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USE OF AGRICULTURAL WASTE PRODUCTS FOR SOIL IMPROVEMENT IN GEOTECHNICAL APPLICATIONS: A REVIEW

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Abstract
Soil improvement using agricultural waste products has attracted considerable attention in recent years, with the aim of reducing the amount of environmental wastes and the harmful environmental effects of traditional binders, such as cement. This paper aims to provide a review on the environmental assessment of using agricultural waste products as binders in soil improvement. The wastes considered include saw dust ash (SDA), rice husk ash (RHA), sugar cane bagasse ash (SCBA), Oyster shell ash (OSA) and oil palm empty fruit bunch ash (OPEFA).Various geotechnical properties were evaluated, including the unconfined compressive strength (UCS), shear strength, and physical properties of the treated soils. Potential opportunities for agricultural waste products in geotechnical engineering and the challenges are also presented.

Keywords: *Sustainable environment, agro waste ash-treated soils; soil improvement; geotechnical properties*

Introduction

It is a well-known fact that almost every civil engineering structure must rest upon soil. However, natural soils can have engineering properties that are unsuitable or inadequate for civil engineering construction works such as highways and buildings (EuroSoilStab, 2002; Al-Tabbaa, and Evans, 2005; Sharifah Zaliha et. al., 2013). Ground improvement is the enhancement of geotechnical properties of marginal soils to obtain the desired and optimal performance (Nicholson, 2014; Schaefer et al., 2012; Mishra et al., 2016; Fatehi et al., 2021). When an unsatisfactory soil is encountered on site, a geotechnical engineer would endeavor to develop the most effective and economical approach of soil treatment considering the underlying soil types, locations required to be treated, treatment depth, desired level of improvement, availability of skilled personnel and materials, environmental friendliness of the method and project costs (Nicholson, 2014).

Nowadays, numerous materials are used for soil treatment and stabilization. Conventional stabilizers such lime and cement are considered among the most popular options (Devi et al., 2017; Negi et al., 2013; Jaritngam et al., 2014). The need to reduce the quantity of wastes for the safety of the environment and the high cost of conventional soil stabilizers has led to continuous studies on the economic utilization of ashes from agricultural wastes for improving the engineering properties of natural soils. In addition to high cost, the production of some industrial based stabilizers such as cement constitutes a greater threat to the ozone layer (Chen et al., 2010; Durastanti and Moretti, 2021). Global warming and climate change are considered the most concerning phenomena in recent decades (Fatehi et al., 2021). In the case of materials used in civil engineering applications, traditional and calcium-based materials, such as cement and lime, and synthetic products, have led to greenhouse gases (GHG) emissions, which are directly related to global warming. Therefore, alternative and less polluting materials should be encouraged (Rahgozar *et al.*, 2018; Etim *et al.*, 2017; Chang et al., 2019)

Cement has been considered one of the main sources of CO_2 emissions, contributing approximately 8% of the global CO_2 emissions (Bauer, 2021). From 2010 to 2018, the global amount of cement production increased from 3310 to 4100 million tons (23.8% increase) (Wang, 2018). To reduce cement usage, researchers have attempted to replace traditional environmentally harmful materials with sustainable techniques and methods, such as ashes developed from waste materials. These ashes generated from these wastes are pozzolanic in nature and their utilization in soil stabilization can lead to promotion of waste management at little or no cost and improved geotechnical properties of soil.

These waste materials can be classified based on source of their generation as follows;

a) Industrial wastes such as ground granulated blast furnace slag, fly ash, waste paper sludge, copper slag, etc.
b) Agricultural wastes such as rice husk ash, sugarcane bagasse ash, ground nut shell ash, saw dust ash, coconut husk ash, millet husk ash etc.
c) Domestic wastes such as incinerator ash, waste tire etc. and
d) Mineral wastes such as quarry dust, marble dust etc.

Several studies have been carried out on the effects and advantages of agricultural waste products as soil modifiers and stabilizers (Adetoro and Adam, 2015; Aziz et al., 2015; Khan and Khan, 2015; Ogunribido, 2012; Harichane et al., 2011; Owolabi and Dada, 2012; Ramaji, 2011; Akinwumi et al., 2012; Akinwumi et al., 2015, Bhaumik and Janani, 2016; Gajera and Thanki, 2015). This study will therefore review the work done by various researchers on the impacts and effectiveness of agricultural waste material from the perspective of geotechnical engineering. The parameters that will be reviewed include unconfined compressive strength (UCS), California Bearing Ratio (CBR), compaction characteristics, and pavement stabilization. The various parameters influencing the improved soil geotechnical performance were evaluated under the optimal conditions for different agro waste.

Sources, Production and Geotechnical Properties of Agro Waste Based Ash

Concise descriptions, sources and properties of the agricultural wastes under review are summarized in this section.

Rice husk ash (RHA)

Rice husk ash is a major agricultural product obtained from paddy. About 10^8 tons of rice husk is generated annually in the world, while in Nigeria, about 2 million tons of rice is produced annually (Oyetola and Abdullahi 2006). Burning of rice husk produces about 15-20% weight of ash (Sarapu, 2016). Since rice husk ash is very light, it is easily carried away by wind and water causing air pollution and water pollution (Qasim et al., 2015). RHA is categorized as a pozzolanic material due to its chemical and minerals composition as shown in Table 1.

Table 1: Chemical composition of RHA

Constituent	Chemical composition of rice husk ash (%)			
Ref.	Sarapu (2016)	Musa (2008)	Oviya and Manikandan (2016)	Usman et al.(2014)
SiO_2	86	67.3	90.8	97.10
Al_2O_3	2.6	4.9	3.5	1.14
Fe_2O_3	1.8	0.95	1.32	0.32
CaO_3	3.6	1.36	1.57	0.07
MgO	0.27	1.81	1.0	0.83
Loss of Ignition	4.2	17.78	0.67	0.97

The maximum percentage of siliceous materials contained in rice husk ash as shown in Table 1 indicates it has potential pozzolanic properties. It can be observed from this review that RHA varies in chemical properties and elemental compositions depending on the climatic conditions, geographic conditions and whether the husk has undergone complete destructive combustion or have been partially burnt.

Most studies have investigated the use of rice husk ash (RHA) is in modification and improvement of soil performance for infrastructural construction (Behak, 2016; Alhassan and Alhaji, 2017; Alhsasan, 2008; Shinde and Patil, 2016; Okafor and Okonkwo, 2009; Nasiri et al., 2016, Anwar, 2011; Muntohar, 2002; Rathan Raj et al., 2016). Different techniques and combination ratio with other hydraulic activators and waste(s) have been adopted by researchers in accessing the effects of RHA on different soil types. Some of the geotechnical properties usually considered are Unconfined Compressive Strength (UCS), Atterberg Limits, Compaction characteristics, and California bearing ratio (CBR). Alhassan (2008) investigated soil-RHA mixture with respect to compaction characteristics, California bearing ratio (CBR) and unconfined compressive strength (UCS) tests. The results obtained indicates a general decrease in the maximum dry density (MDD) and increase in the optimum moisture content (OMC). There was also slight improvement in the CBR and UCS with increase in the RHA content. Similar results were observed by (Okafor and Okonkwo, 2009).

Basha et al., (2005) opined that RHA cannot be used alone in soil stabilization because of its lack of cementations properties but must be combined with the traditional soil stabilizers such as lime and cement for effective and efficient soil stabilization Oviya and Manikandan (2016), conducted a research on the stabilization of soil by incorporating Rice Husk Ash (RHA) and lime as an admixture. In the experiment, the soil was partially replaced by RHA with variation of percentage as 2.5%, 5%, 7.5%, and 10% of the soil sample. The lime was added as a binding material at constant percentage of 2% to enhance the various properties of the soil mixture. Laboratory tests were carried out and the effect on soil properties such as optimum moisture content (OMC), California Bearing Ratio (CBR) and unconfined compressive strength (UCS) was determined in soil mixed with RHA and soil mixed with RHA and lime. From the results, it was concluded that the OMC of the soil was increased with the addition of RHA in soil. The CBR value was increased at 5% replacement of soil with RHA only and this percentage of partial replacement of RHA was increased to 10% when 2% lime was also incorporated in the soil-RHA mixture. The UCS value of natural black cotton soil was found to be 250 kN/m^2. With the addition of lime to Soil-RHA mixture, the UCS value increased to 350 kN/m^2. From the study, it was observed that stabilization of soil using RHA is effective in both cost and strength evaluation. For third world countries and developing nations scouting for readily cheap construction materials, the use of RHA for soil improvement can be adopted as it reduces waste disposal cost.

Sawdust ash (SDA)

Saw dust is a waste material from the timber industry. It is produced as timber is sawn into planks at saw mills (Raheem and Ige, 2019). This process is a daily activity causing heaps of saw dust to be generated after each day. The current practice with saw dust is as fuel for domestic cooking and for sand filling ditches in which case it constitutes environmental nuisance (Raheem et al., 2012; Rominiyi et al., 2017). It is with the view of converting the waste product - saw dust, into a useful by product and protecting the environment through proper waste management that researchers accessed its suitability as a subgrade soil modifier. The oxide composition of different sawdust ash samples obtained after chemical analysis using X-ray fluorescent analyzer is shown in Table 2 (Raheem et al., 2012).

Table 2: Chemical composition of SDA (Raheem et al, 2012)

Chemical constituents	Percentage composition (%)			
	Sample 1	**Sample 2**	**Sample 3**	**Average**
SiO_2	65.42	66.05	65.79	65.75
Al_2O_3	5.69	5.12	4.88	5.23
Fe_2O_3	2.16	2.09	2.01	2.09
CaO	9.82	9.65	9.39	9.62
MgO	4.23	4.11	3.92	4.09
SO_3	1.09	1.20	0.98	1.09
Na_2O	0.04	0.08	0.07	0.06
K_2O	2.38	2.22	2.68	2.43
$CaCO_3$	7.89	7.32	8.54	7.92
LOI	4.89	4.05	3.95	4.30
LSF	1.09	1.98	2.07	1.71
SR	10.53	11.03	10.45	10.67
AR	11.35	12.88	12.73	12.32
Total SiO_2 + Al_2O_3	71.11	71.17	70.67	70.98
Total SiO_2 +Al_2O_3 + Fe_2O3	73.27	73.26	72.68	73.07

The result showed that SDA has combined percentages of (SiO_2 +Al_2 O3 +Fe_2O_3) of 73.07%, (Raheem et al, 2012), which is more than 70% recommended by ASTM C618 (1991).The loss on ignition was also less than the maximum of 12% required. All these are indications that SDA is a good pozzolanic material, with a higher composition of silica.

Numerous research works have been carried out on the use of SDA either as partial replacement in concrete or for modification of engineering properties of different subgrade soil (Raheem, 2012; Ilori and Udo, 2015; Ogunribido, 2012; Arun et al, 2014; joseph et al, 2014). No doubt, it has been found out that SDA can act as a significant pozzolan in concrete. Furthermore, the use of sawdust ash as highway pavement material has been tested and has shown an increase in particle size distribution of lateritic soil and maximum which falls under A-2-7 as per AASHTO classification (Joseph et al., 2014). The geotechnical properties of South-Western Nigerian soils was tested by Ogunribido (2012) who showed that sawdust ash is an effective soil stabilizer for lateritic soil and road quality can be enhanced by its addition to the soil. Similar results were obtained in the research conducted by (Butt et al., 2016). Their research showed that at an optimal SDA content of 4%, there is an improvement in the plasticity properties, specific gravity, unsoaked CBR and UCS of natural soils. The CBR increased by 103.11% and UCS by 26.35%.

Sugarcane Bagasse Ash (SCBA)

The bagasse ash is the fibrous waste produced after the extraction of the sugar juice from sugar cane, which is approximately 50% of the sugar cane quality (Xu et al., 2019). Bagasse is commonly used as a fuel in cogeneration to produce steam and generate electricity. In this process, sugar cane bagasse ash (SCBA) remains as the final waste in the sugar production chain. Each ton of burnt bagasse may generate 25–40 kg of bagasse ash (Sales and Lima, 2010) and, subsequently, a considerable amount of BA could be generated. With the increasing demand for more sugar and ethanol production in recent years, SCBA outputs have substantially increased. Waste products like SCBA pose serious threat wherever those are dumped, be it soil, water or air. It can reduce the fertility of soil, can adversely affect aquatic life and can result in respiratory diseases for humans and animals if left out in open (Hitesh et al., 2016). This menace has prompted researchers to explore new ways of utilizing SCBA. Due to the relatively high amorphous silica content, SCBA has been widely studied as a pozzolanic material to partially replace cement (Montakarntiwong et al., 2013; Cordeiro et al., 2017; Xu et al., 2019; Jamsawang et al., 2017; Eberemu, 2015; Cordeiro et al., 2008; Chhachhia and Mital., 2015; Chavan, and Nagakumar.,2014; Bhaumik and Janani,2016).

Osinubi et al. (2009) investigated the possibility of using SCBA to stabilize lateritic soil and found that SCBA cannot be used as a stabilizer alone and must be used with adequate cement stabilization. Jamsawang et al. (2017) partially replaced ordinary Portland cement (OPC) with SCBA as a cheap pozzolanic material and mixed SCBA with soft clay to produce SCBA-admixed soft clay. The test results showed that the replacement of OPC with SCBA could achieve the same strengthening effect when OPC is used alone. The optimal amount for improving the strength of the soft clay is considered to be 20% replacement of

OPC with SCBA. Wubshet and Tadesse (2014) evaluated the stabilization of expansive soil using bagasse ash and lime. The soil was stabilized using 3% lime, 15% bagasse ash and 15% bagasse ash along with 3% lime by dry weight of the soil. The effect of these additives on the soil was investigated with respect to plasticity, compaction and California Bearing Ratio (CBR) tests. The plasticity index significantly decreased with addition of lime or bagasse ash combined with lime. The maximum dry density of the stabilized soil also decreased with addition of these additives. But there was a significant decrease in case of soil stabilized using combination of bagasse ash and lime. The CBR of the soil was increased with the addition of lime and lime in combination with bagasse ash. But bagasse ash alone has a minor effect on the CBR value. From the results of the study, it was concluded that the combination of bagasse ash and lime can strongly improve the strength of expansive soils.

However, it can be deduced that the increase in the strength of the soil obtained at the optimum SCBA content was not significant enough to warrant its usage as a lone stabilizer for sub-base and base materials, but it can be used for subgrade stabilization. For sub-base and base stabilization, SCBA should be admixed with conventional stabilizers for improved performance.

Oil palm empty fruit bunch ash (OPEFA)

Oil palm empty fruit bunch ash is a product of palm oil production and processing from agro industries (Udoetok, 2012). Tangchirapat et al. (2007) 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.

Researchers over the years have shown that OPEFA could be used in the stabilization of lateritic soil which is used in different geotechnical engineering works. The oxide composition of different OPEFA samples obtained after chemical analysis shows that OPEFBA did not fall under class C, F or N pozzolana since the addition of the percentages of SiO_2, Fe_2O_3 and Al_2O_3 did not sum up to 50% for class C or 70% for class F or N (Oladayo and Osinubi, 2019; Oke et al., 2020). However, the high percentage of CaO indicates the hardening potential of the OPEFBA in soils.

Table 3: Chemical composition of OPEFBA

Oxides	OPEFBA (%) Oladayo (2019)	OPEFBA (%) OKE (2020)
SiO_2	17.06	0.05
Al_2O_3	3.42	0.003
Fe_2O_3	2.12	0.007
K_2O	0.74	1.24
Na_2O	0.82	2.72
CaO	58.46	52.15
MgO	2.05	11.10
SO_3	1.06	-
L.O.I	7.12	0.002

Most studies have investigated the use of OPEFA for soil stabilization (Oladayo and Osinubi, 2019; Oke and Osinubi, 2019; Otunyo and Chukuigwe, 2018). However, some of the accomplished studies showed that OPEFA can be used as a stabilizer for poor and soft soils. Oke and Osinubi (2018) had suggested treating of lateritic soil optimally with 8% oil palm EFBA and compacting with the West African Standard (WAS) compaction energy can be utilized for sub-base construction for low-volume traffic road. Oladayo and Osinubi (2019) evaluated the use of lateritic soil stabilized with cement – oil palm empty fruit bunch ash for California bearing ratio base course, from the result of the investigation the CBR values met the 80% requirement for base course materials.

Oyster Shell Ash

Oyster is the common name for a number of different families of salt-water bivalve molluscs that live in marine or brackish habitats. A large amount of oyster shells ends up as waste, as a way of managing this waste, a number of useful materials have been produced from the discarded shell of oysters. A study of ground oyster shells found that the shell is mainly composed of calcium carbonate and small organic compounds (Yoon et. al., 2003), similar to that of lime, which has been used for soil stabilization (Spangler and Handy, 1982). Ayininuola and Afolayan (2018) 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. Oyster shell ash bonds with soil particles when a significant amount of CaO, Al_2O_3 and SiO_2 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) (Yong and Ouhadi, 2007; Yoon et al., 2003; Guney et al., 2007; Chen et al., 2004). In accessing the effect of this waste on engineering properties of soil, Ayininuola and Afolayan (2018) 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. Etim et. al., (2020), investigated the potential use of oyster shell ash in improving the structural strength of lateritic soil for road construction and reported that the Optimum Moisture Content (OMC) increased while Maximum Dry Density (MDD) decreased. The unconfined compressive strength (UCS) values increased with increasing OSA content and curing age. Even though OSA showed a significant strength improvement on the lateritic soil, it is also recommended to be admixed with conventional stabilizers (lime or cement) to be used in road construction. Gbenga and Olaniyi (2018) from their studies found that the addition of 6% OSA activated with 5% cement will enhance soil geotechnical properties. Construction material mixed with crushed oyster shell and sand was used for sand compaction piles to improve soft soils underneath a breakwater port in Japan (Miyaji and Okamura, 2000). In summary, oyster shell ash 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.

Conclusions and Recommendation

From this above discussed review papers it can be concluded that agricultural wastes can stabilize weak soils in effective and economic manner. These wastes can either be applied alone in a refined form or with other cementing materials thereby improving certain properties in the soil. Consequently, waste adoption as soil modifier leads 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.

The oxide compositions of all the agro wastes considered showed that they are good pozzolanic materials, because the combined percentage composition of their silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3) were more than 70%. It therefore satisfied the requirement for use as pozzolanas according to ASTM C618 (2005), except for Oyster Shell ash and OPEFA but have high CaO content hence, makes them an excellent modifiers and stabilizers. Most of the authors in the literature reviewed failed to carry out an extensive geotechnical tests on their work, concentrating on consistency and strength tests. However, the durability tests such as permeability, swell potential, volumetric shrinkage, strength reduction in index etc. should also be studied on the stabilized soils and relate them with cement stabilized soils. This paper, also, recommends the adoption of agro-waste as a subgrade modifier and stabilizer.

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