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STRENGTH CHARACTERISTICS AND INDEX PROPERTIES OF EXPANSIVE SOIL-BAGASSE ASH MIXTURES

Mengistu Mena Kuleno
Department of Civil Engineering, Wolaita Sodo University, Ethiopia. E-mail: menmena3@gmail.com
Adisu Mesene Mena
Department of Civil Engineering, Wolaita Sodo University, Ethiopia. E-mail:*adisumesene@gmail.com*

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ABSTRACT

The performance of any structure highly controlled by the underlying soil geotechnical characteristics. Soil is a base of the structure, which actually supports the structure from beneath and distributes the load effectively. Problematic soils such as expansive clay cause major problems in the design, construction, and maintenance of civil structures. Enhancing the strength of the soil is essential for successful analysis intended to support structures. Soil stabilization is a mechanism in which the existing properties of soil are improved by different methods. The main objective of the study is to enhance the strength of expansive soil by using the industrial waste product (bagasse ash) as stabilizing material. To meet this objective, a review of related literature had been carried out. Disturbed and undisturbed sample collected from Bole airport expansion project. The strength characteristics of expansive soil were evaluated for different proportions of bagasse ash in replacement. Basic laboratory tests conducted were, atterberg limit, unconfined compression strength (UCS) test, compaction, California bearing ratio (CBR) tests. The results of laboratory tests indicated that, as a bagasse content increases, the plasticity index of the soil decreases, the maximum dry density of black cotton soil increases and further decreases, unconfined compressive strength increases and further decreases and California bearing ratio increases and again further decreases. Based on this finding, the study forwarded conclusions and effective recommendations.

1. INTRODUCTION

Soil can be broadly classified as organic and inorganic. Or-ganic soils are derived from decomposition of plant and an-imal materials. Inorganic soils are derived from the mechan-ical or chemical weathering of rocks from rom rocks and their degradation products. Inorganic soil is residual soil located at the place where it was formed is referred and transported soil which is moved to another location by grav-ity, water or wind. Expansive soils termed black cotton soils are principally residual. In case of Ethiopia, they are derived from the weathering of basic volcanic rocks which cover most of the Ethiopian plateau. Since volcanic rocks are fine textured rocks, the soils so formed from these rocks are in-variably clays or silty clays. Expansive soils are found in areas with poor internal drainage and low to moderate rain-fall. They contain montmorillonite as a principal clay min-eral with additional minerals as kaolinite and halloysite. They are black and gray in color. Expansive soils are soils that expand when water is added, and shrink when they dry out. This continuous change in soil volume can cause homes built on this soil to move unevenly and crack.

According to [1] also black cotton soils are confined to the semi-arid regions of tropical and temperate climatic zones and are abundant where the annual evaporation exceeds the precipitation

Soil is a base of structure, which actually supports the structure from beneath and distributes the load effectively. However, not all naturally occurring materials are suitable for construction. Problematic soils such as expansive clay cause major problems in the design, construction and maintenance of civil structures. As stated by [2] it is estimat-ed that about 40% soil of Ethiopia is covered with expansive clay causing economical and construction challenges to the sector. This urges the need for wider application of cost effec-tive and environmentally friendly stabilization technologies.

Soil stabilization is a mechanism in which existing prop-erties of soil are improved by different methods. Expansive soils are clay soils, black or dark grey in color and they have a potential for heaving with an increase of moisture content and they shrink with a corresponding decrease of moisture content. This change in volume due to increase or decrease of moisture content can be improved by different methods that used to decrease moisture holding capacity and to in-crease the bond strength between soil particles. Some of the methods that are used: Mechanical stabilization: which is rearrangement of soil particles by some of mechanical com-paction, cementing stabilization which is use of cementing material such as cement, lime, bitumen/asphalt etc. to soil. And chemical stabilization which is the use of chemicals in soil such as calcium chloride; sodium chloride etc.

From the above method of stabilization, cementing stabi-lization the most common world widely used and its appli-cation is most easily and effective, because the most locally availability of cementing material such as lime. So, there are so many researches undertaken to come up with the stabili-zation of expansive soils with different locally available ma-terial.

Bagasse ash is a byproduct obtained from sugar and eth-anol industry. Sugarcane bagasse ash is a fibrous material remained after sugar, water and other impurities were re-moved from sugarcane. As stated in [3] bagasse contains amorphous silica, which is an indication of pozzolanic properties, which holds the soil grains together for better shear strength and it can reduce the water holding capacity. The study used bagasse ash as stabilizing material for black cotton soil and checked under various tests such as: stand-ard proctor test (compaction test), unconfined compressive strength (UCS) test, california bearing ratio (CBR) and atter-berg's limit test.

Many researchers attempted to stabilize the black cotton soil with use of cementous materials, industrial waste and agricultural wastes as a combination. The subject of stabili-zation was relatively well researched in Ethiopia and differ-ent parts of the world.

Moses and Saminu [4] stated that expansive soils are referred to as black cotton soil in some parts of the world. They are so named because of their suitability for growing cotton. The color of black cotton soils ranging from light grey to dark grey and black. Black cotton soils are confined to tropical and temperate climatic zones. The study conducted a laboratory test was on black cotton soil to assess its suitabil-ity for use as road pavement material so that cement kiln dust treated black cotton soil and failed to record desired result so that not recommended for use as a single stabiliz-ing agent for road pavements.

As expansive nature of black cotton soil brings much problems for pavement and also any other construction. It affects the performance and life of the pavement. Jadhav and Kulkarni [5] used foundry sand, rice husk ash and bagasse ash to improve the properties of black cotton soil. The cost comparison of the study indicates that the stabilized pave-ment by using industrial wastes saved more.

According to the study of [6] improvement of expansive soil by addition of lime and cement on black cotton soil from different parts of Addis Ababa. Index properties, compaction characteristics and swelling pressure of soil-cement and soil-lime were determined using atterberg limit test, mois-ture-density relations, free swell and swelling pressure tests. The study concluded that Swelling pressure of expansive soil decreases with increasing lime, cement and molding water content. 4-6% of lime and 9-12% of cement yielded significant improvement on plasticity and swelling proper-ties of expansive soils. [7] evaluated lime and liquid stabi-lizer called con-aid for stabilization of potentially expansive subgrade soil on samples collected from Addis-Jimma road which had indicated different pavement damages exacer-bated by the presence of expansive soils. The experimental study involved atterberg limit test, moisture-density relation, UCS, CBR and CBR swell. The findings of the study stated that Addition of lime reduced maximum dry density and increased the optimum moisture content. 4% of lime by dry weight of the soil was optimum lime content to stabilize the soil even though increased quantity of lime led to increased strength. Addition of lime reduces the swelling potential but no significant improvement in the engineering properties of the soil was attained by addition of con-aid.

Peethamparan and Olek [8] had examined the stabilizing effect of four cement kiln dusts (having different physical and chemical characteristics) on Na-Montmorillonite clay. The cement kiln dusts decreased the plasticity index (PI), increased the, initial pH value, UCS and stiffness of the clay. The free lime content of the cement kiln dust was found to be the most significant parameter for the effectiveness of the stabilization along with the duration of curing period.

Osinubi, et al. [9] had studied the effect of compaction de-lay on strength characteristics of black cotton soil stabilized with blast furnace slag and cement, and had found that compaction delay reduces the strength of the stabilized soil.

One of the agricultural and industrial waste products is bagasse ash. When juice is extracted from the cane sugar, the solid waste material is known as bagasse. When this waste is burned it gives ash called as bagasse ash. There are litera-tures that report the effective stabilization of expansive soil by using bagasse ash blended with other materials, some are detailed as follows.

As per the study of Onyelowe [10] stabilized the Soil us-ing cement with variations of bagasse ash ranging from by weight of the dry soil. The OMC, MDD, and CBR tests were carried out on the mixture of soil with cement and with ba-gasse ash as admixture. The results indicate that there is a general reduction in the maximum dry density while there is an increase in the maximum dry density with increase in bagasse ash content at 6% cement content. The optimum moisture content generally increased with increase in the bagasse ash content. There was also a tremendous im-provement in the CBR with Bagasse Ash compared to the natural soil. Kiran and L [11] had studied characteristics of black cotton soil using bagasse ash and additives as stabilize. Under this study laboratory experiments are carried out for different percentages of bagasse ash and additive mix proportions. The strength parameters like CBR, UCS are de-termined. It is observed that, the blend results of bagasse ash with different percentage of cement for black cotton soil gave change in density, CBR and UCS values.

1.1 General Objective

The main objective of study is to approve usage of the industrial waste Product (bagasse ash) as stabilizing material of expansive soil in replacement of cement or lime and others

1.2 Specific Objectives

(1). To study the geotechnical properties of black cotton soil
(2). To study the properties of black cotton soil by adding Bagasse ash.
(3). To find out optimum amount of stabilizer required for stabilization of black cotton soil.
(4). To evaluate the strength characteristics of expansive soil for different proportions of bagasse ash in replacement

1.3 Scope of the Study

This study was supported by secondary resources and by conducting a series of laboratory experiments. Many researches are conducted on stabilization of expansive soils by using bagasse ash blended with different materials and chemicals, this study is based on only using the industrial waste product bagasse ash which collected from wonjji sugar factory. To determine the stabilization capacity of this materials four tests have been conducted that are atterberg limit test, unconfined compression test, compaction test and CBR tests. However, the findings of the research were limited to one soil sample considered in the research which brought from Bole Airport terminal expansion project. The results were also specific to the type of test procedures that have been adopted in the experimental work.

2. MATERIALS AND METHODOLOGY

The present study was started by setting a clear framework of the research and reviewing secondary resources from literature review, research bulletins, previous studies, laboratory manuals and internet.

Expansive soil (black cotton soil) is collected from Bole Airport expansion project as the disturbed and undisturbed sample. Collected soil sample is first dried in direct sunlight; the clods are broken to get a uniform sample and sieved to determine the required sample size. The organic matters, small aggregates, broken wooden material, pieces of glasses were removed carefully from soil sample. Bagasse ash was collected from the wonjji sugar factory of Ethiopia and oven dried for 24hr at 105 oc and then it was sieved at number 200 (75-micron sieve) to make it as cement sized as we are using it as cementing material.

Basic laboratory tests conducted were: atterberg limit, unconfined compression strength (UCS) test, compaction, California bearing ratio (CBR) tests. The four tests first carried out on black cotton soil without blending it with bagasse ash. The stabilization of black cotton soil with bagasse is carried out by blending the soil with different percentages of bagasse ash (3%, 6%, 9% and 12%) and to determine the consistency and strength behavior of black cotton soil with each bagasse ash waste percentage, laboratory tests such as atterberg, compaction, CBR, UCS tests were carried out. By getting the results of all these blends the comparison of the best suitable additive mix was carried out. The optimum percentage of bagasse ash to be added was determined.

2.1 Expansive Soil

The soil used in this study was dark grey in color and was known as black cotton soil, it was obtained from Bole Airport terminal expansion project using the method of dis-turbed sampling. The soil was dried, pulverized and sieved with 4.75 mm sieve size as required by ASTM standard for required laboratory test. Free swell test was carried out be-fore carrying out any test and the value was 160%. Laborato-ry result of soil sample tested in geotechnical laboratory room in order to compare it with soil treated with bagasse ash shown Table 2.

2.2 Bagasse Ash

Bagasse is waste product obtained from sugar factory, when sugarcane crushed for production of sugar juice the residue remaining is bagasse (see Fig. 1). For each 10 tons of sugarcane crushed, a sugar factory produces nearly 3 tons of wet bagasse. It is currently used as a bio fuel, in the manu-facture of pulp and paper products and building materials. Bagasse Ash is a fibrous material containing high amounts of unburned matter, silicon and aluminum oxides as main components. It is nearly black in color. Choudhary [12] stud-ied the chemical composition of bagasse ash by burning in the oven to reduce it to inorganic form (see Table 1).

Table 1 Chemical composition of bagasse ash [12]

Description of properties	Percen tage
Silica (sio2)	64.38
Magnesium (Mgo)	0.85
Calcium (Cao)	10.26
Iron (Fe2o3)	4.56
Sodium (Na2o)	1.05
Potassium (K2o)	3.57
Alumina (Al2o3)	11.67

Table 1 Laboratory evaluated properties of pure black cotton soil

Content description of properties	Obtained results in laboratory
Color	Black grey
Water (w) (air dried)	13%
Liquid limit (WL)	82%
Plastic limit	34.11%
Plastic index	47.9%
Maximum dry density (KN/m^3)	1.46
Optimum moisture content (OMC)	23.94
Unconfined compressive strength (KN/m2)	96.77
California bearing ratio (CBR in %)	16.18 %
Free swell test, %	160

Fig. 1 Industrial waste bagasse ash obtained from wonjji after sieved

Bagasse ash collected from wonjji sugar factory was nearly black in color and has specific gravity of 1.35. Before we use it for stabilization it was oven dried and sieved in 75 microns so that it should resemble to the characteristic of cement.

2.3 Water

Water used for mixing reasonably clean and free of oil, salt, alkali, sugar, vegetables, or other substances injurious to the finished product. Water known of potable quality used without testing

3. Result and Discussions

3.1 Atterberg limit test

Atterberg limit test is conducted to define different boundaries of several states and finally to determine the plasticity characteristics of the soil and soil blended with different percentage of bagasse ash. The plasticity index shows the swelling characteristics of the soil and it differs with different replacement of the stabilizing materials. Table 3 shows the result of atterberg limits for 0%, 3%, 6%, 9% &12% of bagasse ash. Fig. 2 indicates the variation of the result.

Table 2 Atterberg limit result with at percentage content of bagasse ash.

Percentage replacement	0%	3%	6%	9%	12%
Liquid limit	82	78.5	74.8	57.4	49.57
Plastic limit	34.11	33.44	32.01	30.53	28.68
Plasticity index	47.89	45.06	42.79	26.87	20.89

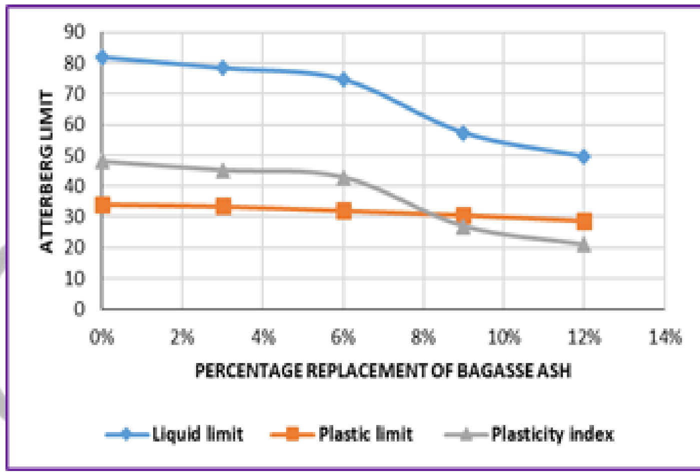

Fig. 2 Variation of atterberg limit test due to percentages of bagasse

Since most widely known that atterberg limit test used as an indicator of expansive potential. Most expansive soils can exist in plastic condition over a wide range of moisture contents. This behavior resulted from the capacity of the ex-pansive clay mineral to contain large amount of water be-tween particles and yet retain a coherent structure through the inter-particle electrical forces. Soil plasticity, a useful in-dicator of swell potential, is influenced by the same micro scale factors that control the swell potential. The two states that defines the soil characteristics determined from atter-berg tests are liquid limit and plasticity index test. It was observed that the addition of bagasse ash to expansive (black cotton) soil affected its plasticity and the liquid limit state value decreased considerably with increasing the amount of bagasse ash percentage. When plasticity index increases the swelling potential of the soil also increases and the reverse may be true. There are relations that relates plas-ticity index with swelling potential as follows. The relation-ship studied by [13] on plasticity index of the swelling po-tential stated that the greater a mineral soil plasticity index, the greater swelling potential (see Table 4).

Table 4 Relations between plasticity index and swelling potential [13]

Plasticity index (%)	Swelling potential
0 – 15	Low
10- 35	Medium
20- 25	High
35 and above	Very high

As the Content of bagasse ash increases the plasticity index decreases. At 12% of bagasse ash plasticity index decreased from 47.89% (very high swelling potential) at pure soil to 20.89% (high or medium swelling potential). The maximum reduction of the plasticity index determined is on the test for the replacement of 12% bagasse ash and the test is as Table 5 and Fig. 3 shows the value of moisture content for 25 blows. According to Fig. 5 which is the Casagrande's plasticity chart (ASTM standards) for laboratory classification of fine-grained soil. Where CL indicates inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays. ML indicates inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity. CH indicates inorganic clays of high plasticity, fat clays and MH indicates inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts. For A-line PI is taken as 0.73(LL-20) and the PI of U-line, approximate upper limit for natural soils is taken as 0.9(LL-8). Depending on the value of liquid limit and plastic limit the soil can be easily categorized.

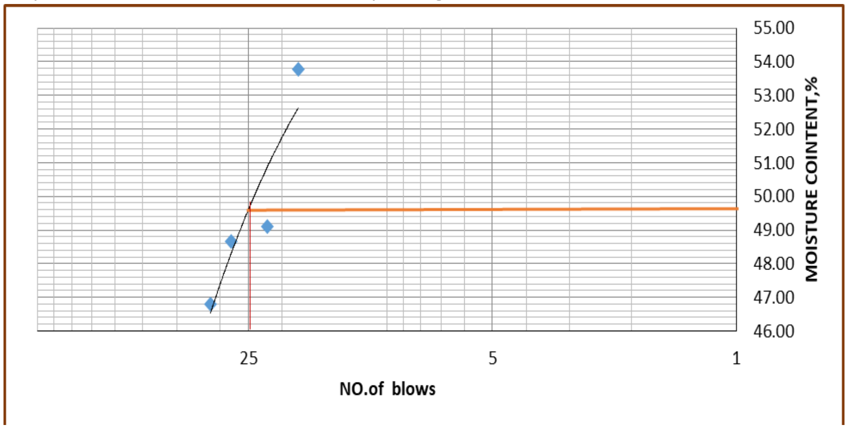

Fig. 2 Liquid limit for 12% blend

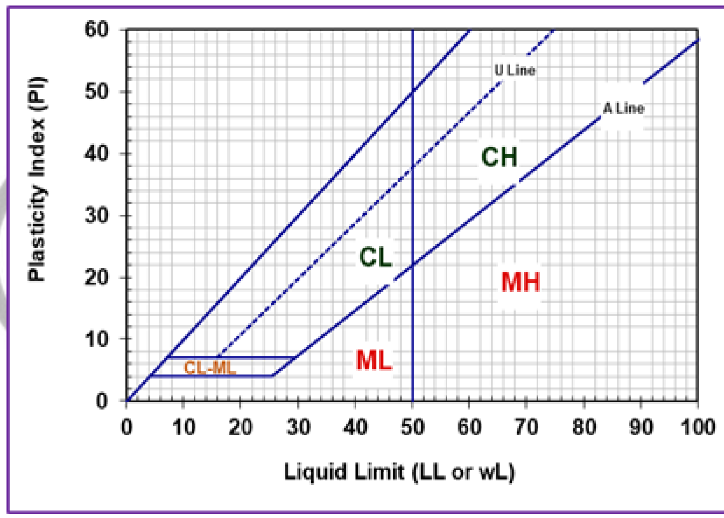

Fig. 3 Casagrande's plasticity chart (ASTM standards) for laboratory classification of fine-grained soil

3.2 Proctor (compaction) test

This test conducted to determine maximum dry density at optimum moisture content and to study the behavior of expansive soil when it blended with different percentage bagasse ash. Results of maximum dry density (MDD) and optimum moisture content (OMC) for black cotton soil stabilized with bagasse ash is listed in Table 5 and clearly explained at Fig. 5 that the maximum dry density is at 9 percentage of bagasse ash.

Table 5 Results of maximum dry density and optimum moisture content

Content of bagasse ash	Black cotton soil + % Bagasse ash	
	MDD (gr/cm^3)	OMC (%)
0	1.46	23.94
3	1.63	27.64
6	1.83	23.81
9	1.95	23.13
12	1.73	25.2

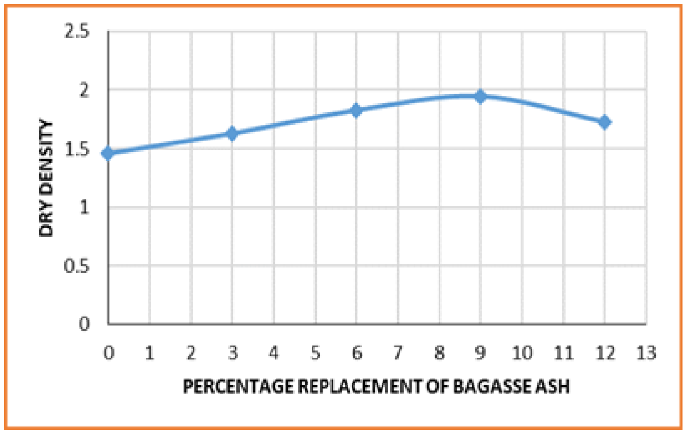

Fig. 4 Maximum dry density for the percent content of bagasse ash

The maximum dry density obtained at optimum moisture content from compaction test is the governing case for design of foundations and for highway subgrades. The soil which have not fulfill the required maximum dry density must be improved by different means. One of the characteristics of black cotton soil is very low maximum dry density at high optimum moisture content. So, when this soil treated with a bagasse ash stabilizer its maximum dry density improves from 1.46 gr/cm^3 at OMC of 23.94% (pure black cotton soil) to 1.95 gr/cm^3 at OMC of 23.13% (at 9% of bagasse ash).

Improvement in the maximum dry density was observed for 3%, 6% and 9% of bagasse ash, but then after further increase in blend MDD decreases. This decrease may be due to low specific gravity of bagasse ash replaces higher specific gravity soil and it is fibrous in nature. As per this study the maximum or replacement for maximum dry density is at 9%. The MDD for 9% of bagasse ash determined from Fig.6.

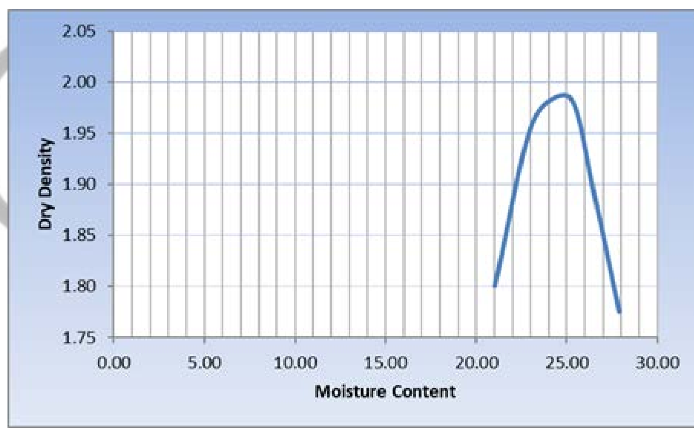

Fig. 5 MDD for 9% of bagasse ash

3.3 Unconfined compression strength test

This test conducted to study the unconfined compressive strength and undrained compressive strength of expansive soil blended with bagasse ash. Fig. 7 is taken while doing unconfined compression strength test in laboratory. The Results of bagasse ash and unconfined compression strength test as indicated in Fig. 8. As the percentage of bagasse ash increases UCS also increases.

a)  b)

Fig. 6 Unconfined compression strength test

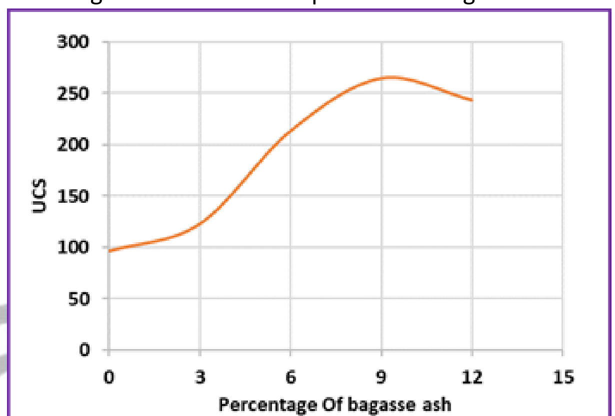

Fig. 7 Unconfined compression strength (UCS) for the bagasse ash replaced

Low compressive strength of foundation materials indicates that low caring capacity of structures built on it, so to become safe design the footings of foundations to be designed with high depth and these increases the total costs of project. The bearing capacity foundation can be increased by different means by treating it with stabilizing materials. When black cotton soil which have low bearing, capacity treated with bagasse ash it shows high improvement of bearing capacity. It's bearing capacity increases from 96.77kpa in pure soil to 264.31kpa at 9% blend of bagasse ash and further decreases.

The strength increases slowly with increase of % of bagasse ash, maximum strength obtained for 9% bagasse ash. Compressive strength then decreases with increase of % bagasse ash. This may be due to grain size effect, specific gravity of both materials etc.

3.4 California bearing ratio (CBR)

The California bearing ratio, abbreviated as CBR is defined as the ratio of the test load to the standard load, expressed as percentage for a given penetration of the plunger. This test conducted to determine the penetration strength of subgrade and sub base materials of flexible pavement for highway foundation. The unsoacked CBR value significantly improved when the black cotton soil stabilized with bagasse ash. The results determined in this is reported. The maximum CBR value has been read at 9 % of blend (see Fig. 9)

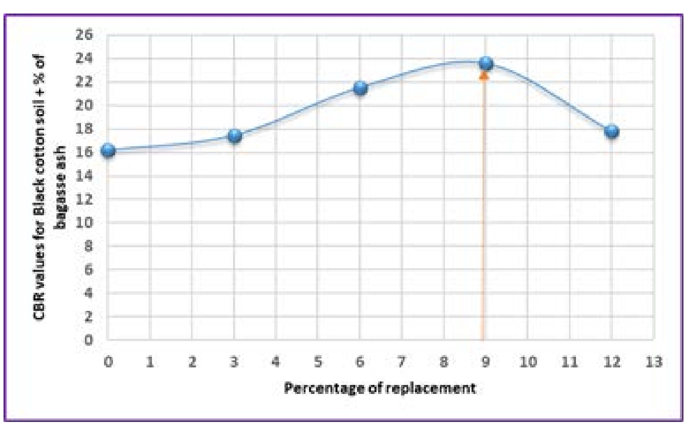

Fig. 8 CBR value for bagasse ash replaced (black cotton soil+ % of bagasse ash CBR values)

The unsoaked CBR values give the idea about the strength and bearing ability of soil. The result shows that, CBR values increase rapidly for 3%, 6% and 9% of bagasse ash, but then after suddenly drop to lower values. We have seen, as % of bagasse ash increase OMC increases for some values and then decreases, which somehow responsible for decrease in CBR values. At low energy levels, less water is available for controlling the process of hydration, which leads to form weak bonds and resulted in less strength. The maximum increase was observed for 9% of bagasse ash. The CBR test is carried out on a compacted soil for 9% of bagasse ash. the stress-strain behavior was well explained in Fig. 10. The CBR result for 12% bagasse ash was repeated to check whether the abrupt change of CBR value is correct or not.

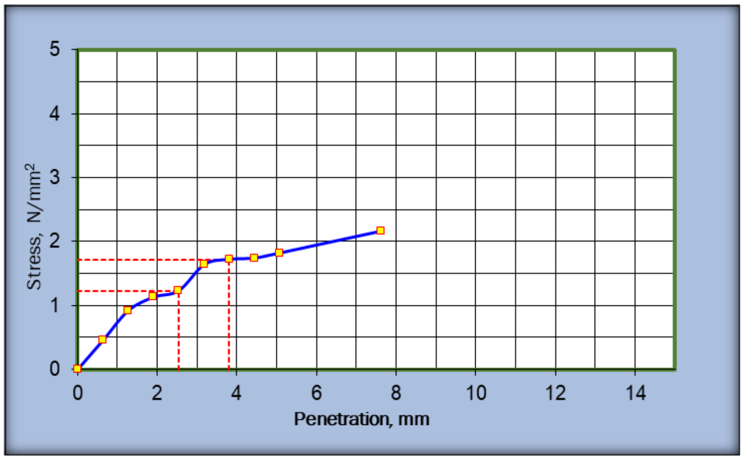

Fig. 9 Stress-Strain Curve

4. Conclusions and Reccomendations

The laboratory study was carried out to stabilize black cotton soil (expansive soil) using bagasse ash to be conducted on atterberg test to get the improved plasticity index, compaction test to increase maximum dry density and to decrease optimum moisture content of the soil, unconfined compression strength to improve bearing capacity of the soil, California bearing ratio to modify the penetration strength of subgrade soil of foundation materials.

From this study it could be observed that bagasse content increases, the plasticity index of soil decreases, maximum dry density of black cotton soil increases and further decreases, unconfined compressive strength increases and further decreases and California bearing ratio increases and again further decreases. According to the findings, conclusion of the study has been summarized as follows:

- ✓ Water taking capacity of Black cotton soil (expansive soil) decreases with increase in content of bagasse ash.
- ✓ Plasticity index of black cotton soil decreases with increase percentage of bagasse ash replacement
- ✓ The maximum dry density of soil increases with at 3%, 6% & 9% of bagasse ash and further replacement decreases.
- ✓ At 9% of bagasse ash MDD increased by 33.56%.
- ✓ Optimum moisture content increases at 3% replacement and decreases 6% & 9% replacement and it shows increasing capacity at 12% replacement.
- ✓ Unconfined compression strength shows significant increase as bagasse ash replacement of at 3%, 6%, 9%.
- ✓ At 9% of bagasse ash, the UCS increased by 173.1%.
- ✓ The unsoaked CBR value is also in replacement of 3%, 6%, & 9% it suddenly drops down to lower value at 12% replacement
- ✓ Totally the optimum bagasse ash amount for three tests that are compaction, unconfined compression strength test and California bearing ratio is 9%.

Depending on conclusions of the study, related reviews and laboratory analysis the study forwarded the following recommendations

- ✓ Totally the optimum bagasse ash amount for three tests that are compaction, unconfined compression strength test and California bearing ratio is 9%.
- ✓ Awareness needs to be raised about use of bagasse ash as soil stabilizer in developing countries like Ethiopia. Testing procedures need to be standardized and available and the proper way of mixing is also needed.
- ✓ Care must be taken after mixing bagasse ash, soil, and water if its exposure to a humidity might make it loses its moisture content before compaction test.
- ✓ Awareness needs be raised about construction practices of stabilization of black cotton soils in Ethiopia using bagasse ash and testing procedures need to be standardized.
- ✓ All the value determined in this study are indicative rather than definitive due to proper and scientifically approved instruments for carrying out specific tests and concluding values according to manual specification.

- ✓ Bagasse ash usage as stabilizer material and for other purpose needs future concentration in Ethiopia due to the expansion of many sugar factories unless it has different impacts on the society, it affects health of society, destructs ecosystem.
- ✓ This could be a cost effective if it carried out with proper lab procedure and professional.

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