PRINT ISSN 1119-8362
Electronic ISSN 2659-1502

Full-text Available Online at
https://www.ajol.info/index.php/jasem
http://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 27 (7) 1551-1556 July 2023

Stabilization of Lateritic Soil with Rubber Wood Ash and Lime for Road Construction

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ABSTRACT: This study involved the investigation of the stabilizing lateritic soil with rubber wood ash (RWA) and lime for road construction. The index and engineering properties of the soil were carried out. Stabilization of the soil was carried out by mixing the soil by weight with 0%, 2%, 4% and 6% RWA mixed with 0.5%, 1%, 1.5% and 2% lime. The soil was classified as A-6 soil group according to AASHTO soil classification system possessing the following characteristics in its natural state; average moisture content of 18.7%, average specific gravity of 2.83 average liquid limit of 34.72%, average plastic limit of 22.02%, average plasticity index of 12.70% and average California Bearing Ratio of 2.47%. Data obtained revealed that the optimum mix ratio for economic and effectiveness was 4% RWA mixed with 1.5% lime which gave a result of 11.34% for soaked sample and 14.30% for the unsoaked sample respectively. Test results also showed that increase in RWA content increased the optimum moisture content but decreased the maximum dry density. The addition of 2% constant RWA with varying lime from 0.5%-2% lime shows that the MDD decreases consistently from $1.89g/cm^3$ to $1.63g/cm^3$ with an increase in OMC from 14.00% to 21.50%. The addition of 4% constant RWA with varying lime from 0.5%-1.5% lime reduce the MDD from the initial value of $1.63g/cm^3$ at 2% RWA to a constant value of $1.62g/cm^3$ and then increases to $1.68g/cm^3$ at 2% lime variation when the additives became too much and vice versa for the OMC. The CBR value of the natural soil is 2.47% which shows that the sample is very poor as subgrade material. The addition of RWA only shows a little improvement but the addition of RWA and lime gave a better result.

DOI: https://dx.doi.org/10.4314/jasem.v27i7.31

Cite this paper as: KAYODE-OJO, N; OSEMWENGIE, F. (2023). Stabilization of Lateritic Soil with Rubber Wood Ash and Lime for Road Construction. *J. Appl. Sci. Environ. Manage.* 27 (7) 151-1556

Keywords: lateritic soil; rubber wood ash; Stabilization; environmental pollution

The construction of roads and buildings to meet present day and future requirements is the greatest challenging tasks for the civil engineers since they are more attentive to technological changes for the benefit of mankind. Lateritic soil, one of the cheapest and oldest building materials is still in use in many regions of the world (Adeyemi, 2003; Kayode-Ojo and Odemerho, 2023). The abundant lateritic soil in Nigeria as well as other tropical regions of the world has made it to be widely used for civil engineering construction works. This lateritic soil (the kaolinite minerals) possesses a relatively good quality for subgrades, but there are instances where a lateritic soil (the montmorillonite minerals) may contain a substantial amount of clay minerals that its strength and stability cannot be guaranteed under load especially in the presence of moisture (Ilesanmi,2012).

Sourcing for alternative soil in most cases may prove economically unwise but rather to improve the available soil to meet the desired objective (Osinubi, 1999). Cement, bituminous products, calcium chloride and lime have been used in time past to modify soils but the geometric increase in their cost has caused the cost of construction of stabilized soils to be high bringing forth the need for inexpensive locally available alternatives. To this end, pozzolanic materials have proven to fit into this category because they also have related if not close attribute as other stabilizers. Most of these pozzolanic materials are obtained from combustion process of industrial waste, husks, shells, bones, leaves as fly ash, rubber wood, rice husk, coconut husk, egg shells, animal such as cattle bones, palm leaves and bamboo leaves respectively except for volcanic ash, all of which are

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waste. If this is improperly handled, these wastes will be a source of land, air, surface water and groundwater pollution. In other to minimize the effects of these wastes, one of the most attractive options of managing such wastes is to look into the possibility of waste minimization and recovery. Thus, utilizing the various available waste yet pozzolanic materials is of a great advantage to the environment, human health and construction practices. Due to inadequate soil construction materials, the cost of removal and bringing or getting an adequate or suitable soil material often prove to be uneconomical. The modifiers and stabilizers available for use are increasingly costly, and pozzolans have been found to suit them partially if not completely. The increasing need for sustainable road materials which will be of good quality and at the same time be economical in the provision of good and durable road networks has led to researches into alternative materials for construction works. Thus, engineers have carried out several test on waste that have pozzolanic properties to help in waste management and also to produce economically durable soils for the arising need of good roads in Nigeria and all over the world. Amongst such waste is rubber wood ash (RWA) which to a considerable extent is produced in Nigeria. A number of researchers have studied the use of wood ash as a stabilizing binder in soil. (Edeh et al., (2013); Ogunribido (2012); Otoko and Honest (2014); Butt et al., (2016); Abdulwahab et al., (2018); Chukwuebuka and Ogbonnaya, (2015); Bayshakhi et al., (2018); Abdullahi, (2006)). In most of these previous works done, the wood ash used were obtained from wood of various species, but in this case the wood ash is gotten from a particular wood type i.e., rubber wood. Hence, the objective of this paper is to investigate the stabilization of lateritic soil with rubber wood ash and lime for road construction.

MATERIALS AND METHOD

Materials: The materials that were used for this work are Lateritic soil, Rubber wood ash and Lime. The lateritic soil sample used for this research was collected from Idogbo community in Ikpoba Okha Local Government Area, Edo State. The area lies at a geographical coordinate of 6°16ˈ55” N and 5°41ˈ55” E. The soil sample was taken at depths of 1m from the ground level after the removal of the top soil using the method of disturbed sampling. The rubber wood was obtained from Okogbo village in Orhionmwon local government area of Edo state, burnt in a locally fabricated furnace under an uncontrolled temperature. It was left until it burned completely into ashes following the procedure in Barathan and Gobinath (2013). Hydrated lime was used for this research work to serve as binder for the rubber wood ash used. It was purchased commercially from the market and stored in a cool and dry place to prevent it from weather effects.

Index and Engineering Properties of the Soil: Natural moisture content, Particle size distribution, Specific gravity, Atterberg limit tests, Proctor compaction test, California bearing ratio test and Loss of Ignition Tests were evaluated in accordance with BS 1377 (1990) standards.

Chemical Analysis of Sample: The chemical composition of the laterite and the RWA were obtained. Analysis of major components of the lime and RWA were performed. They are CaO, SiO_2, Fe_2O_3, Al_2O_3, MgO, TiO_2, Na_2O, K_2O, MnO_2 and other impurities that make up the remaining balance.

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Batch Formulation: The materials used in the batch formulation of the test pieces were laterite, rubber wood ash (RWA) and lime. Various Batches were formulated by weighing the materials in percentage proportions as shown in Table 1.

Table 1 Percentage composition of laterite + RWA + lime

Label	Laterite %	RWA	Lime
Z_0 (Natural Soil)	100	0	0
Z_1	98	2	0
Z_2	96	4	0
Z_3	94	6	0
Z_4	97.5	2	0.5
Z_5	97.0	2	1.0
Z_6	96.5	2	1.5
Z_7	96.0	2	2
Z_8	95.5	4	0.5
Z_9	95.0	4	1.0
Z_{10}	94.5	4	1.5
Z_{11}	94.0	4	2.0
Z_{12}	93.5	6	0.5
Z_{13}	93.0	6	1.0
Z_{14}	92.5	6	1.5
Z_{15}	92.0	6	2.0

RESULT AND DISCUSSION

Atterberg Limits Of Sample Soil: The results of the laboratory test carried out on the control samples are presented in Table 2.

Table 2: Summary of laboratory test on the control sample (Z_0)

AASHTO Classification	A-6
Natural moisture content (%)	18.7
Liquid Limit (%)	34.72
Plastic Limit (%)	22.02
Plasticity Index (%)	12.70
Linear shrinkage (%)	6.1
Specific gravity	2.83
Percentage passing No. 200 BS sieve	55.34
AASHTO Classification	A-6
Group Index	2.49
Maximum dry density (g/cm^3)	1.83
Optimum moisture content (%)	15.00
Unsoaked CBR (%)	3.34
Soaked CBR (%)	2.47

The results of the Atterberg limit tests of the sample are presented in Table 2. The laterite has liquid limit of 34.72%. The plastic limit result is 22.02%. The plasticity index shows a value of 12.70. A plasticity index in the range of 10-25% shows that the soil sample is of medium plasticity. As pointed out by Gogo (1993), plasticity characteristics give an indication of the approximate water content which is likely to give the optimum workability and therefore plays an important role in stabilization. The amount of water used during mixing for optimum workability was found to be between 18% and 35% for the natural soil. From this result, it shows that the sample is of medium plasticity. The laterite was associated with smaller particle size. This will affect the level of inter-particle packing, the level of inter-particle void and therefore water absorption and shrinkages. Using the AASHTO soil classification system (Highway Research Board Classification System) the soil is classified as A-6. Group A-6 represents soils which has minimum of 36% passing through sieve no 200, maximum of 40% liquid limit, minimum of 11% plasticity index and the usual type of significant constituent material is clayey soils. Thus, the soil has 'Fair to poor' drainage characteristic and a 'Fair to poor' general rating as a subgrade.

Chemical Composition of Laterite and RWA: Table 3 shows the chemical composition of the laterite and RWA used in this work. The analysis showed that both RWA and Laterite total percentages of oxides present, are in agreement with ASTM specifications, which specify that total percentage oxides composition must not be less than 70% for pozzolanic materials. Comparatively, the RWA showed a higher percentage which makes it more advantageous for use compared to other conventional materials.

Table 3: Oxide Composition of RWA and the Lateritic Soil

Oxides (%)	RWA	Lateritic Soil
CaO	35.20	5.50
SiO_2	12.7	50.50
Fe_2O_3	2.95	1.50
Al_2O_3	10.15	2.50
MgO	5.25	0.75
TiO_2	1.5	0.65
Na_2O	7.4	0.85
K_2O	14.4	9.80
Loss On Ignition (LOI)	2.78	4.50
Others	7.67	23.45
Total percentages	100	100

The analysis indicates that the RWA have potassium oxide (K_2O) content of 14.4% which is in accordance with Hawa et al., (2014) and Dasaesamoh et al., (2011) which states that potassium oxide component in RWA is 13 – 16%. This potassium oxide is necessary as chemical stabilizer in reacting with the laterite to form a cementitious matrix. There is also an appreciable amount of calcium oxide (CaO) in rubber wood ash (35.20%) which is a key factor for improving the engineering properties of the soil.

Laboratory Test Analysis on Stabilized Soil: Atterberg Limits (Liquid Limit, Plastic Limit, Plasticity Index): The combined plot of the liquid limit, plastic limit and plasticity index of the stabilized laterite as a function of the RWA and lime content is as shown in Tables 4 and 5. The liquid limit (LL) decreases drastically with increase in the RWA and Lime content, (that is 32.79 % at 2 % RWA and 1.0% lime combination to 28.22% at 2% RWA and 1.5% lime combination) than when it was stabilized with 4% RWA and 6% RWA with similar percentage increase in lime (that is 32.39% to 31.91 % for 4% RWA with 1.0% and 1.5% lime combination, 34.39% to 33.85% for 6% RWA with 1.0% and 1.5 % lime combination respectively). The plasticity index (PI) which gives a measure of the plasticity of a soil also decreases just like the LL with an increase in the RWA and lime content. The decrease in the PI value was more when the laterite was stabilized with 4% RWA at varying percentages of lime (that is 4.79 % at 0.5 % lime to 3.28% at 2% lime than when it was stabilized with 6% RWA also at varying percentages of lime (that is 8.53% at 0.5% lime to 7.00% at 1.5% lime and finally dropping to 4.39% at 2% lime).Muntohar (1999), establish that a reduction in the PI of a stabilized soil is an indication of improvement.

Table 4: Atterberg Limit of laterite with RWA only

Natural soil with Percentage variation of RWA Content				
RWA (%)	Laterite (%)	LL (%)	PL (%)	PI (%)
0	100	34.72	22.02	12.70
2	98	32.65	25.72	6.89
4	96	32.17	27.33	4.84
6	94	31.48	23.23	8.25

The RWA and lime application to the laterite soil led to the exchange of hydrated monovalent cations in the contaminated soil with the divalent cations in the lime. Beetham et al., (2014) stated that "the valence of the charge-balancing cations, among several other factors, primarily controls the influence of the diffused double layer. (DDL)".

Consequently, such balancing of the laterite soil surface charges balancing with divalent cat ion has been found capable of reducing DDL thickness (Bohn, 2002), and could be the reason for the decrease in the plasticity index of the stabilized laterite soil. The decrease in the Atterberg limit values were in accordance with the results obtained in Portelinha et al., (2012) and Oyediran and Okosun (2013).

Table 5: Atterberg Limit of laterite with RWA and Lime in varied percentages

Lime (%)	Laterite (%)	LL (%)	PL (%)	PI (%)
2% RWA and Percentage variation of Lime				
0.5	97.5	33.28	21.45	11.83
1.0	97.0	32.79	21.11	11.68
1.5	96.5	28.22	19.00	9.22
2.0	96.0	27.97	20.72	7.25
4% RWA and Percentage variation of Lime				
0.5	95.5	30.26	25.47	4.79
1.0	95.0	32.39	27.77	4.43
1.5	94.5	31.91	27.38	4.53
2.0	94.0	30.56	27.28	3.28
6% RWA and Percentage variation of Lime				
0.5	93.5	36.02	27.49	8.53
1.0	93.0	34.39	29.66	4.74
1.5	92.5	33.85	26.85	7.00
2.0	92.0	30.48	26.09	4.39

Compaction Characteristics: The summary of the compaction characteristics of both the natural and stabilized soil samples is shown in Table 6.

Table 6: Summary of Compaction Test Result

Sample	**Mix ratio (%)**	**Maximum dry density (MDD) (g/cm^3)**	**Optimum moisture content (OMC) (%)**
Natural soil	0	1.83	15.00
Rubber wood ash	2	1.82	15.50
	4	1.84	17.50
	6	1.80	18.50
Rubber wood ash : lime	2 : 0.5	1.89	14.00
	2 : 1	1.70	21.50
	2 : 1.5	1.69	20.00
	2 : 2	1.63	21.50
	4 : 0.5	1.62	22.50
	4 : 1	1.62	24.00
	4 : 1.5	1.62	22.50
	4 : 2	1.68	20.00
	6 : 0.5	1.63	21.00
	6 : 1	1.60	26.60
	6 : 1.5	1.81	19.50
	6 : 2	1.73	17.90

The optimum moisture content for the control soil sample was 15.0%. For the soil-RWA combination, it was observed that the optimum moisture content increases with increasing rubber wood ash from 15.0% to 15.5% at 2% soil – RWA combination, and from 15.5% to 17.5% at 4% soil – RWA combination and finally from 17.5% to 18.5% at 6% soil – RWA combination. With soil – RWA + lime combination, a higher increase in the OMC was observed. At 2% soil – RWA + 0.5% lime combination to 2% soil – RWA + 2% lime combination; there was an increase in OMC from 14.0% to 21.50%. This increase in OMC was also observed at 4% RWA, although this increase was lesser than that observed in 2% RWA. At 4% soil – RWA + 0.5% lime combination to 4% soil – RWA + 1% lime combination; there was an increase in OMC from 22.50% to 24.0%. Still at 4% RWA, there was a reduction in OMC maybe due to too much of the additives. At 4% soil – RWA + 1% lime combination to 4% soil – RWA + 1.5% lime combination, the OMC reduces from 24.0% to 22.5% and from 22.5%, it went down to 20.0% at 4% soil – RWA + 2% lime combination. At 6% soil – RWA + 0.5% lime combination to 6% soil – RWA + 2% lime combination, the OMC reduces from 21.0% to 17.9%. The increase in OMC was due to the fact that addition of RWA decreased the quantity of free silt and clay fraction, and coarser materials with larger surface areas were formed (these processes need water to take place). This increase in the OMC is necessary because of the reduced surface area caused by the flocculation and agglomeration of the particles which requires more water in addition to the free lime that needed more water for the pozzolanic reactions to take place. For the soil-RWA combination, the maximum dry density decreases from the natural value of 1.83 g/cm^3 (that is 0% RWA mixture) to 1.80 g/cm^3 at 6% RWA mixture. For RWA and lime modification, the maximum dry density decreases throughout (that is from 1.89 g/cm3 at 0.5% lime to 1.63 g/cm3 at 2% lime) for the 2% RWA with varying lime content while there was a slight difference at 4% and 6% RWA with varying lime combination where the maximum dry density generally decreases with increasing lime content up to 1.5% lime content and 1.0% lime content respectively. The decrease in maximum dry density can be attributed to the cationic exchange of the lime which induces flocculation and agglomeration of the clay particles. Also contributing to reduction in the maximum dry density is specific gravity of the rubber wood ash which is lower than that of the natural soil sample, therefore the lighter particles fills the voids of the flocculated soil matrix to give a less dense matrix. According to Mountohar and Hantoro (2000), a decrease in the dry density of the soil sample shows that low compactive energy would be required for the soil to attain its maximum dry density. Consequently, the cost of compaction is significantly reduced.

California Bearing Ratio (CBR) Results: The results of the CBR values for the control and stabilized samples are presented in Tables 7- 10. The CBR value for the control soil sample was 2.47% at 5.0mm penetration. Generally, for the soil-RWA and soil-RWA + lime combinations, there was increase in strength from 2.47% untreated soil to 11.34% when it was treated with 4% RWA and 1.5% lime under soaked condition and 14.30% for unsoaked condition as shown in Table 7. The increase could be due to adequate amount of calcium required for the formation of calcium silicate hydrate (CSH) and calcium aluminates hydrate (CAH), which are the major compounds responsible for strength gain. The result of the RWA and lime treated soil is above 10% and it met the requirement for subgrade material for road construction, (Singh et al., 2020). The results obtained from the tests showed that the highest CBR value for the soaked sample was 11.34% at 4% RWA + 1.5%lime stabilization, which indicates a very high increase over the CBR value gotten from the natural soil sample. The lowest soaked CBR value occurred at 6% RWA + 1.0% lime stabilization. The soaked CBR values of the treated soil increased 4.66% to 11.34%. On the other hand, the improved soaked CBR of up to 11.34% is a very stable material for subgrade construction. Also, the highest unsoaked CBR value which is 14.30% occurred at 4% RWA + 1.5% lime stabilization and the minimum unsoaked CBR value which is 5.32% also occurred at 6% RWA + 1.0% lime stabilization. The increment in the CBR value at 4% RWA + 1.5% lime stabilization may be attributed to the gradual formation of cementitious compounds among the rubber wood ash, lime and the calcium hydroxide contained in the soil.

Table 7: CBR Values with Corresponding Increase in RWA

RWA %	Soaked CBR Values %	Unsoaked CBR Values %
0	2.47	3.34
2	3.12	4.27
4	5.48	9.15
6	4.33	5.59

Table 8: CBR Values for 2% RWA with Percentage Increase in Lime

Lime %	Soaked CBR Values %	Unsoaked CBR Values %
0	2.47	3.34
0.5	6.96	7.95
1.0	7.18	8.60
1.5	9.04	10.19
2.0	3.40	5.75

Table 9: CBR Values for 4% RWA with Percentage Increase in Lime

Lime %	Soaked CBR Values	Unsoaked CBR Values
0	2.47	3.34
0.5	2.96	3.89
1.0	5.10	9.97
1.5	11.34	14.30
2.0	8.44	10.08

Table 10: CBR Values for 6% RWA with Percentage Increase in Lime

Lime %	Soaked CBR Values	Unsoaked CBR Values
0	2.47	3.34
0.5	4.66	6.80
1.0	4.66	5.32
1.5	4.82	6.36
2.0	4.49	5.37

The gradual decrease in the CBR values from 6% RWA with varying amount of lime, may be due to excess RWA and lime that was not mobilized in the reaction, which consequently occupies spaces within the sample and therefore reducing bond in the soil, RWA + lime mixtures. CBR values increases with the addition of 2% RWA, i.e. from 2.47% to 3.12% for the soaked sample and 3.34% to 4.27% for the unsoaked sample respectively. An additional increase was achieved with the addition of 4% RWA i.e. from 3.12% to 5.48% for the soaked sample and 4.27% to 9.15%for the unsoaked sample after which the values drops at 6% RWA to 4.33% for soaked and 5.59% for the unsoaked samples although the CBR values were still greater than the natural soil value of 2.47%. The initial increase in the CBR with additive content was due to the fact that the particles were brought closely packed thereby increasing the strength but as the additive content becomes much, decrease in the CBR resulted due to the reduction in the silt and clay content of the soil, which reduces the cohesion of the samples. The increment in the CBR values at 2% RWA and 4% RWA respectively can be attributed to the gradual formation of cementitious compounds between the RWA and CaOH contained in the soil. The result of the study shows good potentials of using RWA only for soil improvement while stabilization with RWA and lime shows a better result with increase in CBR value due to the formation of secondary cementitious compounds with the CaOH produced from the hydration of lime (CaOH). The above results show that the very poor subgrade material has been improved to a better subgrade material with the addition of a little quantity of RWA and lime. This technique can be employed to improve soil materials for use in low density roads.

*Conclusion***:** From this work, it can be concluded that lateritic soil can be improved considerably upon stabilization with RWA mixed with lime.

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