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Utilization of Agricultural Waste in Stabilization of Tropical Soil

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ABSTRACT

Many research works have been carried out all over the world in the direction of utilizing different Agricultural waste product in the stabilization technique of soil. From the literature available it is found that little research has been done the effect of agricultural waste on tropical soil. This project work therefore presents the result of a laboratory study undertaken to investigate tropical soil and the effect of Rice Husk Ash (RHA). The laboratory tests carried out on the natural and stabilized soils include Natural moisture content, Specific gravity, particle size analysis, Atterberg limits, compaction, California Bearing Ratio (CBR) and Unconfirmed Compressive Strength (UCS). The soil was mixed separately for conducting different tests under the same conditions with RHA from 0 to 15% at an increment of 3% by dry weight of the soil. Mixes were prepared and the above mention tests were conducted on the sample according to the standards of American Society for Testing and Materials (ASTM). From the conclusions of the test results, it was found that the liquid limit of the soil decreased from 52 % to 27% when RHA and cement was added from 0 to 15% and from the MDD it increased from 1.74mg/m^3 to 2.78mg/m^{3}and the un-soaked CBR increased from 13.3% to 37.2% and the UCS value increased from 2.88kg/cm^2 to 7.83kg/cm^2. Based on the result it can be concluded that RHA gave satisfactory results in the stabilization of the soil.

Keywords: Agricultural waste, Rice Husk Ash (RHA), Tropical soil, Geotechnical Properties, Stabilization.

INTRODUCTION

Geotechnical, soil improvement could either be by modification or stabilization, or both. Soil modification is the addition of a modifier (cement, lime, etc.) to a soil to change its index properties, while soil stabilization is the treatment of soils to enable their strength and durability to be improved such that they become totally suitable for construction beyond their original classification.

Stabilization of soil plays a very important role during construction as it is a process used to improve the properties of soil such as strength, plasticity its maximum dry density and other relevant properties. Lack of adequate stabilization in poor soil can lead to settlement of the soil and failure of structure which in turn equals to a lot of money lost. Since there is high demand of roads and highways in both developing and developed countries many of the roads and highways will be built over unsuitable soil which will require stabilization techniques, as technology advances and economic conditions change many more chemical agents will be introduced into sub grades to improve their compatibility durability and strength. Bujang B. K. et al (2004).

The use of agricultural waste would not only helps the construction industry, it also helps to keep the environment clean because most of the industrial by-products are non-biodegradable the use of agricultural waste i.e. Rice Husk Ash (RHA), burned olive waste, etc. are an encouraged option compared to using cementing products such as asphalt lime and cement Bujang B. K. et al (2004). RHA is used as a supplementary cementitious material in concrete Zain MFM et al (2011). Previous studies have indicated that up to 20% RHA may be advantageously blended into the mixture without adversely affecting the strength and durability of the resulting concrete Chao-Lung H. et al (2011). The Fact that silica is found in RHA makes it a suitable replacement for cement, rice Husk ash is a highly preferred industrial by product as compared to slag silica or fly ash when it comes to soil stabilization because of its high pozzolanic activity which greatly improves the strength and durability of the soil, rice Husk is also known for reducing plasticity, maximum Dry density (MDD), when Mixed with cement.

The Properties of the rice husk ash depend on its production methods used, influencing Factors include temperature at which the rice husks were burnt at and also type of heat used Alhassan, M. and Mustapha, A. M. (2007). Due to increase demand of rice in Asia more and more rice is grown every year which leads to rice mills producing more rice husk, rice Husk as industrial waste is very difficult to dispose of due to the harmful effects that it has on the environment, These harmful effects come about because of its non-biodegradable (it cannot be decomposed by bacteria) properties. Because of the increase in construction of structures and highways in developed countries and developing countries most of these structures and highways will have to be located on an area that has soil with undesirable properties hence the need for stabilization of the soil so as to improve its properties will arise, many Stabilization techniques require cementing agents such as cement and others require natural resources such as aggregate.

This research was aimed on the investigations on the engineering properties of tropical soils as it has been observed that the poor performance of pavement founded on tropical soils leads to high maintenance costs as a result of undue settlement of the foundation level and occurrence of different types of crack on the structure. However, the utilization of waste products like rice husk ash which would have otherwise caused environmental pollution and degradation, to produce cheap standard construction materials which may directly or indirectly improve the economy of the country. Therefore we intend to determine the engineering properties of the tropical soil, determine the effect of rice husk ash on the properties of the stabilized tropical soil with cement serving as a catalyst and to determine the percentage of Rice Husk Ash (RHA) optimum used for stabilization.

2.0 LITERATURE REVIEW

The properties and behaviour of soil have exercised the mind of builders and engineers from time immemorial. Several studies have been made on soil stabilization using different stabilizing agents. Rao et al. (2012) studied the effect of RHA, lime and gypsum on the index and engineering properties of marine clay. The soil sample was classified as clay of high compressibility (CH) as per Indian standard classification system (ISCS). The soil sample was mixed with 5% lime, RHA (10-40%) and gypsum (2-5%) and tested at various curing periods (4 to 28 days). The optimum mix was found to be 5% lime + 20% RHA + 3% gypsum at 28 days curing, where maximum improvement in soil properties are obtained. Maximum improvement in UCS and CBR was 548% and 1350% respectively. It was concluded that utilization of industrial wastes like RHA, lime and gypsum is an alternative to reduce the construction cost of roads particularly in the rural areas of developing countries.

Sabat (2012) studied the effect of polypropylene fiber on geotechnical properties of RHA and lime stabilized expansive soil. The soil sample was classified as clay of high compressibility (CH) as per ISCS. As percentage of polypropylene fiber increases in the RHA-lime stabilized soil, MDD decreases and OMC increases. The UCS and CBR of the RHA-lime stabilized soil increased up to 1.5% addition of polypropylene fiber and decreases with further increase in fiber content. The hydraulic conductivity of RHA-lime stabilized soil increases as the percentage of fiber increases, whereas swelling pressure decreases. The optimum proportion of soil: fiber: lime: RHA was found to be 84.5: 1.5: 4: 10 where maximum improvement was reported. Rao et al. (2012) studied the effect of adding potassium chloride (KCI) and RHA on the strength and swelling properties of clayey soil. The soil sample was collected from Amalapuram, East Godavari district, Andhra Pradesh and was classified as clay of high compressibility (CH) as per ISCS. The KCI content varies from 0 to 3%, whereas RHA content varies from 0 to 16%. The maximum reduction in plasticity index; swell potential; swelling pressure and improvement in UCS was observed at 1% KCI and 12% RHA content. The UCS of expansive soil has increased by 515% at 28 days curing as compared to unreinforced specimen. It was concluded that utilization of industrial wastes like RHA is an alternative to reduce the construction cost of roads particularly in the rural areas of developing countries.

Kuity and Roy (2013) studied the effect of using waste material and geogrid on the strength behaviour of poor subgrade soil. The soil sample was collected from West Bengal and classified as clay of low compressibility (CL) as per USCS. The waste materials; pond ash (PA) and rice husk ash (RHA) and lime as additive was mixed in different proportions with soil. Geogrids are placed at middle of mould in single layer and at one-third height from both top and bottom of mould. It was found that soaked and un-soaked CBR values of mix increased by 1.22 to 3.72 times and 1.16 to 2.06 times respectively by adding PA, RHA and lime. For single layer of geogrid in soaked and un-soaked condition improvement varies from 7.76 to 12.84 and 1.91 to 7.88 times respectively. For double layer of geogrid in soaked and un-soaked condition improvement varies from 7.49 to 18.21 times and 2.16 to 9.29 times, respectively in comparison to virgin soil. It was concluded that use of geogrid in soil subgrade enhanced the CBR value significantly.

Akinyele et al. (2015) studied the effect of adding RHA in various percentages (i.e. 2, 4, 6, 8 & 10%) on the index and shrinkage properties of poor lateritic clayey soil. The soil sample was collected from Buruku, Nigeria and is classified as clay of low compressibility (CL). It was found that as the percentage of RHA increases, reduction in plasticity index and linear shrinkage is reported. It was concluded that the RHA is an effective stabilizing agent for subgrade in road construction and for backfilling in retaining wall, but the mix should be controlled not to exceed 10%.

Kumar and Gupta (2015) studied the effect of adding pond ash (PA), rice husk ash (RHA), polypropylene fibers and cement on the compaction and strength behaviour of clayey soil. The soil sample was collected from Jalandhar, Punjab and was classified as clay of low compressibility (CL) as per USCS. Pond ash and rice husk ash content varies from 30-45% and 5-20% respectively whereas fibers and cement content varies from 0 to 1.5% and 0 to 4% respectively. To study the effect of curing, specimens are cured for 7, 14 and 28 days. Modified compaction, unconfined compressive strength (UCS) and split tensile strength (STS) tests are conducted. It was found that OMC increased and MDD decreased with increase in RHA content. Fiber addition increased the UCS and STS values with reduction in post peak strength loss and crack formation. The optimum value of pond ash and rice husk ash content in mixture was found as 40% and 10% respectively. Thus it was concluded that admixtures can be used as light weight fill materials.

Raj et al. (2016) studied the effect of RHA addition in various proportions (i.e. 5%, 10%, 20%, 30%, 40%, 50% & 80%) on the engineering properties of clayey and alluvial soil. As the RHA proportion increases, reduction in liquid limit, free swell index and OMC is observed whereas; significant improvement in MDD, CBR and angle of internal friction was reported for both soils. Maximum increase of 160% and 55%, respectively, in CBR was observed for alluvial soil and clayey soil when mixed with 80% RHA. Prakash et al. (2017) studied the effect of adding RHA in various percentages (i.e. 5%, 10%, 15% & 20%) on strength properties of poor subgrade soil. As the percentage of RHA increases, reduction in liquid limit and MDD was reported, whereas OMC increases. The CBR value increases up to 10% RHA content and beyond that it decreases. It was concluded that silica present in RHA is capable to replace the exchangeable ion present in clay mineral, thus can reduce shrinkage and swelling property of clay minerals.

Ghutke et al. (2018) studied the effect of RHA addition on index and strength properties of black cotton soil. The RHA was mixed in various percentages by weight of soil (i.e. 4%, 8%, 12% & 16%). It was found that liquid and plastic limit first increases up to 4% RHA addition and then start decreasing.

Specific Gravity and MDD decreases as the percentage of RHA increases. CBR value increase up to 12% RHA content and beyond that it decreases. It was concluded that optimum ash content in soil was 12% where maximum improvement in properties are occurring.

Stabilization of Soil

Stabilization can be defined as any process used to improve the physical and chemical properties of soil. Stabilization of soil plays a very important role during construction as it is a process used to improve the properties of soil such as strength, plasticity, its maximum dry density and other relevant properties. Lack of adequate stabilization can lead to settlement of the soil and failure of structure which in turn equals to a lot of money lost. Because of the high demand of roads and highways in both developing and developed countries, many of the roads and highways will be built over unsuitable soil which will require stabilization techniques, as technology advances and economic conditions change many more chemical agents will be introduced into sub grades to improve their compatibility, durability and strength.

Use of Stabilization

The primary use of stabilized soil mixture at the present time is in the basic and sub-base construction. A stabilized soil base or sub-base may provide the support for a relatively thin wearing surface that will be subject to light or moderate amounts of traffic or it may function as a base for a high type pavement that will be subjected to a very high volume of traffic. Stabilized soil mixtures also tend themselves to the process of stage constructions, which involves the gradual

Types of Stabilization

The various ways by which soils can be improved or stabilized for highway purposes can be divided into the following main groups:

1. Mechanical stabilization
2. Cement stabilization
3. Lime stabilization
4. Bituminous stabilization
5. Fly-ash stabilization
6. Agricultural stabilization

Rice Husk Ash (RHA)

RHA is used as a supplementary cementitious material in concrete. Previous studies have indicated that up to 20% RHA may be advantageously blended into the mixture without adversely affecting the strength and durability of the resulting concrete. The fact that silica is found in RHA makes it a suitable replacement for cement. Rice husk ash is a highly preferred agricultural waste as compared to slag silica or fly ash when it comes to soil stabilization because of its high pozzolanic activity which greatly improves the strength and durability of the soil, rice husk is also known for reducing plasticity, maximum dry density (MDD), when mixed with cement. The properties of the rice husk ash depend on its production methods used.

MATERIALS AND METHODS

Materials and Sampling

Tropical Soil

The soil sample used for this study was collected in Federal Polytechnic Bauchi State in Northern Eastern part of Nigeria at a depth of between 0.5m to 1.0m.

Rice Husk Ash (RHA)

The rice husk was collected from Federal Polytechnic rice farm, and Gwallemaji area of Bauchi, which is a solid waste disposed in the empty barren land as a solid waste. Rice Husk Ash is by-product material produced from the process of manufacturing puffed rice, contains large amount of iron oxide and silicate.

Cement

Ordinary Port-land Cement was use for the research work.

Methods

Sample Preparation

The samples for testing were prepared according to American standard for Testing. The tropical soil samples were first sieved through the required sieve number (200) for the test. The required amount of soil was weighed out for the test. The material to be added to the soil were also sieved through the required sieve for the test and then the required amount was weighed out on the weight basis as per the percentage to be added to the soil for test. The soil and the material were mixed together in dry conditions thoroughly before testing. The mixed samples were then used for performing the various tests.

Experimental Study

The experimental study was carried out on soil samples collected at a depth of 0.5m to1.0m below ground level. The laboratory tests carried out on the natural and stabilized soils includes moisture content, specific gravity, and particle size distribution, Atterberg limits, compaction, CBR and UCS. For conducting different tests, the soil was mixed together under the same conditions with rice husk ash with cement from 0% to 15% at an increment of 3%. Mixes were prepared and the above-mentioned tests were conducted on these samples/mixes according to the standards of the American society for testing and materials.

Index properties tests

The various index properties test like Specific gravity, moisture content, Attergber limit (Liquid limit test, Plastic limit, shrinkage limit test) were conducted on tropical soil with various proportions ranges from 0%, 3%, 6%, 9% 12% and 15% of Rice Husk Ash with constant 5% of Cement.

Engineering properties tests

The various Engineering properties test like compaction test and California Bearing Ratio tests was conducted on tropical soil with various proportions from 0% to 15%, of Rice Husk Ash with constant 5% of cement.

California Bearing Ratio (CBR): It measures the shearing resistance, controlled density and moisture content. The un-soaked method of CBR was conducted to characterize the tropical soil for constructions.

The CBR value is the resistance to a penetration of 2.5mm of a standard cylindrical plunger of 50mm diameter, expressed as percentage of the known resistance of the plunger to 2.5mm in penetration in crushed aggregate, (taken as 13.2KN). The test was carried out based on BS 1337: part 4: 1990.

Compaction Test: The densification of soil with mechanical equipment thereby rearranging the soil particles which makes them more closely packed resulting in an increase of the ratio horizontal effective size to the vertical effective stress. The degree of compaction is measured in term of its dry weight and it increasing the bearing capacity of road foundation, stability slopes, controls undesirable volume changes and undesirable settlement of structures. To obtain the relationship between compacted dry density and the soil moisture content of varying percentage. This test is to determine the maximum dry density (MDD) and the optimum moisture content (OMC) with a given compaction effort.

Unconfined Compressive Strength Test: Unconfined Compression Test (UCS) is a simple laboratory testing method to assess the mechanical properties of rocks and fine-grained soils. It provides measures of the un-drained strength and the stress-strain characteristics of the rock or soil, the unconfined compressive strength test may be defined as the compressive strength at which an unconfined cylindrical specimen will fail in a simple compression test. The test was conducted according to BS 1924: Part Section4.

RESULTS AND DISCUSSION

General Classifications of the soil

The geotechnical index properties of the tropical soil before addition of stabilizers are shown in Table 1. The overall geotechnical properties of the soil classified as A-7-6 in the AASHTO (1986) classification system, shows that it falls below the standards recommended for most geotechnical construction works and would therefore require stabilization.

Table 1: Properties of the tropical soil before stabilization.

Characteristics	Description
Natural moisture content (%)	22.27
Percent passing B.S sieve. NO. 200 (%)	59.9
Liquid limit (%)	52
Plastic limit (%)	35
Plasticity index (%)	17
AASHTO classification	A-7-6
Maximum Dry Density mg/m^3	1.74
Optimum Moisture Content (%)	21.42
Unconfined Compressive strength (kg/cm^2)	2.88
California Bearing Ratio (%)	13.3
Specific gravity	2.69

The result obtained in this research was classified under A-7-6 sub group of the AASHTO classification system (AASHTO 1986). The liquid limit and plasticity index values ranges from 52.0% to 17% respectively, indicate that the soil is highly plastic. Accordingly, the soil falls below the standard recommended for most geotechnical construction works.

Table 2: ASSHTO Classification for Fine grained soil

Soil Group	Passing No. 200 sieve	Liquid Limit	Plasticity index	Material type	Sub-grade Rating
A-7-6	36%min	41% min	11min and PI $\leq$ LL-30	Silt Clay soil	Fair to poor

Index Properties of Tropical Soil.

Natural moisture content (%)

The natural moisture content of any soil varies from season to season, being highest during rainy season and lowest during dry season. Natural moisture content in soil may range from below 5% to 50% in gravel and sand. The natural moisture content of the tropical soil sample was 22.27 %. The values are fairly high considering the time of test, indicating the soil potential for water retention

Specific Gravity

The specific gravity of the soil sample varied between 2.60 and 2.75 the standard range of values of Specific gravity of soils lies between 2.60 and 2.80. Therefore, the obtained values of specific gravity are expected for the tested soils. Higher values indicate a clayed soil.

Particle size analysis (Dry Sieving method)

Dry sieve test was carried out to quantitatively determine the particles/grain size distribution for soil particles of size smaller than 75micron. The measured soil sample pour in the mechanical sieve vibrator machine and allow to vibrate for about 15-20min. The percentage of the soil passing sieve number 200 was determined. This classified the soil under A-7-6.

Atterberg Characteristics

Table 3: The results of the Atterberg limit test were as follows;

Test/%	0%	3%	6%	9%	12%	15%
LL	52	48	39	34	29	27
PL	35	24	17	13	10	9
PI	17	25	22	21	19	17

Table 5: Index and Engineering properties of soil stabilized with RHA and Cement

% of RHA and CEMENT	0%	3%	6%	9%	12%	15%
LL (%)	52	48	39	34	29	27
PL (%)	35	24	17	13	10	9
PI (%)	17	25	22	21	19	17
MDD(mg/m^3)	1.74	1.71	1.80	1.92	2.19	2.78
OMC (%)	21.42	21.04	20.54	24.50	24.9	25.01
CBR	13.3	25.2	26.4	29.1	34.6	37.2
UCS (kg/cm^2)	2.88	3.57	4.17	4.96	6.35	7.83

Effect of Rice Husk Ash (RHA) and Cement on Atterberg Characteristics (liquid Limit, Plastic Index and Plastic Limit)

The results of liquid limit on the soil treated with different percentages of rice husk ash and cement is shown in figure 1. From the results it can be observed that with increase in different percentages of the admixtures from 0-15 % at an increment of 3%, the liquid limit of the soil goes on decreasing. It decreases from 52% to 27%.

The result of plastic limit test on expansive soil treated with different percentages of rice husk ash and cement shown in figure 1. From the results it can be observed that with increase in different percentages of the admixtures from 0-15 % at an increment of 3%, the plastic limit of the soil goes on decreasing. It decreases from 35% to 9% when rice husk ash and cement was added from 0 to 15%. It can therefore be inferred from the result that rice husk ash and cement combine together is suitable for the stabilization of expansive soil.

The result of plastic index test on expansive soil is shown in table 3. With different percentages of rice husk ash and cement shown in figure 3. From the result it can be observed that with increase in different percentage of the additive from 0 to 15% the plastic index goes on decreasing. It increasing from 17% and decreased back to 17%. It can be inferred from the result that rice husk ash and cement is suitable for the stabilization of expansive soil.

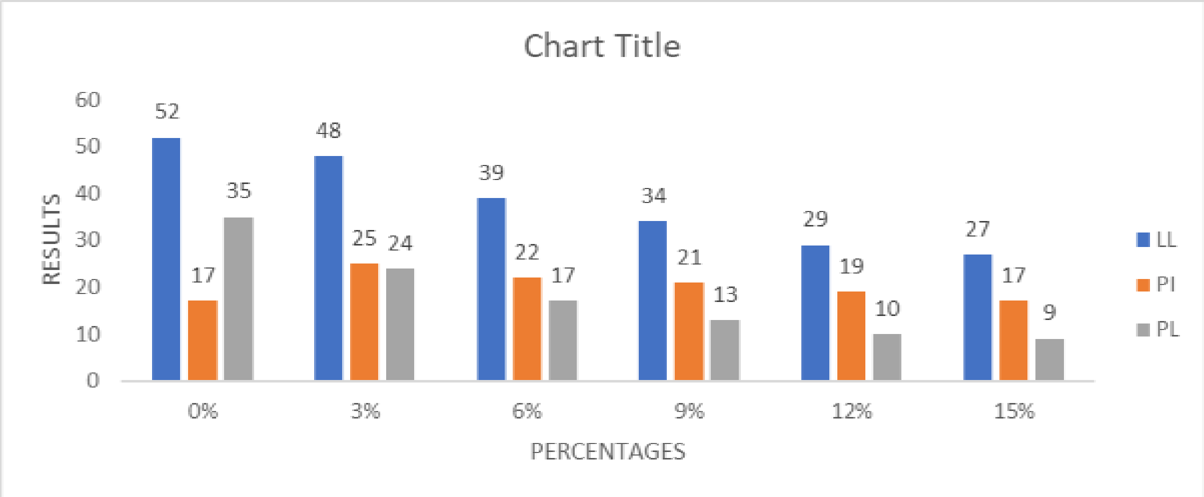

Figure 1: value of liquid limit, plastic index and plastic limit with percentages of rice husk ash and cement

Effect of Rice Husk Ash and Cement on compaction characteristics

The compaction characteristics in **Figure 2** show the variation of maximum dry density (MDD) and Optimum Moisture Content (OMC) mixed with percentages of rice husk ash with cement. With increase in percentage of RHA with constant 5% of cement, the MDD of the soil goes on increasing. The MDD increases from 1.74mg/m^3 to 2.78mg/m^3 when RHA increased with different percentage from 3% to 15% with constant 5% of cement.

With increase in percentage of RHA with cement, the OMC of the soil goes on increasing. The OMC increases from 21.42% to 25.01% with increased in the percentage of RHA from 3% to 15% with constant 5% cement. The reasons for such behavior is due to increase in RHA with cement on soil particles having specific gravity of (2.69).

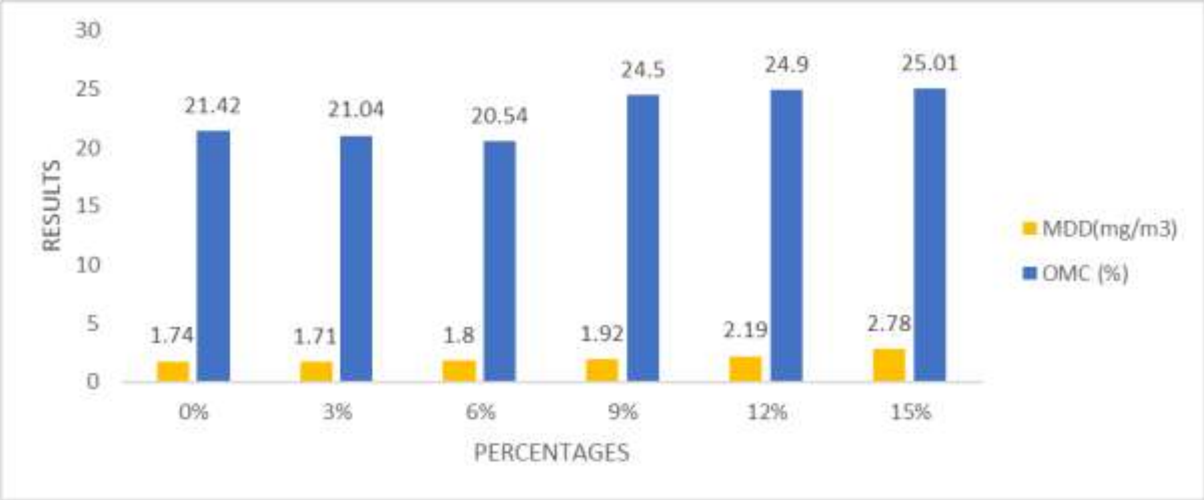

Figure 2: MDD against percentages of rice husk ash and cement

Effect of Rice Husk Ash and Cement on CBR characteristics

The results of un-soak CBR tests on tropical soil treated with different percentages of rice husk ash and cement are shown in **figure 3**. From the results it can be observed that with increase in percentage of RHA with constant 5% of cement, the un-soaked CBR of soil goes on increasing. The un-soaked CBR increased from 13.3% to 37.2% when RHA and Cement were added from 0 to 15%. It can therefore be interpret that rice husk ash and cement has positive effect on CBR characteristics of tropical soil.

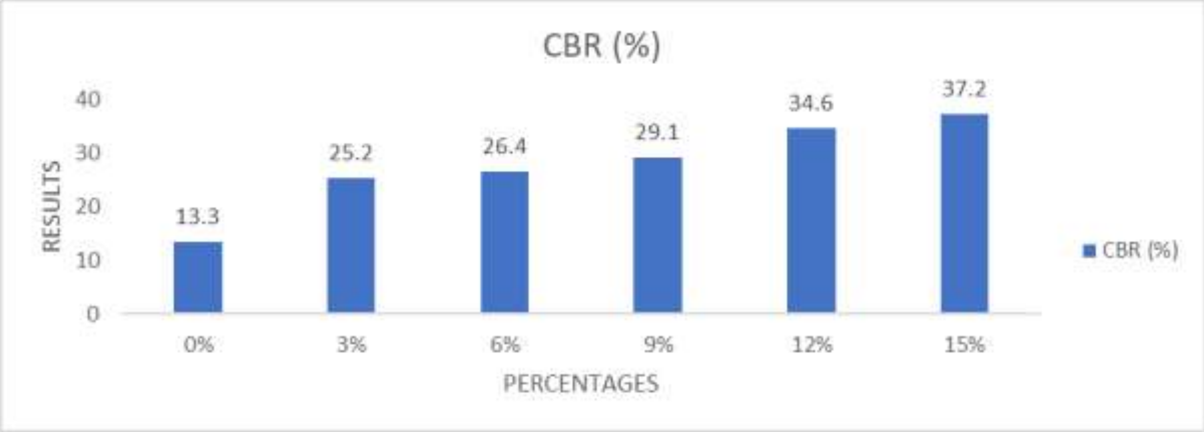

Figure 3: CBR against percentage of RHA with Cement

Effect of Rice Husk Ash and Cement on UCS characteristic

The results of UCS tests on tropical soil treated with different percentages of rice husk ash with constant 5% of cement are shown in **figure 4**. From the figure it can be observed that with increase in percentage of RHA, the UCS of the soil goes on increasing. The UCS increased from 2.88kg/cm^2 to 7.83kg/cm^2 when RHA were added from 3% to 15% with constant 5% of cement. It can therefore be inferred that rice husk ash with cement has positive effect on UCS characteristics of tropical soil.

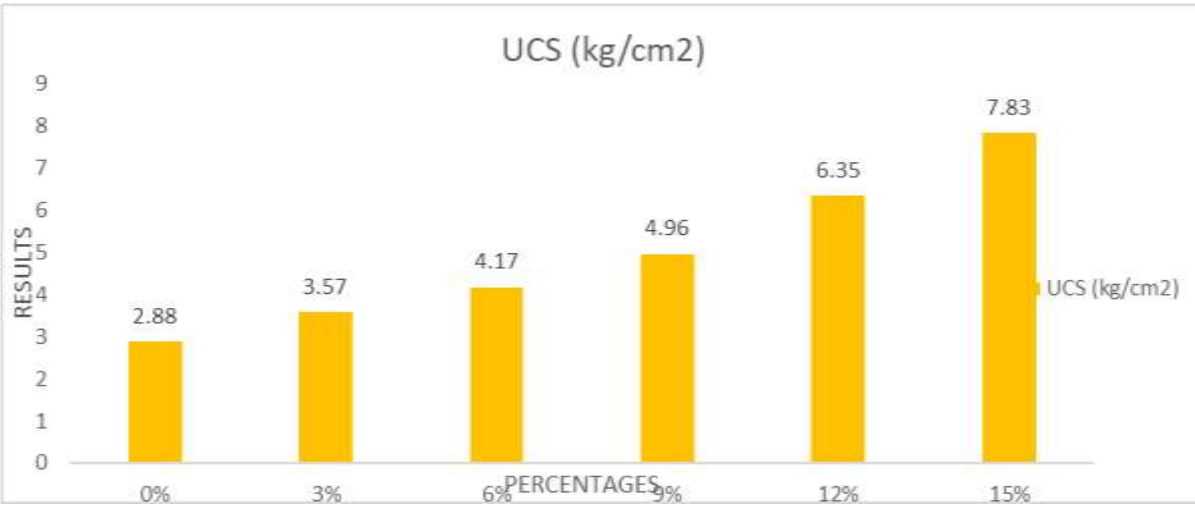

Figure 4 UCS against percentage of RHA and CEMENT

CONCLUSION

The effect of solid wastes namely Rice husk ash with cement on tropical soil on the variation of index properties, compaction characteristics, CBR and UCS values were carried out. From the results, the following conclusion may be drawn.

- The liquid limit of the soil decreased steeply with the increase in the % of RHA with constant 5% of cement. The liquid limit decreased from a value of 52% to 27% for the same quantum of addition of RHA with cement. The decrease in the Plastic limit was from 35% to 9%. The Plastic Index of soil increased from 17% to 25% and decreased from 25% to 17% with the increase in % of RHA with cement respectively.
- The Maximum dry density increased from 1.74mg/m^3 to 2.78mg/m^3.The optimum moisture content increase with the addition in % of RHA with cement from 21.42% to 25.01%.
- The un-soaked CBR value of the soil increased from 13.3% to 37.2% respectively with increase in % of RHA with cement. CBR values of soil are indicator of Sub-grade soil strength and are often used for the design of pavement and super structure. The CBR value obtained in this research work indicate that stabilizing tropical soil with RHA and cement is suitable for the design of pavement and super structures.
- The unconfined compressive strengths of tropical soils increase with addition of RHA with cement from 2.88kg/cm^2 to 7.83kg/cm^2.

This research work concluded that RHA with cement is potentially useful in stabilizing tropical soil. It was found that addition of RHA with cement in stabilizing tropical soil caused the value of shear strength to increase tremendously. Because RHA is a pozolana material, stabilizing soil with RHA will need a lesser amount of cement to achieve a given strength as compared to cement-stabilized soils. However, the stabilizing effect is primarily a function of the chemical composition, fineness and addition of some percentage of RHA with cement. RHA with cement is an effective soil stabilization agent, based on the results observed and describe in this research work

RECOMMENDATIONS

- All of the above mentioned shows that RHA can potentially stabilize tropical soil, either solely or mixed with cement. Utilizing RHA is an alternative; it is available to reduce construction cost, particularly in the rural area of developing countries. The results show that 5% of cement mixed with 15% RHA can result in optimum results.
- When testing whether or material is suitable to be used as a stabilizer the methods of testing used, and accuracy of the results play a big role. The apparatus used in this report to measure the strength properties of soil after addition of RHA with cement to the soil were manually operated which most likely introduced human errors into the reading. Therefore for future study the apparatus used must be of high accuracy and whenever possible automated to eliminate human error.
- Thirdly, rice husk ash reacts differently with different types of soils due to their difference in chemical compositions; hence if RHA is being considered as a soil stabilizer on a particular project, tests should be conducted on all the soils that are present on that site so as to obtain their chemical properties. Of course finding the chemical properties of tropical soil was not in the scope of this research work, even though RHA proves to be a more economical and environmentally friendly, but on its own RHA does not significantly improve the shear strength of the soil, hence a strong binder such as cement or lime needs to added in order to achieve required shear strength.

Therefore I recommended that rice husk ash and cement should be adopted and use as stabilizer for tropical soil.

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