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ENHANCING THE ENGINEERING PROPERTIES OF EXPANSIVE SOIL USING BAGASSE ASH AND HYDRATED LIME

Liet Chi Dang[1], Hayder Hasan[2], Behzad Fatahi[3], Robert Jones[4] and Hadi Khabbaz[5]

[1,2] PhD Candidate, School of Civil and Environmental Engineering, University of Technology Sydney (UTS), Sydney, Australia
[3] Senior Lecturer in Geotechnical Engineering, School of Civil and Environmental Engineering, University of Technology Sydney (UTS), Sydney, Australia
[4] Senior Infrastructure Engineer, Arup, Brisbane, QLD 4001, Australia
[5] Associate Professor of Geotechnical Engineering, School of Civil and Environmental Engineering, University of Technology Sydney (UTS), Sydney, Australia

ABSTRACT: The main objective of this paper is to investigate the influence of hydrated lime and bagasse ash on engineering properties of expansive soil obtained from an array of laboratory tests. Bagasse ash is a readily available waste by-product of the sugar-cane refining industry posing risks to environment. Bagasse ash is considered in this investigation in order to evaluate the potential benefits of its pozzolanic material for stabilisation of expansive soil. The preparation of stabilised soil specimens was conducted by changing the bagasse ash contents from 0 to 25% by dry weight of expansive soil along with an increase in hydrated lime. The bearing capacity and shrinkage properties of stabilised expansive soil were examined through a series of experimental tests including linear shrinkage and California bearing ratio (CBR) after various curing periods of 3, 7 and 28 days. The results reveal that the additions of hydrated lime and bagasse ash improved the strength and bearing capacity of stabilised expansive soil remarkably, and meanwhile significantly reduced the linear shrinkage of treated expansive soil. Hence, the application of hydrated lime and bagasse ash as reinforcing material can not only enhance the engineering properties of expansive soil, but also facilitate sustainable development by using sugarcane waste by-product to improve unusable clay material in road construction.

Keywords: Expansive Soil, Hydrated Lime, Bagasse Ash, Linear Shrinkage, Strength and CBR

1. INTRODUCTION

Expansive soils are fine grained soil or decomposed rocks that show large volume change when exposed to fluctuations of moisture content. Swelling-shrinkage behaviour is likely to take place near ground surface where it is directly subjected to seasonal and environmental variations. The expansive soils are most likely to be unsaturated and have highly reactive clay minerals comprising of montmorillonite. Most of severe damage in relation to expansive soils is depended on the amount of monovalent cations absorbed to the clay minerals.

Construction of residential buildings and other civil engineering structures such as highways, bridges, airports, seaports on expansive soil is highly risky in that such soil is susceptible to cycles of drying and wetting, inducing shrinkage and swelling behaviour under pavements and building foundations, which results in cracking to structural and none structural elements. The average annual cost of damage to structures due to shrinkage and swelling is estimated about £400 million in the UK, $15 billion in the USA, and many billions of dollars worldwide [1]-[3].

An increasing number of ground improvement techniques have been suggested for dealing with problematic soil such as the application of sand cushion technique, belled piers and granular pile-anchors. In addition, chemical stabilisation is the most popular method utilized to enhance the physical and mechanical properties of problematic soils consisting of soft soil and expansive soil. The chemical ground improvement approach is a proven technique in improving engineering properties of problematic soils and is highly applicable for lightly loaded structures such as road pavements and low-rise residential buildings [4]-[6].

In recent years, a considerable number of laboratory and field experiments have been carried out and extensive studies have been conducted on reactive soil using various additives such as cement[7]-[9], and lime [10]. Several by-products including fly ash [11], rice husk ash, bagasse ash [12], just to name a few, have been investigated by using each alone or in combination with other additives. Although a growing number of investigations have been undertaken so as to reinforce reactive soil using waste by-products to diminish the effects of the swelling-shrinkage characteristics and enhance the mechanical properties, there are still not adequate studies on the influence of waste by-products, particularly in bagasse ash stabilised expansive soil.

According to earlier studies [10], [13], lime stabilization of subgrades can provide significantly improved engineering properties. There are essentially two forms of improvement including modification and stabilization. Modification occurs to some extent with almost all fine-grained soils, but the most substantial improvement occurs in clay soils of moderate to high plasticity. Modification occurs primarily due to exchange of calcium cations supplied by the hydrated lime $Ca(OH)_2$, quicklime (CaO) or lime slurry for the normally present cation adsorbed on the surface of the clay minerals. Modification is also caused as the hydrated lime reacts with the clay mineral surface in the high pH environment promoted by the lime-water system. In the high pH environment the clay surface mineralogy is altered as it reacts with the calcium ions to form cementitious products. The results of the mechanisms are plasticity reduction, reduction in moisture holding capacity, swell reduction, improved stability and the ability to construct a solid working platform.

In contrast to lime modification, stabilization is a time-dependent pozzolanic reaction which takes place when the adequate amount of lime is adopted to stabilize reactive soil. Stabilization is a different form to the modification because a significant level of long-term strength gain is developed through a long-term pozzolanic reaction. While an increase in lime quantity added to reactive soil leads to the pH environment of limed soil getting closed to a high level of 12.4, the solubility of silica and alumina minerals from clay surface is most likely to occur and react with calcium from the lime so as to form calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH). CSH and CAH are cementitious products of pozzolanic reactions, which contribute to the strength gain of lime stabilized reactive soil. In addition, such pozzolanic reactivity can not only begin within hours after mixing lime-soil but also can continue for many years. As a result of this long-term pozzolanic reaction, lime stabilized reactive soils are able to result in the increase in strength gain with time, a significantly impermeable barrier, durable and stronger working platform facilitating construction sequences of pavements and their long-term service.

Bagasse ash is an abundant fibrous waste product derived from sugar-refining industry and readily available for use without costs or low costs. This material is increasingly identified to pose a risk to the environment, which requires public attention and research on its safe disposal and for opportunities to use as recycled material. However, bagasse ash is considered as pozzolanic material rich in amorphous silica, which is effectively employed together with hydrated lime in improving the engineering properties of expansive soil. Therefore, it has become a focus of interest in recent years. Many researchers [14]-[16] have performed several studies on bagasse ash to investigate stabilization properties of expansive soil. Based on the test results, they indicated that bagasse ash admixture caused significant modification and improvement in the engineering properties of expansive soil.

Nevertheless, more investigations are essential in order to provide a comprehensive understanding of the engineering properties of expansive soil improved by combination of hydrated lime and bagasse ash in ground improvement. As expected, two key objectives are most likely to be acquired concurrently. They are associated with adopting industrial waste by-products and diminishing the hydrated lime dosage. Meanwhile, the use of hydrated lime-bagasse ash admixture can significantly improve the shrink-swell behaviour and mechanical properties of the treated expansive soil.

In this paper, an array of laboratory experiments including linear shrinkage, compaction, and CBR tests have been performed on untreated and treated expansive soil samples with different hydrate lime and bagasse ash contents after different curing time of 3, 7 and 28 days. Outcomes of this experimental investigation were analysed to obtain a better understanding of the effects of hydrated lime-bagasse ash additions on the shrinkage potential and engineering behaviour of expansive soil.

2. MATERIALS AND EXPERIMENTAL PROGRAM

2.1 Materials

2.1.1 Soil

The soil samples used in this study for current experimental tests were collected from Queensland, Australia. The soil was air-dried and broken into pieces in the laboratory. Table 1 shows the physical properties of the soil used in this investigation. In term of sizes of particles, the soil was classified as clay of high plasticity (CH) according to the Unified Soil Classification System (USCS). The specific gravity of solids (G_s) was 2.62-2.65. The grain size distribution showed that 0.1% of particles were in the range of gravel, 18.3% in the range of sand and 81.6% were fine-grained material (silt/clay). Atterberg limits of the fine portion of material were about 86% liquid limit (LL) and 37% plastic limit (PL), which resulted in a plasticity index (PI) of 49%. The average linear shrinkage and natural moisture content of the samples was 21.7% and 30.8%, respectively. Based on the high linear shrinkage and plasticity index, the soil can be classified as highly expansive soil.

Table 1 Characteristics of natural soil

Characteristics	Value
Gravel (%)	0.1
Sand (%)	18.3
Silt/Clay (%)	81.6
Natural water content (%)	30.8
Liquid limit (%)	86
Plastic limit (%)	37
Plasticity index (%)	49
Linear shrinkage (%)	21.7
Specific gravity	2.62-2.65
USCS classification of the soil	CH

2.1.2 Lime

Hydrated lime has high quality and quantity of calcium oxide that was used in this investigation. The hydrated lime is purchased from a local supplier in Australia. Table 2 shows the physical and chemical properties of hydrated lime provided by the manufacturer.

Table 2 Chemical composition and physical properties of hydrated lime

Physical properties		Chemical Composition	
Property	Value	Components	% by weight
Specific gravity	2.2-2.3	Ignition loss	24%
Bulk density (kg/m^3)	400-600	SiO_2	1.8
		Al_2O_3	0.5
		Fe_2O_3	0.6
		CaO	72.0
		MgO	1.0
		CO_2	2.5

2.1.3 Bagasse Ash

Bagasse ash was collected during cleaning operation of boiler from Isis Central Sugar Mill Company Limited, Queensland, Australia. The bagasse ash was provided at a boiling temperature of 700-800°C. Table 3 provides the similarly physical and chemical properties of bagasse ash employed in this study, which are similar to the bagasse ash utilized in the previous research performed by Anumpam et al. [17]. The bagasse ash used for this research was carefully sieved and passed through 0.425mm aperture sieve to eliminate unburnt and large size particles.

Table 3 Characteristics of bagasse ash determined by Anumpam et al. [17]

Physical properties		Chemical properties	
Property	Value	Components	% by weight
Specific gravity	2.38	Ignition loss	2.11
Liquid limit (%)	41	SiO_2	65.27
Plastic limit (%)	None	Al_2O_3	3.11
Optimum moisture content (%)	48	Fe_2O_3	2.10
Maximum dry density (g/cm^3)	1.27	CaO	11.16
Lime Reactivity (kg/cm^2)	32	MgO	1.27

2.2 Mixing of Materials

Soil samples with particle size smaller than 2.36 mm were prepared by mixing bagasse ash or combination of bagasse ash and hydrated lime (at a ratio of 3:1) at the percentages shown in Table 4. Following this preparation, the specimens were mixed thoroughly. A mechanical mixer was used for the mixing of the expansive soil with hydrated lime and bagasse ash. After mixing of the material, the specimens were prepared for the conventional geotechnical experiments, including compaction and California bearing ratio (CBR) tests in order to determine the optimum moisture contents, the maximum dry densities of selected admixtures and observe the stress strain behaviour of treated and untreated expansive soil samples.

Table 4 Summary of soil sample mixes used in this study

Mix No.	Bagasse ash (%) by dry weight of soil	Hydrated lime (%) by dry weight of soil
1	0	0
2	6	0
3	10	0
4	18	0
5	25	0
6	4.5	1.5
7	7.5	2.5
8	13.5	4.5
9	18.75	6.25

2.3 Experimental Procedure

2.3.1 Linear Shrinkage

In this investigation, a portion of a soil sample of at least 250 g from the material passing the 425 μm sieve was air dried until crumbling of the soil aggregation occurred. This is in accordance with the procedure prescribed in AS 1289.1.1-2001 [18] for the preparation of disturbed soil samples for Atterberg limits and linear shrinkage. In addition, the linear shrinkage values of untreated and treated expansive soil specimens were also determined as specified in accordance with in AS 1289.3.4.1-2008 [19].

2.3.2 California Bearing Ratio Test

Unsoaked and soaked CBR tests were performed on untreated and treated expansive soil in according with the method specified in AS 1289.6.1.1-2014 [20] in order to examine the strength and bearing capacity of expansive soil as subgrade material in support of road and highway systems. Following mixing of expansive soil with bagasse ash and hydrated lime, untreated and treated samples were shaped in a cylindrical metal mould of known volume, with 152 mm in internal diameter and 178 mm in height, at the maximum dry density (MDD) and optimum moisture content (OMC). In order to ensure uniform compaction, the samples were compacted in five equal layers by pressing the spacer disk of 61 mm in thickness with help of testing machine in order to obtain the targeted dry density. The prepared samples were then sealed by using plastic wrap to prevent moisture change, and afterward curing for various periods of 7 and 28 days at a controlled room environment of 25^0C temperature and relatively 80% humidity. After curing, the unsoaked samples were subjected to an annular surcharge of 4.5 kg put on the top of the sample and immediately set up in the conventional unconfined compression apparatus, whereas the soaked samples were submerged in water for 7 days prior to undertaking the same testing procedure for unsoaked samples. The machine was set at a load rate of 1 mm/min, and this was kept consistent for all samples tested. An S-type load cell was used as a transducer to converting the force into an electrical signal, readable on the load cells display. A data logger was used to transfer the data to a readable output. A linear vertical displacement transducer (LVDT) device was set up against the bearing block of the machine to measure the vertical displacement of the samples under the applied load. The LVDT reading was used to plot the load-penetration curve that was commonly used to calculate the CBR values. The CBR values of untreated and treated expansive soil specimens were based on the greater CBR value calculated at 2.5 mm penetration and 5.0 mm penetration. For each type of mixtures, the CBR value was obtained as the average of three CBR tests.

3. RESULTS AND DISCUSSIONS

3.1 Effects on Linear Shrinkage

Fig. 1 provides a comparison of linear shrinkage improvement of hydrated lime and bagasse ash additives stabilised expansive soil after curing period of 7 days. As can be seen in Fig. 1, the increased amount of hydrated lime and bagasse ash content from 0 up to 25% at a given curing period was found to decrease the linear shrinkage remarkably. With the addition of bagasse ash content increasing from 0 up to 25%, the linear shrinkage of bagasse ash mixed with expansive soil significantly decreased by a substantial amount of 46% after only 7 days of curing in comparison with that of virgin soil specimen. The effects of hydrated lime-bagasse ash on linear shrinkage of treated expansive soil, was more pronounced than that of bagasse ash mixed with expansive soil. For example, when the 25% hydrated lime-bagasse ash addition at a ratio of 1:3 was ultilised to stabilise expansive soil, there was a remarkable reduction of linear shrinkage of approximately 80% compared to that of original expansive soil specimen. Hence, it is noteworthy to state that the additions of bagasse ash and hydrated lime-bagasse ash resulted in reducing linear shrinkage of expansive soil even with the application of bagasse ash only.

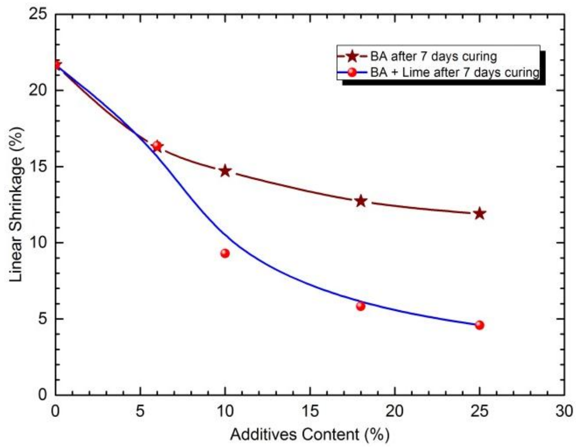

Fig.1 Influence of different bagasse ash and hydrated lime-bagasse ash combination on linear shrinkage of expansive soil after 7 days of curing

In addition, Fig. 2 and Fig. 3 depict the effects of bagasse ash and hydrated lime-bagasse ash admixtures on linear shrinkage of stabilised expansive soil over prolonged curing time. Overall, the increase in bagasse ash and hydrated lime-bagasse ash admixture up to 25% led to the decrease in linear shrinkage of expansive soil significantly with increasing curing periods of 3, 7, 28 days. It is observed that the decrease in linear shrinkage was significant in time during the first 7-day curing period for both bagasse ash and hydrated lime-bagasse ash treated expansive soil specimens for most of particular additive contents. Observation of the results noted a marginal reduction of linear shrinkage of stabilised expansive soil as the curing time increased to 28 days. To be more specific, as plotted in Fig. 2 and Fig. 3, the addition of 6% bagasse ash caused lower decrease in linear shrinkage of stabilised expansive soil after prolonged curing time than that of 6 % hydrated lime-bagasse ash combination. However, the decrease in linear shrinkage of hydrated lime-bagasse ash combinations treated expansive soil in line with increasing curing time was so much lower and more pronounced than their bagasse ash-stabilised counterparts with further increasing stabilisers contents up to 25%. Subsequently, the 28 days final linear shrinkage of treated expansive soil shown in Fig. 3 fell down significantly by almost 84% compared to that of original expansive soil when hydrated lime-bagasse ash combination contents were increased from 0 to 25%, whereas the drop of linear shrinkage of bagasse ash stabilised expansive soil as illustrated in Fig. 2 was roughly half in comparison with that of untreated soil specimen when bagasse ash admixture was increased to 25%. The results indicates that the increasing curing time together with increasing additive contents caused the substantial influence on linear shrinkage of treated expansive soil with bagasse ash and hydrated lime-bagasse ash admixtures. Consequently, the use of the increased amount of either bagasse ash stabilisation or hydrated lime-bagasse ash treatment could be likely beneficial since these stabilisers could provide considerably positive effects on expansive soil in terms of reducing linear shrinkage and cracking, which cause the most damage to buildings and infrastructure such as roads and rail.

The significant improvement in linear shrinkage could be attributed to the flocculation and aggregation phenomena of clay particles induced by the presence of free lime in bagasse ash that caused a decrease in surface of clay particles, then formed the clay particles coarser, and eventually enhanced the friction and strength of treated expansive soil. As a result, the finer clay particles were replaced by relative coarser particles that could be one of the key factors resulting in the considerable decrease in linear shrinkage with increasing the additives contents and age.

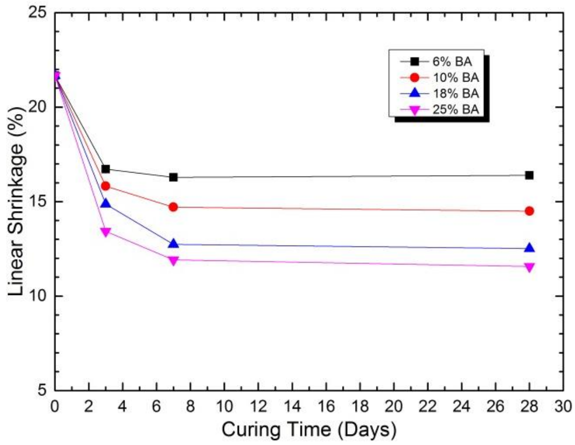

Fig. 2 Linear shrinkage of expansive soil mixed with various bagasse ash contents for different curing time

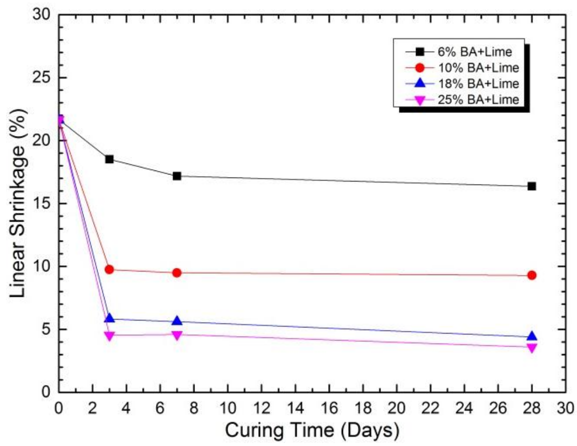

Fig. 3 Linear shrinkage of hydrated lime-bagasse ash treated expansive soil with different additives contents and curing time

3.2 Effects on the California Bearing Ratio

The strength and bearing capacity of subgrade materials are essential factors in pavement engineering. In order to evaluate the strength of pavement resisting repetitive loading by traffic vehicles, the CBR test is one of the most common tests used to assess the quality of base and subgrade materials for highway and road construction. Fig. 4 and Fig. 5 represent the variation of CBR values of expansive soil specimens stabilised with different bagasse ash contents and hydrated lime-bagasse ash combinations from 0 up to 25% along with various curing periods of 7 and 28 days.

In general, the figures depict the appreciable improvement in CBR values with increase in bagasse ash and hydrated lime-bagasse ash combinations together with the increase of age. To be more specific, the CBR values of bagasse ash treated expansive soil plotted in Fig. 4 increased substantially with the additive amount increased and curing time prolonged. For instance, in comparison with the CBR value of parent soil specimen, the CBR values of bagasse ash stabilised expansive soil increased from 7.1% up to 11.5% with increasing bagasse ash additions from 0 to 25% after 7 days of curing. The amount of CBR increase was almost 62% compared with the CBR of original soil. In addition, with the curing time increased from 7 days up to 28 days, the CBR value of bagasse ash treated expansive soil at a content of 25% increased significantly by approximately 83% compared with that of untreated expansive soil. The CBR increase was also about 15% compared to the same bagasse ash content treated expansive soil after 7-day curing. This obviously demonstrates that the surge of CBR values was not only with increasing bagasse ash addition but also the curing time. The increase in CBR values may be due to cementation and pozzolanic reactions in form of frictional resistance contributed from bagasse ash. This agreed well with the early reports presented by researchers [12], [17].

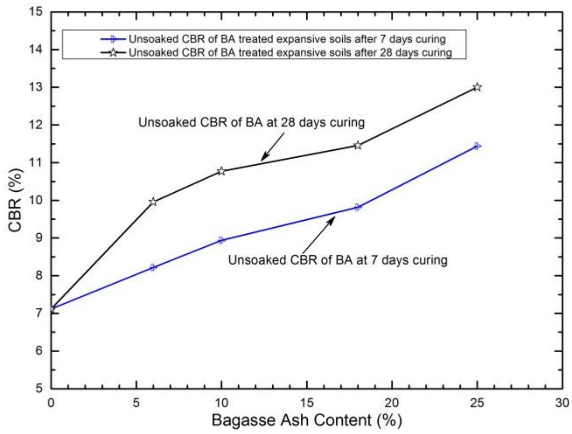

Fig. 4 Influence of bagasse ash admixtures on average unsoaked CBR of treated expansive soil with various curing time

Figure 5 indicates the general effects of bagasse ash and hydrated lime-bagasse ash combinations on the CBR gain of treated expansive soil for varying hydrated lime-bagasse ash contents after 7 days of curing. As illustrated in Fig. 5, the CBR of treated expansive soil specimens rose significantly with an increasing amount of stabilisers up to 25%. To illustrate this, the addition of 10% percentage of hydrated lime-bagasse ash generated the 7-day curing CBR increased by a factor of 3.7 in average, whereas with 25% content of the hydrated lime-bagasse ash addition at a ratio of 1:3 after 7 days of curing, the average CBR increased significantly by a factor of 8.8 in comparison with that of original soil specimen, respectively. Additionally, in order to compare with the same content and curing time of bagasse ash stabilised expansive soil specimens, the 25% combination of hydrated lime and bagasse for treatment of expansive soil after curing period of 7 days resulted in an increase in the average CBR by a factor of 5.5. Hence, it is important to note that the combinations of hydrated lime-bagasse ash treated expansive soil resulted in higher CBR values than bagasse ash alone. This is in agreement with the previous investigations carried out by Osinubi [12].

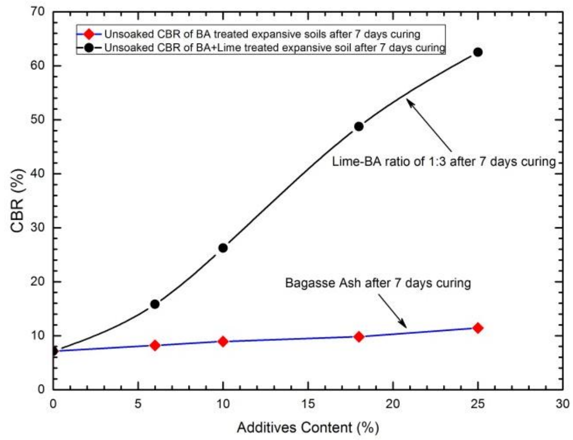

Fig. 5 Influence of hydrated lime and bagasse ash admixtures on average unsoaked CBR of treated expansive soil after curing period of 7 days

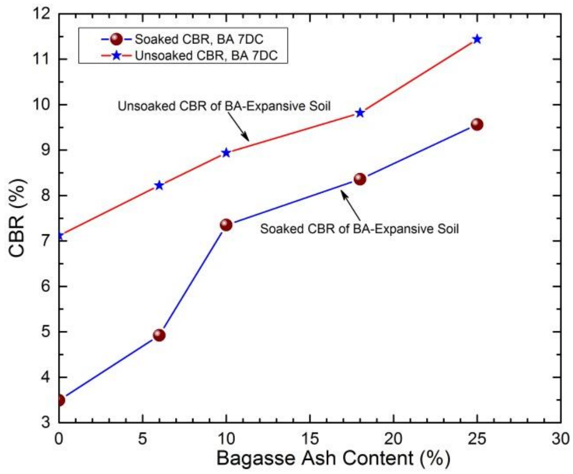

Fig. 6 Influence of bagasse ash admixtures on average unsoaked and soaked CBR of treated expansive soil after curing period of 7 days

Figure 6 illustrates the variation of soaked CBR values in comparison with unsoaked CBR of bagasse ash treated expansive soil after 7 days of curing. Overall, the CBR values of bagasse ash treated expansive soil as plotted in Fig. 6 increased significantly with the increase in bagasse ash content up to 25%. However, the increase in CBR was more pronounced for unsoaked CBR of bagasse stabilised expansive soil. Specifically, to compare with the CBR value of untreated expansive soil, the soaked CBR values of bagasse ash stabilised expansive soil increased from 3.5% to almost 10% with increasing bagasse ash content from 0 to 25% after 7 days of curing and 7 days soaking. The significant improvement of soaked CBR was approximately 175% compared with the CBR of untreated expansive soil. Nonetheless, the 25% bagasse ash addition treated expansive soil resulted in the unsoaked CBR of 11.5%, which was about 20% higher the soaked CBR of the same bagasse ash content treated expansive soil after 7 days of curing.

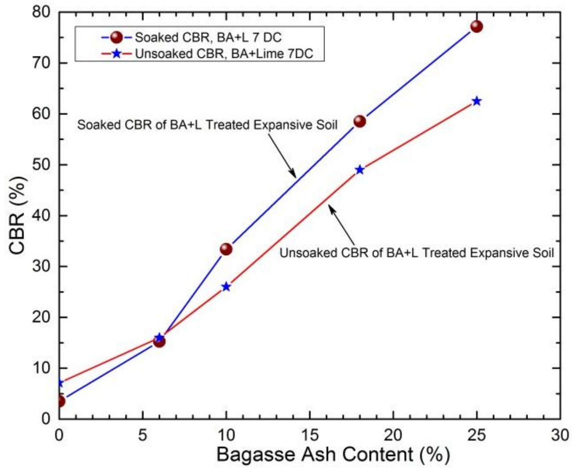

Fig. 7 Influence of hydrated lime and bagasse ash admixtures on average unsoaked and soaked CBR of treated expansive soil after curing period of 7 days

The effects of hydrated lime-bagasse ash admixtures on untreated and treated expansive soil were illustrated in Fig. 7 through a comparison of unsoaked and soaked CBR values after 7 days of curing. It can be noted that the unsoaked and soaked CBR of treated expansive soil increased considerably with the increase in hydrated lime-bagasse ash content from 0 to 25%. However, the increase in soaked CBR value of hydrated lime-bagasse ash treated expansive soil was greater than that of unsoaked CBR when additive contents exceeded 10%. To illustrate this, when a relatively small amount of 10% hydrated lime-bagasse ash admixture was adopted to stabilise expansive soil, the soaked CBR increased by a factor of 4.5 in comparison with that of original soil, whereas with 25% content of the hydrated lime-bagasse ash admixture at a ratio of 1:3 after 7 days of curing, the average CBR increased significantly by a factor of 22.0 in comparison with that of untreated soil specimen. Moreover, the soaked CBR of 25% hydrated lime-bagasse ash admixture was roughly 23% higher the unsoaked CBR of the same additive content. It is observed that the increase in CBR of hydrated lime-bagasse ash admixture stabilized expansive soil was higher for specimens under soaked condition when the addictive content exceeded 10% as shown in Fig. 7, in the author's opinion, which may be attributed to the higher lime content, the more pozzolanic reactions taking place during 7 days of soaking, the better strength gain of hydrated lime-bagasse ash-soil admixtures is most likely to be obtained.

4. CONCLUSION

The following conclusions can be drawn based on the experimental results

The increasing amount of bagasse ash and hydrated lime-bagasse ash admixture from 0 up to 25% (based on dry soil mass) resulted in a significant decrease in linear shrinkage. The effect of hydrated lime-bagasse ash combinations on linear shrinkage of treated expansive soil was more pronounced than that of bagasse ash mixed with expansive soil. As a result, the application of hydrated lime-bagasse ash treatment works promising as a ground improvement solution for expansive soils.

There was significant improvement in CBR values with increase in bagasse ash and hydrated lime-bagasse ash combinations from 0 up to 25%. Overall, the hydrated lime-bagasse ash admixture stabilised expansive soil could satisfy the requirements of most specifications for either subgrade or even subbase course materials for road and highway construction purposes on the basis of CBR.

This experimental investigation exhibits the additions of bagasse ash and hydrated lime-bagasse ash can stabilise expansive soil, enhance engineering properties and remarkably diminish linear shrinkage of treated soil samples. Hence, the hydrated lime-bagasse ash combination could be used to treat expansive soil with potential benefits being, which undeniably helps not only impede the influence of waste by-product bagasse ash on the environmental issues but also provide novel construction materials for sustainable development together with a tremendous amount of construction cost saving on the basis of decrease in dosages of conventional stabilisers including lime and cement.

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Corresponding Author: Liet Chi Dang