for Marginal Laterites

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Key words: Marginal laterite, stabilization, class-c fly ash, California bearing ratio, unconfined compressive strength

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Abstract: Two laterites samples known for their deficiency in road construction were used to assess the efficacy of Class-C fly ash in improving their engineering properties. The two samples were taken from Danbare and Dausayi localities within Kano Metropolis and the fly ash was sourced from the Nigerian Coal Corporation, Enugu. Preliminary tests on the two samples confirmed their deficiency for use in road construction. The processed fly ash was blended with the laterite samples at 0, 3, 6, 9, 12, 15 and 18%. Hence, the treated soil samples were tested for plasticity, compaction and strength properties. Results obtained revealed reduction in plasticity properties as the fly ash contents increases. Similarly, Maximum Dry Density (MDD) decreases as the fly ash content increases while the Optimum Moisture Content (OMC) of the treated soils increased respectively for the two samples. The treated soil sample shows reasonable increment in the strength properties higher than the natural soils. Peak CBR values of 16 and 35% were obtained at 9 and 15% fly ash contents for samples 1 and 2, respectively. The unconfined compression tests showed considerable improvement in strength properties higher than the values of the natural soils. The peak 7 days strength of 630 and 1410 kN m^{-2} were observed at 12 and 15% fly ash content for samples 1 and 2, respectively.

INTRODUCTION

The exploitation and use of resources for development ultimately results in end products that are disposed off as wastes. The rate at which these end products are generated coupled with environmental issues surrounding waste disposal and the lack of disposal sites within the urban setting have made re-use of disposed materials attractive. Thus, waste items such as incinerator bottom ash, rice husk, bagasse, palm kernel, palm oil fibre among others are beneficially employed by mixing their ashes with other materials to obtain the desired properties from the mixed or blended materials[1]. Furthermore, fly ash is also disposed of as a by-product of a coal-fired power plant by either sluicing to ponds or at solid waste disposal areas. In view of the perceived composition of fly ash, it has been usefully employed as a pozzolanic material in soil stabilization[2].

It was reported by Ahmaruzaman[3] that about 0.6 billion tonnes of coal ash is produced annually with fly ash amounting to more than three-quarter of the global ash production. Hence, disposal of this waste has generated serious concern in relation to environmental safety. Enormous amount of literature exists on the sources, type, chemical composition and applications of fly ash in engineering practice some of which can be found in the review of fly ash provided by Ahmaruzzaman[3], Adriano *et al*.[4] and Iyer *et al*.[5] According to ASTM two classes of fly ash are commonly produced and are referred to as class C and F fly ashes. Class C fly ash is generally, pozzolanic, highly cementitious and is usually produced as a by-product of lignite. While, class F is usually produced by burning of anthracite or bituminous coal and is typically pozzolanic. Similarly, fly ash not meeting the requirements in ASTM is also produced and these are chiefly put to non-concrete applications. Coal ash is popularly used in construction industries for many reasons some of which includes: minimization of disposal costs, freeing land which could have been used as a disposal area for other more important purposes, financial returns from the sale of the by-products and it could also replace some expensive natural resources. Fly ash finds many applications in addition to its use as a stabilizer of soils for engineering applications. These may includes the utilization of fly ash to replace cement in the production of concrete, light weight aggregate in concrete, structural/land fill material, hydraulic barriers in solid waste containment facility and other related soil improvement applications.

Recent researches suggested the use of class-C fly ash for minimizing sulphate heaves in lime-stabilized soils[6]. Similarly, Ghosh and Dey[7] examined the bearing capacity and deformation modulus of soft soil modified with reinforced fly ash and reported the feasibility of constructing roads over soft soils. It was also reported by Chauhan *et al*.[8] that strength properties of silty sand soil has substantially improved after it was stabilized with optimum amount of coal ash and fiber. Improvement in strength and reduction in hydraulic conductivity of marginal lateritic soil have been reported by Prabakar *et al*.[9], Sezer *et al*.[10]. Similar study by Cristelo *et al*.[11] stabilized a marginal soil with coal ash activated with alkaline to facilitate self compaction in earth construction. Therefore, this study examines the potentials as well as the efficiency of using fly ash in stabilizing marginal lateritic soils.

MATERIALS AND METHODS

Proprietary fly ash sample was supplied by the Nigerian Coal Corporation, Enugu State of Nigeria. Two 50 kg weight of fly ash were procured. The laterite samples were also obtained from two burrow pits known for their deficiency for road construction. The two burrow pits are located at Danbare (Sample 1) and Dausayi (Sample 2) villages in Kano which are 10 km and 12 km from Kano city Centre, respectively. The samples were collected at 1.5 m depth.

Sample preparation: Air dried soil samples were prepared by adding appropriate fly ash content to the soil and mixing thoroughly at OMC of the soil. Portion of the fly ash that passes B. S, sieve No. 200 was used in the sample preparation. Fly ash contents of 0, 3, 6, 9, 12, 15 and 18% by dry weight of the soil were used with the 0% fly ash content being used as control. The amount of water used at each stage of the sample preparation was based on the predetermined optimum moisture content of the soil samples. Hence, the soil specimens were manually prepared and careful steps were followed to have uniform mixtures of the specimens before any experiment.

Index properties: The index properties of a soil are essentially used in the classification of the soil for engineering applications. In this research, tests conducted include plasticity properties, natural moisture content, grain size analysis and specific gravity.

Standard proctor compaction: Compaction was carried out to obtain the Optimum Moisture Content (OMC) at which a given soil is compacted to attain its Maximum Dry Density (MDD). The laboratory standard proctor compaction test was performed in this study.

Unconfined compressive strength: This is another form of triaxial test in which the confining pressure is reduced to zero. Thus, the soil specimen was subjected to failure by gradual increase in axial loading. The load frame method was used in determining the compressive strength of the soil specimens.

California bearing ratio: The California Bearing Ratio (CBR) test is one of the common method of determining the bearing capacity of subgrade material in pavement design practices. Hence, the soil samples were soaked for 48 h before testing.

RESULTS AND DISCUSSION

Laterite soils: The two laterites soil samples used in the study were collected from Danbare and Dausayi villages which are 10 and 12 km away from Kano city centre, respectively. Index properties of the soil were determined for classification purpose. The soil samples were classified as A-7-5(15) and A-6(5) for samples 1 and 2, respectively based on the American Association of State Highway and Transportation Officials (AASHTO). Table 1 presents the summary of the properties of the two soil samples.

Atterberg limits

Liquid limit: It was observed that plasticity properties of the soil decreases as the fly ash content increases.

Table 1: Index and engineering properties of the soil samples

	Results	
	Red laterite	White laterite
Properties	S1	S2
Nature moisture content (%)	11.4	5.5
Liquid limit (%)	62.5	39.5
Plastic limit (%)	30.5	26.7
Plasticity index (%)	32.0	12.8
Linear shrinkage (%)	8.6	7.1
Specific gravity (%)	2.87	2.53
MDD(Mg m^{-3})	1.83	1.90
OMC (%)	9.86	8.60
CBR (%)	7.0	15.0
UCS (kN m^{-2})	300	600
Water erosion (%)	10.9	12.2
AASHTO classification	A-7-5	A-6
Group index	15	5
Clay proportion (%)	46.1	44.6
Silt proportion (%)	11.0	10.5
Percentage passing B.S. No. 200	57.1	55.1
Colour	Reddish brown	Dark brown

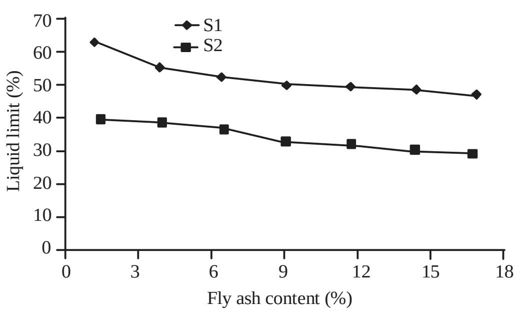

Fig. 1: Variation of fly ash content with liquid limit

Figure 1 present the observed changes in liquid limit of the two soil samples as the fly ash content increases. The liquid limit generally decreases at all fly ash contents for the stabilized soil samples. For sample 1, the liquid limit decreased from 55.0 at 3% fly ash content to 46.1 at 18% fly ash content. Similarly, there was a general decrease from 38.2 at 3% fly ash content to 28.4 at 18% fly ash content for the liquid limit of sample 2. The trend generally was that the liquid limit decreases as the fly ash content increases; this can be attributed to the gradual raise in the pozzolanic reactions that aided flocculation of the fine particles as the fly ash contents increases. Thus, the effective grain size of the soil mass now increases due to aggregation of the clay particles. The aggregation converts fine soil particles into coarser particles and this decreases the liquid limit of the soil. This finding is in good agreement with Goswami and Singh[12]. Specifically, the liquid limit decreased to 46.1% and 28.4 at 18% fly ash content for samples 1 and 2, respectively.

The plastic limits of the natural soils were 30.5 and 26.7% for samples 1 and 2, respectively. For sample 1, there was no regular pattern of variations of plastic limit

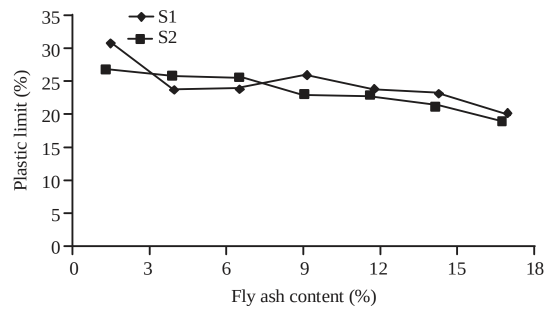

Fig. 2: Variation of fly ash content with plastic limit

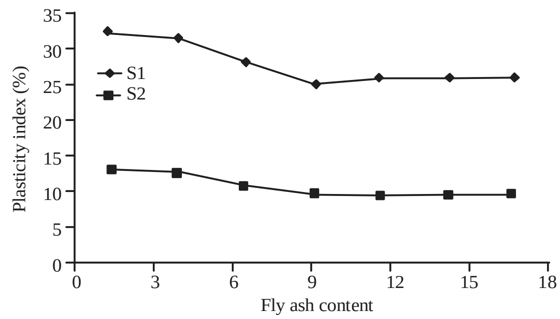

Fig. 3: Variation of fly ash content with plasticity index

as the fly ash content increases. However, sample 2 showed greater consistent behaviour in which the plastic limit decreases continuously for all the soil-fly ash combinations that is from 25.8-18.8%. This may be due to aggregation of the clay content by the fly ash which is a pozzolana as described by Goswami and Singh[12]. Figure 2 presents the results of the plastic limit at different percentages of fly ash combination with the soils.

Figure 3 shows the changes in the plasticity index of the soil at different fly ash contents. This study revealed that the plasticity index reduces as the fly ash content increases for the two soil samples. Meanwhile, the plasticity index decreases sharply at between 6-9% fly ash content for the stabilized samples, beyond which the decrease becomes less pronounced for sample 2 and increases at 18% fly ash content. For sample 1, there was an increase in the plasticity index at between 12-18% fly ash. Consequently, the general decrease in the plasticity indices at all fly ash contents is an indication of the improvement in the workability of the stabilized soils making them better for use as a construction material[12].

Optimum moisture content: The detailed results of the optimum moisture content of the soil samples at various fly ash contents are shown in Fig. 4. The optimum moisture contents of the natural soils are 9.86% and 8.60% for samples 1 and 2, respectively. The OMC increases with increase in fly ash content up to 12%

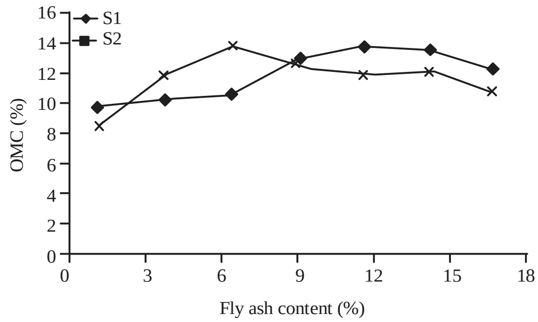

Fig. 4: Variation of fly ash content with optimum moisture contents

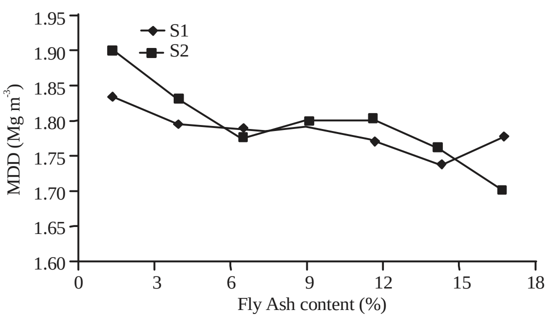

Fig. 5: Variation of fly ash content with MDD

beyond which there was continuous decrease in the OMC for sample 1. Similarly, for sample 2, the OMC increases with the addition of fly ash content up to 6%, after which the OMC decreases. Addition of the ash resulted into the increase in the fine particles of the soil mass which in turn need additional quantity of water to enable the reaction between the fly ash and the soil mineral particles as such increasing the OMC of the soil. Therefore, more water is required to lubricate the entire soil and the stabilizer to enhance compaction.

Maximum dry density: The MDD obtained at varying soil-fly ash combinations are presented in Fig. 5. The maximum dry densities for the soils are 1.83 mg m^{-3} and 1.90 mg m^{-3} for samples 1 and 2 respectively. The MDD decreases as the fly ash contents increases up to 6% after which it remains constant between 6-9% and the decrease continues from 9-15% fly ash content for sample 1. The trend is similar for sample 2; the MDD also reduces as a result of the increase in the ash content, thereafter, the decrease remain constant at 9-12% fly ash content and continue to decrease at15-18% fly ash content. Hence, the decrease in dry density is an indication that the stabilized soil can achieved its maximum dry density at lower compactive energy than the natural soil; thereby reducing the cost of compaction.

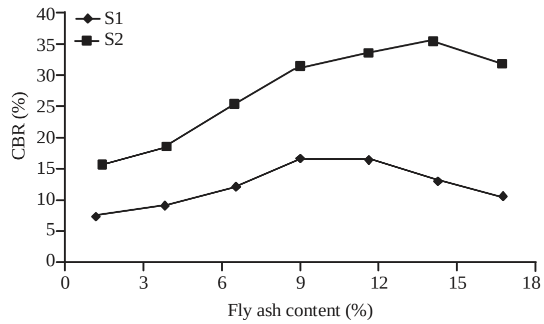

Fig. 6: Variation of fly ash content with CBR

California Bearing Ratio (CBR): The CBR test results of the natural samples at optimum moisture content are respectively 7 and 15% for samples 1 and 2. Figure 6 above presents the CBR of the two soil samples after the addition of varying proportions of fly ash. It can be deduced from the study that the CBR values increases with the addition of fly ash content for the two samples. For sample 1, there was a general increase in the CBR of the soil treated with fly ash up to 9%; thereafter, it remain constant up to 12% fly ash content and then decreased from 12-18% fly ash content. Whereas, for sample 2, the CBR increases with the addition of fly ash up to 15% beyond which it decreases. Hence, significant increase in the CBR of >100% was observed for samples 1 and 2 at 9 and 15% fly ash contents, respectively. This may be attributed to the reactions between the soil and the fly ash that resulted in the formation of cementitious compound that binds the soil particles together thereby improving the strength[13]. Hence, improvement of marginal lateritic soils using fly ash by cation exchange can be very prospective. This is because fly ash can provides substantial cations that facilitates flocculation of clay particles under ionized conditions[14].

Unconfined Compressive Strength (UCS): Figure 7 depicted the correlation between the addition of fly ash and the UCS results of the treated soils. The addition of the fly ash at varying percentages to the soils increases the UCS values up to 15% fly ash content beyond which it decreased at 18% for the two samples. For sample 1, the increase in the UCS was from 300 kN m^{-2} at 0% fly ash content to 630 kN m^{-2} at 12% fly ash content. While for sample 2 the UCS increased from 600 kN m^{-2} at 0% fly ash content to 1410 kN m^{-2} at 15% fly ash content. The strength improvement of fly ash treated soil is ascribed to the soil-fly ash reaction which results in the creation of cementitious compound that binds the soil aggregates. Generally, it has been established that fly ash could be utilized effectively to treat most coarse and medium-grained soils with PI of not >25% as

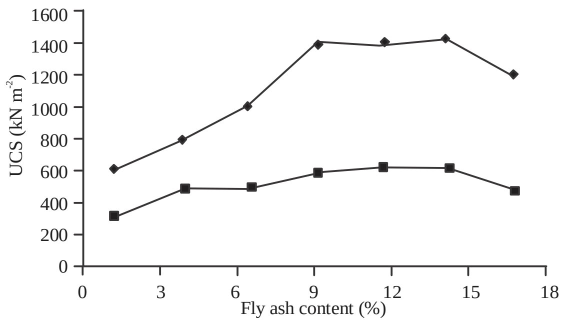

Fig. 7: Variation of fly ash content with UCS

postulated by Beeghly[15]. Hence, the noticeable improvement in the strength properties of sample 2 having a PI value of 12.8% (<25%) gives credence to this research effort. While for sample 1 having a PI value of 32.0% (>25%), the improvement in strength is not appreciable when compared with that of sample 2[16].

CONCLUSION

The laterite samples used in the study were classified as A-7-5(15) and A-6(5) soils using the AASHTO system. The particle size analysis shows that the soil samples are largely fine-grained with some gravel contents. Thus, the two soil samples in their natural state were found to be unsuitable for some engineering applications.

The plasticity properties of the soils reduces as the fly ash increases. The reduction in the plasticity index was due to the reduction in liquid limit. Specifically, the plasticity indices of the treated samples decreased from 32.0-24.7 at 9% fly ash content and from 12.8-9.0 at 15% fly ash content for samples 1 and 2, respectively. Hence, an optimum dose may be found between 9-15% fly ash content to reduce the plasticity of the natural soils.

The maximum dry densities of the natural soils were considerably altered due to the addition of fly ash in the soils. The MDD decreased as the fly ash content increases while the OMC of the treated soils increased. Hence, the decrease in the dry densities indicates that the treated soils need low compactive energy than the natural soils to attain the maximum dry densities at OMC as such the cost of compaction could be economical.

The soil-fly ash combinations showed substantial improvement in the CBR of the soils, particularly at 9% fly ash content for sample 1 where the peak CBR value of 16% was obtained. Likewise, a peak CBR value of 35% was also obtained at 15% fly ash content for sample 2. Hence, fly ash content of 9-15% could be use to stabilize these soils.

The unconfined compression tests showed considerable improvement in the strength properties of the treated soils. The peak 7 days strength of 630 and 1410 kN m^{-2} were observed at 12 and 15% fly ash content for samples 1 and 2, respectively.

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