Research Journal of Applied Sciences, Engineering and Technology 2(6): 543-546, 2010
ISSN: 2040-7467

Submitted Date: June 04, 2010 Accepted Date: July 08, 2010 Published Date: September 10, 2010

Effects of Dissolved Alum on the Geotechnical Properties of Lateritic Soil for Road Construction

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Abstract: This research was carried out to study the effects of dissolved alum on the geotechnical properties of lateritic soil for road construction. Preliminary tests were performed on three samples, A, B and C for identification and classification purposes followed by the consistency limit tests. Geotechnical property tests (compaction, California Bearing Ratio (CBR), unconfined compression test and triaxial) were also performed on the samples, both at the stabilized and unstabilized states by adding varying amounts of alum (5, 10 and 15g of alum/liter) to the soil samples. The results showed that the addition of alum significantly reduced the strength of the three soil samples. Maximum Dry Density (MDD) increased simultaneously as the Optimum Moisture Content (OMC) increased, the CBR values decreased from 15.2 to 0.9%, 13.1 to 1.3% and 14.0 to 1.2% in samples A, B and C, respectively. Shear strength values also decreased from 43 to 15, 49 to 16, and 41 to 16 kN/m^2 in samples A, B and C, respectively. The study concluded that alum-soil is detrimental to the geotechnical properties of lateritic soil for road construction.

Key words: Alternative material, alum treatment, construction method, material strength, road upgrade, stabilization

INTRODUCTION

The necessities to improve soil properties for road construction result in the use of various stabilizers. Some of these stabilizers are either costly or scarce. For example, cement stabilization was adjudged the most viable due to its abundance; however the growing cost of cement has limited its use. It therefore became necessary to utilize the excellent properties of the common chemical compounds in alum and determine the effects on the geotechnical properties of lateritic soil. This will encourage the use of alum both as a coagulant and stabilizer, thereby reducing the cost of soil stabilization required for road construction.

Lateritic soils are often found in tropical regions, which are characterized by distinct dry and wet seasons. They may be formed over a wide variety of rock such as shale, sandstone and most crystalline rocks. Regardless of the parent material, what is essential is the adequate supply of sesquioxide of iron. The iron sesquioxide may originate from the underlying parent material or from an adjacent area of higher topography. Topography plays an important role in the development of laterite profiles. It controls the drainage condition and hence the proportion of rain water that infiltrates and leaches the weathered zone. Accumulation of sesquioxide of iron is an important feature of laterite formation (Ahn, 1970). The two peculiar problems of lateritic soil are mechanical and thermal instabilities. The mechanical instability, which may manifest in form of remolding and manipulation, results in the breakdown of cementation and structure. The engineering properties affected by this mechanical instability include particle size, Atterberg's limits and moisture-density distribution (Townsend, 1985). Thermal instability is shown through sensitivity to drying and what Gidigasu (1974) has described as 'potential self-stabilization'. The affected engineering parameters are Atterberg's limits and particle size distribution. The effects of these problems therefore affect the strength of the material (Malomo, 1977).

The most important properties of soil that are of interest to the engineers are permeability, shear strength, and compressibility. The shear strength is the internal resistance per unit area that the soil mass can offer against failure along any plane inside it (Das, 1990). When this resistance is exceeded, failure occurs. A material is said to be permeable if it will permit the passage of a fluid by a flow process under the action of externally applied forces. To be permeable, the void spaces in the material must be continuous. The rate at which the soil allows water to pass through would affect the behavior of the soil especially due to seasonal variations. Then in places where frost action is critical, permeability of the soil becomes a very critical factor to consider in pavement design. A change in the stress system acting on a soil mass will result in a change in volume of the mass. Such changes in volume have an important influence on the engineering properties of the soils. They change the

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permeability characteristics of the soil, the inter-particle forces both in the magnitude and orientation, which has a critical influence on the shearing resistance of the soil, causing displacements at the boundaries of the mass. The resulting displacements affect the structure of the soil mass.

Soil stabilization, in the broadest sense, is the alteration of any property of a soil to improve its engineering performance. It also comprises any process which increases or maintains the natural strength of the soil. In this sense, it includes compaction, drainage and sowing of grass and planting trees on banks (Capper and Cassie, 1969). Although soil stabilization was originally done to increase the strength or stability of soil, gradually, techniques of soil treatment have been developed until soil stabilization is now used to increase or decrease almost every engineering property of soil. Stabilization techniques could be mechanical or chemical.

Over the years there has been technological advancement in transportation engineering which involves mentioning a few the discoveries of better materials for road construction. Kamon and Nontananandh (1991) combined industrial waste with lime to stabilize soil. James and Rao (1986) studied the potential of burnt agricultural by-product, rice husk, as a soil stabilizer. In agriculture countries there are studies on the long-term effects of treating poultry litter with alum on phosphorus availability in soils. Until the late 19th century, alum was an essential ingredient for several industrial processes. Its main use was in the textile industry, where it was used as a mordant or fixing agent, for holding natural dyes to fabrics. England's most important medieval industry, the wool trade, relied upon a steady supply of alum since the value of the cloth depended on how well it was dyed. The main sources of alum during this period were the Middle East, and after 1461, the Papal States north of Rome. These sources were susceptible to disruption; however, a domestic supply of alum was sought in England. In chemical terms, alum is a group of double salts that contain aluminum sulphate in combination with a second sulphate (either potassium or ammonium). Alum can form as a natural mineral (alunite) under volcanic conditions, where it solidifies from solution to form large crystals of a characteristic shape. Alum is a colorless, white mineral with density of 1.76. It has a vitreous luster and white streak; it is a water soluble mineral which partly justifies its use in water treatment. It is also non-fluorescent and cleavage indistinct, fractures developed in brittle materials characterized by smoothly curving surfaces, (e.g., quartz). In a short communication study by Eltaif and Gharaibeh (2008), it was showed that alum was effective in improving soil aggregate stability and decreasing aggregate rupture stress. In a related work by Bugbee and Frink (2006), dried alum was found to improve the physical properties of potting media and to function as a liming material. Wang *et al.* (2004) used alum sludge derived from a municipal wastewater plant as a soil amendment in a greenhouse study.

This study intends to take advantage of the excellent properties of the common chemical compounds in alum and determine the effects on the geotechnical properties of lateritic soil. This will encourage the use of alum both as a coagulant and stabilizer, thereby reducing the cost of soil stabilization required for road construction.

MATERIALS AND METHODS

This study was conducted between March 2007 and January 2008 in the Geotechnics Laboratory of the Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria.

Materials and preparation: The materials used for this study are: the lateritic soil samples, Alum and water. Three soil samples named A, B, and C were obtained at different locations from the borrow pit of Reynolds Construction Company located at Ogudu road, Ile-Ife, Nigeria. They were collected at depths representative of the soil stratum and not less than the 1.2 m below the natural ground level. These were kept safe and dry in jute bags in the Geotechnics Laboratory of the Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife and marked, indicating the soil description, sampling depth and date of sampling. They were air dried for two weeks to allow for partial elimination of natural water which may affect analysis. They were thereafter sieved with sieve No. 4 (4.76 mm opening) to obtain the final soil samples for the tests. After the drying period, lumps in the samples were slightly pulverized with minimal pressure. The potash alum was obtained from a market in Ile Ife. This was covered before and after use to avoid exposure to atmospheric water and moisture from the ground and from being disturbed during practical classes. This was safely kept in the laboratory and pulverized before use.

Methods: Classification test (natural moisture content, specific gravity, particle size analysis and Atterberg's limits test) was performed on the three soil samples. Alum of 5, 10 and 15 g dissolved in 1 L of water were mixed with the soil samples. Atterberg's limits and geotechnical property tests (compaction, California Bearing Ratio (CBR), undrained triaxial) were performed on them. The effects of the dissolved quantities of alum were thereafter determined on the geotechnical properties of the soil samples. The procedures for the various tests were carried out in accordance with that stipulated in BS 1377-1990:1-8.

Table 1: Summary of the preliminary analysis of soil samples

Sample	Natural moisture content (%)	Specific gravity	Liquid limit (%)	Plastic limit (%)	Plastic index (%)	AASTHO classification
A	18.06	2.95	38	22	16	A-7-6 (0)
B	19.93	2.37	36	21	15	A-7-5 (0)
C	12.30	2.82	33	20	13	A-7-6 (7)

Table 2: Summary of atterberg's limits test

Sample	Dosage/liter	Liquid limit (LL)%	Plastic limit (PL)%	Plastic index (PI) %
A	5g Alum	22	11	11
	10g Alum	23	14	9
	15g Alum	20	12	8
B	5g Alum	21	11	10
	10g Alum	24	15	9
	15g Alum	19	11	8
C	5g Alum	26	14	12
	10g Alum	23	13	10
	15g Alum	21	12	9

RESULTS AND DISCUSSION

The results from the preliminary tests (grain size analysis, natural moisture contents, specific gravity, and Atterberg's limits) as well as the geotechnical property tests (compaction, CBR and unconsolidated undrained triaxial) are discussed below:

Preliminary tests: Table 1 shows the summary of the preliminary analysis results of the samples. The natural moisture contents of samples A, B and C are 18.06, 19.93 and 12.30%, respectively. Sample B had the highest natural moisture content and sample C the lowest. Sample B probably had the largest void ratio compared to others. The specific gravities of samples A, B and C are 2.95, 2.37 and 2.82, respectively. According to the values given in Braja (2000) for clay minerals, sample B is Halloysite (2.0-2.55) and samples A and C are Biotites (2.8-3.2).

The samples were classified using the AASHTO soil classification system. All the samples fell within the SILT-CLAY minerals under the general classification since the percentages passing 75 µm sieve were all greater than 35%. Based on their LL and PI, samples A, B and C were further classified as A-7-6(0), A-7-5(0) and A-7-6(7) respectively.

The natural Liquid Limits (LL), Plastic Limits (PL) and the Plastic Index (PI) for sample A are 38, 22 and 16%, sample B are 36, 21 and 15% and 33, 20 and 13% for sample C. According to Whitlow (1995), liquid limit less than 35% indicates low plasticity, between 35 and 50% indicates intermediate plasticity, between 50% and 70% high plasticity and between 70 and 90% very high plasticity and greater than 90% extremely high plasticity. This shows that samples A, and B, have intermediate plasticity while sample C has low plasticity. The addition of increasing dosages of alum into the samples caused all the Atterberg's limits to reduce (Table 2). However, dried alum was found to improve the physical properties of potting media (Bugbee and Frink, 2006).

Table 3: Summary of compaction test results

Sample	Dosage/liter	Optimum moisture content (OMC) (%)	Maximum dry density (kg/m^3)
A	0g Alum	8.5	1900
	5g Alum	13.3	2188
	10g Alum	13.0	2160
	15g Alum	11.0	2300
B	0g Alum	8.7	1950
	5g Alum	11.0	2240
	10g Alum	12.4	2245
	15g Alum	14.0	2270
C	0g Alum	8.9	1960
	5g Alum	12.0	2270
	10g Alum	13.0	2240
	15g Alum	13.2	2290

Geotechnical property tests: The summary of the compaction test results are shown in Table 3. The natural Optimum Moisture Contents (OMC) for samples A, B and C are 8.5, 8.7 and 8.9% and Maximum Dry Densities (MDD) of 1900, 1950 and 1960 kg/m^3, respectively. The addition of dosages of alum caused OMC increases to 13.3, 14.0 and 13.2% and increases in MDD to 2300, 2270 and 2290 kg/m^3, respectively for sample A, B and C. This supports the work of Eltaif and Gharaibeh (2008). The increase in OMC is probably as a result of the additional water held within the flocculant soil structure due to the interaction of alum. Principally an increase in MDD is an indicator of soil improvement.

The results of the California Bearing Ratio (CBR) test are shown in Fig. 1-3. The addition of alum caused a significant decrease in the CBR values of all the samples. This shows that the load bearing capacity of all the soil samples decreased with the addition of alum. This supports the work of Wang *et al.* (2004) that specially prepared alum can be used for soil amendment.

The values for all the alum-soil samples were observed to be lower than the 10% CBR required for subgrade. Therefore none of the three alum-soil samples can qualify as road construction material.

Table 4 shows the summary of the unconsolidated unconfined triaxial test results. The shear strengths of

Table 4: Variation of shear strength with increasing alum dosage

Sample	Dosage/liter	Cohesion, c (kN/m^2)	Internal friction angle (ϕ)	Normal stress (σ_1 - σ_3) kN/m^2	Shear stress $\tau = c + (\sigma_1 - \sigma_3) \tan\phi$ (kN/m^2)
A	0g Alum	17	20	72.25	43
	5g Alum	9	17	61.45	35
	10g Alum	6	14	54.59	19
	15g Alum	4	12	52.38	15
B	0g Alum	16	22	80.45	49
	5g Alum	8	18	63.49	29
	10g Alum	7	14	58.19	22
	15g Alum	5	12	51.13	16
C	0g Alum	18	19	67.75	41
	5g Alum	10	15	61.49	26
	10g Alum	8	13	53.21	20
	15g Alum	7	11	47.59	16

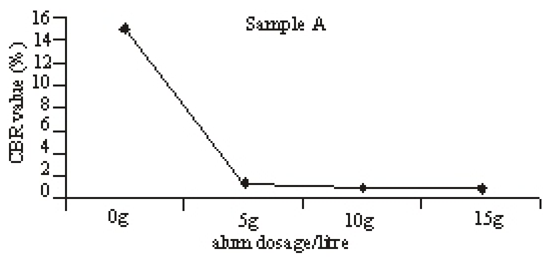

Fig. 1: CBR values with increasing alum dosage for sample A

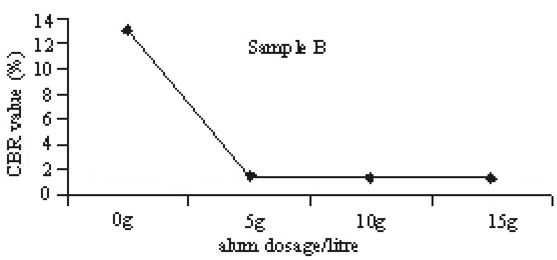

Fig. 2: CBR values with increasing alum dosage for sample B

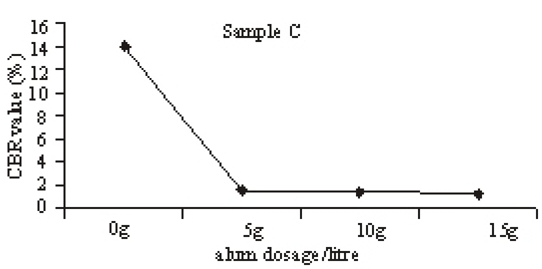

Fig. 3: CBR values with increasing alum dosage for sample C

samples A, B and C decreased with the addition of alum. This also disqualifies the use of alum-soil as road construction material.

CONCLUSION

The addition of alum improved the qualities of the soil samples by significantly reducing their plastic indices. The optimum moisture contents and maximum dry densities of all samples were also increased. However, the addition of alum significantly reduced the CBR values and the shear strengths of all the soil samples. It is therefore concluded that alum cannot be effectively used to improve the geotechnical strength property of lateritic soil.

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