Influence of Bagasse Ash and Hydrated Lime on Strength and Mechanical Behaviour of Stabilised Expansive Soil

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ABSTRACT
This paper presents the results of an experimental study undertaken to investigate the effects of using bagasse ash and hydrated lime for improving the strength and mechanical properties of expansive soil. The bagasse ash, a fibrous waste by-product of the sugar cane refining industry, and the expansive soil samples were collected from Queensland, Australia. The specimens were prepared by varying the percentage of bagasse ash up to 25% by dry weight of expansive soil mixed with various hydrated lime contents. A series of experimental tests have been undertaken on untreated and treated soil samples consisting of Atterberg limits, linear shrinkage, compaction, unconfined compressive strength (UCS) tests after various curing periods of 3, 7 and 28 days. Results of this investigation are analysed to illustrate the influence of hydrated lime and bagasse ash treatment on mechanical properties and stress-strain behaviour of expansive soil. The findings indicate a considerable increase in strength and stiffness, mechanical properties with increased hydrated lime-bagasse ash contents and curing time. An optimum combination of hydrated lime and the soil bagasse ash stabilised expansive soil are also presented. Results are significant in that the chemical stabilisation using hydrated lime-bagasse ash not only improves the strength and mechanical properties of expansive soil, but also the use of waste material facilitates to cope with environmental issues.

RÉSUMÉ
Cet article présente les résultats d'une étude expérimentale menée pour étudier les effets de l'utilisation de cendres de bagasse et de chaux hydratée pour améliorer la résistance et les propriétés mécaniques d'un sol expansif. La cendre de bagasse, résidu fibreux sous-produit de l'industrie du raffinage de la canne à sucre, et les échantillons de sol expansif ont été prélevés dans l'état de Queensland, en Australie. Les échantillons ont été préparés en variant le pourcentage de cendres de bagasse, en allant jusqu'à 25% du poids sec du sol mélangé avec différentes teneurs en chaux hydratée. Une série d'essais expérimentaux, comprenant les limites d'Atterberg, le retrait linéaire, le compactage et la résistance à la compression non confinée (UCS), ont été entrepris sur les échantillons de sols traités et non traités après différentes périodes de durcissement de 3, 7 et 28 jours. Les résultats de cette enquête sont analysés pour illustrer l'influence de la chaux hydratée et du traitement aux cendres de bagasse sur les propriétés mécaniques et le comportement contrainte-déformation du sol expansif. Les résultats montrent une augmentation considérable de résistance, de rigidité et des propriétés mécaniques suivant une augmentation du contenu en chaux hydratée et en cendres de bagasse et du temps de durcissement. Une combinaison optimale de chaux hydratée et de cendre de bagasse pour un sol expansif stabilisé est également présentée. Les résultats sont significatifs, non seulement car la stabilisation chimique utilisant le mélange chaux-cendres de bagasse améliore la résistance et les propriétés mécaniques du sol, mais aussi parce que l'utilisation de déchets permet de faire face aux enjeux environnementaux.

1 INTRODUCTION

Expansive soils are fine grained soil or decomposed rocks that show significant volume change when exposed to the fluctuations of moisture content. Swelling-shrinkage behaviour is likely to take place near ground surface where it is directly subjected to seasonal and environmental ups and downs. The expansive soils are most likely to be unsaturated and have montmorillonite clay minerals. 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 building foundations, which results in cracking to structural and none structural elements of those structures. As reported in previous publications (Viswanadham et al. 2009; Gourley et al. 1993; Nelson and Miller 1997), 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.

An increasing number of ground improvement techniques have been suggested for dealing with the swelling-shrinkage problem of expansive soils such as the use of sand cushion technique (Satyanarayana 1966), belled piers (Chen 1988) and granular pile-anchors (Phanikumar 1997). In addition, chemical stabilisation is the most popular method utilized to enhance the physical and mechanical properties of problematic soils consisting of soft soils and expansive clay soils. This method is a proven technique for improving problematic soil's engineering properties and is highly applicable for lightly loaded structures such as road pavement and low-rise residential buildings (Phanikumar 2009; Çokça 2001; Edil et al. 2006; Fatahi et al. 2012a; Fatahi et al. 2013a; Khabbaz & Fatahi 2012, Fatahi & Khabbaz 2013; Bergado et al. 1996; Osinubi et al. 2009).

In recent years, a tremendous quantity of laboratory and field experiments have been carried out and extensive studies have been conducted on problematic soil using various additives such as cement (Miller & Azad 2000; Consoli et al 1998; Lorenzo & Bergado 2004; Fatahi et al. 2012b; Fatahi et al. 2013b; Nguyen et al. 2014), lime (Okagbue & Yakubu 2000). The potential for using by-product for stabilisation of expansive soil is promising.

Several by-products including fly ash (Martin et al. 1990), rice husk ash (Rahman 1986), (Basha et al. 2003), bagasse ash (Osinubi et al. 2009), silica fume (Bagherpour & Choobbasti 2003), just to name a few have been investigated by using each alone or in combination with other additives. Although an increasing number of investigations have been carried out on reinforced expansive soil with waste by-products to diminish the effects of the swelling-shrinkage characteristics, more research is needed to investigate the influence of industrial waste by-products on the engineering behaviour of problematic soils, particularly in bagasse ash stabilised expansive soil.

Bagasse ash, a fibrous waste product obtained from sugar-refining industry, is readily available for use without costs. This material poses threats to the environment and needs to attract to public attention on its safe disposal. However, bagasse ash is considered a pozzolanic rich in amorphous silica, which is effectively employed together with hydrated lime in improving the engineering properties of expansive soils. Therefore, it has become a focus of interest in recent years. Several studies (Ogbonyomi 1998; Sujjavanidi & Duangchan 2004; Osinubi et al. 2009a; Manikandan & Moganraj 2014) have been performed on bagasse ash in searching of beneficial approaches to stabilise expansive soils. Based on the test results, they indicated that bagasse ash inclusion caused significant modification and improvement in the engineering properties of expansive soil. However, more investigations are essential to consider in combination of hydrated lime and bagasse ash to reduce the shrinkage potential and enhance the engineering of expansive soil. If the effect of shrinkage characteristics of bagasse ash stabilised expansive soil with using hydrated lime can be improved, two main goals of using waste by-products in line with minimizing hydrated lime dosage can be concurrently acquired.

In this paper, an array of laboratory experiments including linear shrinkage, compaction, unconfined compressive strength (UCS) tests have been undertaken on untreated and treated expansive soil samples with different hydrate lime and bagasse ash contents after various curing time periods of 3, 7 and 28 days. Results of these tests are analysed to comprehend the effect of hydrated lime-bagasse ash addition on the shrinkage potential and stress-strain 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 the specific area of 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 compressibility (CH) according to the Unified Soil Classification System. The specific gravity of solids (Gs) was 2.62-2.65. The grain size distribution showed that 0.06 % of particles were in the range of gravel, 18.3 % in the range of sand and 81.64 % 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 yielded to a plasticity index (PI) of 49 %. The average linear shrinkage and natural moisture content of the samples was 21.67 and 30.76%, 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 (%)	0.06
Sand (%)	18.30
Silt/Clay (%)	81.64
Natural water content (%)	30.76
Liquid limit (%)	86
Plastic limit (%)	37
Plasticity index (%)	49
Linear Shrinkage (%)	21.67
Specific gravity	2.62-2.65
USCS classification of the soil	CH

2.1.2 Lime

In this investigation, the hydrated lime used has 75–80% of calcium hydroxide and 7% silica. The Hydrated lime is locally purchased from Cement Australia supplier, one of the most widely used construction materials in Australia.

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 taken from this company at a boiling temperature of 700-800°C. Table 2 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 (Anupam et al. 2013). The bagasse ash used for this research was carefully sieved and passed through 0.425mm aperture sieve to eliminate undesirable materials.

Table 2. Characteristics of bagasse ash after Anupam et al. (2013)

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 particles size smaller than 2.36 mm were prepared by mixing hydrated lime and bagasse ash at a ratio of 1:3 in the ranges shown in Table 3. 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 unconfined compressive strength 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 3. Summary of mixes used in this study

Mix No.	Bagasse Ash (%)	Hydrated Lime (%)
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	18.25	6.25

2.3 Experimental Procedure

2.3.1 Linear Shrinkage

In this investigation, portions of a soil sample of at least 250g from the material either passing the 425 μm sieve by drying method or passing the 75 μm sieve by washing method were oven-dried at a temperature not exceeding 50^0C or air dried until it is dried enough to permit crumbling of the soil aggregation, which has been prepared in according with the procedure prescribed in AS 1289.1.1 for the preparation of disturbed soil samples for Atterberg limits and linear shrinkage. Then, the linear shrinkage values of untreated and treated expansive soil specimens were determined as specified in accordance with in AS 1289.3.4.1-2008.

2.3.2 Unconfined compression tests

The compression testing was conducted in according with AS 5101.4-2008. After conducting the mixture process of expansive soil mixed with bagasse ash and hydrated lime, untreated and treated samples were shaped in a mould with 50 mm in diameter and 100 mm in height, at the maximum dry density (MDD) and optimum moisture content (OMC). In order to ensure uniform compaction, the samples were place in three layers using the tamping technique to obtain the targeted dry density. In addition, the samples were extruded prior to testing process, sealed by a plastic wrap to prevent moisture change, and then cured for different periods of 3, 7, and 28 days at a controlled room environment of 25^0C temperature and relatively 80% humidity . After sample preparation and curing for different periods of 3, 7, and 28 days, the samples were weighed and their dimensions were measured. Then the samples were set up in the conventional unconfined compression apparatus. 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. An LVDT displacement transducer 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 calculate the strain of the samples. The axial stress at failure or the unconfined compressive strength (UCS) of the samples was then calculated based on the axial stress to section area of the samples. For each type of mixtures, the unconfined compressive strength value was obtained as the average of three unconfined compressive strength tests.

3 RESULTS AND DISCUSSIONS

3.1 Influence of hydrated lime and bagasse ash on linear shrinkage (LS) of expansive soil

Figure 1 shows the effects of hydrated lime and bagasse ash additives on linear shrinkage with different curing days. It can be noted that with the addition of hydrated lime and bagasse ash, the linear shrinkage decreased considerably with the increase in bagasse ash and hydrated lime-bagasse ash combination contents from 0 up to 25%. Specifically, with the addition of 25% bagasse ash after 28 days curing, there was a reduction of roughly 47% in the percentage compared with that of virgin soil specimen. Similarly, the trend of linear shrinkage change can be obviously seen with the 25% hydrated lime-bagasse ash combination at hydrated lime-bagasse ash ratio of 1:3 after 28 days curing, the linear shrinkage of the combination reduced significantly about 83.5%

compare with that of untreated expansive soil specimen. Based on the test results of linear shrinkage, it can be concluded that linear shrinkage of treated expansive soil specimens decreased substantially with an increase of stabilisers contents and curing periods of time. The hydrated lime-bagasse ash combinations gave rise to higher reduction of linear shrinkage than only bagasse ash stabilisation. 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 shrinkages with increasing the additives contents and age.

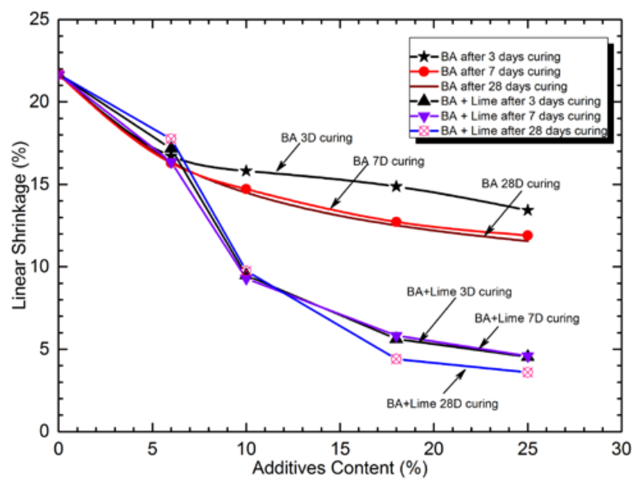

Figure 1. Linear shrinkage of expansive soil mixed with various additives contents for different curing times

3.2 Influence of Hydrated Lime-Bagasse Ash Addition on the Unconfined Compressive Strength (UCS) of Expansive Soil

3.2.1 Influence of Bagasse Ash and Hydrated Lime-Bagasse Ash Admixtures on Stress-Strain Behaviour of Expansive Soil

The stress-strain curves attained from unconfined compressive strength tests are depicted in Figure 2 for bagasse ash treated expansive soil and Figure 3 for hydrated lime-bagasse ash combination treated expansive soil after 7 days curing. As can be seen from Figure 2, the stress-strain behaviour of untreated expansive soil are compared with that of bagasse ash treated expansive soil with various bagasse percentages up to 25%. The untreated expansive soil reached a peak stress of 138 kPa and at a strain of 3.5%. With the addition of bagasse ash, however, the peak stress and strain increased progressively with the increasing bagasse content up to 18% and then followed by a drop slightly to 25% bagasse ash content. It can be noted that the peak stress and strain at 18% bagasse ash were 183kPa and 6.5%, respectively, which reveal an increase of 33% in stress and a significant improvement of 87% in strain. This means when bagasse ash added to expansive soil, the treated expansive soil is very much better in terms of material ductility. In general, there was a considerable improvement in mechanical properties of bagasse ash treated expansive soil. Nonetheless, the unconfined compressive strength of treated expansive soil specimen reduced slightly when the bagasse ash content used was added up to 25%, which indicates that 18% bagasse ash content could be the optimum bagasse ash dosage. In addition, Figure 3 illustrates the Influence of different hydrated lime-bagasse ash contents on stress-strain behaviour of expansive soil after 7 days curing. It is obviously observed that the peak stress increased dramatically with an increase of hydrated lime-bagasse ash content and the stabilised expansive soil also displays a marked stiffness and brittleness. To be more specific, at 25% hydrated lime-bagasse ash addition, the failure stress and strain of treated expansive soil specimens were about 475 kPa and 1.05%, respectively, which shows a substantial increase of 247% in stress and an enormous reduction of 70% in strain. The failure strain is so much smaller in comparison with that of untreated expansive soil.

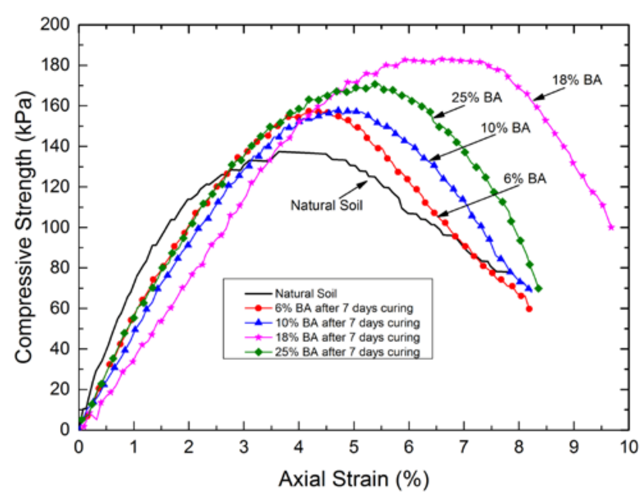

Figure 2. Influence of different bagasse ash contents on stress-strain behaviour of expansive soil after 7 days curing

It can be expressed that bagasse ash and hydrated lime inclusion to expansive soil leads to chemical reaction in forms of cation exchange, pozzolanic reaction, carbonation, and cementation. In regard with the pozzolanic reaction, flocculation of clay particles happening and then giving rise to agglomeration in to coarse particles that help resist the compressive stress much more effectively in comparison with those of virgin soil. The cementation is attributed to play a key role in giving rise to cementitious materials that facilitate preventing the higher load applied. As a result, the stress-strain behaviour of stabilised expansive soil was greatly enhanced with the increase of additives contents. This is a good agreement with previous research reported by (Osinubi et al. 2009b; Manikandan & Moganraj 2014;

Sharma et al. 2008; Goyal et al. 2007; Ganesan et al. 2007).

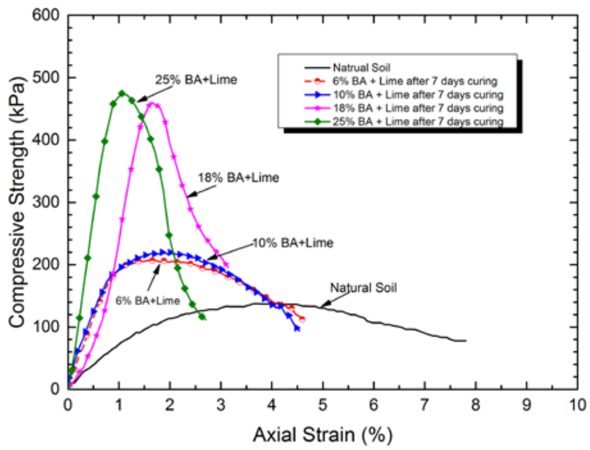

Figure 3. Influence of different hydrated lime-bagasse ash contents on stress-strain behaviour of expansive soil after 7 days curing

3.2.2 Influence of Bagasse Ash and Hydrated Lime-Bagasse Ash Addition on UCS Values of Stabilised Expansive Soil

Figure 3 presents that the effect of different bagasse ash contents used alone and different percentages of hydrated lime-bagasse ash combination on unconfined compressive strength of treated expansive soil after curing periods of 7 days. The unconfined compressive strength increased with an increasing amount of additives up to 25% applied to expansive soil for a given curing period. The 7 days UCS values of treated expansive soil were 184 kPa for specimens mixed with bagasse ash and 460 kPa for specimens mixed hydrated lime-bagasse ash combination at the same used content of 18%**.** It is observed that with combination of hydrated lime and bagasse ash, the values of UCS at 18% hydrated lime-bagasse ash addition was 2.5 times higher that of bagasse ash alone stabilised expansive soil. Therefore, the effect of only bagasse ash addition on UCS values of stabilised expansive soil is not considerable. This agrees well with earlier findings expressed by (Osinubi et al. 2009).

In addition, as plotted in Figure 3, the 7 days UCS increased dramatically when hydrated lime-bagasse ash combination was increased to 18% and then went slightly up to 25% bagasse ash used, hydrated lime-bagasse ash combination. This reveals that for any particular combination of hydrated lime and bagasse ash greater than 18%, it causes a marginal increment in strength, demonstrating that 18% could be the optimum combination for hydrated lime-bagasse ash treated expansive soil. In cases of bagasse ash alone treated expansive, moreover, the UCS values increased steadily to 18% bagasse content applied to the soil and then followed by a slightly drop to 25 %. Hence, this obviously confirms that 18% might be the optimum combination for both bagasse ash and the hydrated lime-bagasse ash combination stabilised expansive soil.

It is noteworthy to state that addition of bagasse ash and combination of hydrated lime and bagasse ash used to stabilise expansive soil caused significant improvement in the strength gain of treated expansive soil. The improvement is more pronounced for the combined hydrated lime and bagasse ash dosages stabilised expansive soil. The substantial improvement in compressive strength could be attributed to pozzolanic reaction due to high amount of silica and lime existed in bagasse ash. When it is exposed to water, it chemically reacts and forms a cementitious bond between clay particles, which is more likely to enhance the resistance to the applied load better of bagasse ash admixture. Correspondingly, the addition of hydrated lime aids in accelerating the reactivity of the pozzolan in order to further enhance the compressive strength of treated expansive soil. The higher pozzolanic reaction of hydrated lime-bagasse admixture contains, the better compressive strength of the admixture is obtained. This was in conformity with the previous research reported by (Usman et al. 2014; Osinubi et al. 2009b).

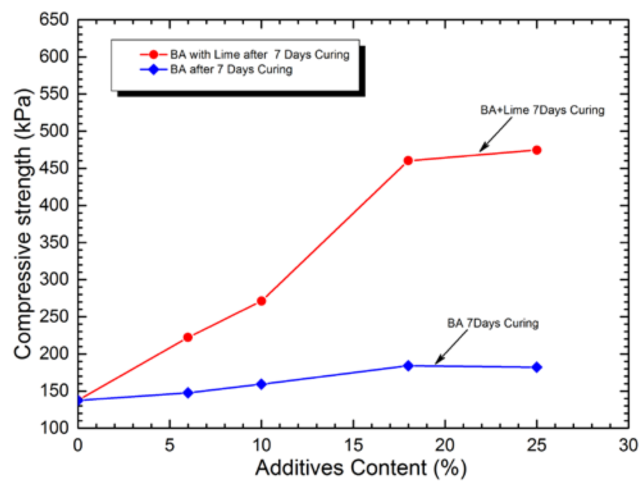

Figure 3. Influence of different hydrated lime and bagasse ash additives contents on average unconfined compressive strength of expansive soil after 7 days curing

3.2.3 Influence of Curing Time on UCS Values of Various Bagasse Ash and Hydrated Lime-Bagasse Ash Admixtures Stabilised Expansive Soil

Figures 4 and 5 exhibit the variation of unconfined compressive strength of expansive clay specimens mixed with various bagasse ash, hydrated lime and bagasse ash contents, respectively, after different curing periods of 3, 7, and 28 days. Overall, as illustrated in the figures, the unconfined compressive strength in all treated expansive soil specimens increased with increasing curing time from 3 days to 28 days. For example, for the specimens mixed with 18% bagasse ash contents observed at 28 days of curing as shown in Figure 4, there was roughly 20 %, 48% increase in the unconfined compressive strength observed in comparison with that of bagasse treated expansive soil specimens at 3-day curing and the UCS of untreated expansive soil specimens, respectively.

However, according to Figure 5, the combination of hydrated lime and bagasse ash stabilised expansive soil yielded higher strength than bagasse ash alone. Specifically, with 18% contents of the hydrated lime-bagasse ash addition at a ratio of 1:3 after curing for 28 days, the unconfined compressive strength was increased by almost 300%, 169% compared to that of untreated soil specimens and the same content and curing time of bagasse ash treated expansive soil specimens. The increase in strength with the curing time prolonged may be due to lime-soil reaction, which generates the formation of cementitious bonds that provides the linkage effect on soil aggregates.

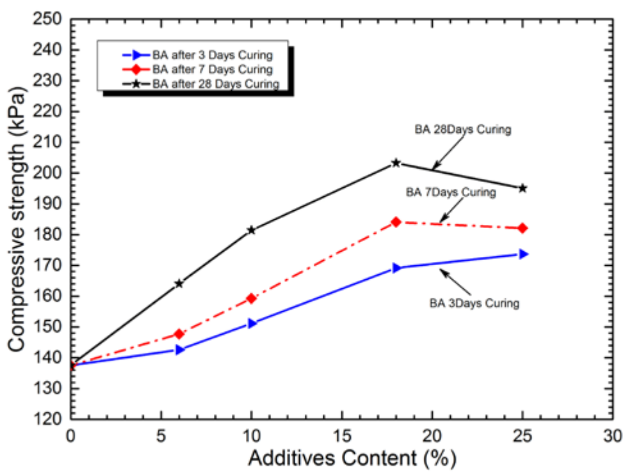

Figure 4. Influence of bagasse ash addition on average UCS of treated expansive soil with various curing time

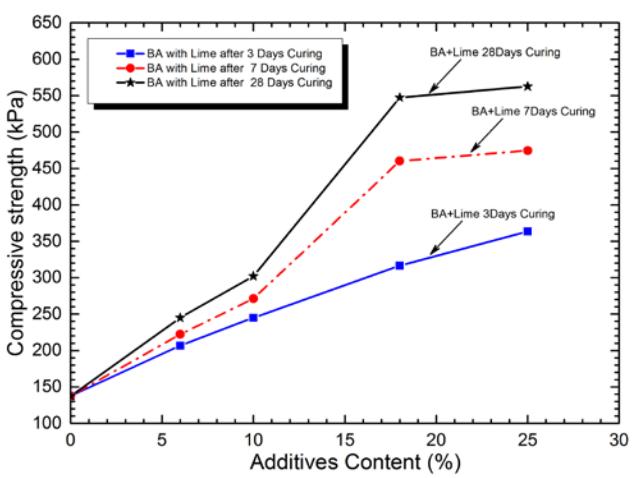

Figure 5. Influence of hydrated lime and bagasse ash combination on average UCS of treated expansive soil with various curing time

4 CONCLUSIONS

The influence of bagasse ash and hydrated lime-bagasse ash addition on the improvement of strength and stress-strain relationship of expansive soil was investigated. An array of laboratory tests were carried out on untreated and treated expansive soil samples. The key conclusions that can be drawn, based on the experimental results, are as follows:

There was a remarkable decrease in linear shrinkage with varying additives contents and increasing curing time observed for using bagasse ash, and hydrated lime-bagasse ash combination treated expansive soil. The significant improvement was more pronounced for the admixture of hydrated lime and bagasse ash combination treated expansive soil. With the 25% combination after curing for 28 days, the linear decreased by 83.5 % compared with that of untreated expansive soil.

The unconfined compressive strength of treated expansive soil samples surged considerably with the increase of bagasse ash and hydrated lime dosages along with curing time prolonged. The increase in strength of the combined hydrated lime and bagasse ash addition is definitely higher than that of bagasse ash employed alone. With the addition of bagasse ash treated expansive soil, the UCS values rose up to 18% bagasse ash contents and then followed by the drop in strength to 25% bagasse ash, which implies the 18% bagasse ash might be the optimum content for use. Meanwhile, the unconfined compressive strength of hydrated lime-bagasse ash treated expansive soil specimens caused notable increase up to 18% stabilisers contents and then went up gradually to 25% additive contents. These results also confirm the 18% stabilisers addition could be the optimum content.

The findings of this experimental investigation demonstrate the substantial improvement of bagasse ash and hydrated lime-bagasse ash addition treated expansive soil. The combination of hydrated lime-bagasse ash yielded higher strength and reduced linear shrinkage lower than bagasse ash alone. It should be note that the use of hydrated lime-bagasse ash combination in expansive soil treatment undoubtedly reduces the impacts of waste by-product bagasse ash on the environmental issues in line with lowering construction costs on the basis of decrease in the lime dosage.

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