Stabilization of Expansive Clay Using Lime and Sugarcane Bagasse Ash

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ABSTRACT

The scarcity and rising cost of traditional stabilizers like Lime and Cement has led to the research into clay soil stabilizing potential of bagasse ash that is cheaper, readily available and environmental friendly and ha s a serious disposal problem. Bagasse is a fibrous residue of sugar cane stalks that remains after extraction of sugar and when incinerated gives the ash. The chemical analysis on bagasse ash carried out at the Ministry of Mining Kenya was found to contain mainly silica, and potasium, iron, calcium, aluminium, magnesium as minor components and exhibit pozzolanic properties. The research investigated the properties of expansive clay soil when stabilized by lime, ash and combination of lime and ash. The experiment covered grading test, Plasticity index (Atterberg) and California bearing ratio (CBR). First, particles size distribution was determined from grading test, secondly varying percentages (4%, 5%, and 6%) of lime was used to stabilize clay soil and then plasticity and CBR were determined. The same procedure was repeated for bagasse ash and finally the varying mix ratios of lime and ash 1:4, 2:3, 3:2 and 4:1 were used on the sample. The PI of the stabilized clay soil decreased with increase in the quantity of lime, ash and ratio lime to ash in all the samples. The addition of lime or bagasse ash helps to reduce the shrinkage and swelling behavior of soil hence reduction in plasticity. The plasticity reduction in this study was quantified using the linear shrinkage and swelling tests. The california bearing ratio increased remarkably with increase in lime quantity added but decreased for bagasse ash. The combination of lime and ash gave good results that meet the set standard by road design manual part III of minimum CBR of 20 for sub base road. From the results of swelling, negligible shrinkage and poor CBR values; it was concluded that sugarcane bagasse ash cannot singly be used in stabilisation of expansive clay soil. It was found that both lime and bagasse ash reduced the linear shrinkage, however, the addition of lime reduced the linear shrinkage to a greater degree than the same percentage of bagasse ash. When lime and bagasse ash are combined at the optimum ratio of 4:1, the stabilisation results conforms with the set standard of California bearing ratio of 36, plasticity index 20, Linear shrinkage of 9.0, negligible swelling.

Key words: Clay soil, sugarcane bagasse ash, Lime, stabilization, Plasticity Index, CBR,

INTRODUCTION

The high cost of traditional soil stabilizers and industrial waste disposal problem has led to intense global research towards economical utilization of industrial and agricultural waste for engineering purposes. This research evaluated the effect of partial replacement of lime by Sugarcane bagasse ash in stabilization of problematic clay soil in construction works.

Bagasse is the fibrous residue generated after the juice has been extracted from the sugar cane plant. It is normally deposited as waste and it litters the environment. Most of the bagasse produced, amounting to one-third of all the cane crushed in some cases supplies the fuel for the generation of steam (Bilba et. al., 2003) which eventually results in bagasse ash **Fig 1**. The resulting ash is deposited in stockpiles which are normally dumped in waste landfills and constitute environmental problems to the society. When bagasse is left in the open, it ferments and decays; this brings about the need for safe disposal of the pollutant, which when inhaled in large doses can result in respiratory disease known as bagassiosis (Laurianne, 2004).
Bagasse ash is a pozzolanic material which is very rich in the oxides of, silica and aluminum and sometimes calcium (Guilherme et al, 2004). Pozzolans usually require the presence of water in order for silica to combine with calcium hydroxide to form stable calcium silicate, which has cementitious properties.

Lime is calcium oxide (CaO) or hydroxides of Calium and Magnesium and is made by calcining limestone into either Calcitic lime (high in calcium) or dolomitic lime (high in Magnesium). Lime stabilization is the most widely used means of chemically transforming unstable soils into structurally sound construction foundations. The use of lime in stabilization creates a number of important engineering properties in soils, including improved strength; improved resistance to fracture, fatigue, and permanent deformation; improved resilient properties; reduced swelling; and resistance to the damaging effects of moisture. The most substantial improvements in these properties are seen in moderately to highly plastic soils, such as heavy clays (Little et al. 2003).

Expansive soils also called as Black soils or Black cotton soils are encountered in many construction sites and have poor engineering properties. West (1995) defines expansive soils as those soils that consist of clays which shrink and swell with the primary clay being Smectite (Montmorillonite). Expansive soils are problematic to engineering structures because of their tendency to heave during wet season and shrink during dry season (Mishra et al. 2008). In order to make deficient expansive soils useful and meet geotechnical engineering design requirements, the process of stabilization is applied. Traditionally the three most commonly used stabilizers are cement, Lime and asphalt or bituminous compound but the high cost of processing has made them expensive deterring their usage. In order to mitigate the problem mentioned above, alternatives to traditional stabilizers is being considered along with other benefits that may accrue from these alternatives. Several materials such as Rice Husk Ash (RHA), Pulverized Fuel Ash (PFA), lime, Sugarcane Bagasse Ash (SCBA), volcanic ash, etc are in use in many countries. There are basically two types of pozzolanas, namely natural and artificial pozzolanas. Natural pozzolanas are essentially volcanic ashes from geologically recent volcanic activity and artificial pozzolanas result from various industrial and agricultural processes, usually as by-products. The most important artificial pozzolanas are burnt clay, pulverized-fuel ash (PFA), ground granulated blast furnace slag (GGBFS) and rice husk ash (RHA). These admixtures (fly ash, cold bottom ash, crushed concrete powder, bagasse ash and blast furnace slag and phosphoric waste) have been employed in research works (Osinubi et al., 1997, 2008), during soil stabilization. The aim of the study was to determine the effect of using SCBA blended with lime to stabilize expansive clay.

MATERIALS

Sugar cane bagasse ash

The Sugar Cane bagasse Ash (SCBA) was collected from Nzoia Sugar Company Ltd, situated in Bungoma county Western part of Kenya. Bagasse is defined as fibrous residue of sugar cane stalks that remains after extraction of sugar" (Hofsetz& Silva, 2012). The chemical composition analysis of the Ash was carried out by Atomic Absorption Spectrophotometer (AAS) machine at Government laboratory of mines and Geology, Ministry of Mining and results were as shown in **Table 1**. The method used was atomic absorption of characteristic excitation energy. The sample was first grounded to fine particles of 100um or less and then digested to known weight by using a mixture of acid such as aquareqia, hydrofluoric and boric and then stocked to known volume. Each metal element was analyzed at a time using its known characteristic energy excitation. For refractory method such as Aluminium, Silicon, Titanium etc a flame temperature of 3500^{o}c was used and non refractory used 2000^{o}c to create ground state from sample solution. The AAS machine is calibrated using certified reference standards whose concentration of the metal analyzed are known. The unknown samples are then analyzed against the calibration obtained for the particular element being analyzed at that time. The ash was found to contain mainly silicon, sulphate, calcium, magnesium and aluminium

Fig 1; Sample; Bagasse ash on weighing balance

Table 1 Chemical analysis of Bagasse Ash

Description	**Abbreviation**	**Ash (%)**
Silica	Sio_2	66.23
Iron	Fe_2o_3	3.09
Calcium	Cao	2.81
Magnesium	Mgo	1.54
Sodium	Na_20	0.26
Potassium	K_2o	6.44
Loss of Ignition	-	16.36
Alumina	Al_2o_3	1.90
Titanium	Tio_2	0.07
Manganese	Mn	0.60

Expansive clay Soil

The clay soil shown in **Fig 2** was collected from various sites in Bungoma county and Standard tests were performed to determine the physical and chemical properties of the soil and details shown in **Table 2.** The grain size distribution of the clay is shown in **Figure 3** The soil was then subjected to X-ray analysis and results are shown in **Fig 4** which indicated that the soil had larger percentage of smectite (montimorilonte). The smectite group of clays is commonly classified as swelling clays because they demonstrate high peak values in untreated (air dried) and glycolated samples but designate lower values when heated. This indicates that the structure collapses with less/decreasing moisture content. Generally, the peak values of the glycolated samples show values in the range of 12.56-18.92 Å, 13.36-17.46 Å for untreated/air dried samples and values of 9.04-10.22 Å for heated samples.

Fig 2; Clay soil on weighing balance

Table 2 Chemical analysis of Black cotton soil

Description	**Abbreviation**	**Clay (%)**
Silica	Sio_2	52.85
Iron	$Fe_{2}o_{3}$	8.04
Calcium	Cao	6.01
Magnesium	Mgo	0.48
Sodium	$Na_{2}0$	0.26
Loss of Ignition	-	16.18
Alumina	$Al_{2}o_{3}$	12.24
Titanium	Tio_2	0.24

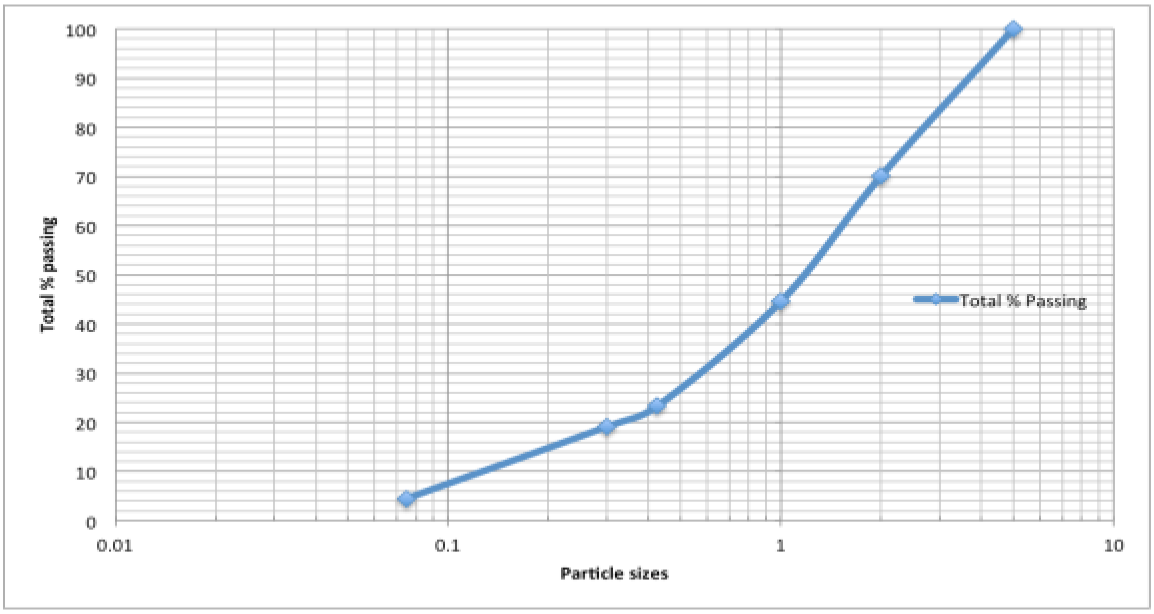

Fig 3 ; Grading curve analysis

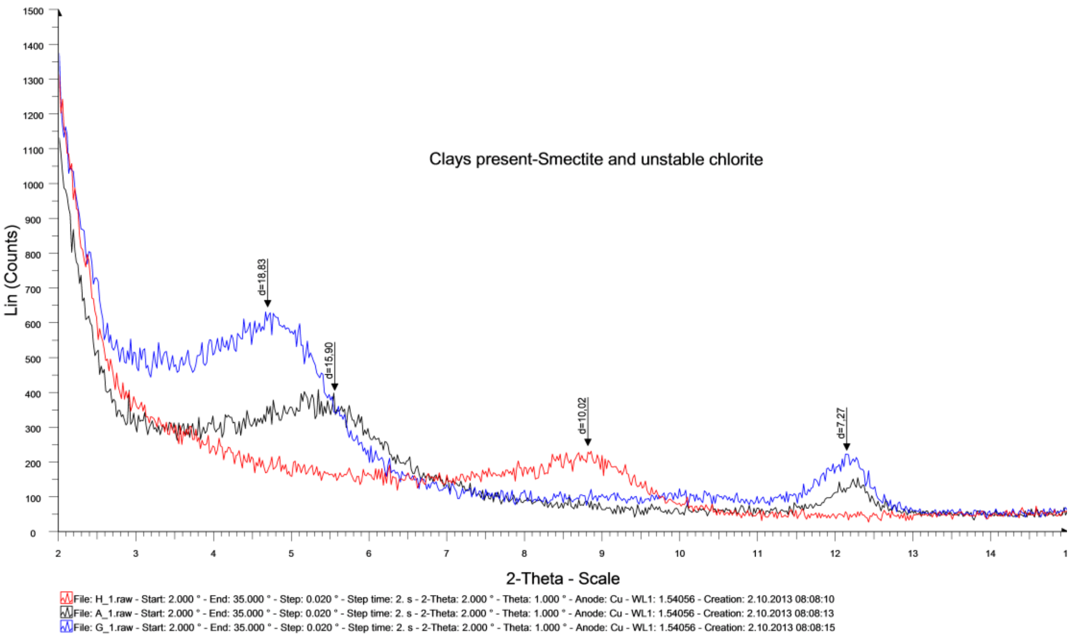

Fig 4 Clay present – smectite and unstable chlorite

Lime

Lime which contain calcium oxide (cao) commonly known as burnt lime, or quicklime, is a white, caustic and alkaline crystalline solid at room temperature. As a commercial product, lime often also contains magnesium oxide, silicon oxide and smaller amounts of aluminum oxide and iron oxide. Lime that satisfies the KEBS requirements was purchased from hardware shops.

Muntohar et, al 2013 gave the chemical composition of Lime as in **Table 3-3**

Table 3 Chemical analysis of Lime

Description	Abbreviation	lime (%)
Silica	Sio_2	0.00
Iron	Fe_2o_3	0.08
Calcium	Cao	95.03
Magnesium	Mgo	0.04
Sodium	Na_20	0.05
Potassium	K_2o	0.03
Loss of Ignition	-	4.33
Alumina	Al_2O_3	0.13
Sulphur trioxide	SO_3	0.02
Manganese	Mno	0.60
Phosphorus	P_2O_5	0.00
Water	H_2O	0.04

Laboratory Studies

The experiment conducted on the clay soil samples included determination of the physical and chemical properties of soils at their natural state. The clay sample was divided into three parts; one part was stabilized with lime only, another part with ash only and last part with varying percentage ratio of lime to ash then testing program conducted included, Atterberg limits, swelling and shrinkage and California bearing ratio.

Liquid limit: The liquid limit test was conducted on samples passing 0.425 mm (No. 40) sieve; clayey soils and soil mixed with (4, 5 and 6%) Lime, ash and both combined using Casagrande's liquid limit apparatus as per the procedures laid down in ASTM D 4318-00.

Plastic limit: The plastic limit test was conducted on samples passing 0.425 mm (No. 40) sieve; clayey soils and soil mixed with (4, 5 and 6%) Lime, ash and both combined, as per the specifications laid down in ASTM D 4318-00.

Compaction: The standard compaction tests were performed in accordance with ASTM D 1557. The specimens were of 102 mm diameter and 116 mm height. The degree of compaction of soil influences several of its engineering properties such as CBR value, compressibility, stiffness, compressive strength, permeability, shrink, and swell potential. It is, therefore, important to achieve the desired degree of relative compaction necessary to meet the required soil characteristics.

Swelling: Consolidation test ASTM D 2435-02 setup was used for determining the cyclic swell-shrink behavior of the soil. The sample was 75 mm high and 19 mm in diameter. The sample was prepared at dry density

RESULTS

The study explains the effect of Lime, Ash and combination of the two in percentages on clay soil properties. The results of this study with their discussion are presented as following;

Liquid limit and plastic limit of clay sample treated by lime and SCBA showed decrease with increase of quantities of lime and ash added as illustrated in **Table 4-6** and **Fig 5.** The addition of lime and SCBA has remarkable effect on the plasticity and linear shrinkage of cohesive soils. The general decrease in liquid limit at all soil- Lime and bagasse ash combination is attributed to the fact that the compounds formed possess cementitious properties due to calcium silicate with soil particles. This trend conforms to findings of Muntohar and Hantoro (2000) who found that the liquid limit reduces with increasing lime and rice husk ash combinations. The effect is also due to the partial replacement of high plastic particles of clay with the low plasticity lime and SCBA particles. The ratio of lime to ash gave positive results of reduction in Plasticity Index, Linear Shrinkage and swelling as given in **Fig 6**. Although the effect of ash on the plasticity and linear shrinkage of cohesive soils are remarkable but are inferior to those which occur by addition of lime only

The ratio of SCBA to blend with lime for optimum clay soil stabilization was determined by considering strength attained that meets KRDM values. The CBR values increased with the increase in the quantity of lime added but decreased when sugarcane bagasse ash alone was added as given in **Table 5** and **Fig 7.** The increase could be attributed to the decrease in compressibility caused by the decrease in porosity of the treated clay. The density of stabilized clay increased due to flocculation and agglomeration of particles which resulted into modification of particles size distribution. On application of SCBA alone 4-6 % the CBR decreased terribly because of the low content of calcium element which limited the cementitious reaction. When the blended mixture of lime and ash was used the CBR increased remarkably because of the reaction between calcium and silicate as indicated in **Fig 8**. The ash being alkaline when mixed with the sample in the presence of lime and moisture, the PH is lowest hence more silica from clay dissolves and facilitate pozolanic reaction.

Table 4 Lime only stabilization

Black cotton soil	LIME			Requirements (KRDM, 1987)	
	4 %	5 %	6 %	Wet areas	Dry areas
Liquid Limit (LL)%	55	46	41		
Plastic Limit (PL)%	29	25	27		
Plasticity modulus (PM)%	1768	1428	952		
Linear shrinkage(LS)	13	10	6		
Swelling	0.5	0.5	0.4		
Calirfonia bearing ratio	38	45	50		
Plasticity Index (PI)%	26	21	14	Min.5 – Max.20	Min.10 – Max.30

Table 5 Bagasse ash only stabilization

Black cotton soil	ASH			Requirements (KRDM, 1987)	
	4 %	5 %	6 %	Wet areas	Dry areas
Liquid Limit (LL)%	70	67	64		
Plastic Limit (PL)%	36	34	34		
Plasticity modulus (PM)%	2312	2244	1920		
Linear shrinkage(LS)	16	16	15		
Swelling	0.8	0.9	0.9		
Calirfonia bearing ratio	6	4	2		
Plasticity Index (PI)%	34	33	30	Min.5 – Max.20	Min.10 – Max.30

Table 6 lime and bagasse ash stabilization

Black cotton soil	LIME:ASH				Requirements (KRDM, 1987)	
	1:4	2:3	3:2	4:1	Wet areas	Dry areas
Liquid Limit (LL)%	66	62	57	47		
Plastic Limit (PL)%	34	33	33	27		
Plasticity modulus (PM)%	2176	1972	1632	1360		
Linear shrinkage(LS)	16	13	13	9.0		
Swelling	0.6	0.6	0.5	0.5		
Calirfonia bearing ratio	19	27	30	36		
Plasticity Index (PI)%	32	29	24	20	Min.5 – Max.20	Min.10 – Max.30

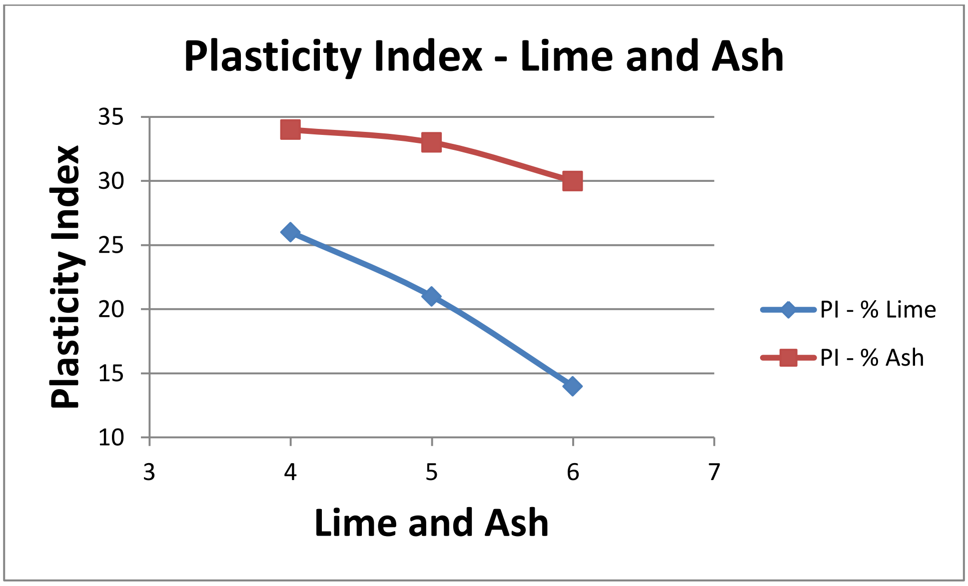

Fig 5; Plasticity index of lime and Ash

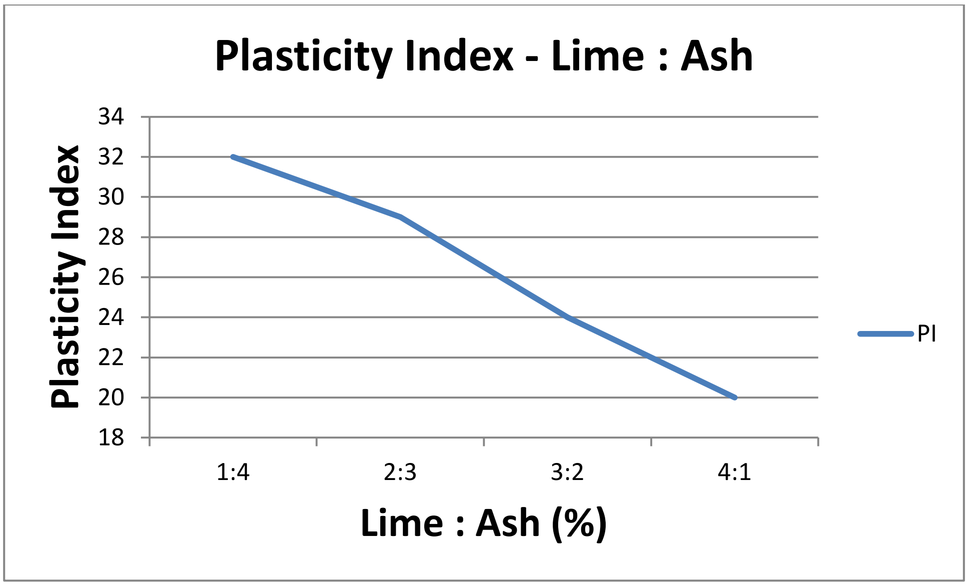

Fig 6; Plasticity index; ratio of lime to Ash

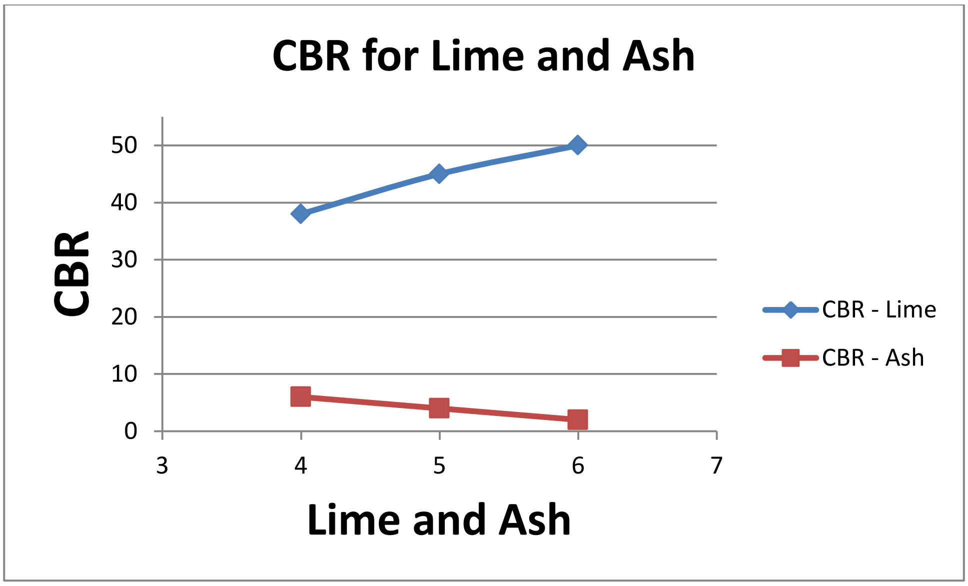

Fig 7; CBR Lime and Ash

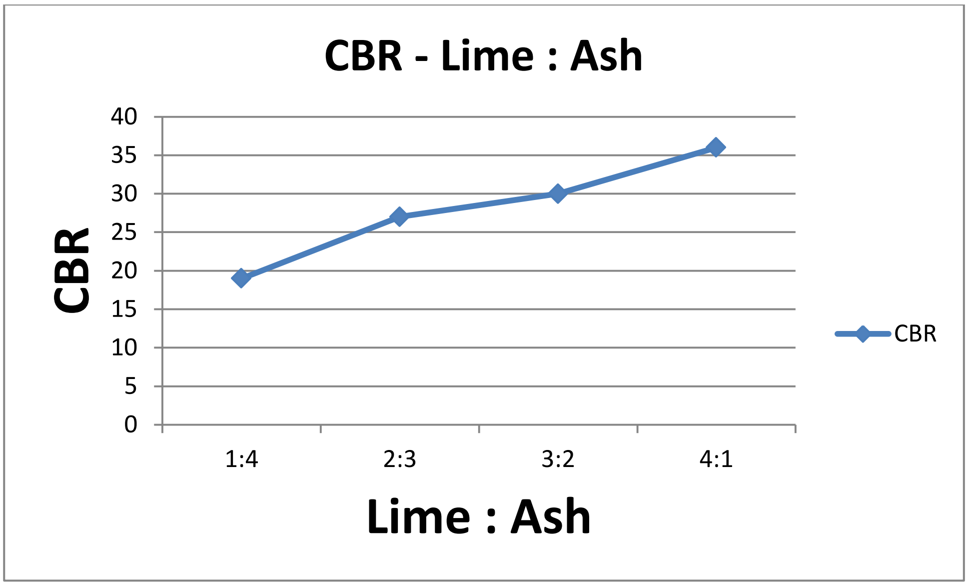

Fig 8; CBR for ratio of lime to ash (%)

CONCLUSIONS

From the results of the investigation carried out within the scope of the study, the following conclusions can be drawn:

1. The Plasticity Index of the clay soils decreased from 35 to 20 with the addition of 4:1 Lime to ash, which was about 43%.
2. The optimum ratio (4:1) of lime to bagasse ash is required to adequately stabilize expansive clay soil to achieve results that conforms with road design manual part III of minimum California bearing ratio of 36, plasticity index 20, Linear shrinkage of 9.0 and negligible swelling.
3. Bagasse ash cannot singlely be used as clay soil stabilizing agent because of huge reduction of California bearing ratio (11-2) although there was slight reduction on plasticity index as well.

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