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Remediation of Expansive Soils Using Agricultural Waste Bagasse Ash

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Abstract

Bagasse is a fibrous material remaining after crushing sugarcane to extract its juice; and bagasse ash is produced after burning bagasse. Improper disposal of this material can create environmental problems around sugar manufacturing plants. Bagasse ash, comprising a high percentage of silica (SiO_2), is considered as a sensible pozzolanic material with non-reactive behaviour and has potential to be used in road subgrade stabilisation. One of the main challenges for transportation organisations in Australia is to treat subgrades including expansive soils. Expansive soils exhibit significant movements when the moisture content changes, and hence it causes substantial damage to road pavements constructed over these type of soils. Road engineers need to employ materials having acceptable strength, relatively low price and being eco-friendly. In order to demonstrate the potential ability of bagasse ash in curtailing the adverse effects of expansive soils on roads, an array of experimental tests using bagasse ash have been conducted. In this study to activate and improve the effectiveness of bagasse ash, hydrated lime was used and mixed with black soil samples, collected from Queensland Australia. Samples were prepared using different contents of bagasse ash and hydrated lime (0%, 6%, 10%, 18% and 25% by the dry mass of soil), at a ratio of 3:1, respectively. The results of free swell ratio (FSR) test, unconfined compression strength (UCS) and California bearing ratio (CBR) tests are presented for untreated and treated samples after various curing time periods of 3, 7 and 28 days. The outcomes of these tests clearly demonstrate that stabilisation of expansive soils using bagasse ash and hydrated lime not only improves the strength, but also facilitates to cope with environmental concerns through reduction of sugar industry waste material.

Keywords: Expansive soils, Bagasse ash, Hydrated lime, Free swell ratio (FSR), Unconfined compression strength (UCS), California bearing ratio, (CBR)

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1 Introduction

Expansive soil has tendency to swell when its moisture content increases, and may impose a potential risk to safety of many civil engineering structures such as roads, railways and airport runway foundation constructed on this type of soil. When the soil strength properties cannot be improved via mechanical stabilisation (compaction), the chemical admixture technique is used to achieve the desired strength. Attempts have been made to utilize waste product materials to minimise cost of project spent on lime or cement. The addition of waste products and fibers together with chemical agents can improve the stiffness and strength properties of soft soils (Fatahi et al., 2013, and Fatahi and Khabbaz, 2012). Bagasse ash is an agricultural by-product of sugarcane bagasse combustion to generate electricity and its improper deposit poses a serious environmental problem. The benefit from applying baggage ash for soil stabilisations with lime is related to chemical reaction between calcium hydroxide produced by lime with pozzolan that is supplied from bagasse ash. Similar to cement reaction with soil (Nguyen et al., 2014) this chemical reaction can be explained by two individual processes: (1) short-term reaction, consisting of cation exchange and flocculation as a result of the reaction between clay, bagasse ash and lime; and (2) long-term reaction, involving time and temperature dependent pozzolanic activity, in which new cementations compounds-calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) responsible for long-term strength in soils are produced. Many researchers (e.g. Osinubi et al., 2009; Kharade et al., 2014, and Submarine et al., 2015) have reported limited improvements to the strength and durability of fine grained soils when bagasse ash was used alone. However, the plasticity and shrink-swell potential of expansive soils could be reduced significantly with the addition of bagasse ash. According to the results of the solubilisation and leaching tests, conducted by Faria et al. (2012) and Sales and Lima (2010), bagasse ash was classified as an inert and non-hazardous solid waste material.

The aim of this research is to utilize the sugarcane bagasse ash as a pozzolanic material to reduce the lime content for curtailing soil movement and improve the compressive strength of compacted expansive soil, while avoiding the adverse health and environmental problems that can be induced due to the disposal of this material.

2 Materials

2.1 Expansive Soil

The soil used in this study was obtained from a road subgrade construction site in Queensland, Australia. It was dried at room temperature, and then, the soil was broken by a rubber hammer into small crumbs passing through 2.36 mm Australian Standard AS1289 (2014) sieve.

The geotechnical properties of soil including particle size distribution, consistency limits and the specific gravity were determined in accordance with AS1289. The soil was classified as high plasticity clay (CH). The particle size distribution curve of this soil determined based on wet sieving is shown in Figure 1. The index properties of the expansive soil are summarized in Table 1.

2.2 Sugarcane Bagasse Ash and Lime

The sugarcane bagasse ash was collected from a sugar mill factory in Queensland. Since the physical properties of bagasse ash depend on size of particles (Cordeiro et al. 2008), bagasse ash passing through 425 µm sieve was used in this research. Bagasse ash was classified as a non-plastic material and the specific gravity of BA was measured to be 2.32. The lime, used in this investigation, is a commercial hydrated lime, manufactured in Adelaide in Australia.

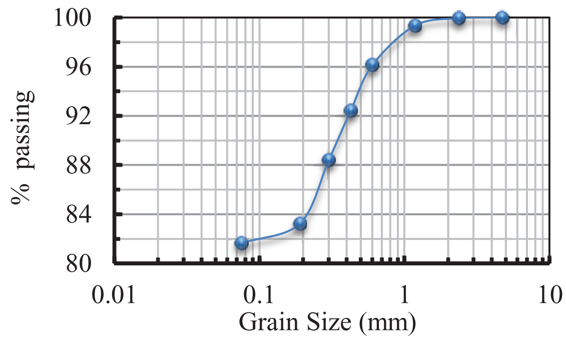

Figure 1: Particle size distribution of the utilized expansive soil

Property	
USCS classification of the soil	CH
Particle size analysis (%)	
Sand (4.75-0.075 mm)	18.4
Silt & Clay (<0.075)	81.6
Atterberg limits (%)	
Liquid limit	86
Plastic limit	37
Plasticity index (%)	49
Linear shrinkage (%)	21.6
Specific gravity	2.65
Free swell ratio (%)	9.8
Swell pressure (kPa)	80
Maximum dry density (g/cm^3)	1.29
Optimum moisture content (%)	36.5
Unconfined compressive strength (kPa)	149
CBR Unsoaked (%)	7.1
CBR Soaked (%)	3.2

Table 1: Index properties of the expansive soil

3 Mix Design and Testing Plan

In this study, the additives contents are defined by the ratio of the weight of a particular additive to the dry weight of the soil, expressed as a percentage. The geotechnical properties of bagasse ash are similar to fly ash (Class F). Several studies have found that the most effective soil improvement can be achieved at about 1:3 ratio (lime to fly ash) (Khabbaz and Fatahi, 2011; Wesche, 2004; Conner, 1990). Experimental UCS and CBR tests conducted by the authors on selected expansive soil samples with different lime-bagasse ash ratios revealed that the optimum ratio could be between 1:2 and 1:3. Accordingly, the lime/bagasse ash ratio used in this experimental research was 1:3. The bagasse ash contents were 4.5%, 7.5%, 13.5% and the corresponding lime contents were 1.5%, 2.5%, 4.5%, 6.25%. The soil samples were examined to determine the free swell ratio (FSR) indicating the expansiveness potential of a soil. This test was developed by Prakash and Sridharan (2004) and it was adopted by ASTM. The free swell ratio reflects the potential for expansion of the soil by comparing the ratio of the volume of dried soil passing a 425 μm sieve in water to the volume of soil in kerosene. The FSR is expressed by Equation (1). The expansion potential for the FSR is shown in Table 2.

$$FSR= V_s/V_k \tag{1}$$

where V_s denotes the volume of soil in water and V_k is the volume of soil in kerosene.

Free Swell Ratio	Clay Type	Soil Expansivity	Dominate Clay Mineral Type
1	Non-swelling	Negligible	Kaolinitic
1.0 - 1.5	Mixture of swelling and non-swelling	Low	Mixture of Kaolinitic and Montmorillonitic
1.5 - 2.0	Swelling	Moderate	Montmorillonitic
2.0 - 4.0	Swelling	High	Montmorillonitic
> 4.0	Swelling	Very High	Montmorillonitic

Table 2: Classification of Soils based on FSR (after Prakash and Sridharan, 2004)

The California bearing ratio (CBR) and unconfined compressive strength (UCS) tests were conducted on samples prepared at water content similar to optimum moisture content for untreated soil with various dry densities depending on standard compaction as per AS1289(2014). The UCS and CBR tests were conducted on three various groups with different curing times (i.e. 3, 7 and 28 days). In the first step, a series of tests were conducted on untreated expansive soil samples. The second set of tests was associated with bagasse ash-lime treated soil and the final set of tests was conducted on lime treated soil samples.

4 Results and Discussion

4.1 Natural Soil Characteristics

The geotechnical properties of soil are summarised in Table 1. The soil at natural state has a liquid limit of 85.7%, a plastic limit of 36.8 and a linear shrinkage of 21.6%. From these parameters, the soil is considered as a critical expansive soil, which has high shrinkage and swelling characteristics, and may causes damage to road pavements.

4.2 Compaction Characteristics

The compaction tests were performed at moisture content 36.5% (the optimum moisture content of untreated soil) for all various combinations of soil, bagasse ash and lime mixtures, as shown in Figure 2. Results indicate that with an increase in the admixture content, the dry density slightly decreases. As expected, the lower specific gravity of bagasse ash and lime may be the reason of the reduction in dry density, in comparison to the compacted natural soil.

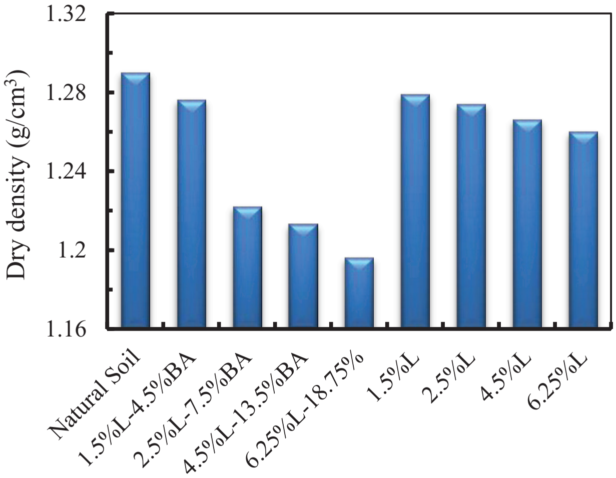

Figure 2: Effect of variation bagasse ash-lime content on dry density at 36.5% moisture content

4.3 Free Swell Ratio (FSR) Test

Tests results of untreated and treated soil with different BA-lime contents are shown in Table 3. The predominant clay mineral present in the soil was montmorillonite and the soil was classified as high swell-shrink soil according to Prakash and Sridharan (2004). As reported in Table 3, the FRS values slightly decrease as the percentage of bagasse ash increases. The minimum FRS belongs to the samples with 18.75% BA-6.25% L. The FSR values decreased as the percentage of bagasse ash and lime increased. Referring to Table 3, combination of bagasse ash with lime was more effective in reducing the FSR than the lime only. This is because of bagasse ash can provide an adequate array of divalent and trivalent cations (Ca^{2+}, Al^{3+}, Fe^{3+}, etc) that increase cation exchange and flocculation (Chen, 1988). In addition, BA non-expansive material replaces the expansive clay contributing to a notable reduction in FSR.

BA-L% content	FSR	Soil Expansivity
Black Soil	2.5	High
Soil-13.5%BA	2.1	High
Soil-18.75%BA	1.8	Moderate
Soil-4.5%L	1.5	Moderate
Soil-6.25%L	1.5	Moderate
Soil-4.5%L-13.5%BA	1.5	Moderate
Soil-6.25%L-18.75%BA	1.4	Low

Table 3: FSR value and soil expansivity of untreated and treated with variation BA-L content

4.4 California Bearing Ratio (CBR) Results

The CBR value gives a rough idea about the shear strength and bearing capacity of soil. Tables 4 and 5 provide the CBR values of different bagasse ash (BA)-lime (L) mixes after 7 and 28 days of curing. It can be noted that the CBR values increased considerably for 6%, 10%, 18% and 25% of BA-

L at 7 and 28 curing days. The extent of CBR improvement with various BA-L at mixtures 28 days of curing was greater than the corresponding values for 7 days of curing. The increase in CBR value could be attributed to the progressive cementation of soil-BA-L as a result of hydration and the pozzolanic reaction. The same trend was found for the lime treated soil samples as presented in Tables 5. It can be seen that, the CBR value increased rapidly by addition of up to 4.5% L, while its value was changed only slightly after 4.5% L. The CBR value of soil treated with BA-L was close to soil treated with L, as shown in Figure 3. Referring to Table 4 the positive effect of bagasse ash was more evident for soaked condition.

BA-L % content	CBR % for soaked /unsoaked soil		
	7 days curing (Unsoaked)	28 days curing (Unsoaked)	28 days curing &7 days Soaked
Untreated soil	7.1	7.1	3.2
4.5% BA-1.5% L	15.2	20.0	14.4
7.5% BA-2.5% L	26.4	33.5	23.6
13.5% BA-4.5% L	48.2	52.9	49.7
18.75% BA-6.25% L	58.6	62.6	54.8

Table 4: CBR values of untreated soil and treated with bagasse ash-Lime

Lime % content	CBR % for unsoaked soil	
	7 days curing (Unsoaked)	28 days curing (Unsoaked)
Untreated soil	7.1	7.1
1.5% L	16.0	18.5
2.5% L	28.0	33.0
4.5% L	54.2	62.4
6.25% L	56.6	61.7

Table 5: CBR values of untreated soil and treated with Lime

4.5 Unconfined Compressive Strength (UCS)

The UCS of soil-bagasse ash-lime mixtures, and soil-lime mixtures, after 3, 7and 28 days of curing are presented in Figures 4 and 5. It can be seen that the UCS increased with the lime content. For example, the UCS for soil-bagasse ash-lime at 3 days curing was 197, 306, 469 and 480 kPa, when the bagasse ash-lime content was 6%, 10%, 18% and 25%, respectively. The UCS of treated soil with 25% of BA was 3.2 times greater than the untreated sample (natural soil). In addition, the UCS increased by 8 times when the samples were cured for 28 days. Based on the previous discussion, the increase in UCS can be related to the hydration and pozzolanic reaction between soil, bagasse ash and lime forming CSH and CAH, thus fills the void space, and binds the particles together improving the strength of the mass. Figure 6 shows that the improvement in the UCS of bagasse ash-lime treated soil in comparison to the compacted soil is as good as the lime treated soil. Overall, application of bagasse ash in road construction can result in reduction of the cost of lime. At the same time, utilisation of bagasse ash as a fill material can help to address the issue of the disposal of bagasse ash in landfills.

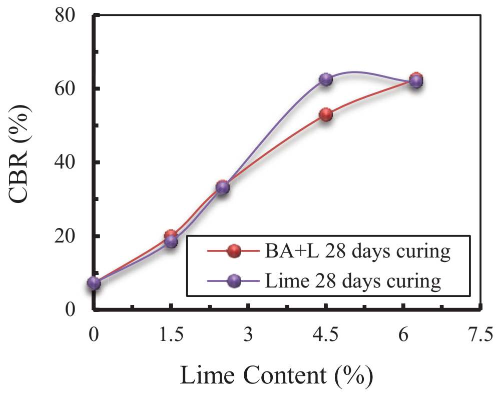

Figure 3: : CBR value of the soil-Bagasse ash and soil mixed with varying percentage of lime at 28 days curing (Unsoaked)

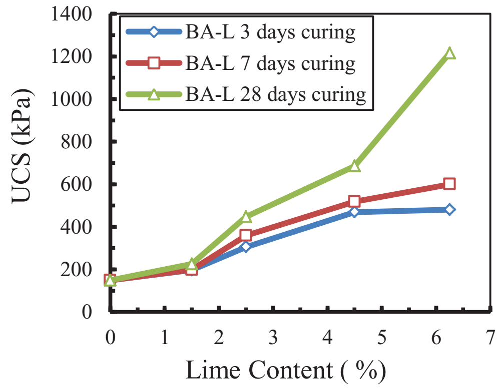

Figure 4: Effect of lime on UCS of soil-bagasse ash mixes at 3,7 and 28 curing days

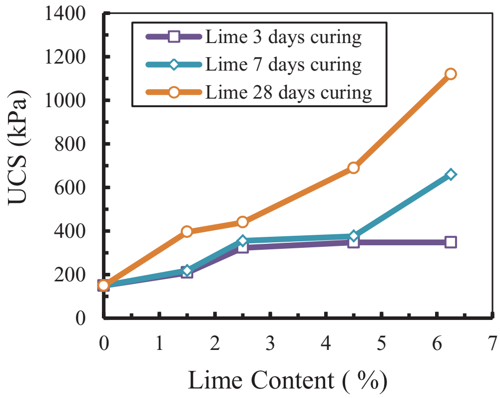

Figure 5: Effect of lime on UCS of soil at 3,7 and 28 curing days

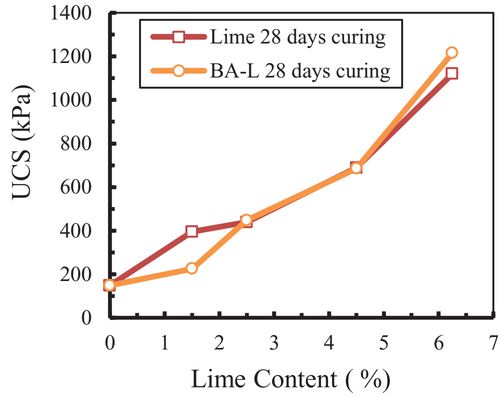

Figure 6: Effect of lime on UCS of soil-bagasse ash mixes after 28 days of curing

5 Conclusions

Bagasse ash added to expansive clayey soil treated with lime has modest effect on the soil strength. However, the use of bagasse ash has a significant effect on reduction of the shrink-swell capacity of soil. Based on the study presented in this paper, the following conclusions can be drawn:

- With the increase of bagasse ash (BA)-lime (L) content, the dry density of soil-BA-L mixes slightly decreased.
- Addition of bagasse ash to expansive soil decreases its swelling, because bagasse ash is non-plastic material. The free swell ratio (FSR) decreases as percentage of bagasse ash increases. The use of bagasse ash with lime is more effective than lime only in curtailing the swelling tendency of soil. Addition of BA-L rapidly increased the unsoaked CBR values for 7 and 28 days. The effect of BA-L on soil in soaked condition had the similar trend to that of unsoaked condition.
- When the BA-L content increased from 0 to 25%, the unconfined compressive strength increased by 80%.
- The CBR and UCS values of bagasse ash-lime treated soils are as good as lime treated soils. However, the soaked CBR results indicated that bagasse ash had the ability to protect the treated

expansive soil from the adverse effect of saturation. Furthermore, BA decreased the swell potential of expansive soil by replacing composition of clay minerals.
- Using bagasse ash, a sugarcane waste by-product, in soil stabilisation may produce highly positive outcomes in terms of cost of lime stabilization and solving the problems posed by the disposal of bagasse ash.

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