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# Compressibilty Characteristics of Lateritic Soil Admixed with Coconut Husk Ash and Lime

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***Abstract*** **-This study is aimed at determining the effect on the compressibility characteristics of lateritic soil obtained from Nsukka local government area in Enugu State, Nigeria with coconut husk ash and lime. To undertake this experiment, one dimensional consolidation was carried out on the compacted lateritic soil at optimum moisture content. The coconut husk ash was added in the ratio of 0, 5, 10, 15 and 20% by weight of the lateritic soil while the lime was kept constant at 4% for all mix ratios. Observation from the experiment and analysis of the consolidation parameters such as the void ratio, compression index, coefficient of volume compressibility and the coefficient of consolidation carried out on the various mix ratios clearly indicates that the optimum mix ratio to improve the compressive characteristics was 5% coconut husk ash and 4% lime.**

***Keywords- Compressibility; coconut shell ash; compaction; lateritic soil; lime***

## I. INTRODUCTION

Safe disposal of wastes in our society has increasingly posed serious challenges to our environment. Several attempts in recent past have been made towards converting waste into very useful materials. Inadequate disposal and improper handling of the waste could lead to land, air, surface water and groundwater pollution [1]. One of such waste that require proper disposal is the coconut husk which is available in many tropical countries of the world ( [2], [3]) and of which about 90% of it are often thrown away or burnt in open air or some are left to settle in waste pond [4].

According to [5], the coconut husk is that 5-10 cm thick fibrous covering of the coconut fruit which envelops the hard shell structure of 3.5 mm thickness and its external appearance husk varies from decidedly dull brown when fully ripe to bright green when immature. The husk is full of long, coarse fibers, all running in one direction. The fibers are embedded in a matrix of material called coir dust. Coconut husk is known to be porous which enables it to absorb or retain water [6]. It can be processed by two main methods described by [5], which are the mechanical and the manual processes, and its husk can be removed from the coconut husk by using a long stick sharpened to a point at one end. The opposite end of the stick must be firmly planted into the ground with the sharpened end pointing up [7].

The coconut husk can be burnt into ash. The ash produced from the burning of the coconut husk is pozzolanic in nature with about 67-70% silica and, approximately 4.9 and 0.95% of aluminium and iron oxides, respectively [8]. A pozzolana as described by the American Society of Testing and Materials (ASTM) is a siliceous or aluminous materials which possess little or no cementitious properties but will react with lime $[Ca(OH)_2]$ at ordinary temperature to form a compound with pozzolanic properties in the presence of moisture.

The pozzolanic nature of the coconut husk ash has been vastly explored in the construction industries mostly in the improvement of strength of concrete or in the manufacturing of concrete blocks. However, only very little research has been conducted in the utilization of coconut husk ash in the areas of geotechnical engineering. One of the very few researches that have been carried out is in the utilization of coconut husk ash in geotechnical engineering is in the stabilization of poor lateritic soil [1]. The research focuses more on the improvement of the California bearing ratio of poor lateritic soil that was collected in Oyo state, Nigeria.

Lateritic soils are highly weathered and altered residual soils formed by the in-situ weathering and decomposition of rocks under tropical condition [9], [10] and [11]. Lateritic soils are rich in sesquioxides ($Fe_2O_3$ or $Al_2O_3$; or both) and low in bases. Their engineering properties are highly influenced by the presence of sesquioxides which appear to act as cementing agents that bind the other mineral constituents into clusters or aggregations [12].

The lateritic soil could be problematic or non problematic [12]. The problematic laterites consists of lateritic clays with high natural water contents and liquid limits, low natural densities and friable and/or crumble structure [13]. Due to this inherent negative quality of the problematic lateritic soil, proper treatment and study of the soil has to be undertaken before any structure is placed on it otherwise this could adversely undermine the integrity of the structure. One of such study is the compressibility characteristics of the soil.

However, very little literature exists on the compressibility characteristics of compacted lateritic soil. Several other tests such as the effect of rice husk ash on the permeability of lateritic soil have been carried out by [14] on the lateritic soil with less attention on the compressibility characteristics of the soil. This research therefore aims at studying the effect of the coconut husk ash and lime when added to lateritic soil and obtaining the resulting compressibility characteristics of the soil.

## II. MATERIALS AND METHOD

### A. *Materials*

#### *(a) Lateritic Soil*

The lateritic soil used in this research was collected through disturbed sampling method with the help of hand trowel from Nsukka (latitude: 6º 5ˈ 24ˈˈN and longitude: 7º 23ˈ 45ˈˈE) opposite the University of Nigeria, Nsukka (UNN) main gate. Hand hammer was used to pulverize the collected lateritic soil. After pulverizing the lateritic soil, it was carefully placed in an air tight bag to avoid ingress of moisture. The collected sample was immediately conveyed to the University of Nigeria, Nsukka (UNN) Laboratory where the various tests were carried out. The samples were then sieved through an aperture size of 20mm in accordance with [16]. Also, oxides composition of the lateritic soil was carried out using the X-ray Flourescence Spectrometer Method at the centre for Energy Research Technology (CERT), Amadu Bello University of Zaria, Nigeria. The oxides composition from table 1 shows that the soil has a high abundance of sesquioxides ($Fe_2O_3$ or $Al_2O_3$).

Table 1: Chemical composition of the lateritic soil

| Oxides | $SiO_2$ | $Al_2O_3$ | $P_2O_5$ | $SO_3$ | $Na_2O$ | $K_2O$ | CaO | MgO | $TiO_2$ | MnO | $Fe_2O_3$ | L.O.I |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chemical composition (%) | 32.99 | 29.44 | 0.02 | - | 0.05 | 0.27 | 1.14 | 0.07 | 1.31 | 0.02 | 24.56 | 10.12 |

#### *(b) Coconut Husk Ash*

The coconut was collected from Enugu-Eke, Eke town in Udi local government area of Enugu state, Nigeria. The husk which is one of the three constituent of the coconut was separated from the coconut using the manual process described by [7]. Other constituents of the coconut include the shell and copra also known as the meat of the coconut. The three constituent are shown in plate 1. Burning of the coconut husk was done in a furnace whose temperature was maintained at 700ºC for about 7-8 hours until it was completely reduced to ash. The resulting coconut husk ash (CHA) produced was carefully scooped out with hand trowel and poured into an air tight bag and sealed to prevent moisture from gaining entrance into it throughout the duration of the experiment.

Table 2 shows the result of the oxide composition of the coconut husk ash carried out in the same place as the lateritic soil. The oxide composition clearly indicates that the CHA is a class C pozzolan. A class pozzolan according to ASTM C6 18 has a combination of $SiO_3$+ $Al_2O_3$+ $Fe_2O_3$ greater than 50% and a loss on ignition to be less than 6%.

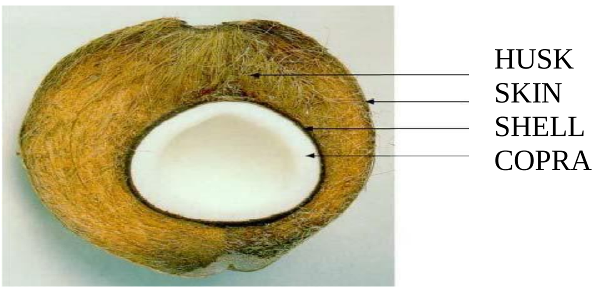


Plate 1: Different layers of coconut.

Table 2: Chemical composition of the coconut husk ash

| Oxides | $SiO_2$ | $Al_2O_3$ | $P_2O_5$ | $SO_3$ | $Na_2O$ | $K_2O$ | CaO | MgO | $TiO_2$ | MnO | $Fe_2O_3$ | L.O.I |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chemical composition (%) | 37.00 | 7.74 | 2.62 | 0.79 | 0.24 | 43.62 | 2.14 | 0.21 | 0.04 | - | 5.56 | N/A |

*(c) Lime*

Lime used for this study was calcium oxide (CaO) also known as quicklime or burnt lime. It is a white, caustic, alkaline, crystalline solid at room temperature (http://en.wikipedia.org/wiki/Calcium_oxide). It is relatively inexpensive and it is manufactured by heating limestone, coral, sea shells, or chalk, which are mainly $CaCO_3$, to drive off carbon dioxide. It has a melting point of 2600$^oC$ .

*B. Methods of testing*

The method described by [16] for the determination of geotechnical properties of soils was adopted in this research. Sieve analysis, atterberg's limit, specific gravity, differential free swell, compaction and consolidation were carried out on the natural lateritic soil and the mixture of lateritic soil + coconut husk ash + lime. The coconut husk ash was added in the ratio of 0, 4, 8, 12, 16 and 20% by weight of the black cotton soil. The lime percentage was kept at 4% for all mix ratios.

*(a) Specific gravity*

Specific gravity of the samples was determined using the method described by BS 1377: Part 2: 1990. The specific gravity of the natural soil sample and that of optimum mix for lateritic soil + CHA + lime were determined in this study.

*(b) Atterberg's Limit test*

Atterberg limits on the natural lateritic soil and that of the optimum mix ratio for lateritic soil + CHA + lime were carried out as described by BS 1377: Part 2: 1990 for proper identification and classification of the soil. The classification methods used in the experiment are the American Association for highway and Testing Organization (AASHTO) and the unified soil classification system (USCS).

*(c) Compaction test*

The standard proctor test described by BS 1377: Part 4: 1990 was employed in determination of the compaction characteristic of the natural lateritic soil and also for other mix ratios. The optimum moisture content at which the individual maximum dry density was attained for the various mix ratios was derived from the proctor test carried out on them.

*(d) Consolidation test*

BS 1377: Part 6: 1990 description for the one dimensional consolidation was used for the consolidation characteristics. Before carrying the test, the sample was air-dried and then sieved through 4.75mm sieve size aperture. Consolidation was carried out on the natural lateritic soil and also on the various mix ratios. The samples in the oedometer ring during the course of the consolidation experiment were subjected to a pressure increment of 10 KN/m, 25 KN/m, 50 KN/m, 100 KN/m and 200KN/m$^2$. The height of solid method was then used to analyze the results for the void ratio, compression index and coefficient of volume compressibility while the coefficient of consolidation was analyzed using Taylor's square root of time fitting method.

## III. RESULTS AND DISCUSSION

*A. Preliminary results*

The index properties of the natural lateritic soil are shown in table 3. It shows that natural lateritic soil has a liquid limit of 42.0 and a plasticity index of 10.84. According to Atterberg (1911) on the classification of plasticity of soil based on their plasticity index, a soil whose plasticity is between 7 to17 has a medium plasticity. Also, from table 3, the percentage of fines was found to be 92.04. The high percentage of fine together with the medium plasticity indicates that the soil needs to be treated before construction work can be carried out on it.

Table 3: Index properties of the natural soil before stabilization

| S/No | Property | Value |
|---|---|---|
| 1 | Specific Gravity | 2.71 |
| 2 | Natural Moisture Content (%) | 7.2 |
| 3 | Percent passing sieve No. 200 | 24 |
| 3 | Liquid Limit (%) | 42.0 |
| 4 | Plastic Limit (%) | 31.16 |
| 5 | Plasticity Index (%) | 10.84 |
| 6 | AASHTO Classification | A-2-7 |
| 7 | USCS Classification | SP |
| 8 | Group Index | 6 |
| 9 | Maximum Dry Density (Kg/m$^3$) | 1.77 |
| 10 | Optimum Moisture Content (%) | 16 |
| 11 | Colour | Brown |
| 12 | Percentage of fines | 92.04 |
| 13 | Compression index | 0.505 |

*B. Compaction characteristics*

The compaction characteristics of the lateritic soil with CHA + 4%lime are shown in Figures 1 and 2. It is observed that the Maximum Dry Density (MDD) decreased with increased CHA content for up to 20% treatment. The MDD decrease was from 1.75g/cm$^3$ to 1.54g/m$^3$ at 20% CHA content. Also, the Optimum Moisture Content (OMC) increased from 15.96% to 23.5%. The reduction in the MDD shown in figure 1 was because the addition of CHA-4%lime to the soil induces friction between the soil particles and the mix, thus leading to a weak bond between them and thereby generating a larger void than expected which eventually leads to a reduction in the MDD.

While in figure 2, the increase observed in the OMC could be attributed to the increase in the CHA-lime mix whose additional increase results in binding the lateritic soil and the CHA –lime mix reducing friction thereby rearranging the particle matrix to form a more stable and coarser material. The overall process thus requires an additional water to be absorbed as the CHA-lime mix increases.

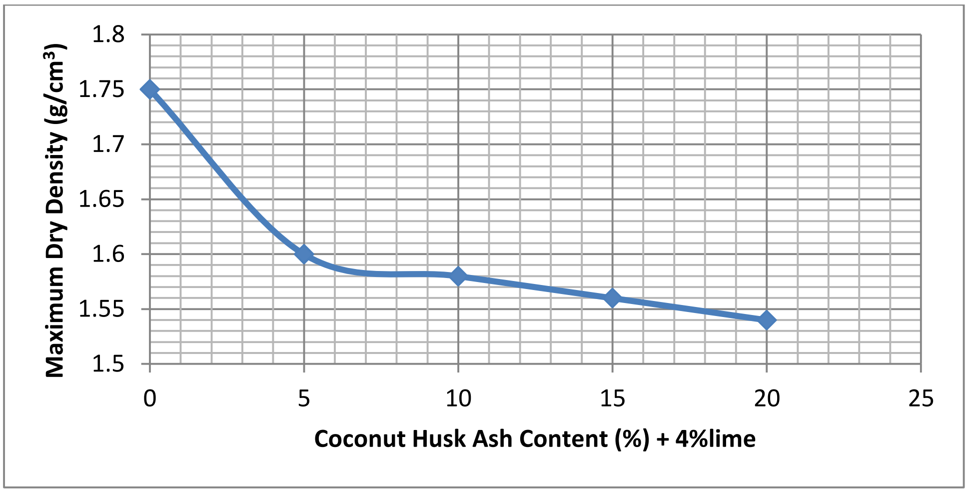


Figure 1: Maximum dry density against CHA content

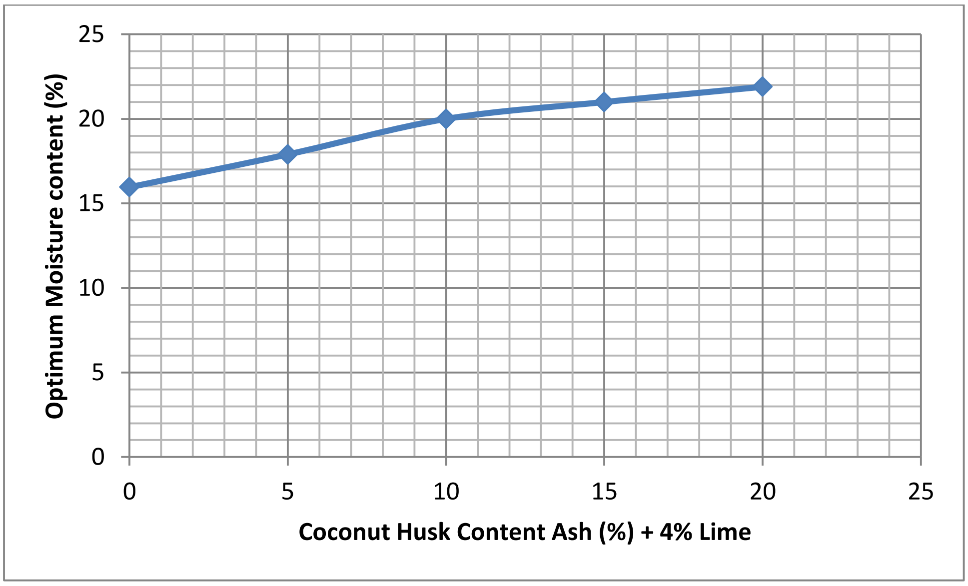


Figure 2: Optimum moisture content against CHA + 4% lime content

*C. Consolidation characteristics*

*(a) Void ratio*

The graph of void ratio against pressure is shown in figure 3. The void ratio decreased with increased pressure during the loading stage from 10kN/m$^2$ to 200kN/m$^2$ for all curves for each of the CHA-lime mix. The uniform decrease observed in the void ratio for all the curves for the various mix is as a result of the rearrangement of the soil particles when pressed together thereby expelling air from the voids. The mix ratio of 5% CHA + 4% Lime proved to be more effective as there was a significant drop in the void ratio of from the curve.

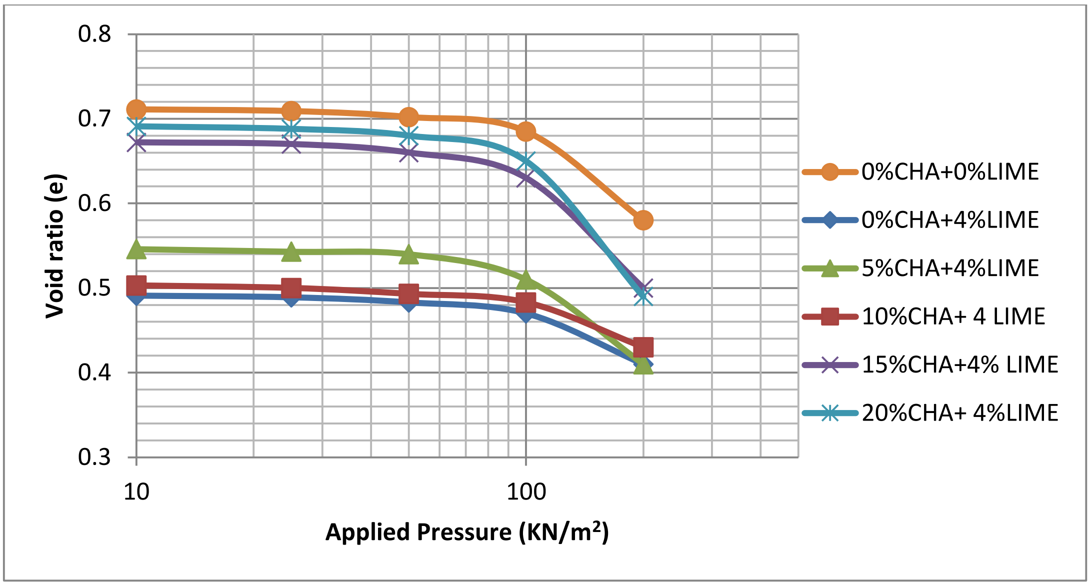


Figure 3: Void ratio against applied pressure

*(b) Coefficient of volume compressibility*

As can be seen in figure 4, there was a decrease in the volume of compressibility from 0% to 5% upon the addition of CHA + 4%lime and latter it increases gradually till it got to 10% CHA + 4%lime before a noticeable drop in the volume of compressibility. The initial decrease in the volume of compressibility could be as a result of the quick pozzolanic action taking place between the lateritic soil and the CHA +4% lime mixture under the influence of the initial applied pressure on the mixture making the soil to assume a more compact and stable state by forming a strong bond between the lateritic soil and the additive.

In figure 5, all the curves in the graph show a similar trend as there was an initial increase in the volume of compressibility with a corresponding increase in pressure. This increase in the volume of compressibility observed for each of the curves could be as a result in the soil additive matrix.

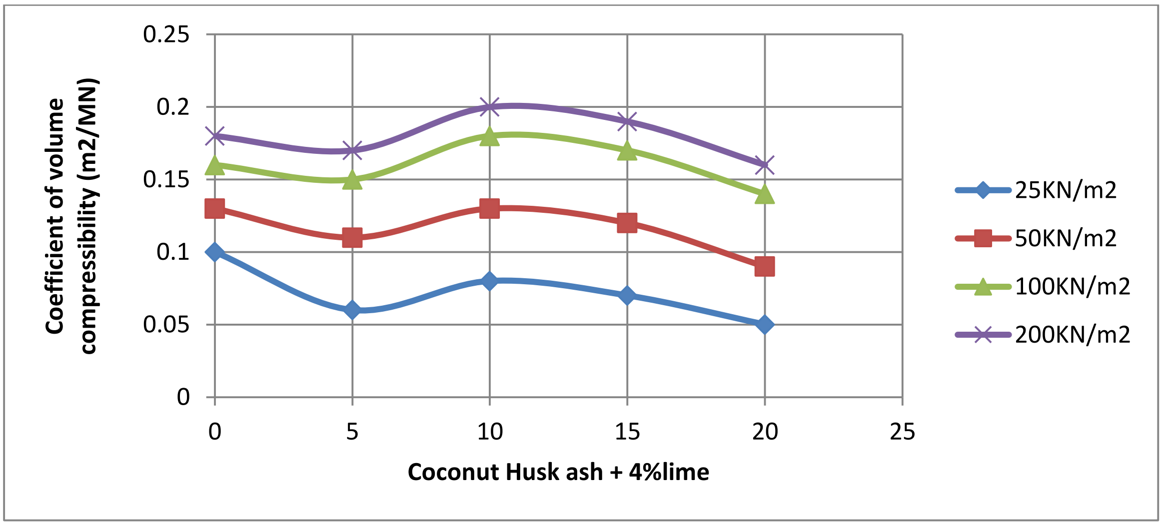


Figure 4: Coefficient of volume compressibility against CHA content

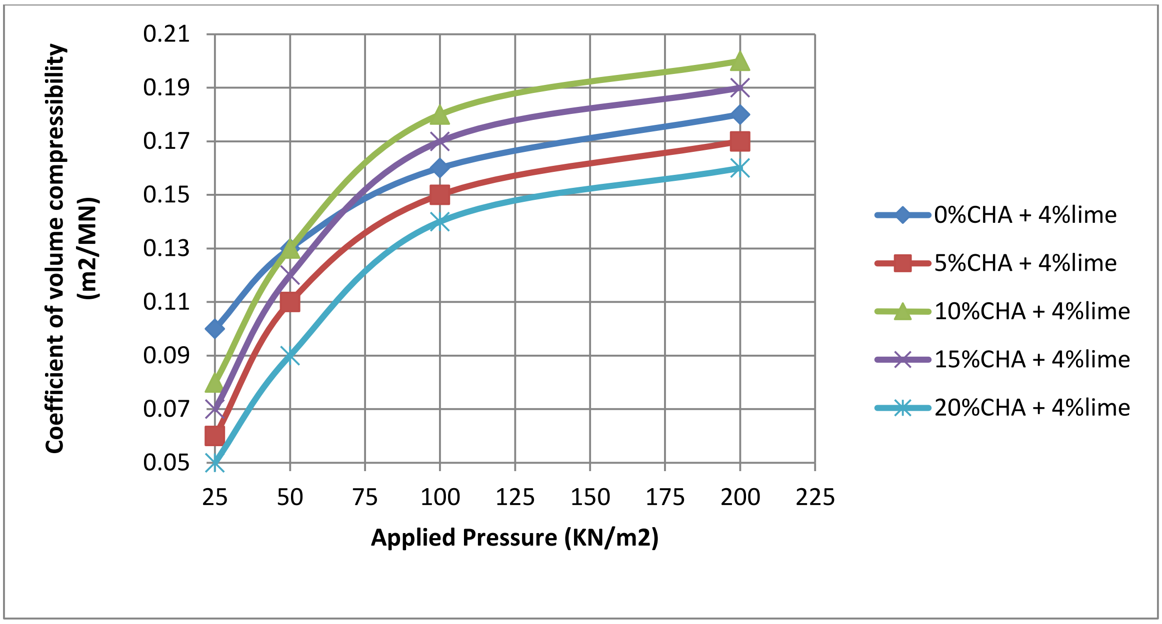


Figure 5: Coefficient of volume compressibility against applied pressure

*(c) Coefficient of consolidation*

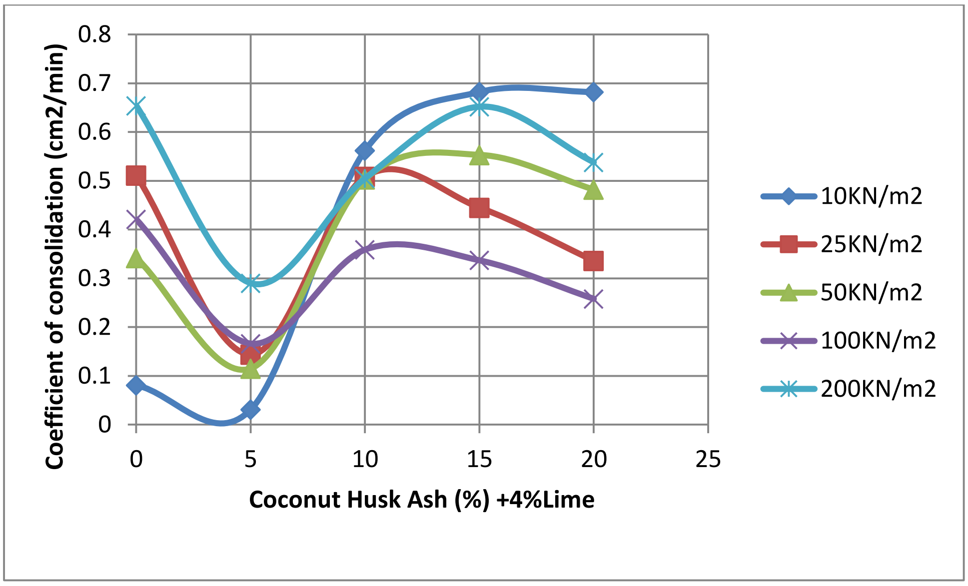


Figure 6: Coefficient of consolidation against CHA + 4% Lime content

From figure 6 there was an initial decrease in the coefficient of consolidation due to the expulsion of air from the soil particles as a result of the rearrangement of the soil particles to form a more stable mass upon the addition of 5% CHA and 4%lime and also as a result of the coating of the particles with the additive thereby forming a larger mass which later led to the increase in the particle size forming a larger void among the particles in the process and subsequent increase in the coefficient of consolidation.

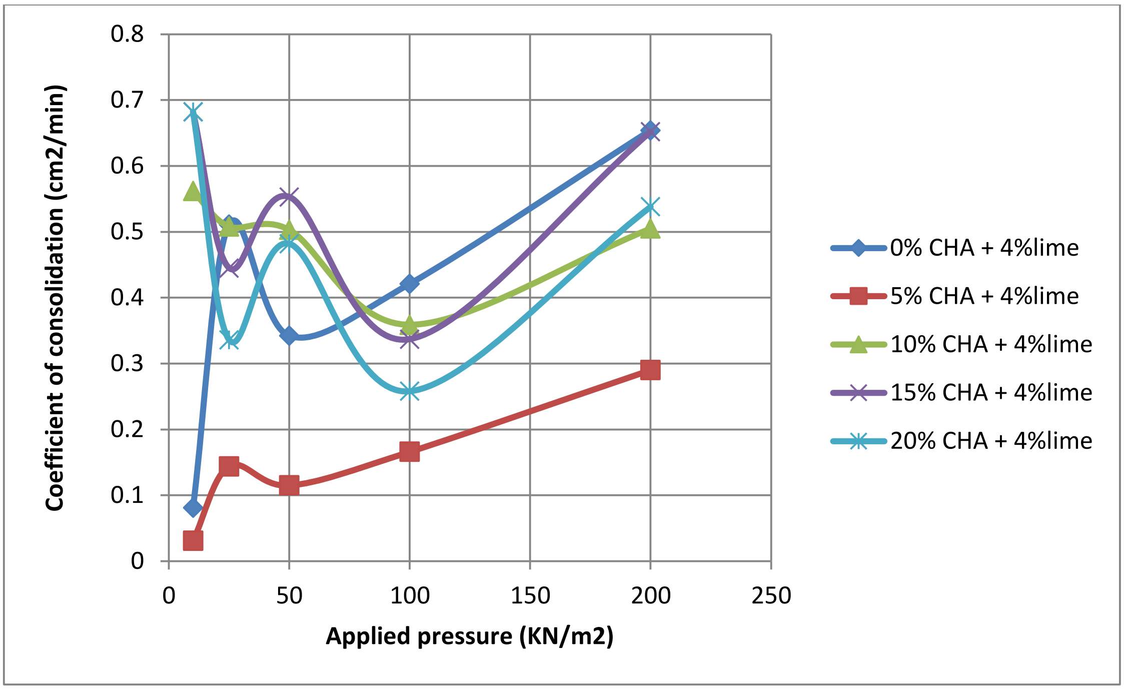


Figure 7: Coefficient of consolidation against applied pressure

*(d) Compression index*

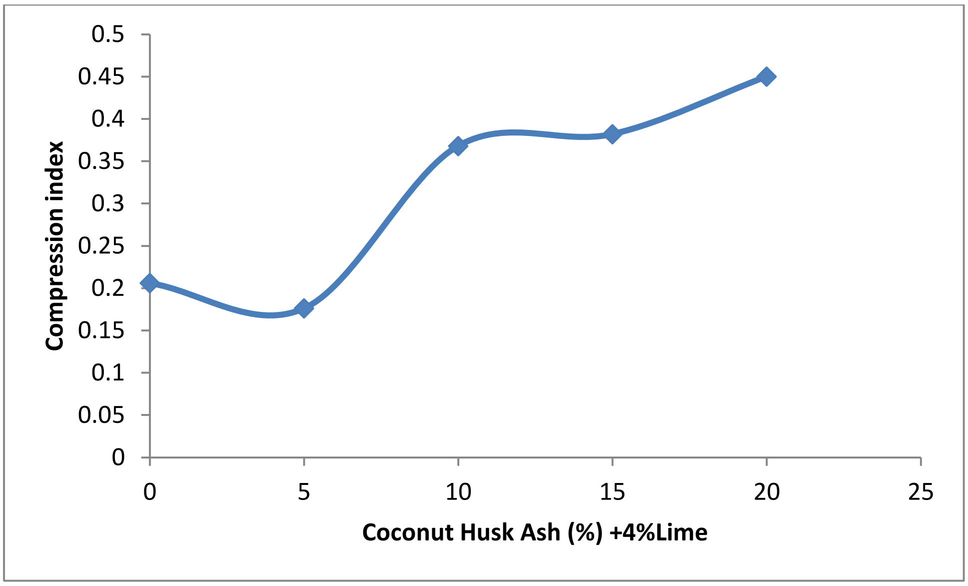


Figure 8: Compression index against coconut husk ash (%) + 4%lime

Figure 8 shows that there was a decrease in the value of the compression index at 5% CHA and which increased thereafter with the addition of more additive. The initial reduction in the compression index is as a result of the agglomeration and flocculation of the coconut husk ash and lime with the lateritic soil until it got to a fixation point where further increase of additive in the mixture does not cause any corresponding reduction in the compression index. This agglomeration of the particles resulted in the mixture forming a larger void than expected thus leading to an increase in the compression index of the overall mixture

### *D. Optimum Mix Ratio Characteristics*

Table 4: Optimum mix ratio with lateritic soil

| S/No | Property | Value |
|---|---|---|
| 1 | Specific gravity | 2.78 |
| 2 | Liquid limit (%) | 33.0 |
| 3 | Plastic limit (%) | 27.0 |
| 4 | Plasticity Index (%) | 6.0 |

Table 4 shows the optimum mix ratio (5%CHA +4% lime) with the lateritic soil. The results indicate that there was an improvement in the geotechnical properties of the lateritic soil. The Specific gravity of the soil was found to have increased and there was a great reduction in the plasticity index when compared to the result obtained from the natural lateritic soil.

## IV. CONCLUSION

Based on the observation from the results obtained from the various test on the compressibility of the lateritic soil admixed with coconut husk ash and lime, it can be deduced that the mixture of 5%CHA and 4% lime to the lateritic soil would produced effective result for both the compaction and compressibility characteristics.

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