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Evaluation of the Strength Characteristics of Compacted Clay Soil Stabilized with Bio-Enzymes

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ABSTRACT
Bio-enzymes are organic degradable materials, currently introduced as soil improvement additives. This paper evaluated the strength and compaction characteristics of selected clay soils using Urease bio-enzymes. The soils were stabilized with 5, 10, 15 and 20% by weight of urease bio-enzymes. From the results, the liquid limits obtained are 41% and 50.50 %, Plastic Limit 28.08% and 35.86%, Plasticity index is 12.92% and 14.64% for samples A and B respectively. The moisture content and specific gravity for samples A and B obtained were 16.9 and 21.6% and 2.79 and 2.75 respectively. From the compaction tests results, the OMC decreases from 12.60% to 9.60% with an increase in enzyme percentage from 0% to 20% for sample A while the same decreases was observed for sample B from 17.20% to 14.00%. In addition, the work revealed a 116.98% increment in CBR value of stabilized soil (improvement) from 20.79 to 45.11% for A-7-6 clay and 315.41% increment in CBR value, from 10.06 to 41.79% for A-7-5 clay when both samples were cured for 28 days with 0 to 20% Urease bio-enzymes. After 28 days curing, there is 150 -175% increment in UCS of A-7-6 with 5-20% of urease enzymes. Similarly a 125 -156% increment in UCS of A-7-5 soil was recorded with 5 -20% urease enzymes. Bio-Enzymes is therefore recommended as stabilizing agents for use in road or other constructions, especially where weak clay soils are encountered.

Keywords: *Bio-Enzymes, Compaction, Clay Soil, Soil Stabilization*

1 INTRODUCTION

Weak clay is a problematic soil in geotechnical engineering practice. It is amongst wide spread soil types available for construction in Nigeria. Its vulnerability to severe shear strength loss is one of its properties when its natural structure is disturbed due to remoulding (Brand and Brenner, 1981). These clays cannot be safely and economically used for the construction of civil engineering structures without adopting some stabilization measures (Abolarinwa, 2010). Hence, the need for sustainable soil improvement methods has led researchers to the discovery of novel and innovative methods.

In the construction industry, maintaining a balance between performance and cost and satisfying environmental regulations has become a challenge for building material manufacturers, design engineers, and contractors. This challenge has led to identification and use of new construction materials and techniques. Geotechnical engineering projects are closely related to economic and environmental issues; therefore, improving sustainability of materials used in these projects may help in attaining overall sustainable development (Jefferis, 2008). Unfortunately, planning and design phases of these projects are dictated by financial interests and are even more affected by lack of knowledge about the effect of the geotechnical process on the environment (Abreu *et al.*, 2008). Manufacturing of readily used construction materials, such as cement and lime, has a deteriorating effect on the environment; the production of cement and lime is energy demanding, and production of only one ton of cement emits about one ton of CO_2 (Khedari *et al.*, 2005)

Recently Bio-Enzymes have emerged as a new chemical for soil stabilization. Bio-Enzymes are chemical, organic, and liquid concentrated substances which are used to improve the stability of soil sub-base of pavement structures. It is a natural, non-toxic, non-flammable, noncorrosive liquid enzyme formulation fermented from vegetable extracts that improves the engineering properties of soil, facilitates higher soil compaction and increases strength (Joydeep and Jitendra, 2015)

The Bio-Enzyme stabilization has shown little to very high improvement in physical properties of soil. This little improvement may be due to chemical constituent of the soil, which has low reactivity with Bio-Enzyme. In the cases of highly clay moderate soil, like silty soil to sandy soil (Velasquez *et al.*, 2005). The effect of stabilization has improved the CBR and unconfined compression strength. Bergmann (2000) concluded that the Bio-Enzymes require some clay content in the aggregate material in order to create the reaction that will strengthen the material. The successful stabilization could be achieved with as little as 2 percent clay in the aggregate material but best result seems to be achieved with 10 to 15 percent clay.

Kestler (2009), suggested that enzymes are proprietary of their supplier; unless they provide the composition, it is very difficult to determine the precise composition and stabilization mechanism. The enzymes are absorbed by the clay lattice and are afterwards freed upon exchange with metals cations. They have a significant role in the behaviour of the clay lattice, first causing them to get bigger and then to stiffen (Rauch *et al.*, 2003).

Scholen (1992), proposed that enzymes increase the rate of chemical reaction, which occurs at a much slower speed in the absence of enzymes, without becoming a component of the final product. Research shows that Unconfined compression tests on different soils treated with enzymes were also carried out by (Peng *et al.*, 2011). The treated samples were cured in two different conditions; sealed in polythene and air-dried. No improvement was recorded for soil samples cured in a

sealed condition, whereas a maximum of 10% gain in strength was observed for soil samples cured in an air-dry condition. However, Venkatasubramanian and

Dhinakaran (2011) used three soils with clay content of 20, 12.5, and 8% with PIs of 6.5 and 6% respectively. Increases in unconfined compressive strength from 200% to 400% after 2 weeks and 4 weeks, respectively, and were recorded for the enzyme treated soils. A maximum increase of 450% in unconfined compressive strength was recorded by Shankar *et al.* (2009) when a lateritic soil (LL = 45% and PI = 10%) was treated with 4 times the recommended dosage by the enzyme supplier

TerraZyme. Part of this substantial improvement could have been due to moisture loss because the moisture content at the time of the sample preparation and testing was not mentioned in these two studies.

2 METHODOLOGY

2.1 Materials

Test Soil: The soil sample used for this study was collected from borrow pits around Birigi village, near Lapai-Gwari Community, a suburb of Minna, Niger State, Nigeria using disturbed sampling technique at depths of

0.5m, 1.0m, 1.5 and 2.0 meters from two clusters, A and B. The samples were pulverised and air-dried for further analysis as shown in Plate I.

Plate I: Collection of air dried sample for analysis

Bio-Enzymes: Urease Bio-Enzymes was produced in the Biology Laboratory of the Federal University of Technology Minna. It was extracted from the bacteria *Lysinibacillus fusiformis* Strain and grown in B4 medium.

2.2 Methods

Index properties: Natural moisture content, specific gravities, particle size analysis and Atterberg limits tests were conducted in accordance with tests procedures specified in BS 1377: 1990.

Compaction characteristics: Compaction of clay soil stabilized with and without Bio-Enzymes specimens was conducted in accordance with the guidelines specified in BS 1377 (1990) to compute the required parameters. The Reduced British Standard light (RBSL) compactive effort was used. The RBSL compaction is the energy resulting from 2.5 kg rammer falling through a height of 30 cm onto three layers, each receiving 15 blows.

Unconfined compressive strength (UCS): The UCS test was conducted in accordance with the procedure specified in BS, 1377: (1990). The clay soil was stabilized with varying percentages of 5, 10, 15 and 20% relative to OMC and compacted with Reduced British Standard Light (2.5 kg Hammer) compactive energy. The compacted specimens were cured for 28 days in the laboratory at temperature of 24 ± 2°C

California bearing ratio (CBR): The soaked CBR of stabilized clay specimens was conducted in accordance with the guidelines specified in BS 1377 (1990) to compute the required parameters as shown in Plate II. 6 kg of pulverized mixed samples divided to five parts were poured into CBR mould and rammed with 4.5 kg rammer into five layers, each receiving 62 blows. The attached upper and lower dial gauges measures the upper and lower penetrations of the plunger.

Plate II: California bearing ratio test of sample

Table 1: Physical Properties of Urease Enzymes

Identification as it appears	Urease Enzymes
Hazardous Compounds	None
Boiling point	100°C
Specific Gravity	2.70
Evaporation Rate	Same as water
Melting Point	Liquid
Solubility in water	Complete
Colour	Amber
Odour	Non-Obnoxious

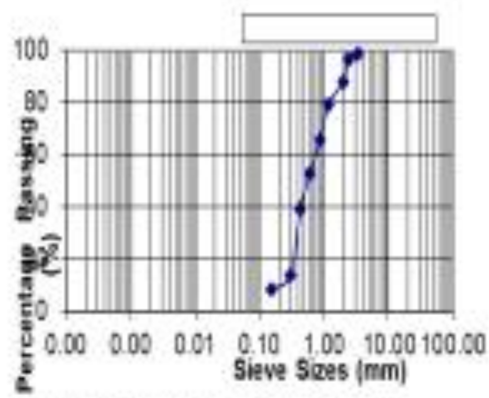

Figure 1: Sieve Analysis of A-7-5 Sample

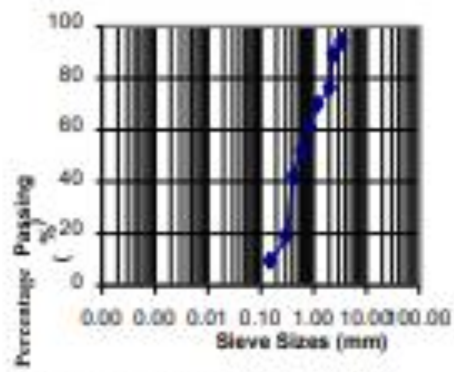

Figure 2: Sieve Analysis of A-7-6 Sample

3.0 RESULTS AND DISCUSSION

Index properties of the natural Soil: The index properties of the natural clay soil and urease enzymes are shown in Figure 1 and Table 1. The fraction passing No 200 sieve is 61.83 and 84.01% for A-7-6 and A-7-5 soils respectively. An average value of 16.9% and 21.6% were obtained as natural moisture content for A-7-6 and A-7-5 soils respectively. The mean Specific gravity for value for

A-7-6 was 2.76g/cm^3 while that for A-7-5 soil was 2.75g/cm^3. The plasticity index of the soils indicates that, the soil is suitable as sub-grade materials in road construction because they fall below the maximum 25% recommended for sub-grade tropical soils by Simon *et al.* (1973). The soil is classified as CL or, A – 7 – 6 and A – 7 – 5 according to Unified Soil Classification and AASHTO soil classification systems respectively (AASHTO, 1986; ASTM, 1992).

According to Kestler (2009), enzymes may work suitably for soils containing 12–24% clay fraction with a plasticity index between 8 and 35. Sample A and B soil fall into this category, and therefore are quite fitting for enzyme functioning and performance in soil stabilization. The properties of the urease enzymes according to Peng *et al.* (2011) is shown in Table 1. The grading curves from the sieve analysis shown in Figures 1 and 2, while the summary of geotechnical properties of the test samples is shown in Table 2.

Table 2: Geotechnical Properties of Natural Soils

Properties (Average)	A A-7-6	B A-7-5
Specific gravity of soil	2.79	2.75
Natural moisture content (%)	16.9	21.6
Atterberg Limits		
Liquid limit (%)	41	50.50
Plastic limit (%)	28.08	35.86
Plasticity index	12.92	14.64
% Passing BS No. 200 sieve	61.83	84.01
Classification		
USCS	CL	CL
AASHTO	A-7-6	A-7-5

Effect of varying dosages of Urease Enzymes on Compaction Characteristics of test soils

Compaction characteristics of soft clay soil (untreated) were determined using the standard compaction effort (ASTM D698), and the same procedure was used to identify any change in compaction characteristics due to enzymes. The result is shown in Table 4. Three important factors that affect the compaction of soil are moisture content, soil type, and compaction effort. The OMC and MDD for the compacted soil stabilized with 0% enzymes are 12. 60% and 1.91g/cm³ as well as 17.20% and 1.72g/cm3 for A-7-6 soil and A-7-5 clay soils respectively.

For A-7-6 soils, there is a decrease in OMC from 12.60 to 10.80 due to the addition of 5% enzymes which further increased to 10.50% OMC with an increase of 10% enzymes. This is accompanied with a considerable increase of MDD from 1.91glcm³ to 1.98g/cm3 for A-76 soils. The same decrease in OMC and increase in MDD is observed with A-7-5 soils up to 20% enzymes. It is observed that the OMC for both A-7 sub-class soils decreases with increasing MDD.

It is seen that after the addition of urease enzymes, the OMC decreases and maximum dry density increases for both A-7-6 and A-7-5 soils. It indicates that the voids between the soil particles have decreased and the soil has achieved greater compaction at minimal compactive effort. The variation in compaction parameters of stabilized soil is shown in Table 3.

Table 3: Compaction parameters of Urease Enzymes stabilized soil

Sample Enzyme %	A-7-6 OMC% MDD(g/cm³)	MDD(g/cm³)	A-7-5 OMC (%)	
0	12.60	1.91	17.20	1.72
5	10.80	1.95	17.00	1.76
10	10.50	1.97	15.00	1.79
15	9.70	1.98	15.20	1.80
20	9.60	1.97	14.50	1.78

Effect of varying dosages of Urease Enzymes on Soaked California Bearing Ratio (CBR)

The results of the soaked CBR is displayed in Table 4.0 which influence of soaking is evident in the results obtained. Both the CBR and UCS are often used to estimate the bearing capacity of highway sub-grade and sub-base soils (Gidigasu, 1980). Urease Enzymes was added in varying percentages of 5, 10, 15 and 20% and soaked for 28 days. The CBR values are shown graphically in Figure 3. It is evident that the CBR values increases with the increase in urease dosage.

Enzymes primarily attaches to the clay molecules, alters clay molecules and later detaches itself from the modified clay by shifting to its original form after the completion of the reaction. When an enzyme-substrate complex is formed, the enzymes convert the local conditions in the reaction site entirely different to those outside the reaction site. This way, the changes in pH and temperature do not hinder the clay modification. The improvement in soaked CBR Values is due to modification of clay molecules. With the addition of 5% enzymes, the soaked CBR values increased to 29.01 and 17.48 % for A-7-6 and A-7-5 soils respectively. There is a progressive increase to 45.11 and 41.79 % with an increase to 20% enzymes for both A-7-6 and A-7-5 soils respectively. It is observed that the increase effect is more on A-7-6 soils than A-7-5 soils generally. Therefore enzyme stabilization increased the CBR of A-7-6 by 116.98% (from 20.79 to 45.11%), and A-7-5 by 315.41% (from 10.06 to 41.79%). With the CBR values of 45.11% and 41.79%, these enzyme-stabilized clay are suitable for road base and sub-base application according to FMWH (1997) and Nigerian General Specification (1997).

Table 4: Variation California Bearing Ratio (Soaked) with Urease Enzymes

Sample	A-7-6	Cum. Incr.	A-7-5	Cum. Incr.
Urease %	CBR %	CBR %	CBR %	CBR%
0	20.79	0	10.06	0
5	29.01	28	17.48	42
10	31.81	37	20.17	55
15	38.07	53	32.32	93
20	45.11	69	41.79	116

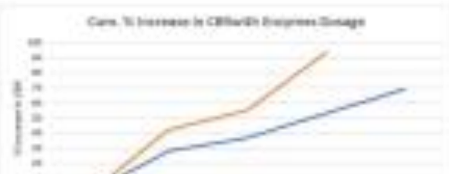

Figure 3: CBR values of enzymes-stabilized clay

Effect of varying dosages of Urease Enzymes on Unconfined Compressive Strength (UCS)

The Unconfined Compressive Strength of soft clay soil was evaluated by stabilization with different dosages of urease at 5, 10, 15 and 20% and cured in desiccators for 28 days.

The positive effect of curing is evident in the observed values of Unconfined Compressive Strength (UCS) as displayed in Table 5.0 The UCS was observed to increase with the increase in the enzyme percentage for samples A-7-6 and A-7-5 both cured for 28 days. This phenomenon according to Adeyemi and Abolarin (2000) is as a result of moisture affinity of grains of soil attributable to surface chemical reaction. Figure 4.0 presents the Unconfined Compressive Strength of A-7-6 and A-7-5 soils stabilized with and without urease and the effect of curing on the Unconfined Compressive Strength Value.

The Unconfined Compressive Strength of A-7-6 stabilized with urease has shown tremendous improvement with increase in dosage amount. The Unconfined Compressive Strength of 0% enzymes soil was 232.3 and 370.04 kN/m^2 for A-7-6 and A-7-5 soils respectively. There is a progressive increase from 349.40 to 407.73 kN/m^2 with 5-20% increase of urease enzymes on A-7-6. A similar increase is observed on A-7-5 soil from 463.50 to 576.64 kN/m^2 with 5 to 20% increase in enzymes. The increment was noticed after the both samples were cured after 28 days as shown in Table 5 and Figure 4.

Table 5: UCS of enzymes stabilized clay soil

Sample	A-7-6	Cum.% Incr. in	A-7-5	Cum% Incr. in
Urease %	UCS (kN/m^2)	UCS	UCS (kN/m^2	UCS
0	232.30	0	370.04	0
5	349.40	34	463.50	20
10	357.58	36	529.60	32
15	372.27	40	553.97	36
20	407.73	49	576.64	40

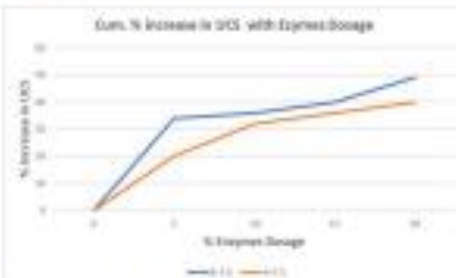

Figure 4: Increase in UCS with enzymes dosage

4 CONCLUSION

An investigation into the effect of increasing Urease Enzymes content on the geotechnical properties of some soft clay from Lapai-Gwari Borrow pit in Birigi Community, Niger State led to the following conclusions.

Stabilization of the soils with urease enzymes increased the MDD, CBR and thus produced denser and stronger samples while there was a reduction in OMC as enzyme was increasingly added.

With the use of Urease enzyme, the strength of the soil increases which is evident by the increase in UCS and CBR values. Urease enzyme decreases the voids between the soil particles and thus increases the compaction and density of the soil.

The CBR value for the 0% enzymes stabilized soil was found to be 20.79 and 10.06% for A-7-6 and A-7-5 soils respectively. When soaked for 28 days with the addition of urease enzymes from 5% to 20%, there was an increase in the CBR value to 45.11 and 41.79% for A-7-6 and A7-5 soils respectively. Enzyme stabilization increased the CBR of A-7-6 by 116.98% (from 20.79 to 45.11%), and A-7-5 by 315.41% (from 10.06 to 41.79%). With the CBR values of 45.11% and

41.79%, these enzyme-stabilized clay are suitable for road base and sub-base application.

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After 28 days curing, there is 150 -175% increment in UCS of A-7-6 with 5-20% of urease enzymes. Similarly a 125 -156% increment in UCS of A-7-5 soil was recorded with 5 -20% urease enzymes.
Thus, Urease enzyme is a satisfactory stabilizing agent for clayey soils. The utilization of the urease enzymes as an alternative to the expensive stabilizing agents, would reduce construction cost. This is more probable in the construction of low - medium traffic volume roads or other construction where these type of problematic clay may be encountered.

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