An Investigation Into The Use Of Lime-Stabilized Clay As Subgrade Material

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ABSTRACT: This study involves the collection of clay sample at a site along Ise / Ikere Road at Ikere-Ekiti region and evaluation of its properties in natural state and after stabilization with lime. The major objective of the study is to determine the optimum lime content that will stabilize the clay soil adequately. Also, it investigates the level of improvement that could be achieved by stabilizing clayey soil with lime. The tests carried out include mechanical sieve analysis and hydrometer test, specific gravity, moisture content, Atterberg limit test, compaction test, and California bearing ratio test. The high moisture content of the natual clay soil clearly shows its high water absorption capability. The addition of lime reduces the plasticity index at 8% and 10% lime content. The maximum dry density (MDD) increases with an increase in lime content from 0 to 8%, while a reduction in the MDD was observed at 10%. The maximum optimum moisture content (OMC) was recorded at 10% lime content. The California bearing ratio (CBR) of the lime stabilized clay increases for lime content of 2% to 8%, with the maximum value obtained at 8%, while a reduction in the CBR was observed at 10%. The reduction in the CBR at 10% might be due to the excess lime in the clay not required for the early strength gain as a result of flocculation.

KEYWORDS: Stabilization, Lime, Clay, Soil, Strength, compaction, maximum dry density, optimum moisture content

1 INTRODUCTION

Stabilization is the process of blending and mixing materials with a soil to improve certain properties of the soil. The process may include the blending of soils to achieve a desired gradation or the mixing of commercially available additives that may alter the gradation, texture or plasticity, or act as a binder for cementation of the soil [1] [2]. Lime stabilization is one of the methods of improving the properties of soils especially the cohesive soils. Lime in the form of quicklime (calcium oxide – CaO), hydrated lime (calcium hydroxide – $Ca[OH]_2$), or lime slurry can be used to treat soils. Quicklime is manufactured by chemically transforming calcium carbonate (limestone – $CaCO_3$) into calcium oxide. Hydrated lime is created when quicklime chemically reacts with water [3]. Lime stabilization creates long-lasting changes in soil characteristics. When lime is admixed with a moist clay, a number of reactions take place including cation exchange,, pozzolanic reaction and carbonation [4]. The cation exchange is responsible for aggregation of the soil particles leading to early strength development. The pozzolanic reaction takes place slowly and is responsible for late strength development. Lime has been applied in stabilizing subgrades subbase and bases materials in road construction. Lime stabilization chemically changes most clay soils in the following ways [5]: reduction of shrinkage and swell characteristics of clay soils; Increase in unconfined compressive strength by as much as 40 times; substantial increase in load-bearing values as measured by such tests as CBR, R-value, Resilient Modulus, and the Triaxial tests; development of beam strength in the stabilized layer and great increase in the tensile or flexural strength; creation of a water-resistant barrier; impedes migration of surface water from above and capillary moisture from below; thus helping to maintain foundation strength and in addition to lowering the plasticity in most cases and initially strengthening the improved soil, the strengthening effect increases over time.

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The need for soil stabilization may arise, if the natural soil to be built on in an area is of poor engineering properties or when a section of the land is found not suitable to support the foundation in its natural state. In some cases, for instance in road pavement construction, the stabilization of layers of the pavement like the subgrade, subbase and the base may be carried out as a way of reducing the cost of construction, which is achieved by improving the load carrying capacity of these layers and consequently reducing the thickness of the surfacing layer (asphalt concrete or cement concrete, which is the most expensive). The problem associated with clay soil is due to high swelling (caused by its high water absoption capability) and shrinkage of the soil, compaction difficulty and high plasticity of the soil. The properties of soil-lime mixtures are dependent on many variables such as soil type, lime type, lime percentage and curing conditions (time, temperature, moisture) [1]. Feng [6] stated that lime is widely used for stabilization due to the wide range application for various soil types, low cost, availability and permanent effects. Rajani and Padmakumar [7] investigated clay collected from Thonnackal in Trivandrum district in which kaolinite is the predominant clay mineral. They observed that there is no appreciable improvement in the optimum moisture content and maximum dry density for the soil treated with lime solution of different molarity. Hoewever, the strength of soil was found to increase with increase in the concentration of lime up to 1.25 M. Tang et al [8] studied clay collected from a site near Tours, a city in central France. They investigated the small strain shear modulus, *Gmax* of compacted lime-treated soil using bender elements and found that the lime treatment significantly increases *Gmax* of the soil, giving rise to *Gmax* values independent of the moulding water content about 200 h after lime treatment. Also, for the four maximum soil aggregates sizes, *Dmax* considered, they observed that the larger the value of *Dmax*, the lower is the value of *Gmax*. This clearly shows the soil gradation determines the level of improvement achieved. They also discovered that due to the appearance of micro-cracks, cyclic wetting-drying induced significant decrease of *Gmax* of untreated specimens, while for treated specimens, the changes of *Gmax* during wetting-drying cycles are less significant. In the present study, the clay soil is subjected to test such as mechanical sieve analysis and hydrometer test, specific gravity, moisture content test, Atterberg limit test- liquid limit, plastic limit and shrinkage limit, compaction test and California bearing ratio both in its natural state and after stabilization with lime in the range 2% to 10% of the soil-lime mixture.

2 MATERIALS AND METHODS

2.1 Materials
The materials used for this test are natural clay soil, high calcium hydrated lime and water. The natural clay soil sample was collected along Ise / Ikere Road, Ikere-Ekiti, Ekiti State, Nigeria. It was collected at 1m depth below the ground level. The sample was taken to the laboratory in a polythene bag. The sample used for the moisture content test was kept in a small polythene bag and sealed to prevent loss of moisture. The lime (hydrated high calcium lime, ($Ca(OH)_{2)}$ and was procured from a retail chemical store at Ado Ekiti and was properly packed in order to ensure the material remain in its original state before being used. It was ensured that the water used is fit drinking.

2.2 Methods
The samples were subjected to the following laboratory tests carried out.

2.2.1 Mechanical sieve analysis and hydrometer test:
The sample was prepared by washing it through a 75 μm micron sieve. The portion retained on the sieve was dried and sieved through a series of sieve. The portion passing the 75 μm sieve was subjected to hydrometer test which involves determining the density of the soil-water mixture at fixed time intervals. The results of both tests were combined. The procedures for the tests are detailed in British Standard [9].

2.2.2 Specific gravity
The specific gravity was determined using the pyknometer method. The sample was oven-dried at 105°C and was weighed in the pyknometer with and without water. The test was carried out in accordance with British Standard [9]. The specific gravity was calculated as shown in equation 1.

$$Gs = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)} \quad (1)$$

Where m_1 = mass of container (g); m_2 = mass of the container and soil (g); m_3 = mass of container, soil and water (g) and m_4 = mass of container and water (g)

2.2.3 Moisture content
The moisture content is the ratio of the weight of water (Ww) in a given volume of soil to the weight of dry soil (W_d) particles in that same volume of soil. This involves measuring the weight of the clay soil collected and sealed in the polythene to prevent the loss of moisture. The soil was dried at 105°C and the natural moisture content calculated as shown in equation 2. The test was carried out in accordance with British Standard [9].

$$\text{Moisture content, w (\%)} = \frac{Ww}{Wd} \times 100\% \quad (2)$$

Where, Ww = Weight of water and W_d = Weight of dry soil

2.2.4 Atterberg limit tests
The Atterberg limit tests include the plastic limit, liquid limit and the shrinkage limit tests. The plastic limit is the moisture at which a soil becomes too dry to be in plastic condition, and becomes friable and crumbly [4]. The liquid limit is the moisture content at which a soil passes from the liquid to plastic state and the shrinkage limit is the moisture content at which an initially dry soil sample is just saturated with and change in its total volume [4]. The tests were conducted in accordance with British Standard [9]. The shrinkage limit was calculated as shown in equation 3.

$$\text{Linear shrinkage (\%)} = \frac{L_o - L_f}{L_o} \quad (3)$$

Where L_o = Length of wet soil bar, and L_f = Length of dry soil bar

2.2.5 Compaction test
The standard Proctor test was adopted for this study. The test was carried out to evaluate the compaction characteristics of the natural clay soil and lime-modified clay soil. This involves compacting air-dried soil sample into a cylindrical mould. The mass of the soil was determined and its bulk and dry densities calculated as shown in equations 4 and 5, respectively. The process was repeated until the mass of the soil in the mould was less than the preceeding measurement. The test procedure is described in British Standard [9].

$$\text{Bulk density, } \ell \text{ (kg/m}^3\text{)} = \frac{M_a - M_b}{Volume\ of\ mould} \quad (4)$$

Where, M_a = Weight of mould + compacted soil; and M_b = Weight of mould

$$\text{Dry density (kg/m}^3\text{)} = \frac{\ell}{1 + w} \quad (5)$$

where ℓ = bulk density and w = moisture content

2.2.6 California bearing ratio (CBR) test
This test was used to assess the strength of the natural clay and lime-modified clay soil. The test involves compacting the natural clay or the lime stabilized clay in the CBR mould at the optimum moisture content determined from the compaction test. The plunger of the CBR machine is made to penetrate the compacted soil at 0.25 mm interval up till 7.5 mm. The load at each penetration is recorded and the CBR is calculated as shown in equation 6. The test procedure is detailed in British Standard [9].

$$CBR = \frac{Test\,load}{Standard\,load} \times 100\% \quad (6)$$

3 RESULTS

3.1 Mechanical sieve analysis and hydrometer test

The sieve analysis and hydrometer test were conducted on the clay soil sample and the results are shown in Figure 1. Figure 1 shows that the soil is fine-grained as more than 30% of the soil fraction passes sieve No 200 (0.0075mm). The high value of the fine content indicates the soil might be clay or silt. Adopting AASHTO classification system, the soil falls within the range of A4 to A7 soils. Further classification reveals that it is an A-7–5 soil as the liquid limit and plasticity index are greater than 41 and 11, respectively. The soils in this group are classified as clay and with group index of zero and they are rated as poor subgrade material.

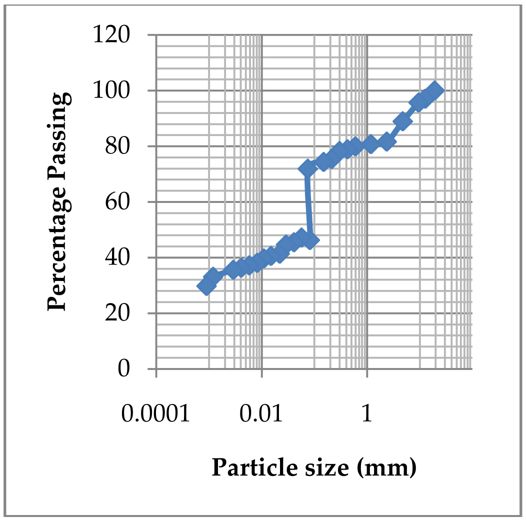

Figure 1: Particle size distribution curve of the clay soil

3.2 Specific gravity

The specific gravity results are shown in Table 1. The specific gravity of clay normally varies between 2.6 and 2.9. The value of 2.48 may indicate the presence of organic substances in the soil.

Table 1: Specific Gravity of Natural Clay Soil

Sample	A	B
Weight of density bottle, m_1(g)	29.2	29.2
Weight of density bottle + soil, m_2(g)	529.5	531.0
Weight of density bottle + soil +water, m_3(g)	868.8	870.0
Weight of density + water (full), m_4(g)	570.4	571.0
Specific gravity	2.48	2.47
Average specific gravity	2.48	

3.3 Moisture content

The moisture content results of the sample collected are shown in Table 2. The average moisture content of the soil was found to be 20.2%. The high moisture content of the soil clearly shows the high water absorption capability of the soil. Also, this gives an insight to the volume stability problem that is associated with the absorption and loss of water from clay.

Table 2: Moisture Content of the Natural Clay soil.

Sample No	1	2	3	4	5
Container no (cup)	A	B	C	D	E
Mass of cup + wet soil	53.3	53.5	54.9	56.1	58.1
Mass of cup + dry soil	47.0	46.9	48.5	49.1	51.4
Mass of cup	15.8	15.7	16.0	15.7	15.7
Mass of dry soil, M_d	31.2	31.2	32.5	33.4	35.7
Mass of water, M_w	6.3	6.6	6.4	7.0	6.7
Moisture content, w%	20.2	21.2	19.7	21.0	18.8
Average Moisture content, w%	20.2%				

3.4 Atterberg limit tests

The results of the Atterberg limit tests, that is the liquid limit, Plastic limit, Plasticity index and shrinkage limit for the natural and lime-stabilized clay are shown in Figure 2. The liquid limit of the natural clay (63.9) indicates that it is clay of high plasticity. Figure 2 shows that the addition of lime to the clay soil reduces its liquid limit steadily for 2% to 8 % lime content, indicating a reduction in plasticity of the clay. However, the liquid limit increases with 10% lime content. The reduction in the liquid limit could be as a result of the pores in the clay soil being occupied by lime. In the case of the plastic limit, the value increases at 8% and 10% lime content. Addition of 2%, 4% and 6% lime to the clay soil increases the plasticity index, while at 8% and 10% lime content, the plasticity index reduces. The shrinkage limit of the soil sample reduces with increase in the percentage of the lime content with the lowest value at 10% lime content. This implies that addition of lime reduces the susceptibility of the clay soil to volume change.

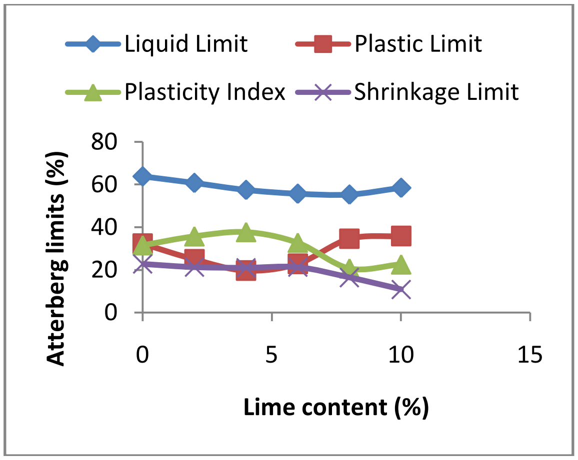

Figure 2: Atterberg Limit Test results

3.5 Compaction Test

The results of the compaction test showing the maximum dry density (MDD) and the optimum moisture content of the natural and lime-stabilized clay are shown in Figure 3. As shown in Figure 3, the MDD increases with increasing lime content from 0 to 8%, while a reduction in the MDD was observed at 10%. Knowing that compaction of soil involves the packing of the soil particles such that its voids are reduced to the minimum possible. A reduction in the MDD at 10% lime content indicates that the lime content in the soil-lime mixture was in excess of the amount needed to improve the gradation of the soil. Also, figure 3 reveals that optimum moisture content required to achieve the MDD increases with the addition of lime. Although, the results did not establish a definite trend, it can be seen that the optimum moisture content at 2% lime content was greater than OMC required at 4%, 6% and 8%. The maximum OMC was recorded at 10% lime content. This increase in the OMC observed with the addition of lime is caused hydration reactions between the cations of the clay particles and the lime.

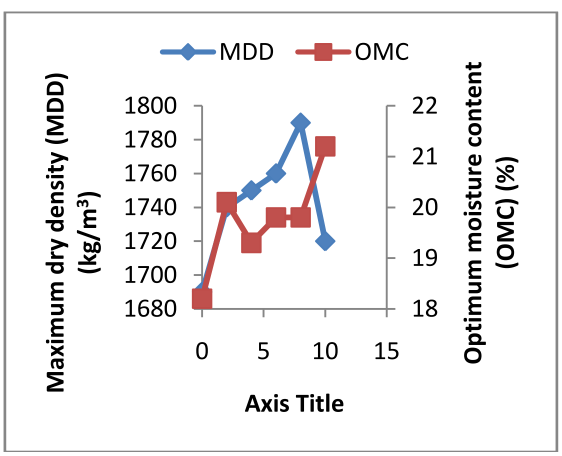

Figure 3: Maximum dry density (MDD) and Optimum moisture content (OMC) versus lime content

3.6 California bearing ratio (CBR)

The CBR value of the natural clay soil sample was found to be 17% (see Figure 4). This value is below the CBR value of 35%, the minimum value required for subsurface material specified for road construction in Nigeria Roads and Bridges General Specification [10]. This confirms as shown in the classification of the soil, the unsuitability of the clay soil in its natural state as subgrade material. Figure 4 shows that the CBR of the lime stabilized soil increases for lime content of 2% to 8%, with the maximum value obtained at 8%, while reduction in the CBR was observed at 10%. The reduction in the CBR at 10% might be due to the excess lime in the clay not required for the early strength gain as a result of flocculation.

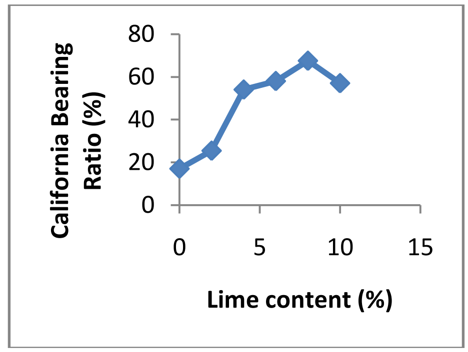

Figure 5: California Bearing Ratio (C.B.R) versus lime content

4.0 CONCLUSIONS

The study showed that the clay soil is unsuitable as subgrade material in its natural state as its California bearing ratio of 17% is less than CBR of 35% specified for subsurface material in Nigeria Roads and Bridges General Specification, hence the necessity for its properties to be improved. It was found in this study that the properties of the clay can be improved by adding lime. As shown in this study, the stabilization of lime reduces the plasticity index of the clay, consequently, the workability of the clay soil is improved. Also, it was discovered that the maximum dry density and the strength increase with increasing lime content up to 8%, while reduction in the MDD and CBR was noticed at 10%. The reduction in the MDD and CBR at 10% was attributed to the excess lime in the mixture not required for the cation exchange. Therefore, it was concluded that the lime content of 8% will best be suited for stabilization of the clay. However, it must be stated that the long term performance of the clay soil-lime mixture was not studied. It is believed the excess lime will take part in the pozollanic reaction that may further improve the strength of the lime-stabilized clay in the long-term.

REFERENCES

[1]. DANA. Soil stabilization for pavements. Department of the Army, the Navy and the Airforce, Washinghton D.C. TM 5-822-14/AFJMAN 32-1019, 1994.

[2]. USACE . Soil Stabilization for Pavements. US Army Corps of Engineers. EM 1110-3-137, 1984.

[3]. LMA. Lime-treated Soil Construction Manual: Lime Stabilization & Lime Modification. National Lime Association. Bulletin 326, 2004.

[4]. C.A. O'Flaherty. Highways: The Location, Design, Construction and Maintenance of Pavements. 4th Edition, Butterworth-Heinemann, Oxford, United Kingdom, 2002

[5]. www.graymont.com. Quality lime and stone products that improve your world.

[6]. T. Feng. Effect of Small Cement Content on Consolidation Behavior of a Lacustrine Clay, *ASTM Geotechnical Testing Journal*, GTJODJ, 25 (1) ,pp 53-60, 2002.

[7]. S.C. Rajani and G.P. Padmakumar Stabilization of Clayey Soil Using Lime Solution. *10th National Conference on Technological Trends* (NCTT09) 6-7 Nov 2009. Pp 73-77, 2009

[8]. A.M Tang, M.N Vu and Y.Cui. Effects of the maximum soil aggregates size and cyclic wetting-drying on the stiffness of a lime-treated clayey soil. *Géotechnique* 61, 5 (2011) 421-429, DOI : 10.1680/geot.SIP11.005, 2011.

[9]. BS 1377. Method of Test for Soils for Civil Engineering Purposes, British Standard Institution, London, 1990.

[10]. FGN . Government of the Federal Republic of Nigeria, General Specification (Roads and Bridges)" Volume II, 1997.