UNIVERSITY OF NAIROBI

Investigation of the effects of Rice Husk Ash (RHA) on the engineering properties of red coffee soil for sub-grade

By Maina R Samuel F16/3541/2008

Project supervisor: Eng J.R Ruigu

Examiner: Dr. S.N Osano

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Abstract

Traditionally, rice husk has been considered a waste material and has generally been disposed off by damping or burning, although some has been used as low grade fuel. However, when burned, the resulting Rice Husk Ash (RHA) is a pozzolanic material that could be potentially used in stabilization of clayey soils for road construction. This study investigates the effects of RHA on the engineering properties of one of the common road construction material in Kenya, the red coffee soil. The investigation includes laboratory tests and analysis of the results of the tested samples. The properties that were evaluated includes the California Bearing Ratio (CBR), plasticity index (PI), and linear shrinkage with Rice Husk Ash content of 3%, 5%, 7%, 9% and 11% by weight of the dry soil.

From analyzing the laboratory results, it was found that addition of RHA to the natural soil generally reduced the liquid limit and the linear shrinkage, with a maximum reduction of 13% and 44% respectively after treatment with RHA content of 11%. In addition, the soaked CBR and plastic limit increased by approximately 500% and 31% respectively after addition of 11% RHA. It was also found that the plasticity index of the stabilized red coffee soil also reduced by 48% after treatment with 11% Rice Husk Ash.

Dedication

First, I dedicate this project to the almighty God for the strength and good health He has given me throughout my studies.

Secondly, I dedicate this project to my late mom (Ruth Wamurang'a Migwi) for the inspiration she continues to give me even in her absence. May your soul rest in peace.

I also dedicate this project to my siblings Peter Muriithi, Serah Micere and Charles Murimi Wamurang'a and my uncle Peter Mwangi Migwi for their steady moral and financial support without whom the completion of this work would not have been possible.

Acknowledgements

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Additionally, I would like to appreciate my family for the unwavering support they offered me throughout my studies.

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CHAPTER ONE

Introduction

1.1 General

Soil is one of the most abundant naturally occurring construction materials. However, before it can be used in any construction practice, an understanding of its properties is a MUST so that it does not lead to construction errors that are costly in both effort and materials. Generally, the suitability of a soil for a particular use should be determined based on its engineering characteristics. In most cases, soils need to be ‘improved’ in order to meet the geotechnical characteristics/properties required for a specific project.

Soil improvement could be either by modification or stabilization, or even both. Generally, soil modification is the addition of a modifier (lime, cement, etc) to a soil in order to change its index properties, while soil stabilization involves 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.

A considerable amount of research concerning stabilization of soil with additives such as cement, lime, bitumen and polymers has already been extensively carried out and is available in literature. However, in recent years, the use of various waste products in civil engineering construction has gained considerable attention in view of shortage and high cost of convectional construction materials, increasing cost of waste disposal, and environmental constraints. Rice husk is one of the waste products that has been mentioned with potential to be used for stabilization of soil for road construction. When burnt, the resulting Rice Husk Ash contains high percentage of siliceous compounds, making it an excellent material for road construction.

1.2 Problem Statement

Over the years, cement and lime have been the two main materials used for stabilization/ improving the engineering properties of soil. However, these cost of these materials has rapidly increased, largely due to the sharp increase in the cost of energy. The overdependence on the utilization of industrially manufactured soil improving additives (lime, cement, etc) has consequently kept the cost of construction of stabilized roads financially high. This trend has therefore continued to discourage the poor and developing nations of the world from providing accessible roads to their rural dwellers, who constitute the higher percentage of their population, and are mostly agriculturally dependent. Thus, the use of agricultural wastes in road construction, such as Rice Husk Ash (RHA), will considerably reduce the cost of construction and as well reduce the environmental hazards they cause.

In addition, Sear (2005) reported that by the nature of its chemistry, Portland cement produces large quantities of carbon dioxide (CO_2) for every ton of its final product. Therefore, replacing proportions of the Portland cement in soil stabilization with a secondary cementitious material such as RHA will not only reduce the cost of construction but also reduce the overall environmental impact of the stabilization process.

1.3 Objectives

The primary objective of this project is to investigate the effect of Rice Husk Ash on the geotechnical properties of red coffee soil for sub-grade purpose.

1.4 Scope of the Project

The study narrows down to laboratory tests to determine the effects of RHA on the strength and index properties of red soil for sub-grade purpose. The amount of RHA introduced to the virgin soil will also be varied to study the effects of different mix percentages on the red coffee soil. The effect of RHA on the red soil is investigated with respect to the California Bearing Ratio (CBR), and the attergberg limits.

1.5 Material Used

In this project, the stabilizer will be Rice Husk Ash binder. The sample of red soil investigated was obtained from Dagoretti near the southern By-pass. Finally, the rice husk was obtained from Mwea in Kirinyaga County.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Sub-grade soils are a very essential component of the road pavement and as such, inadequate sub-grade performance is the cause of many premature pavement failures. The quality and stability of the sub-grade soil is a major factor responsible for the adequate performance and service of the road during its lifespan. The physical properties of the sub-grade soil determine the total thickness requirement of the pavement structure which it supports and the life of the structure in good working conditions. Generally, Sub-grade performance depends on three basic characteristics:

1. **Strength.** The sub-grade must be able to support loads transmitted from the pavement structure. This load-bearing capacity is often affected by degree of compaction, moisture content, and soil type. A sub-grade having a California Bearing Ratio (CBR) of 10 or greater is considered essential and can support heavy loads and repetitious loading without excessive deformation (Spangler, 1982).

2. **Moisture content.** Moisture tends to affect a number of sub-grade properties, including load-bearing capacity, shrinkage, and swelling. Moisture content can be influenced by a number of factors, such as drainage, groundwater table elevation, infiltration, or pavement porosity (which can be affected by cracks in the pavement). Generally, excessively wet sub-grades will deform under load.

3. **Shrinkage and/or swelling.** Some soils shrink or swell, depending upon their moisture content. Additionally, soils with excessive fines content may be susceptible to frost heave in northern climates. Shrinkage, swelling, and frost heave will tend to deform and crack any pavement type constructed over them.

Whether it be a temporary access road or a permanent road built over a soft sub-grade, large deformations of the sub-grade will lead to deterioration of the paved or unpaved surface. Clay sub-grades in particular may provide inadequate support, especially when saturated. Soils with significant plasticity may also shrink and swell substantially with changes in moisture conditions. These changes in volume can cause the pavement to shift or heave with changes in moisture content and may cause a reduction in the density and strength of the sub-grade, thereby accelerating pavement deterioration.

The available soil need not always have adequate strength to support the wheel loads. Sometimes, this can be rectified by borrowing soil having better strength characteristics from nearby sites and replacing the weak soils or by improving the available soil with or without help of admixtures, thereby increasing its strength. There is substantial history of the use of soil stabilization admixtures to improve poor sub-grade soil performance by controlling volume change and increasing strength.

The main objective of stabilization is to improve the performance of a material by increasing its strength, stiffness and durability. Generally, the performance of the stabilized material should be at least equal to, if not better than that of a good quality natural material.

2.2 Stabilization in road pavements

There are many different reasons for stabilization of materials for road construction, ranging from lack of good quality materials to a desire to reduce material usage by reducing the thickness of the pavement layers. Ultimately, stabilization will usually result in cost saving. The engineer is trying to build a problem-free pavement that will last for its intended design life for the most economic price. The cost savings associated with stabilization can take many forms such as reduced construction cost, reduced maintenance costs throughout the life of the pavement or even an extension of the normal pavement life.

Additionally, the location of suitable materials for road construction is becoming increasingly difficult as convectional high-quality materials are depleted in many areas. Also, the costs of hauling materials from farther away add to the cost of construction. One solution to this problem is to improve the locally available materials that presently may not conform to the existing specifications.

From the point of view of bearing capacity, the best materials for road construction are those that derive their shear strength partly from friction and partly from cohesion. For stabilization to be successful, the material should attain the desired strength, i.e., should be capable of sustaining the applied loads without significant deformations and should retain its strength and stability indefinitely.

Spangler (1982) noted that it is crucial for highway engineers to develop a sub-grade with a CBR value of at least 10. Research has shown that if a sub-grade has a CBR value of less than 10, the sub base material will deflect under traffic loadings in the same manner as the sub-grade and cause pavement deterioration.

It is important to note that not all materials can be successfully stabilized. For instance, if cement is used as the stabilizer, then a sandy soil is much more likely to yield satisfactory results than a soft clay (Watson, 1994). It is therefore paramount that the material to be stabilized be tested to ensure that it is compatible with the intended stabilizer.

2.3 The role of sub-grade

The importance of soil as a highway sub-grade lies in the fact that it acts as an integral part of the road pavement. The soil, as a highway sub-grade, serves the following functions.

- Provide stability to the road pavement
- Provide adequate support to the road pavement
- Provide good drainage of rain water percolating through the road pavement
- Has substantial impact on base and subsurface drainage requirements and on long-term pavement ride quality and overall performance.

The sub-grade in flexible pavements is more vulnerable to failure under the vehicular traffic loading due to non-uniform distribution of the load from overlying layers and presence of high moisture content. Ironically, the sub-grade layer gets less emphasis compared to the other layers of the pavement, despite the fact that most of the pavement failure is caused by the bearing capacity failure of the sub-grade layer. Some sub-grade soils, especially clayey soils, have great strength at low moisture content. However, they become very weak and less workable with the increase in water content beyond the optimum value. Such soils require to be either replaced with superior quality fill material or to be stabilized with a suitable stabilizing admixture to attain the required specifications.

Figure 1.0 fine grained soil- difficult to compact, slow drying, and poor working platform

Figure 1.2 sub-grade failure cracks

2.4 Types of stabilization

There are a number of different types of stabilization, each having its own benefits and potential problems. Some of the most frequently used types of stabilization include the following.

a) Mechanical stabilization

Mechanical stabilization of a material is usually achieved by adding a different material in order to improve the grading or decrease the plasticity of the original material. Normally, this type of stabilization is achieved in the absence of any chemical reaction. The mixing/blending of the two or more materials may take place at the construction site, a central plant or at a borrow area. The blended materials are then spread and compacted to required densities by the convectional methods (Gordon R. Sullivan, 1994). The benefits and limitations of mechanical stabilization, however, are well understood and so they will not be discussed farther in this project.

b) Cement stabilization

The addition of cement to a material, in the presence of moisture, produces a hydrated calcium aluminate and silicate gels, which then crystallize and bind the materials together. The reaction can be represented in the following equation.

$Ca_3SO_2 + H_2O = Ca_3S_2H_3 + Ca(OH)_2$

$Ca_2SO_2 + H_2O = Ca_3S_2H_3 + Ca(OH)_2$

Generally, most of the strength of a cement stabilized material comes from the physical strength of the matrix of hydrated cement. A chemical reaction also takes place between the material and lime, which is released as the cement is hydrated, leading to a farther increase in strength. Since this project does not focus on the use of cement in stabilization, the benefits and limitations of cement stabilization will not be discussed farther.

c) Lime stabilization

The stabilization of pavement materials using lime is not new, with examples of lime stabilization being recorded in the construction of early roman roads. Lime stabilization involves the addition of lime to the soil, especially clayey soils, to trigger an exchange of cations that eventually result in a decrease of the plasticity of the soil. Lime is produced from chalk or limestone by heating and combining with water. Generally, the term 'lime' is broad and covers the following main types.

a) Quicklime- calcium oxide (CaO)
b) Carbonate of lime-calcium carbonate ($CaCO_3$)
c) Slaked or hydrated lime- calcium hydroxide ($Ca(OH)_2$)

Lime stabilization will only be effective with materials that contain enough clay for a positive reaction to take place. Attempts to use lime as a general binder in the same way as cement will therefore not be successful (Watson,1994).It is also important to note that only quicklime and hydrated lime are used as stabilizers in road construction.

Hydrated lime is used extensively for the stabilization of soil, especially soils with high clay content. Its main advantage is raising the plasticity index of the clayey soil. Small quantities of lime may result in small increase in CBR strength although no significant increase in compressive or tensile strength should be expected (Paige-Green 1998). Generally, the strengthening effect of lime is significantly less than an equivalent quantity of cement, unless the host material contains very high quantities of clay. The lime can added in solid form although it can also be mixed with water and applied as slurry.

d) Pozzolanas

A pozzolan can be defined as a finely divided siliceous and/or aluminous material, which in the presence of water and calcium hydroxide will form a cemented product. The cemented products are calcium based hydrates which are basically the same hydrates that form during the hydration of Portland cement. Examples of pozzolanas include fly ash and Rice Husk Ash.

e) Lime-pozollana stabilization

A pozzolanic reaction occurs when lime reacts with soluble silica from the clay or if the material does not have adequate pozzolans, the reactive silica from pozzolanic materials such as Rice Husk Ash and fly ash. The reaction produces calcium-silicate hydrates and calcium-aluminate hydrates, which are essentially the same as the cemented products responsible for strength and durability of convectional cement. The pozzolanic reaction can be illustrated by the following equations.

Ca^{2+} + OH^{-}+ soluble silica=calcium-silicate hydrate

Ca^{2+} +OH^{-}+ soluble aluminate=calcium-aluminate hydrate

2.5 Characteristics of red coffee soil as a construction material

Extensive areas in the world are covered by clay soils of high swelling potential. These clays are often referred to as "active clays" due to their behavior, which changes with their moisture content. Red clays belong to this group of active clays. In arid and semi arid regions, the clay exists in unsaturated conditions due to the deep laying water table. As a result, the clay tends to change its moisture content with seasonal climatic changes or as a result of placement of a relatively impervious covering layer. This moisture variation has a detrimental effect on the properties of the clay as a construction material. In particular, the volume stability and shear strength properties of clay are among the most important properties that may be adversely affected.

2.5.1 Problems associated with red clays

a) Swelling of the clay due to wetting
b) Shrinkage of clay due to drying
c) Development of swelling pressures in clay which is confined and cannot swell
d) Decrease in strength and bearing capacity of clay as a resul of swelling. This often leads to cracks.

2.5.2 Clay types and origin

Clay is formed from rock by mechanical disintegration, chemical decomposition, or both. Disintegration may result from the action of running water, by abrasion, thawing and freezing. Decomposition, on the other hand, is associated with oxidation or hydration. The combined mechanical and chemical process is called weathering. Those clays that are developed by disintegration and decomposition of bedrock in place are termed as residual clays. Their texture can be predicted reasonably well from knowledge of the environmental conditions and the type of rock from which the soil was derived. Mountain soils are typical example of these clays. They are usually brown to red in colour and highly plastic. The parent material is sedimentary rock like dolomite, hard limestone and calcareous shale and they possess significant amount of clay minerals.

Other residual clays are those that are developed from igneous rock such as basalt and volcanic rocks. They are frequently brown to black in colour and possess a high percentage of colloidal material. Another category of clays, from the viewpoint of origin and formation, are those that are formed from transported sediments.

2.5.3 The clay profile

Residual and transported clays are constantly undergoing changes in physical and chemical properties as a result of weathering. The leaching of top soil through the removal of soluble salts and colloids and the disposition of these materials in the sub soils causes the development of layers, termed as horizons. The complete cross-section of a soil material from the surface to its parent rock is called the pedological soil profile. Important factors in the development of the pedological soil profiles are the parent material of the clay profile, topography, climate, vegetation and time of weathering.

2.5.4 Clay minerals

The predominant clay minerals are

i) Halloysite
ii) Illite
iii) Montmorillonite
iv) kaolinite

The red coffee soil belongs to the kaolinite group of clays as far as clay mineralogy is concerned. In Kenya, the red coffee soil is found in most parts of Nairobi and central Kenya. As such, it is the most common highway material in these regions.

2.6 Rice Husk Ash binders

2.6.1 General production process of RHA binders

Rice husk is an agricultural waste obtained from milling of rice. Processing of rice generally yields 20-25% husks relative to the weight of paddy (A. Das. and M Rai, 1979). Rice Husk Ash is obtained from burning of the rice husk. When burned, rice husks yield 20-25% of their own weight as a silica rich ash with pozzolanic properties.

Rice Husk Ash can be produced by two methods.

a) Burning rice husks in a controlled manner (less than 700ºC) in a special purpose incinerator or kiln. This usually results in amorphous RHA.
b) Burning the rice husks in a heap, and usually at temperatures above 800ºC. The result is a rather crystalline form of silica.

The pozzolanic properties of RHA are derived from the predominantly non-crystalline nature of silica in the ash. The burning temperature plays a great role in retaining the non-crystalline form of silica in RHA. If the temperature of incineration of rice husk exceeds 700ºC, the silica will bend to transform to crystalline form and the ash would lose most of its reactivity, i.e., its ability to combine with lime in forming cementitious material.

2.6.2 The technical characteristics of RHA binders

The chemical composition of a typical sample of Rice Husk Ash would consist of silica as the major constituent. These major constituents help mobilize the CAOH in the soil for the formation of cementitious compounds. The ash would also contain the oxides of sodium, manganese, iron, magnesium, aluminium, calcium, phosphorus, and potassium.

In the following table, the composition of RHA from Mwea and Ahero are compared. (Kamau and Kithinji, 1993) carried out the chemical analysis of the Kenyan rice husk ash samples from Mwea and Ahero and focused on the determination of the $Si0_2$ content. Controlled burning of the rice husk in a kiln produced the ash.

Technical characteristics of RHA binders

CONSITITUENT	PERCENTAGE BY WEIGHT (%)	
	MWEA (N=10)	**AHERO (N=6)**
$Si0_2$	85.00 ± 1.47	89.44 ± 0.52
Fe_20_3	0.23 ± 0.06	0.41 ± 0.02
Mn_20	0.12 ± 0.01	0.14 ± 0.01
Mg0	0.43 ± 0.12	0.42 ± 0.31
Ca	0.67 ± 0.30	0.58 ± 0.05
Na_2	0.07 ± 0.02	0.47 ± 0.08
$Al0_3$	0.32 ± 0.08	0.46 ± 0.11
K_20	1.24 ± 0.29	1.35 ± 0.08
P_20_5	0.71 ± 0.42	1.55 ± 0.25
Loss on ignition	6.93 ± 1.33	3.66 ± 0.06
Total %	95.72 ± 1.25	98.48 ± 0.41
	N=no. of samples analyzed in triplicate	

Source: International Journal of BioChemiPhysics,Vol.2 Nos. 1 & 2, 1993

The American Society for Testing of Materials (ASTM) has defined pozzolana on the basis of chemical composition. The amount of SiO_2, Fe_2O_3 and Al_2O_3 should be at least 70.0% for good binding properties. For the Mwea and Ahero samples, the average total amount of these components is 85.5% and 90.3% respectively. This indicates that on the basis of chemical composition, the ash from Kenyan rice husk is a suitable pozzolanic material.

2.6.3 A review of previous studies on the use of RHA in stabilization

Several research results with waste materials such as fly ash, plastics and Rice Husk Ash have been published along with their benefits. Some of the recent relevant research work has briefly mentioned here. Alhassan (2008) has shown the potential benefits of using RHA with the natural soil. Alhassan reported that both the CBR as well as the unconfined compression values increased with the addition of RHA to natural soil. In addition, the OMC (Optimum Moisture Content) increase while MDD (Maximum Dry Density) decreased due to RHA mixed with natural soil. Brooks (2009) reported the soil stabilization with RHA and fly ash mixed with natural soil. This study also showed improvement in CBR values and unconfined compression strength. Sabat and Nanda (2011) have also studied the effect of marble dust with RHA in a mix with expansive soil. The study found that with addition of RHA and marble dust to natural soil, the MDD deceased and OMC increased. Also the CBR and UCS values increased substantially due to adding these two with the natural soil. The study by Yulianto and Mochtar (2010) also shows the effectiveness of using Rice Husk Ash (RHA) and lime as a pozzolanic material with natural soil. The results showed good improvement on the physical and engineering behavior of the stabilized peat soil. The values of wet unit weight and specific gravity increased while the water content and void ratio decreased with the increase of curing period. The increment of curing period is also altered and its engineering behavior reported. Increasing the curing period resulted to increasing the soil strength and reducing its compressibility.

CHAPTER 3

3.0 RESEARCH METHODOLOGY

3.1.0 Introduction

The project involved sample collection and laboratory tests. The tests were conducted for the neat soil and the improved soil samples with varying percentages of rice husk ash.

3.1.1 Preparation of Rice Husk Ash (RHA)

The rice husks were obtained from Mwea, Kirinyaga County, in central Kenya. The husks were burnt in a furnace at 500ºC for about 2 hours. The rice husk ash obtained was then crushed into very fine particles.

3.1.2 The soil sample

The soil sample used in the experiment was obtained from Dagoretti near the southern by-pass.

3.1.3 Objectives

a) To investigate the effects of Rice Husk Ash (RHA) on California Bearing Ratio (CBR) of the red soil

b) To investigate the effects of RHA on the Plasticity Index of the red soil

To achieve these objectives, the following laboratory tests were carried out:

i) Sieve analysis

ii) Consistency or attergberg limits for the neat and improved soil samples

iii) Standard Proctor Compaction test (light compaction) for the neat soil

iv) California Bearing Ratio test (CBR) for the neat and improved soil samples

The neat sample was used as the control test. The improved samples consisted of various percentages of RHA. The percentage of RHA added was varied to obtain the mix ratio that would have the optimum effect on the CBR and PI of the red coffee soil. The samples tested contained the following percentages of Rice Husk Ash.

Sample number	RHA %
1(NEAT)	0.00
2	3.0
3	5.0
4	7.0
5	9.0
6	11.0

The research data was collected in the following ways:

- Visits to the field to collect red soil and collecting the rice husk
- Laboratory tests to ascertain the engineering properties of the red soil under investigation.
- Laboratory tests on stabilized red soil with Rice Husk Ash.

Then comparison of results attained of the stabilized red soil with road design manual requirements for material being used as sub-grade material was done.

After collecting the red soil sample and the rice husks some tests were done to determine their properties. The tests were done according to BS 1377-2, 1990. First moisture content determination, particle size distribution, plasticity index, liquid limit and linear shrinkage were done and then compaction and CBR test were done.

3.2 LABORATORY TESTS

The following tests were carried out according to BS1377–2, 1990.

3.2.1 Moisture content determination

This test was done to establish the field moisture content of the red soil, where at least 20g of the soil was used.

Equipment

- Moisture tin
- Oven (105^0C)

- Weighing balance

Procedure

- moisture container was cleaned and weighed - w1
- sample mixed thoroughly and represented amount crumbled and loosely put in the moisture tin
- moisture tin and its contents were weighed –w2
- the sample was Oven dried at 105^0C and weighed again- w3

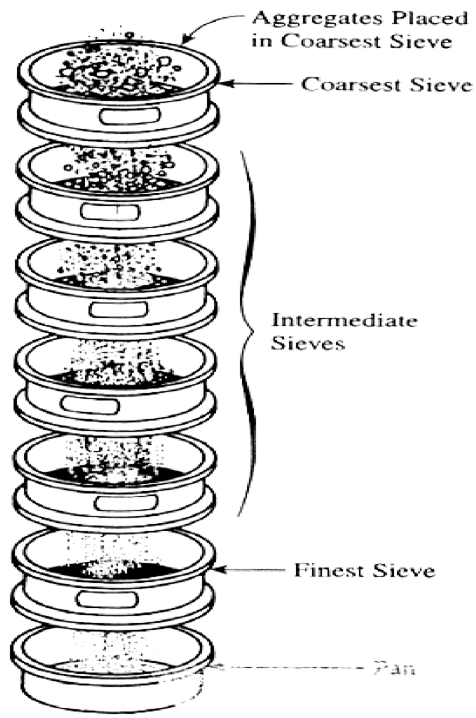
Moisture content= {(w2-w3)/(w3-w1)}*100%

3.2.2 Particle size distribution

This was done to determine the percentage particle size distribution of a given sample of red soil. Dry Sieving analysis was performed on the soil where 300g of red soil was used.

Sieving analysis

This was aimed at determining the particle size distribution or gradation of the soil sample used .This was done through wet sieving to 75µm sieve. The data obtained was presented in form of graph plotted on grading chart.



Sieve analysis arrangement.

Equipment:

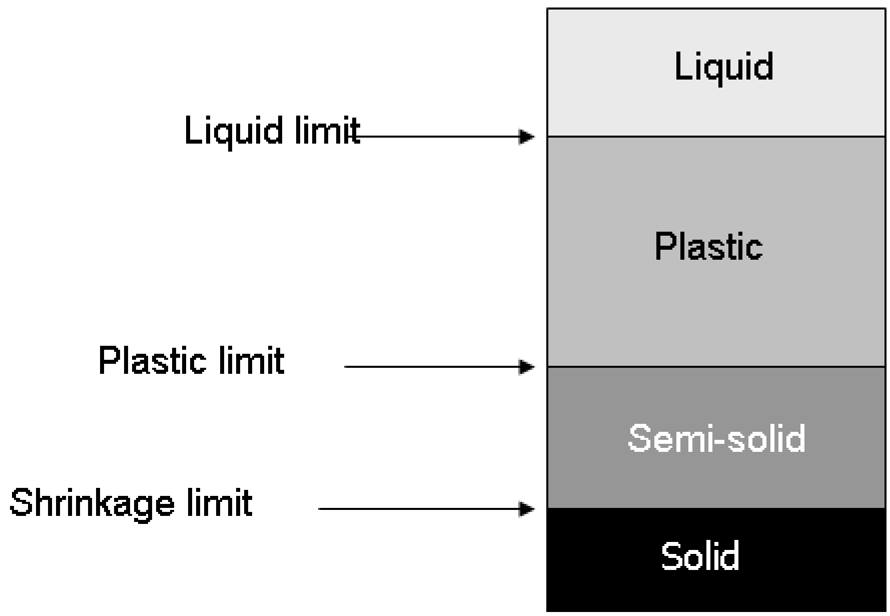
- Standard sieves with pan: 50,37.5,28,20,10,5,2,1,0.425 and 0.075mm
- Balance accurate to 0.5g
- Weighing trays
- Sieve brushes
- Riffle boxes

Procedure

- The soil sample was riffled to obtain a suitable amount that is manageable.
- About 300g of the sample was soaked for 24hrs
- The sample was thoroughly washed on 0.075mm and oven dried for 24hrs at 105^0c
- Sieves were arranged with descending sieve size from top to the bottom with a receiver fixed below the smallest sieve.
- The sample was put on the top sieve and hand shaken
- Sieve analysis was done and percentage retained and cumulative percentage passing calculated for each sieve.

3.2.3 Attergberg limits tests

The attergberg limits determined includes plastic limit, liquid limit and plasticity index



Variation of consistency of fine-grained soil in proportion to the water content

3.2.3.1 Plastic limit

The test was done to determine the lowest moisture content at which the soil is plastic.A sample of about 300g of the red soil was passed through the 0.425mm sieve. The plastic limit of the neat red soil was determined first and then different percentages of the RHA were added to the soil and the plastic index determined for each percentage.

Equipment

- A flat glass-10mm thick and 500mm square
- Two palette knives
- Moisture tins

Procedure

- A sample weighing about 100g was taken from the material passing through 0.425mm sieve
- Sample was mixed thoroughly with distilled water on the glass plate until it became homogenous and plastic enough to form into a ball shape

- Soil ball was moulded between fingers and rolled between palms of hands until the heat of the hands dried the soil sufficiently for slight change to appear on its surface
- The ball was divided into parts which were rolled to about 6mm diameter and maintaining uniform rolling pressure, rolling was done till the rolls were 3mm diameter
- Sample was then packed up and moulded again until the thread sheared both longitudinally and transversely when rolled to about 3mm in diameter
- Portions of crumbled soil thread were gathered in moisture tin of known weight and weighed and oven dried to determine moisture content
- Other rolls were treated the same way and average moisture content was calculated and adopted as the moisture content of the soil.

3.2.3.2 Liquid limit

Liquid limit is the moisture content of a sample at which a standard cone penetrometer penetrates a depth of 20mm into the sample OR;

Is the moisture content at which two sides of groove cut in the soil sample contained in the cup of casagrande apparatus would touch over a 13mm length after 25 blows.

Casagrande liquid limit apparatus

Procedure

- A sample of about 400g of air-dried soil that passed a 425µm sieve was put into a container and mixed thoroughly with distilled water using palette knives until a thick and uniform paste resulted.

- A portion of the mixed soil was placed into the cup of the liquid limit device and leveled off parallel to the base to a maximum depth of 10mm using palette knife.

- The grooving tool was drawn through the sample along the symmetrical axis of the cup, always holding the tool perpendicular to the cup at the point of contact.

- The crank of the device was turned at a rate of two revolutions per second and in so doing the cup is lifted and dropped through a distance of 10mm. The number of blows (drops) necessary to close the gap in the soil specimen for a length of 13mm was recorded. Care was taken to ensure that the groove closed by the flow of soil and not by slipping of soil against the surface of the cup.

- Approximately 10g of the soil from near the closed groove was taken for moisture determination.

- The operation was repeated while altering the amount of water in the soil to obtain two set of moisture contents above 25 blows and two below 25 blow marks.

- The relationship between the moisture content and the number of blows was plotted on a semi-logarithmic chart with the percentage moisture content as ordinates on the linear scale and the number of blows as abscissa on the logarithmic scale and the best line of fit drawn through the resulting points. The moisture content corresponding to 25 blow ordinate was read off as the liquid limit of the soil.

Plastic index

Plastic index will be calculated using the following equation

PI = LL – PL

3.2.3.3 Linear shrinkage

This is a measure of how a soil sample will reduce in length upon drying expressed as a percentage of the original length.

Linear shrinkage test was carried out to determine the linear shrinkage characteristics of the red soil sample when completely dry and also the linear shrinkage characteristics of the soil when various percentages of RHA were added.

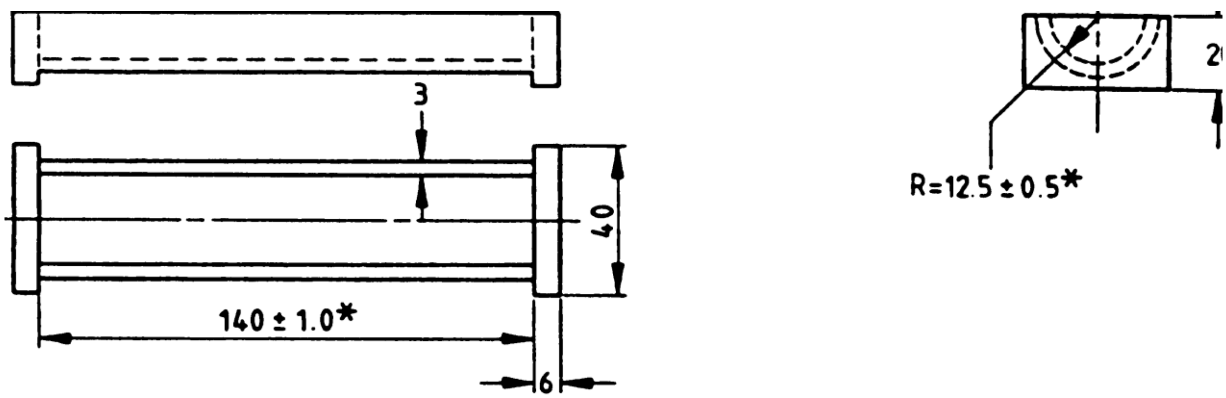
Equipments:

- A flat glass – 10mm thick and 500mm square
- Two palette knives
- Shrinkage mould
- Oven capable of maintaining temperatures of 105 -110^{0}C
- Greasing or oil for lubricating the mould

Procedure

- Shrinkage moulds were cleaned thoroughly and a thin layer of oil applied to its inner wall in order to prevent the soil from adhering to the mould.
- Part of the material used during liquid limit determination was applied on the shrinkage mould for linear shrinkage determination.
- Excess soil was struck off to give a smooth surface and soil adhering to the rim of the mould was removed by wiping with dump cloth.
- Mould was placed in an oven first at 60 – 65^{0}C until shrinkage had largely ceased and then at 105 -110^{0}C to complete dryness and remove carefully from the mould.
- Mould and soil were cooled and mean length of soil bar measured.

% linear shrinkage = (length of oven dried specimen / initial length of specimen) *100



All dimensions in mm

Mould for linear shrinkage test

3.2.4 Compaction test

3.2.4.1 Proctor compaction test

This test was done to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the sample material. It was done on the neat soil sample and when various percentages of RHA were added on the red soil and then the MDD and OMC determined.

Equipment:

- ❖ Cylindrical metal mould- 150mm internal diameter, effective height 115.5mm and volume 956cm^3
- ❖ Detachable base plate and removable collar of approximately 50mm height
- ❖ Metal rammer with a 50mm circular diameter weighing 4.5kg with steep to allow a drop distance of 300mm without friction
- ❖ Weighing balance readable to an accuracy of 1g
- ❖ Sieve 20mm with receiver
- ❖ Straight edge
- ❖ Moisture tins

- Steel rods
- Container for thorough mixing of soil
- Palette knives or trowel
- Brush

Procedure

- Sample passing through 20mm sieve was weighed into four 4000g portions of the passing material and put in different trays/basins
- The mould was assembled on the base plate and weighed
- The collar was then fitted on the mould and the whole internal oiled to ensure soil doesn't stick to the mould
- Each of the four 4000g portions was mixed thoroughly with percentage amount of water in increasing order at an interval of 100ml
- Compactions for the portions were done with the 2.5kg hammer in three layers each layer 25 blows.
- The collar was then removed carefully and excess soil on the mould trimmed with straight edge
- The externally attached particles were cleaned with a brush and the mould with wet soil weighed
- The compacted soil was removed from the mould using a steel rod
- The specimen was broken down, the sample was then taken for moisture content determination and the process repeated for all other portions
- Dry densities were determined through calculations (considering mould factor -0.99) and moisture contents obtained.

3.2.4.2 California Bearing Ratio (CBR)

CBR test was done to determine the strength of a sample material and how it will behave when subjected to loading. This was determined by measuring the relationship between force and penetration when a cylindrical plunger of cross sectional area 1935mm^2 is made to penetrate the soil at given rate.

At any penetration value the ratio of the force to a standard force is defined as the California Bearing Ratio.

Dynamic CBR test

A sample passing through 20mm was used; moisture content of sample was determined and then stored for 24hrs in a sealed place before compaction. This test was also be done on the sample with various percentages of RHA.

Equipment:

- BS sieve 20mm
- CBR mould (internal diameter of 152mm and internal effective height of 127mm) with detachable base plate and top plate and a collar 50mm deep
- Cylindrical plunger of hardened steel and cross sectional area 1935mm^2 approximately 250mm long
- Machine for applying force to plunger
- Three steel basins
- Means of measuring penetration of plunger into the specimen
- Three annular surcharge discs each having a mass of 2kg, internal diameter of 14.5mm to 150mm
- Metal rammer 4.5kg with a weight of fall being 450mm
- Steel straight edge (dimensions 300mm*25mm*3mm)
- Spatula (blade of approximately 100mm*20mm dimensions)
- Means of measuring movement of top of specimen during soaking
- Weighing balance accurate 5g
- Moisture tins
- Filter papers 150mm in diameter

Moulding

- Moulding was done for three points i.e. 100%-62blows, 95%-25 blows, and 90% - 10blows.
- The mould was cleaned and weighed, then assembled on base plate and the collar fitted on it.
- Required amount of water was mixed with the sample portion thoroughly
- 3 layers were compacted, each layer was compacted with 62 blows such that the fifth layer will end immediately at the brim of the mould
- The collar was removed carefully and excess material trimmed to flush with the top of the mould using steel straight edge
- The mould with base plate after removing any external material stuck on mould and base plate using a brush was weighed
- The moulding procedure was repeated for the 95% and 90% moulding points

Submersion/soaking

- Soaking was done to determine the materials rate of absorption of water and degree of swell
- For the neat soil sample, the perforated mould with surcharge weights was soaked for 4 days and then removed from water and after removing surcharge weights the moulds was drained for 15mins before CBR penetrations
- For the stabilised soil sample, the mould with surcharge weights was first covered for seven days and then soaked for seven days before CBR penetrations.

CBR Penetration

- Each mould was placed on CBR machine with plate in position
- Surcharge masses were placed on the specimen and machine set such that the plunger is set on the specimen.
- Readings gauges was set and adjusted to prevent zero errors
- When the machine was switched and for bearing ratio above 30% the plunger was made to penetrate the specimen at a uniform rate of 1mm/min (at a plunger force of 250N)the readings of force was be taken at intervals of penetration of 0.5m a to a total penetration not exceeding 7.5m

- Penetration on the mould was done for both top and bottom and readings taken as before. This was done for the three point moulds
- A graph showing force on the plunger against penetration was plotted and smooth curve was drawn through the points
- The force read from the smooth curve required to cause a given penetration expressed as a percentage of force required to cause the same penetration on standard curve is defined as the CBR value of the penetration
- The CBR value was calculated at penetrations of 2.5 and 5.0mm and the higher value was taken. A graph was drawn for penetrations against dry densities in mould
- After penetrations the mould was removed and wet soil from the 100% - 62 blow moulds oven dried and graded to determine the particle distribution as influenced by compaction.

CHAPTER FOUR

Results, Analysis and discussion

4.1 Results

The study was carried out chiefly to investigate the effects of Rice Husk Ash (RHA) in improving the engineering properties of red coffee soil as a highway material. The analysis and discussion that follow therefore revolve around the effects of RHA on the plastic index and California Bearing Ratio (CBR) of the tested samples.

% RHA	LL	PL	PI	Linear shrinkage	CBR
0% (neat)	65.5	29.0	36.5	12.9	6
3%	65	30	35	10.0	11.7
5%	64	33.3	30.7	9.23	25.62
7%	61	35	26	8.57	27.59
9%	58	36.7	21.3	7.85	29.92
11%	57	38	19	7.14	37.44

4.2 analysis

The liquid limit

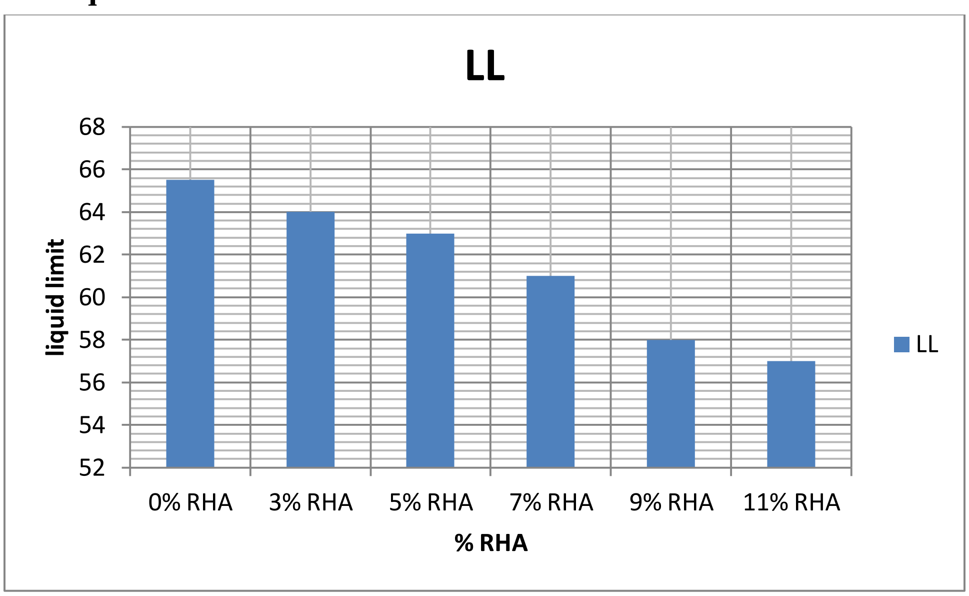


Fig 09097: variation of the Liquid Limit of red coffee soil treated with Rice Husk Ash (RHA)

Plastic limit

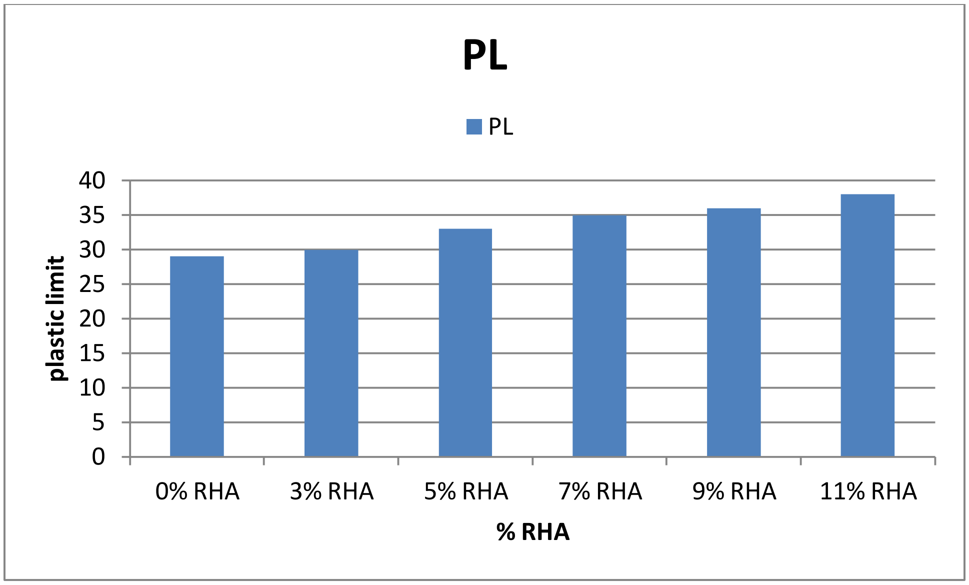


Fig 098767: variation of plastic limit of red coffee soil treated with Rice Husk Ash (RHA)

Plasticity index

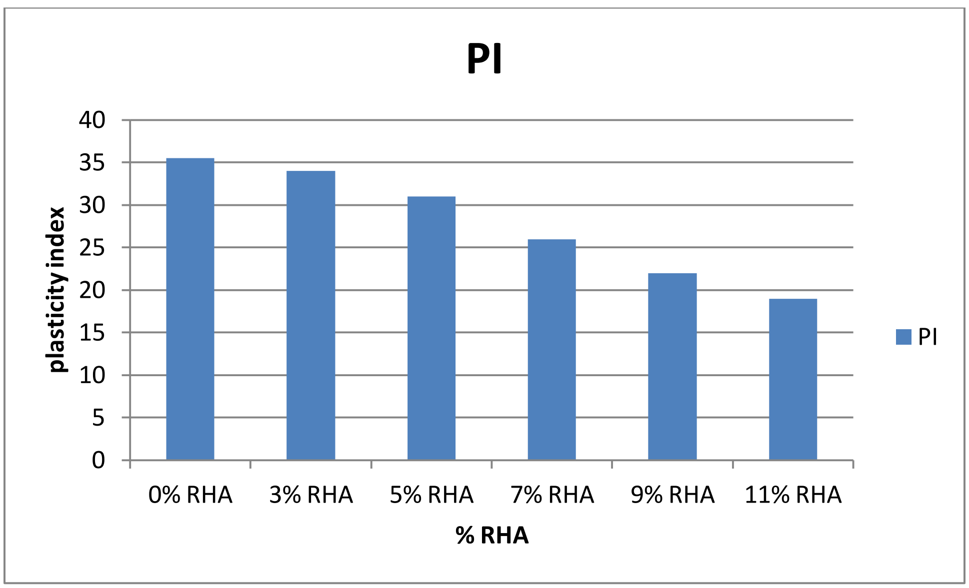
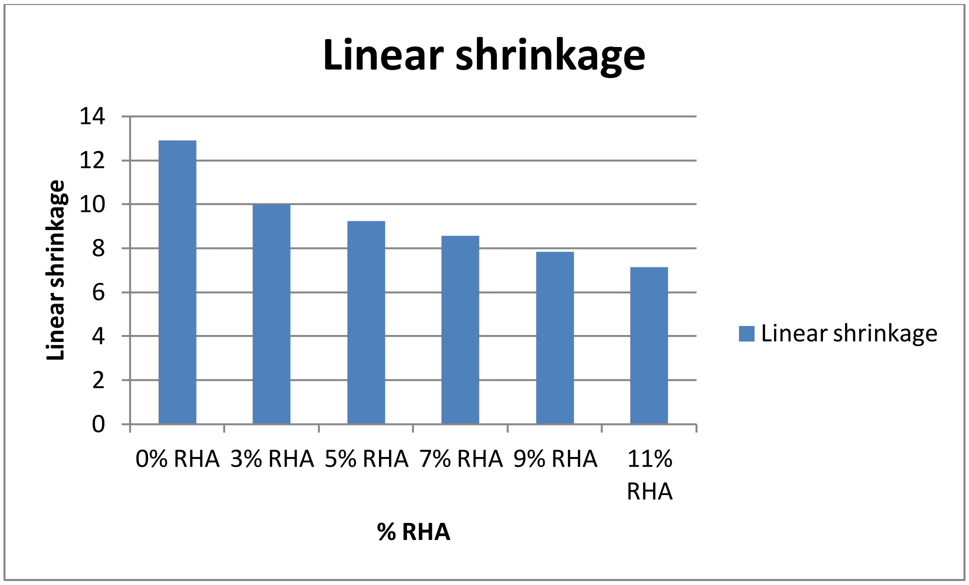


Fig 7656768: variation of plasticity index of red coffee soil treated with Rice Husk Ash (RHA)

Linear shrinkage



Variation of the linear shrinkage of red coffee soil treated with Rice Husk Ash

The variation of the plastic index of the soil sample with the amount of RHA can be represented as follows

The following findings were made

1) There was a general decrease in the liquid limit, linear shrinkage, and plasticity index in all the soil-RHA combinations. The plastic limit of the improved soil increased with increasing RHA content.
2) There was a general decrease in the plastic index of the red coffee soils treated with RHA.
3) The reduction in the plastic index increased with increase in the amount of Rice Husk Ash. The maximum reduction was approximately 49% at 11% RHA.
4) The linear shrinkage of the red coffee soil decreased with increasing ratio of RHA. The maximum reduction was 44.65 at 11% RHA.

California Bearing Ratio (CBR)

The variation of the CBR values of the red coffee soil with the amount of RHA can be represented as follows.

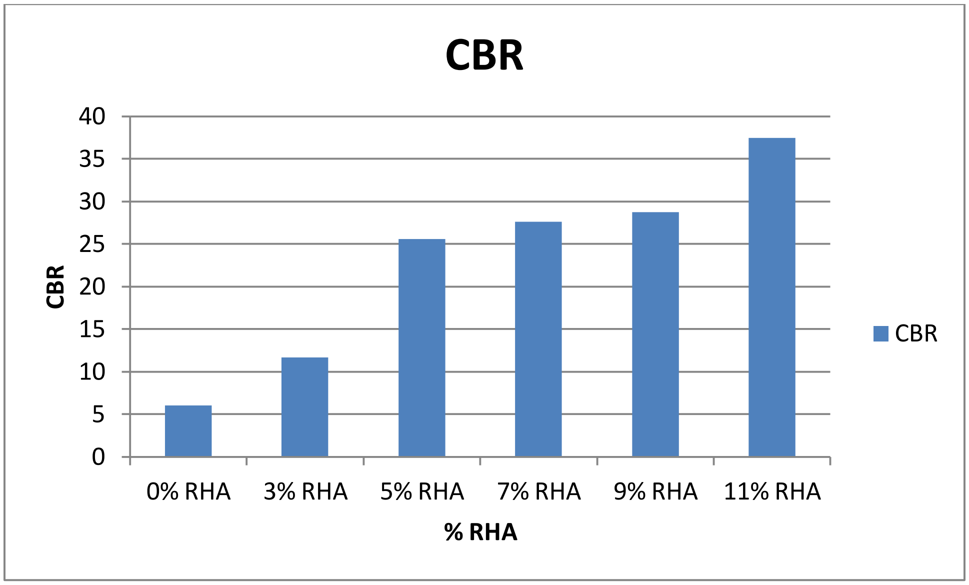


Fig 87657: variation of CBR of red coffee soil treated with Rice Husk Ash (RHA)

The following findings were made

1) There was a significant increase in the CBR value of the red coffee soil with addition of Rice Husk Ash.
2) The CBR of the tested samples increased with increasing quantities of RHA. The largest increase was noted as 500% increase after addition of 11% RHA. Addition of 3% RHA resulted in a 95% increase in the CBR value.

4.3 Discussion

4.3.1 Effects of RHA on attergberg limits

In all admixture contents, the liquid limit decreased while the plastic limit increased. It is also observed that addition of RHA achieved a considerable reduction in the PI (approximately 49%) from 36.5 down to 19.0. the linear shrinkage also dropped by 44.64% at 11% RHA. Gromko (1974) reviewed that plasticity index, and especially linear shrinkage, are early indicators of potential expansion because soil expansion occurs at water contents between these indices.

4.3.2 Effects of RHA on the California bearing ratio

As observed in the experimental results, there is a general increase in the CBR of the red coffee soil treated with Rice Husk Ash. This increase in CBR is primarily as a result of pozzolanic reaction between the silica and/or alumina in the soil to form cementitious compounds after the reaction between the rha and the red coffee soil. It is important to note that the CBR was taken after curing the samples for 14 days (7 days soaked). The presence of water aided this reaction.

CHAPTER FIVE

Conclusion and recommendations

5.1 Conclusion

Based on the analysis carried out on the experimental data obtained, the following conclusions can be drawn.

1) The treatment of red coffee soil with Rice Husk Ash showed significant improvement in its engineering properties.
2) Treatment of red coffee soil with RHA altered the attergberg limits of the red clay. The plasticity index reduced significantly after the addition of 11% RHA (49%)
3) Treatment of red coffee soil with RHA improved the CBR of the soil significantly.
4) Rice Husk Ash can be used to stabilize red coffee soil to be used as sub-grade material for all subgrade strength classes (Road Note 31)

5.2 Recommendations

Based on the analysis carried out on the experimental data obtained, the following recommendations are made.

1) More soil samples of different soils should be investigated to establish the changes in the properties of these soils and determine which soils are more responsive to the Rice Husk Ash treatment.
2) An optimum soil-RHA combination should be clearly established
3) Pilot roads treated with Rice Husk Ash should be carried out and their performance evaluated
4) Durability tests should be conducted in line with field performances and the results compared with the laboratory results
5) Farther studies should be carried out to determine materials that enhance the performance of RHA in soil stabilization. These materials may include lime, fly ash and volcanic ash. Studies should also be carried out to identify materials that are detrimental to the stabilizer.
6) An economic analysis of the effectiveness of use of Rice Husk Ash in road stabilization should be conducted to evaluate the viability of adopting RHA in road construction.

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