Use of some agricultural wastes to modify the engineering properties of subgrade soils: A review

O. D. Afolayan* , O. M. Olofinade and I. I. Akinwumi

Civil Engineering Department, Covenant University, Ota, Ogun State, Nigeria.
Corresponding Author: olaniyi.afolayan@covenantuniversity.edu.ng

Abstract-
The drive to diversify the economy in some developing countries have resulted in increased agricultural production and consequently increased agricultural waste. This study reviews some published research works on the reuse of some agricultural wastes for modifying soils with poor engineering properties. The review shows that some agricultural wastes, such as palm oil fuel ash, palm kernel shell ash, rice husk ash, sea-shell powder and sawdust ash, are effective modifiers of subgrade soil and become more effective when combined with traditional stabilizers. The use of stabilizers from agricultural wastes has the potential of reducing the amount of waste disposed of in landfills/dump sites, and at the same time reduce the carbon footprints caused by the use of traditional stabilizers like cement, and the cost of highway construction.

Key words: Sustainable environment; agricultural waste; engineering properties; poor subgrade soil

1. Introduction
To discourage improper waste management, while also searching for sustainable low-cost materials as alternatives to depleting natural resources [1], [2], researchers must find ways of reusing solid wastes in large quantities for engineering applications. Solid wastes can broadly be classified into industrial, agricultural and municipal wastes [3]. Rapid growth in population and industrialization has resulted in the generation of large quantities of solid wastes, the bulk of which are from industrial, commercial, agricultural, mining and domestic activities.

Owing to the drop in the gross domestic product (GDP) of Nigeria, the economy is being diversified from oil exploration and exportation, with specific emphasis on the agricultural sector. This has led to increased agricultural production and consequently, increased generation of agricultural wastes. However, most of the agricultural wastes generated get disposed of.

Although the estimate of agricultural wastes is rare to find in waste collection surveys, agricultural wastes significantly contribute to the total waste streams of some countries [4]. In a research conducted by Bakare [5] of bioenergy consult, Nigeria generates more than 32 million tons of solid waste annually, out of which only 20-30% is collected. Consequently, this large amount of waste generated constitutes environmental hazards and alteration of the ecosystem’s balance if not properly disposed of. In tackling this menace, there arises a need to cater for the present without depriving future generations of their right to available natural resources. Worldwide, waste reduce, recycle and re-use (RRR) policy has been widely accepted in other to foster a sustainable environment. Through this policy, locally available agricultural waste can be effectively treated and adopted for modification of soil properties for infrastructural applications.
Soil modification, as explained and exemplified in [1], [6], [7], and [8] is the alteration of one or more soil properties for certain engineering application through mechanical compaction and or incorporation of chemical additives. However, due to the negative effect of the traditional binders, owing to its releasing significant quantity of CO2 to the atmosphere and the need to manage effectively the abundant agricultural waste, researchers took a dive into accessing the suitability of agricultural waste as a soil modifier.

Studies carried out by Amu et al [9], Oriola and George [10], Oyetola and Abdulahi [11], Ramaji [12], Aziz et al [13], Owolabi and Dada [14], Quasim et al [15], Harichane et al [16], Nagarajan et al [17], Khan and Khan [18], Ogunribido [19] and Adetoro and Adam [20] established that various agricultural wastes can be adopted in refined form as a soil modifier and stabilizer. However, despite the numerous locally available agricultural waste, this review article selected a few that are readily available in Nigeria.

2. Particulate of Agricultural waste

2.1 Palm oil fuel ash (POFA)

POFA, a by-product of oil palm, is obtained by controlled burning of oil palm fruit bunches [21], [22], [23], [24], and [25] identified increase in structure’s lifespan, reduction in carbon footprint and energy release and use, reduction in greenhouse gases, effective and effective waste disposal and reduction in amount of these waste dumped into landfills among others as the identified environmental benefits associated with utilizing these waste as construction materials.

According to Pourakbar et al., [26], palm oil fuel ash (POFA) is one of the most abundantly produced waste materials in tropical regions which has a strong potential of improving the physical and chemical properties of soft subgrade soils due to its high silica content and amorphous nature. This high silica and alumina content was stated in the research of [27] where they stated the chemical composition of POFA as 3.98% Fe₂O₃, 0.33%TiO₂, 25.59%CaO, 61.26%SiO₂, 0.93%MgO, 4.98%Al₂O₃ and 0.60% K₂O. Owing to the large amount of silica in POFA, calcium aluminate hydrates (CAH) and calcium silicate hydrates (CSH) are formed during hydration reaction [28], [29] which are responsible for the pozzolanic time-dependent improvement in the engineering properties of soils on addition with soil.

Fauzi et al [27] investigated the use of POFA as a chemical additive for the improvement of the engineering properties of an A-7-6 subgrade soil. This they achieve by employing this additive at 0-12% addition to the soil. Their research observed its effect through chemical composition at each incremental additive content compaction characteristics and California bearing ratio (CBR). The oxides chemical composition of the POFA-clay mixture showed that there is a significant increase in the pozzolanity of the mixture which resulted into a decreased maximum dry density (MDD) and increased OMC and CBR values with increasing ash content. Furthermore, the research of [26] showed that addition of POFA and POFA- cement to soils significantly reduced soil plasticity index and optimum moisture content, increased maximum dry density and unconfined compressive strength value across adopted mix design for a curing period of 28 days. Brown et al. [30] reported that clayey soils treated with POFA exhibit a decreasing maximum dry density despite an increase in optimum moisture water content with increasing POFA content. In summary, POFA is a good modifier for poor subgrade soil but for
optimal performance it must be combined with lime, fly ash and or cement for cohesive and dispersive soils.

2.2 Palm Kernel Shell Ash (PKSA)

Palm kernel shell ash (PKSA) a variant of POFA, is obtained from the controlled combustion of palm kernel shells at a temperature ranging from 600 and 1000°C [21]. Comparative studies on the oxide composition of PKSA and POFA from studies conducted by [25], [29], [31] and [32] showed that both have higher silica and alumina content which makes them a good pozzolana. This was further supported by other researchers as presented in table 1.

Table 1: Chemical composition of PKSA

|          | Chemical Composition (%) | Reference |
|----------|--------------------------|-----------|
| SiO₂     | 54.81                    | [33]      |
| Al₂O₃    | 11.40                    |           |
| Fe₂O₃    | 0.36                     |           |
| CaO      | 8.79                     |           |
| MgO      | -                        |           |
| TiO₂     | -                        |           |
| Na₂O     | 6.25                     |           |
| K₂O      | 12.55                    | [34]      |
| LOI      | 2.01                     |           |

Ekeocha and Agwuncha [35] investigated the possibility of PKSA and PKS- asphalt mixture for stabilization of a soil matrix. In their research, asphalt was varied from 2-8% by dry weight and PKS from 0-100% at an incremental rate of 2% and 25% respectively. From their investigation, there was an observed increase of plasticity index of the test soil at 25% PKS addition. Subsequently, addition of 4% asphalt to the soil- 25% PKS led to further decreased plasticity index. From this result, it can be deduced that adopting palm kernel shell ash alone cannot positively alter the engineering properties of lateritic soil but stabilizes soil by improving its unconfined compressive strength when 25% of it substituted for the test soil and activated with 5% asphalt.

Adetoro and Adekanmi [36] and Adetoro and Adam [20] carried out a research on assessing the effect of PKSA at an incremental rate of 2% by dry weight on the engineering property of a subgrade soil. Onyelowe et al [34] assessed the effect of PKSA at an incremental rate of 2% on an A-7-6 subgrade soil. The result of their experiment showed a great reduction in the plasticity index, improvement of the CBR and the unconfined compressive strength of the stabilized sample at 10% PKSA addition. However, from these researches, the PKSA stabilized soil does not fully conform to relevant standards for usage as an interlayer material for pavement construction. Nnochiri et al [21] on noticing these trends, investigated the effect of PKSA on lime stabilized A-7-6 subgrade soil. The result of their experiment shows a reduction in the plasticity properties, improvement in the maximum dry densities, CBR value and the unconfined compressive strength test. This improvement was optimally achieved at 4% PKSA addition to the poor subgrade soil.

In summary, addition of PKSA to the soil either alone or with other stabilizer significantly improves its plasticity and strength properties at an optimal content of 10% to enhance sustainable environment. However, to incorporate more of this waste as a stabilizer and for usage as an interlayer material for pavement construction, there is a need to incorporate other traditional stabilizers with PKSA.

2.3 Rice Husk Ash (RHA)
One of the major staple food worldwide is Rice. When cultivated and during harvesting, its husk is removed from the paddy as a by-product. The husk is usually generated with respect to the volume of the rice paddy harvested. Therefore, the larger the rice plantation, the larger the volume of husk generated as waste. However, in order to reduce this waste volume, rice husk is normally incinerated or open-air burnt leading to environmental hazards [36]. Under controlled burning, rice husk (RH) gives about 15-25% of ash [15], [38] which can be used for varying applications, one of which is as a pozzolan due to its chemical and minerals composition as shown in Table 2.

### Table 2: Chemical composition of RHA

| Chemical Composition (%) | Reference |
|-------------------------|-----------|
| SiO₂                    | 82.14     | [39]     |
| Al₂O₃                   | 1.34      |          |
| Fe₂O₃                   | 1.27      |          |
| CaO                     | 1.21      |          |
| MgO                     | 1.96      |          |
| SO₃                     | 0.17      |          |
| Na₂O                    | 0.14      |          |
| K₂O                     | 2.09      |          |
| LOI                     | -         |          |

The high percentage of siliceous materials in rice husk ash as shown in Table 1 indicates it has potential pozzolanic properties. Furthermore, properties of RHA depends on climatic conditions, geographic conditions and whether the husk has undergone complete destructive combustion or have been partially burnt [45]. On the basis of temperature range and burning duration, [45] classified crystalline or amorphous form of silica obtained RHA as carbon free ash, low carbon ash and high carbon char. Review of [46], [37], [47], [48], [49], [50], [38], [51], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61], [62] showed that one of the prominent use of rice husk ash (RHA) is in modification and improvement of soil performance for infrastructural construction. These researchers adopted different methodologies and combination ratio with other hydraulic activators and waste(s) in accessing its effect on different soil types. Some of the properties considered are index, mechanical, strength, and hydraulic properties. However, [37] and [62] opined that RHA owing to its lack of cementitious properties but must be combined with the traditional soil stabilizers such as lime and cement for effective and efficient soil stabilization. Of particular note is the work of [37], who investigated on the suitability of RHA and lime on four different sandy soils. The researcher performed X-ray diffraction and loss of ignition tests on the RHA, and compaction and unconfined compressive strength test (UCS) on the mixture of sandy soil, lime and RHA. In this experiment, RHA was varied from 0-20%, and lime from 0-10%. Results showed a gain of UCS over time is observed for all studied RHA and lime combinations. Consequentially, in nations with high rice production, the use of RHA for soil improvement can be adopted as it reduces waste disposal cost and preserves non-renewable resources.

### 2.4 Sea Shell Powder
Sea shells are regarded as a natural biomaterial owing to their chemical composition, possesses excellent fracture strength and toughness properties due to its laminated microstructure and are mineral materials which composed primarily of protein matrix lain calcium carbonate crystals [63], [64], [65]. Ayininuola and Afolayan [66] stated that oyster shell ash, a representative sea shell contains 59.75% CaO, 15.91% silica, 4.38% iron oxide, 4.85% alumina and 0.26% MgO. Chou-Fu and Hung-Yu [67] revealed that seashell has similar chemical and microstructure analyses to lime establishing its usage as a cementing material. Sea shell ash bonds with soil particles when a significant amount of CaO, Al₂O₃ and SiO₂ react with water in the soil. As a pozzolana, the Si ions and Al ions in the ash combine with the available Ca ions in the soil, resulting in formation of Calcium Silicate Hydrates (CSH) and Calcium Aluminate Hydrates (CAH) [68], [69], [70], [71], and [72].

In accessing the effect of this waste on engineering properties of soil, [66] researched on calcined oyster shell ash which they added to lateritic soil by dry weight from 0-15% with an increment of 5%. In their experiment, index and strength properties of the soil were affected at 6% optimum content; it greatly improves the plasticity index, strength characteristic and swelling potential of the samples. Ruiz and Pierre [73] in their experiment added crushed Peruvian scallop shell at 20-80% to a silty-sandy subgrade as it increases its MDD when less water is used. Its addition increased the CBR of sandy soil by 51->100%.

Otoko and Esenwa [74] worked on the effect of pulverized periwinkle shell deltaic clay with an increment of 10%.MDD, CBR value shows no significant improvement, gradation of the soil changes from CL to SC. Hence the reduction in plasticity at the optimum content. Otoko and Itode [75] worked on crushed periwinkle shell where they added it to black cotton soil at 12-18% by dry weight, research showed that compressive strength and CBR value increased. Furthermore, research of [76], [77] ascertain the suitability of sea shell powder as a modifier. In summary, collectively combining researchers work, sea shell powder has an optimal content of 20% on soil if calcinated before application.

### 2.5 Sawdust ash (SDA)

Sawdust is generated in large quantities from wood milling factories, these wastes when not properly dispose of contaminates the environment [18], [78], [79]. According to Khan and Khan [18], about 10-13% of wood timbered are converted to ash which is usually deposited in landfills or subjected to open-air burning. It is with the view of protecting the environment through proper waste management thereby reducing the amount of SDA that goes to landfills that researchers accessed its suitability as a subgrade soil modifier. Consequently, researchers established its suitability as soil modifier owing to its pozzolanic nature as shown in Table 3.

| Chemical Composition (%) | Reference |
|--------------------------|-----------|
| SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | MgO | SO₃ | Na₂O | K₂O | MnO | P₂O₅ | LO |
| 86   | 2.6   | 1.8   | 3.6 | 0.27 | -   | -    | -   | -   | -    | 4.2| [79] |
From Table 3, it can be seen that SDA possesses high silica and alumina content, hence forms cementitious compound on reaction with soil, [18], [28], and [80]. In addition, [79] stated that SDA is an inert material and not as reactive with soil compared to lime and fly ash. [18], [36], [79], [80], [81], [82], [83], [84], [85] investigated the possibility of sawdust ash for modification of engineering properties of different subgrade soil. These, they did by combining it in different mix variations with different types of soil and it was observed that it has modifying effect on the geotechnical properties of cohesive soils [84].

In the experiment carried out by [80], [83], [86], the investigation was made on the effect of the varying proportion of SDA on the engineering properties of fine soil. Results of the experiment showed that sawdust ash effectively modified the index and strength properties of the soil with an optimum performance of 12%. Ogunribido [19], added SDA to subgrade soil from 0 to 10% to check its effect on its properties. His research observed a decreased specific gravity, liquid limit, shear strength and UCS but an increased CBR with corresponding SDA addition, hence he recommended an addition of a traditional stabilizer to modify the strength properties of the SDA modified soil. Butt et al [80] in their research combined SDA (0 to 12%) at an incremental rate of 4% with subgrade soil. Their research observed that at an optimal SDA content of 4%, there is an improvement in the plasticity properties, specific gravity, unsoaked CBR and UCS of the soil. The CBR increased by 103.11% and UCS by 26.35%.

3 Conclusion and Recommendation

Based on the few agricultural wastes considered, in terms of pozzolannity RHA>SDA>POFA>PKSA>SSP due to the SiO₂, Al₂O₃ and Fe₂O₃ content. This oxides is responsible for their behavior as a modifier and stabilizer. SSP is least based on this oxides but has the highest CaO content hence, an excellent modifier and stabilizer. However, despite the low comparative pozolannity of PKSA, Onyelowe et al (2016) affirmed its superiority as a poor subgrade soil modifier over coconut shell ash.

On the basis of work done by researchers over the year, the use of recycled materials sourced from agricultural waste has been effectively employed to stabilize and or modify cohesive and cohesionless soils for various civil engineering applications. This is made possible by either applying these waste alone in a refined form or with other cementing materials thereby inhibiting certain properties in the soil. Consequently, waste adoption as soil modifier led to a reduction in environmental pollution associated with waste disposal and also helps in cost reduction associated with landfill and highway construction as reuse of these waste materials helps to reduce the dependency on virgin materials and importation of foreign materials. This paper, therefore, recommends the adoption of agro-waste as a subgrade modifier and stabilizer.

Acknowledgements

The authors wish to acknowledge the financial support offered by Covenant University in actualization of this research work for publication

Reference
[1] Gobinath R., Akinwumi I. I., Afolayan O. D., Karthikeyan S., Manojkumar M., Gowtham S. and Ayyasamy Manikandan. Banana Fibre-Reinforcement of a Soil Stabilized with Sodium Silicate. Silicon, https://doi.org/10.1007/s12633-019-00124-6

[2] Akinwumi, I. I. (2014). Soil Modification by the Application of Steel Slag. Periodica Polytechnica Civil Engineering, 58(4), 371–377.

[3] Singh M. and Mittal A. (2014). A Review on the Soil Stabilization with Waste Materials.” International Journal of Engineering Research and Applications. National Conference on Advances in Engineering and Technology. (IJERA), India, pp 11-16

[4] Obi F. O., Ugwuishiwu B. O. and Nwakaire J. N. (2016). Agricultural waste concept, generation, utilization and management. Nigerian Journal of Technology (NIJOTECH), Vol. 35, No. 4, pp. 957 – 964

[5] Bakare, W. (2019). Solid Waste Management in Nigeria, BioEnergy Consult. assessed from https://www.bioenergyconsult.com/solid-waste-nigeria/

[6] Akinwumi I. I., Ukegbu I. (2015) Soil modification by addition of cactus mucilage. Geomech Eng 8(2015):649–661. https://doi.org/10.12989/gae.2015.8.5.649

[7] Akinwumi I. I., Booth C. A. (2015) Experimental insights of using waste marble fines to modify the geotechnical properties of a lateritic soil. J Environ Eng Landsc Manag 23:121–128

[8] Abidoye, A. O., Afolayan, O. D. and Akinwumi, I. I. (2018) Effects of lead nitrate on the geotechnical properties of lateritic soils. International Journal of Civil Engineering and Technology, 9 (7), pp. 522-530. ISSN 0976-6316

[9] Amu O.O., J. B. Adeyeri, A. O. Haastrup and A.A. Eboru, “Effect of Palm Kernel Shells in Lateritic Soil for Asphalt Stabilization.” Research Journal of Environmental Sciences, Vol. 2(2), pp. 132 – 138, 2008.

[10] Oriola F., and M. George, “Groundnut Shell Ash Stabilization of Black Cotton Soil.” Electronic Journal of Geotechnical Engineering, vol. 15, pp. 415 – 428, 2010.

[11] Oyetola E.B., and M. Abdulahi, “The Use of Rice Husk Ash in Low-cost Sandcrete Block Production.”, Leonardo Electronic Journal of Practice and Technologies, issue 8, pp. 58 – 70, 2006.

[12] Ramaji A. E., “A Review on the Soil Stabilization using Low – cost Methods.”, Journal of Applied Sciences Research, vol. 8 (4), pp. 2193 – 2196, 2012.

[13] Aziz M., M. Saleem, and M. Irfan, “Engineering Behaviour of Expansive Soils treated with Rice Husk Ash,” Geomechanics and Engineering, vol. 8 (2), pp. 173 - 186, 2015.

[14] Owolabi A.O., and M.O. Dada, “Cocoa Pod and Palm Kernel Shell Ashes as Partial Replacement of Portland Cement in Stabilizing Laterite for a Road Construction,” Journal of Applied Scienceand Technology, vol. 17(1/2), pp. 53, 2012.

[15] Qasim, M. Bashir, A. Tanvir, M. and Anees, M. M. (2015).Effect of Rice husk on soil stabilization. Bulletin of Energy Economics, 3(1), 10-17.

[16] Harichane K., M. Ghrici, and S. Kenai, “Effect of Combination of Lime and Natural Pozzolana on the Compaction and Strength Soft Clayey Soils: A Preliminary Study”, Environmental Earth Science, DOI: 10.1007/s12665 – 011 – 1441 - x, pp. 1 -10, 2011.

[17] Nagarajan V. K., S. A. Devi, S. P. Manohanaini, and M. M. Santha (2014), “Experimental Study on Partial Replacement of Cement with Coconut Shell Ash in Concrete.”, International Journal of Science and Research, vol. 3 (3), pp.651 - 661.

[18] Khan S., and H. Khan (2015) “Improvement of Mechanical Properties by Waste Saw dust
Ash Addition into Soil.” Electronic Journal of Geotechnical Engineering, Vol. 20 Bund. 7, pp.1901 - 1914.

[19] Ogunrhibido, T. H. T., “Potentials of Sugar Cane Straw Ash for Lateritic Soil Stabilization in Road Construction”, Int.J. Sci. Emerging Tech., vol. 3, no. 5, pp. 102 – 106, 2012.

[20] Adetoro E. A and Adam J O (2015). Analysis of Influences of Locally Available Additives on Geotechnical Properties of Ekiti State Soil, Southwestern, Nigeria. International Journal of Innovative Research in Science, Engineering and Technology. Vol. 4, Issue 8 pp 7093-7099.

[21] Nnochiri E S., Ogundipe O M., Oluwatuyi O E. Effects of palm kernel shell ash on Lime-stabilized lateritic soil. Slovak Journal of Civil Engineering Vol. 25, 2017, No. 3, 1 – 7

[22] Awal, A.S.M.A. and Nguong, S.K. (2010) A Short-Term Investigation on High Volume Palm Oil Fuel Ash (POFA) Concrete. Proceedings of the 35th Conference on our World in Concrete and Structure, Singapore, 185-192

[23] Johari, M.A. M., Zeyad A.M., Bunnori N. M., Ariffin K.S. Engineering and transport properties of high-strength green concrete containing high volume of ultrafine palm oil fuel ash. Construction and Building Materials 30 (2012) 281–288

[24] Awal, A.S.M.A. and Hussin, M.W. (2011) Effect of Palm Oil Fuel Ash in Controlling Heat of Hydration of Concrete. The Twelfth East Asia-Pacific Conference on Structural Engineering and Construction. Procedia Engineering, 14; 2650-2657.

[25] Tangchirapat W, Saeting T, Jaturapitakkul C, Kiattikomol K, Siripanichgorn A. Use of waste ash from palm oil industry in concrete. Waste Manage 2007;27:81–8.

[26] Pourakbar, S., Asadi, A., Huat, B. B. K., Fasihnikoutalab M. H. (2015) Stabilization of clayey soil using ultrafine palm oil fuel ash (POFA) and cement. Transportation Geotechnics 3, 24-35.

[27] Fauzia A, Fauzi U J and Nazmi W M 2013 Engineering quality improvement of kuantan clay subgrade using recycling and reused materials as stabilizer, The 2nd International Conference on Rehabilitation and Maintenance in Civil Engineering, Procedia Engineering 54 675 – 689.

[28] A. Seco, F. Ramirez, L. Miqueleiz, P. Urmeneta, B. García, E. Prieto, et al. Types of waste for the production of pozzolanic materials – a review Industrial waste, Intech, Shanghai (2012), pp. 141-150

[29] Sooraj V.M. (2013). Effect of Palm Oil Fuel Ash (POFA) on Strength Properties of Concrete International Journal of Scientific and Research Publications, Volume 3, Issue 6, pp 1-7

[30] Brown, M.B.B.M. Yusof, M.R.B. Salim, K. Ahmed. Compaction parameters of kaolin clay modified with palm oil fuel ash as landfill liner. 2011 IEEE first conference on Clean Energy and Technology (CET), IEEE (2011), pp. 199-204

[31] AbdulAwal, A.S.M. and WaridHussin, M. (2011). Effects of palm oil fuel ash in controlling heat of hydration of concrete. Procedia Engineering 14, 2050-2057.

[32] Olutoge, F. A., Quadri, H. A. and Olafusi, O. S. (2012). Investigation of the Strength Properties of Palm Kernel Shell Ash Concrete. Engineering, Technology and Applied Science Research, 2(6): 315-319.

[33] Adeyemi, E. A. and Joseph, O. A. (2015) Comparative Analysis of Ekiti State Soil Stabilized with Different Additives. Asian Journal of Science and Technology. Vol. 06, No 12, pp. 2054-2058.

[34] Onyelowe, K. C , Ubachukwu, O.A, Onuoha, I.C, Ikpa, C and Umoren, P (2016)
Comparison between the Strength Characteristics of Pozzolan Stabilized Lateritic Soil of Coconut Shell Husk Ash and Palm Kernel Shell Husk Ash Admixtures. American Research Journal of Civil and Structural Engineering (ARJCSE), pp 1-7

[35] Ekeocha, N. E and Agwuncha, F. N (2014). Evaluation of Palm Kernel Shells for use as Stabilizing Agents of Lateritic Soils. Asian Transactions on Basic and Applied Sciences (ATBAS ISSN: 2221-4291) Volume 04 Issue 02, pp 1-7.

[36] Adetoro A. E. and, Adekanmi S. J. (2015). Potentials Of Palm Kernel Shell And Sawdust Ashes For Stabilization Of Gbonyin Local Government Area Soil, Nigeria. Journal of Multidisciplinary Engineering Science and Technology (JMEST), Vol. 2 Issue 8, pp2315-19.

[37] Behak L. (2017). Soil Stabilization with Rice Husk Ash (In Rice Technology and Production).Intech Open.pg 29-45. http://dx.doi.org/10.5772/66311

[38] Alabi A. B., Olutaiwo A. O and Adeboje A. O. (2015) Evaluation of Rice Husk Ash Stabilized Lateritic Soil as Sub-base in Road Construction British Journal of Applied Science & Technology 9(4): 374-382

[39] Raheem, A. A. and Kareem, M. A. (2017). Chemical Composition and Physical Characteristics of Rice Husk Ash Blended Cement. International Journal of Engineering Research in Africa, 32: 25-35.

[40] Oviya R. and Manikandan R. (2016). Stabilizing the soil using rice husk ash with lime as admixture paper. International Journal of Informative and Futuristic Research, pp. 3511-3519

[41] Usman, A. M., Raji, A. and Waziri, N. H. (2014). Characterization of Girei Rice Husk Ash for Silica Potential. IOSR-JESTFT, 8(1): 68-71.

[42] Oyejobi, D. O., Abdulkadir, T. S. and Ajibola, V. (2014). Investigation of rice husk ash cementitious constituent in concrete. International Journal of Agricultural Technology 10(3):533- 542.

[43] Abalaka, A. E. and Okoli, O. G. (2013). Comparative Effects of Air and Water Curing on Concrete Containing Optimum Rice Husk Ash Replacement. Journal of Emerging Trends in Engineering and Applied Sciences, 4(1): 60-65.

[44] Dabai, M.U., Muhammad, C., Bagudo, B.U. and Musa, A. (2009). Studies on the Effect of Rice Husk Ash as Cement Admixture. Nigerian Journal of Basic and Applied Science, 17(2): 252-256.

[45] Prasad P.D., Nagarnaik P.B. and Gajbhiye A.R. (2012) “Utilization of Solid Waste for Soil Stabilization: A Review.” EJGE Journal, pp2443-2461.

[46] Ramli R., Shukur N.A.A, T. I. Walid and J.Idrus (2018).Engineering Properties of clayey soil using rice husk ash and coconut shell for road works. AIP Conference Proceedings, Malaysia. 2020, 020030, pp.1-9

[47] Nasiri M., Lotfalian M., Modarres A., and Wu W. (2016). Optimum utilization of rice husk ash for stabilization of sub-base materials in construction and repair projects of forest roads. Croatian Journal for Engineering. 37 (2), pp. 333-343

[48] Edhe J. E., Samson I. and Terhemba A. (2016) “Rice Husk Ash-Carbide Waste Stabilization of Reclaimed Asphalt Pavement.” Nigerian Journal of Technology (NIJOTECH), Vol. 35, No 3, pp 465-472.

[49] Shinde S.S. and Patil G. K. (2016).”Study on Utilization of Agricultural Waste as Soil Stabilizer.” International Journal of Latest trend in Engineering and Technology. Vol. 7 issue 1, pp 227-230.
[50] Chakraborty S., Deb B. K., Chorna, T., Konieczny V., Taylor C.W. and Hassan G. (2016). “Improvement of Subgrade by Lime and Rice Husk ash admixtures. International Journal of Innovative Research in Science Engineering and Technology, Vol. 3, Issue 4.pp1-8
[51] Rahmat N.M., Muhammad R. R. and Norsalima I. (2014). ”Utilization of Agricultural Waste in Stabilization of Landfill soil.” MATEC web of conferences 15,001 (Malaysia).
[52] Milani Ana Paula Da Silva et al (2012) “Physical, Mechanical and Thermal Performance of cement-stabilized rammed earth-rice husk ash walls.” Journal of Materials in Civil Engineering, ASCE, 775-782.
[53] Hussin, M.W., Muthusamy, K. and Zakaria, F. (2010) Effect of Mixing Constituent Toward Engineering Properties of POFA Cement–Based Aerated Concrete. Journal of Materials in Civil Engineering, 287.
[54] Anwar H. K. (2011) “Stabilized Soils Incorporating Combinations of Rice Husk Ash and Cement Kiln Dust.” Journal of Material in Civil Engineering, Volume 23, ASCE, 1320–1327
[55] Roy T. K. (2010). Influence of Lime on Alluvial Soil Strengthened with Pond Ash and Rice Husk Ash for Construction of Subgrade of Road.” Proceeding of Geology, Shanghai. pp 385-391.
[56] Muntohar A.S. (2002) “Utilization of Uncontrolled Burnt Rice Husk Ash In Soil Improvement.” Dimensi Teknik Sipil Journal, Volume 4, 100-105.
[57] Alhassan M. Potentials of Rice Husk Ash for Soil Stabilization. Assumption University Journal of Thailand. 2008; 11(4) : 246–250.
[58] Sharma, R., Phanikumar, B., and Rao, B. (2008). “Engineering Behavior of Remolded Expansive Clay Blended with Lime, Calcium Chloride, and Rice-Husk Ash.” Journal of Material in Civil Engineering, Volume 20, ASCE, 509–515.
[59] Murty, V. and Praveen, G. (2008). “Use of Chemically Stabilized Soil as Cushion Material below Light Weight Structures Founded on Expansive Soils.” Journal of Materials in Civil Engineering, ASCE, Volume 20, 392–400.
[60] Mustapha M. (2007) “Effect of Rice Husk Ash on Cement Stabilized Laterite.” Leonardo Electronic Journal of Practices and Technologies, Issue 11, 47-58.
[61] Alhassan M. and Mustaphar M. (2007) “Effect of Rice Husk ash on Cement stabilized laterite.” Leonardo Journal of Practices and Technology, ISSN 1583-1078 pp 47-58
[62] Basha, E. A., Hashim, R., Mahmud, H. B, Muntohar AS. Stabilization of Residual Soil with Rice Husk Ash and Cement. Construction and Building Materials. 2005; 19: 448–453.
[63] Chen, B., Peng, X., Wang, J.G. and Wu, X. (2004): Laminated Microstructure of Bivalva Shell and Research of Biomimetic Ceramic/Polymer Composite, Ceramic International Journal 30: 2011–2014.
[64] Zolotoyabko, E., Caspi, E.N., Fieramosca, J.S. and Dreele, R.B. (2009): Bond length Differences between the mollusk-made and geological calcium carbonate. Material Science Engineering Journal 524:77–81.
[65] Chatignier, D. (2010) Voyaging around nacre with the X-ray shuttle from Bio-mineralization to prosthetics via mollusc phylogeny; Material Science Engineering Journal, 528: 37–51.
[66] Ayiniuola G. M and Afolayan O. D. (2018) Potential of Oyster Shell Ash Activated with Cement as soil Stabilizer for Road Construction. International Journal of Engineering and...
Advanced Technology (IJET) ISSN: 2249 – 8958, Volume-7 Issue-5, pp. 118-126

[67] Chou-Fu, L. and Hung-Yu, W. (2013): Feasibility of Pulverized Oyster Shell as a Cementing Material. Advances in Materials Science and Engineering Journal Volume 2013

[68] Chen, L. and Lin, D.F. (2009): Stabilization Treatment of Soft Subgrade Soil by Sewage Sludge ash and Cement. Journal of Hazardous Materials 162.1: 321-327.

[69] Guney Y., Sari D., Cetin M. and Tuncan M. 2007: Impact of cyclic wetting-drying on swelling behavior of lime-stabilized soil. Building and Environment Journal 42.2: 681-688.

[70] Yong, R. N. and Ouhadi, V.R. (2007): Experimental study on instability of bases on natural and lime/cement-stabilized clayey soils, Applied Clay Science Journal 35.3-4: 238-249.

[71] Yoon, G.L., Kim, B.T., Kim, B.O. and Han, S.H. (2003): Chemical-mechanical characteristics of crushed oyster-shell. Journal of waste management. 23:825-834.

[72] Dermatas, D. and Meng, X. 2003: Utilization of Fly ash for Stabilization/Solidification of Heavy Metal Contaminated Soils, Engineering Geology Journal 70.3-4: 377-394

[73] Ruiz G.M. and Pierre F. (2016). “Use of crushed seashell by-products for sandy subgrade stabilization for pavement purpose.” 14th LACCEI International Multi-conference for Engineering, Education and Technology, San Jose, Costa Rica.

[74] Otoko G. R. and Esenwa I. C. (2014) “Mechanical Stabilization of a Deltaic clayey soil using crushed waste periwinkle shells.” Global Journal of Engineering Science and Researches, ISSN 2348-8034.

[75] Otoko G. R. and Itode M. W. (2014) “Pulverized Periwinkle Shell stabilization of a Nigerian Lateritic soil.” International Journal of Engineering and Technology Research, ISSN 2327-0349, Vol. 2, No. 5, pp1-7.

[76] Mounika K., Satya N. B. , Manohar D. , Vardhan K. S. (2014). Influence of Sea Shells Powder on Black Cotton Soil during Stabilization. International Journal of Advances in Engineering & Technology. Vol. 7, Issue 5, pp. 1476-1482

[77] Chand A. M. and Babu V. R. (2016). "Effect of Sea shell powder on the Unconfined Compressive Strength of Black Cotton Soil." International Journal of Scientific & Engineering Research, vol. 7, Issue 3,

[78] Raheem A.A., Ige A.I. (2019).Chemical composition and physicomechanical characteristics of sawdust ash blended cement Journal of Building Engineering.21 (404-408)

[79] Koteswara RD, Anusha M, Pranav PRT (2012) Effect of ferric chloride and rice husk ash in the stabilization of expansive soil for the pavement subgrades. International Journal of Engineering Science Advance Technology 2(2):146–153

[80] Butt W. A., Gupta K and. Jha J. N. Strength behavior of clayey soil stabilized with saw dust ash. International Journal of GeoEngineering. (2016) 7:18 pp 1-9

[81] Shawl Z Z, Parkash E. V, Kumar E. V (2017). Use of Lime and Saw Dust Ash in Soil Stabilization. International Journal of Innovative Research in Science, Engineering and Technology. Vol. 6, Issue 2, pp 1682- 1685

[82] Akinwumi I. I., Ojuri O. O., Ogbiey S. A. and Booth C.A (2017). Engineering properties of tropical clay and bentonite modified with sawdust. Acta Geotechnica Slovenica.14(2), 47-57.

[83] Ilori, A. O. and Udo, E. A. (2015). Investigation of Geotechnical Properties of a Lateritic
Soil with Saw Dust Ash *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), Volume 12, Issue I Ver. II, pp 11-14.*

[84] Adetoro A.E. and Oladapo. S.A. (2015) Effects of Sawdust and Palm Kernel Shell Ashes on Geotechnical Properties of Emure / Ise-orun Local Government Areas Soil, Nigeria. Scientific Research Journal (SCIRJ), Volume III, Issue VII, pp 35-38.

[85] Arun, K. K., Padmanabhan N., and Chiranthana N. (2014). Stability Of Red Clay & Laterite Soil With Sawdust As An Ammendment. International Journal of Combined Research & Development (IICRD) Volume: 2; Issue: 2; pp 18-23

[86] Jasim O. H. and Çetin D. (2016). Effect of sawdust usage on the shear strength behavior of clayey silt soil, Sigma J Eng & Nat Sci 34 (1), 31-41.