# STABILISATION OF CLAY SOIL WITH LIME AND MELON HUSK ASH FOR USE IN FARM STRUCTURES

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**Abstract**
The rising cost of traditional stabilising agents and the need for economical utilisation of industrial and agricultural waste for beneficial engineering purposes has encouraged an investigation into the stabilization of clay soil with lime and melon husk ash. The chemical composition of the melon husk ash that was used in stabilising clay soil was determined. The clay soil was divided into two parts, one part was used to determine the index properties while the other part was treated at British Standard Light (BSL) compaction energy with 0 %, 2 %, 4 %, 6 % and 8 % melon husk ash by dry weight of the soil and each was admixed with 2 %, 4 %, 6 % and 8 % lime. The stabilised clay soil was cured for 7, 14 and 28 days before the unconfined compressive strength were determined while the coefficients of permeability of the stabilised clay soil were also determined at 28 days of curing. The data obtained from the experiment was subjected to analysis of variance to examine the significance at 5% level. Results showed that the natural clay soil belong to A-7-6 or CH (clay of high plasticity) in the American Association of State Highway Transportation Official (AASHTO) and Unified Soil Classification System (1986). The chemical composition of the ash had aluminum oxide, iron oxide and silicon dioxide values of 18.5%, 2.82% and 51.24% respectively. The unconfined compressive strength and coefficient of permeability of the natural clay soil was determined to be 285 $kN/m^2$ and 1.45 x $10^{-5}$ cm/s, respectively. Increase in melon husk ash and lime percent increases the unconfined compressive strength (UCS) of the stabilised clay soil significantly ($p < 0.05$) and decrease the coefficient of permeability when compared with the natural clay soil. The peak values of unconfined compressive strength for 7, 14 and 28 days of curing are 1200 $kN/m^2$, 1598 $kN/m^2$ and 1695 $kN/m^2$ respectively at 6% MHA and 8% lime content while the lowest value for coefficient of permeability was 0.98 x $10^{-6}$ cm/s at 6% MHA and 8% lime. These results indicate that 6% MHA can be used to increase UCS and reduce permeability of the clay soil.

**Keywords:** Lime, melon husk ash, unconfined compressive strength, coefficient of permeability

## 1. Introduction

Clay is an impermeable soil, as opposed to permeable soil that allows water to rapidly drain, like gravel or sand. It is also an expansive soil and is formed under the conditions of poor drainage from basic rocks or limestone under alternating wet or dry climatic conditions (Koteswara *et al.,* 2012). Clay usually exhibits high shrink-swell characteristics with surface cracks, opening during the dry seasons which are more than 50mm or more wide and several mm deep. These cracks close during the wet season and an uneven soil surface is produced by irregular swelling and heaving (Ijimdiya *et al.*, 2012).

Moderately saturated clayey soils having high plasticity are very sensitive to variations in water content and show excessive volume changes. When such soils increase in volume because of an increase in water contents, they are classified as expansive soils. This highly plastic soil may create cracks and damage on the pavements, railways, highway embankments, roadways, building foundations, channel and reservoir linings, irrigation systems, water lines and sewer lines (Grytan *et al.*, 2012). So, highly plastic soil exhibits undesirable engineering properties under load. They have low shear strengths and tend to lose shear strength further upon wetting or other physical disturbances. Therefore, these plastic soils are very prone to shear failure due to the constant load over time and are considered poor material for foundations (Liu and Evett, 2008).

Soft soil environment is characterized by low strength and show a large deformation upon loading so that they do not suit the designed engineering properties, hence require reinforcement treatments. One of the indications for soft soil is undrained shear strength smaller than 40kPa. According to the classification in Nederlander norm (NEN) 6740 standard the soil types which suit this indication and considered to be weak are primarily peat and clay (NEN, 2006). The ground improvement methods for the soft soil can be categorised according to the mode of treating the soil. Mass improvement is the method that is capable of improving the soil by modifying either its physical or chemical properties or both in such a way that the soil becomes reliable hence increasing the strength and reducing deformability and permeability. This can be done by compaction or consolidation acceleration methods or by stabilising reagents. The most accepted chemical binders are lime and cement and their task is to bind the particles and aggregate together thus improving the soil structure and properties, While the compactions and consolidation methods take rather a long time for the soil to consolidate (months to years) especially with the cohesive soil, the stabilising reagents effect can be seen immediately and after one week the site could be ready for construction (Barends, 2011).

Numerous researchers have concluded that the severity and extent of damage inflicted by soil deposits of swelling nature, to various structures, throughout the world (Ganapathy, 2000; Agarwala and Khanna, 2005; Abduljauwad, 2003). Improving the strength of soil by stabilisation technique was performed by PrasadaRaju (2004) and Bansal *et al.,* (2011). The loss caused due to damaged structures proved the need for more reliable investigation, of such soils and necessary methods to eliminate or reduce the effect of soil volume change. Over the time, there are two main materials used for soil stabilisation, these are cement and lime. The prices of these materials keep increasing due to the high increase in energy cost since 1970s (Neville, 2000). This situation motivated researches aimed at finding alternative soil stabilising materials especially those that are locally available and less costly (Mustapha 2005; Alhassan, 2005; Oyetola and Abdullahi 2006). This study was aimed at evaluating the effect of melon husk ash and lime on stabilized clay soil.

## 2. Materials and Test Procedure

### *2.1 Materials Used*

The soil samples used in this investigation were collected from a borrow pit located at kuyi village 3km from Maikunkele (latitude 90 37’N and 60 33’E) along Minna- Zungeru road, using the method of disturbed sampling at a depth of 1.5 to 2.0 meters. A study of the geological and soil maps of Nigeria by Akintola (1982) showed that the samples taken belonged to the group of ferruginous tropical soils derived from acid metamorphic and igneous rocks. Industrial hydrated lime was used in this study, which has high content of calcium and < 5 % magnesium oxides in accordance with O’Flaherty (1974). The melon husk used in this study was sourced locally from melon millers at Kpakungu Minna, Niger state, Nigeria. The melon husk was burnt at a temperature of 500 $^{0}$C to 700 $^{0}$C in a furnace to obtain its ash. The ash was sieved through 75µmm British Standard (BS) sieve after grinding in line with Murat (2013). The ash was subjected to further analysis and its resultant oxide composition was confirmed.

### *2.2 Preparation of Specimens and Test Procedure*

The soil-lime-Melon Husk Ash (MHA) mixtures used for permeability test specimens were obtained by first thoroughly mixing dry predetermined quantities of pulverized soil, lime and MHA to obtain a uniform mix. The required quantity of water which is determined from the moisture-density relation for the soil-lime-MHA mixtures was then added and the mixing continued. After compaction, the specimens and molds were placed in transparent cellophane bags which were sealed and then cured for 28 days at 21 °C temperature. After the curing, the specimens and the molds were removed from the sealed cellophane bags for permeability test in accordance with Alhassan (2008). According to the requirements of ASTM D5102 (2009) cylindrical specimens with 38 mm diameter and 80 mm height were used for the unconfined compressive strength (UCS) test. Then, clay, lime and MHA were thoroughly mixed in dry conditions for every combination. Water was added to the mixture according to the optimum moisture content value for each mix. This mixture was divided into five portions and each portion was compacted in a 16 mm layer in a mold of 38 mm inner diameter and 80 mm length with additional detachable collars at both ends. After removal of the compacted specimen from the mold, the sample was then wrapped with a plastic membrane in a curing box for 7, 14 and 28 days at 21 °C temperature (Murat, 2013).

The compaction mold with the specimen in it was used as part of the permeameter in order to eliminate disturbance of the specimens on extrusion from the molds. The falling head test was used for the analysis. In order to carry out the permeability tests, the specimens were first saturated in the molds. The saturation process involved placing the permeameter in a small water container. The permeability tests were performed in accordance with Anon, (1990) and the coefficient of permeability reported are the average of ten tests per specimen performed on three specimens for any given soil-lime-MHA mixtures. Unconfined compressive strength (UCS) tests were conducted under strain-controlled condition at constant loading rate of 1.0 mm per min, in accordance with ASTM D2166 (2006). The loading was continued until the axial strain ($\varepsilon$) value of lime-melon husk ash additive samples was 15% or when the samples fail.

### *2.3 Statistical Analysis*

The results obtained from the unconfined compressive strength and permeability test were subjected to statistical analysis. The analysis took into consideration the effects of variation in proportion of the melon husk ash and lime on the unconfined compressive strength and permeability of the stabilized clay soil; two – way Anova (analysis of variance) was used to establish the presence or absence of significance in proportion of the variables at 5 % level of significance.

## 3. Results and Discussion

### *3.1 Soil Identification*

The index properties of the natural soil are presented in Table 1. The overall index properties of the soil show that it can be classified under the A-7-6 subgroup of the AASHTO (1986) soil classification system and CH (Clay of High Plasticity) in the Unified Soil Classification System. It is a dark grey, well graded soil with liquid limit and plasticity index values of 65.9 % and 43.11 % respectively, suggesting that the soil is highly plastic. Thus, the soil falls below the standard recommended for most geotechnical works (Butcher and Sailie, 1984). It therefore, needs to be stabilised.

Table 1: Properties of the Natural Clay Soil before Treatment

| **Properties** | **Quantity** |
|---|---|
| Natural Moisture Content (%) | 14.41 |
| Specific Gravity | 2.48 |
| Plastic Limit (%) | 25.64 |
| Liquid Limit (%) | 65.9 |
| Plasticity Index (%) | 43.11 |
| AASHTO Classification | A-7-6 |
| USCS | CH |
| Percentage passing BS No 200 sieve | 60.40 |
| Coefficient of Permeability (cm/s) | $1.45 \times 10^{-5}$ |
| Unconfined Compressive Strength ($KN/m^2$) | 285 |
| Maximum Dry Density ($Kg/m^3$) | 1544 |
| Optimum Moisture Content (%) | 17.62 |
| Colour | Dark Grey |

### *3.2 Chemical Analysis of Melon Husk Ash*

Table 2 shows the results of the chemical analysis of melon husk ash. The total percentage composition of aluminum oxide ($Al_2O_3$ = 18.5 %), Iron oxide ($Fe_2O_3$ = 2.82 %) and silicon dioxide ($SiO_2$ = 51.24 %) was found to be 72.56 %. This is more than the minimum requirement for pozzolana (ASTM C 618-94, 1994). The loss on ignition obtained was 5.67 % which is less than the 10.0 % maximum as required for pozzolana (ASTM C 618-94, 1994). This means that it does not contained un-burnt carbon which can reduce its pozzolana activity.

Table 2: Chemical Composition of Melon Husk Ash

| Constituent | Oxide Composition % |
|---|---|
| $SiO_2$ | 51.24 |
| $Al_2O_3$ | 18.5 |
| $Fe_2O_3$ | 2.82 |
| CaO | 15.3 |
| MgO | 6.8 |
| $K_2O$ | 11.43 |
| NaO | 3.4 |
| L.O.I | 5.67 |

L.O.I: Loss on ignition

### 3.3. Compaction Characteristics

*3.3.1 Maximum Dry Density*

The effects of lime and melon husk ash content on the Maximum Dry Density (MDD) of the clay soil are illustrated in Figure 1. The MDD decrease with increase in lime content conforms to the normal trend which is in agreement with earlier findings by (Alhassan, 2008). This decrease resulted from the flocculation and agglomeration of clay particles, caused by the cation exchange reaction, leading to corresponding decrease in dry density as reported by (Lees *et al.*, 1982). The (MDD) further decreases with the introduction and subsequent increase of melon husk ash (MHA) at specified lime contents. This decrease is due to the presence of large, low density aggregate of particles which is in line with Osula (1991) findings.

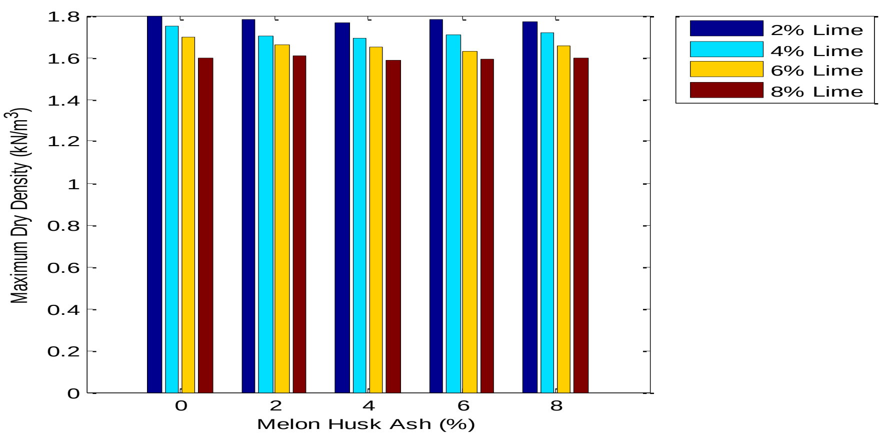


Figure 1: Variation of maximum dry density with melon husk ash and lime content

*3.3.2 Optimum Moisture Content*

Figure 2 shows the optimum moisture content as a function of the melon husk ash and lime content. There is an increase in Optimum Moisture Content (OMC) with increasing lime content. This is in agreement with Osula, (1991) but not in agreement with the work of Osinubi (1998). The reason advanced is that the increased desire for water is somewhat commensurate to the increasing amount of lime as more water is needed for the dissociation of lime into Ca and OH ions to supply more Ca ions for the cation exchange reaction. The OMC increase with the introduction of melon husk ash, this increment could be attributed as a result of increasing demand for water by various cations and the clay mineral particles to undergo hydration reaction (Moses, 2008).

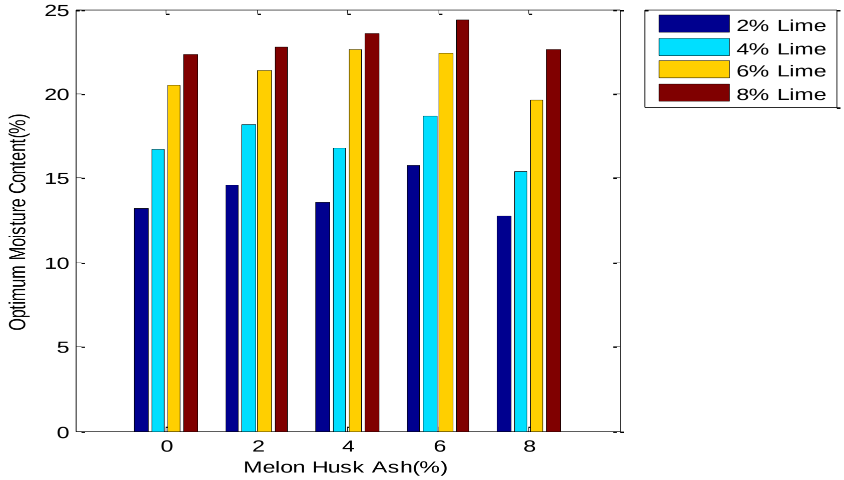


Figure 2: Variation of optimum moisture content with melon husk ash and lime content

### *3.4 Unconfined Compressive Strength*

The effects of each parameter on the results (Unconfined Compressive Strength) of the stabilized clay samples are shown in Figures 3, 4 and 5. There was a tremendous development in the unconfined compressive strength (UCS) with addition of lime and melon husk ash to the natural clay soil when compared with the low UCS value of 285KN/m$^2$ for the natural clay soil. The improvement in strength of the lime and clay soil at 0% melon husk ash contents is in agreement with the earlier findings of Osinubi (1998). This is attributed to soil-lime reaction, which results in the formation of cementitious compounds that binds soil aggregates (Alhassan, 2008).

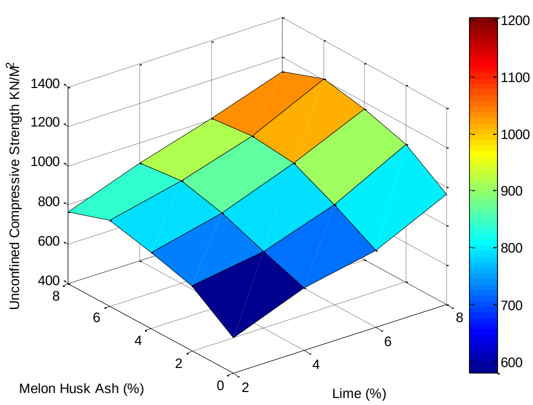


Figure 3: 3D Response surface of variation in 7 days unconfined compressive strength with melon husk ash and lime content

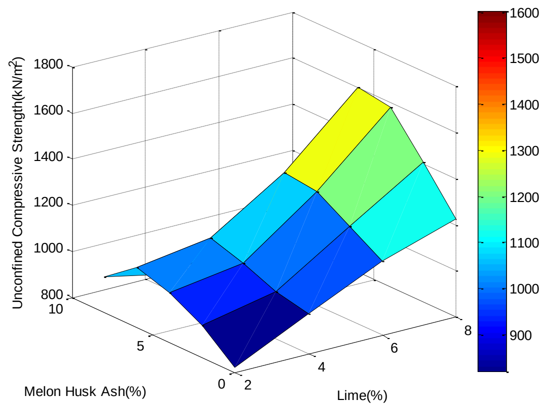


Figure 4: 3D Response surface of variation of 14 days unconfined compressive strength with melon husk ash and lime content

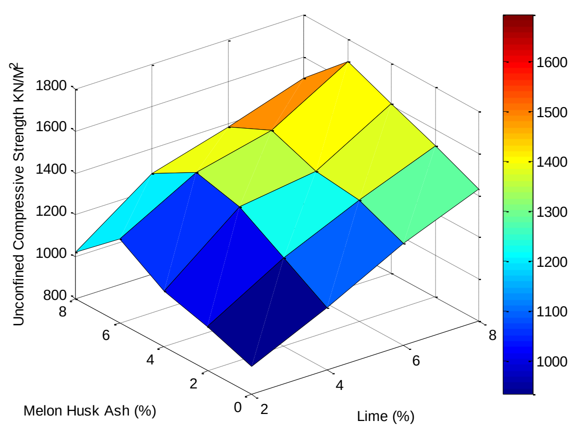


Figure 5: 3D Response surface of variation of 28 days unconfined compressive strength with melon husk ash and lime content

The curing period was fixed and the effect of the melon husk ash and lime were shown. The addition of both lime and MHA was significantly at $p < 0.05$ important on the UCS change (Figs 3 to 4). Using increased lime content without MHA produced high strength at 8% which is 960 KN/m$^2$, while increased MHA content without the lime produced high strength at 6% which is 850 KN/m$^2$ and reduced to 748 KN/m$^2$ at 8%. However, using these two additives together the UCS value increases to 1200 KN/m$^2$ at 6% and then dropped to 1080 KN/m$^2$ at 8%. Considering Figures 4 and 5 the trend is the same with that of Figure 3 but unconfined compressive strength keeps on increasing, This increment of strength could be attributed to curing age and utilization of readily available silica and alumina from melon husk ash by the Calcium from the lime to form cementitious compounds which binds the soil aggregates. The decrease in strength after 6% melon husk ash could be attributed to the excess melon husk ash that could not be utilized for the cementation reaction. ASTM D 4609 (2008) states that if the UCS value reaches 345.0 kPa in any soil, the stabilisation procedure can be considered to be effective. When the limit value was considered, even if the lime content is at minimum percentage of 2 %, the UCS value obtained was more than 760 kN/m$^2$ with increased melon husk ash (8 %).

The ANOVA results of the additives for Unconfined Compressive Strength (UCS) are depicted in Table 3: The p – value for the lime effect is 0.00025. This is a strong indication that the Unconfined Compressive Strength varies from one level of lime to the other level.

Table 3: ANOVA of the Additives (Melon Husk Ash and Lime) for Unconfined Compressive Strength

| Source | SS | df | MS | F | Prob>F |
|---|---|---|---|---|---|
| Lime | 2034598.5 | 3 | 678199.5 | 62.21 | 0.00025 |
| MHA | 432466.6 | 4 | 108116.6 | 9.92 | 0.0039 |
| Lime*MHA | 31173.3 | 12 | 2597.8 | 0.24 | 0.9948 |
| Error | 436036.7 | 40 | 10900.9 | | |
| Total | 2934275 | 59 | | | |

The p – value for the melon husk ash effects is 0.0039 which is also highly significant. This indicate that one level of the melon husk ash is out – performing than the other in the Unconfined Compressive Strength of the stabilized clay soil.

### *3.5 Permeability*

The variation of coefficient of permeability with melon husk ash and lime content are shown in Figure 6. There was a decrease in the coefficient of permeability with increase in lime content at 0% melon husk ash content.

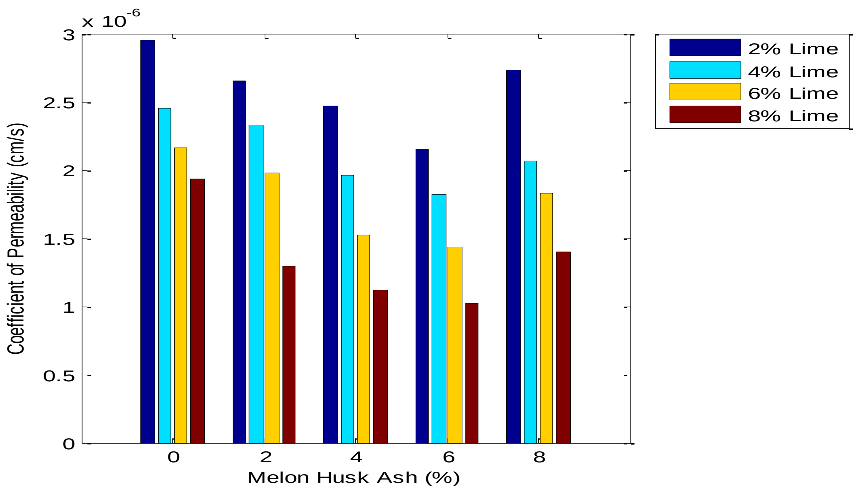


Figure 6: Variation of 28 day permeability with melon husk ash and lime content

This is due to the increase in the pH value of the molding water as a result of the partial dissociation of the calcium hydroxide. The calcium ions in turn combined with the reactive silica or alumina, or both, which obstructed flow through the soil voids (Osinubi, 1998). As melon husk ash was introduced into the soil-lime specimens, there was a decrease in coefficient of permeability. This decrease was rapid at specified lime contents from 0 to 6% melon husk ash after which the decrease reduces in rate. This decrease was as a result of the formation of cementitious compounds by calcium from lime and the readily available silica and/or alumina from both the soil and melon husk ash, which fills the soil voids thereby obstructing the flow of water.

## 4. Conclusion

The clay soil was identified to be A – 7 – 6 soil on American Association of State Highway Transportation Official, (1986) classification system. It is also a Clay of High Plasticity (CH) according to Unified System of classification (USC). Chemical compositions of the melon husk ash meet up with the standard for pozzolana. The unconfined compressive strength of the stabilised clay soil with maximum melon husk ash content of 6% increases appreciably at 28 days of curing.

The peak values of the unconfined compressive strength of the stabilized clay soil for 7, 14 and 28 days of curing are obtained to be 1200 $kN/m^2$ at 6% melon husk ash admixed with 8% lime, 1598 $kN/m^2$ at 6% melon husk ash admixed with 8% lime and 1695 $kN/m^2$ melon husk ash admixed with 8% lime. These values are greater than the conventional 1034.25 $kN/m^2$ for adequate lime stabilisation specified by Alhassan, (2008).

The permeability of the stabilized clay soil increase with curing period when compared with the natural clay soil, At the curing period, permeability decrease to a corresponding minimum at 6% melon husk ash content at specified lime content, further increase in melon husk ash show a gradual rise in the coefficient of permeability. These studies show that melon husk ash of 6% can be effectively used to stabilize clay soil in order to increase its strength and reduce permeability.

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