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Behaviour of Expansive Soils Stabilized with Hydrated Lime and Bagasse Fibres

Liet Chi Dang[1*], Behzad Fatahi[1†], and Hadi Khabbaz [1‡]
[1]*University of Technology Sydney (UTS), Sydney, Australia*
lietchi.dang@student.uts.edu.au, behzad.fatahi@uts.edu.au, hadi.khabbaz@uts.edu.au

Abstract
Soil stabilization is the most common ground improvement technique adopted to improve problematic soil properties. This investigation exhibits a series of laboratory tests conducted to evaluate the influences of bagasse fibres and hydrated lime addition on the engineering properties and shrink-swell behaviour of stabilised expansive soils. Bagasse fibre is industrial waste by-product left after the crushing of sugar cane for juice extraction that was used in this study as reinforcing component for expansive soil stabilization. The expansive soils used in this investigation were collected from Queensland, Australia. In order to investigate the influences of bagasse fibres on the engineering behaviour of expansive soil, varying proportions of randomly distributed bagasse fibres of 0.5%, 1.0%, and 2.0% were added to expansive soil and hydrated lime-expansive soils mixed with different bagasse fibre proportions were also investigated. Although, an array of experimental tests have been undertaken on untreated and treated expansive soil samples, merely the outcomes of linear shrinkage, unconfined compressive strength (UCS) tests after various curing periods of 3, 7 and 28 days are presented in this paper. Other test results have been identified as follow up research. The findings of this experimental investigation indicate that bagasse fibre reinforcement blended with hydrated lime increased the compressive strength of expansive soil with increase in curing time and additives contents, whereas the linear shrinkage of stabilised expansive soils decreased with increasing hydrated lime and bagasse fibre proportions and curing periods. Based on the reasonable laboratory test results, it can be noted that the expansive soils can be successfully stabilized by combination of hydrated lime and bagasse fibres.

Keywords: Expansive Soils, Hydrated Lime, Bagasse Fibres, Linear Shrinkage, UCS Test

1 Introduction

Expansive soils are fine grained soil or decomposed rocks that show huge 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

[*] Masterminded EasyChair and created the first stable version of this document
[†] Created the first draft of this document
[‡] Created the first draft of this document

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variations. 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. 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 (Jones & Jefferson, 2012).

Many efforts have been used in practice to overcome the adverse effects of expansive soil including replacement of existing expansive soil with non-expansive soil, maintaining a constant moisture content, expansive soil stabilisation and so on. These control methods of expansive soil have their benefits and drawbacks based on different site conditions. However, this investigation is mainly concerned with chemical stabilization technique using lime and natural fibres in improving expansive soil.

Lime stabilization is the most commonly used method for controlling shrink-swell behaviour of expansive soil due to seasonal variations. Lime reacts with expansive clay in the presence of water and changes the physico-chemical properties of expansive soil, which in turn alters the engineering properties of treated soil (Bell, 1996; Nguyen at al., 2014). Moreover, soil improvement and reinforcement using industrial waste by-products consisting of fly ash, bagasse ash (Dang et al., 2015; Dang et al., 2016), rice husk ash (Sharma et al., 2008), coconut coir fibres (Jayasree et al., 2015), polypropylene fibres (Fatahi et al., 2013a), recycled carpet fibres (Fatahi et al., 2013b) and bagasse fibres, just to name a few has become a focus of research interest in recent years.

Bagasse fibre is an abundant fibrous waste by-product of the sugar cane industry, left after the crushing of sugar cane for juice extraction. Bagasse fibre has been used for many purposes as a combustible material for energy supply in sugar cane factories, a pulp raw material in paper industries, and building materials like bagasse-cement composites (Bilba et al., 2003), treated bagasse fibre reinforced biodegradable composites (Cao et al., 2006). Since bagasse fibres are renewable, biodegradable, environmentally friendly, low density and low-cost materials that have similarly physical and mechanical properties of other natural fibres such as jute, sisal, pineapple and coir fibres, bagasse fibre has the highly potential application in the area of construction as building materials and reinforcing component for soil reinforcement in support of subgrade beneath pavements and roads. However, very few studies on bagasse fibres reinforced problematic soil have been performed so far; therefore, more investigations are essential in order to comprehend the engineering properties of bagasse fibres reinforced expansive soil in means of the individual or combination of hydrated lime and bagasse fibres adopted in ground improvement method. As expected, such expansive soil reinforcement method aims to achieve these two main objectives simultaneously consisting of curtailing industrial waste by-product of bagasse fibres in line with diminishing hydrated lime dosage if the application of bagasse fibres, hydrated lime-bagasse fibre combination treated expansive soils can result in the appreciable improvement of shrink-swell behaviour and mechanical properties.

In this present study, an array of laboratory experiments including linear shrinkage, UCS tests were conducted on untreated and treated expansive soil samples with different hydrate lime contents and various proportions of randomly distributed bagasse fibres after curing periods of 3, 7 and 28 days. The findings of this experimental investigation were analysed and discussed for better understanding of the impacts of bagasse fibres alone or hydrated lime-bagasse fibre combination on the potential shrinkage and engineering characteristics of treated expansive soils.

2 Materials

2.1 Expansive 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. The physical properties of expansive soil used in this investigation were investigated and identified in detail. In term of sizes of particles, the soil wss classified as clay of high plasticity (CH) according to the Unified Soil Classification System (USCS), ASTM D2487-2011. 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 yielded to 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.

2.2 Hydrated Lime

Hydrated lime has 85–95% of calcium hydroxide that was used in this investigation. The Hydrated lime was locally purchased in Sydney from Cement Australia supplier, one of the most widely used construction materials in Australia.

2.3 Bagasse Fibres

Bagasse fibres used this study were obtained from Isis Central Sugar Mill Company Limited, Queensland in Australia. The bagasse fibres had an average moisture content of 99.84%, diameter ranging from 0.3 mm to 3.1 mm and length ranging from 0.3 mm to 13.8 mm. The specific gravity of bagasse fibres (G_f) was about 1.55 (Elsunni & Collier, 1996) and their average tensile strength was 96.24 ± 29.95 MPa (Vilay et al., 2008). The obtained fibres were air dried at a controlled room environment of 25°C temperature and relatively 80% humidity until its mass remained constant. Then, the dried fibres were carefully sieved and passed through 9.5 mm aperture sieve and retained on 300 μm aperture sieve, which were selected for this investigation.

3 Experimental Program

3.1 Mixing of Materials

Soil samples with particles size smaller than 2.36 mm were prepared by mixing bagasse fibres or hydrated lime combined with bagasse fibres in the ranges shown in Table 1. 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 fibres. After mixing of the materials, the specimens were prepared for the conventional geotechnical experiments, including compaction and unconfined compression strength tests in order to determine the optimum moisture contents, maximum dry densities of selected admixtures, strength and stiffness, and observe the stress–strain behaviour of treated and untreated expansive soil samples.

3.2 Linear Shrinkage

In this investigation, portion of a soil sample of at least 250g from the material passing the 425 μm sieve by drying method was air dried until it was dried enough to permit crumbling of the soil aggregation, which has been prepared in according with the procedure prescribed in AS 1289-2001 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 1289-2001.

Mix No.	Bagasse Fibres (%) by dry weight of soil	Hydrated Lime (%) by dry weight of soil
1	0	0
2	0.5	0
3	1	0
4	2	0
5	0.5	2.5
6	0.5	4.5
7	0.5	6.25
8	0.5	9.0

Table 1: Summary of mixes used in this study

3.3 Unconfined Compression Test

The compression testing was conducted in according with AS 5101.4-2008. After conducting the mixture process of expansive soil mixed with bagasse fibres and hydrated lime, untreated and treated soil 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°C 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. 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 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.

4 Results and Discussions

4.1 Effects of Additives on Linear Shrinkage (LS) of Expansive Soil

Figure 1 displays the effects of bagasse fibre addition on linear shrinkage with different curing days. It can be noted that when bagasse fibre content was increased from 0 to 2.0%, the linear shrinkage decreased gradually with increasing curing time. Specifically, with the addition of 2% bagasse fibres after 3 days curing, the linear shrinkage of reinforced expansive soil reduced by almost 40% compared with that of virgin soil specimen. When the curing time was increased from 0 to 28 days, the linear shrinkage of bagasse fibres reinforced expansive soil decreased to 7 days curing and then remained constant with longer curing periods. In addition, Figure 2 demonstrates the effects of combined hydrated lime-bagasse fibre addition on linear shrinkage of expansive soil after curing for 7 days. According to Figure 2, the similar trend of linear shrinkage of treated expansive soil can be found that the linear shrinkage reduced with the increase in bagasse fibres and hydrated lime percentages. For example, when the individual addition of hydrated lime content was increased from 0 to 6.25%, the reduction of linear shrinkage of treated expansive soil was approximately 63%. Meanwhile, the linear shrinkage of 6.25% hydrated lime combined with 2% bagasse fibres treated expansive soil decreased significantly by almost 86% in comparison with the linear shrinkage of untreated expansive soil. As revealed in Figure 1 and 2, it is noteworthy to state that the combinations of hydrated lime and bagasse fibres yielded higher reduction of linear shrinkage than only bagasse fibres reinforced expansive soil. The significant improvement of linear shrinkage could be attributed to the flocculation and aggregation phenomena of clay particles induced by the presence of free lime dosage that caused a decrease in surface of clay particles, and then the clay particles become coarser and less plastic. 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. The addition of bagasse fibre reinforcement, moreover, resulted in the decrease in linear shrinkage of untreated and treated expansive soils that may be due to the development of interaction between bagasse fibre surface and soil matrix with time, which could be essentially beneficial of fibre reinforcement.

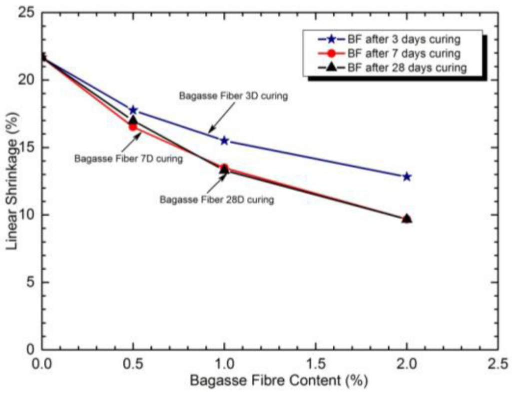

Figure 1: Linear shrinkage of expansive soil mixed with various bagasse fibre contents along with different curing periods

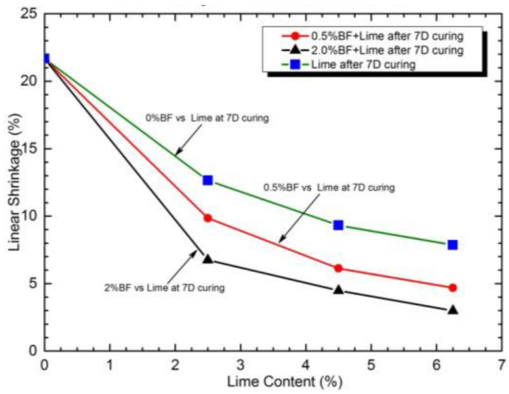

Figure 2: Linear shrinkage of expansive soil mixed with various bagasse fibres-lime contents after 7 days curing

4.2 Effects of Additives on Stress-Strain Behaviour of Expansive Soil

Figure 3 depicts the stress-strain relationships of hydrated lime-bagasse fibre combination treated expansive soil after 28 days curing obtained from unconfined compressive strength tests. As can be seen from Figure 3, the peak stress increased dramatically with an increase of hydrated lime-bagasse fibre content and the stabilised expansive soil also displays a marked stiffness and relative brittleness compared to original soil. To be more specific, with merely 0.5% bagasse fibre addition, when hydrated lime content was increased from 0 to 6.25%, the failure stress and strain of treated expansive soil specimens increased aggressively to almost 480 kPa and 1.5%, respectively. With the same fibre content, the increased amount of axial stress of 6.25% hydrated lime stabilised expansive soil was approximately 64% and 250% in comparison with the 2.5% hydrated lime stabilised expansive soil and non-stabilised soil, respectively, whereas the axial strain of 6.25% hydrated lime increased by roughly 35% compared to that of 2.5% hydrated lime stabilised expansive soil and was almost 43% axial strain of non-stabilised expansive soil. Additionally, with any particular percentage of hydrated lime greater than 6.25% added to bagasse fibres-hydrated lime-soil admixture, the compressive strength of treated expansive soil remained constant, which implies that 6.25% hydrated lime combined with a given bagasse fibre content could be the optimum additive content. According to Tang et al. (2007), the axial failure strain for typical cemented clayey soil is ranging from 0.5% to 0.75% that is very much smaller in comparison with the axial failure strain of untreated soil and fibre-reinforced expansive soils. Hence, the axial failure strain of bagasse fibres-hydrated lime combination treated expansive obtained in this investigation ranging from 1.1% to 1.7% could be considered the remarkable improvement in ductility of fibres reinforced expansive soil. This also agrees well with the previous research reported by Fatahi et al. (2012).

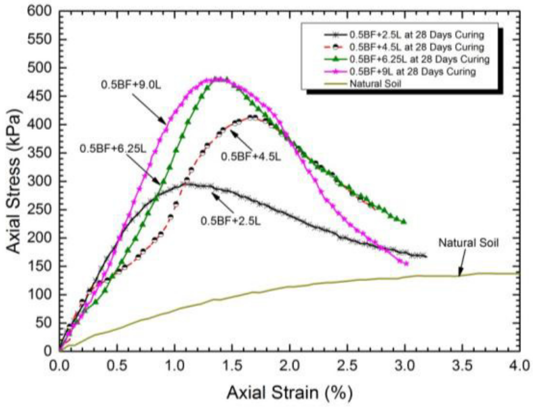

Figure 3: Influence of 0.5% bagasse fibres (BF) versus varied hydrated lime (L) percentages on stress-strain behaviour of expansive soil after 28 days curing

4.3 Effects of Additives on UCS Values of Stabilised Expansive Soil

Figures 4 and 5 exhibit the fluctuation of unconfined compressive strength of expansive soil specimens mixed with various bagasse fibres and hydrated lime-bagasse fibre 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 additive content and curing time. According to in Figure 4, for example, when the bagasse fibre content was increased from 0 to 2% at the same curing period of 3 days, the gradually increased UCS amount was approximately 20%. The comparable trend can be observed with longer curing time of 7 and 28 days. Correspondingly, there was a relative increase in UCS with curing time prolonged. To take 2% bagasse fibres reinforced expansive soil as an example, the UCS value rose slightly by 20% compared to that of the same fibre contents after 3 days curing. However, it is obviously observed the UCS increase with longer 7-day curing was insignificant. The strength improvement of bagasse fibres reinforced expansive soil could be attributed to the interaction and interlock mechanism between clay particles and fibres developed during specimen preparation process by compactive effort and with age. The increase in fibre content leads to the increase in fibre surface area exposed to soil matrix, which facilitates better resistance to imposed load. In addition, to comprehend the effect of hydrated lime on treated expansive soil, only 0.5% bagasse fibres added to lime-soil admixture as plotted in Figure 5, the UCS values of varied hydrated lime percentages increased steadily upward 6.25% hydrated lime and then rose slightly for any particular lime content greater than 6.25%, regardless of any curing time. This behaviour reveals that 6.25% hydrated lime content may be the optimum additive combination for expansive soil stabilization. It is noteworthy to state that the UCS improvement is more pronounced for the combined hydrated lime-bagasse fibre dosages than bagasse fibres individually stabilised expansive soil. The substantial improvement in compressive strength could be attributed to cation exchange between calcium ions in lime and metal ions on surfaces of clay particles. Then, such physical and chemical reactions form agglomeration and flocculation of clay particles, make the clay particles become coarser, more brittle and less plastic, which facilitate to promote friction resistance of soil matrix. Following is pozzolanic reactions that are time dependent. Such pozzolanic reactions take place relatively slowly and are facilitated by high alkaline soil, pH around 12.4 produced by lime-soil admixture, which give rise to the dissolution of silica and alumina from clay mineral lattice. The dissolved silica and alumina from the lattice of clay minerals react with calcium available in the lime in order to establish new cementitious compounds, calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH). These compounds crystallize with time and give rise to increase in compressive strength of treated expansive soil. The higher pozzolanic reactions of hydrated lime-bagasse fiber-expansive soil admixture contains, the better compressive strength of the admixture is obtained. This is in conformity with the early research presented by Bell (1996).

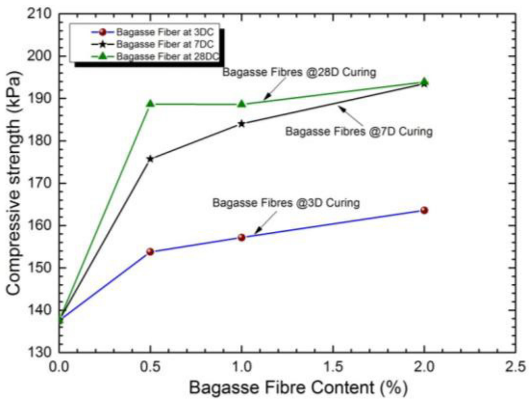

Figure 4: Influence of bagasse fibre addition on average UCS values of treated expansive soil with various curing time

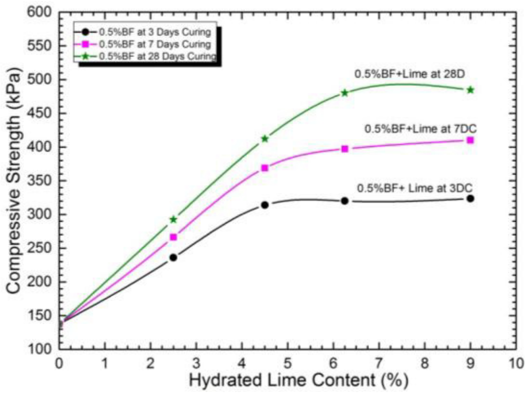

Figure 5: Influence of 0.5% bagasse fibres versus varied hydrated lime contents on average UCS values of treated expansive soil with various curing time

5 Conclusions

The key conclusions that can be drawn, based on the experimental results, are as follows:

- Linear shrinkage of treated expansive soils reduced significantly with varying additive contents and increasing curing time. The remarkable improvement was more pronounced for the admixtures of hydrated lime-bagasse fibres than merely bagasse fibres treated expansive soils.
- The UCS values of treated expansive soils increased with the increase in bagasse fibres and hydrated lime-bagasse fibre proportions along with curing time prolonged. The increase in strength of the combined hydrated lime-bagasse fibre addition is definitely higher than that of bagasse fibres employed alone.
- The findings of this experimental investigation demonstrate the combination of hydrated lime-bagasse fibres yielded higher strength and reduced linear shrinkage lower than bagasse fibres alone. It should be note that the use of hydrated lime-bagasse fibre combination in expansive soil stabilisation undoubtedly facilitates to impede the impacts of industrial waste by-product bagasse fibres on the environment in line with lowering construction costs on the basis of decrease in the lime dosage for sustainable development.

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