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Geotechnical Evaluation of Wood ash Stabilized Clay Soil

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Abstract-This study examines the effects of wood ash on the index and strength properties of clay soil. The properties of the natural clay soil were determined. Moisture content test, sieve analysis , specific gravity test, Atterberg's limit test and unconfined compressive strength (UCS) were carried out on the clay soil sample. The proportion of wood ash content used are 0%, 5%, 10%, 15%, 20% , 25% and 30% respectively as wood ash –soil mixtures. The investigated clay soil has natural moisture content of 9.2% , specific gravity of 2.72 and 68 % weight of Silty- clay particles. The results of Atterberg's limit shows liquid limit and plastic limit increases with wood ash addition while the plasticity index decreases with higher wood ash content. Decrease in Plasticity limit is an indication of reduction in expansion potential of the clay soil. The OMC increase with wood ash addition while the MDD decreases from 1.77 to 1.65 with higher wood ash content. The UCS increase significantly from 163.7 to 209 kN/m²·. Therefore, wood ash can be used as partial replacement for cement and lime.

Key words: Evaluation, Strength Properties , Wood ash , Stabilization, Clay Soil.

I. INTRODUCTION

Soils with higher percentage of clay minerals like montmorillonite, expandable illite and vermiculite, are susceptible to swelling and shrinkage (Firoozi et al., 216). They cause numerous costly damages to the roadways, buildings, bridges and other civil engineering infrastructures. Furthermore, clay soils are generally stiff in dry state but when become saturated, they lose their stiffness.

The reduction in bearing capacity of soft clays results in compressive failure and excessive settlement, leading to severe damage to buildings and foundations (Venkaramuthyalu et al., 2012). Soft clays are characterized by low compressive strength and excessive compressibility.Maintenance and rehabilitation costs for the infrastructure on these soils reach billions of dollars annually.

Clay soil swell when moisture is introduced and shrink when the same moisture is retracted. In the case where the soil undergoes excessive heat, i.e. drought, expansive soils tend to contract and shrink excessively (Chittoori et al., 2013). Clay minerals occurs in various forms and the relative quantities of each type of these minerals that are important factors contributing to the swell/shrink behavior along with the dry density, soil structure, and loading conditions present (Al-Rawas, A.A. and M.F. Goosen, 2006). Other researchers added that the arid climate, alkaline environment, and local geology are accountable for the expansive nature of soils (Sirivitmaitrie et al., 2008). The objective of this investigation is to examine the effects of wood as on the index properties of clay soils.

Generally, clays are naturally occurring materials composed of fine-grained minerals that exhibit plasticity when mixed with the right amount of moisture and solidify when dried or burnt (Das ., 2015). Characteristics of clay soil are::

- Fine particles (usually smaller than 0.002 mm).
- Net negative charge.
- Show plasticity when mixed with moisture.

Most soils require improvement on their engineering properties before they are used in construction work, and the improvement normally brings them within acceptable limits for engineering works such as road pavement construction, landfills and building foundation construction.

Clay soil is the most important phase of expansive soil since it contains Montmorillonite which has the capability of absorbing water and presenting volumetric change (Das, 2008). Expansive soil with constant water content will not usually cause a problem, however, as liquid limit increases, the plasticity index increases, according to the American Society of Testing Materials "ASTM". Test method D 4829 presents the "expansion index" to quantify the results, the range of expansive soil and its swell

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potential. Expansion index limits ranging from 0 to 20 is regarded as very low, from 21 to 50 is low, from 51 to 90 is medium, from 91 to 130 is high, and plasticity index over 130 presents very high expansion potential.

1.2. Statement of Problems

The construction industry needs alternative and substitute alternatives for cement because of its price and pollution-prone manufacturing process. In addition, the cement industry accounts for around 7% of global CO emissions, with around 650–920 kg CO_2 released during the preparation of one ton of cement (Tavakoli et al., 2018). Thus, a product capable of reducing cement needs and the associated CO emission is an urgent requirement. Hence the use of wood ash to stabilize clay soil is an environmental friendly process with no adverse effects.

1.3 Significant of the Study

a. Gives a highlight of clay soil expansive effects on foundations.
b. It provides the basis for evaluating wood ash as a potential stabilizer of clay soil.
c. It examines the effects of wood ash on the index properties of clay soil.
d. It provides an environmental friendly stabilization alternative with less dependency on cement and lime.
e. It examine wood ash as a cost effective and readily available stabilizing agent for road construction in clayey fill sites.

1.4 Objective of the Study

The objectives of this study are:

a. To collect sample of clay soil.
b. To determine the preliminary index property of clay soil.
c. To prepare wood ash.
d. To determine the index properties of wood ash stabilized clay soil.

II. LITERATURE REVIEW

2.1 Structure of Clay Soil

Clay minerals are generally crystalline sheet like structure, that consist of hydrous alumino-silicates and metallic ions. The nomenclature of clay structure is based on the arrangement of stacks, bonding, isomorphous substitution, and presence of metallic ions, different clay minerals can be constituted. Some of the common clay minerals are kaolinite, montmorillonite, illite, nontronite and muscovite (Peng et al., 2006). However, for engineering purpose kaolinite, montmorillonite and illite have particular importance in geotechnical engineering (Hwang, 2002)

2.2 Effects of Clay Soil on Foundations

Soils rich in silt or clay have the greatest swelling potential and therefore the greatest potential for foundation damage. They can cause foundation settlement, heaving, and cracks which are costly to repair. Expansive clay soil contains high contents of absorbent clay, meaning it swells when wet. This swelling results in pressure that can be enough to crack your foundation walls and floor slabs, resulting in foundation movement that can cause damage to the stability of structures (Align Foundation Repair, L.L.C., 2023).

2.3 Soil Stabilization

Soil stabilization is a technique used to improve the geotechnical properties of soil, either physically or chemically. Compaction and the use of admixtures are two methods for soil stabilization. Lime and cement are two often used stabilizers for modifying the characteristics of soils. Different types of stabilization methods exist, and each process varies with the type of additive used. Additives include lime, cement, bitumen geosynthetics, and some industrial by-products like fly ash, slag, coal, and stone dust, chemicals, reagents, and recycled materials like rubber tire chips, waste plastics, and crushed glass that follows recent advanced bio-stabilization techniques like microbial induced calcite precipitation and enzyme-induced calcite precipitation (Almajed et al., 2021).

Igwe (2017) investigated stabilization of clay soil using granite and dolerite dusts by conducting compaction test, California Bearing Ratio "CBR", test and Atterberg limit tests. When granite and dolerite dust were added with 20, and 10 % respectively to the soil, a reduction was observed in plasticity by 6.7% and 6.8% respectively.

2.4 Wood Ash

Wood ash is the powdery residue remaining after the combustion of wood, such as burning wood in a fireplace, bonfire, or an industrial power plant. It is largely composed of calcium compounds along with other non-combustible trace elements present in the wood. It has been used for many purposes throughout history.

Agricultural wastes are typically incorporated into building in the form of ash. However, concerns about sustainable development and zero-waste innovation have prompted particular ashes as cement substitutes (Sabzi, 2018). Some research for applications of wood ash (WA) utilization in road construction has been conducted in few past years. However, most of the WA application is moderately effective to improve the physical and mechanical parameter of soil.

Ekinci et al., (2020) examined the strength, stiffness, and microstructural response of marine-deposited clays in Cyprus modified with cement and wood-ash as a cement substitute. Portland cement (7, 10, and 13% by weight) was substituted with varying amounts of wood ash (5 and 10% by weight) to produce concrete with two varied dry densities (1400 and 1600 kg/m3) and three different curing times (7, 28, and 60 days). UCS, porosity, direct shear, and pulse velocity testing were conducted.

2.5 Production of Wood Ash
When different types of wood, such as chips and barks, are ignited, a substance termed wood ash (WA) is formed. WA is produced globally through ignition in woodfired power plants, sawmills, paper mills, and other timber manufacturing processes (Jamaluddin and Munirwan, 2022).

Table 1: Chemical Composition of Wood Ash

Compound	*Composition (%)*	
	Sefene, 2020	*Nath et al, 2018*
Al_2O_3	23.6	14.72
SiO_2	27	25.8
K_2O	6.3	9.55
CaO	21.5	29.8
Fe_2O_3	2.7	0.95
MgO	11	5.25
Na_2O	7.9	7.5
LOI	-	2.7

III. MATERIALS AND METHOD

3.1 Materials
Sample of clay was collected from Kaura Namoda Local Government Area of Zamfara State. .The wood ash used for the investigation was prepared burning the collected woods into ash. The wood ash prepared was stored in a polythene bag for the investigation,

3.2 Research Method
a. Collection of clay soil sample.
b. Preparation of wood ash.
c. Determination of the natural moisture content, specific gravity, and particle size distribution of the clay sample.
d. Determination of Atterberg's limits (LL, PL and PI) of wood ash – clay soil mixtures containing 0%, 10%, 15%, 20% , 25 % and 30% wood ash.

3.2.1 Determination Natural Moisture Content
The natural water content is the ratio of the weight of water to the weight of the solids in a given mass of soil. This ratio is usually expressed as percentage. The knowledge of the natural moisture content is essential in all studies of soil mechanics. The natural moisture content gives an idea of the state of soil in the field. The moisture content of the clay soil sample was determined by oven drying method, a standard laboratory procedure in accordance with BS 1377 (1990) Part 2.

3.2.2 Determination of Specific Gravity of the Soil
Specific gravity 'G' is defined as the ratio of the weight of an equal volume of distilled water at that temperature both weights taken in air. The knowledge of specific gravity is needed in calculation of soil properties like void ratio, degree of saturation (Institute of Aeronautical Engineering, 2000).

3.3 Atterberg Limit
This test method is done to determine the liquid limit, plastic limit, and the plasticity index of the soil. There are two methods mentioned within ASTM code which is a multipoint test and one-point test (American society for testing and materials, 2010).

Clay soil specimens containing 0%, 5%, 10%, 15%, 20%, 25% and 30% of wood ash content by the weight of the soil were prepared and each proportion was mixed with 200 grams of soil sieved through 0.425mm BS sieve. All specimens were kept in the vacuum for 24 hours after mixing it with water. About 20 grams was extracted from each specimen to be used for plastic limit and the remaining soil was used for the liquid limit. While doing the liquid limit test the number of drops was recorded at approximately 13 mm groove closing. Small specimens were taken from the closing groove and placed in empty cans and kept in the oven for 24 hours at 110 ± 5 C° to calculate the water content.

A wide variety of soil engineering properties have been correlated to the liquid and plastic limits, and these Atterberg limits are also used to classify a fine-grained soil according to the Unified Soil Classification system or AASHTO system.

3.3.1 Liquid Limit

The liquid limit (LL) is arbitrarily defined as the water content, in percent, at which a part of soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm (1/2 in.) when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of two shocks per second. The liquid limit is the moisture content that defines where the soil changes from a plastic to a viscous fluid state.

3.3.3 Plastic Limit

The plastic limit (PL) is the water content, in percent, at which a soil can no longer be deformed by rolling into 3.2 mm (1/8 in.) diameter threads without crumbling (ASTM D 4318). The plastic limit is the moisture content that defines where the soil changes from a semi-solid to a plastic (flexible) state.

3.3.4 Plasticity Index

The Plasticity index (PI) is defined as the difference between the liquid limit (LL) and the Plastic limit (PL) (Salaam, 2000) as shown in equation 1.

PI=LL – PL ------------------------------------(1)

IV. RESULTS AND DISCUSSION

4.1 Properties of the Soil

The properties of the soil sample are presented in Table 2. All tests conducted were in accordance with BS1377 (Part2;1990).

Table 2: Properties of the Clay Soil

S.No.	Properties	Value
1	Percentage of fines(silt and clay) < 0.075mm	68 %
2	Sand	12 %
	Coarse	10 %
3	Natural moisture content	9.2%
4	Specific gravity (GS)	2.72
5	Liquid limit (LL)	53%
6	Plastic limit (PL)	21%
7	Plasticity Index (PI)	32%
8	Unified Soil Classification System (USCS)	High Plasticity Clay (CH)

4.2 Result of Moisture Content

The result of natural moisture content of the soil is shown in Table 3.

Table 3: Natural Moisture content determination

Container Mark	M1 (g)	M2 (g)	M3(g)	MC (%)
A5	13.83	38.85	36.74	9.2
A7	15.1	42.4	40.1	9.21
A8	13.8	49.18	46.2	9.19

Average moisture content (Mc) = 9.2%

- Weight of empty Cont. = M_1
- Weight of Cont. + Moist Sample = M_2
- Weight of Cont. + Oven dried sample = M_3

$$Mc = \frac{M_2-M_3}{M_3-M_1} X\ 100$$

4.3 Specific Gravity (GS) Test Result

The specific gravity of the soil sample was determined in accordance to the BS 1377 (Part2;1990) :

$$\text{Specific gravity (Gs)} = \frac{M_2-M_1}{(M_4-M_1)-(M_3-M_2)}$$

- Weight of empty pycnometer + the stopper = M_1
- Weight of pycnometer + stopper + 20g sieved sample = M_2
- Weight of pycnometer + stopper + 20g sieved sample + distilled water filled = M_3
- Weight of pycnometer + stopper + distilled water filled to the brim= M_4

The specific gravity of the clay soil decreases with wood ash addition as shown in Figure 3 . This result is associated to the increasing content of wood ash of much lower specific gravity occupying the soil void. The Specific gravity test result is presented in Table 4, while the specific gravity variation curve is shown in Figure 3.

Table 4: Specific Gravity Test Result

Wood Ash Content (%)	*Specific Gravity (GS)*
0	*2.72*

5	*2.66*
10	*2.64*
15	*2.58*
20	*2.52*
25	*2.48*
30	*2.41*

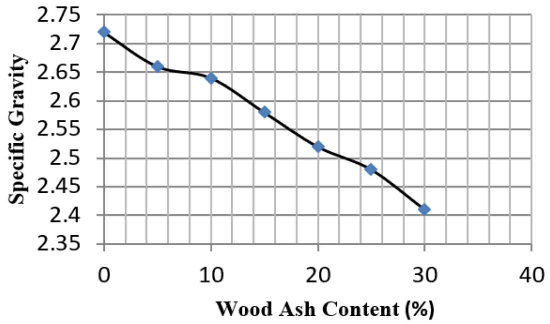

Fig. 3: Variation of Specific gravity with Wood Ash Content

4.4 Result of Sieve Analysis

The result shows the percentage of finer particles (silt and clay) decrease with wood ash addition while significant increase in sand was observed as wood ash content increases. Therefore reduction in clay and silt is an indication of improvement in the strength property of the clay soil. Figure 4 shows Particle size distribution curve for the clay sample, while Figure 5 shows particle size variation with wood ash content.

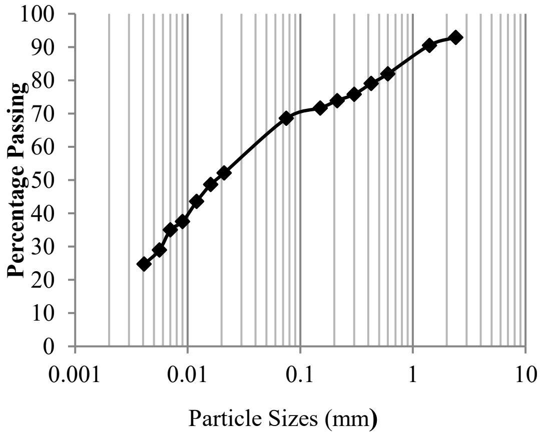

Fig. 4 : Particle size distribution curve for the clay soil sample

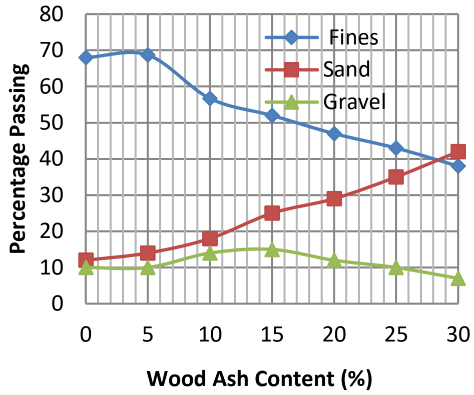

Fig. 5: Particle Size Variation With Wood Ash Content

Table 5: Result of Particle Size Variation with Wood Ash Content

Wood Ash Content (%)	*Silt & Clay (Fines)*	*Sand*	*Gravel*
0	*68*	*12*	*10*
5	*68.7*	*14*	*10*
10	*56.7*	*18*	*14*
15	*52*	*25*	*15*
20	*47*	*29*	*12*
25	*43*	*35*	*10*
30	*38*	*42*	*7*

4.5 Results of Atterberg's Limit

Table 6 shows the summary of result of Atterberg limit test conducted on the clay soil sample.

Table 6: Atterberg Limits Test Result

Wood Ash (%)	*Liquid Limit (%)*	*Plastic Limit (%)*	*Pasticity Index (%)*
0	*53*	*24*	*29*
5	*56*	*29*	*27*
10	*58*	*32*	*26*
15	*59*	*34.2*	*24.8*
20	*60.5*	*37*	*23.5*
25	*61*	*38.5*	*22.5*
30	*61.3*	*39.6*	*21.7*

Figure 6 shows the variation in liquid limit, plastic limit and plasticity index respectively. The result indicates liquid limit and plastic limit increase with wood ash addition, while the plasticity index decrease with wood ash addition. The trend of reduction in plasticity index is an indication of improvement in the strength property of the clay soil.

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Admassu, (2018), also reported reduction in plasticity index with higher natural pozzolana content and affirmed that the reduction in plasticity index is an indication of improvement associated with increase in strength, reduction in swelling and compressibility of the stabilized soil.

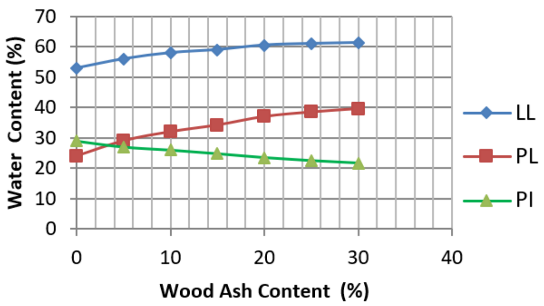

Fig 6: Variation of Atterberg Limit with Wood Ash Content

4.6 Compaction Characteristics of Wood Ash Stabilized Clay Soil

4.6.1 Optimum Moisture Content Result

Table 7: Variation of Optimum Moisture Content with Wood Ash

Wood As content (%)	*OMC (%)*
0	*19.2*
5	*19.5*
10	*19.7*
15	*20.1*
20	*20.5*
25	*20.7*
30	*21.1*

The variation in optimum moisture content is represented in Figure 7. The result shows OMC increase with wood ash addition , (from 19.2 to 21.1) %. This result can be attributed to high water retention capacity of wood ash.

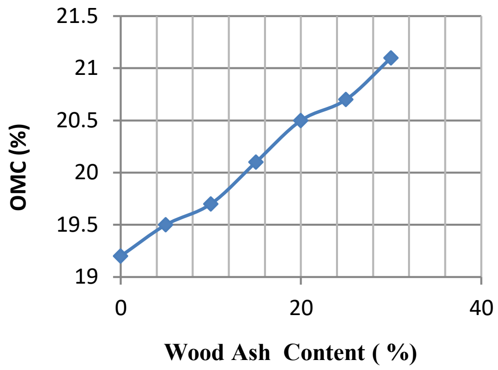

Fig.7 : variation of Optimum moisture content (OMC) with Wood Ash .

4.6.2 Maximum Dry Density (MDD)

The result of MDD are presented in Table 8 and Figure 8 respectively for the wood ash stabilized clay soil.

Table 8: Maximum Dry Density (MDD)

Wood Ash Content (%)	*MDD (g/cm^3)*
0	*1.77*
5	*1.70*
10	*1.68*
15	*1.66*
20	*1.65*
25	*1.63*
30	*1.625*

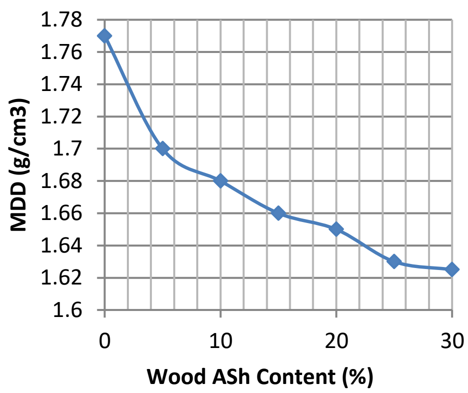

Fig. 8: Variation of Maximum Dry Density with Wood Ash Content

The result shows that MDD decreases with higher wood ash content. The decrease in MDD with higher wood ash content may be attributed to agglomeration and flocculation of clay particles caused by cation exchange reaction (Nath et al., 2017).

4.7 Unconfined Compressive Strength (UCS)

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Unconfined compressive strength is an essential element in the design of soil stabilization mixtures and also used as a design criteria for selecting suitable pavement materials (Ola, 1983).

The result of Unconfined Compressive Strength (UCS) test carried out on the wood ash stabilized clay soil is presented in Table 9 and Fig.9 respectively. The result shows UCS increase with higher wood ash content. The UCS value increase significantly from 163.7 kN /m^2 to 209 kN /m^2 , this increase is an indication of improvement on the strength property of the clay soil stabilized with wood ash. Therefore, wood ash content of 20% gave the peak value of UCS (209 kN /m^2) while reductions in UCS were recorded for wood ash content of 25% and 30% respectively.

The acceptable UCS standard for subbase is 687 to 1373 kN/m^2 (Ingles and Metcalf, 1972). Hence, the maximum UCS 209 kN/m^2 recorded from wood ash stabilization of clay soil do not satisfy the acceptable UCS standard and cannot be used for subbase.

Table 9: Unconfined Compressive Strength (UCS)

Wood Ash Content (%)	*UCS (kN /m^2)*
0	*163.7*
5	*172*
10	*186*
15	*195*
20	*209*
25	*207*
30	*198*

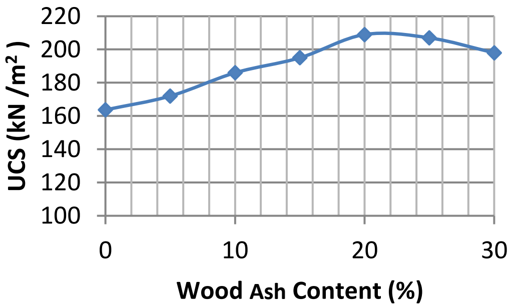

Fig.9: Variation of UCS with Wood Ash Content

V. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The following conclusions were drawn from the results of the investigation:

1. The liquid limit and Plastic limit increase with higher wood ash content while the plasticity index decrease from 29% to 21.7 % with higher wood ash content.
2. The Specific gravity (GS) decreases from 2.72 to 2.41 with higher wood ash content.
3. The OMC increase from 19.2% to 21.1% with wood ash addition , meanwhile the MDD decreases from 1.77 g/cm^3 to 1.65 g/cm^3 with wood ash addition.
4. The unconfined compressive strength (UCS) increase from 163.3 kN /m^2 to 209 kN /m^2 with wood ash addition.
5. This improvement in strength property of clay soil stabilized with wood ash shows that wood ash can be used as partial replacement for cement and lime to minimize construction cost.

5.2 Recommendations

- Wood ash should be used as partial replacement for cement, lime and other chemical additives to stabilize clay soil.
- Wood ash content of 20% should adopted to achieve optimum stabilization performance of clay soil.
- Further investigation should be conducted to determine the level of stabilization that can be achieved with wood ash and lime mixtures on clay soil.

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