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ORIGINAL RESEARCH ARTICLE

EVALUATION OF GEOTECHNICAL AND STRUCTURAL PERFORMANCE OF CEMENT-STABILIZED SOIL WITH SAW DUST ASH (SDA)

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ABSTRACT
Availability of good soils for the construction of Civil engineering works is pivotal to the development and progress of any nation. Where good soils are lacking, it is necessary to make the soil fit through soil improvement methods. This study investigates the geotechnical performance of soil stabilized with the blend of cement and saw dust ash (SDA). The blend consists of 9% cement by weight and up to 10% of SDA at interval of 2%. The tests conducted on both stabilized and unstabilized soils samples at three different locations, identified as A, B, and C were: particle size distribution, natural moisture content, Atterberg's limits, compaction, California Bearing Ratio (CBR) and Unconfined Compression Strength (UCS). The results showed decrease in plasticity index from high to medium, increase in CBR values: 4 – 10% for sample A, 2 – 12% for sample B and 5 – 8% for sample C, and increase in unconfined compression strength values: 45.23 – 65.88 kN/m^2 for sample A, 34.01 – 59.18 kN/m^2 for B and 41.80 – 63.94 kN/m^2 for C. The results of this investigation showed that improvement of soil for construction purpose can be achieved when SDA is applied as a stabilizer in a cement-stabilized soil, up to 6% by weight of cement. Specifically, improved shear stress demonstrated up to 6% replacement is an indication of fitness for application of such soil in the design of footing, especially for columns, where shear stresses usually control the footing thickness.

1.0 Introduction

No Civil Engineering Construction is possible with a foundation on weak soil, neither can any Civil Engineering structure exist for long without being founded on soil with adequate strength and settlement characteristics. Thus, the importance of good soil cannot be overemphasized for enduring Civil Engineering infrastructures. There are instances however, when an engineer has no alternative than to work with soils of inadequate bearing capacity. In such instance, he can avail himself of any of the available soil improvement methods such as stabilization, aimed at altering the soil properties for improved engineering performance. According to Ola (2013), soil stabilization is an improvement technique in which the resistance of the soil to various types of deformations and forces are increased. This may be achieved through compaction, preloading, drainage, densification, grouting, use of geotextiles and application of chemical admixtures (Boyles, 1998). The chemical stabilization of soil, the subject of this paper, involves the use of lime, cement, fly ash, bituminous materials, and or combination of two or more of these (Boyles, 1998, Ola, 2013) to make it good for founding Civil engineering structures. The use of cement as soil stabilizer has been found to considerably improve the bearing capacity of the soil (Boyles, 1998). The optimum dosage of cement ranges between 2 and 12% (Ola, 2013; Anthanasopoulou, 2016), depending on the type of soil. It is believed that when cement is added to a soil, the liquid limit, plastic limit and the potential for volume change of soils are usually reduced, while there is an increase in the shrinkage and shear strength behaviors (Anthanasopoulou, 2016).The reduced plasticity has been attributed to the partial or complete destruction or even the alteration of any clay minerals. Increased compressive and tensile strength of the cement treated soil is provided by strength-forming cementitious reactions (primary and secondary) in the soil-cement matrix in the presence of the soil pore water. The di- and tricalcium silicates (C_2S and C_3S), tri-calcium aluminate (C_3A) and tetracalcium aluminoferrite (C_4AF) in the cement, with water formed the C-S-H gel that is responsible for strength development. But using cement as stabilizer is expensive, thereby necessitating the need to research into finding a suitable but cheap, available and accessible replacement, especially from anthropogenic wastes. One of the wastes examined in this investigation as a possible stabilizer, is saw dust ash (SDA). Saw dust ash (SDA) is produced, when saw dust, which is a waste material from the saw mill industry, is burnt into ashes. Due to lack of efficient disposal systems, saw dust waste presently constitutes environmental problems. Fapohunda et al. (2018) did a comprehensive review on SDA and other wood products, highlighting their properties and application potentials for construction purposes in built environment. Particularly, the review showed that the sum of SiO_2 + Al_2O_3 + Fe_2O_3 of SDA in the review was above 50%, indicating a cementitious pozzolanic traits of Classes C and N, and thus, a potential material for cement replacement. But the review, despite its extensiveness, contains very little literature on the use of SDA as a soil stabilizing agent. Few literature (Amu et al., 2011, Butt et al., 2016), however showed that when SDA is used in conjunction with lime in soil stabilization, improved geotechnical properties resulted. However, no researcher has looked into the possibility of using SDA with cement as a soil stabilizer. The present study investigates some geotechnical properties of lateritic soil stabilized with a blend of cement-SDA. Lateritic soil occurs in all wet tropical regions of East, West and Central Africa, Indonesia, Thailand, Brazil and various island such as Hawaii and Cuba (Figure1).

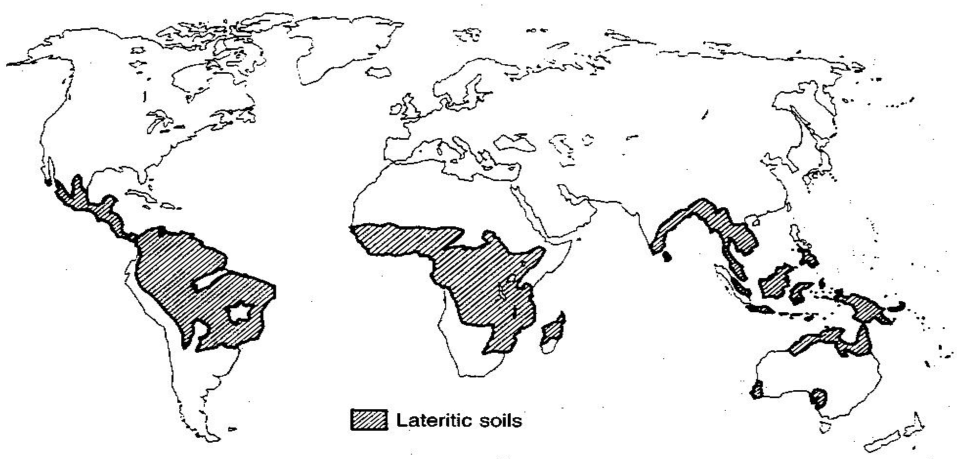

Figure 1: Distribution of Lateritic Soil (Source: Thagesen, 1996)

According to Boyles (1998), lateritic soil is characterized by high porosity and relative incompressibility. Some of the effects of these include, poor compaction due to high moisture

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content, sensitivity to fluctuations in moisture, where strength may be significantly reduced with a slight increase in water content, low bearing capacity and low strength (Bello et al., 2015). It is thus imperative for researchers to come out with improvement strategy for lateritic soils where it is available. Its abundance in Nigeria, is the justification for its choice, in an attempt to investigate and evaluate its geotechnical fitness for constructional purpose with cement-SDA blends as stabilizing agent. In attempts to improve its properties to make it suitable and fit for use as a material on which to found Civil engineering foundations, researchers have carried out stabilization of lateritic soil with different of materials. For example, Amu et al. (2011) worked with lime; Bello et al. (2015) with cassava peel ash; Nnochiri and Aderinlewo (2016) with banana leaf ash; Todingrara et al. (2017) with lime and cement; Aderinola and Nnochiri (2017) with terrasil solution; and Nnochiri et al. (2017) with palm kernel shell ash. Thus, the aim of this work is to evaluate the geotechnical performance of lateritic soil stabilized with cement-SDA blend. In carrying out the investigation, the percent of cement was at a constant value of 9% by weight of the lateritic soil. The SDA was varied from 0 to 10% at increment of 2% by weight of cement.

2. Materials and Methods

2.1 Materials

The materials used for this investigation were, laterite, SDA, ordinary Portland cement (OPC), and water. The lateritic soils used for the investigation was obtained from three different locations within the new market clearing area of Tonkere gate of Obafemi Awolowo University, Ile-Ife. The sampling area was so selected so that the results of this investigation will be representative of lateritic soil found in the field. The samples were labelled as Sample A, B and C for the purpose of identification. The sawdust that was used in this investigation was obtained from sawmills along Ondo Road in Ile-Ife. The saw dust was then air-dried so as to aid better combustion and was subsequently burnt using open burning system using the method suggested by Oyekan and Kamiyo (2011). The ash that was obtained from the combustion process was then sieved through 212μm sieve aperture, collected and stored in air-tight container. For this work, Ordinary Portland cement (OPC), classified as grade 42.5 and meeting the requirements of BS 12 (1996) and NIS 441 (2014) was used. Clean and potable water was used for this investigation.

2.2 Methods

In order to determine the index properties of the samples, preliminary investigations were carried out to obtain the followings: the moisture content, specific gravity, particle size distribution, Atterberg limits, and the density. The moisture content was determined in accordance to ASTM D 2216 (1996). Specific gravity bottle was used to determine the specific gravity of the soil samples. The particle size distribution of the soil samples was obtained by carrying out mechanical sieve analysis. The Atterberg limits consisting of the liquid limit and plastic limit were carried out using Atterberg limits apparatus as per BS (1990). Geotechnical tests such as compaction test, California Bearing Ratio and unconfined compression tests were conducted on samples with cement only (at 9%), that is, 0% SDA and subsequently on cement-SDA blends. For the compaction test, the standard proctor compaction test was used. This test was carried out both on untreated and treated soil sample so that the effect of the additive could be measured as per BS: 1377-4 (1990). Unsoaked soil samples was used for CBR test in accordance to (NGS, 1997). The unconfined compression test was performed in accordance to BS 1377 (1990) The proportion SDA in the mix was varied from 0 – 10% at interval of 2%.

3. Results and Discussion

3.1 Index Properties

The properties of samples A, B and C are presented in Table 1. It can be seen that sample B has the highest moisture content of 10.12% while sample A has the lowest of 6.23%. Lambe and Whiteman (1979) stated that the moisture content of a soil depends on the void ratio of the soil, thus these values are indicative of the void spaces present in each soil sample. It can therefore be inferred from this statement that Sample B has the largest void ratio out of the three samples.

Table 1: Summary of Lateritic Soils Index Properties

Soil Property	Sample A	Sample B	Sample C
Percentage passing BS No 200 sieve (%)	57.60	48.00	54.00
Natural Moisture Content	6.23%	10.12%	7.15%
Specific Gravity	2.684	2.267	2.318
Liquid limit (%)	48	34	42.7
Plastic limit (%)	23.01	13.18	21.03
Plasticity Index (%)	24.99	20.82	21.67
GI	25	6	9
USCS Classification	CL	CL	CL
AASHTO Classification	A-7-6	A-6	A-7-6
Maximum Dry Density kg/m^3	1689.60	1566.80	1649.90
Optimum moisture content (%)	13.00	16.83	17.24
California Bearing Ratio (%)	3	2	4
Compressive strength (kPa)	72.576	45.484	54.432

The specific gravity (SG) of the samples is in the range of 2.27 – 2.68. When viewed against the observation of Das (2006) that the SG of sand, silt, clay, clay/silty-clay, halloysite and organic soils are respectively in the range 2.63 – 2.67, 2.65 – 2.7, 2.67 – 2.90, 2.0 – 2.55, and less than 2.0, it is obvious that none of the lateritic soil samples is organic. The fact that SG of the samples are very close suggests the same degree of laterization (Ola, 2013). Based on the USCS classification system, it is shown from Table 1 that all the three soils samples belonged to the lean clay (CL) group implying that they are silts and clays with liquid limit 50% or less. Inorganic clays of low to medium plasticity, gravely clays, sandy clays, silty clays and lean clays are all considered to belong to CL group. Though the Association of American State Highway Transport Official (AASHTO) classification system puts the soil samples as A-7-6 (25), A-6 (6) and A-7-6 (9), it is obvious that in real sense, it agrees with Unified Soil Classification System (USCS) in that both classes are characterized as containing materials such as silty or clayey with more than 35% passing the 75μm sieve. This type of soil is not good as foundation material because of susceptibility to compressibility. This conclusion can also be deduced from the values of the Atterberg limits. From Table 1, it is obvious that the samples are of intermediate plasticity as the Liquid limit fell between 35 and 50% (Areola, 1982). However, high values of plasticity index (PI), above 20%, is an indication of potential geotechnical problems if the lateritic soil is to be used as foundation materials (Ola, 2013), necessitating the need for improvement efforts through stabilization.

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3.2 Geotechnical Properties

The results of geotechnical properties of the samples after stabilization with cement-SDA blends, keeping the cement content at 9% but varying the SDA content from 0-10% at incremental rate of 2% are presented in Figure 1 and Tables 2 – 4. From Figure 1, the plasticity index, (which is the range of water content between liquid and plastic limits within which the soil behaves as plastic material), of the samples decreased with increase in SDA addition and then starts to increase again. The lowest values for samples A and C occurred at 6% of SDA while that of sample B occurred at 4% of SDA. The progressive decrease in the values of the plasticity index is an indication of geotechnical improvement of the soil using SDA as stabilizing agent, until 6% SDA for samples A and B, as well as 4% SDA for sample B. The decrease could be attributed to the probable stoppage of pozzolanic activities of SDA, due to exhaustion of pore water in the soil (Neville, 2011, White et al., 2015, Anthanasopoulou, 2016). However, the highest numerical values of the PI obtained from all the stabilized lateritic soil samples was 14.51% for sample A at 4% of SDA replacement. Thus, the plasticity index of all samples fell between 10 and 20%, indicating medium plasticity (Bowles, 1998).

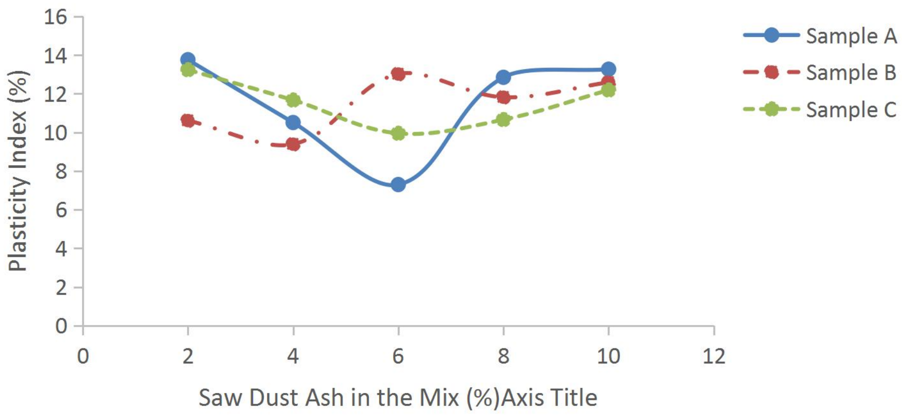

Figure 1: Effect of SDA on the Plasticity of the Lateritic Soil

The unstabilized lateritic soil samples have PIs of between 20.82 and 24.99 indicating high plasticity. The plasticity of soil was classified as follows: 0 as non-plastic, 1-5 as slightly plastic, 5 – 10 as Low plasticity, 10 – 20 as medium plasticity, 20 – 40 as high plasticity and greater than 40 as very high plasticity (Das, 2006). The results of this investigation clearly demonstrate improvement in the lateritic soil from high plasticity to medium plasticity when stabilized with cement-SDA blends. The results of the optimum moisture contents (OMC) and maximum dry density (MDD) are presented in Table 2. Moisture content is an indication of compacting effort required to achieve full compaction of soil samples (Das, 2006 and Ola, 2013). From Table 2, it can be observed that OMC values obtained do not affect the MDD of the soil samples. The nature of the variation of the MDD with OMC for all samples displayed a striking resemblance to that of sand (Bowles, 1998), though the samples were found to tend towards silt-clay as earlier explained. The absence of marked increase in the MDD in the samples, according to Das (2006), are due to capillary tension in the pore water, which resists the tendency of soil particles to move and be densely packed. It is possible that the pozzolanic action of SDA turned the lateritic samples found to be silty-clay, into sand particles.

Table 2: Summary of Compaction Results for the Stabilized Soil Samples

Sample	SDA (%)	Optimum Moisture Content (OMM) (%)	Maximum Dry Density MDD (kg/m^3)
A	0	14.65	1825.00
	2	16.63	1729.90
	4	20.38	1715.90
	6	19.00	1744.00
	8	18.00	1758.00
	10	19.50	1760.00
B	0	17.20	1694.00
	2	17.40	1672.00
	4	17.80	1696.00
	6	20.10	1692.00
	8	19.60	1686.00
	10	19.80	1688.00
C	0	17.55	1774.00
	2	17.60	1776.00
	4	18.00	1682.00
	6	19.40	1696.00
	8	20.40	1704.00
	10	20.00	1692.00

The results of the unsoaked CBR tests for the stabilized lateritic soil samples are shown in Table 3. From Table 3, it can be seen that the unsoaked CBR value of the cement-SDA mix at 0, 2, 4, 6, 8 and 10% SDA contents for sample A are 3, 5, 11, 11, 6 and 8% respectively; for sample B: 3, 8, 10, 12, 7 and 5% respectively while for sample C, 4, 4, 6, 9, 7 and 6% respectively. All these values demonstrate a general increasing trend up to 6% for all the samples before decline in values set in. This demonstrates that application of SDA to stabilized lateritic soil incorporating cement, up to 6% will bring improvement in the properties of the soil. The observed increase in the CBR values was attributed to secondary cementitious materials resulting from the strength forming C-S-H gel product of pozzolanic reaction of SDA in the presence of water. The observed decrease after 6% replacement value could be due to consumption of pore water that is needed to sustain the hydration process (Alp et al., 2009; Falade et al. 2014). However, from Table 3, it is obvious that addition of SDA generally has a beneficial effect on the cement-stabilized lateritic soil and practically produces optimal improvement at 6% replacement value.

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Table 3: Summary of Unsoaked CBR Results for the Soil Samples

Sample	SDA (%)	CBR Top (%)	CBR Bottom (%)
A	0	3	4
	2	5	6
	4	11	9
	6	11	10
	8	6	6
	10	8	8
B	0	3	2
	2	8	9
	4	10	11
	6	12	12
	8	7	7
	10	5	6
C	0	4	5
	2	4	5
	4	6	5
	6	9	8
	8	7	7
	10	6	6

The results of the unconfined compression strength (UCS) conducted on the unstabilized and stabilized lateritic soil is shown in Table 4. Unconfined compression strength test is the main test recommended for the determination of the required amount of additive to be used in stabilization of the soils (Butt et al., 2016). As a general convention, for a given type of stabilization, the higher the compressive strength, the better is the quality of the stabilized material. It can thus be seen in Table 4 that strength of stabilized samples increased up to 4% of SDA for samples A and B, but up to 6% of SDA for sample C. For all the samples, a pattern of progressive increase is followed by progressive decrease with increase in SDA. The unconfined compression strength of the cement-SDA mix at 0, 2, 4, 6, 8 and 10% SDA contents for sample A were 90.458kN/m^2, 111.565kN/m^2, 131.768kN/m^2, 83.251kN/m^2, 95.498kN/m^2 and 110.525kN/m^2 respectively; for sample B 68.027kN/m^2, 80.398kN/m^2, 118.367kN/m^2, 113.369kN/m^2, 37.829kN/m^2 and 31.295kN/m^2; for sample C 82.355kN/m^2, 114.610kN/m^2, 127.871kN/m^2, 135.456kN/m^2, 106.416kN/m^2 and 77.760kN/m^2. The values of the unconfined compressive strength are also indication of the level of consistency of clayey soil (Ola, 2013). It has previously been shown from the observed index properties that the lateritic soil used in the work is clayey. According to Das (2006), consistency of a clayey soil can be determined as follows: 0–25 kN/m^2 indicates very soft, 25–50 kN/m^2 is soft, 50–100 kN/m^2 is medium soft, 100–200 kN/m^2 is stiff 200–400 kN/m^2 is very stiff and greater than 400 kN/m^2 indicates hard clay.

Table 4: Summary of UCS Results for the Soil Samples

Sample	SDA (%)	Normal Stress σ (kN/m^2)	Shear Stress (kN/m^2)
A	0	90.458	45.229
	2	111.565	55.783
	4	131.768	65.884
	6	83.251	41.626
	8	95.498	47.749
	10	110.525	55.263
B	0	68.027	34.014
	2	80.398	40.199
	4	118.367	59.184
	6	113.369	56.685
	8	37.829	18.915
	10	31.295	15.648
C	0	82.355	41.178
	2	114.610	57.305
	4	127.871	63.936
	6	135.456	67.728
	8	106.416	53.208
	10	77.760	38.880

From the study addition of SDA to cement-stabilized lateritic soil changes the consistency from very soft to soft at the optimal levels of replacement, which is 4% for samples A and B; and 6% for sample C. The maximum values of compressive strength were at 4% SDA for samples A and B, but at 6% for sample C. Thus at these values, the use of SDA will enhance geotechnical properties of the soil and subsequently promote its use in construction.

4. Conclusion

From the analysis of the results of investigations carried out on the lateritic soil stabilized with cement-SDA blends, the following conclusions were drawn:

The lateritic soil investigated was clayey materials according to both Unified Soil Classification System (USCS) and the American Association of State Highways and Transportation Officials (AASHTO) soil classification systems. It was rated as fair to poor subgrade and foundation material, thus needing improvement for Civil engineering application.

Addition of saw dust ash (SDA)s to cement-stabilized lateritic soil, at the levels considered, resulted in reduction of plasticity index with optimum values for all samples recorded at 6%.

Addition of aw dust ash (SDA) increased the CBR values of cement-stabilized lateritic soil, but a replacement with SDA up to 6% resulted in optimum performance.

Addition of saw dust ash (SDA) of up to 6% to cement stabilized lateritic soil increased the unconfined compression strength (UCS) of the samples.

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The results of this investigation showed that improvement of soil for construction purpose can be achieved when SDA is applied as a stabilizer in a cement-stabilized soil, up to 6% by weight of cement. When this is juxtaposed against the background of the fact that SDA is an unavoidable waste, and as such, constitutes environmental menace, using it as stabilizer is an efficient and innovative wastes disposal and environmental management system and strategy. Furthermore, soil stabilization with cement has been found not to be economical. Therefore, using SDA, which is cheaper than cement will results in drastic reduction in cost when applied for stabilization purpose.

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