Effect of wood ash as a partial replacement of lime in the stabilisation of laterite soil for pavement layers

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ABSTRACT: This research considered the use of wood ash (WA) as a partial replacement of lime in stabilisation of laterite soil for pavement layers. The study investigated the physical properties and chemical composition of wood ash and laterite soil sample. The results showed that WA is a good pozzolan with combined SiO_2, Al_2O_3 and Fe_2O_3 of 56.34% exceeding the minimum requirement of 50%. Laterite soil was categorised as Clayey Gravel with Sand, A-2-7(1), using the AASHTO classification system. The Initial Consumption of Lime of the soil sample, from the pH tests, was determined as 4%. The 4% lime content was gradually substituted with appropriate amounts of WA in proportions of 0%, 10%, 20%, 30%, 40% and 50% from which the geotechnical properties of the soil-lime-WA mixtures were investigated. The index and strength parameters of the laterite soil improved substantially. The results support the idea of making use of on-site materials and thus lowering construction costs. At the same time, the rapid fill-up rate of landfills would be solved.

1 INTRODUCTION

Rock and soil with satisfactory engineering characteristics play a major role in the design and construction of most of the civil engineering projects. Engineers are always faced with the challenge of improving the properties of soils that do not meet the required index and strength standards. The common approaches for enhancing the properties of weak soils can be categorised into; displacement, replacement, reinforcement and stabilisation (Hassan et al. 2016). Reinforcement and stabilisation methods enable the use of on-site soils hence reducing the cost of construction.

Over the years, cement and lime have dominated as the main materials used for improving soil properties through stabilisation. However, these materials have rapidly increased in price due to share increase in the cost of energy (Ayininuola & Oyedemi 2013). In order to beat the sky-rocketing price of these soil additives, there is a need to look for alternatives which are cheap and readily available like wood ash which is a product of the biomass.

Biomass is used in all sectors of the economy of Uganda. According to MEMD (2014), close to 100% of rural households and 98% of urban households use biomass energy for cooking. At present, a large fraction of the wood ash produced is disposed in landfills. In some cases, it is used to improve certain properties of soil for agriculture. Since wood ash is a waste resources material, there should be a way of harnessing it for effectiveness of soil used in the construction industry. Finding ways to utilise these ashes in an environmentally friendly and economically efficient manner is thus an important goal throughout the country (MEMD 2014). The disposal of wood ash has been negatively associated with heavy metals and high alkalinity to the environment (Naik et al. 2001). Additionally, the cost of landfilling is increasing due to strict environmental regulations and limited availability of space

Wood ash has a pozzolanic property which positively alters most soil properties, hence becoming suitable for construction (Okagbue 2007). This paper explored the application of wood ash as a partial replacement of lime in stabilisation of laterite soil for pavement layers. This would enhance environmental protection through reducing the volumes of wood ash to be landfilled and/or indiscriminate disposal of the wood ash waste while at the same time reducing the cost of pavement layers.

2 MATERIALS AND METHODS

2.1 *Laterite Soil*

Bulk samples of laterite soil were collected by disturbed sampling from a borrow pit at depths between 1.0 and 2.0 m on Kisoga-Nyenga road in Nkokonjeru, at chainage 14 + 740 – 300 m LHS, co-ordinates $0^0 14' 40''$N, $32^0 54' 43''$E, Buikwe district, Uganda.

The samples were taken to the laboratory in sacks and air-dried for 2 weeks. The dry sample was pulverized using a manual hammer and sieved through a sieve of 4.75 m aperture. According to AASHTO designation, the soil sample was classified as yellowish-brown Clayey Gravel with Sand. It had a liquid limit of 54.4 %, plastic limit of 24.7 %, linear shrinkage of 15.0 %, Maximum Dry Density (MDD) of 1.763 g/cm^3 with corresponding Optimum Moisture Content (OMC) of 19.0 %, California Bearing Ratio (CBR) of 4.91 % and Unconfined Compressive Strength (UCS) of 305.7 kN/m^2 as presented in Table 1.

2.2 *Wood Ash*

Wood ash was obtained from Shaka-Zulu restaurant in Bugolobi, Kampala, Uganda. The collected ash was further subjected to incineration at 900^{o}C in order to obtain a pure and whitish product. The burning at very high temperatures reduces or completely removes the organic content (impurities). The ash from the incinerator was then sieved through a US Sieve of 75 µm to obtain the fraction passing needed for ash-soil reaction. The portions of ash collected on the pan were immediately stored in air-tight containers to avoid pre-hydration.

2.3 *Lime*

Lime was sourced from Muhokya Lime Works in Kasese, Uganda.

2.4 *Sample Preparation*

The pulverized soil sample was mixed with lime in proportions of 0 %, 1 %, 2 %, 3 %, 4 %, 5 % and 6 %. Each mix was subjected to pH tests to determine the Initial Consumption of Lime (ICL). ICL was the amount of lime at which the corresponding pH values remained constant.

Soil and WA specimens were kept in an oven at 105^{o}C overnight to remove moisture and repress microbial activity. The two prepared specimens, together with lime, were then mixed manually on a large tray in a dry state with proper care to avoid the possibility of non-uniform mixing.

In order to investigate the effect of WA and lime on the mechanical properties of treated lateritic soils, specimens with specified amounts of WA partially substituting the ICL were prepared in different blends of:

- 4.0 % Lime and 0.0 % WA,
- 3.6 % Lime and 0.4 % WA,
- 3.2 % Lime and 0.8 % WA
- 2.8 % Lime and 1.2 % WA
- 2.4 % Lime and 1.6 % WA
- 2.0 % Lime and 2.0 % WA

In order to maintain consistency between the sample preparations, the mixing water was controlled. In this study, samples were prepared at their corresponding OMC.

2.5 *Tests*

The following tests were carried out on the un-treated and treated prepared specimens:

- Atterberg limits and linear shrinkage for both natural and stabilised soil according to BS 1377: Part 2: 1990.
- Compaction test for both natural and stabilised laterite soil according to BS 1377: Part 4: 1990.
- CBR test for both natural and stabilised laterite soil according to BS 1377: Part 4: 1990.
- Uncured UCS test for both natural and stabilised laterite soil according to ASTM D-2166.

3 RESULTS AND DISCUSSION

3.1 *Identification of Lateritic Soil and WA*

The index properties of the untreated laterite soil are shown in Table 1 and Figure 1. The soil was classified as A-2-7 (1) using the AASHTO system.

Quantitative analysis of the percentage composition of the WA was carried out using the XRF Spectroscopy, Simadzu 9200 and results presented in Table 2. The combined percent composition of SiO_2, Al_2O_3 and Fe_2O_3 is 56.34 %. This shows that, it is a fairly good pozzolana that could help mobilise the CaOH in the soil for the formation of cementitious compounds (Alhassan 2008). A pozzolana is a siliceous material which by itself does not possess cementitious properties. However, in finely divided form in the presence of water, reacts with $Ca(OH)_2$ to form cementitious products (Kadyali & Lal 2008). WA qualifies as a pozzolana since the percentage sum of its SiO_2, Al_2O_3 and Fe_2O_3 components (56.34%) exceeds the minimum requirement of 50% (Kanning et al. 2014).

Table 1. Properties of laterite soil determined from laboratory

Property	Quantity
Natural moisture content (%)	14.7
Liquid limit (LL) %	54.4
Plastic limit (PL) %	24.7
Plasticity index (PI) %	29.7
Linear shrinkage (LS) %	15.0
AASHTO classification	A-2-7
Soil type	Clayey Gravel with Sand
Group index	1
Color	Yellowish-Brown
Maximum dry density (MDD) g/cc	1.763
Optimum moisture content (OMC) %	19.0
California Bearing Ratio (CBR) %	4.91
Unconfined Compressive Strength (UCS) kN/m^2	305.7

Table 2. Chemical characteristics/composition of wood ash

Parameter	Result **(%)**
Alumina, Al_2O_3	6.28
Calcium Carbonate, $CaCO_3$	10.34
Calcium Oxide, CaO	15.88
Chromium Oxide, Cr_2O_3	2.98
Iron Oxide, Fe_2O_3	7.84
Manganese Oxide, MnO_2	2.24
Phosphorus Oxide, P_2O_5	1.21
Silica, SiO_2	42.22
Sodium Oxide, NaO_2	1.32
Sulphur trioxide, SO_3	1.12

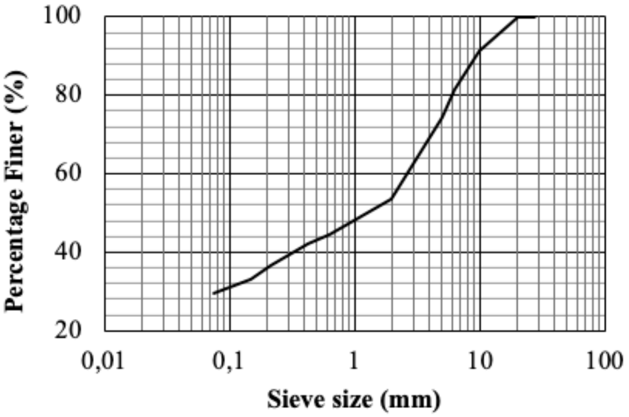

Figure 1. Particle size distribution of un-treated Laterite soil

3.2 *Atterberg Limits and Linear Shrinkage*

The liquid limit generally decreased with increasing WA content, while the plastic limit increased, resulting in a decrease in plasticity index as seen in Table 3 and Figure 2. These trends are similar to those produced when soils are treated with lime provided by Nwadiogbu & Salahdeen (2014) and Joel & Edeh (2015). The partial addition of WA causes a decrease in the swell potentials depicted by decrease in the plasticity index. The reduction in the swell potential is as a result of the cation exchange which occurs when Ca^{2+} ions from the additive replace weaker cation in the soil, thereby causing a better sealing of the voids by agglomeration. In this way, water absorption is reduced and hence swelling and shrinkage, leading to improved workability as the treated soil becomes more friable. In addition, cation exchange and flocculation take place so rapidly that it produces immediate change in the index properties of treated soil depicted by the immediate increase in both liquid limit and plastic limit.

Table 3. Atterberg limits and linear shrinkage of the treated specimens

% WA	LL (%)	PL (%)	PI (%)	LS (%)
0	52.4	23.9	28.5	14.2
10	55.0	27.0	28.0	13.8
20	51.8	28.0	23.8	11.5
30	50.6	29.0	21.6	10.8
40	51.0	29.9	21.1	10.6
50	49.7	32.1	17.6	9.9

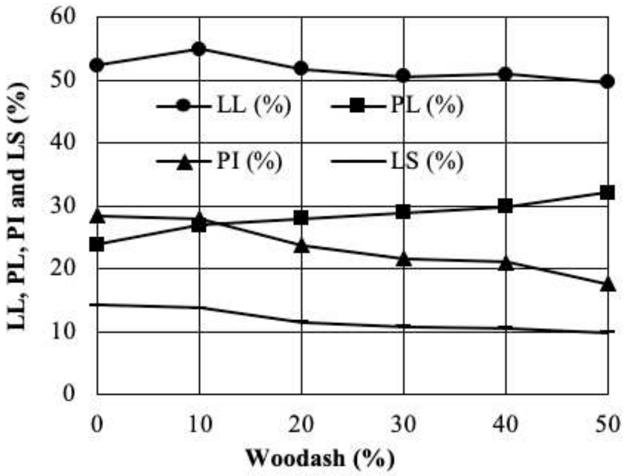

Figure 2. Variation of LL, PL, PI and LS with WA content

3.3 *Compaction Properties*

The OMC generally increased whilst MDD generally decreased with increasing WA content as observed from Table 4 and Figures 3-4. The increasing optimum moisture content with increasing WA content is thought to result from the increasing desire for water as WA content increases for cation exchange and pozzolanic reaction of the admixture. Therefore, more water is required for the formation of the lime-like product, $Ca(OH)_2$, and dissolution of this product into Ca^{2+} and OH^- ions, in order to supply more Ca^{2+} ions for the cation exchange reaction (Joel & Edeh 2015, Okagbue 2007)

The initial increase in the maximum dry density from 0 % WA content to 10 % ash content could be due to molecular rearrangement in the formation of “transitional compounds” with higher densities, maximum at 10 % WA content (Adefemi & Wole 2013). However, a further decrease in maximum dry density is attributed to the flocculated and agglomerated clay particles in the soil (caused by the cation exchange reaction) occupying larger spaces, thus increasing the volume of the voids and consequently reducing the weight to volume ratio hence reducing the density (Alhassan 2008).

Table 4. Compaction properties of the treated specimen soil

% Wood Ash	OMC (%)	MDD (g/cc)
0	20.0	1.716
10	20.1	1.722
20	20.5	1.672
30	21.5	1.642
40	21.5	1.635
50	22.0	1.629

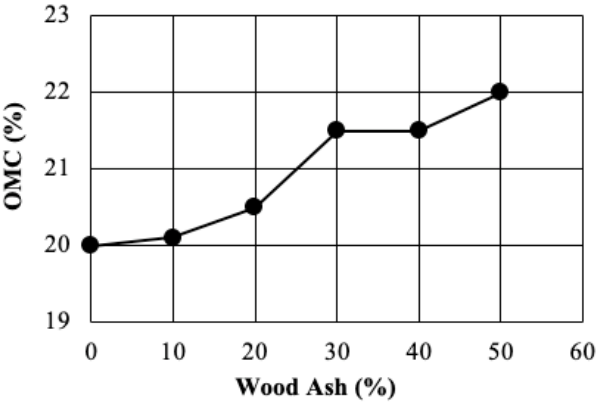

Figure 3. Variation of OMC with WA content

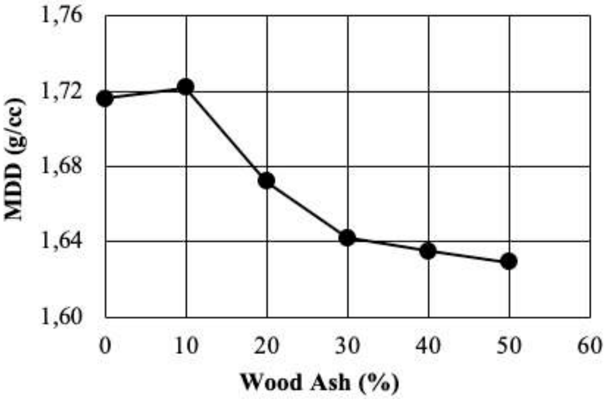

Figure 4. Variation of MDD with WA content

3.4 *California Bearing Ratio*

It can be seen, from Table 5 and Figure 5, that the CBR values registered on 4-days treated specimens first decreased from 0 % to 10 % WA; then it increased to an optimum level from which a decline was finally noted as the percentage of WA increases. The optimum was reached at 40 % WA.

Various explanations have been put forward for the improvement of the CBR by various authors. The initial decrease in the CBR is due to the reduction in the lime content in the mix which is a major contributor of Ca^{2+} for pozzolanic reaction. The subsequent increment in the CBR after 10 % WA could be attributed to the gradual formation of cementitious compounds between the WA and CaOH contained in the soil (Alhassan 2008). The gradual decrease in the CBR after 40 % WA may be due to excess WA that was not mobilised in the reaction, which consequently occupies spaces within the sample and therefore reducing bond in the soil-WA mixtures (Alhassan 2008).

Table 5. CBR of the specimen soil containing the additives

% Wood Ash	CBR (%)
0	26.2
10	15.3
20	15.6
30	20.4
40	22.8
50	12.9

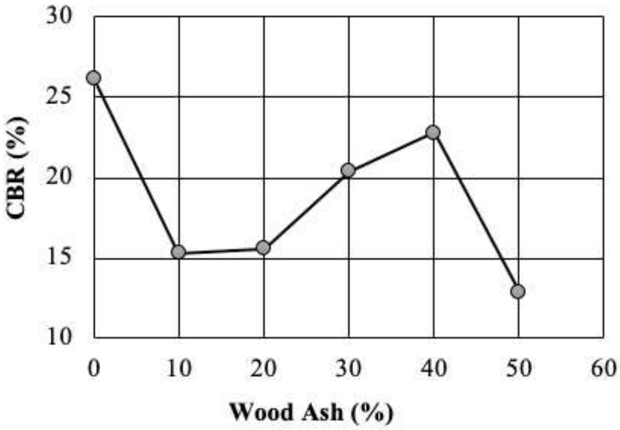

Figure 5. Variation of CBR with WA content

3.5 *Unconfined Compressive Strength*

UCS tests were conducted on specimens compacted at maximum dry density and optimum moisture content. Initially the UCS values decreased with increasing WA content. This was followed by an increase in UCS between 20 % and 40 % WA percentages. After 40 %, the UCS values dropped again. This trend was observed after 7 days of curing of specimens.

The initial decrease could be due to a reduction in the lime contents in the mix which is a major contributor of Ca^{2+} for pozzolanic reaction whilst the subsequent decrease above 40 % WA treatment may be due to the excess WA introduced to the soil and therefore forming weak bonds between the soil and the cementitious compounds formed (Alhassan, 2008). The increase in the UCS was primarily due to the formation of secondary cementitious materials such as calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) and micro fabric changes, which are responsible for strength development (Sadeeq et al. 2015). In the soil-admixture blend, the laterite soil is the source of the silica and alumina, while the WA and lime are the sources of $Ca(OH)_2$ from its CaO content.

Table 6. UCS of the specimen soil containing additives

% Wood Ash	UCS (kN/m^2)
0	510.8
10	399.3
20	312.9
30	330.9
40	399.3
50	338.1

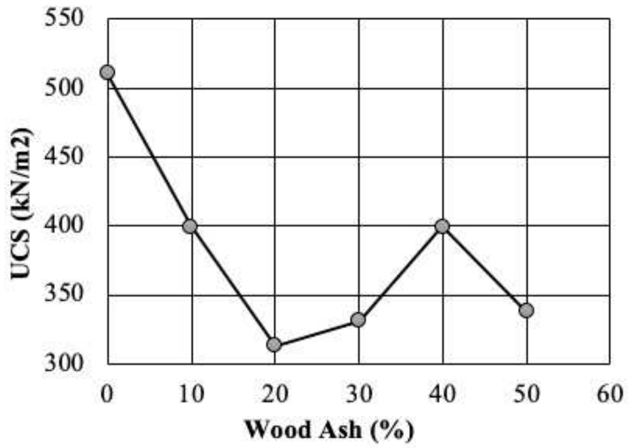

Figure 6. Variation of UCS with WA content

4 CONCLUSION

The natural gravel obtained was not suitable for use as a pavement layer because it did not satisfy the requirements as per the Ministry of Works, Housing and Communications (MoWHC) General Specifications for National Roads of 2004. None of the blends met the requirements for sub-base and base pavement layers. Blends of 3.2 % Lime and 0.8 % WA, 2.8 % Lime and 1.2 % WA, 2.4 % Lime and 1.6 % WA could be used in subgrade construction since they had PI < 25 and CBR > 15 %.

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