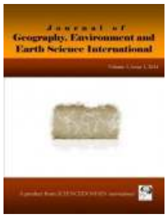

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Enhancing Some Geotechnical Characteristics of Laterite Soils Using Limestone Ash Waste

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

Aims: The potential of limestone ash for the improvement of some geotechnical properties of Laterite soils for construction purposes was evaluated. The assessment involved the determination of the engineering properties of Laterite soil in its natural state as well as when mixed with varying proportions of limestone ash.
Study Design: Experimental study was employed to achieve the aim of the study. The experiment was conducted in the geotechnical laboratory.
Place and Duration of Study: The study was conducted at Nsukka in Enugu State, South-Eastern Nigeria. Fieldwork was carried out for a period of one month while the laboratory experiments were conducted over a period of five months from June to December 2013.
Methodology: Lateritic soil samples were obtained from freshly exposed gully cuts to a depth of 1.5 m in Enugu, Nigeria. The soil samples were air-dried for two weeks after which the following parameters were tested for: Atterberg limits, grain size analyses, compaction characteristics, California Bearing Ratio (CBR) and compressive strength. Natural moisture content of the soil was determined by placing 38 g of the sample in an oven for a period of 24 hours in which the moisture content was obtained by subtracting the weight of the of dry soil from the weight of the wet soil and the container, multiplied by 100%. The geotechnical properties of the soil were determined both in the natural state and after stabilisation with varying percentages of limestone ash waste at a normal

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curing of 6 hours. Accelerated curing at 40℃, 60℃ an d 80℃ for 24 hours was carried out for compressive strength tests for 4% and 6% respectively due to similarities in the values of both the CBR and compressive strength.

Results: The dry density and plasticity index decreased while liquid limit, plastic limit, compressive strength and CBR increased with increasing percentages of limestone ash. Maximum strength was achieved at 6% proportion of limestone ash for CBR and compressive strength respectively.

Conclusion: The results of this research indicate that limestone ash is comparatively suitable for the chemical stabilisation of Laterite soils as lime is, as reported by other researchers.

Keywords: Limestone ash waste; laterites; chemical stabilization; geotechnical properties; road construction.

1. INTRODUCTION

Many researchers have performed vast experiments on soil stabilisation using chemical additives. The use of chemical additives is most often considered as a stabilisation option for red tropical soils that fail to meet various engineering specifications in the natural state. Various chemical additives such as lime, cement, bitumen, Pulverised Fuel Ash (PFA), sodium silicate and calcium chloride have been used in stabilizing red tropical soils [1-8]. In 2010, [7] reiterate that the successful road performance under tropical conditions of sand-clay surfacing having silt and clay contents considerably higher than the standard stipulated in “Specification of Road and Bridge works” [9] have been attributed in part, to the effects of iron oxide in binding smaller particles into larger aggregates and to the relatively low activity of kaolin in red tropical soils. The settlement and dynamics of soil as foundation material under different loading conditions have been studied [10-13].

The availability and abundance of Laterite soils in tropical Africa encourage its use for road construction and for making bricks. It has been argued that the weathering of large masses of solid rocks in tropical regions of Nigeria (Fig. 1) [14] is characterised by heavy rainfall during the wet season, followed by a dry season with high temperature and rapid evaporation which result in the formation of soils [15-17]. Due to high degree of plasticity of Laterite soils which makes it to be seemingly unsuitable for construction purposes in its natural state; its engineering properties can however, be improved by the application of limestone ash in order to stabilise it chemically.

Rocks in the study area have undergone intensive tropical weathering and most of the Siltstones are ferrugenised. The parent material is a prime factor affecting the iron and mineral composition and distribution for lateritic soils [18]. The Shale in the study area is characterised by reddish-brown colour and exhibit pisolitic structures. The crevices in the Shale are extensively weathered due to the action of water permeating the rock. The main effects of weathering have been the removal of carbon in sediments, the oxidation of pyrite and irregular pigmentation of the rocks by iron oxides [19,20].

Laterisation; a progressive and accelerated form of podzolization [21] is the process of leaching that removes all the soluble materials in a soil profile in humid tropical climate. Laterites have certain chemical characteristics which after desiccation, hardens irreversibly. Gidigasu [22] presented several classifications of Laterite materials by different authors using morphological, chemical, textural or hardening properties or a combination of all these characteristics. The important features of Laterites are their unique colour, poor soil fertility regime for agriculture and lower cation exchange capacity (CEC). More so, lateritic soils contain substantial amount of iron and aluminum oxides [23] and the iron oxides, which exist mainly in the amorphous and crystalline inorganic forms, are one of major components in many soil orders known globally.

It has been established that the specific surface area is an invaluable property in assessing the physical interaction of clay particles with chemical additives. A group of researchers [24] argued that Laterite clay samples based on Brunauer–Emmett–Teller (BET) results show that the presence of iron oxides as part of soil’s secondary constituents could contribute to obtaining higher surface area values which could have some effects on chemically stabilised soils. The authors also established that the presence of free iron oxides in the form of micro-aggregates could contribute to achieving higher

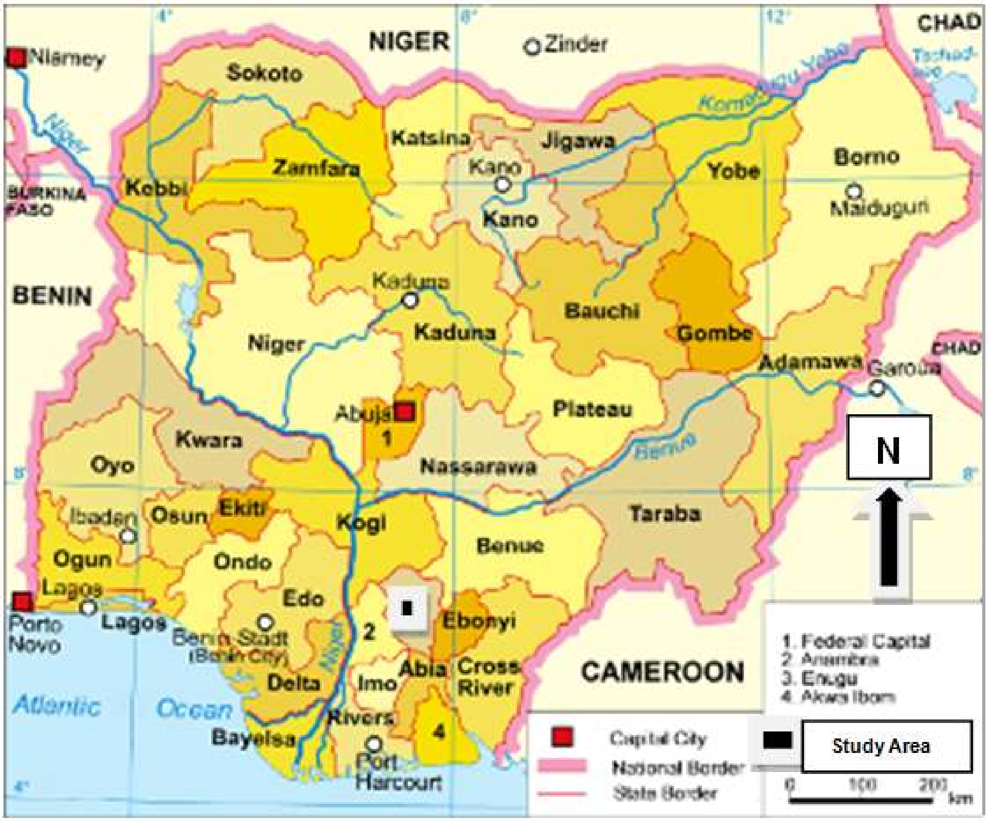

Fig. 1. Map of Nigeria showing the location of the study area
(Source: https://en.wikipedia.org/wiki/Template:Nigeria_states_map, 2015)

surface area values. The research conducted by [25] supports the fact that most of the chemical reactions in soils take place at the surface of particles.

Limestone ash is a waste product and possesses the characteristics of cement which is obtained from the processing of limestone for the manufacture of cement at the Nigerian Cement Manufacturing Company (Nigercem) at Nkalagu in Enugu State, South-Eastern Nigeria. The focus of this study is on the determination of the effects of mixture of various percentages of limestone ash on the engineering properties of Laterite soils formed from shale and sandstone of the Nsukka formation of South-Eastern Nigeria, with a view to evaluating their suitability for road construction.

2. MATERIALS AND METHODS

Lateritic soil samples were obtained from freshly exposed gully cuts to a depth of 1.5 m in Enugu, Nigeria and conveyed to the geotechnical laboratory for analyses. The study was conducted over a period of six months from June to December 2013. The soil samples were air-dried for two weeks after which the following parameters were tested for: Atterberg limits, grain size analyses, compaction characteristics, CBR and compressive strength in accordance with BS 1377 [9,26-29]. Natural moisture content of the soil was determined by placing 38 g of the sample in an oven for a period of 24 hours in which the moisture content was obtained by subtracting the weight of the of dry soil from the weight of the wet soil and the container, multiplied by 100%.

Various geotechnical properties of the soil were determined both in the natural state and after stabilization with 2%, 4%, 6%, 8% and 10% of limestone ash waste at a normal curing of 6 hours. Accelerated curing at 40℃, 60℃ and 80℃ for 24 hours was carried out for compressive strength tests for 4% and 6% respectively due to similarities in the values of both the CBR and compressive strength.

The curing time was determined by adding distilled water to an admixture of 3% of the limestone ash and 600 g of soil sample and was thoroughly mixed for complete reaction to take place. Soil samples were washed through the sieve in order to disintegrate the soil materials before carrying out the particle size distribution test while all other tests on the soil were conducted in the natural state and after mixing it with varying percentages of limestone ash. Both soaked and unsoaked compaction tests were carried out using moulds in order to determine the CBR values at various moisture contents and compactions.

3. RESULTS

The results of the laboratory analyses carried out on soil samples for the various tests are presented below.

3.1 Atterberg Limits Test

The engineering behaviour of a soil is related to the amount of water it contains. 200 g of the soil sample was used for each test, both in the natural state and when mixed with 2%, 4%, 6%, 8% and 10% by weight of limestone ash. The results of the liquid limit (w_L), plastic limit (w_p), plasticity index (I_p) and linear shrinkage tests were obtained for the untreated and treated soil samples as shown in Table 1, Figs. 2 and 3 respectively.

It is evident from the above graphs that both the liquid and the plastic limits increased with the addition of limestone ash while the plasticity index and linear shrinkage decreased respectively, showing a correlation with the research findings of other workers in the field of geotechnical engineering. For example [4,30,31] proposed that certain factors are responsible for the improvement of geotechnical properties of soils when treated with lime. These factors include flocculation of the clay materials, cation exchange capacity, agglomeration and pozzolanic reactions. He opined that the treated soil becomes more friable and this tends to improve its workability.

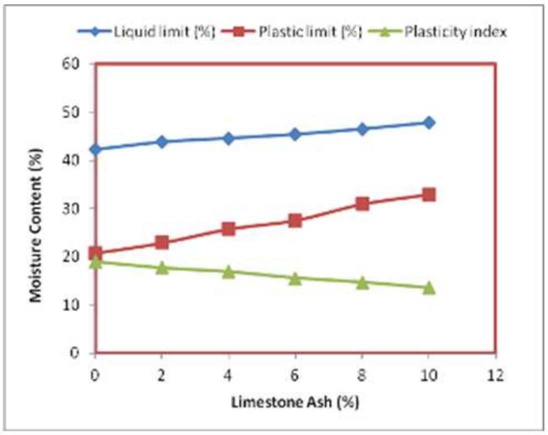

Fig. 2. Relationship amongst liquid limit, plastic limit and plasticity index

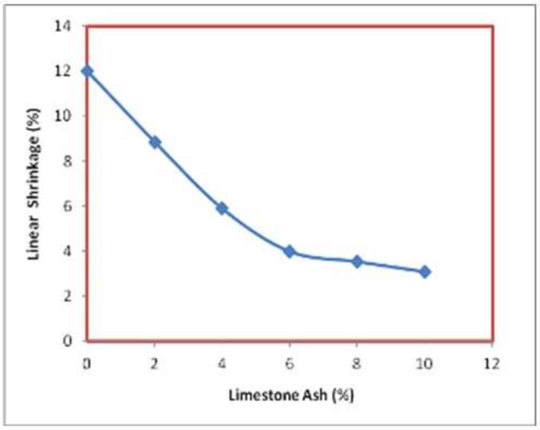

Fig. 3. Relationship between linear shrinkage and different percentages of limestone ash

Table 1. Atterberg limits and linear shrinkage test results

Limestone ash (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index	Shrinkage limit (%)
0	42.3	20.8	19.0	12.0
2	43.8	23.0	17.7	8.9
4	44.6	25.8	16.9	5.9
6	45.4	27.6	15.6	4.0
8	46.5	30.9	14.7	3.6
10	47.8	32.9	13.5	3.1

3.2 Grain Size Distribution Test

This test is widely used for the classification of soils with respect to their grain sizes. The method of sieve analysis is employed in delineating the distribution of various grain sizes which involves the shaking of the soil through a stack of wire screens with openings of known sizes [32,33]. From geotechnical engineering point of view, soil permeability and capillarity are related to an effective particle size diameter. The grain size distribution test was carried out by mixing 500g of the soil sample with various percentages of limestone ash and cured for 6 hours. The sample was placed in the topmost sieve and placed in the mechanical shaker for a minimum of 15 minutes.

The sieves and the soil retained on them were weighed and the initial weights of the sieves were deducted to obtain the weight of the soil retained. Hence, percentage retained on any sieve was calculated thus: Weight of soil retained divided by soil weight, multiplied by 100. The experiment was repeated for various percentages of limestone ash and the grain size curves were obtained and were used in the identification and classification of the grain sizes as shown in Table 2 and Figs. 4 to 9 respectively. The curves show that substantial amount of the Laterite soil samples are sandy in nature but they generally range from coarse silt to fine gravel.

Table 2. Grain size distribution results for the natural and ash-treated soil samples

Sieve no.	Sieve opening (mm)	Mass of sieve (g)	Mass of soil retained on each sieve (g) at varying percentages						Percentage passing					
			0%	2%	4%	6%	8%	10%	0 %	2%	4%	6%	8%	10%
8	2.380	417	3.00	6.00	1.00	2.00	0.00	3.00	99.42	98.80	99.80	99.50	100.00	99.50
10	2.000	436	3.00	4.00	2.00	1.00	1.00	3.00	98.84	98.00	99.40	99.30	99.80	99.00
12	1.680	419	4.00	6.00	3.00	2.00	2.00	4.00	98.06	96.80	98.80	98.90	99.40	98.30
16	1.190	402	20.00	29.00	18.00	12.00	11.00	18.00	94.06	91.20	95.30	96.70	97.40	95.00
22	0.700	382	46.00	54.00	45.00	38.00	38.00	46.00	85.22	80.80	86.50	89.60	90.40	86.40
30	0.590	355	73.00	84.00	74.00	64.00	74.00	76.00	71.02	64.70	72.10	77.60	76.70	72.80
44	0.350	341	93.00	104.00	85.00	87.00	102.00	91.00	52.93	44.70	55.50	61.30	57.80	56.30
60	0.250	323	77.00	64.00	78.00	72.00	60.00	63.00	37.95	32.40	40.30	47.80	46.70	44.80
85	0.178	314	70.00	58.00	66.00	68.00	103.00	82.00	24.33	21.30	27.40	22.90	27.60	29.90
120	0.125	305	59.00	43.00	53.00	65.00	67.00	35.00	12.85	13.00	17.10	22.90	15.20	23.50
150	0.104	310	17.00	13.00	10.00	23.00	8.00	19.00	9.54	10.50	15.20	18.60	13.70	20.00
170	0.090	302	14.00	21.00	21.00	20.00	22.00	44.00	6.82	6.50	11.10	14.90	9.60	12.00
300	0.050	248	36.00	22.00	31.00	20.00	26.00	31.00	1.75	2.30	5.10	11.20	4.80	6.40
PAN	0.000	434	9.00	13.00	26.00	60.00	26.00	35.00	0.00	0.00	0.00	0.00	0.00	0.00

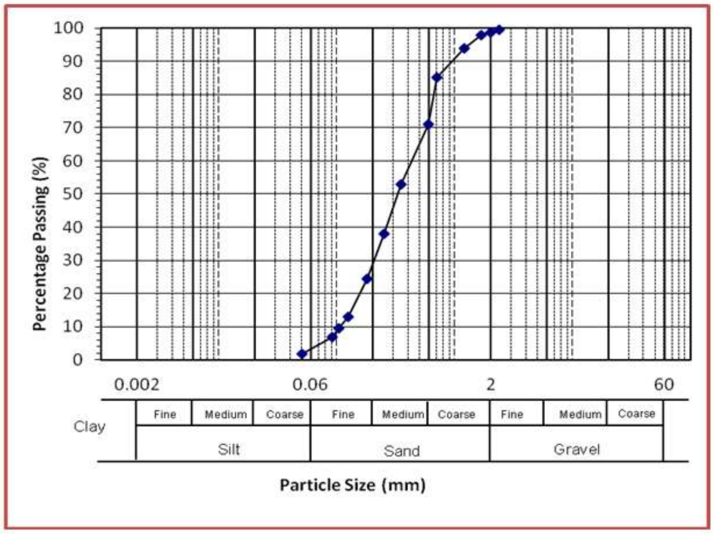

Fig. 4. Sieve analysis curve for 0% limestone ash

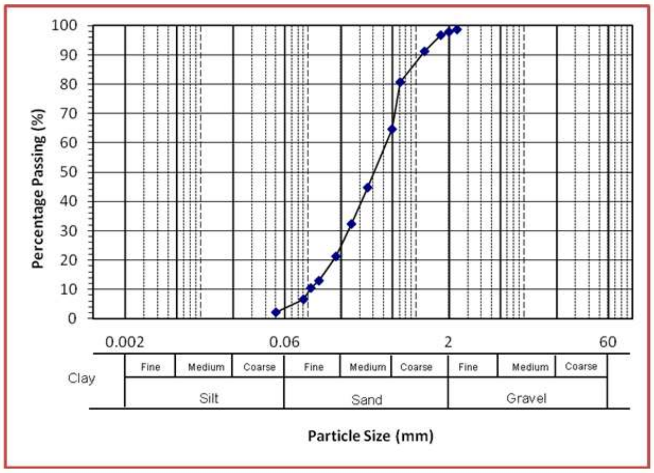

Fig. 5. Sieve analysis curve for 2% limestone ash

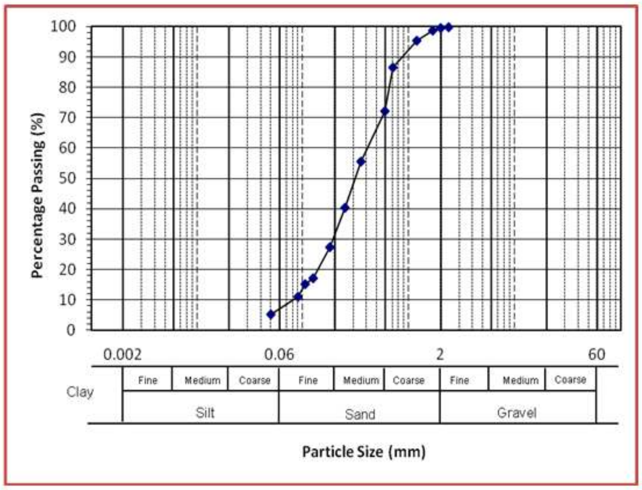

Fig. 6. Sieve analysis curve for 4% limestone ash

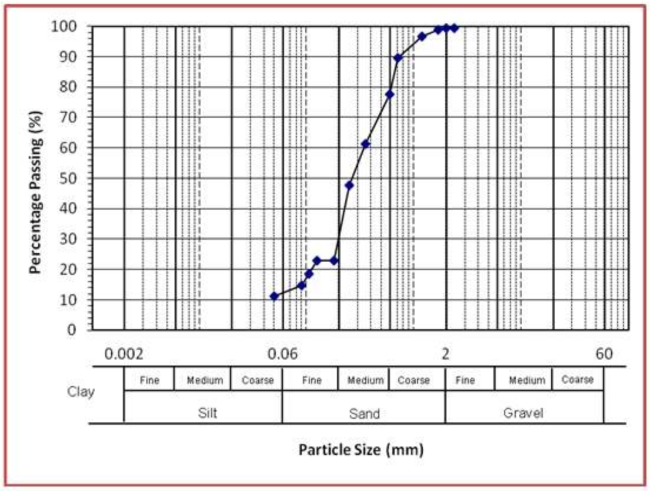

Fig. 7. Sieve analysis curve for 6% limestone ash

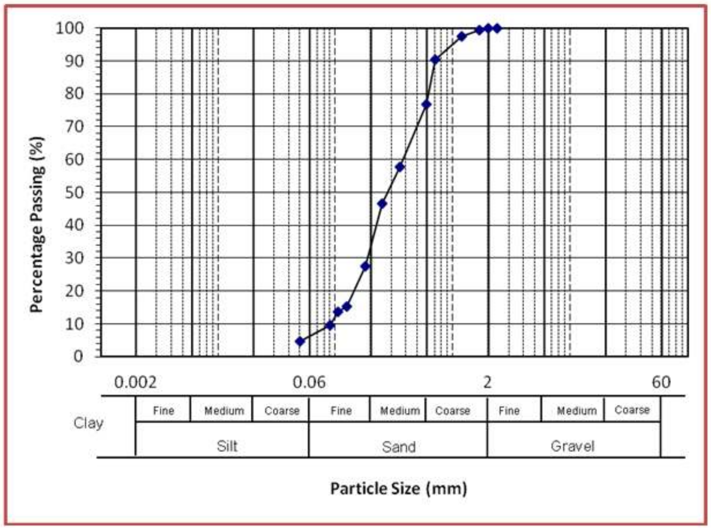

Fig. 8. Sieve analysis curve for 8% limestone ash

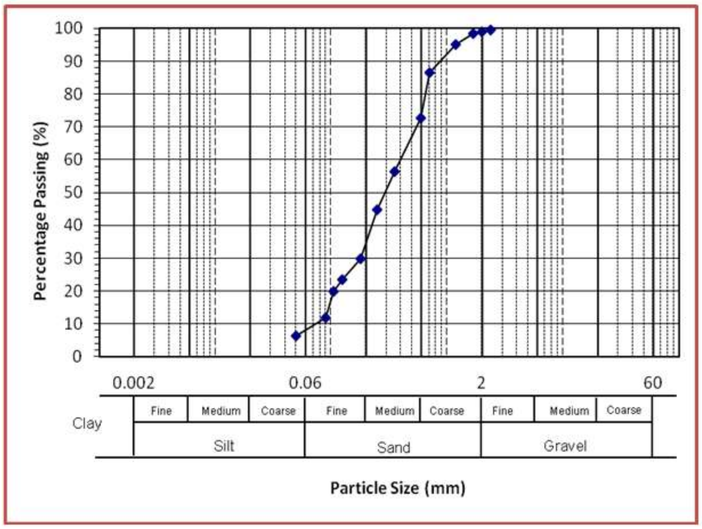

Fig. 9. Sieve analysis curve for 10% limestone ash

3.3 Compaction Test

The compaction characteristics results of the soil both in its untreated and treated states are shown in Table 3 while Figs. 10 and 11 are the graphic illustrations. These results were obtained using the Modified British Standard compaction efforts.

Table 3. Results of compaction tests using the Modified British Standard (Mod BS) procedure

Limestone ash (%)	Maximum dry density (kg/m^3)	Optimum moisture content (OMC), (%)
0	2000.5	15.0
2	1978.9	15.3
4	1955.0	15.6
6	1940.8	15.8
8	1930.6	16.0
10	1928.9	16.2

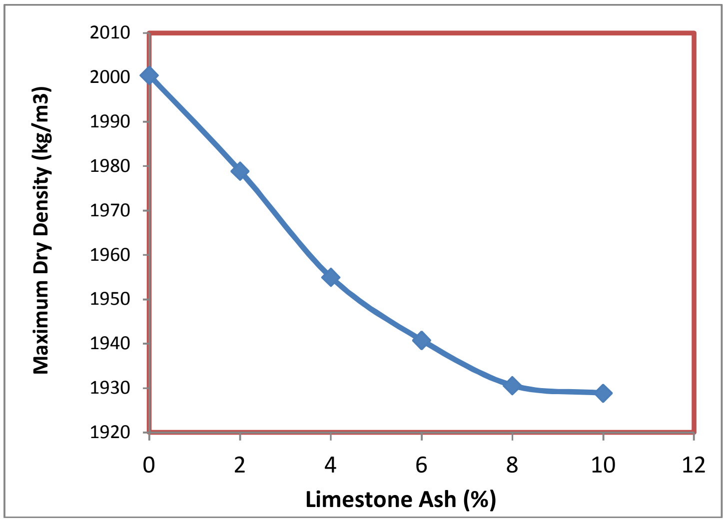

Fig. 10. Relationship between maximum dry density and different percentages of limestone ash

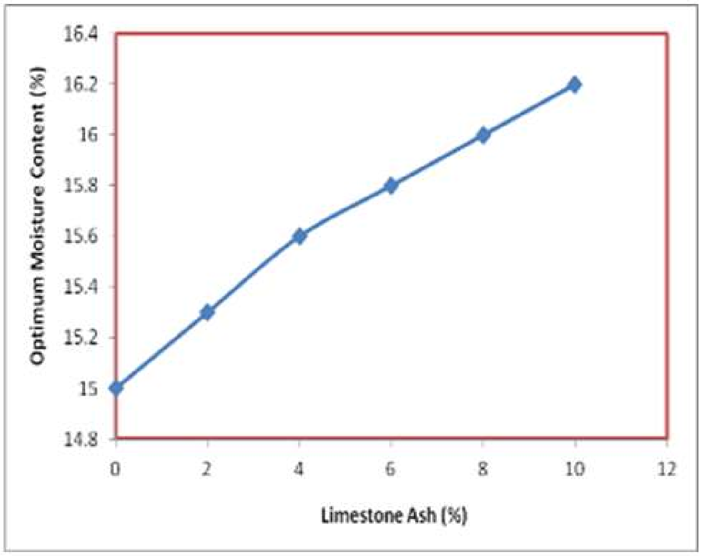

Fig. 11. Relationship between optimum moisture content and different percentages of limestone ash

It can be seen from the above illustrations that the dry density decreases with higher proportions of limestone ash while the optimum moisture content increases accordingly which is in consonance with the results of other researchers who have used lime as a chemical additive for the improvement of Lateritic soils. The research conducted by [34-36] give reasons for the decrease in dry density taking cognizance of the fact that lime has the tendency to cause agglomeration of the soil particles in a manner that the effective particle grain size distribution is altered and that the specific gravity of lime is believed to be lower than that of the Laterite soils. The result further show that there was an initial drop in maximum dry density with increase in addition of limestone ash content up to 6% after which there was a decline with more than 6% additive.

3.4 California Bearing Ratio (CBR)

The effects of the addition of varying amounts of limestone ash to the soil sample using the

California bearing ratio procedure has been assessed. The results obtained are shown in Table 4 and depicted graphically in Fig. 12 respectively.

The values of CBR increased with respect to an increase in the percentage of limestone ash to an optimum level; after which there was a decline in the CBR values accordingly. Similarly, an optimum level was attained at 6% limestone ash for the soaked and unsoaked soil samples compacted at Modified BS compaction effort. This result corroborates the research outputs of other authors who have used lime to stabilise soils and has been related to the lime fixation point. The work of [37] presents some explanations for the improvement of CBR which is attributed to the cation exchange, flocculation and agglomeration reactions taking place within the admixtures [28,36]. From the foregoing, it is likely that 6% limestone ash would be desirable for engineering construction and design as revealed by this research.

3.5 Shear Strength

The shear strength of the Laterite soil sample in its unconsolidated undrained triaxial test was conducted on both the treated and untreated samples which were compacted at maximum dry density and optimum moisture content. There was a decrease in friction angle and an increase in the cohesion values with increasing proportions of limestone ash for all the samples as shown in Table 5, Figs. 13 and 14 respectively. Ola [34,35] proposed that lateritic soil samples stabilized with lime were suitable for use as sub-base or base material respectively while [38] also found that clayey soils stabilised with lime are good for road construction.

Table 4. California bearing ratio (CBR) test results for soil samples compacted following the Modified British Standard

Limestone ash (%)	Modified BS (Unsoaked)	Modified BS (Soaked)
0	68.5	24.5
2	71.2	38.1
4	80.1	63.2
6	88.4	73.5
8	76.5	63.5
10	69.2	39.5

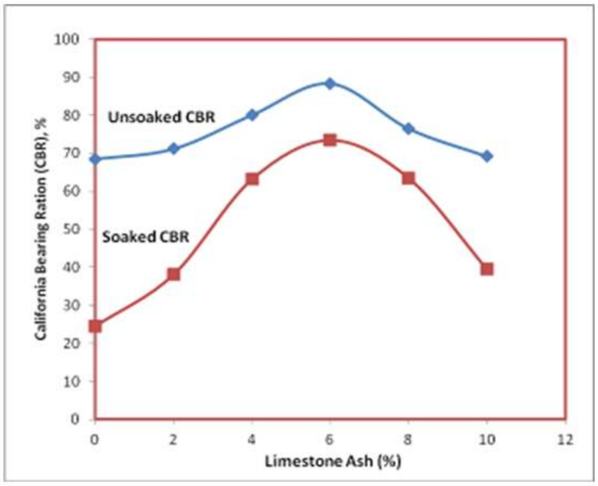

Fig. 12. Relationship between CBR and different percentages of limestone ash

Table 5. Results of Triaxial tests for the Laterite soil samples compacted using the Modified British Standard

Limestone ash (%)	Cohesion (kN/m^2)	Angle of shearing resistance (°)
0	34	22
2	49	19
4	70	17
6	93	14
8	100	12
10	122	11

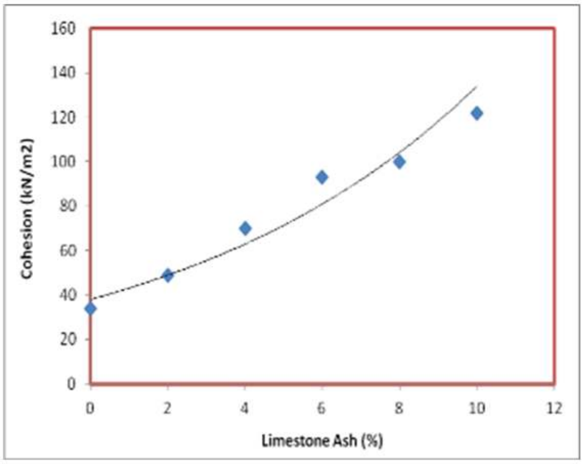

Fig. 13. Relationship between cohesion and different percentages of limestone ash following the Modified British Standard (Mod BS)

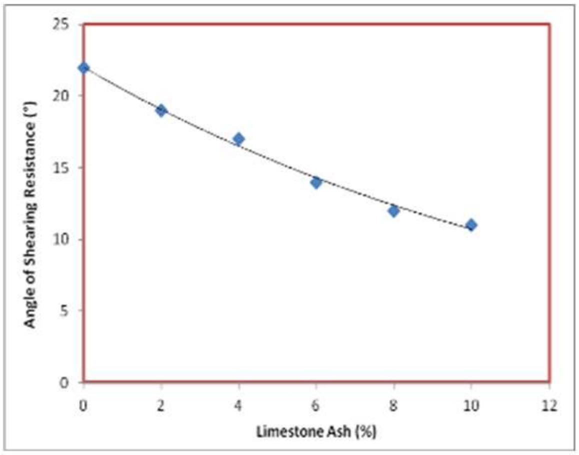

Fig. 14. Relationship between the angle of shearing resistance and different percentages of limestone ash following the Modified British Standard (Mod BS)

4. DISCUSSION

The results obtained from the various geotechnical tests carried out showed a decrease in plasticity index and shrinkage limit for treated soil samples and an increase in plastic and liquid limits implying a general improvement in the workability of laterites. The outcome of the study also shows an increase in CBR with the addition of up to 6% of limestone ash, this is the level at which the initial trend decrease in maximum dry density begins to modify.

It was noted that the shear strength of the soil has been improved with the addition of limestone ash as depicted graphically above. However, while considering the potential uses of soil samples treated with lime, the effects of wetting cannot be overemphasized [29]. Therefore, soaked CBR values are fundamental when considering the use of soil samples treated with limestone ash [28]. Generally, the results obtained and their interpretation shows comparative trends exhibited by Laterite soil samples treated with lime as reported by some authors. Meanwhile, the results also indicate that a double portion of the quantity of limestone ash waste may be required to achieve the same level of soil improvement using lime.

5. CONCLUSION

The concept of chemical stabilisation of Laterite soil using varying percentages of limestone ash has been evaluated for road construction. The geotechnical parameters tested included Atterberg limits, grain size analyses, compaction characteristics, CBR and compressive strength. It was noted that the shear strength of the soil has been improved with the addition of limestone ash as indicated in the research output at optimum value of 6%.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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