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Improvement of California Bearing Ratio of Fine Grained Soil Treated with Bagasse Ash, US

Nasiru Sani Rimintsiwa
Lecturer, Department of Civil Engineering, Baze University Abuja, Nigeria

Abstract:
The increasing price of old stabilizing agents and the necessity for the efficient application of industrial and agricultural waste for engineering purposes has encouraged a study into the stabilizing potential of sugarcane bagasse ash (SCBA) in fine gained soil. The grain size analysis (GSA) indicate that the soil in the study has 53% silt, 11% clay, 34% sand and 2% gravel and therefore is classified as fine sandy silt. The maximum dry density (MDD) and the optimum moisture content (OMC) of the natural soil were 1.640Mg/m3 and 19.5% respectively. The top and bottom California bearing ratio (CBR) values of the natural soil were 3% and 2.9% respectively. LL and PI increase with increasing SCBA content while PL decreases with increasing SCBA content. The MDD decreases while the OMC increases with increasing SCBA content. Peak top and bottom CBR values of 18% and 20% were attained by treating the soil with 2% SCBA content. These values fell short of the requirement of the CBR value for sub-base or sub-grade material. However, for very less traffic roads, the values can be considered good for sub-grade material.

Keywords: *Sugarcane bagasse ash, compaction, California bearing ratio*

1. Introduction

1.1. Background

Soil in its natural state seldom have or possess the necessary engineering properties for use in road construction. Therefore, the term 'soil stabilization' i.e. the addition of chemicals or additives to soil in order to improve its engineering properties and make it suitable for road construction, has become a common practice.

Soil stability is needed to make a solid and suitable foundation. A suitable foundation is required for a good road. Thus, the extent of stability is a primary function of the road material resistance to lateral movement. However, for resisting lateral movement, different methods are required for different types of road soil materials. For example, in fine grained soil, stability is much reliant on moisture. Unfortunately, fine grained soil does not naturally possess the basic engineering properties to serve as a good foundation material for roads. As a result, bagasse ash is used in this present study as a soil stabilizing additive to develop the necessary properties of the fine grained soil to make it fit for road construction.

The application of bagasse ash in improving the engineering properties of soil to make it suitable for use in road construction has been widely considered with great interest in recent years. This application has been noted to produce major changes in the road soil characteristics that influence soil stabilization. The successful use of the ash as a soil stabilization agent provides a suitable remedy to make use of the waste material rather than disposed as a waste. It also brought the advantage of reducing the cost of construction.

Bagasse is a fibrous residue that remains after the extraction of sugar juice from the cane in sugar factories, and it is used again as a good source of energy in boilers for the generation of vapor and high temperature.

Bagasse ash is an industrial waste which is used in sugar cane industries as a source of energy in most part of the world. SCBA is produced as a combustion result from sugar and alcohol water heating tanks in the cane factories. It is a waste product consisting of resembling fibers used in the sugar cane refining industries. The burning of the waste produces ashes with high amount of unburned substance; silicon and aluminium oxides as such leads to the excretion of greenhouse gasses into the environment. For this reason, urgent ways of handling the waste have been developed. Bagasse ash has been physically and chemically distinguished with the prospect of replacing cement as a material in the concrete industries.

Fine grained soils are soils composed of at least 50% of silt or clay. Clay soil is a soil of high plasticity (i.e. they become soft and plastic when worked) and adhesiveness. When a clay soil is in a completely drained condition, it provides a hard surface with excellent trafficability. However, it hardly ever dries completely except in dry climates because it absorbs water very slowly and takes a very long time for the water to dissipate. This is why the clay is characterized as a soil of very low permeability. On the other hand, silt soil is a soil that composes of at least 50% of silt content. It exhibits excellent trafficability when dry even though they may be very dusty. One basic difference between the silt soil and the clay soil is that the silt soil absorbs water very quickly and tends to turn into a soft mud quickly.

The California bearing ratio (CBR) test is kind of a simple penetration test done in order to evaluate the subgrade strengths and potency of roads and pavement. It has to do with causing a plunger of typical section or area to make a way into a soil sample which can be done in the laboratory as well as on the site. The strength of subgrade which is the soil below the pavement is usually assessed through this test. Most of the design charts for road foundations are based on the CBR value of the soil below the pavement. The California bearing ratio is the ratio of the force per unit area needed to penetrate a given mass of soil with a standard circular piston at the rate of 1.25mm/min to the force per unit area required for the corresponding penetration of a standard material.

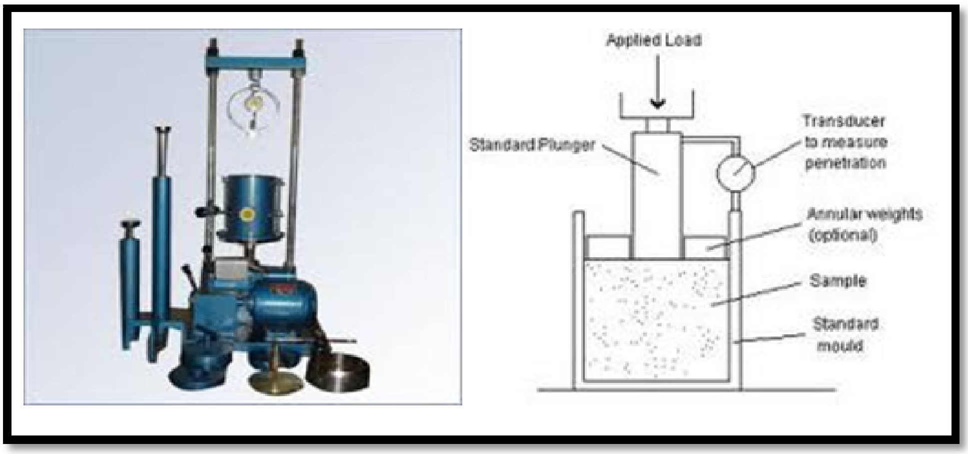

Figure 1: The California Bearing Ratio Equipment and Its Labeled Parts

The California bearing ratio (CBR) test is important because it helps to determine how strong and reliable a soil can be for use in road construction. Knowing that the higher the CBR reading the stronger the soil, this test makes it easier to determine and find the required strength of subgrade needed for a proposed pavement design or road construction. It also provides a considerable way of cost saving.

1.2. Aim of Research

In this present investigation, efforts have been made to treat fine grained soils by stabilizing with bagasse ash and to improve the California bearing ratio (CBR) value of the stabilized or treated soils. Therefore, the primary aim of this study is; "To improve the strength of fine-grained soils the suitability of using bagasse ash as additive for soil stabilization".

1.2.1. Objectives

In order to achieve this aim successfully, however, the following list of objectives should be successfully accomplished;

- Collect fine grained soil from the site and investigate the natural suitability and strength of the soil by determining its natural index properties and the California bearing ratio (CBR) value of the soil.
- Stabilize the soil by preparing some soil-bagasse ash mixtures for the soil sample, example by mixing 1%, 2%,3%,4% and 5% of bagasse ash (by weight) with the soil sample.
- Determine the index properties of all the mixtures and carry out the standard compaction test in order to determine the compaction characteristics like the maximum dry density and the optimum moisture content.
- Carry out the California bearing ratio (CBR) test on each mixture and determine the corresponding CBR values.

1.3. Problem Statement

Most of the natural soils do not satisfy the conditions to be used as subgrades (i.e. soils below the road or pavement) which may be due to poor engineering properties. As a result there is urgent call for the improvement of the soil properties by treating with soil stabilizers. The addition of these stabilizers to the soil will improve, soothe or make the soil suitable for intended purpose. In this present study, fine grained soil is being stabilized by treating with bagasse ash. Therefore, the bagasse ash is the intended stabilizer.

The fact that most research works that have been carried out focused mainly on the effectiveness of utilizing other ashes as soil treatment agents do not make bagasse ash less important. In this present study, attempts have been made to soothe and improve the bearing capacity of fine grained soils by treating with bagasse ash or in other words by using bagasse ash as a soil stabilizing agent

By treating the soil with bagasse ash, i.e. adding or mixing the fine grained soil with a particular percentage of bagasse ash, possibilities are that the soil properties like the index properties, compaction characteristics and California bearing ratio (CBR) of the fine grained soil will improve.

However, in order to know the whether the desired properties of the soil like the strength and bearing capacity, certain tests are required depending on the kind of property needed to be improved. California bearing ratio is the test needed to be carried out in order to test the strength and bearing capacity of the soil.

1.4. Scope of Study

In the proposed study, I will only investigate the effect of adding bagasse ash to fine grained soils. The study will focus on the suitability of using bagasse ash as a fine grained soil stabilizing agent. In other words, the study will focus on the improvement of the engineering properties of fine grained soils by treating with bagasse ash. However, the improvement of the engineering properties of other types of soils (like coarse grained soils) will not be included in the study. Also, the suitability of using other ashes as stabilizing agents will not be included in the study.

Different kinds of test are available in order to investigate the engineering properties of soils. Some of these tests include consolidation, compaction test, plastic limit test, liquid limit test, California bearing ratio test, etc. however the focus of this study is the California bearing ratio test which is carried out to assess the strength of soils for use in road construction or pavement design.

2. Literature Review

2.1. Location of Study Area

Malaysia is a tropical country that is blessed with tropical weather throughout the year. As a result, soil excavated from any part of the country is likely to be found to be partially or fully saturated. A sample of clay was obtained from a construction site in the outskirts of Seremban, Negeri Sembilan.

Bagasse was obtained from a bagasse dump in a sugar mill in Nilai area of Negeri Sembilan. The bagasse was quite wet when collected from the dump and had to be dried for a period of 24 hours. It was locally turned into ash by burning in blast furnace for a period of 6 to 7 hours.

2.2. Soil

There is variation in the definition of soil which however depends on the person considering it. According to a farmer, soil may be considered as the medium that supports plant life by nourishing and supplying water to the crops. To a miner, it is just a material that is blocking the way and must be removed. To a scientist, even though different scientists may hold different definitions, a soil is a complex, unconsolidated inorganic, organic and living material that is found on the immediate surface of the earth that supports activities such as the growth of plants, etc. (R. Scharf, 2010).

Basically, soil can be considered as a mixture of mineral and organic materials containing air and water. It is a layer of material on the earth surface in which we grow our plants and on which we lay our building foundations and other constructions. It is made up of many things such as weathered rocks, decayed plants and animal matter. However, the contents of soil vary with different locations and it keeps changing. Therefore, different kinds of soil differ in certain characteristics ranging from composition to color. So plants life, buildings foundations and/or other constructions all depend solely on the kind of soil present.

In this paper, however, soil is considered as an engineering material because it is to be treated in order to improve its engineering properties.

<u>2.2.1. Soil as an Engineering Material</u>

The engineer sees soil as a material that : foundations to buildings and bridges can be built on, roads, embankments, runaways, and dams can be built with, tunnels, culverts and basements can be built in, and with which retaining walls and quays can be supported.

Consequently, there are three main properties of soil in which the engineer is interested:

- Strength
- Stiffness
- Permeability

These properties, however, depend on a number of factors such as nature of soil grains, the current stress, the water content and the unit weight.

<u>2.2.2. Soil Formation</u>

The formation of soil is a very long and slow process. For a soil to form, it can take to thousands of years. Scientist discovered long ago that soil form spontaneously from rocks. The rock being the parent material breaks down into smaller pieces under the strong influence of physical factors like assault by wind, hail, rain and ice, deformation by heat and cold, and the massive levering forces of water expanding into ice, etc, a process known as weathering. However, the smaller fragments of rock particles gotten from the breakdown of the parent rock still have same properties with the parent rock. The crystals of the minerals in these pieces formed under high temperature and pressure are to some extent unstable at surface temperature and pressure. When these pieces are attacked, particularly by acid that removes away the soluble constituents in the minerals, the crystals slowly fall or drop away from each other. This process is known as spontaneous weathering. The process's speed is then very much increased under the influence of vegetation and acids, another process called chemical weathering. (Dr. J. Floor, 2000).

The main idea about physical and chemical weathering is that, in physical weathering, the products' properties remain unchanged from the parent material, while in chemical weathering; the hard materials are changed into soft materials.

The complex nature of soil means that the type of soil that a region has, depends on a number of factors. However, the main factors of soil formation are:

- Parent material
- Climate
- Atmospheric pressure
- Topography
- Organisms

(Dr. J. Floor Anthoni, 2000)

2.3. Atterberg limits

The Atterberg limit defines the nature of the fine-grained particles of a soil. The nature of these fine particles can be in different states, liquid state, plastic state, semi-solid state, solid state. The boundary between the liquid state and the plastic state is called the liquid limit (LL), boundary between the plastic limit and the semi-solid state is the plastic limit (PL), while that between the semi-solid state and the solid state is called the shrinkage limit (SL).

The liquid limit (LL) defines the percentage of the water in the soil at the point where the soil starts exhibiting plastic behaviors.

The plastic limit (PL) defines the percentage of water or the moisture content of water in the soil when it begins to behave in a semisolid way.

The percentage of water at the point the soil becomes solid is the shrinkage limit.

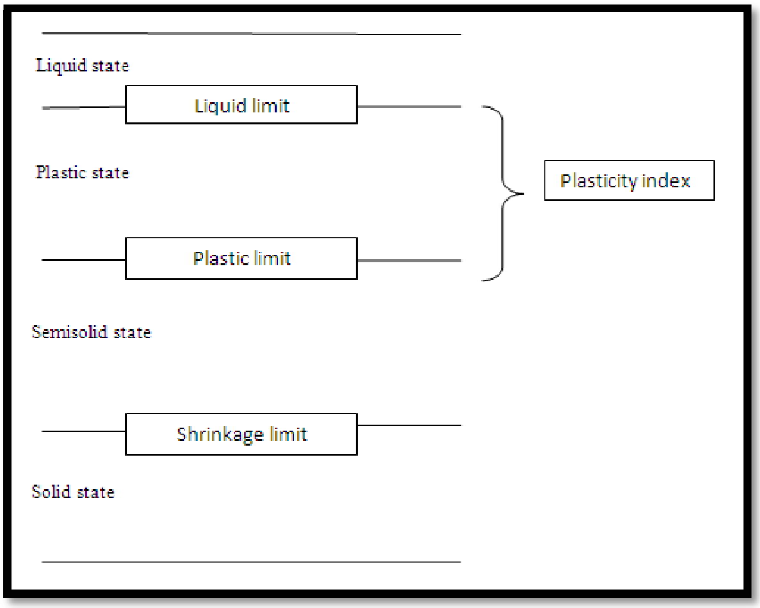

Figure 2: Atterberg Limits

Plasticity index (PI) is a measure of the plasticity of soil. It is the amount of water in the soil as it begins to behave in a plastic way. It is calculated by subtracting the PL from the LL. i.e. PI = LL – PL. However, soil with high PI is termed as clay soil while the soil with low PI is termed as silt soil. The soil with PI equals zero is said to have very little or no clay or silt content in it.

Liquidity Index (LI) is the ratio of the difference between the natural water content and the plastic limit to the plasticity index.

i.e. $LI = \frac{w - PL}{LL - PL} = \frac{w - PL}{PI}$ (where w is the water content)

2.4. Bagasse Ash

<u>2.4.1. Sugarcane Bagasse</u>

Sugarcane is a large grass that has a bamboo-like stalk, which usually grows to about 8 to 15ft high, and the stalk holds large amount of sucrose in it. Diverse varieties emerge throughout the tropical and the semi tropical regions of the world; they are the result of types of cultivation, varied conditions, weather. (Aul, Pechan, 1993)

Bagasse is the fiber that remained after the juice has been extracted out from the sugarcane. It may be seen as the entwined cellulose fiber residue that is processed in the sugarcane industry from sugarcane. This entwined or matted residue was previously being disposed and burnt as a solid waste. Consequently, as the cost of fuel, natural gas, and electricity has increased, bagasse has been considerably regarded as a good source of energy rather than waste in the sugar industries. (Aigbodon, 2008)

Figure 3: Sugarcane and the Bagasse after the Extraction of the Juice

According to Ganesan, 1 ton of sugarcane generates 280kg of bagasse and based on economics and environmental related matters, substantial attempts have been directed worldwide towards bagasse management problems ranging from utilization, storage to disposal.

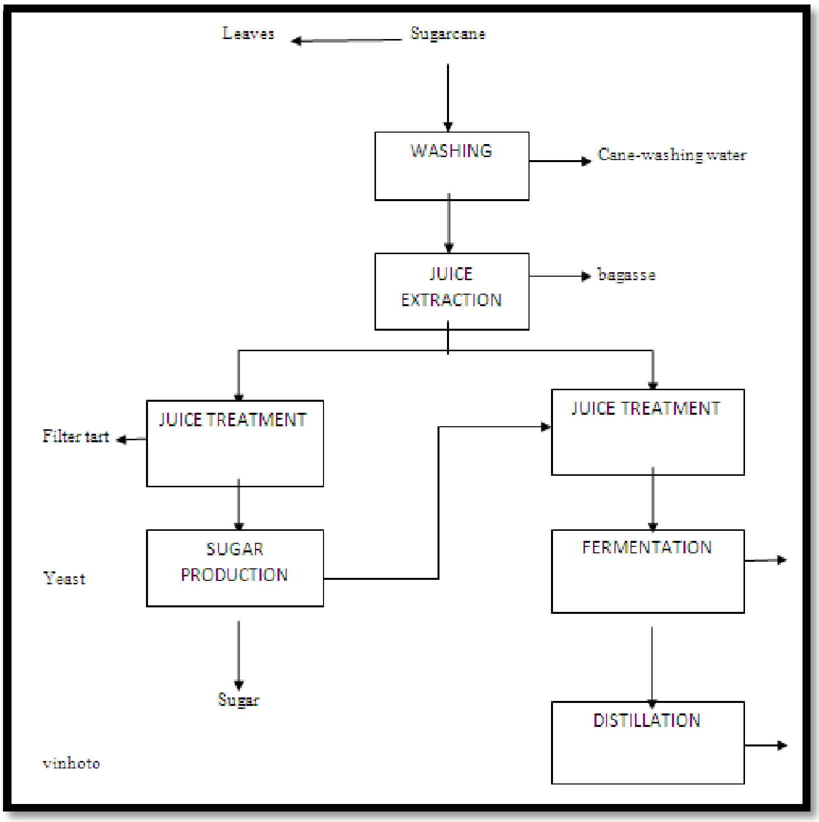

Figure 4: Production Process of Sugar, the Bagasse and Other Sugar by Products (Moreira, J.R. and Goldemberg, 1999)

2.4.2. Bagasse Ash

The sugarcane bagasse ash (SCBA) is a byproduct produced from the combustion of bagasse in boilers of sugar and ethanol plants, usually at a temperature of about 600ºC to 1200ºC. It consists mainly of silica (SiO_2) which is the characteristic property that shows the possibility of using the SCBA as a mineral admixture because the silica is presented in a noncrystalline or a partially crystalline state. (Cordeiro, 2008)

Figure 5: The Bagasse Ash after Combustion of the Bagasse

In the previous years, the use of cement, lime, bitumen, phosphatic and pulverized coal bottom ash to improve the engineering properties and/or quality of fine grained soils has received more attention thereby giving stabilization using bagasse ash very little attention. However, as the price of additives such as cement, lime and bitumen become vastly on the increase and bagasse ash is quite inexpensive and also readily available locally through the combustion of bagasse, the ash eventually attract more attention and come to be regarded as a good additive for soil stabilization.

2.4.3. Compositions

The sugar cane bagasse consists of approximately 50% of cellulose, 25% of hemicellulose and 25%. A tone of sugarcane is estimated to generate about 26% of bagasse (at a moisture content of 50%) and 0.62% of residual ash. The residue after combustion presents a chemical composition dominated by silicon oxide (SiO_2). (Romildo D. Toledo Filho, 2004)

According to Ahmad and Shaik (1992), the physical and chemical properties of sugarcane bagasse ash are found to be satisfactory and conform to the requirements for class N pozzolanos (ASTM C618-78). The main oxides of bagasse ash are SiO_2, Al_2O_3, Fe_2O_3, CaO, Na_2O, P_2O_5, MgO, K_2O and MnO.

Component	**% by weight**
SiO_2	78.34
$Al2O_3$	8.55
Fe_2O_3	3.61
CaO	2.15
Na_2O	0.12
K_2O	3.46
MnO	0.13
TiO_2	0.5
MgO	1.65
BaO	0.16
P_2O_5	1.07
loss on ignition	0.42

Table 1: Chemical Composition of Sugarcane Bagasse Ash (Romildo, 2004)

2.5. Soil Improvement

2.5.1. The Need for Soil Improvement

In geotechnical engineering, engineers come across many problems ranging from original materials with weak engineering properties (that is materials that are unable to reach the required specification), and many more. Most of these problems encountered like the soft soils such as clay give large settlement during construction, the alteration of the chemical materials in the soils and settlement in materials with high organic content. Consequences like these may cause serious problems even after the completion of construction. A typical example of a problem that may arise as a result of such consequences is the differential settlement.

Therefore, there is serious need for soil improvement. It is an important stage in construction because there would be risks of losing a lot: money, time and even life. Hence, before any construction is carried out, site investigation is very important in order to evaluate the properties of the soil at the site.

Site investigation is the process of gathering information about a proposed location for construction. It ascertains the ground condition such as the soil present and its properties. This is important because it assists in determining the present feature of a site location so that if there is any failure, the failure can then be investigated and possible remedies will be provided.

Soil investigation on the other hand, is a part of site investigation which gives the detailed information about the soil condition in a proposed construction site. This is equally important because it provides the engineers with all the possible problems that may arise as a result of the soil present so that preliminary measures can be taken.

2.5.2. Soil Stabilization

Treatment technology for contaminated soil is known as soil stabilization. Stabilization changes harmful and hazardous components into less soluble or toxic foams. Example, mixing the right combination of required reagents into contaminated soils allows them to be dug out and disposed of in a landfill, or recycled in site to support redevelopment.
In other terms, soil stabilization may be seen as the alteration or preservation of the properties of a particular soil in order to improve its engineering characteristics and behavior. There are different methods of soil stabilization such as mechanical method and the additive method. The mechanical method includes preloading, vibration by vibroflotation or dewatering by vertical drains. However, this study will be focused on the additive method.

2.5.2.1. Additive method

An additive refers to a commercial product that when mixed in right proportion with the soil, improves the overall quality of the soil. Examples of additives that can be used to stabilize the soil include cement, lime, fly ash, bitumen, bagasse ash etc. However, to achieve the desired stability, the additive must be incorporated with the soil.
Percentage selection of additives depends on soil classification and the quality of the soil required. Generally, smaller amounts of additives are sufficient enough to alter soil properties such as workability, gradation, and plasticity. After preparing the soil additive mixture, spreading and compaction are carried out by conventional means.

2.5.3. Compaction

Compaction is the process of increasing the density of soil by mechanically decreasing the soil air voids. Compaction is a very important part of the building process because if done improperly or skipped, settlement of the soil could occur and may result in structure failure and unnecessary maintenance costs. Normally water is added to the soil before compaction so as to decrease the surface tension of the soil, thus making compaction easier to be accomplished.
Compaction is very important for a number of reasons such as

- To provide stability
- To prevent frost damage and soil settlement
- To reduce settlement of soil if any.
- To reduce water seepage
- To reduce swelling and contraction

There are four main types of compaction efforts on soil namely; vibration, kneading, impact and pressure. However, to achieve the required compaction level, the soil type is should be matched with its proper compaction method.

2.6. California Bearing Ratio

2.6.1. California Bearing Ratio (CBR) Value

The CBR value can be defined as the ratio of the pressure required to penetrate a given mass of soil with a typical circular piston at the speed of 1.25mm/min. to the pressure needed for the equivalent penetration of a standard material.

$$\text{CBR} = \frac{\text{force applied on soil mass}}{\text{force on standard material}} * 100$$

The table below shows the standard loads adopted for different penetrations for a standard material with CBR value of 100%:

Penetration of Plunger (mm)	Standard Load (kg)
2.5	1370
5.0	2055
7.5	2630
10.0	3180
12.5	3600

Table 2: Penetration Depth Per Load

The CBR value is used to indicate the load bearing capacity of a compacted soil which can be a sub-grade, a sub-base or a base coarse. It is a number which shows conformity with the specified requirement of certain layers in an embankment.

Soil Type	CBR Range
Clay	1-3
Sandy clay	4-7
Well graded sand	15-40
Well graded sandy gravel	20-60

Table 3: Typical Values of CBR Rating for Different Materials (Head, K.H., 1982)

The CBR value is used as a manifestation of soil strength and bearing capacity. The value is generally used in the design of base and sub-base material for pavement. It is a proverbial indicator test used in the evaluation of strength of soils for road or pavement design. (Nicholson, 1994)

2.6.2. The Need for CBR Test

All sections of a designed pavement should not at all occasions be subjected to excessive deformation which could lead to localized settlement. This means that during the design process of flexible pavements which are usually built with a number of layers, engineers need to ensure that none of the layers is overstressed under the application of load.

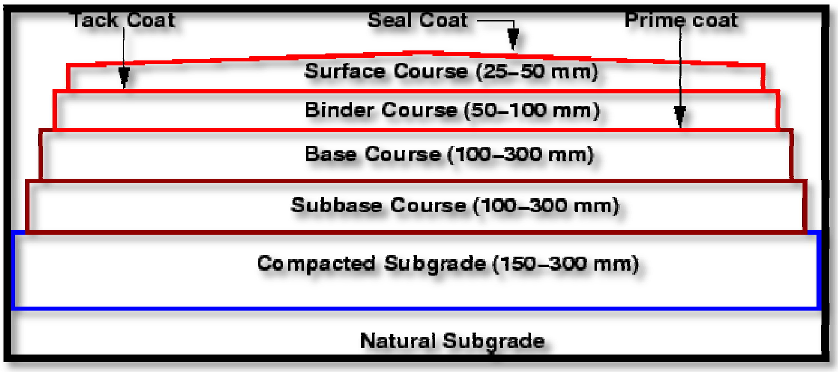

Figure 6: Typical Cross Section of a Flexible Pavement. (Prof. Tom V., 2009)

The CBR test is an in-situ penetration test meant to estimate the bearing value and mechanical strength of sub-grades for road and pavement design. The results obtained from the test are used to determine the thickness of pavement and its component layers.

2.6.3. Bagasse Ash Stabilization Process

Bagasse ash stabilization is a simple process meant to improve the engineering properties and quality of soil by mixing with bagasse ash. The process involves a number of stages in order to achieve desired result. This stages or steps include scarification and pulverization, a preliminary mixing, a preliminary curing, final mixing and curing, compaction of the final mixture, final curing, and finally the California bearing ratio test.

Pulverization is the mechanical process of reducing a substance of coarse particles to a substance of fine particles through crushing or grinding. Generally, after recycling the residual waste (bagasse) is separated mechanically and then pulverized into fine particles or ash.

The preliminary mixing is the introductory mixing of the soil with the stabilizer in order to prepare it for preliminary curing.

The preliminary curing is a preparatory curing stage that involves preserving the mixture by drying it for a specific period.

Final mixing and curing is the last and conclusive stage of preparing the soil-additive mixture and corresponding curing.

Curing of the final mixture is then followed by compaction test. the next step is the final curing of the compacted sample.

Finally, the cured sample is then tested for CBR. This stage is aimed at finding the strength and bearing capacity if the sample.

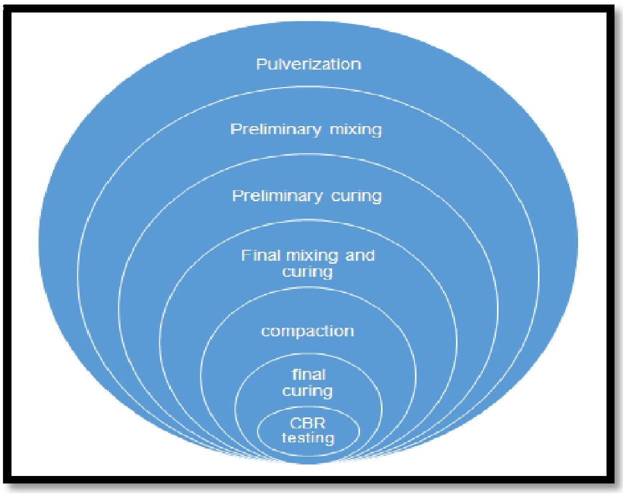

Figure 7: Procedure of Sub-Grade Stabilization Geotechnical Engineering & Soil Testing by Amir Wadi, Orlando Andersland, 1992

2.7. Similar Work

2.7.1. Lateritic Soil Treated with Bagasse Ash

An experiment carried out in Nigeria to treat lateritic soils with bagasse ash was explained in the book "Appropriate technologies for environmental protection" by Ernest K. Yanful.

Samples of lateritic soils were obtained and the bagasse ash was obtained locally from a bagasse dump. The natural soil and the soil stabilized with bagasse ash were compacted and the OMC and the MDD were determined.

It was noted that the MDD shows a general trend of decrease in value with higher bagasse ash content. It was reported that the decrease in density may be as result of the flocculated and the agglomerated fine particles caused by cat ion exchange occupying larger spaces leading to corresponding decrease in dry density. However, it was noted that the OMC shows a general trend of increase with bagasse ash content. This was reported to be as a result of pozzolanic reaction of lime of bagasse ash with clay fraction of the soil in conformity with the reason for the MDD decrease. It was concluded that the increase in OMC with bagasse ash content and the corresponding decrease in MDD is an advantage because it enabled compaction to be achieved easily.

The compacted soil-bagasse ash mixtures were wrapped with polythene sheet and cured for 6 days and soaked for 1 day before tested for CBR. It was recorded that the peak value 16% was reached at 2% bagasse ash content. Decrease in CBR value was then noted with bagasse ash up to 6% and thereafter followed by slight increase between 8-12% bagasse ash content. It was concluded that if soaked CBR values of 10%, 20-30% and 60-80% for sub-grade, sub-base and base course materials respectively are considered then only the sub grade requirement of a minimum CBR value of 10% is met at 2% bagasse ash treatment.

Finally, it was concluded that if the pozzolonic nature of the soli-bagasse ash reaction is taken into consideration, 2% bagasse ash can be said to be the adequate content for sub-base course construction.

2.7.2. Fine Grained Soils Treated with a Different Additive (Fly Ash)

An experiment was conducted in the University of Botswana, Gaborone by B.K. Sahu in order to improve the California bearing ratio of various soils treated with fly ash.

Fine grained soil (clay) was collected along with 5 other types of soil from different locations in Botswana. The soils were mixed with different proportions of fly ash. The mixtures were compacted using the modified AASHTO compaction effort to determine their maximum dry density (MDD) and the optimum moisture content (OMC). The result of the compaction test which is shown below indicates that there is hardly an effect of fly ash on OMC. However, MDD was found to slightly increase up to 16% of fly-ash and then decreased.

Fly Ash	**Clay Soil**	
	OMC%	MDD(kg/m³)
+0%	20	1544
+4+	22	1550
+8%	22.7	1564
+16%	21.4	1584
+24%	23.5	1508

Table 4: Effects of Increasing Fly Ash on OMC and MDD

The samples were then cured for 7 days using gunny bags. These samples were kept wet at all time. The mixtures were then all soaked for 4 days in water under a specific surcharge. At the end of the fourth day, the samples were taken out, drained and then the CBR of all the samples were determined. It was observed that increase in fly ash content slightly increases the CBR of the clay.

2.7.3. Proposed Stabilization of Fine Grained Soil with Bagasse Ash

Fine grained soil will be obtained from a construction site around mantin area. The sample will be classified in the laboratory according to the required classification test. Bagasse will be obtained from a sugar industry and will be processed into ash locally by burning in a furnace.

After the classification of the natural soil, it will be compacted in order to obtain it optimum moisture content and the maximum dry density. The soil will then be tested for CBR in order to know the natural strength of the soil.

Specified percentage of bagasse ash by weight will then added to 6 different specimens of the soil and mixed thoroughly. The OMC and the MDD of all the mixtures will then be determined after compaction. The compacted mixtures will then be wrapped in a protective bag and then cured for 7 days.

After successfully curing the mixed specimens for 7 days, they will then be brought out and soaked in water for a maximum of time 48hours without disturbance, at the end of which they will taken out and drained.

Finally the California bearing ratio value of each of these samples will then be determined.

3. Materials and Method

3.1. Methods of Testing

The methodology describes the methods, procedures and manner of approach to be followed in order to successfully carry out the research. As the study is about the improvement of California bearing ratio (CBR) of fine grained soils treated with bagasse ash, there are a series of laboratory tests required to be carried out on the natural soil before treating. The laboratory tests include

- The soil classification test (particle size distribution and Atterberg limits),
- Compaction test (to determine the moisture content and the density) and
- The California bearing ratio test.

However, some of these tests are carried out before and after the soil stabilization;

- compaction and
- CBR tests.

A summary of the methodology of this study can be seen in the figure below.

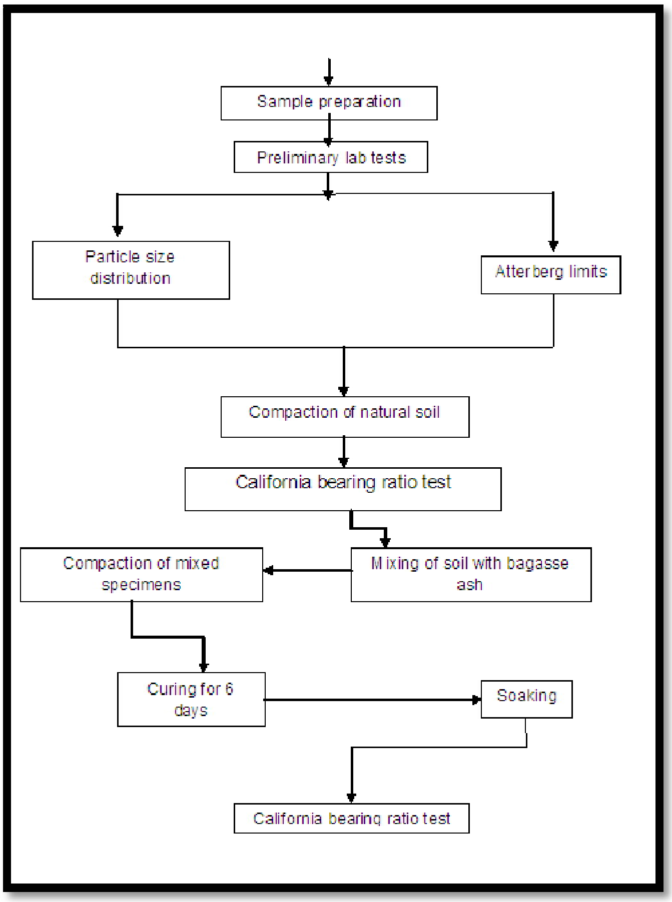

Figure 8: A Summary of the Methodology of the Study

3.2. Collections of Materials and Preparation

3.2.1. Materials

The materials will serve as the main specimens which the whole study topic is focused on. They are those specimens needed for the whole laboratory exercise or experiment of the study. These materials include the collected fine grained soil from a construction site and the bagasse ash from the local combustion of the bagasse dump.

3.2.1.1. Fine Grained Soil

Malaysia is a tropical country that is blessed with tropical weather throughout the year. As a result, soil excavated from any part of the country is found to be partially or fully saturated.

A sample of clay was obtained from a construction site in the Mantin area of Negeri Sembilan. The sample is quite saturated and consists of lots of impurities like unwanted stones, tree roots, barks and lots of decaying matter.

3.2.1.2. Bagasse Ash

Bagasse was obtained from a bagasse dump in a sugar mill in Nilai area of Negeri Sembilan. The bagasse was quite wet when collected from the dump and was accompanied with lots of unwanted materials like used plastic bags, tiny particles if wood, etc.

3.2.2. Sample Preparation

This is the process of transforming samples from their state at collection point into a state of readiness for laboratory experiments. However, this process solely depends on the state of the sample it was collected or obtained i.e. it depends on the initial conditions of the sample, the plasticity of the sample, the efficiency and the need for other tests on the sample.

3.2.2.1. Clay Sample

The clay sample obtained from the field is usually in a saturated condition and contains some unwanted matter. Therefore;

- The soil sample should be air dried.
- Possible clods should be smashed by the use of a wooden stick as it may help to speed up drying.
- Unwanted soil matter like tree roots, stones, barks, etc can be removed from the sample by hand picking.
- A sufficient quantity by weight should be selected to represent the sample for the experiment.
- This quantity should be thoroughly dried in an oven at a temperature of about 105^{0}c to 120^{0}c.
- This dried sample should be used as the specimen for the experiment.

3.2.2.2. Bagasse

The bagasse also containing some unwanted matter in its initial condition should also be prepared into a state of readiness before the experiment in the following ways;

- The bagasse from the bagasse dump should be air dried thoroughly by spreading under the sun for a minimum period of 24hours.
- All unwanted matter contained in the bagasse should be removed by hand picking.
- The dried bagasse should then be combusted in a furnace at a temperature of about 700^{0}c to obtain the ash.
- The ash should be sieved to get the finest part. This can be done by passing the burned bagasse through the smallest sieve size (i.e. BS sieve no. 200).
- This part is then used as the specimen for the experiment.

3.3. Preliminary Lab Experiments

These are the lab tests that precede the main laboratory experiments of the study. They prepare the specimens for the major tasks ahead. However, these tests depend on the condition of the sample as it is brought into the lab and also on the kind of main laboratory exercise intended to be carried out.

For this study, the preliminary test to be carried out is the soil classification test which includes the particle size distribution and the Atterberg limits.

3.3.1. Particle Size Distribution

This is a standard laboratory analysis meant for the determination of the grain size of a soil. Most soils consist of discrete particles of various shapes and sizes. In order to group these particles into different ranges of sizes, the sieve analysis of particle size distribution is employed. The sieve analysis includes the dry sieving and the wet sieving. For the purpose of this study, only the dry sieving will be employed.

3.3.1.1. Apparatus

The set of apparatus required for this task include

- Stack of sieves with different aperture sizes (ranging from 75mm to 63μm) and appropriate receivers.
- Balance with decimal reading up to 0.01g.
- Rubber pestle, mortar (for crushing in case of clod formation).
- Brush.
- An oven drier with controlled temperature.
- A mechanical sieve shaker or vibrator.

3.3.1.2. Test Procedure

- The oven dried sample of the soil is taken out and weighed 500g or 0.1% of its total mass.
- The sample should then be placed in the mortar provided and crushed any lump
- The mass of the sample should then be accurately determined and labeled W_t in grams.
- Prepare a stack of sieves with diminishing aperture sizes, the larger opening sizes at the top to the last one with smaller opening sizes.
- Pour the soil in the top most sieve of the stack place the cover and put it in the sieve vibrator making sure the clamps are well tightened. Adjust the time to about 5 to 1o minutes and turn the shaker on.
- Take it out at the end of the time set to vibrate, each sieve aperture + retained soil from the top sieve to the pan should be weighed. The percentage passing the 63μm is checked by the weighing the amount in the receiver.
- Record all the weight in a result sheet.

3.3.2. Atterberg Limits

The Atterberg limit tests to be carried out are the liquid limit test and the plastic limit tests. These two tests are used to determine the index properties of the soil sample (the plasticity index and the liquidity index).

3.3.2.1. Liquid Limit Test

This test can be carried out by the use of the cone penetrometer or the Casagrande's apparatus. The cone penetrometer is the apparatus to be used for the purpose of this study.

In the cone penetrometer test, the moisture content at which an 80g, 30^0 cone sinks exactly 20mm into a cup of remolded soil in a brief period of 5seconds is the liquid limit of the soil. The soil will be found to be very soft at this moisture content.

3.3.2.2. Plastic Limit Test

This test is carried out to determine the plastic limit of a soil which is the lowest moisture content at which the soil is plastic.

The apparatus needed for the test include a flat glass plate of convenient size, at least two spatulas, a rod of length 100mm and a diameter of about 3mm.

According to BS 1377, the test procedure is as follows

- A sample weighing about 20g which passes through the 425μm sieve should be taken and placed on the flat glass plate. Mix it with little amount of distilled water.
- Allow it on the plate to partially dry until it has become plastic enough to be shaped.
- The shaped sample is molded around the fingers and rolled between the palms until it is sufficiently dried for at least slight cracks to appear on the surface. Divide the samples into two sub samples of approximately 10g each. Each sub sample is then further divided into four or less equal parts.
- Mold the soil in the fingers to make moisture distribution even and then form it into a thread of about 6mm diameter.
- Roll the thread on the plate using the finger tip with a pressure sufficient enough to reduce its diameter to about 3mm in a complete 5 to 10 to and fro motion. A uniform rolling pressure should be maintained.
- Pick up the soil and mold it between the fingers for further drying, form it into a thread and roll it out again.
- Repeat the above step until the thread shears after it has been rolled to about 3mm diameter as gauged by the rod. The pieces should not be gathered together to continue rolling after crumbling as the first crumbling point is the plastic limit.
- The crumbled soil are packed together and placed in a container and the lid closed.
- Repeat steps 4 and 8 on the other 3 further divided samples. The moisture content can then be determined.
- Steps 3 to 9 should be repeated on the other duplicate sample formed in step 3.
- The moisture content of both samples should be calculated and then the average of the two values calculated should be determined. This is the plastic limit.

3.3.2.3. Index properties

The moisture content of the fraction passing the a 425μm has been determined as w_c

The plasticity index is given by

PI = LL – PL

The liquidity index is given by

LI = (w_c – LL)/PI

3.4. Compaction Test

Compaction is the mechanical means of packing soil particles together in a constrained state by reduction in the volume of air voids between individual particles. BS provides 3 specifications for soil laboratory compaction, namely;

- 2.5kg rammer method,
- 4.5kg rammer method, and
- Vibrating hammer (for granular soils).

However, for the purpose of this study, the 4.5kg method will be adopted. The objective of compaction test of a soil is to determine the optimum moisture content (OMC) and the maximum dry density (MDD) of the soil.

3.4.1 Apparatus

- A standard proctor mould with a detectable collar and a base plate. The mould will have an internal diameter of 106.1mm, height of 116.3mm and a capacity of $950cm^3$.
- Manual rammer weighing 4.5kg and equipped to drop freely for a distance of 45.7cm.
- A cube of concrete weighing not less than 45kg.

Figure 9: Proctor Compaction Apparatus
Mr Ashok/Mr. Shyan Arora, Sangmeshwar, 2010

- A straight edge of approximately 30cm in length.
- A sensitive balance.
- Sieves (5mm, 18mm and 40mm).
- Mixing tools such as mixing pans, spoons, trowel, and a water bottle with sprinkler top.
- An oven for drying.

3.4.2 Test Procedure

Weigh out four 2.2kg samples in four different pans and label 1, 2, 3 and 4. Estimate the natural moisture content of the soil. Estimate optimum moisture for the soil and the quantity of water required to bracket the optimum. Strive for a spread two percent in moisture between the samples with two samples below optimum and two above. Add required amount of water to sample No. 3, mix thoroughly and examine. If it is not over the optimum moisture add more water. Adjust the amount of water to be added to the other samples by an equal amount. If sample 3 appears too far above optimum when the required estimate of water is added, then it may be called sample 4. Reduce the quantity of water added to the other samples by an appropriate amount. Assemble the mould and place it on the compaction base. Compact the mixed sample in the mould in five equal layers to give a total compacted depth of approximately 127mm. compact each layer with 25 blows from the rammer dropping freely from a height of 457mm. distribute the blows uniformly over the surface of the layer being compacted. After the compaction, remove the collar from the mould and use the straight edge to trim the compacted soils even with the top. Remove the mould from the base plate, remove the compacted specimen and remove the liner. Weigh the specimen and record the weight to the nearest gram. Slice through the sample vertically and remove approximately 100grms of soil from the central section of the specimen for moisture content determination. Place the sample on a tarred aluminum can, weigh and oven dry at 110^{0}c. Determine the difference between the wet and dry weights and record as weight of moisture for calculation of moisture content. Repeat the procedure for compacting and moisture content determination for each of the remaining samples (i.e. the two specimens below optimum moisture).

3.5. California Bearing Ratio (CBR) Test

After the compaction test then comes the major test for this study i.e. the CBR test which is meant for the evaluation of the bearing capacity of the soil as a sub-grade for pavement design. CBR test can be done in the laboratory (hand operated or machine operated) as well as in the field. For the purpose of this study, the hand operated laboratory experiment will be used.

3.5.1. Apparatus

- Mould and steel cutting collar.
- Spacer disc
- Surcharge weight.

Figure 10: Laboratory CBR Apparatus (Sangmeshwar, 2010)

- Dial gauges and sieves.
- Penetration plunger.
- Loading machine.
- Miscellaneous loading.

3.5.2. Test Procedure

According to the British standard (BS 1377) part 4, the CBR laboratory test is carried out as written below. Normally after the compaction and the determination of the moisture content, the mould plus the compacted sample are weighed.

- The mould is soaked in tank filled with water for a period of 96 hours (ignore this step for un-soaked sample).
- The swell reading and the percentage age swell are measured at the end of 4 days.
- Take the mould out of the tank and allow water to drain.
- The sample is then place under the penetration piston and a surcharge load of 10 lb is applied and the penetration load values are determined.
- The penetration depth is then plotted against the penetration load, and the CBR value is determined from the graph.
- Also percentage age CBR and the dry density graph can be plotted in order to find the CBR at required degree of compaction.

3.6. Mixing

This is the stage in which mixtures of soil-bagasse ash will be prepared. It is the most important stage in this study because it will help determine the effect of the proposed stabilizer (bagasse ash) on the results of the two main tests of the study (i.e. compaction and CBR tests).

3.6.1. Preparing the Soil-Bagasse Ash Mixtures

- The four different samples of soil that were compacted and tested for CBR should each be placed on a mixing pan.
- The mixtures will be prepared by adding 1%, 2%, 3% and 4% of bagasse ash by weight to the 1st, 2nd, 3rd and 4th samples of soil respectively.
- After the addition of the bagasse ash, thorough mixing should follow to ensure even distribution of the ash in each sample.
- However, maximum care must be taken in order not to add the wrong proportion of bagasse ash to any sample.

3.6.2. Compaction of Mixtures

After preparation of the mixtures, this is another important phase of the study as it helps to determine the compaction characteristics of the mixtures. However, the index properties of the mixtures can be determined before compaction if necessary. Each mixture should be compacted (using the standard compaction method) in order to define its optimum moisture content and the maximum dry density. The OMC and the MDD of all mixtures should then be recorded. Then OMC against bagasse ash percentage should be plotted and MDD against bagasse ash should also be plotted.

3.6.3. Curing and Soaking

- After the compaction of the mixtures, the mixtures should be wrapped in protective bags like gunny bags.
- The wrapped mixtures should then be cured for a period of 7 days.
- At the end of the seventh day, the mixtures should then be soaked in tanks filled with water for a period of 4 days.

3.6.4. California Bearing Ratio of the Stabilized Soil Samples

The last and final phase of the laboratory exercise is the determination of the California bearing ratio values of the stabilized soil samples. These values would however, show how the CBR values would behave with increasing bagasse ash content.

- After 96 hours of soaking (i.e. at the end of the fourth day), the mixtures should be taken out of the tanks.
- Water should be drained out.
- Simple penetration test should be carried out on the mixtures to determine their CBR.
- Graph of penetration depth against the penetration loads should then be plotted.

4. Results and Discussion

4.1. Natural Soil

4.1.1. Control Tests

4.1.1.1. Natural Moisture Content

The test was carried out in accordance with the BS1377:1990, Part 2. This test is essential because in most soil tests the natural water content must be determined to help give an idea of the natural state of the soil in the field. Also, it is used in determining bearing capacity and settlement.

Five different samples of the soil were taken for the test and the summary of the test result can be seen in Table 5 below.

Sample No.	1	2	3	4	5
Wt. of container m1(g)	14.86	15.06	16.44	17.32	17.86
Wt. of wet soil + container m2 (g)	104.82	103.79	100.1	99.91	100.16
Wt. of dry soil + container m3 (g)	82.35	81.82	79.20	79.30	80.09
Wt. of water m4(g)	22.47	21.97	20.90	20.61	20.07
Wt. of dry soil m5(g)	67.49	66.76	62.76	61.98	62.23
Moisture content w%	33.29	32.91	33.30	33.25	32.25
Av. moisture	33%				

Table 5: Summary of Natural Moisture Content Test Result

Showing calculation of test sample 1;
m1= 14.86g; m2 = 104.82g; m3 = 82.35g;
m4 = m2 – m3 = 104.82 – 82.3 = 22.47g
m5 = m3 – m1 = 82.35 – 14.86= 67.49g
w = (m4/m5)*10 = (22.47/67.49)*100 = 33.29%

From the result obtained, it can be deduced that the natural water content of the soil which is the ratio of the weight of water to the weight of solids in the given mass of soil is 33%.

4.1.1.2. Specific Gravity

Two different samples of the soil were taken and tested for specific gravity according to the BS 1377: part 2: 1990, method 8.3. The summary of the test result is given in Table 6 below.

Pyknometer No.	3	4
Mass of bottle+soil+water	79.9841	80.9064
Mass of bottle+soil	32.2528	33.3715
Mass of bottle full of water	76.7308	77.5638
Mass of bottle	27.0023	27.9796
Mass of soil, A	5.2505	5.3919
Mass of water in full bottle, B	49.7285	49.5842
Mass of water used, C	47.7313	47.5349
Vol. of soil particles, D = B - C	1.9972	2.0493
Particle density = A / D	2.629	2.631
Average Particle Density	2.63	

Table 6: Specific Gravity Test Result

4.1.1.3. Grain Size Analysis

This test was carried out in accordance to the BS 1377:1990 part 2, methods 9.2, 9.3 and 9.5. However, summary of the result can be seen in tables 4.2 and 4.3 below.

Size (mm)	Weight of retained soil (g)	Percent retained (%)	Percent passing (%)
20.0	0.0	0.0	100.0
14.0	0.0	0.0	100.0
10.0	0.0	0.0	100.0
5.0	0.3	0.6	99.4
2.0	0.9	1.8	97.6
0.60	7.6	15.2	82.4
0.425	1.8	3.6	78.8
0.30	1.8	3.6	75.2
0.212	2.0	4.0	71.2
0.15	2.0	4.0	67.2
0.063	1.6	3.2	64.0
pan			

Table 7: Sieve Analysis Result
Initial Mass of Soil M1= 50.0g

Particle density: 2.62			m1 = 50.0g		Hydrometer	
Elapsed time t(min)	Hydrometer reading Rh'	True reading Rh	Effective depth Hr(mm)	Modified reading R	Particle diameter D (mm)	% finer
1	18.0	18.5	122.0	18.5	0.0437	59.7
2	16.5	17.0	128.0	17.0	0.0317	54.9
4	14.5	15.0	136.0	15.0	0.0231	48.4
30	11.0	11.5	150.0	11.5	0.0089	37.1
60	8.5	9.0	160.0	9.0	0.0065	29.0
120	6.0	6.5	170.0	6.5	0.0047	21.0
240	3.5	4.0	180.0	4.0	0.0034	12.9
1440	2.5	3.0	184.0	3.0	0.0014	9.7

Table 8: Hydrometer Analysis

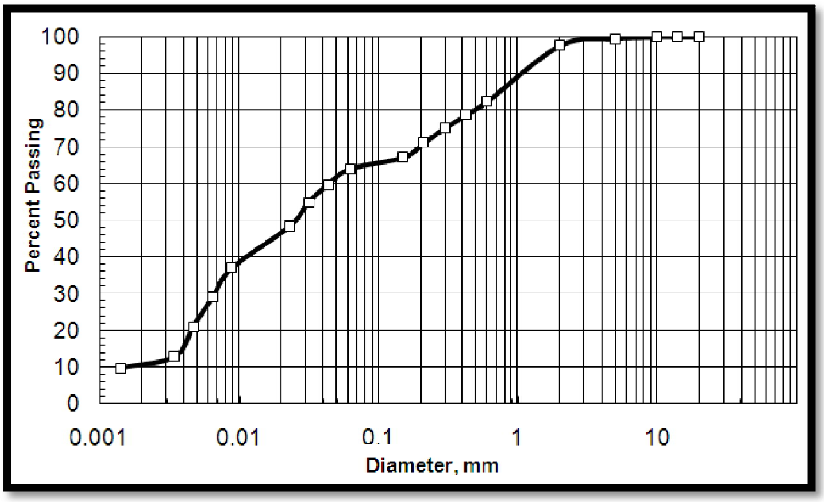

Figure 11: Particle Size Distribution Curve of Untreated Soil Sample

Clay	Silt			Sand			Gravel		
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse
Symbol	CLAY, %		SILT, %		SAND, %		GRAVEL, %		
O	11		53		34		2		

Table 9: Results of Grain Size Analysis

From the grain size analysis, the results obtained indicate that the soil has 11% clay, 34% sand, 53% silt and 2% gravel. According to BS 5930:1990 any soil that has more than 35% clay and silt content, it is considered as a fine grained soil.

Component	% by weight
SiO_2	78.34
$Al2O_3$	8.55
Fe_2O_3	3.61
CaO	2.15
Na_2O	0.12
K_2O	3.46
MnO	0.13
TiO_2	0.5
MgO	1.65
BaO	0.16
P_2O_5	1.07
loss on ignition	0.42

Table 10: Chemical Composition of Sugarcane Bagasse Ash (Romildo Et Al., 2004)

4.1.2. Atterberg Limits

The Atterberg limits (liquid and plastic) which describe the nature of fine-grained particles of the soil were determined in accordance to the BS 1377; 1990, part 2, and method 4.3. However, the results of the tests for both the liquid and plastic limits are summarized in tables 4.4 and 4.5 respectively.

Determination no.	L1	L2	L3	L4
container no.	589	639	1021	1100
cone penetration (mm)	17.0	18.7	21.0	23.0
wt. of container + wet soil (g)	63.24	63.94	74.87	72.82
wt. of container + dry soil (g)	48.50	49.12	55.63	52.25
wt. of water (g)	14.74	14.82	19.24	20.57
wt. of container (g)	15.39	17.87	17.95	15.21
wt. of dry soil (g)	33.11	31.25	37.68	37.04
moisture content %	44.42	47.42	51.06	55.53
Av. moisture content = liquid limit	50			

Table 11: Liquid Limit Test Result

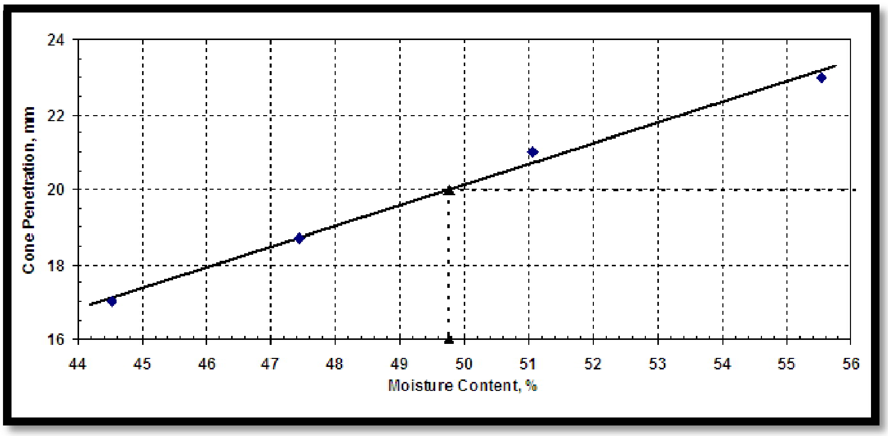

Figure 12: Liquid Limit: Penetration of Cone against Moisture Content

Determination No	P1	P2
container no.	144	614
wt. of container + wet soil (g)	17.97	17.43
wt. of container + dry soil (g)	17.09	16.75
wt. of water (g)	0.88	0.68
wt. of container (g)	15.04	15.18
wt. of dry soil (g)	2.05	1.57
moisture content %	42.93	43.31
Av. Moisture content = plastic limit	43	

Table 12: Plastic Limit Test Result

From the results;
Liquid limit (LL) = 50%
Plastic limit (PL) = 43%
Plasticity Index (PI) = 50 – 43 = 7%
Percentage passing 425µm = 79%
From above, it can be deduced that the moisture content at which the soil begins to behave in a plastic way is 7%. With the low value of PI = 7%, the soil can be termed as a sandy silt with a yellow brown color.
From the results obtained, it is then adjudged that the soil is unsuitable for direct use as a sub-grade material.

4.1.3. Compaction

Five different samples of the soil were prepared for compaction test. The standard compaction test was carried out in accordance to BS 1377: Part 4: 1990, Method 3.5 using 4.5kg rammer. The result of the test is shown below.

Test No	1	2	3	4	5
wt. of mold + wet soil	5788	5872	5954	5915	5872
wt. of mold	3997	3997	3997	3997	3997
wt. of wet soil	1791	1875	1957	1918	1875
bulk density ρ	1.791	1.875	1.957	1.918	1.875

Table 13: Determination of Bulk Density

test no/top $ bottom	1/T	1/B	2/T	2/B	3/T	3/B	4/T	4/B	5/T	5/B
container no	614	379	825	178	823	408	72	555	786	465
wt. of wet soil + cont.	106.0	91.5	74.1	72.6	82.05	52.82	111.0	127.1	115.20	102.10
wt. of dry soil + cont.	94.60	82.10	65.50	64.50	71.46	46.60	92.50	106.50	94.80	84.40
wt. of cont.	15.20	15.00	14.60	15.80	17.50	14.40	14.80	15.20	15.30	15.10
wt. of water	11.40	9.40	8.60	8.10	10.59	6.22	18.50	20.60	20.40	17.70
wt. of dry soil	79.40	67.10	50.90	48.70	53.96	32.20	77.70	91.30	79.50	69.30
moisture content	14.36	14.01	16.90	16.63	19.63	19.32	23.81	22.56	25.66	25.54
Av. moisture content	14.18		16.76		19.47		23.19		25.60	
$\rho d = \frac{100\ \rho}{100 + w}$	1.569		1.606		1.638		1.557		1.493	

Table 14: Moisture Content and Dry Density ρd

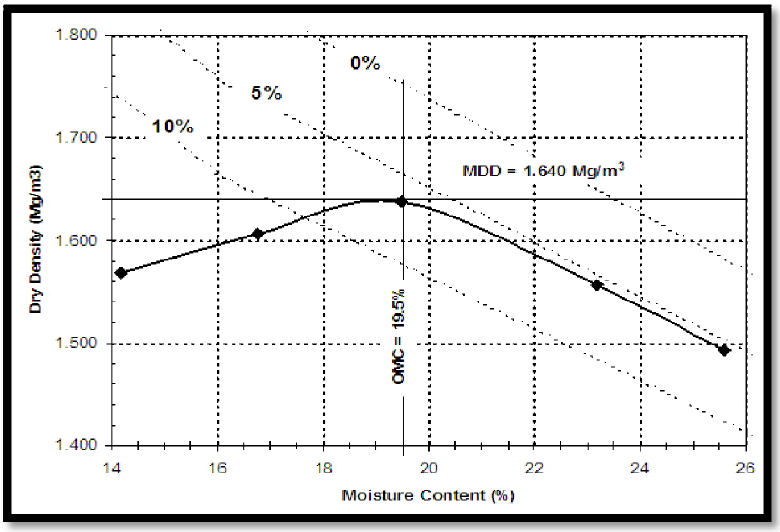

Figure 13: Dry Density and Moisture Content Relationship

Maximum Dry Density = 1.640 Mg/m^3
Optimum Moisture Content = 19.5%
Specific Gravity = 2.63
Natural Moisture Content = 33%
Volume of mold = 1000cm^3
No of Blows per layer = 27
No of Layers = 5
Total Mass of Sample = 10,000 g
Retained on 20mm sieve = 0 g
(BS 1377: Part 4: 1990, Method 3.5)

4.1.4. California Bearing Ratio (CBR)

The California bearing ratio value of the natural soil compacted at optimum water content was determined. The CBR test reported was carried out in accordance to BS 1377: 1990, part 4, method 7.2. The summary of the test result of the test is shown below.

Penetration of Plunger, mm	**10 kN Proving Ring Deflection, One (1) Division = 0.002 mm = 0.0086**			
	Top		**Bottom**	
	Div	kN	Div	kN
0.00	0	0	0	0
0.25	4.0	0.034	6.6	0.057
0.50	8.3	0.071	11.9	0.102
0.75	13.7	0.118	16.3	0.140
1.00	18.3	0.157	21.0	0.181
1.25	25.8	0.222	24.3	0.209
1.50	30.6	0.263	28.4	0.244
1.75	35.6	0.306	32.4	0.279
2.00	42.3	0.364	36.5	0.314
2.25	46.5	0.400	40.1	0.345
2.50	51.4	0.442	42.7	0.367
3.00	58.7	0.505	49.2	0.423
3.50	64.4	0.554	54.0	0.464
4.00	69.4	0.597	58.6	0.504
4.50	72.7	0.625	63.5	0.546
5.00	76.4	0.657	66.9	0.575
5.50	79.9	0.687	72.2	0.621
6.00	84.8	0.729	74.5	0.641
6.50	87.2	0.750	78.1	0.672
7.00	90.9	0.782	82.0	0.705
7.50	94.0	0.808	84.7	0.728
8.00	97.1	0.835	88.5	0.761
Tested / Corrected CBR / CBR 2.50 CBR 5.00	3.4% 3.3%		2.8% 2.9%	
CBR		3%		2.9%

Table 15: Summary of CBR Result for Untreated Soil Sample

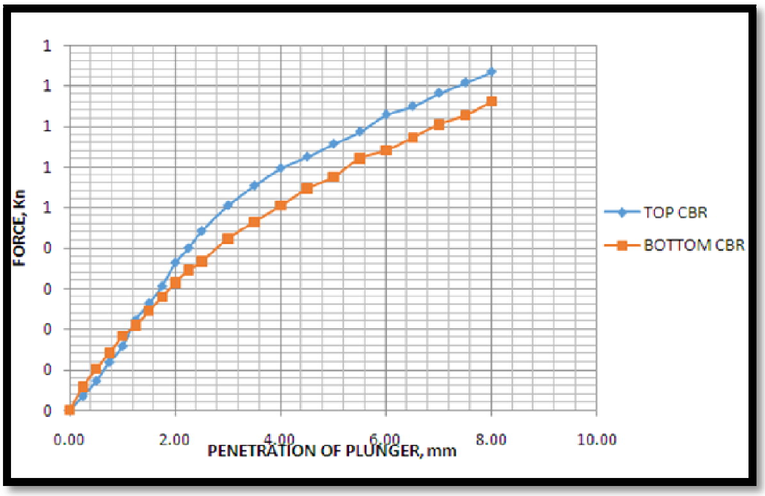

Figure 14: CBR of Untreated Soil Sample: Depth of Penetration of Plunger with Force

The graph above shows how the penetration of plunger varies with load for the untreated soil. For both the top and bottom of the sample, it can be seen that the depth of penetration increase with increasing load. The test result revealed that the top and bottom CBR values of the soil are 3% and 2.9% respectively.

It is necessary to infer the CBR value of an untreated compacted soil in the perspective of the common relationship between the CBR value and the quality of the soil used when it comes to pavement design (Bowles, 1992). CBR values ranging from 3 to 7% are considered as poor in terms of consistency. This means that the untreated compacted soil in this study has poor consistency according to its CBR value.

4.1.5. Summary of Properties of the Untreated Soil

The engineering properties of the untreated soil determined in the laboratory are summarized in the table below:

Natural Moisture Content	**33%**
Liquid limit	50
Plastic limit	43
Plasticity index	7%
Specific gravity	2.63
Percentage passing 425µm	79%
Optimum moisture content	19.5%
Maximum dry density	1.640 Mg/m^3
Top CBR	3%
Bottom CBR	2.9%
Colour	yellow brown
Clay content	11%
Silt content	53%
Sand content	34%
Gravel content	2%

Table 16: Engineering Properties of Untreated Soil Sample

From the engineering properties of the untreated soil determined by the series of tests conducted, it is adjudged that the soil in its natural state cannot be used directly as a sub-grade material. This is on the basis of its plasticity and the percentage passing the BS sieve No. 200 as well as its California bearing ratio value. Fine grained soil with a at least 25 percent passing the BS sieve No. 200 and a plasticity index greater than 10 is considered a good candidate for stabilization(NLA, 2004). From grain size analysis, it was found that 79% is passing the BS sieve No. 200, and the top and bottom CBR values of the sample are 3% and 2.9% respectively which do not meet the strength requirement to be used for a sub-grade, hence the soil requires treatment.

4.2. Treated Soil

4.2.1. Atterberg Limits

The LL of the untreated soil sample is 50%. 1% bagasse ash treatment increases the LL to 69%. Another sample of the soil was treated with 2% bagasse ash and the LL dropped to 68%. 3% bagasse as treatment also decreases the LL to 67%. Further treatment of the soil with 4% bagasse ash further decreases the LL to 66%.

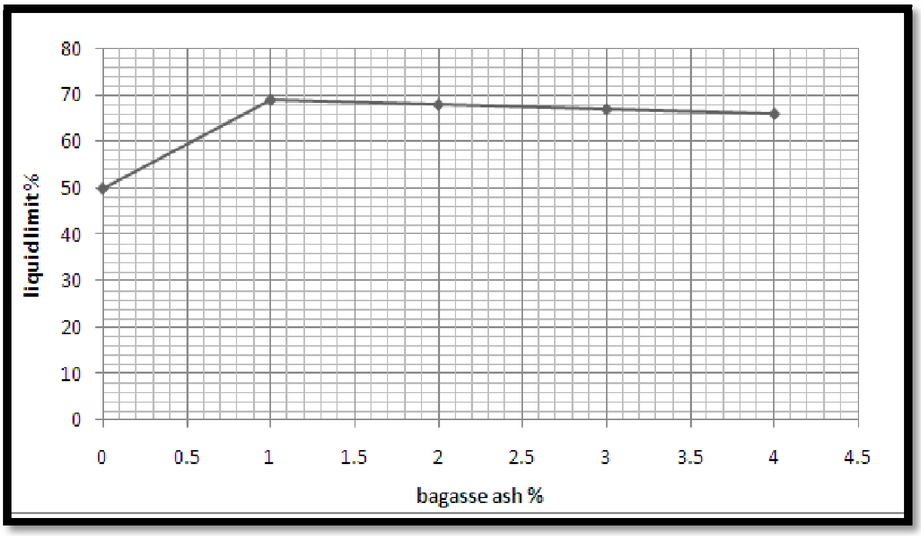

Figure 15: Variation of Liquid Limit with Increasing Bagasse Ash Content

From the PL graph, it can be seen that plastic limit increases with increasing bagasse ash content. However, 1% bagasse ash treatment has more effect on the PL than the remaining percentages. This is so because 1% treatment massively increases the PL from 43% to 62.5% while other percentages only increase the PL with small value.

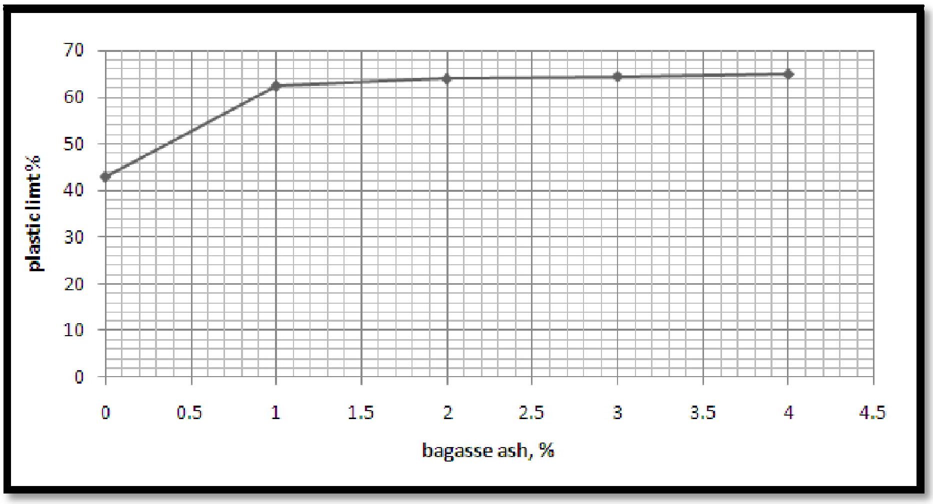

Figure 16: Variation of Plastic Limit with Increasing Bagasse Ash Content

The PI graph shows that increasing bagasse ash content drastically reduces the PI. The PI of the soil decreases from 7% down to 1% after treatment.

Figure 17: Variation of Plasticity Index with Increasing Bagasse Ash Content

The possible explanation for this is that as bagasse ash (a pozzolana) content increases, it supported further flocculation and aggregation of the clay particles in the soil sample. This in turn increases the effective grain size due to the agglomeration of the clay particles. The agglomeration turned clayey soil to a silty soil and thus, by itself decreases the liquid limit of the soil because of the lower surface area and plastic limit increases (Mu'azu, 2007).

LL and PI indicate the amount as well as the activity of clay minerals in the soil; therefore, increment in their values will make the soil to become poorer subgrade in terms of pavement support. Therefore, bagasse ash can be said to be a good stabilizer because it decreases the LL and PI of the soil in study.

4.2.2. Compaction Characteristics

4.2.2.1. Maximum Dry Density (MDD)

The MDD shows a general trend of decrease with increasing bagasse ash content. 1% bagasse ash treatment causes the MDD to decrease from 1.640 Mg/m^3 to 1.623Mg/m^3. With 2% treatment, the MDD further drops to 1.601Mg/m^3. 3% bagasse ash treatment decreases the MDD to 1.506Mg/m^3. 4% bagasse ash treatment further causes the MDD of the soil to drop to 1.456Mg/m^3.

The general drop in MDD is as a result of the flocculation and agglomeration of clay particles (caused by cat ion exchange) occupying larger spaces which leads to corresponding decrease in dry density. The drop in density with increasing bagasse ash content may be attributed to the replacement of soil particles with specific gravity of 2.62 in a given volume by particles of the ash which has a relatively lower specific gravity (Ernest, 2007).

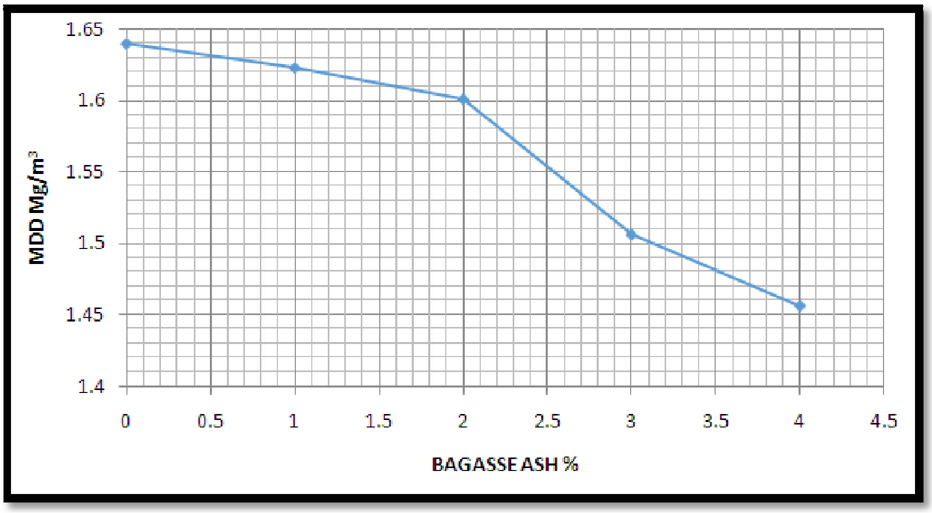

Figure 18: Variation of MDD with Increasing Bagasse Ash Content

4.2.2.2. Optimum Moisture Content (OMC)

The OMC shows a general trend of increase with increasing bagasse ash content. 1% bagasse ash treatment causes the OMC increases from 19.5% to 22.6%. With 2% treatment, the OMC increases to 23.27%. 3% bagasse ash treatment increases the OMC to 24.19%. 4% bagasse ash treatment further increases the OMC to 25.0%.

The increment in OMC is as a result of pozzolanic reaction of the lime present in bagasse ash with clay percentage of the soil (Ola, 1983). The simple explanation for this is when the lime present in the ash dissociates in the presence of water into calcium and hydroxyl ions either of the following situations arise; the calcium either replaces cations of other elements present at the cation sites in the soil or calcium ions were absorbed by the soil if there were other unattached anions apart from hydroxyl ions on the soil surface.

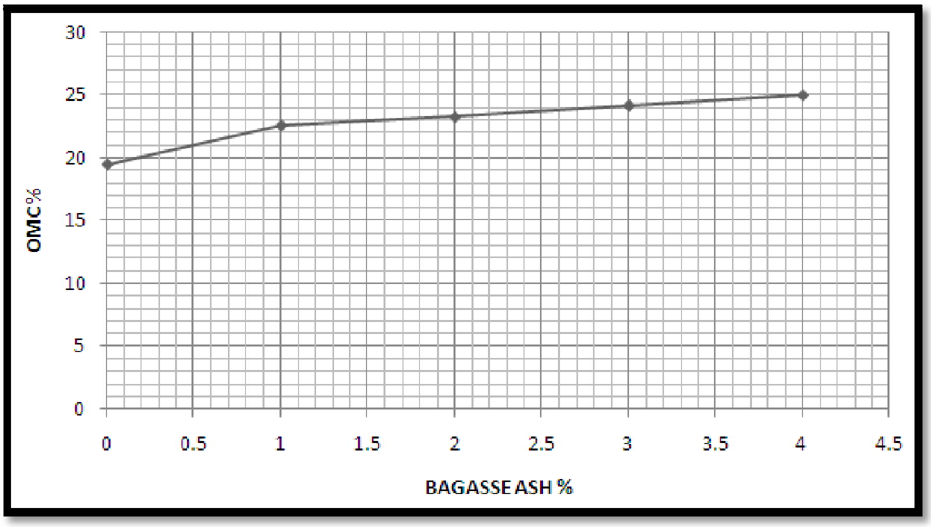

Figure 19: Variation of OMC with Increasing Bagasse Ash Content

In other words, the effect of bagasse ash content on MDD and OMC can be explained using its specificgravity which is less than that of soil. As the bagasse ash content increases it reduces the MDD while the OMC increases as the bagasse ash content increases because of extra water required for the pozzolanic reaction of bagasse. Reaction of any pozzolanic material like bagasse ash and clay present in the soil laterite requires extra water, which explains the increase in the OMC (Mua'zu, 2007).

However, the decrease in MDD with increasing bagasse ash content and the corresponding increase in OMC is beneficial because it eased the achievement of compaction with wet soil. Thus, there is less need for the soil to be dried to lower moisture content before compaction.

4.2.3. California Bearing Ratio (CBR)

The variation of CBR with increasing bagasse ash content can be seen in figure 6. The results show that the top and bottom CBR values of the soil sample increase with 1% bagasse ash content. The values further increase with 2% bagasse ash content. However, this was followed by a decrease in the CBR values with 3% and 4% bagasse content.

The peak CBR values of 18% and 20% for top and bottom respectively were achieved by treating the soil with exactly 2% bagasse ash content. Therefore, if the pozzolanic nature of soil-bagasse ash reaction is taken into consideration, then 2% bagasse ash treatment can be said to be the adequate for sub-base course construction (Ernest, 2007).

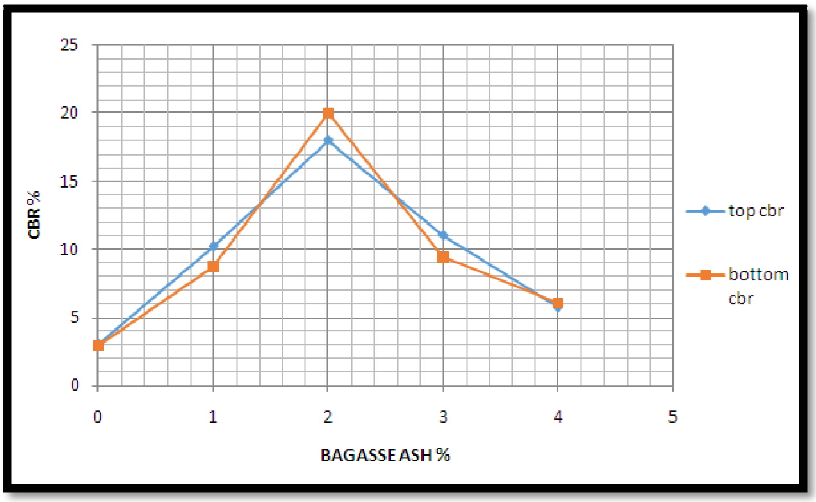

Figure 20: Variation of CBR with Increasing Bagasse Ash Content

However, in road construction capping layers are sometimes introduced to help in reducing wetting up and losing strength of sub-grades during construction. If capping is required, then CBR value of 3% or less is considered poor for a sub-grade material. In the case of widely encountered CBR range where capping is considered according to road category, CBR value of 3 to 5% is considered as normal for a sub-grade material. If capping is totally unnecessary, then CBR value of 5 to 15% is considered good for sub-grade material.

Taking the above into consideration, then the top and bottom CBR values of 18% and 20% attained at 2% bagasse ash treatment can be said to be good for sub-grade strength. This means 2% bagasse ash treatment can stand as adequate for sub-grade strength.

5. Conclusions and Recommendations

5.1. Conclusion

An investigation was undertaken to assess the suitability of using bagasse ash as a good additive for soil stabilization. Effects of the ash on the geotechnical properties of fine grained soil were determined. The following conclusion has been drawn based on the findings of the investigation:

- The soil in study was classified according to the grain size analysis and the consistency limits as well-graded yellow brown sandy silt. It is a good candidate for treatment.
- There was a general reduction in the percentage of fines with increase in bagasse ash content. The changes in shape of curves are very apparent to sieve 5mm to 20mm, and more marked at sieve 0.0014 down to clay particle size. The percentage-passing sieve BS 200 was reduced to almost zero which was as a result of flocculation and agglomeration of mixture of the clay fraction to form pseudo-silt sizes.
- With respect to the consistency limit, liquid limit reduces while the plastic limit increases and consequently the plasticity index reduce with increase in bagasse ash content. The reduction in plasticity was due to the reduction in liquid limit. The effect of bagasse ash content on liquid limit, plastic limit islinked with the pozzolanic action of bagasse ash in aiding the flocculation and agglomeration of fines (clay particles) in the soil. This brought aboutincrease in effective grain size due to agglomeration of the clay particles. The agglomeration turned the clayey soil to a silty soil and this by itself decreases the liquid limit of the soil because of an increase in surface area, thus increases the plastic limit.
- For the compaction characteristics, the optimum moisture content (OMC) increases while maximum dry density (MDD) decreases with increasing bagasse ash content. This compaction behavior occurs as a result of both the grain size distribution and specific gravities of the soil and the bagasse in this case. The modifier initially coats the soils to form larger aggregates, which consequently occupy larger spaces. This trend is for the fine-grained soil to decrease in dry density especially with bagasse and which has specific gravity lower than that of soil. The increase in optimum moisture content may also be attributed due to extra water requirement for pozzolanic reaction of the ash with the proportion of fines (clay particles) in the soil sample. However, the conclusion to this is that there is benefit in the general trend of change in both the OMC and the MDD because in construction that involves wet soil, there is less need for the soil to be dried prior to compaction.
- Soil CBR is asignificantguide determined for usage as road base or sub-basematerial. Test result indicates that the top and bottom CBR values of the soil increase by treating from 1% to 2% bagasse ash content and then begin to drop by treating from 3% to 4% bagasse ash content. Peak top and bottom CBR values of 18 and 20 respectively

were attained by treating the soil with 2% bagasse ash content. For lightly traffic roads, 2% bagasse ash treatment could be recommended for sub-base coarse material.

Finally, considering that bagasse ash treatment reduces the percentage of fines (clay particles) in the soil, decreases the liquid limit and the plasticity index of the soil, increases the OMC and decreases the MDD of the soil, increases the CBR value after 1% treatment and 2% treatment, then it can be concluded that bagasse ash could be used as a good additive for soil stabilization.

5.2. Recommendations

Based on the findings of the study, the following recommendations are proposed:

- More percentages of bagasse ash (5%, 6%, 7%, etc.) could be usedin order to find out whether a CBR value higher than the peak CBR value attained in this study could be achieved.
- Soils other than fine grained soils could also be treated with bagasse ash in order to gain more knowledge on the usage of bagasse ash as a possible additive for soil stabilization.
- More strength tests like unconfined compressive strength (UCS) test could be carried out on bagasse ash treated soil sample in order to know the effect of the ash on the UCS value as well as the curing days.
- Other additives like fly ash could also be mixed with soil similar to that of the study for possible treatment. This will give an idea on which of the additives used is a better one for soil stabilization.

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