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MODIFICATION OF CEMENT STABILIZED STRUCTURAL LATERITIC WOOD ASH

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Abstract: This paper investigates cement stabilized structural soil samples modified with wood ash as complement for cement in structural works and hence reduced the cost of construction. Soil samples were collected from three different excavated foundations labelled sample A, B, and C. Preliminary tests were performed on the samples at their natural states and when stabilized at optimum cement. Engineering tests were also performed on samples at their natural states, when stabilized with optimum cement and when wood ash powder (WAP) was introduced at 2, 4, and 6%. Results of the engineering tests showed that WAP increased the maximum dry density (MDD) of all the samples. At 2% WAP content, and with the optimum cement content kept at 10% for samples A and B and 8% for sample C, the MDD values increased from 1587.99 to 1588.23kg/m^3, 1548.89 to 1604.08kg/m^3 and 1506.45 to 1529.42kg/m^3 in samples A, B and C respectively. The samples shear strengths also increased from its natural state, samples A, B and C increased from 100.26 to 112.66kN/m^2, 95.76 to 133.27kN/m^2 and 64.88 to 92.95kN/m^2 at 4% WAP contents respectively. It was therefore concluded that WAP is an effective additive on cement stabilized lateritic soil for foundation construction.
Keywords: wood ash powder, cement stabilization, lateritic soil, structural foundation

INTRODUCTION

Structural soil foundation improvement could either be by modification or stabilization or both. Soil modification is the addition of a modifier (cement, lime and others) to a soil to change its index properties, while soil stabilization is the treatment of soil to improve its strength and durability, such that it becomes totally suitable for construction beyond its original classification.

Over time, cement and lime are the two main materials used for stabilizing soils, though these materials have rapidly increased in price due to a sharp increase in the cost of energy since 1970s (Neville, 2000).

The over dependence on the utilization of industrially manufactured soil improving additives (cement, lime and others) have kept the cost of structural engineering projects very high. This hitherto has continued to deter the developing, underdeveloped and poor nations of the world from providing relatively standard structures to dwellers that constitute the higher percentage of their population (Alhassan and Mustapha, 2007). The quest to discover materials that can serve as a replacement for cement in soil foundation amount to a worthwhile effort.

Adequate strength and engineering properties of soil material are prerequisites for standard structural foundation, the treatment of the natural soil to improve its engineering properties is known as soil stabilization. Because of the sowing construction cost of cement stabilizers, waste product from wood known as wood ash is considered as a pozzolan. Wood ash is available everywhere on earth especially in domestic places. Wood ash is a waste product derived from burning of wood, discovered as a suitable pozzolan used for partial replacement of cement in stabilization of lateritic soil. According to Amu (2010), when the quality of the sub-grade material meets the requirements expected of a sub-base, then a sub-base is not necessary. But in cases where suitable sub-base materials are not readily available, the in-situ material can be treated to meet the required engineering properties. The materials can be stabilized using any of these stabilizing agents like Portland cement, asphalt and lime.

— Lateritic Soils

Lateritic soils form a group comprising a wide variety of red, brown, and yellow fine-grained residual soils of light texture as well as nodular gravels and cemented soils (O'Flaherty, 2002). They may vary from a loose material to a massive rock. They are characterized by the presence of iron and aluminum oxides or hydroxides, particularly those of iron, which give the colours to the soils. For engineering purposes, the term laterite is confined to the coarse-grained vermicular concrete material, including massive laterite. O'Flaherty (2002) referred the term lateritic soils as materials with lower concentrations of oxides.

Laterization is the removal of silicon through hydrolysis and oxidation that results in the formation of laterites and lateritic soils (Okunade, 2007). The degree of laterization is estimated by the silica-sesquioxide (S-S) ratio [SiO_2 / (Fe_2O_3 + Al_2O_3)]. Lateritic soils can be effectively stabilized to improve their properties for particular uses. However, because of the wide range of silica-sesquioxidein the lateritic soil characteristics, no one stabilizing agent has been found successful for all lateritic materials. Laboratory studies, or preferably field tests, must be performed to determine which stabilizing agent, in what quantity that will perform adequately on a particular soil (Army Study Guide, 2008). Some stabilizing agents that have been used successfully are cement, asphalt and lime.

In analyzing the engineering properties of soil, three basic parameters that are of keen interest to Engineers are permeability, shear strength and compressibility (Okunade, 2007). Permeability is the soil property that permits the passage of fluid by a flow process under the action of eternally applied forces (Okunade, 2007). For the material to be permeable, the void spaces within it must be continuous. The rate at which the soil allows water to pass through would affect the behaviour of the soil especially due to seasonal variations. In places where frost action is critical, permeability of the soil is a very critical factor to consider in pavement design. The shear strength of a soil is defined as the maximum or limiting value of shear stress that may be induced within its mass before the soil yields (Whitlow, 1995). The order of shear resistance within the soil mass must be accurately understood before the computation of slope stability and lateral pressure on earth retaining structure can be successfully carried out. The purpose of shear strength testing is to establish empirical values for the shear strength parameters.

Compressibility is a change in the stress system acting on a soil mass that results in a change in the volume of mass. Such changes in volume have important influence on the engineering properties of the soil. The compressibility of a soil is determined experimentally by the triaxial compression, unconfined compression.

— Soil-Cement Stabilization

Stabilization is the process of blending and mixing materials with a soil to improve certain properties of the soil (O'Flaherty, 2002).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 (United State Army, 1994).According to O'Flaherty (2002), there are three types of soil-and-cement mixtures as follows; Plastic soil-cement is a hardened mixture of soil and cement that contains, at the time of placing, enough water to produce a consistency similar to plastering mortar. It is used to line or pave ditches, slopes, and other areas that are subject to erosion.

Cement-modified soil is an unhardened or semi hardened mixture of soil and cement. When relatively small quantities of Portland cement are added to granular soil or silt-clay soil, the chemical and physical properties of that soil are changed. Cement reduces the plasticity and water-holding capacity of the soil and increases its bearing value. The degree of improvement depends upon the quantity of the cement used and the type of soil. In cement-modified soil, only enough cement is used to change the physical properties of the soil to the degree desired. Cement-modified soils may be used for structural foundation base, sub base, and as trench backfill material.

Compacted soil-cement, often referred to as simply soil-cement, is a mixture of pulverized soil and calculated amounts of Portland cement and water that is compacted to a high density. The result is a rigid slab having moderate compressive strength and resistance to the disintegrating effects of wetting and drying and freezing and thawing.

— Availability of Fuel Wood and Charcoal

The predominantly rural population depends mainly on fuel wood to meet basic energy needs for cooking and heating. Recent studies revealed that Nigeria produces about 1 million tons of charcoal annually of which 80% is consumed in the cities (FDF, 1986). Fuel wood and charcoal account for about 50% of the national primary energy consumption. Fuel wood is demanded by both household and industrial sectors in all ecological zones of the country. It is estimated that about 90% of the rural households in Southern Nigeria and up-to 98% in the Northern Nigeria depend on fuel wood as their source of domestic energy. Industrial uses include those by institutions, food and craft industries. Fuel wood is very important in local restaurant, bakeries, local breweries, pottery, blacksmith and burnt brick factories. Institutions such as hospitals, prisons and schools also demand fuel wood for cooking. The per capita consumption of fuel wood in rural area is 393.43 kg/annum while the urban households consume 255.75 kg/ annum.

— Pozzolan

Pozzolan can be defined as a siliceous and aluminous material, which in itself possesses little or no cementation value but will in a finely divided form, such as a powder or liquid and in the presence of moisture, chemically react with calcium hydroxide at ordinary room temperature to form permanent, insoluble compound possessing cementitious properties. Pozzolan is a fine powdered material which is added to non-hydraulic lime mortars to accelerate the set. The material possesses little or no cementitious value, but in a finely divided form, it will react with calcium hydroxide in the presence of moisture to provide a chemical set (Traditional lime, 2010). The first pozzolans were used by eruptions. One of the compelling reasons for incorporating pozzolans in concrete today is to improve quality and to extend service life by enhancing the durability of this ubiquitous construction material. To function properly, pozzolans must be amorphous or glassy and generally finer than 325 mesh in particle size. Finer particle sizes generally have greater reactivity helping in the early strength development (Vitrominerals, 2005). Pozzolans can continue to react in concrete for many years, further strengthening the concrete and making it harder and more durable during its service life. Pozzolans also serve to increase density and reduce the permeability of concrete, which helps to make it more resistant to deterioration and swelling associated with various exposure conditions.

The two major types of pozzolans are; natural and artificial pozzolans. The natural pozzolans are present on earth's surface such as diatomaceous earth, opaline shale, volcanic ash, tuff and pumiced. These materials require further accessing such as calcining, grinding, drying and so on. The Aegean island of Santorini has volcanic ash, volcanic tuffs, pumicites and opaline shale are found in the west of River Mississippi in Oklahoma, Nevada, Arizona and California. Fly ash is an example of artificial pozzolan produced when pulverized coal is burnt in electric power plants. The glassy spherical particulars are the active pozzolani portion of the fly ash. Fly ash is 66 - 68% glass. Class F fly ash readily reacts with lime (produced when Portland cement hydrates) and alkalis to form cementitious compounds. Class C fly ash also may exhibit hydraulic (self-cementing) properties.

— Wood Ash

Wood ash is a by-product of combustion from wood-fired boilers, at a typical paper mills and other wood burning facilities (Abdullahi, 2006). Main producers of wood ash are wood industries and power plants. Since wood is a renewable source of energy and environmentally benign friendly material, there will be increased use of wood in energy production in the future. As a result, there will be increased amount of wood ash generation. Approximately three million tons of wood ash is produced annually. Approximately 70% of the wood ash is being land filled, around 20% is being used as soil supplement, and the remaining 10% is being used in miscellaneous applications. The cost of land filling is increasing due to passes of strict environmental regulations and limited availability of landfill space (Naik, 2000).In the light of these, it has become essential to develop beneficial uses of wood ashes to solve the problems associated with their disposal.

The physical and chemical properties of wood ash vary significantly depending upon various factors such as type or species of trees/wood, method and manner of combustion, efficiency of the boiler, and other supplementary fuel used with wood (Naik and Kraus, 2003). Wood ash is composed of both inorganic and organic compounds. Typically between 0.43 and 1.82 percent of the mass of burned wood (dry basis) results in ash. Many types of ash are found near campsites Naik (2000). The composition of wood ash is influenced by the type of wood that has been burned. Also the conditions of the combustion affect the composition and amount of the residue ash, thus higher temperature will reduce ash yield. Wood ash contains calcium carbonate as its major component, representing 25 or even 45 percent. According to Naik and Kraus (2003), less than 10 percent is potash, and less than 1 percent phosphate; there are trace elements of iron, manganese, zinc, copper and some heavy metals. However these numbers vary as combustion temperature is an important variable in determining wood ash composition. Presence of heavy metals and/or high alkalinity in wood ash may limit its application on land under a stricter environmental regulation.

— Wood Ash as a Pozzolanic Material

Pozzolan can be defined as a siliceous and aluminous material, which in itself possesses little or no cementation value but will in a finely divided form, such as a powder or liquid and in the presence of moisture, chemically react with calcium hydroxide at ordinary room temperature to form permanent, insoluble compound possessing cementitious properties. Pozzolans are commonly used as an addition (the technical term is "cement extender") to Portland cement concrete mixtures to increase the long-term strength and other material properties of Portland cement concrete and in some cases reduce the material cost of concrete. Pozzolans are primarily vitreous siliceous materials which react with calcium hydroxide to form calcium silicates; other cementitious materials may also be formed depending on the constituents of the pozzolan (Abdullahi, 2006).

Misra et al. (1993) found the major elements in wood ash to be calcium, potassium and magnesium, while sulfur, phosphorus and manganese are present at around 1% and iron, aluminium, copper, zinc, sodium, silicon and boron are present in relatively smaller amounts. They found the chemical compositions of wood ash to be mainly carbonates and oxides of the alkali metals, namely $CaCO_3$, $K_2Ca(CO_3)_2$, $Ca(OH)_2$, MgO, CaO, $Ca_4Mn_3O_{10}$, K_2SO_4 and others. Naik et al. (2003) have tested many sources of wood ash from the USA and Canada and have found their specific gravity to be between 1.6 and 2.8 and unit weight between 365 and 980 kg/m3 (Naik and Kraus, 2003). They also found that the major elements in wood ash to be carbon, calcium, potassium, magnesium, phosphorus and sodium, all in various proportions. Abdullahi (2006) found the specific gravity of wood ash obtained from a bakery in Minna, Niger State, Nigeria to be 2.13 and the bulk density 760 kg/m3 and his analysis showed the chemical constituents as SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, TiO_2, K_2O, SO_3 and organic matter (loss on ignition LOI = 27%).

Because of its being usually rich in calcium carbonate, which is a good binding agent and its other chemical components, wood ash acts as a pozzolana with good stabilizing properties. Naik (2000) performed some investigations into the properties of wood ash from different sources and established their potential for being used in cement-based construction materials. Naik et al. (2003), in an investigation into the use of wood ash in cement-based materials, found that wood ash could be utilized in making self-compacting Controlled Low-Strength Materials (CLSM), air-entrained and non-air-entrained concretes and bricks / blocks / paving stones. Initial test results indicated that wood ash could be successfully used in making:

CLSM (with up to 90% of total materials);
air-entrained structural-grade concrete up to 28-day compressive strength of 50 MPa with wood or its blends (up to 40%) of wood ash and coal fly ash;
non-air-entrained structural-grade concrete (up to 60 MPa 28-day compressive strength) with wood ash or its blends with coal fly ash (up to 40%) as partial replacement of cement and,
good quality bricks/blocks/paving stones with wood ash or its blends with coal fly ash (up to 35%) as partial replacement of cement.

Employing the Pozzolanic property of sawdust ash, it has been used by Elinwa and Ejeh (2004) and with acceptable results as partial replacement for Portland cement in the production of cement mortar. Udoeyo and Dashibil (2002) utilized it as partial replacement for Portland cement in concrete. Though the compressive strength of specimens with sawdust ash was lower at the 28th day, it was observed to gain rapid strength at later ages, indicating a pozzolanic activity of the ash. Abdullahi (2006) successfully used a wood ash obtained from a bakery in Minna, Niger State, Nigeria as partial replacement for Portland cement in the production of concrete. With regards to the usage of wood ash for soil stabilization, according to Andres and Honkala (1978), wood ash is one of the oldest stabilizers known. It is a good water proofer and its binding properties are adequate for stabilizing traditional adobe. It provides strength to the block and prevents cracking because of its chemical composition especially the potassium components, which aid the bonding properties. Fajobi and Ogunbanjo (1994) have used wood ash to impart greater strength to traditional adobe bricks and have determined that the amount of wood ash to be added to soil for optimum compressive strength is about 10% by weight, while Amu et al. (2005) have used wood ash (sawdust) in the stabilization of lateritic soil.

MATERIALS AND METHODS

The materials used include lateritic soil samples, Portland cement, wood ash and water. The lateritic soil samples were collected from excavated foundations located in Ojo, Akinyele at Ibadan, Oyo State and Mokuro at Ile-Ife in Osun State Nigeria. These were designated as samples A, B, and C. The soil samples pre-treatment was ensured before the commencement of the study. For easy identification of the soil samples, tags were placed on them to describe their dates of excavation, depths of excavation from the source and locations.

The soil samples were spread on sacks in the laboratory to air-dry them for a minimum of two weeks. The sacks were frequently turned to prevent water contamination and direct contact with sunlight. The required quantity of ordinary Portland cement for the study was obtained locally. Wood ash was obtained from hardwood (Iroko tree/planks), bought from a sawmill in Ile-Ife area and burnt in an open drum to get the required wood ash that was sufficient for the study. Potable water was obtained from treated water available in the laboratory.

Preliminary tests such as the natural moisture content, specific gravity, particle size analysis and Atterberg's limits were carried out on three unstabilized soil samples to determine their index properties. The major stabilizing material, cement was thoroughly mixed with the soil samples in varying percentages of (2, 4, 6, 8, 10) % by weight of the soil samples, so as to determine the optimum requirement of cement in the different soil samples. This was done by determine PI from Atterberg's limit test. The point of lowest PI gives the optimum amount of cement required. Hence, engineering properties of cement stabilized soil was determined. These engineering properties are used as the control against which the engineering properties of cement stabilized lateritic soil modified with wood ash are compared. The main objective of the study is to determine the change in the engineering properties of the stabilized soil sample modified with wood ash.

Engineering tests such as compaction, California bearing ratio (CBR) and undrained traixial were also performed on them at their natural states, when stabilized with optimum cement and when wood ash powder (WAP) was introduced as pozollan to the samples. The various tests were carried out with standard procedures stipulated in BS 1377-1990:1-8.

RESULTS AND DISCUSSION

The results from the preliminary tests (grain size analysis, natural moisture contents, specific gravity, and Atterberg's limits test) as well as the engineering test (compaction test, California Bearing Ratio test and triaxial test) are presented and discussed below:

— Preliminary Test

The summary of the preliminary test results for soil samples A, B, C are shown in Table 1. The natural moisture content of the selected soil samples A, B and C are 20.19%, 17.72% and 2.39% respectively. The result showed that sample A has the highest natural moisture content and sample C the lowest. The specific gravity of samples A, B and C are 2.33, 2.33 and 2.77 respectively. Bwalya (1998) stated that the performance of lateritic soil may be influenced by the climate, the topography and hydrological regime of the area in which the structure is to be constructed which influences the strength of the soil. The results of the sieve analysis indicated that all the soil samples fall within the granular material group and ranged between A1 - A3 in the AASHTO classification system, suggesting that they are fairly good materials for construction, according to Fajobi (2008), soil is classified into seven major groups A-1 to A-7, soil classified under groups A-l, A-2, A-3 are granular materials while soil classified under groups A-4, A-5, A-6 and A-7 is mostly silt and clay-type materials. Bwalya (1998) in his studies on the relationship between the natural moisture content and the plastic limit indicated generally that soils with natural moisture contents lower than the plastic limits are normal lateritic soils, therefore samples A and B are normal lateritic soils.

Table 1: Summary of preliminary test for soil samples

Sample	Natural Moisture Content (%)	Specific Gravity	Liquid Limit (LL) (%)	Plastic Limit (PL) (%)	Plastic Index (PI) (%)
A	20.191	2.33	66.858	44.850	22.008
B	17.721	2.33	50.782	27.399	23.384
C	2.390	2.77	54.152	45.567	8.585

The variations in the Atterberg's limits tests for the samples at the natural state and when stabilized with 2-10% cement are shown in Figures 1-3, the liquid limits, plastic limits and the plastic index for the natural soil samples respectively for sample A are 66.86%, 44.85% and 22.01%, for sample B are 50.78%, 27.40% and 23.38% respectively, and 54.15%, 45.57% and 8.59% respectively for sample C. The addition of cement in percentages desired (2%, 4%, 6%, 8% and 10%) to the soil samples caused a change in the Atterberg's limits of all the soil samples. The optimum cement stabilized for samples A and B were obtained at 10% and at 8% for sample C.

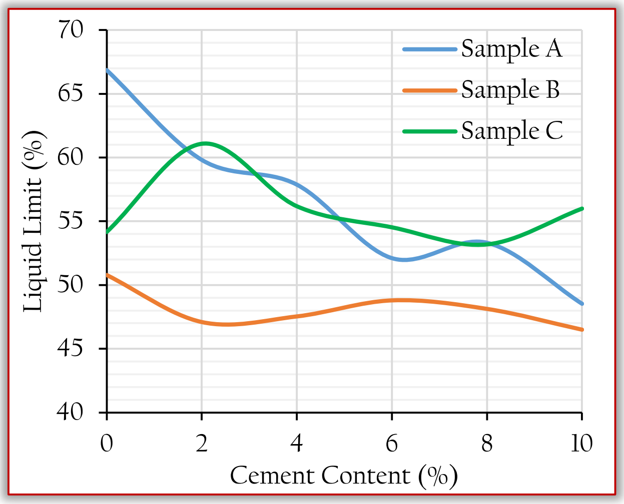

Figure 1: Variation in Liquid Limits for soil samples A, B and C with application of wood ash

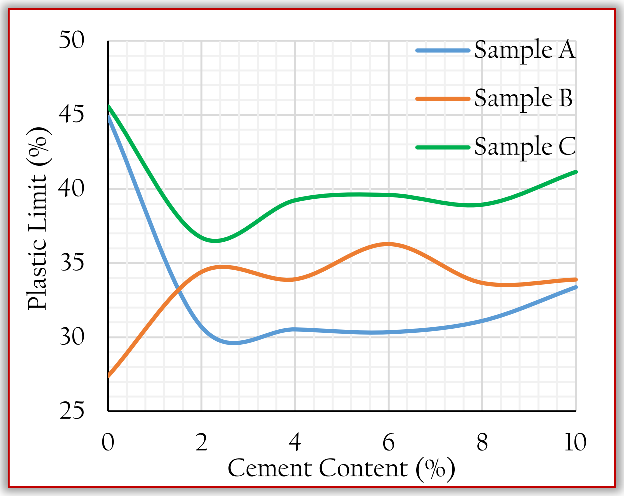

Figure 2: Variation in Plastic Limits for soil samples A, B and C with application of wood ash

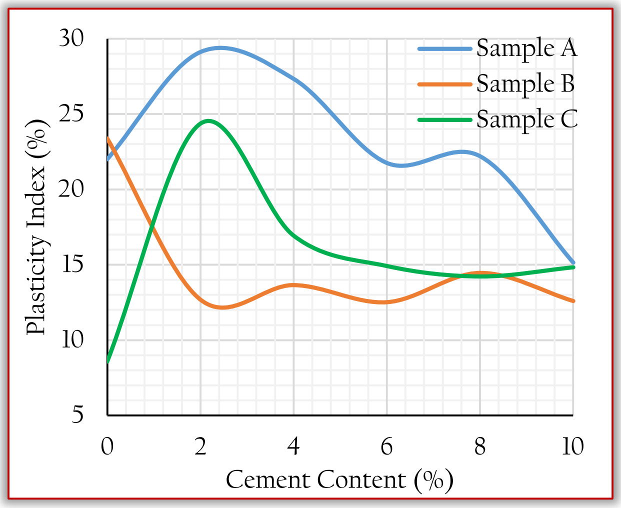

Figure 3: Variation in Plasticity Index for soil samples A, B and C with application of wood ash

— Engineering Strength Tests

Table 2 shows the summary of the compaction test results at optimum cement stabilization. The Maximum Dry Densities (MDD) of all the samples attained maximum values at 2% wood ash stabilization before dropping. This indicates that the optimum MDD potential for the samples A and B is at 10% cement and 2% wood ash stabilization while that of sample C is at 8% cement and 2% wood ash stabilization.

Table 2: Summary of compaction test results for samples A, B and C at optimum cement

Sample	Percentage Stabilization Cement Wood-ash ratio (%)	Optimum Moisture Content (OMC) (%)	Maximum Dry Density (kg/m³)
A	0	20.28	1587.99
	10 : 0	19.30	1588.76
	10 : 2	22.80	1588.23
	10 : 4	26.61	1483.78
	10 : 6	21.29	1462.64
B	0	24.19	1548.89
	10 : 0	20.96	1636.09
	10 : 2	22.27	1604.08
	10 : 4	24.61	1547.05
	10 : 6	21.16	1512.61
C	0	32.49	1506.45
	8 : 0	24.22	1555.67
	8 : 2	26.32	1529.42
	8 : 4	27.28	1524.51
	8 : 6	27.22	1523.62

The result of the CBR test on samples A, B and C at optimum cement is summarized in Table 3. The addition of wood ash lowered the unsoaked CBR of all the samples. The CBR value of sample A reduced from 11.00 to a minimum of 7.00 at both 2% and 4% wood ash stabilization, while those of samples B and C reduced from 17.00 and 5.00 to 6.00 and 2.00 at 6% and 2% respectively wood ash stabilization.

The summary of undrained triaxial shear strength tests results is presented in Table 4. The shear stresses of the samples increased when stabilized with wood ash at optimum cement contents. Sample C with a natural shear stress value of 64.88 kN/m² increased to 141.14 kN/m² after stabilization with optimum 8% cement and 6% wood ash contents while those of samples A and B increased from 100.26 kN/m² and 95.76 kN/m² to 112.66 kN/m² and 133.27 kN/m² respectively after stabilization with optimum 10% cement and 4% wood ash contents.

Table 3: Summary of CBR test results

Sample	Percentage Stabilization Cement Wood-ash ratio (%)	CBR Value
A	0	2.00
	10 : 0	11.00
	10 : 2	7.00
	10 : 4	7.00
	10 : 6	8.00
B	0	4.00
	10 : 0	17.00
	10 : 2	9.00
	10 : 4	7.00
	10 : 6	6.00
C	0	2.00
	8 : 0	5.00
	8 : 2	2.00
	8 : 4	4.00
	8 : 6	4.00

Table 4: Summary of undrained triaxial test results

Sample	Cement, Wood-ash ratio (%)	Deviator stress (kN/m²)	Cohesion (kN/m²)	Angle of internal friction (Ø)	Shear stress (τ) (kN/m²)
	0	160.63	35.56	21.94	100.26
	10 : 0	180.07	38.67	23.57	117.23
A	10 : 2	135.56	18.28	26.81	86.79
	10 : 4	156.39	19.47	30.79	112.66
	10 : 6	130.38	18.55	26.92	84.75
	0	175.83	72.70	7.47	95.76
	10 : 0	190.72	40.17	24.40	126.68
B	10 : 2	220.03	99.62	6.49	124.68
	10 : 4	221.75	125.37	2.04	133.27
	10 : 6	182.70	35.79	27.49	130.86
	0	116.67	28.96	17.11	64.88
	8 : 0	173.25	35.67	27.86	143.64
C	8 : 2	161.62	45.77	17.20	95.8
	8 : 4	151.28	32.81	21.68	92.95
	8 : 6	181.55	23.19	33.01	141.14

CONCLUSION

Stabilization of cement lateritic soil with wood ash improved the quality of soil by significantly reducing the plasticity index, plastic limit and liquid limit of the soil samples. Addition of cement with wood ash to subsoil samples increased their maximum dry densities by significant amount.

The CBR values for the unstabilized subsoil samples were also increased. The CBR values for the stabilized soil samples A and B, increased with the addition of 10% cement and up-to 6% wood ash. The CBR values for the stabilized soil sample C increased with the addition of 8% cement and 6% of Wood Ash.

It could also inferred from the shear stress test results that the addition of optimum cement content of 10% and 2% WAP content to sample A and B increased the shear stress of the soil samples while addition of optimum cement content at 8% and 2% WAP content increased the shear stress of the soil sample C.

It was therefore concluded that WAP is an effective additive on cement stabilized lateritic soil that improves the properties of the subsoil foundation and helps in forming colloidal particles and reduction in the tendency of the subsoil to swell when wet.

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