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A REVIEW OF THE STABILIZATION OF LATERITIC SOILS WITH SOME AGRICULTURAL WASTE PRODUCTS

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Abstract: An attempt to reduce the amount of environmental wastes and the high cost of conventional stabilizers has led to continuous studies on the economic utilization of ash from agro-wastes for improving the engineering properties of soil. This paper therefore reviewed the impacts of some of these waste products to establish their effectiveness in improving geotechnical properties of lateritic soils. The wastes considered include saw dust ash (SDA), coconut husk ash (CHA), millet husk ash (MHA), corn cob ash (CCA), rice husk ash (RHA), bagasse ash (BA) and locust bean pod ash (LPBA). It was established that these ashes are good pozzolanic materials having satisfied the required standards. Also, increase in ash contents led to a significant decrease in the liquid limit, plasticity index, swelling index and shrinkage limit of soils. The maximum dry density of soil increased from 0 to 4% substitutions of SDA, CHA and CCA while it decreased with the addition of ashes from other wastes. CBR and UCS generally increased with increasing amount of the stabilizers whereas soil permeability and swell potential decreased as the ash content increased. Ash produced from these wastes can be used to improve the geotechnical properties of soil, to synthesize a stable soil mix, suitable for highway construction purposes.
Keywords: Lateritic soil; soil stabilization; agro wastes ash; oxide composition; indexing and strength properties

1. INTRODUCTION

The need to reduce the quantity of wastes to keep environment safe and the high cost of soil stabilizers has led to continuous studies on the economic utilization of ash from wastes for improving engineering properties of soil. In addition to high cost, the production of some industrial based stabilizers such as cement constitutes a greater threat to the ozone layer. Cement, which is the principal hydraulic binder and stabilizer used in many modern day constructions, is the product of an industry that is not only energy – intensive but also responsible for the large emission of carbon dioxide into the atmosphere (Mehta and Monterio, 2006; Oluremi *et al.,* 2014; 2016). The production of one tonne of Portland cement clinker emits nearly one tonne of CO_2 into the atmosphere (Mehta and Monterio, 2006). According to Badur and Chaudhary (2008), the Portland cement accounts for 7 percent of the total global emission of CO_2. Hence, an attempt to manage the increasing waste materials in our surrounding and to find alternatives stabilizers has given birth to the use of waste material in modifying the engineering properties of some problematic soils.

Lateritic soils are commonly found in the leached soils of the humid tropics and are formed as products of tropical weathering processes. The soils may be problematic and non-problematic types depending on field performance (Eberemu, 2015). The problematic ones composed of high moisture contents, high liquid limits and low natural densities (Osinubi, 1998). When possible, they are used in many construction works such as roads, earth dams, embankments and bridges. The properties of non-problematic lateritic soils in the vicinity of the construction project may not meet the required specification. Such soils need to be stabilized in order to meet the required geotechnical specification for the desired engineering application. Recently, the focus of several studies (Osinubi *et al*., 2009; Oluremi *et al*., 2012; Eberemu, 2015; Adedokun *et al*., 2016) in the field of engineering have been on the effective utilization of agricultural and industrial wastes. Because the most common, cheap and readily available alternative materials to replace the expensive chemical stabilizers in the developing countries, are ashes developed from agro based wastes. Notable among these wastes ash are Saw Dust Ash (SDA), Coconut Husk Ash (CHA), Millet Husk Ash (MHA), Corn Cob Ash (CCA), Rice Husk Ash (RHA), Bagasse Ash (BA) and Locust Bean Ash (LBA). These waste ashes are pozzolanic in nature and their utilization in soil stabilization can lead to promotion of waste management at little or no cost, reduction in environmental pollution, low stabilization cost and improved geotechnical properties of soil. This would thereby minimize the consumption of the industrial based stabilizers like cement, which will eventually lead to conservation of limestone deposits and reduction of CO_2 emission to the atmosphere. This study therefore reviewed the impacts and effectiveness of these agricultural and industrial waste products on the geotechnical properties of lateritic soils.

2. SOURCES AND PRODUCTION OF AGRO AND INDUSTRIAL WASTE BASED ASH

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

— Saw dust ash (SDA)

Saw dust is a by-product of timber which can be collected from sawmills industries across Nigeria. Although it has found its alternative use in growth of mush room and has litters in poultry keeping, the heap of sawdust still constitute environmental pollution and the only mean of getting rid of it is by burning which generate ash. According to Fuwape,

(1998) 93.32% of the total number of wood based industries in Nigeria is sawmill industry (Figure 1). The recovery factor of lumber in most of sawmills ranges between 45 to 50% (Alviar, 1983 and Fuwape, 1989; Ogunbode *et al,* 2013) which means that about 50 to 55% of log input ends up as wood residues in sawmills.

Figure 1. Heaps of sawdust in typical Nigeria sawmill. Source: (Ogunbode *et al,* 2013)

In production, saw dusts were air dried, burnt to ashes and then sieved through a British Standard sieve of size 75µm to get very fine ash (Ogunribido, 2012; Otoko and Honest, 2014; Ilori and Udo, 2015). The oxide composition of different sawdust ash samples obtained after chemical analysis using X-ray fluorescent analyzer is shown in Table 1. The summation of the composition of silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3) in the SDA ranged from 71.5 to 89.4 (Udoeyo and Dashibil, 2002; Raheem *et al*, 2012; Mujelu *et al*, 2014; Otoko and Braide, 2014; Malik *et al*, 2015; Khan and Khan, 2015, Prusty *et al*, 2016), which is greater than 70% recommended by ASTM C618 (2005). The loss on ignition was also between 3.67 and 8.40, which is less than the maximum of 12% required. All these are indications that SDA is a good pozzolanic material, with a higher composition of silica. Based on the reviewed studies on SDA, the specific gravity of the saw dust ash ranged between 1.15 and 2.19.

— Coconut husk ash (CHA)

Coconut husk (Figure 2) is an agricultural waste rich in lignin and cellulose with a high calorific value of 18.62MJ/kg consists of cellulose, lignin, pyroligneous acid, gas, charcoal, tar, tannin, and potassium as chemical composition. It is commonly use in direct combustion to generate fire, otherwise it is thrown away (BioEnergy Consult, 2015).

According to Oluremi *et al,* (2012), Oyediran and Fadamoro (2015) and Amu *et al,* (2011), the coconut husks used were obtained from South Western Nigeria and burnt in open air with the resulting ash sieved through sieve No.200 (75µm). The oxide composition of the coconut husk ash is as shown in Table 1. From the table, the combined proportion of silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3) for CHA was 73.35 % (Oyediran and Fadamoro, 2015). This shows that CHA is pozzolanic material because it satisfies the requirement given by ASTM C618 (2005) that the summation of the oxides of aluminum, silicon and iron oxides should not be less than 70%. Also, the loss on ignition of CHA (9.34) was also less than the maximum 12 % required.

Figure 2. Typical coconut husk as discarded waste material. Source: (BioEnergy Consult, 2015)

— Millet husk ash (MHA)

FAO (2007) reported that there are nine species of millet in the world with total production of 28.38 million tons, out of which 11.36 tons (40%) were produced in Africa. Nigeria produces about 40% of the millet produced in Africa (4.53 million tons) and, also more than 80% of the millet are produced in the Northern part of Nigeria due to their low rainfall and adverse weather condition (Obilana, 2002; Uche *et al*, 2012). Nigeria is rated as the second largest producer of millet in the world (FAO, 2007). The millet husk (Figure 3) is produced in large quantity due to large amount of millet cultivated which is almost consumed locally. Akande (2002) reported that about 40% of the weight of the harvested millet is removed as husk from the stalk. The husk is sometimes used as landfill and seldom used as an admixture together with laterite in building mud houses or burnt and return to farm as manure. The husk is usually found in heaps, unused because of its availability everywhere in areas where millet cultivated, resulting into environmental pollution along highways

Figure 3. Typical appearance of millet in plantation and after harvesting

and rural areas. The major method of disposal is by burning resulting in the formation of ash. According to Uche and Ahmed (2013), the husk was burnt into ashes to obtain millet husk ash (MHA). The chemical analysis of MHA was conducted by X-Ray Fluorescent (XRF) method at various companies in Nigeria and the results showed that MHA contained major cementitious compounds like the ordinary Portland cement (OPC). The combined percentage of silica (SiO2), alumina (Al2O3) and iron oxide (Fe2O3) ranged between 73.2 and 77.3. This shows that MHA met the ASTM standard for a good pozzolana and could help in stabilizing the lateritic soil.

— Corn cob ash (CCA)

Corn cob (Figure 4) is one of the agricultural wastes obtained from maize or guinea corn, which is the most important cereal crop in Sub-Saharan Africa. The corn is produced in every part of Nigeria and many other countries of the world. According to the data released by food and agriculture organization (FAO) in the year 2000, 589 million tons of maize were produced all over the world in 2000 (FAO, 2002). FAO further stated that about 20% of the weight of maize is the husk, with the recorded wastes of about 117.8 million tons from world produce in 2000. The USA was the largest producer of maize with about 43% of world production.

Figure 4. Typical corn corb in stalk and grounded forms

According to IITA (2002), Africa produced 7% of the world's maize and Nigeria was the second largest producer of maize in Africa after South Africa. In producing corn cob ash, based on the work of Adesanya and Raheem (2009a), the corn cobs were ground into 4mm in order to ensure adequate combustion and reduce the carbon content that affects their pozzolanic properties. The cobs were then burnt in open air for some hours with temperatures ranging from 560°C to 650 °C. The ashes produced after burning were allowed to pass through the sieve with openings of 0.075 mm. The CCA was then analysed using X-ray Fluorescence Analyser (XRF) and its oxide composition of the CCA is as presented in Table 1. The results of the chemical analysis indicated that the combined percentages of (SiO_2 + Al_2O_3 + Fe_2O_3) ranged from 72.4 to 83.0% (Adesanya and Raheem, 2009b; Raheem *et al*, 2010; Raheem and Adesanya, 2011; Mujelu *et al*, 2014; Jimoh and Apampa, 2014; Akinwumi and Aidomojie, 2015), which is more than 70%. This indicates that the CCA is a good pozzolanic material in accordance with the requirements stated in ASTM. According to Oluborode and Olofintuyi (2015), the specify gravity of CCA is 2.27, and this falls within the range of 1.9 and 2.4 recommended for pulverized fuel ash in ASTM C618 (2005).

— Rice husk ash (RHA)

According to Oyetola and Abdullahi (2006), Rice Husk (Figure 5) is an agricultural waste obtained from milling of rice. Large quantity of rice husk is generated annually in Nigeria and many countries of the world.

RHA is obtained from burnt rice husk at a temperature of 400°C to 700°C, after which the ash was allowed to pass through 75µmm BS sieve size. Several studies (Oyetola and Abdullahi, 2006; Alhassan, 2008; Okafor and Okonkwo, 2009; Dabai *et al*, 2012; Nagrale *et al*, 2012; Ayininuola and Olaosebikan, 2013; Sule *et al*, 2014; Alabi *et al*, 2015; Akeke and Osadebe, 2016) have categorized RHA as a pozzolanic material, with about 67-89% silica and about 2.21-4.9%, Alumina and 0.68-0.95% iron oxides. The chemical composition of the RHA presented in Table 1 showed that the combined percent composition of silica, alumina and iron oxide is more than 70% (70.2-90.7%). This is an indication that RHA is a good pozzolanic material with a specific gravity value ranging from 1.65 to 2.11. It can be observed from this reviewed that RHA varied in chemical properties and elemental compositions depending on the locations.

Figure 5. Rice in raw shieve and waste husk shieve being burnt

— Bagasse ash (BA)

Bagasse is a fibrous waste obtained from sugar cane after the extraction of sugar juice at sugar cane mills (Osinubi and Stephen, 2007). This material (Figure) is readily available in large quantity and usually poses a disposal problem in sugar factories, particularly in tropical countries. It is mostly left off in heap to stink and breed worm under rain and sometimes burn to ash. Researchers produced bagasse ash (BA) by collecting, air-drying and burning the bagasse waste into ashes under atmospheric conditions. The ash obtained was passed through British Standard sieve no. 200 in accordance with BS 1924 (1990) and ASTM C618 (2005). BA produced was then analysed using X-ray fluorescene to determine its oxide compositions, which are summarized in Table 1. The combined percentages of silica, alumina and iron oxide ranged from 70.1 to 83.6 (Osinubi et al, 2009; Onyelowe, 2012; Chavan and Nagakumar, 2014; Kharade et al, 2014; Sadeeq et al, 2015;

Murari et al, 2015; Chhachhia and Mital, 2015; Bhaumik and Janani, 2016). According to Cordeiro et al, (2008), the pozzolanic reactivity of sugar cane bagasse ash depends strongly on the incinerating temperature and its maximum reactivity occurred at 500°C. The major reason why BA has poor pozzolanic activity can be attributed to overburning under the temperature range that favours the development of crystalline (less reactive) rather than amorphous (more reactive) particles. This review showed that the specific gravity of the Bagasse ash ranged from 1.92 to 2.34.

Figure 6. Bagasse in a waste form

— Locust bean pod ash (LBPA)

Cultivation of locust bean tree is important to the economic of Africa especially West Africa, because the entire tree is a valuable material especially the seeds which are good source of lipid (29%), protein (35%), carbohydrate (16%), and a good source of fat and calcium (Ntui, et al, 2012). In northern Nigeria, annual production of locust bean seeds is estimated at around 200,000 tonnes. Locust bean husks (Figure 7) are readily available as waste products of agricultural processing of the locust bean fruits during the harvest season (Adama and Jimoh, 2012). Large quantity of locust bean husks generated annually in many West African countries were normally burnt to ash in an open air as a method of disposal.

Figure 7. Locust bean pod before extraction of locust bean

According to the researchers (Osinubi, 2009; Ovuarume, 2011; Adama *et al*, 2013; Samaila and srividya, 2015; Osinubi *et al*, 2016), heaps of locust bean pod were allow to dry and burn to ash in an open air at a temperature range from 500 – 700^{0}C. The locust bean pod ash (LBPA) obtained was allowed to cool before being passed through BS No. 200 sieve with 75 μm aperture to meet the requirements of Class N Pozzolanas (ASTM C 618 -78). The results of the chemical analysis of the LBPA through X-ray fluorescence (XRF) method showed that the total compositions of silicon, aluminium and iron oxides ranged between 63.6 and 70.6, depending on the burning temperature of the ash. (Osinubi, 2009; Ovuarume, 2011; Adama *et al*, 2013; Samaila and srividya, 2015; Osinubi *et al*, 2016).

— Chemical Properties of the Agro Waste Products

The oxide composition of the agro-wastes presented in Table 1 showed that all the ashes from the agricultural wastes, satisfied pozzolanic material requirement with the sum of silicon, aluminum and iron oxides greater than 70% (ASTM C618, 2005). It can also be observed from the result that the ashes from these wastes contain higher percentages of silica and lower composition of calcium oxide.

Table 1. Oxide compositions of the agricultural and industrial waste products

Oxides	Oxide composition						
	SDA	CHA	MHA	CCA	RHA	BA	LBPA
SiO_2	64.8-85.0	72.3	67.3-73.1	56.4-67.4	67.3-89.1	57.1-64.4	39.0-55.4
Al_2O_3	0.89-5.69	0.86-6.69	0.03-4.90	5.85-17.6	0.91-4.9	6.98-23.7	13.1-14.9
Fe_2O_3	0.85-2.57	0.18-4.65	0.95-4.2	2.95-9.07	0.52-0.95	2.75-6.98	0.28-11.5
CaO	0.58-9.82	0.29-0.85	1.5-36	3.50-11.8	0.11-1.36	2.51-4.52	1.08-15.7
MgO	0.96-5.8	0.02	0.20-1.81	2.06-4.06	0.87-1.96	0.11-4.47	2.01
SO_3	1.06-1.33	1.4-6.38	0.04-0.72	1.06-1.41	0.14	0.02-1.48	-
Na_2O	0.04-0.43	-	0.1-104	0.41-1.91	0.01-1.58	-	0.18-1.21
K_2O	0.11-2.43	4.77	0.5-7.5	1.98-8.42	0.85-1.98	2.41-8.72	2.00-5.62
$CaCO_3$	7.89-7.92	4.77	-	-	-	-	-
Loss on ignition	3.67-8.40	9.34	11.0-17.8	8.55	6.06-18.3	4.38-17.6	0.63-6.00
$SiO_2+Al_2O_3+Fe_2O_3$	71.5-89.4	73.35	73.2-77.3	72.4-83.0	70.2-90.7	70.1-83.6	63.6-70.6

3. GEOTECHNICAL PROPERTIES OF THE AGRO WASTE PRODUCTS

— Atterberg limits

Saw dust ash

Otoko and Braide (2014) carried out the stabilization of Nigerian deltaic laterites with various percentages of Saw Dust Ash (SDA) i.e. 0 to 10% by weight of the soil. Effect of the SDA on the liquid limit, plasticity index and linear shrinkage limit of the lateritic soil was conducted in the study. The result showed that the liquid limit decreased as the saw dust ash contents increased. Similar trend was also observed for both plasticity index and shrinkage limit. This is indication that the SDA has less affinity for water and yielded a decrease in the atterberg limits of the lateritic soil. Researchers (Ogunribido, 2012; Ilori and Udo, 2015; Naranagowda *et al,* 2015; Khan and Khan, 2015) also investigated the effect of SDA on the consistency limits of the lateritic soil and concluded that swelling index, liquid limit and plasticity index of the soil decreased with increasing contents of the SDA. This can be attributed to reduced affinity for water by soil-SDA mixture which makes the soil to be less plastic. This shows that SDA can be used to improve some of the soil index properties such as the liquid limit and plasticity index, which will thereby give rise to a stable soil suitable for highway construction purposes. According to Khan and Khan (2015), the addition of SDA enhanced the shrinkage capacity of the soil, which therefore reduced the ability of the soil to expand.

Coconut ash

Amu et al, (2011) examined the consistency limits of lateritic soils modified with coconut shell ash (CHA) with a purpose of obtaining a cheaper and effective road stabilizer. They reported that geotechnical properties were further improved at 4% addition of CHA, with a reduction of nearly 18-46% in plasticity index of the lateritic soil. Another study on the stabilization of poor lateritic soil with coconut husk ash by Oluremi et al, (2012) concluded that the addition of CHA increased the plastic limit while it decreased the plasticity index of the soil. The liquid limit also decreased from 0 to 4% addition of CHA. Both researchers concluded with possibility of using not more than 4% CHA to stabilized lateritic soil for good modification of its consistency limits.

Millet husk ash

Uche and Ahmed (2013) have investigated the effects of MHA on index properties of marginal lateritic soil at Maikunkele area of Minna (Lat. 9°36″N and Long. 6°30″E), Nigeria. The study was conducted in accordance with BS 1377 (1990) and Head (1992), and concluded that addition MHA to the soil decreased the liquid, plastic and liner shrinkage limits of the lateritic soil (Figure 8). The decreased in the Atterberg limits is attributed to cation- exchange reaction that predominates in the early stage of stabilization, resulting into agglomeration and flocculation of the soil particles. This thereby leads to an improvement on the classification properties of the lateritic soil which is also in agreement with the previous findings (Osinubi and Katte, 1977; Emesiobi, 2000; Uche and Abubakar, 2010)

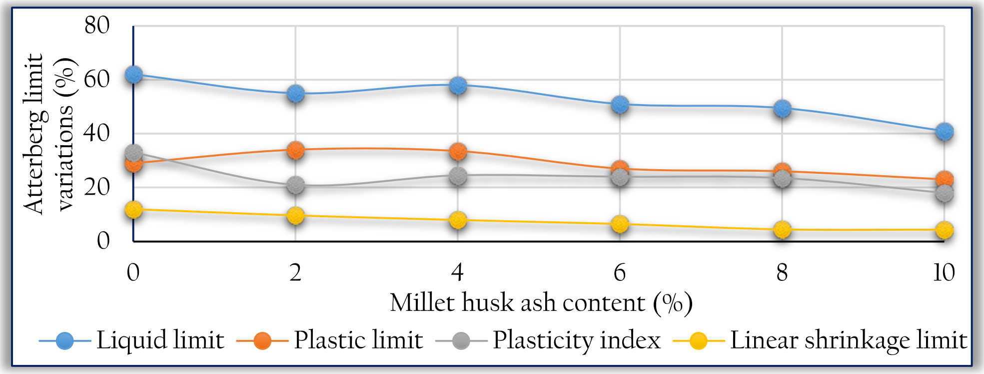

Figure 8. Effects of millet husk ash on the Atterberg limits of the lateritic soil (Uche and Ahmed, 2013)

Rice husk ash

Okafor and Okonkwo (2009) studied the effects of the rice husk ash on some geotechnical properties of lateritic soil obtained from Obukpa, Enugu State, Nigeria. The soil was replaced with MHA from 0-12.5% by mass of the soil at interval of 2.5%. The results of the study showed a decrease in liquid and plastic limits as the rice husk ash increased from 0 to 7.5% but these properties increased with further addition of the RHA. In addition, increasing ash contents also led to a continuous increase in plasticity index and linear shrinkage limit of the stabilized soil.

Corn cob ash

Akinwumi and Aidomojie (2015) determined the effect of CCA on the geotechnical properties of lateritic soil stabilized with Portland cement and noted that the liquid limit of the soil decreased with increasing content of CCA. The plastic and linear shrinkage limits increased while plasticity index decreased as the amount of CCA addition increased. Jimoh and Apampa (2014) carried out an evaluation of the influence of CCA on the strength parameters of lateritic soils and concluded that liquid limit, plastic limit and plasticity index slightly increased with increasing corn cob ash content from 0 to 7.5%.

Bagasse ash

Sadeeq et al, (2015) investigated the influence of bagasse ash on the index properties of an oil contaminated lateritic soil in accordance with British Standards BS1377 (1990) and BS 1924 (1990). The specimens were prepared by mixing the soil with bagasse ash of 0, 2, 4, 6 and 8% by weight of the soil. It was observed from the results that liquid limit of the stabilized soil initially increased at 2% but decreased with further increment of the bagasse ash. The plastic limit increased while the plasticity index of the soil decreased with increasing content of the bagasse ash. The study attributed the decrease in plasticity index to the depressed double layer thickness due to cation exchange by potassium, calcium and ferricions, which is also in line with the previous findings (Osinubi, 2000; Suhail *et al*, 2008).

— Compaction

Otoko and Braide (2014) and Ogunribido (2012) used saw dust ash to stabilize lateritic soil and noted that Maximum Dry Density (MDD) of the soil increased with an increase in the percentage of the saw dust ash from 0 to 4% (Figure 9).

However, MDD decreased with further addition of the SDA. The study showed that Optimum Moisture Content (OMC) is inversely proportional to the MDD, with decreasing values between 0 and 4% addition of SDA and increasing values beyond these additions. A decrease in the dry unit weight beyond 4% addition of SDA may be due to lower specific gravity of the saw dust ash, while an increase in the OMC may be as a result of water needed to be hydrated. Khan and Khan (2015) reported that dry density of the soil improved by 7.8% with addition 12% addition of saw dust ash. According to Naranagowda *et al*, (2015), MDD of an expansive soil increased from 1.93 to 1.94 g/cc when saw dust ash was raised from 0 to 10% and further decreased from 1.86 to 1.79 g/cc for 20 to 30 % addition of SDA.

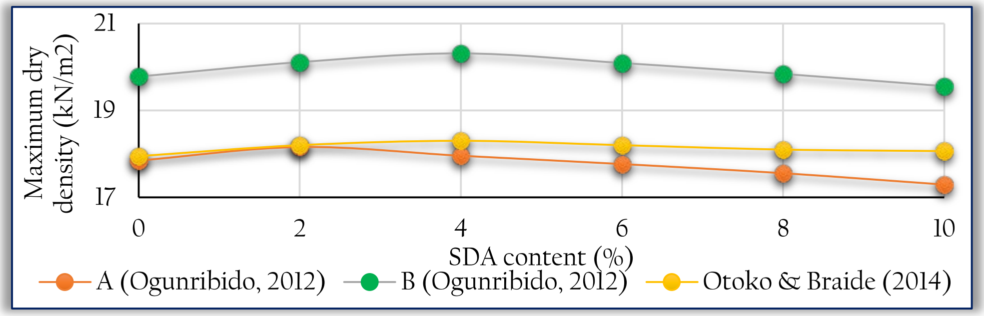

Figure 9. Effect of saw dust ash on maximum dry density of the lateritic soil

Coconut husk ash

The result of the compaction test conducted by Oluremi et al, (2012) on the lateritic soil stabilized with CHA revealed that MDD of the soil increased from 0% to 4% CHA addition but reduced after 4%. This showed that 4% addition of CHA is the effective optimum value because minimum OMC was also observed at this value.

Millet husk ash

According to Uche and Ahmed (2013), the addition of MHA to lateritic soil decreased the maximum dry density of the soil, whereas the optimum moisture content increased with increasing content of MHA. The decreased in dry density was attributed to the agglomeration and flocculation of soil which thereby resulting into particles occupying larger spaces in the process. This is in line with earlier findings by Ola (1978), Osula (1984) as well as Uche and Abubakar (2010).

Rice husk ash

The results of the research carried out by Alhassan (2008), Okafor and Okonkwo (2009) and Alabi et al, (2015) revealed a general decrease in the MDD but a considerable increase in OMC of the soil with increasing RHA content (Figure 10). The decrease in dry density may be due to replacement of the soil by RHA which has lower specific gravity compared to that of the soil as well as the coating of the soil by the ash content, resulting into large particles with greater voids and decreased soil density.

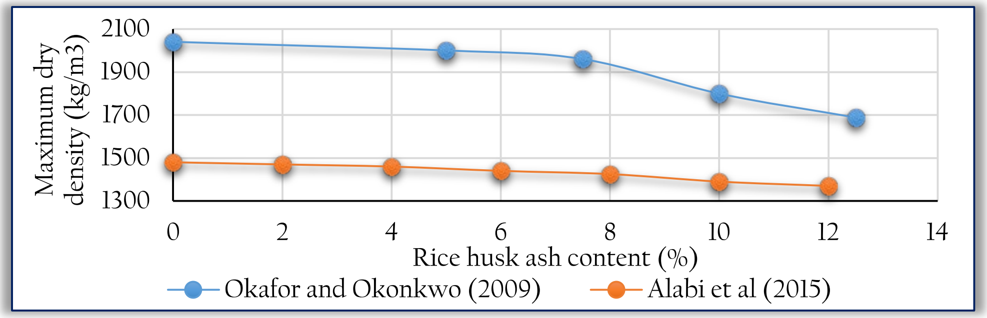

Figure 10. Effect of rice husk ash on maximum dry density of the lateritic soil

Corn cob ash

According to Akinwumi and Aidomojie (2015), treatment of the lateritic soil with varying percentages of corn cob ash increased the maximum dry density of the soil from 0 to 4% but further addition of the CCA decreased MDD. Whereas the optimum moisture content of the soil increased from 0-8% addition of the stabilizer. However, Jimoh and Apampa (2014) reported that the addition of CCA to lateritic soil decreased MDD sharply from the control value of 1.905g/cm^3 to 1.827g/cm^3 from 0 to 7.5% CCA .The OMC increased as the binder content was progressively increased from 0% to 7.5%.

Bagasse ash

Reseachers (Osinubi et al, 2009; Onyelowe, 2012; Sadeeq et al, 2015) have performed compaction tests on the bagasse ash stabilized lateritic soils in accordance with British Standard (BS 1377, 1990). Osinubi et al (2009) and Sadeeq et al (2015) reported that the maximum dry density of soil decreased with the addition of bagasse ash whereas in the case of optimum moisture content, it increased as the percentage of BA increased. The study attributed the general drop in MDD to the flocculation and agglomeration of fine particles (due to cation exchange) which occupy larger spaces, resulting into corresponding decrease in the density. Onyelowe (2012) carried out compaction test on the stabilization of soil with 4% and 6% cement with varying percentages of BA (0, 2%, 4%, 6%, 8%, and 10%) by weight of the dry soil. It was observed from the study that there was a reduction in MDD with increasing BA content for 4% cement addition. However for specimen with 6% cement, the density increased as the bagasse ash content became higher. Bhaumik and Janani (2016) also observed that addition of bagasse ash decreased the maximum density of the lateritic soil.

Locust bean pod ash

Adama et al (2013) and Samaila and Srividhya (2015) conducted compaction tests to investigate the effects of the various contents of locust bean waste ash (between 0 and12%) on the maximum dry density and optimum moisture content of weak lateritic soils in accordance with British Standard 1924 (1990) and Indian Standard 2720 (1980) respectively. The two studies showed that MDD decreased with increasing amount of the ash, whereas OMC increased with ash content.

— California bearing ratio (CBR)

The effect SDA on the California bearing ratio (CBR) of Nigerian deltaic lateritic soil was investigated by Otoko and Braide (2014), in which it was noted that CBR values increased from 0 to 4% addition of SDA (Figure 11). However, it decreased with further increment of the SDA additions. According to Ogunribido (2012), the CBR values of the lateritic soil taken from South Western Nigeria increased at 2-4% addition of SDA than that of the natural soil, but decreased with further addition of saw dust ash.

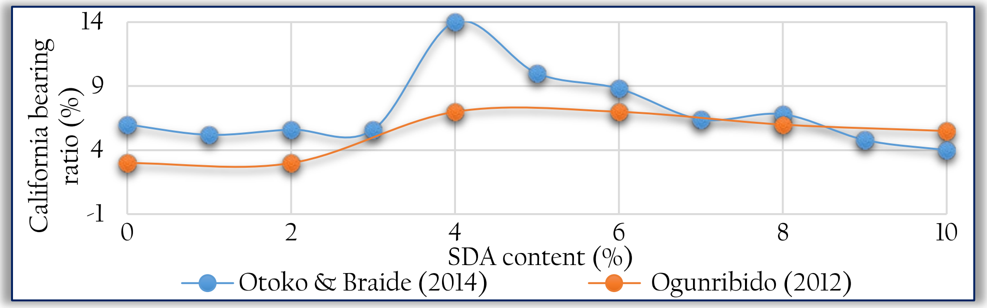

Figure 11. Effect of saw dust ash on the California bearing ratio of the lateritic soil

Coconut husk ash

Oluremi et al., (2012) reported based on the results of their experiment on the stabilization of poor lateritic soil with coconut husk ash that CHA continuously increased the CBR values of the soil from 0 to 10% addition of CHA. The test results indicated that CHA can be effectively utilized to improve soils with low CBR values.

Millet husk ash

The results of the study conducted by Uche and Ahmed (2013) to examine the California bearing ratio of MHA treated lateritic showed that both soaked and unsoaked CBR values increased significantly with increasing amount of the MHA treatments. The soaked CBR ranged from 37.99 - 51.3%, while those of unsoaked CBR ranged from 44-65% for 0-10% MHA additions respectively. The improved soaked CBR values at 10% treatment made the soil an acceptable material for both subgrade and subbase (Emesiobi, 2000; Uche and Ahmed, 2013).

Rice husk ash

The effect of RHA addition on the California bearing ratio of the lateritic soil was investigated by Alhassan (2008), Okafor and Okonkwo (2009) and Alabi et al (2015). The results from these investigations showed were similar and showed a significant increase in CBR values as the RHA content increased. The CBR values observed for the stabilized soil samples were much higher than that of the natural soil, with the highest strength improvement obtained between 5 and 10% RHA additions. The study attributed the improvement in the CBR at this range of RHA treatment to the gradual formation of cementitious compounds between the rice husk ash and Calcium hydroxide present in the lateritic soil.

Corn cob ash

Jimoh and Apampa (2014) conducted both soaked and unsoaked CBR tests to determine the effect of corn cob ash on the CBR values of the lateritic soil in accordance with Nigerian General Specification (1997). The ash was added to the soil in proportions of 0, 1.5, 3, 4.5, 6 and 12%, by dry weight of the soil and thoroughly mixed to ensure homogeneous mixture of CCA-stabilized soil. The results of the study showed that the CBR values of the soil increased with increasing amount of CCA from 0 to 1.5%, after which a further addition of CCA reduced the CBR.

Bagasse ash

Osinubi et al (2009), Onyelowe (2012), Sadeeq et al (2015) and Bhaumik and Janani (2016) have investigated the impacts of bagasse ash on the California bearing ratio of the lateritic soil, with BA additions varying from 0 to 12% by weight of the dry soil. Osinubi et al (2009) reported that CBR showed a peak value at 2% BA addition but was followed by a decreased

CBR value with BA content of 6%. The strength thereafter increased slightly between 8 and 12% stabilizer addition. The results according to Sadeeq et al (2015) showed an increase in CBR value from 0 to 8% addition of the BA. However, the results of the study conducted on BA stabilized lateritic soil by Onyelowe (2012) is quite in agreement with that of Bhaumik and Janani (2016), which revealed a continuous increase in CBR with increasing content of the bagasse ash from 0 to 12%. The increase in strength was attributed to the formation of different compounds such as calcium silicate hydrates, calcium aluminate hydrates and micro fabric changes, which aid strength development.

Locust bean pod ash

Adama and Jimoh (2012) examined the impact of locust bean pod ash on the soaked and unsoaked CBR of three soil samples according to British Standard 1377 (1990). The results as presented in Fig. 5 showed that CBR of all the soil samples increased with increasing amount of LBPA from 0 to 8% but the strength reduced at 12% LBPA addition. The study showed that the percentage increases in CBR values were in the ranges of 11-100% and 8-46% for soaked and unsoaked conditions respectively. The results of another study by Samaila and Srividhya (2015) also revealed an increase in CBR values as the content of the locust bean pod ash became higher.

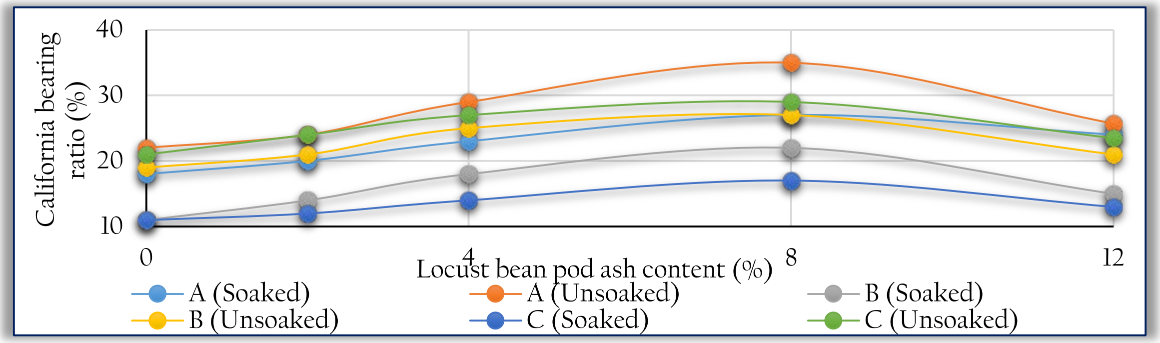

Figure 12. Effect of saw dust ash on the California bearing ratio of the weak lateritic soil samples (Adama and Jimoh, 2012)

— Unconfined Compressive Strength

Sawdust ash

Otoko and Braide (2014) reported that treatment of lateritic soil with saw dust ash showed an increase in the Unconfined Compressive Strength (UCS) of soil from 0 to 4% addition of the SDA but the UCS value decreased beyond this SDA content (Figure 13).

Rice husk ash

The impact of RHA additions (0-12%) on the unconfined compressive strength of the lateritic soil at 7, 14 and 28 days curing periods was investigated by Alhassan (2008) in accordance with BS 1377. The study reported a slight increase in UCS value of the soil with subsequent addition of RHA, with the maximum value obtained at between 6-8% RHA contents. The results also indicated a continuous increase in strength with curing period, with the lowest and highest strengths observed for 7 and 28 days respectively.

Corn cob ash

Jimoh and Apampa (2014) studied the influence of CCA on the unconfined compression strength of the lateritic soil sample and concluded that UCS values significantly increased from 403 kN/m^2 for the natural soil to 992 kN/m^2 for 1.5% CCA addition. However, the strength decreased steadily with further addition of CCA. The study suggested that 1.5% CCA addition is the optimum phase of the pozzolanic reaction after the attainment of the cation exchange capacity of the lateritic soil.

Bagasse ash

The results of the studies carried out by several researchers (Osinubi *et al,* 2009; Onyelowe, 2012; Sadeeq *et al*, 2015; Bhaumik and Janani, 2016) to determine the effect on UCS values of the BA stabilized lateritic soil showed a similar trend to those of CBR.

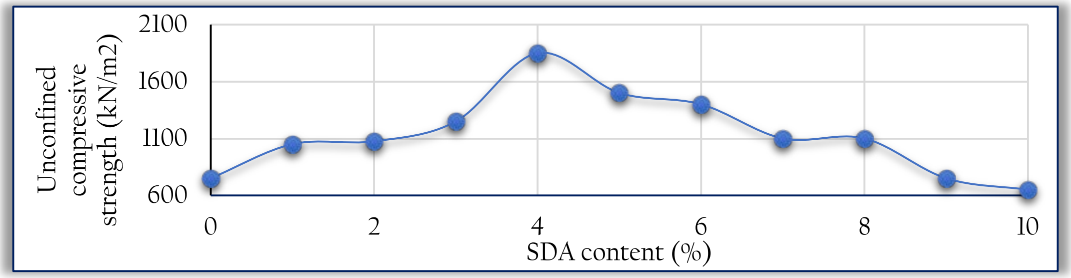

Figure 13. Effect of saw dust ash on the unconfined compressive strengths of the lateritic soil (Otoko and Braide, 2014)

— Permeability

Ayininuola and Olaosebikan (2013) investigated the influence of the rice husk ash on the permeability of the lateritic soil. The coefficients of permeability of both stabilized and unstabilized soil samples were determined using falling head permeameter in accordance with British Standard (BS 1377, 1990). The study reported that the coefficients of permeability of all the four different soil samples decreased with increasing contents of the rice husk ash. They also explained that the decrease of permeability can be attributed to the addition of RHA which fills up the pore spaces of the soil samples, leading to increase in the bond between the soil particles. Another important point is that the formation of cementitous material in form of hydrated calcium silicate gel (CSH) and hydrated calcium aluminate gel (CAH) between the silicates in the soil and RHA help in bonding the soil particles together which reduced the rate of flow of water within the soil.

Corn cob ash

Akinwumi and Aidomojie (2015) investigated the impacts of the CCA addition on the permeability of the lateritic soil. They reported that the coefficient of permeability of the stabilized soil decreased with increasing amount of the CCA in the soil. The study attributed the decrease of permeability with CCA to the reduction in the void ratio and porosity of the soil, which is in agreement with the previous findings (Akinwumi *et al.*, 2012; Akinwumi *et al.*, 2014).

— Swell potential

The effect of the corn cob ash on the swell potential of the lateritic soil was examined by Akinwumi and Aidomojie (2015). Sample specimens compacted in the CBR mould and subjected to the preloading pressure were immersed in water for a period of 24 hours, so as to allow the specimens to swell. After immersion, the swell potential of the specimens were determined as the ratio of difference in the height of the specimens to their initial heights. The results of the tests showed that swell potential of the soil significantly reduced with increasing addition of the corn cob ash.

— Strength reduction index

Strength reduction index test as a type of durability tests was conducted on the bagasse ash stabilized lateritic soil by Osinubi *et al* (2009) to determine its performance under unfavourable weather condition. This was carried out by evaluating the resistance to loss in strength of specimens wax-cured for 7 days, dewaxed at top and bottom and later immersed in water for an another 7 days. The loss in strength for specimens treated with 2% bagasse ash was 91%, which is much higher than the allowable 20% recommended by conventional specifications. This showed that the specimen did not withstand the durability test and therefore requires the incorporation of other potent additives like cement or lime to meet the durability requirement.

4. CONCLUSIONS

Based on the extensive reviews of previous studies on the stabilization of lateritic soils with various agro and industrial waste products, the following conclusions have been drawn:

- The results of the reviews on the oxide compositions of all the agro and industrial 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). It was also observed from the results that the ashes from these wastes were obtained at temperatures ranging between 400 and 700^oC and contained higher percentages of amorphous silica and lower composition of calcium oxide when compared with Portland cement.
- The liquid limit, plasticity index, swelling index and shrinkage limit of the lateritic soils stabilized with saw dust ash, coconut husk ash, millet husk ash, rice husk ash, corn cob ash and bagasse ash decreased with increasing contents of the stabilizers. This is an indication that agro and industrial waste products can be used to improve soil index properties, which will thereby give rise to a stable soil suitable for highway construction purposes.
- It was observed that saw dust ash, coconut husk ash and corn cob ash increased the maximum dry density of the soil from 0 to 4% increase in ash content but the maximum dry density decreased with further increment of the stabilizers. This increase in density was attributed to the flocculation and agglomeration of fine particles (due to cation exchange) to form pseudo-larger size soil particle. However, the maximum dry density of the soil stabilized with millet husk ash, rice husk ash, bagasse ash and locust bean pod ash showed a decrease in value with increasing amount of the ashes. The general drop in MDD was attributed to the presence of excessive amount of unreactive ash of low specific gravity within the soil matrix thereby resulting into corresponding decrease in density.
- California bearing ratio of the stabilized soil generally increased with the increasing content of stabilizers but the rate of increase was dependent on the type of stabilizer. The CBR values of the CHA, MHA, RHA, BA and LBPA stabilized soil increased continuously from 0 to 10% addition, whereas those of SDA and CCA modified soils showed an increase in value from 0-4% and 0-1.5% additions respectively. The increase in strength was attributed to the formation of cementitious compounds such as calcium silicate hydrates, calcium aluminate hydrates and micro fabric changes which aid strength development.

- Increase in unconfined compressive strength of the agro and industrial wastes ash stabilized soil followed similar trends with California bearing ratio. However the strength increased with curing age.
- For all the agro based and industrial stabilizers considered under this review the coefficient of permeability of the stabilized soil decreased with increasing amount of the stabilizers in the soil. The study attributed the decrease of permeability with ashes content to the increase in the void ratio and porosity of the soil.
- The swell potential of the lateritic soil stabilized with corn cob ash (CCA) revealed that there is a significant reduction in the swell potential with increasing CCA content. The strength reduction index of the bagasse ash stabilized lateritic soil was higher than allowable 20% recommended by conventional specifications. This indicates BA stabilized lateritic soils require the incorporation of other potent additives like cement or lime to meet the durability requirement.

5. RECOMMENDATIONS

Based on the extensive reviews of previous studies on the stabilization of lateritic soils with various agro and industrial waste products, the following recommendations can be made for future studies.

- Few studies have been reported on the stabilization of lateritic soils with agro and industrial waste products. Most of the authors did not carried out complete basic geotechnical tests on their work. Therefore, there is a need for exhaustive study of geotechnical properties on every agro and industrial waste stabilized lateritic soil to be carried out and compared with cement stabilized soils.
- The study revealed that only the consistency and strength tests were conducted on almost all the agro and industrial waste stabilized lateritic soils. However, the durability tests such as permeability, swell potential, volumetric shrinkage strength reduction index etc could also be studied on the stabilized soils and relate them with cement stabilized lateritic soils.

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