



## Effects of Periwinkle Shell Ash on Lime-Stabilized Lateritic Soil

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**ABSTRACT:** This study assesses the effects of periwinkle shell ash (PSA) on lime-stabilized lateritic soil. Preliminary tests were carried out on the natural soil sample for the purposes of identification and classification. The soil sample was classified as A-7-5. Thereafter, the soil sample was mixed with lime at percentages of 2, 4, 6, 8 and 10. These were later subjected to atterberg limit tests to get the optimum amount of lime, which was 10% because the least value of plasticity index was recorded at this state. PSA was added to the lime-treated soil sample at varying proportions of 2, 4, 6, 8 and 10%. The mixes were subjected to compaction, California bearing ratio (CBR), atterberg limits and unconfined compressive strength (UCS) tests, in so doing, the values of the CBR and UCS increased considerably. It can be concluded that the PSA performs satisfactorily as a cheap complement for lime in soil stabilization. © JASEM

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**Keywords:** atterberg limits, lateritic soil, lime stabilization, periwinkle shell ash, soil stabilization

According to Ige et al., (2014), laterite is a highly weathered material rich in secondary oxides of Iron, Aluminum or both. It is void or nearly voids of bases, primary silicates, but may contain large amounts of quartz and kaolinite. They are formed in hot, wet tropical regions with an average annual rainfall of at least 1200mm and a daily temperature in excess of 25 °C and typically occur in humid tropical climate within 30 °N and 30 °S of the equator. Laterites develop beneath the surface in soil zones, unconsolidated sediments or decomposed rocks where interrelations of ground water, soil/water table and topography are favourable. A major factor in its formation is an alternating or variable moisture cycle and it is formed in association with grasslands and forests on lowland surfaces in tropical and temperate regions. It has been found that lateritic soils are generally good construction materials and are therefore extensively used in construction. Also, laterites have been defined as a residual of rock decay that is red, reddish in colour and have a high content of oxides of Iron and hydroxides of Aluminum and low proportion of silica. In the tropical part of the world, lateritic soils are used as road making material and they form the subgrade of most tropical roads, also, they are used as subbase and bases for low cost roads and these carry low to medium traffic. In rural areas of Nigeria, they are used as building material for moulding blocks and plastering (Amu and Adetuberu, 2010a). There are five factors that influence the formation of laterites as identified by Ola (1983), they are: climate (precipitation, leaching, capillary rise and temperature), topography (drainage), vegetation, parent rock (iron rich rocks) and time, of these primary factors, climate is considered to be the most important factor. Most lateritic soils in their natural states generally have low bearing capacity and low strength due to high content of clay. When lateritic soil contains large amount of clay materials its strength and stability

cannot be guaranteed under load especially in the presence of moisture, hence, the need for stabilization (Bello et al., 2015a).

Amu and Adetuberu (2010b) defined soil stabilization as the process of creating or improving certain desired properties in a soil material so as to render it stable and useful for a specific purpose. There are three chief purposes for stabilization, these include; strength improvement, dust control and soil waterproofing. The improvement in the strength and durability of lateritic soil in the recent time has become needful; this has geared researchers towards using stabilizing materials that can be sourced locally at a very low cost. These materials can be classified as either agricultural or industrial wastes. The ability to blend the naturally occurring lateritic soil with some chemical additives to give it better engineering properties in both strength and waterproofing is essential (Bello et al., 2015b).

**Aim of the Study:** The aim of this study is to assess the effect of periwinkle shell ash (PSA) on lime-stabilized soil.

**Periwinkle Shell Ash:** Periwinkle shell is a waste product gotten from the consumption of a small greenish-blue marine snail (periwinkle), housed in a V-shaped spiral shell, it is commonly found in coastal communities within Nigeria and world-wide. Its shells are hard, strong and brittle in nature and are usually disposed off as waste material. The periwinkle shells are dried in the sun to rid it of moisture and later calcined at 1000°C in an electric muffle in the laboratory. This calcined product is ground and sieved through BS sieve (75microns) to obtain fine ash (Olutoge et al., 2012).

**Lime Stabilization:** Lime provides an economical method of stabilizing soil. Lime modification

describes an increase in strength by increase in cation exchange capacity rather than cementing effect as a result of pozzolanic reaction. In soil modification, as clay particles flocculate, they also transform natural plate like clay particles into needle-like interlocking metallic structures, clay turns drier and less susceptible to water content changes. Lime stabilization may refer to pozzolanic reaction in which pozzolana materials react with lime in presence of water to produce cementitious compounds. The effect can be brought about by either quicklime CaO or hydrated lime, Ca(OH)<sub>2</sub> (Makusa, 2012).

**Location and Geology of Study Area:** Akure, Nigeria, being the study area lies within Longitude 7°18' N and 7°16' N North of the equator and between Latitude 5° 09' E and 5° 11.5' E of Greenwich meridian. The study area occurred within the pre-cambrian crystalline rocks of the basement complex of southwestern Nigeria. The predominant rock types in the study area are charnockites, granites gneiss and migmatitic rock. In some places in the study, these rocks have undergone deep weathering (Ogunribido, 2011a).

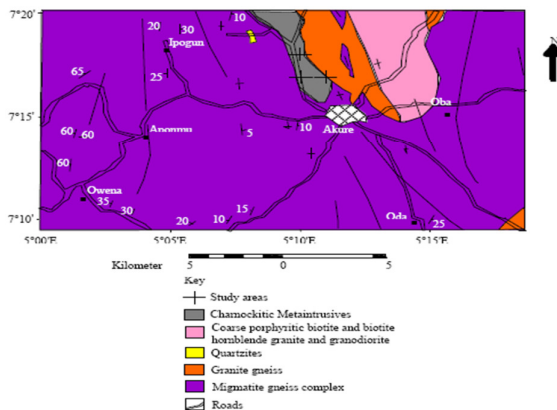


Fig.1: Study Area-Akure, Nigeria: Source: Ademeso (2009)

## MATERIALS AND METHODS

*The materials used for this research were:*

**Hydrated lime:** this was purchased at a licensed chemical store in Akure.

**Lateritic soil:** lateritic soil sample was gotten at a depth of not less than 1.2metre in Akure. The soil sample was taken to the Geotechnical Engineering Laboratory of the Federal University of Technology, Akure, Nigeria where it was stored.

**Periwinkle shell ash:** The periwinkle shell was obtained from Warri, Delta state, Nigeria. It was properly cleaned and dried in the sun to rid it of moisture. The shells were later calcined in an electric muffle furnace in the laboratory at 1000°C, ground and sieved through 75 micron sieve to obtain fine ash.

**Water:** Potable water was obtained from the running taps in the laboratory.

Preliminary tests such as natural moisture content, atterberg limits, specific gravity and particle size distribution for the purposes of identification and classification were performed on the lateritic soil sample in accordance with BS 1377 (1990a) and BS 1924 (1990a) respectively. Hydrated lime was added to the soil in proportions of 2, 4, 6, 8 and 10% by weight of soil. These mixes were subjected to atterberg limit tests. The percentage of added lime with the least value of plasticity index was adopted as the optimal amount of lime required and thus, became the adopted standard for the further mixing of periwinkle shell ash; which was done at varying proportions of 2, 4, 6, 8 and 10%. All the stages of the mixes were subjected to engineering tests; such as atterberg limit, compaction (Maximum dry density and optimum moisture content), California bearing ratio, unconfined compressive strength tests.

**Atterberg limits test:** The Atterberg limits tests were carried out in accordance with the British Standard Methods-BS 1377: Part 2 (1990b). The lateritic soil sample was sieved through 0.425mm. Materials that were retained on the sieve was discarded and not used for the test. The soil sample was oven-dried for at least 2 hours before the test. For the stabilized specimens; the tests were carried out on the soils mixed with a fixed optimal amount of 10% lime and varying proportions of 2, 4, 6, 8 and 10% PSA.

### Compaction Characteristics

The proctor standard compaction method was adopted for this study. The test was carried out according to BS 1377-1990: Part 4 (1990c), with the purpose of determining the maximum dry density (MDD) and the optimum moisture content (OMC) of the soils. The soil mixtures (with or without additives) were thoroughly mixed with various moisture content and allowed to equilibrate for 24 hours before compaction. The first aspect of the compaction test involved determining the compaction properties of the natural soil sample. At the second stage, tests were performed to determine the proctor compaction properties of soil sample upon stabilization with 10% lime-optimal amount of lime and the added varying amounts of PSA (2, 4, 6, 8 and 10%).

### California bearing ratio (CBR)

The BS 1924 (1990b) stipulates the procedures to follow in carrying out this test. This, was however modified in conformity with the recommendation of the Nigerian General Specification (FMWH,1997a) which stipulates that specimens be cured for six days unsoaked, immersed in water for 24 hours and allowed to drain for 15 minutes before testing.

### Unconfined Compressive Strength (UCS)

The BS 1924 (1990c) stipulates the procedure for carrying out this test and was adopted for the natural soil sample. For the stabilized soil mixtures, specimen were prepared by carefully and completely mixing dry quantities of pulverized soil with the fixed optimal amount of hydrated lime-10% by weight of soil and varying proportions of 2, 4, 6, 8 and 10% PSA. The needed amount of water was determined from moisture-density relationships for stabilized-soil mixtures were subsequently added to the mixture. For each of the mix, three specimens were prepared as stipulated by the Nigerian General Specification (Federal Ministry of Works and Housing, 1997b).

## RESULTS AND DISCUSSIONS

From table 1, the value of the specific gravity of the soil sample is 2.08, according to Das (2000), soils that have value of specific gravity value within the range of 1.9-2.6 are classified as halloysites, thus, the soil sample with specific gravity 2.08 aptly qualifies as halloysites. From the particle size distribution results, 36.50% passed through sieve No 200; thus suggesting that the soil sample belonged to groups, A-4, A-5, A-6 and A-7. The value of liquid limit is 48.85%, thereby, falling into the A-5 and A-7 groups. According to Whitlow (1995), materials with liquid limit less than 35% indicates low plasticity, between 35% and 50% and between 51% and 70% indicate intermediate plasticity and high plasticity respectively. While values greater than 70%, indicates very high plasticity. Since value of liquid limit is 48.85%, it is therefore of intermediate plasticity. Considering that the plasticity index is 16.25%, it falls into the A-7 group. For A-7-5 group, plasticity index  $\leq LL-30$ ;  $16.25 \leq 48.85 - 30 = (18.85)$ . The soil sample therefore falls into the A-7-5 subgroup (Garber and Hoel, 2009). The soil sample is fine-grained inorganic soil and it is also plastic in nature therefore render them unsuitable for construction works (Holtz and Kovacs, 1981).

**Table 1:** Summary of preliminary tests results

Property	Amount
Natural Moisture Content (%)	21.85
Specific gravity	2.08
Percentage passing No. 200 Sieve	36.50
Liquid Limit (%)	48.85
Plastic Limit (%)	32.60
Plasticity Index (%)	16.25
Unsoaked CBR (%)	9.5
Soaked CBR (%)	5.5
Maximum Dry Density (Kg/m <sup>3</sup> )	1650
Optimum Moisture Content (%)	12.45
Unconfined Compressive Strength (UCS) (kN/m <sup>2</sup> )	190
AASHTO Classification	A-7-5
USCS Classification	CL

Table 2 shows some important elemental oxides which are present both in the periwinkle shell ash and

hydrated lime, thus, the periwinkle shell ash have chemical properties in common with the hydrated lime. Table 3 shows that the least value of plasticity index is 13% which is at 10% lime, 10% lime therefore is the optimum amount of lime required and adopted standard for further addition of periwinkle shell ash.

**Table 2:** Chemical composition of periwinkle shell ash (PSA) and hydrated lime used for the study

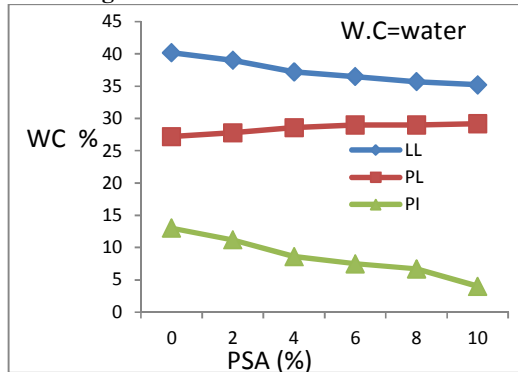
Elemental Oxide (%)	PSA (%)	Hydrated Lime (%)
SiO <sub>2</sub>	35.37	1.71
Al <sub>2</sub> O <sub>3</sub>	9.6	0.72
Fe <sub>2</sub> O <sub>3</sub>	4.84	0.05
CaO	41.35	68.12
MgO	0.50	1.38
SO <sub>3</sub>	0.20	-
K <sub>2</sub> O	0.20	0.06
Na <sub>2</sub> O	0.21	0.03
TiO <sub>2</sub>	0.05	-
LOI	6.20	-

From table 3, the addition of lime to the lateritic soil sample resulted to the decrease in the values of liquid limit and plasticity indices of the soil sample. The trend observed with the lime can be attributed to agglomeration of fine clay particles into coarse, friable particles by a base exchange with the calcium cations from lime displacing sodium or hydrogen ions, with a subsequent dewatering of the clay fraction of the laterite, referred to as cation exchange reaction (Joel and Edeh, 2015a). According to Osinubi (1995), the reduction in the plasticity is attributed to the change in soil nature (granular nature after flocculation and agglomeration) and the modified soil as crumbly as silt soil, which is characterized by low surface area and low liquid limit because of the plastic nature of the lime. In figure 2; the addition of periwinkle shell ash to the lime-treated lateritic soil sample further reduced the liquid limit values and its plasticity index values. This, may be attributed to the higher release of Ca<sup>2+</sup> and Si<sup>2+</sup> cations with increased lime+PSA (Iorliam et al., 2012a). The addition of the PSA to the lime-treated soil reduced the plasticity index which is an indication of improvement of soil properties (Basha et al., 2005). In addition to this, according to the Federal Ministry of Works and Housing (1997c), subgrade or fill material is expected to have a liquid limit value of less than 50% and plasticity index should be equal or less than 30%, while for sub base, liquid limit is expected to be equal or less than 30% and plasticity index should be equal or less than 12%. With the addition of PSA to the lime-treated soil, the plasticity index of the soil reduced to a level where it can be adequately used for sub base in Nigerian roads since soils with plasticity index higher than 12% are not suitable for use as sub base materials for roads in Nigeria (Oyediran and Kalejaye, 2011).

**Table 3:** effects of lime on soil properties

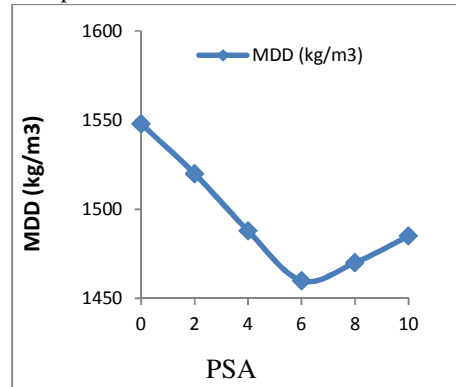
Lime (%)	LL	PL	PI	MDD	OMC	Unsoaked CBR	Soaked CBR
0	48.85	32.6	16.25	1650	12.45	9.5	5.5
2	47.25	31.35	15.90	1630	13.50	20.65	11.35
4	46.40	31.00	15.40	1605	14.30	35.75	25.65
6	43.80	29.00	14.80	1587	15.40	62.80	51.70
8	42.30	28.30	14.00	1570	16.55	56.88	43.40
10	40.20	27.20	13.00	1548	17.74	50.45	40.70

**Atterberg limits**



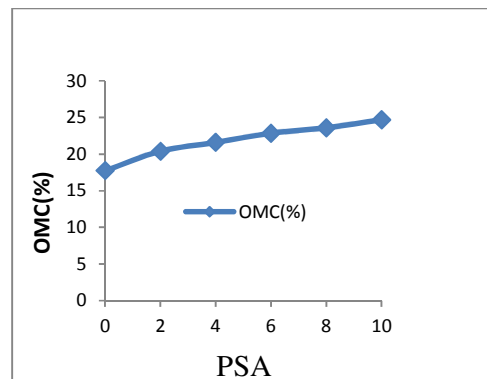
**Fig 2:** Effect of PSA on atterberg limits of lime-stabilized soil.

**Compaction Characteristics**



**Fig 3:** Effect of PSA on MDD of lime-stabilized soil.

From table 1, the maximum dry density (MDD) of the lateritic soil sample at its natural state was 1650 kg/m<sup>3</sup>. From table 3; the addition of lime to the soil sample resulted to gradual decrease of value of MDD from 1650 kg/m<sup>3</sup> at 0% lime (natural state) to the lowest value of 1548 kg/m<sup>3</sup> at 10% lime. Also, from **figure 3**, the addition of periwinkle shell ash (PSA) to lime-treated soil led to the increase in value of MDD from 1548 kg/m<sup>3</sup> at 0% PSA to highest value of 1560 kg/m<sup>3</sup> at 6% PSA, values of MDD started falling at 8% PSA of 1535 kg/m<sup>3</sup> and finally to 1515 kg/m<sup>3</sup> at 10% PSA. According to Iorliam *et al.* (2012b), increase in MDD may be as a result of the combined action of lime and PSA, PSA released more silica, lime released Calcium Oxide that caused the flocculation and agglomeration of clay particles. This flocculation-agglomeration process results in floc formation. The enlarged particle size causes the void ratio to increase. This increase in void ratio reflects the decrease in maximum dry density. The increase in density from minimum **at 6% PSA content to 8% PSA content** could be done to molecular rearrangement in the formation of 'transitional compounds' which have higher densities at 6% PSA content (Alhassan and Mustapha, 2007a). The variation of OMC with increase in PSA in the soil-lime mixture can be seen in **figure 4**. The increase in OMC with increase PSA in the lime-treated soil may be attributable to the decrease in 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 connotes that aside the water needed to take place, more water was needed in order to compact the soil-lime-PSA mixtures (Alhassan and Mustapha, 2007b).



**Fig 4:** Effect of PSA on OMC of lime-stabilized soil.

California Bearing Ratio: Table 3 shows that with the addition of lime to natural soil CBR values of both unsoaked and soaked states increased appreciably. Unsoaked and soaked values at 0% lime, were 9.5% and 5.5%, these increased to maximum values of 62.80% and 51.70% both at 6% lime, values of CBR started falling at 8% lime. Increase in CBR may be due to the cation exchange and pozzolanic reaction of lime (Joel and Edeh, 2015b). **Figure 5** shows that the addition of PSA to the lime-treated lateritic soil further increased the CBR values of both unsoaked and soaked values from 0% PSA at 50.45% and 40.70% to 70.60% and 56.60% both at 6% PSA respectively. This increase could be due to the presence of adequate amounts of calcium required for the formation of Calcium silicate hydrate (CSH) and Calcium aluminate hydrate (CAH), which are the major compounds responsible for strength gain (Sadeeq *et al.*, 2015). The reduction in CBR values at 8% PSA may be due to excess PSA and lime that was not mobilized in the reaction, therefore, reducing bond in the lime-PSA-soil (Ogunribido, 2011b)

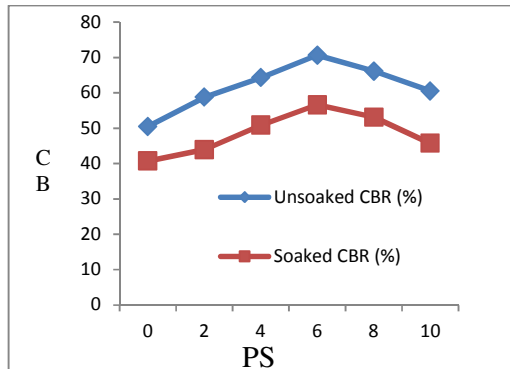


Fig 5: Effect of PSA on CBR of lime-stabilized soil.

Unconfined Compressive Strength: From table 4, the improvement in value of UCS upon addition of lime to soil may be attributed to soil-lime reaction, which

Table 4: Effect of lime on unconfined compressive strength properties of lateritic soil

Lime (%)	7 days (kN/m <sup>2</sup> )	14 days (kN/m <sup>2</sup> )	28 days (kN/m <sup>2</sup> )
0	190	190	190
2	220	289	360
4	275	359	400
6	325	410	459
8	360	452	491
10	390	480	530

Table 5: Effect of PSA on unconfined compressive strength on lime stabilized lateritic soil

Lime (%)	7 days (kN/m <sup>2</sup> )	14 days (kN/m <sup>2</sup> )	28 days (kN/m <sup>2</sup> )
0	390	480	530
2	430	513	557
4	455	547	590
6	483	570	639
8	510	592	670
10	540	630	704

*Conclusion:* Based on AASHTO classification, the soil sample was classified into subgroup A-7-5, a poor soil. The chemical composition of the periwinkle shell ash clearly shows that the periwinkle shell ash has some active elemental oxides in common with hydrated lime. The addition of lime to natural soil reduced the liquid limit and plasticity index values; the addition of periwinkle shell ash further reduced the values of liquid limit and plasticity index, an indication of soil improvement. The addition of hydrated lime to natural soil increased the strength properties-such as California bearing ratio (CBR) and unconfined compressive strength (UCS) of the soil and the addition of periwinkle shell ash further increased the strength values of the soil. It can therefore be concluded that the periwinkle shell ash can adequately serve as a cheap complement for lime in soil stabilization.

## REFERENCES

- Ademeso, OA (2009). Deformation Traits in Charnockitic Rocks of Akure Area, Southwestern Nigeria. *Asian Journal of Earth Sciences*, 2: 113-120.
- Alhassan, M; Mustapha, M (2007a). Effect of Rice Husk Ash on Cement Stabilized Laterite. *Leonardo Electronic Journal of Practices and Technologies, Issue 11*. Pg. 47-58.
- Alhassan, M; Mustapha, M (2007b). Effect of Rice Husk Ash on Cement Stabilized Laterite. *Leonardo Electronic Journal of Practices and Technologies, Issue 11*. Pg. 47-58.
- Amu, OO; Adetuberu, AA (2010a). Characteristics of Bamboo Leaf Ash Stabilization on Lateritic Soil in Highway Construction, *International Journal of Engineering and Technology, Vol. 2(4)*, pp. 212-219.
- Amu, OO; Adetuberu, AA (2010b). Characteristics of Bamboo Leaf Ash Stabilization on Lateritic Soil in Highway Construction, *International Journal of Engineering and Technology, Vol. 2(4)*, pp. 212-219.
- Basha, EA; Hashim, R; Mahmud, HB; Muntohar, AS (2005). Stabilization of Residual Soil with Rice Husk Ash and Cement. *Construction and*

results in the formation of cementitious compounds that binds soil aggregates. This strength improvement also increased with age. Also, from table 5, the introduction of the PSA into the lime-treated soil further increased the UCS. The increase in value of UCS was observed from 0% to 10% PSA. This may be due to the utilization of readily available silica and alumina from PSA by the calcium from the lime to form cementitious compounds that binds the soil aggregates. It was also observed that the UCS increased with curing age at the specified lime content (10%). This may be due to the pozzolanic reaction between the lime and PSA resulting in the formation of more cementitious compounds (Alhassan, 2008).

- Building Materials*. 19. Pp 448-453.
- Bello, AA; Ige, JA; Ayodele, H (2015a). Stabilization of Lateritic Soil with Cassava Peels Ash, *British Journal of Applied Science and Technology* 7(6): 642-650. Article no BJAST, 180
- Bello, AA; Ige, JA; Ayodele, H (2015b). Stabilization of Lateritic Soil with Cassava Peels Ash, *British Journal of Applied Science and Technology* 7(6): 642-650. Article no BJAST, 180
- Das, BM (2000). *Fundamental of Geotechnical Engineering*. U K: Brooks/Cole.
- Federal Ministry of Works and Housing (FMWH) (1997a). *General Specifications for Roads and Bridges. Volume II. Federal Highway Department, Lagos, Nigeria.*
- Federal Ministry of Works and Housing (FMWH) (1997b). *General Specifications for Roads and Bridges. Volume II. Federal Highway Department, Lagos, Nigeria*
- Federal Ministry of Works and Housing (FMWH) (1997c). *General Specifications for Roads and Bridges. Volume II. Federal Highway Department, Lagos, Nigeria*
- Garber, NJ; Hoel, LA (2009). *Traffic and Highway Engineering*. Fourth Edition. Canada: CENGAGE Learning
- Holtz, RD; Kovacs, WD (1981). *An Introduction to Geotechnical Engineering*. Prentice Hall.
- Iorliam, AY; Agbede, IO; Joel, M (2012a). Effect of Bamboo Leaf Ash on Cement Stabilization of Flexible Pavement Construction Material. *American Journal of Scientific and Industrial Research*. 3(3): 166-174.
- Iorliam, AY; Agbede, IO; Joel, M (2012b) Effect of Bamboo Leaf Ash on Cement Stabilization of Flexible Pavement Construction Material *American Journal of Scientific and Industrial Research*. 3(3): 166-174.
- Joel, M; Edeh, JE (2015a) Comparative Analysis of Cement and Lime Modification of Ikpayongo Laterite for Effective and Economic Stabilization. *Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS)* 6(1): 49-56.
- Joel, M; Edeh, JE (2015b) Comparative Analysis of Cement and Lime Modification of Ikpayongo Laterite for Effective and Economic Stabilization. *Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS)* 6(1): 49-56.
- Makusa, GP (2012). *Soil stabilization methods and materials*. (Doctoral thesis, Lulea University of Technology, Lulea, Sweden). Retrieved from <https://www.diva-portal.org/smash/get/diva2:997094/FULLTEXT01>. Pdf
- Okonkwo, UN (2015). *Optimization of Baggase Ash content in Cement*. (Doctoral thesis, University of Nigeria, Nsukka, Nigeria). Retrieved from <https://www.unn.edu.ng/publications/files/17685>
- Ogunribido, THT (2011a). Potentials of Sugar cane Straw Ash for Lateritic Soil Stabilization in Road Construction. *Int. J Sci. Emerging Tech. Vol-3 No 5*.
- Ogunribido, THT (2011b). Potentials of Sugar cane Straw Ash for Lateritic Soil Stabilization in Road Construction. *Int. J Sci. Emerging Tech. Vol-3 No 5*
- Ola, SA (1983). Geotechnical properties and behavior of some Nigerian lateritic Soils: In, S. A. Ola, (ed.), *Tropical Soils of Nigeria in Engineering Practice*, (pp 61-84) A. A. Balkana / Rotterdam: Netherlands.
- Olutoge, FA; Okeyinka, OM; Olaniyan, OS (2012). Assesment of the suitability of periwinkle shell ash (PSA) as Partial replacement for ordinary Portland cement (OPC) in concrete. *International Journal of Research and Reviews in Applied Sciences (IJRRAS)*, 10 (3)
- Osinubi, K (1995). Lime Modification of Black Cotton Soil. *Spectrum Journal*, 2(1), 112-122.
- Oyediran, AI; Kalejaiye, M (2011) Effect of Increasing Cement Content on Strength and Compaction Parameters of Some Lateritic Soil in Southwestern Nigeria, *Electronic Journal of Geotechnical Engineering (EJGE)*, vol. 16, p. 1504.
- Sadeeq, JA; Ochepe, J; Salahudeen, AB; Tijjani, ST (2015) Effect of Bagasse Ash on Lime Stabilized Lateritic Soil, *Jordan Journal of Civil Engineering*, Volume 9, No 2
- Whitlow, R (1995) *Basic Soil Mechanics*, 3<sup>rd</sup> Edition, Edinburgh Gate: Addison Wesley, London Ltd.