Improvement of Strength of Expansive Black Cotton Soil Using Sugarcane Bagasse Ash-Lime as Stabilizer

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ABSTRACT
Expansive soils which contain montmorillonite clay minerals swell in contact with water and shrink when dried and these problematic soils have been a major cause for the damage losses due to natural hazards. Light weight structures and pavements are more prone to damages due to expansive soils. Many investigators have already reported the utilization of lime for stabilizing expansive soils, such as Black cotton soil. In this study, an attempt has been made to utilize sugarcane bagasse ash for stabilization of black cotton soils. Bagasse ash is an agro industrial residue, posing an environmental concern due to its disposal into landfills. The expansive Black cotton soil treated with bagasse ash-lime mixture enhances the pozzolanic nature, thus reducing the swelling potential and increasing the unconfined compressive strength of expansive soils. During the study, it was found that 20% of Bagasse ash by weight of soil and 3% lime are found to be the optimum percentages to be mixed with expansive soils for improvement of strength with and without curing. The mechanism for achieving sustainability and beneficial effects of bagasse ash have been studied in this paper, with generalized conclusions for utilization in pavement subgrade soils.

Les sols expansifs qui contiennent des minéraux argileux montmorillonitiques se gonflent au contact de l'eau et rétrécissent lorsqu'ils sont séchés, et ces sols problématiques ont été une cause majeure des pertes dues aux dommages naturels. Les structures légères et les chaussées sont plus sujettes aux dommages dus aux sols expansifs. De nombreux chercheurs ont déjà signalé l'utilisation de la chaux pour stabiliser les sols expansifs, tels que le sol de coton noir. Dans cette étude, on a essayé d'utiliser la cendre de bagasse de canne à sucre pour stabiliser les sols de coton noir. La cendre de bagasse est un résidu agroindustriel qui pose un problème environnemental du fait de sa mise en décharge. Le sol en coton noir expansif traité avec un mélange de bagasse et de chaux et de chaux renforce la nature pouzzolanique, réduisant ainsi le potentiel de gonflement et augmentant la résistance à la compression non confinée des sols expansifs. Au cours de l'étude, on a trouvé que 20% des cendres de la bagasse en poids de sol et 3% de chaux sont des pourcentages optimaux à mélanger avec les sols expansifs pour l'amélioration de la résistance avec et sans durcissement. Le mécanisme de réalisation de la durabilité et des effets bénéfiques de la cendre de bagasse a été étudié dans ce document, avec des conclusions générales pour l'utilisation dans les sols de fondation.

1 INTRODUCTION

In a tropical country such as India, various soil deposits exist, throughout which large variation in engineering behaviour can be found. One among them is Black cotton soil, covering about 20% of land area in India. Black Cotton soils, expansive in nature, consists of Montmorillonite as a primary clay mineral. Expansion in soils results from the changes in the soil water system caused by the disturbance in the internal stress equilibrium. The factors influencing the shrink-swell potential of a soil can be considered in three different groups, the soil characteristics that influence the basic nature of the internal force field, the environmental factors that influence the changes that may occur in the internal force system, and the state of stress (*Nelson& Miller*). The present trend in Geotechnical engineering is to alter the engineering properties of the native problematic soils to meet the design specifications. There is a worldwide interest in innovative research, knowledge transfer and best practice regarding the development of new ground improvement methods. One of the important emerging technologies of ground improvement methods being soil stabilization, aims at improving soil strength and increasing resistance to softening by water through bonding the soil particles together, water proofing the particles or combination of the two (*Sherwood, 1993*). The simplest stabilization processes are compaction, drainage and improving gradation of particle size and further improvement can be achieved by adding binders to the weak soils *(Rogers et al, 1996*). In chemical stabilization, it depends mainly on chemical reactions between stabilizer (cementitious material) and soil minerals (pozzolanic materials) to achieve the desired effect. The stabilized soil materials have a higher strength, lower permeability and lower compressibility than the native soil. The latest trend in soil stabilization have evolved innovative techniques of utilizing locally available environmental and industrial waste materials for the modification and stabilization of deficient soil.

Next to Brazil, India is the second largest producer of sugarcane in the world with the annual production exceeding 300 million tonnes. It is estimated that the processing of this quantity of sugarcane in sugar mills results in the production of approximately 100 million tonnes of wet bagasse annually. Sugarcane bagasse is the fibrous matter that remains as a residue after sugarcane stalks are crushed to extract their juice. The residue obtained when bagasse is burnt as a fuel in sugar mill boilers, is known to possess pozzolanic properties, but unfortunately due to lack of awareness most of it is disposed in landfills. When left in the open, it ferments and decays, thus necessitating the safe disposal of the pollutant. Also, when the pollutant is inhaled in large doses it can cause a respiratory disease known as bagassiosis (*Aigbodion,2004*).

Bagasse ash is presently used as a biofuel and in the manufacture of pulp and paper products and building materials. Recently, sugarcane bagasse ash has been tested in some parts of the world for its pozzolanic property. Few studies have been reported on the use of bagasse ash as a partial cement replacement material in respect to cement mortars. with this background, an effort has been made to study the behaviour of bagasse ash as a stabilizer for expansive soils and develop a rational approach for its usage in expansive subgrade soils underlying pavement.

2 MATERIALS AND METHODS

2.1 Black Cotton Soil

Black cotton soil, a typically expansive clay soil , was collected at a depth of 1.5m from Butkurki village, Ramdurga Taluk, Belgaum district, India. To ensure the uniformity of the soil sample it was oven dried, pulverized and sieved through a 425 micron BIS sieve before used in the present investigation.The physical and engineering properties of the soil are listed in Table 1.The soil is classified as sandy clay of high compressibility (CH) as per Unified soil classification system (USCS) and

Table 1. Basic properties of Black cotton soil

Type of test	Values
Colour	Dark grey
Specific Gravity	2.61
Liquid limit (%)	72.01
Plastic limit (%)	39.06
Plasticity Index (%)	33.00
Shrinkage limit (%)	9.36
Sand fraction (%)	11.00
Silt fraction (%)	44.00
Clay fraction (%)	45.00
Maximum dry density(kN/m^3)	14.00
Optimum moisture content (%)	33.00
Unconfined compressive strength(kPa)	134.00

2.2 Sugarcane Bagasse Ash

Sugarcane bagasse ash (BA) was obtained from Mandya sugarcane Factory, Mysore district, Karnataka, India.Sugarcane bagasse ash was burnt in controlled temperature conditions for 400^0 C for 2 hours to remove the unburnt carbon present and the bagasse ash so the generated material is likely to contain amorphous silica which is known to possess pozzolanic properties. After burning BA, it is pulverized and passing through 425 micron BIS sieve was used in the present investigation. The physical and engineering properties of the BA are listed in Table 2.

Table 2. Basic properties of Bagasse ash

Properties	Values
Specific Gravity	1.55
Liquid limit (%)	35.20
Plastic limit (%)	NP
Shrinkage limit (%)	23.40
Loss on Ignition (%)	18.20
Amorphous Silica as SiO_2(%)	66.91
Alumina as Al_2O_3(%)	4.44

2.3 Lime

Commercially available pure hydrated lime $Ca(OH)_2$ obtained from Vasu scientific house, Bengaluru with 99% purity was used in this work.

2.4 Experimental Program

In the present investigation the bagasse ash and lime used are in percentage by weight of soil.The optimum percentages of Bagasse ash and lime content to be added to black cotton soil have been determined based on unconfined compressive strength. The optimization of Bagasse ash for black cotton soil have been determined by adding 10 - 60% of Bagasse ash to black cotton soil. It was found that 20% of Bagasse ash for black cotton soil and 4% lime to be optimum for black cotton soil - Bagasse ash mixture.

The soil samples of black cotton soil-bagasse ash treated with optimum lime percentage were prepared at maximum dry density (MDD) and optimum moisture content (OMC).

Compaction tests were conducted using a mini compaction test apparatus as per the procedure of Sridharan and Sivapullaiah [2005], Unconfined compressive strength tests were carried out as per BIS: 2720 (part X) [1973], for various combinations of lime treated black cotton soil with bagasse ash. All samples were prepared at their respective maximum dry density and optimum moisture content. The prepared samples were kept in airtight plastic bags and kept in the desiccators and maintained at 100% humidity for prolonged curing periods in such a way that there was no moisture movement.

3 RESULTS AND DISCUSSIONS

3.1 Effect of Bagasse Ash and Lime on Compaction Behaviour of Black Cotton Soil

The strength of the soil can be enhanced by densification by compaction. However, when adequate mechanical stability cannot be obtained even with the increase in compactive effort or when enhanced strength or resistance to water softening is required, admixtures for stabilization combined with compaction becomes necessary. Hence, the compaction behaviour of BCS on the addition of bagasse ash and lime has been studied.

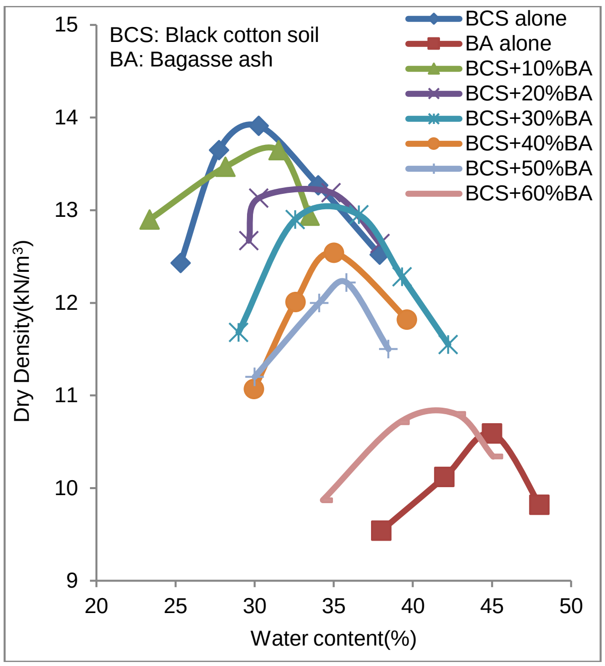

Figure 1. Dry Density–Water Content of Black Cotton Soil treated with Bagasse ash

Figure.1shows the compaction test results of Black Cotton Soil treated with 10% to 60% bagasse ash. From the compaction tests it was found that Maximum dry density(MDD) of the black cotton soil decreases and the optimum moisture content(OMC) increases, with the addition of bagasse ash and lime. The reduction in maximum dry density may be attributed to the replacement of bagasse ash in the soil mixture which has a relatively lower specific gravity than that of soil and needs a lower compactive energy to attain its maximum dry density (*Osula 1991*). The decrease in maximum dry density may also be attributed to the flocculation and agglomeration of soil particles with the large void spaces replaced by bagasse ash leading to a corresponding decrease in maximum dry density (Ola 1977). The increase in optimum moisture content is probably a consequence of the additional water held within the flocculent soil structure resulting from the bagasse ash interaction and the increased water absorption by the soil- bagasse ash mixture as a result of its lower specific gravity.

The optimization of lime soil mixtures has been done by adding various percentages of lime to the black cotton soil. On addition of 1% to 5% lime to the black cotton soil, the maximum dry density increased up to 4% witha decrease in optimum moisture content as shown in Figure 2.

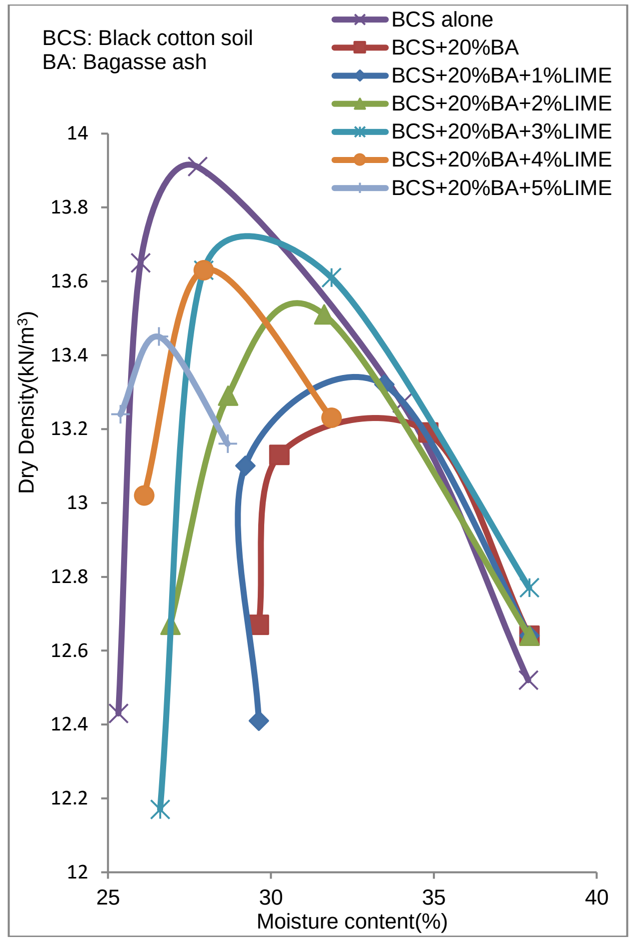

Figure 2. Dry Density–Water Content of Black Cotton Soil -Bagasse ash mixtures with lime.

Beyond 4% lime, the dry density of soil mixtures decreases with increase in optimum moisture content. This is due to the increased flocculation and agglomeration of soil particles having large void spaces occupied by lime (*Ola, 1978*) with increase in availability of lime content. This would increase the repulsive forces of the soil particles, thereby increasing the resistance to compactive effort. The increase in OMC of expansive clays treated with lime may be caused by flocculation so that when compacted the soil each have an increased volume of voids compared with untreated soil, in addition the increase in hydroxyl ions liberated by lime, increases the affinity of the surfaces of clay particles for water (*Bell, 1987*).

3.2 Effect of Lime and Bagasse Ash on Unconfined Compressive Strength Behavior of Black Cotton Soil.

The tests were conducted on strength properties as to determine the Optimum amount of bagasse ash and lime to be added to black cotton soil by unconfined compression Strength test. On addition of 10% to 60% of bagasse ash to black cotton soil, the strength increases up to 20% of bagasse ash addition on immediate testing as well as with increased curing periods due to decrease in diffuse double layer thickness and flocculation of the clay particles.

The decrease in the strength of black cotton soil treated with bagasse ash beyond 20% addition may be because of the matrix of the black cotton soil is disturbed more and more with the increase of bagasse ash. Hence, 20 % addition of bagasse ash to the black cotton soil has been chosen as the optimum percentage. The variation of unconfined compressive strength of black cotton soil treated with various percentages of bagasse ash for immediate and 7 days curing period are shown in Figure 3.

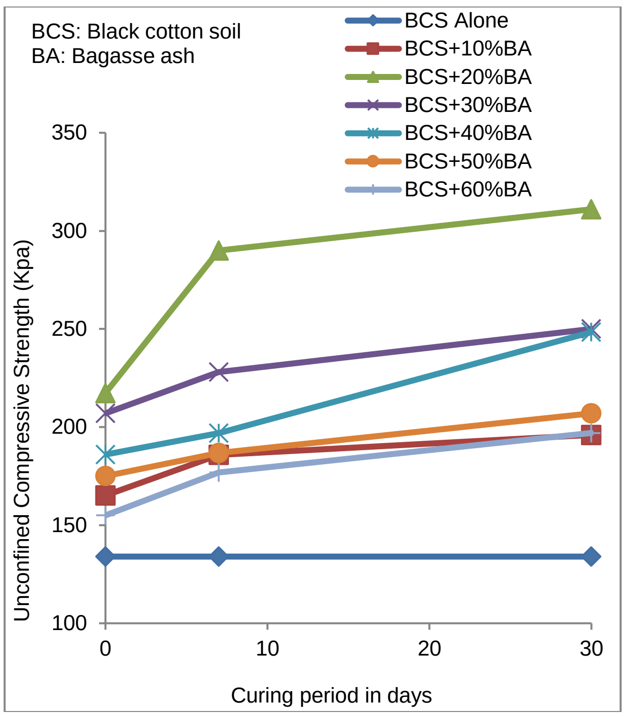

Figure 3.Variation of UCS of Black Cotton Soil -Bagasse ash mixtures with curing.

Addition of various percentages of lime to black cotton soil treated with optimum percentage of bagasse ash the strength increases up to 4% addition of lime, there after strength decreases with the increase in percentage of lime on immediate testing and curing period. The increase in strength up to 4% addition of lime may be due to pozzolanic reactions between reactive silica and free lime. Effective penetration of lime and the formation of new cementitious products such as calcium silicate hydrate and calcium aluminium hydrate (C-S-H and C-A-H), binds the soil particles together (*Narasimha Rao, 1997*). Hence 4% of lime to black cotton soil and bagasse ash mixture has been chosen as optimum lime content for the mixture.The variation in strength of black cotton soil treated with optimum percentages of bagasse ash for Immediate,7 and 30 days curing period with various percentages of lime are shown in Figure 4.

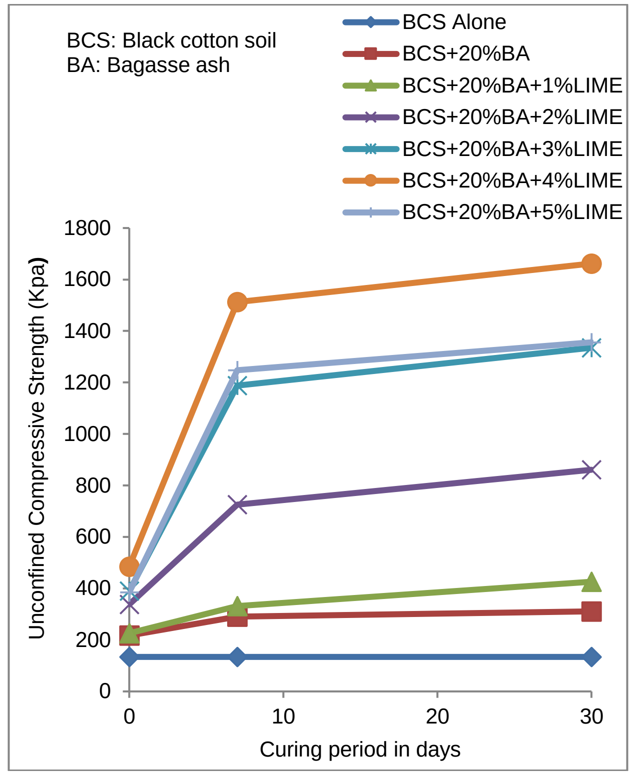

Figure 4.Variation of UCS of Black Cotton Soil -Bagasse ash mixtures with lime with different curing time.

Unconfined compressive strength tests were conducted on expansive soils treated with bagasse ash and lime and the effect of curing is presented in Table 3. On addition of 20% bagasse ash to the black cotton soil alone, the UCC strength increased from 217.36kpa to 512kpa for 0 to 60 days testing respectively. Figure 5. shows the variation of strength ratio v/s curing period in days. The strength ratio of BCS alone for the optimum condition is 1. It remained constant for the different curing period conditions because there was no addition of chemicals, therefore there is no reactions in the strength ratio. On addition of 20% bagasse ash to the black cotton soil alone, the strength ratio increased from 1 to 2.36 for 60 days testing respectively This was may be due to the pozzolanic reactions between reactive silica and free lime and also due to the effective penetration of lime in which the formation of new compounds i.e., cementitious compounds (C-S-H and C-A-H) takes place, which binds the black cotton soil and lime effectively.

Table 3. Strength of BCS with BA and lime mixtures with various curing period

Mixture	Curing period in Days				
	0	7	30	45	60
	Unconfined compressive strength (kPa)				
BCS alone	134	134	134	134	134
BCS+20%BA	217	290	311	432	512
BCS+20%BA +4%LIME	485	1513	1662	1699	1781

BCS: Black cotton soil BA: Bagasse ash

With addition of 4% lime to the black cotton soil and optimum bagasse ash mixtures, the UCC strength increased from 485kpa to 1781kpa for 0 to 60 days testing respectively. The increase in strength was due to the decrease in diffused double layer thickness and flocculation of clay particles. On addition of 4% lime to the black cotton soil and optimum bagasse ash mixtures, as shown in Table 4. The strength ratio increased from 1 to 3.67 for 0 to 60 days testing respectively. The increase in strength ratio was due to the decrease in diffused double layer thickness and flocculation of clay particles.

Table 4. Strength Ratio of BCS with BA and lime mixtures with various curing period

Mixture	Curing period in Days				
	0	7	30	45	60
	Strength Ratio				
BCS alone	1.00	1.00	1.00	1.00	1.00
BCS+20%BA	1.00	1.33	1.43	1.99	2.36
BCS+20%BA+ 4%LIME	1.00	3.12	3.43	3.50	3.67

BCS: Black cotton soil BA: Bagasse ash

3.3 Stress strain Behaviour of Expansive Soil with Bagasse Ash and Lime

Figure 5, 6 and 7. Show the stress-strain curve of bagasse ash treated black cotton soil treated with optimum percentage of lime compacted at optimum water content with and without curing periods. The stress-strain curve becomes more and more linear with the increase in strength of the soil. It is interesting to note that though the peak stress is almost the same for both the samples, the strain corresponding to peak stress is higher for the samples compacted at optimum moisture content.

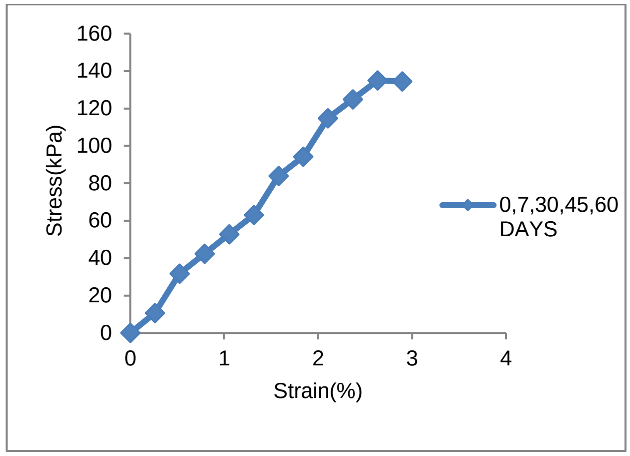

Figure 5.stress –strain curves of Black cotton soil with different curing time

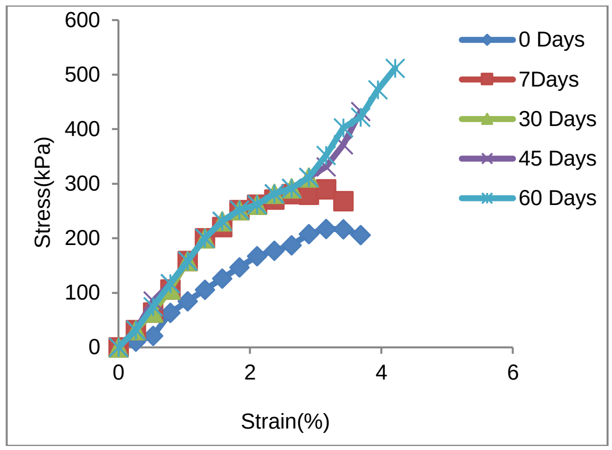

Figure 6.Stress –Strain curves of Black cotton soil – Bagasse ash mixtures with different curing time

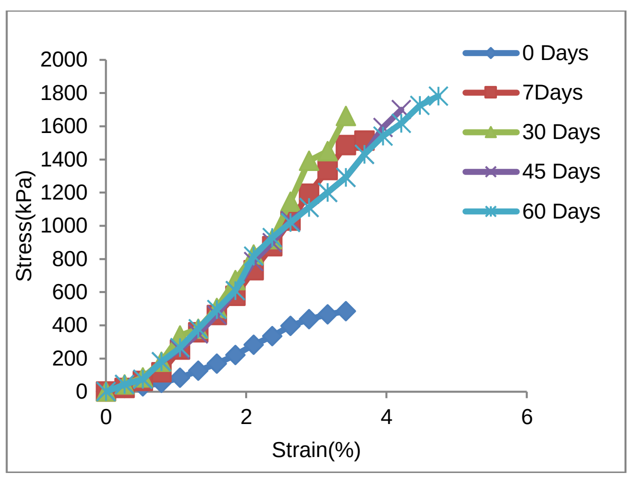

Figure 7. stress –strain curves of Soil-Bagasse ash-lime mixtures with different curing time.

4 CONCLUSIONS

Based on the experimental results and analysis, the following conclusions have been drawn:

1. Maximum dry density decreases and optimum moisture content increases for expansive black cotton soil treated with various percentages of bagasse ash. This may be due to lower density of bagasse ash replaced with a higher density of soils, resulting in the decrease of the specific gravity.
2. Addition of various percentages of bagasse ash to expansive black cotton soil the strength increases with an increase in curing period. The maximum strength was observed at 20% (by weight of soil) bagasse ash addition to black cotton soil fora 30 day of curing period. Hence, addition of 20% bagasse ash to the black cotton soil was considered the optimum percentage.
3. Upon addition of various percentages of lime to black cotton soil the strength increases with increase in curing period. The maximum strength was observed at 4% lime addition for expansive soils. Hence, 4% of lime content for the soil is considered as the optimum percentage.
4. In the design of flexible pavements, the subgrade strength is a vital parameter. Hence, an indication of increase in strength ratio of expansive soil with bagasse ash and lime with curing, suggests the utilization in pavements on expansive soils, positive impacts on the stress strain behaviour of soils with admixtures was also observed.

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