Assessment of the geotechnical and microstructural characteristics of lime stabilised expansive soil with bagasse ash

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ABSTRACT
Bagasse ash is a readily available waste by-product of the sugar-cane refining industry; its improper disposal can cause adverse environmental impacts. Therefore, bagasse ash is considered in this assessment to investigate the possibility of utilising it as an additive for stabilisation of expansive soils. This study aims to assess the improvement in geotechnical properties of expansive soil stabilised with various contents of bagasse ash and lime. The geotechnical characteristics of stabilised soil were examined through a series of unconfined compressive strength (UCS) tests of untreated and treated soil specimens for various curing periods of 3, 7, 28, and 56 days. A preliminary study on the microstructure development of untreated and treated soils was also conducted using scanning electron microscopy (SEM) technique. The results of the UCS tests reveal that the additions of hydrated lime alone, and combined hydrated lime-bagasse ash improved the compressive strength and the stiffness of stabilised soil remarkably. The significant strength development of lime treated soils with bagasse ash was observed not only at the initial stage of 28 days of curing but also at the subsequent 28 days irrespective of additive content. However, for soil samples treated with hydrated lime alone, the predominant strength gain was obtained at the initial stage of 28 days of curing. Subsequently, the compressive strength remained almost constant when curing time exceeded 28 days. The outcomes of the SEM analysis indicate the change in microstructure of the stabilised soils and the formation of new cementitious compounds of Calcium-Silicate-Hydrate (C-S-H). The findings of this study reveal that the application of hydrated lime and bagasse ash combination, as reinforcing construction materials, enhances the geotechnical properties of expansive soil. Using bagasse ash combined with lime can address the coming environmental impacts of bagasse ash disposal, while providing cost-effective and alternative construction materials for sustainable infrastructure development.

RÉSUMÉ
La cendre de bagasse est un sous-produit de déchets facilement disponible de l'industrie du raffinage de la canne à sucre; son élimination inadéquate peut entraîner des impacts environnementaux négatifs. Par conséquent, la cendre de bagasse est considérée dans cette évaluation pour étudier la possibilité de l'utiliser comme additif pour la stabilisation des sols expansifs. Cette étude vise à évaluer l'amélioration des propriétés géotechniques du sol expansif stabilisé avec diverses teneurs en cendres de la bagasse et chaux. Les caractéristiques géotechniques du sol stabilisé ont été examinées au moyen d'une série d'essais de résistance à la compression non confinée (UCS) d'échantillons de sol non traités et traités pendant diverses périodes de cure de 3, 7, 28 et 56 jours. Une étude préliminaire sur le développement de la microstructure des sols non traités et traités a également été réalisée à l'aide de la technique de microscopie électronique à balayage (MEB). Les résultats des tests UCS révèlent que les ajouts de chaux hydratée seule et de cendre de chaux-bagasse hydratée combinée améliorent remarquablement la résistance à la compression et la rigidité du sol stabilisé. Le développement significatif de la force des sols traités à la chaux avec de la cendre de bagasse a été observé non seulement au stade initial de 28 jours de durcissement, mais également au cours des 28 jours suivants, indépendamment de la teneur en additif. Cependant, pour les échantillons de sol traités avec de la chaux hydratée seule, le gain de résistance prédominant a été obtenu au stade initial de 28 jours de durcissement. Par la suite, la résistance à la compression est restée presque constante lorsque le temps de durcissement a dépassé 28 jours. Les résultats de l'analyse MEB indiquent la modification de la microstructure des sols stabilisés et la formation de nouveaux composés cimentaires de calcium-silicate-hydrate (C-S-H). Les résultats de cette étude révèlent que l'application de la chaux hydratée et de la combinaison de cendre de bagasse, en tant que matériaux de construction renforçant, améliore les propriétés géotechniques du sol expansif. L'utilisation de la cendre de bagasse associée à la chaux peut permettre de faire face aux impacts environnementaux futurs de l'élimination des cendres de bagasse, tout en fournissant des matériaux de construction rentables et alternatifs pour le développement d'infrastructures durables.

1 INTRODUCTION

Expansive soils exhibit massive volume change against fluctuations in moisture content. Shrinkage and expansion of expansive soil can commonly take place near the ground surface, where it is directly subjected to seasonal and environmental variations. Construction of civil engineering structures on expansive soils is highly risky, as this type of soil is susceptible to seasonal drying and wetting cycles, causing significant deformations. Frequent soil movements can generate cracks and damage residential buildings, roads, and other civil structures directly placed on this type of problematic soil. 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 applied 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, and ground improvement techniques such as the application of granular pile-anchors, sand cushion technique, belled piers, soil stabilisation with chemical agents (e.g. lime or cement) and so on. On top of that, lime stabilisation is the most commonly used method for controlling the shrink-swell behaviour of expansive soil due to seasonal variations (Dash & Hussain 2012; Elkady et al. 2015). Lime reacts with expansive clay in the presence of water and changes the physicochemical properties of expansive soil, which in turn alters the engineering properties of treated soil. Moreover, according to a number of researchers (Basha et al. 2005; Celik & Nalbantoglu 2013; Dang et al. 2016b; Dang & Khabbaz 2018a, 2018b; Dang et al. 2017b, 2017c; Kumar et al. 2007), expansive soil stabilisation and reinforcement using lime combined with agricultural and industrial waste by-products can extend the effectiveness of lime stabilised expansive soil behaviour such as the compressive and shear strength, the shrink-swell behavior, etc. Applications of lime and waste by-products combination for expansive soil stabilisation can provide novel, low-cost, and green materials for sustainable construction development. Moreover, it is interesting to state that as well-documented in the literature, lime stabilisation of clay expansive soils with waste byproducts (e.g. recycled fibre reinforcement) can be used as an alternative earth load transfer platform in support of high embankments constructed on columns improved soft grounds (Dang et al. 2016a; Dang et al. 2017a, 2018a, 2018b, 2018c).

Agricultural and industrial (agro-industrial) waste by-products include silica fume, fly ash, bottom ash, rice husk ash, blast furnace slag, bagasse ash, bagasse fibres, coconut coir fibres, rubber crumbs, textiles, carpet fibre wastes and so on. These agro-industrial waste by-products have increasingly been identified to cause adverse effects on the environment, which requires public attention on their safe disposal and searching opportunities for utilisation as recycled materials in the areas such as construction and soil stabilisation. In practice, land-filling and incinerators are widely used to eliminate these by-products. Nonetheless, due to increasing costs of disposal and lack of readily available landfill spaces, the incinerator measure is generally regarded as an acceptable disposal solution of agricultural and industrial by-products. As a result of the incinerator process, the ashes and non-combustible residues are generated from the agro-industrial waste by-products, which are estimated to account for 10% of the total amount of the agro-industrial waste by-products (Punthutaecha 2002). Moreover, the production of the residues and ashes has increased over the years due to the development of industrial production. Taking sugar production in Brazil as an example, a double increase in sugar-cane production from 568 million tons of sugar-cane in 2008 to 1000 million tons of sugar-canes in 2020 is forecasted (Frías et al. 2011). This implies that a significant landfill space would be required to dispose of the ashes and non-combustible residues. Therefore, to overcome the issue of disposal of agro-industrial waste by-products inducing the environment and health issues, utilisation of the agro-industrial waste by-products such as fly ash, bagasse ash and fibres in the areas of construction and soil stabilisation are indispensable to investigate further. These methods are predicted to offer a better practical solution than simply landfilling the waste.

Sugar-cane bagasse is obtained in abundant quantities from sugar-refining industry. After crushing of sugar-cane in sugar mills and extraction of juice from processed sugar-cane by milling, the discarded fibrous matter is called bagasse fibre (bagasse). Bagasse is utilised as fuel in the cogeneration boiler to produce steam for the production of sugar and electricity. Bagasse is probably burnt at a high temperature of around 700°C to 900°C in a controlled process to use its maximum fuel value, while producing bagasse ash with high amorphous silica, low carbon content and high specific surface area (Cordeiro et al. 2009a). Generally, bagasse ash is disposed in a landfill and now is becoming an environmental burden. It is estimated that more than 200,000 tons of bagasse ash are produced every year in Thailand (Chusilp et al. 2009); 10,000 tons of bagasse ash are produced every day in Brazil (Lima et al. 2012) and numerous amount of bagasse ash is produced in other tropical countries worldwide.

As it is well reported in the literature, sugar-cane bagasse ash is classified as pozzolanic material because it is rich in amorphous silica, which is effectively used together with hydrated lime as a replacement for cement in improving the engineering properties of concrete. Several studies on bagasse ash utilisation in concrete technology (Bahurudeen & Santhanam 2014; Frías et al. 2011) indicated that well-burnt bagasse ash is most likely able to substitute up to 20% cement content in concrete admixtures without bringing adverse effects on the physical and mechanical characteristics of concrete. The main benefits of bagasse ash, replacing cement in concrete, are the enhancement of early high compressive strength, reduction in water permeability, considerable resistance to chloride permeation and diffusion, and increase in durability of reinforced concrete structures (Amin 2011). Moreover, in high-performance concrete technology, Cordeiro et al. (2009b) corroborated that replacing cement with up to 20% by ultrafine ground bagasse ash can produce high-performance concrete having similar mechanical properties compared with concrete produced using only cement as the cementitious material.

Although the potential use of bagasse ash as cement replacement material in concrete has become a focus of interest in recent years, only a few studies have been performed by researchers (Anupam et al. 2013; Dang et al. 2015a; Dang et al. 2018d; Faria et al. 2012; Osinubi et al. 2009) on the potential application of bagasse ash in soil stabilisation. Based on available literature, bagasse ash alone, and a combination of lime/cement and bagasse ash used in soil stabilisation can cause significant modification and improvement in the engineering properties of treated soils. However, further investigations are indispensable in order to gain a better understanding of the geotechnical characteristics of expansive soils improved with the hydrated lime and bagasse ash.

The main objectives of this research are to investigate the engineering characteristics of hydrated lime stabilised expansive soil without or with bagasse ash combination. The preparation of stabilised soil specimens was conducted by changing contents of hydrated lime and bagasse ash combination at a ratio of 1:3 from 0% to 25% by the dry mass of expansive soil. A series of unconfined compressive strength (UCS) tests have been performed on untreated and treated soil samples with different combined additive contents in line with various curing times of 3, 7, 28, and 56 days. Another array of comprehensive study on the microstructure development of untreated and treated soils was carried out using scanning electron microscopy (SEM) technique. The outcomes of this experimental investigation were analysed and discussed to obtain a comprehensive understanding of the effects of additive content and curing time on the compressive strength and the stiffness, and the brittleness (or the ductility) characteristics of the untreated and treated soils. It should be noted that the only results obtained from the UCS tests and the SEM analysis are presented in this paper, which are part of an ongoing research project of characterisation and treatment of expansive soils using agricultural waste by-products (e.g. bagasse ash and fibres). Further experimental evaluations of the influence of bagasse ash addition on the shrink-swell behaviour of stabilised expansive soils could be found in previous publications by the authors (Dang et al. 2016c; Dang et al. 2015b), which are beyond the scope of this paper.

2 MATERIALS

2.1 Natural soil

Soil samples collected from Queensland, Australia, were used in this experimental investigation. After removal of visible organic matters such as tree roots and leaves, the soil was air-dried and broken into pieces in the laboratory. Table 1 shows the physical properties of the soil used in this assessment. The specific gravity of soil solids (G_s) was 2.64$\pm$0.02. The grain size distribution (Figure 1) illustrates that there were 0.1% of particles in the range of gravel, 11% in the range of sand and 89.9 % of fine-grained material (i.e. silt/clay). Atterberg limits of the fine-grained 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 were 21.7% and 30.8%, respectively. In terms of sizes of particles, the soil was classified as high plasticity clay (CH) according to the Unified Soil Classification System (USCS). Based on the high linear shrinkage and plasticity index, the soil can be classified as highly expansive soil.

2.2 Bagasse Ash

Bagasse ash (Figure 2) was collected during the cleaning operation of boilers from ISIS Central Sugar Mill Ltd., Queensland, Australia. The bagasse ash was taken at burning temperatures ranging between 700-800°C, depending on the moisture content of bagasse. Table 2 provides the physical and chemical properties of typical bagasse ash utilised in this investigation. It is noted that for preparation of bagasse ash samples employed in this study, the fine bagasse ash (Figure 3) was selected after carefully sieved and passed through 0.15 mm aperture sieve to eliminate unburnt and oversize particles in order to enhance the pozzolanic reactivity of the bagasse ash, as recommended by Bahurudeen et al. (2016).

Table 1. Characteristics of natural soil

Characteristics	Value
Gravel content (diameter > 2mm, %)	0.06
Sand content (0.06mm< diameter < 2mm, %)	10.97
Silt content (0.002mm< diameter < 0.06mm, %)	78.00
Clay content (diameter < 0.002mm, %)	10.97
Natural water content (%)	30.76
Liquid limit (%)	86
Plastic limit (%)	37
Plasticity index (%)	49
Linear shrinkage (%)	21.67
Swell potential (%)	9.80
Specific gravity	2.64$\pm$0.02
Specific surface area (m^2/kg)	1475
USCS classification of the soil	CH

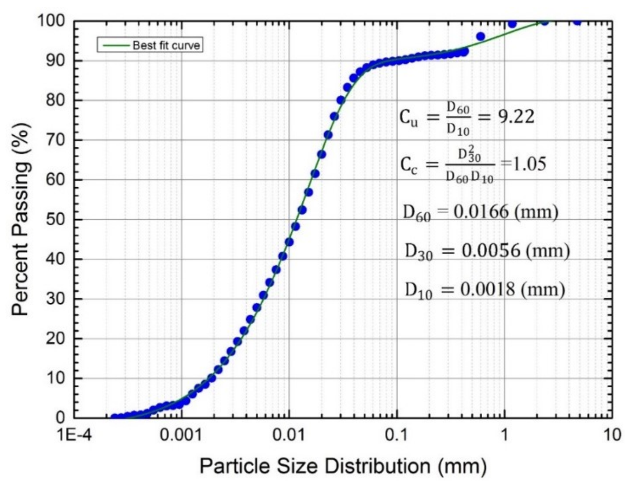


Figure 1. Particle size distribution curve for natural expansive soil

2.3 Hydrated Lime

Hydrated lime utilised in this study (Figure 4) has about 90% of calcium hydroxide. The hydrated lime was locally purchased in Sydney. Table 3 shows the physical and chemical properties of hydrated lime provided by the producer.

Figure 2. Sugar-cane bagasse ash

Table 2. Physical and chemical characteristics of sugar-cane bagasse ash

Physical properties		Chemical Composition	
Property	Value	Components	Content (%)
Specific gravity	2.32	MgO	1.98
Specific surface area (m^2/kg)	228	Al_2O_3	5.95
		SiO_2	78.30
pH	8.64	CaO	2.43
		FeO	5.25
		SO_3	0.89
		K_2O	3.27
		Na_2O	0.54
		TiO_2	0.36
		P_2O_5	1.03

Figure 3. Selected sugar-cane bagasse ash employed in this study

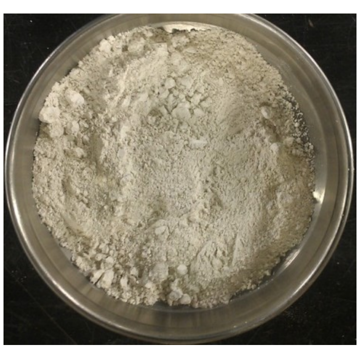


Figure 4. Hydrated lime used in this investigation

Table 3. Chemical composition and physical properties of hydrated lime

Physical properties		Chemical Composition	
Property	Value	Components	Content (%)
Specific gravity	2.2-2.3	Ignition loss	24%
Bulk density (kg/m^3)	400-600	SiO_2	1.8
pH	12.0	Al_2O_3	0.5
		Fe_2O_3	0.6
		CaO	72.0
		MgO	1.0
		CO_2	2.5

3 SAMPLE PREPARATION AND EXPERIMENTAL PROGRAM

3.1 Mixing of materials

Soil samples were prepared by thoroughly mixing the pulverised natural soil with hydrated lime and bagasse ash combination as shown in Table 4 to become homogeneous mixtures before tap water was added at the target water content by the dry mass of each mixture. It can be noted that the hydrated lime-bagasse ash combination ratio of 1:3, which is considered as an optimum combination ratio, was derived from a number of preliminary UCS tests conducted on treated expansive soil after 28 days of curing by changing the combination ratio of hydrated lime to bagasse ash from 1:1 to 1:5. Following this preparation, the mixtures were mixed thoroughly using a mechanical mixer. After mixing of the materials, soil specimens were prepared for many conventional geotechnical experiments.

Table 4. Summary of mixes used in this study

Mix No.	Bagasse Ash (%)	Hydrated Lime (%)	Notes
1	0	0	Natural soil
2	0	6.25	Lime & soil
3	4.5	1.5	Lime, bagasse ash & soil
4	7.5	2.5	
5	13.5	4.5	
6	18.75	6.25	

3.2 Unconfined Compression Test

The unconfined compression test was conducted in accordance with AS 5101.4 (AS 2008). After mixing the expansive soil with waste by-product of bagasse ash and hydrated lime, untreated and treated soil samples were compacted in a mould 50 mm in diameter and 100 mm in height, at their dry density against the moisture content of 36.5% (the optimum moisture content of the untreated soil). To ensure that each sample was compacted uniformly, the soil was placed in three equal layers using the tamping technique to obtain the target dry density. In addition, the samples were extruded prior to testing process, sealed by a proper plastic wrap to prevent moisture change, and then cured for different periods of 3, 7, 28 and 56 days at a controlled room environment of 25°C temperature and 80%

relative humidity. After sample preparation and curing, the samples were weighed and their dimensions were measured. Then the samples were set up in a 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 for converting the force into an electrical signal, readable on the load cell display. A data logger was used to transfer the data from the load cell and a linear variable differential transformer (LVDT) to a readable output. The LVDT reading was used to calculate the strain of the samples. The axial stress at failure defined as the unconfined compressive strength of the samples was then calculated. For each type of mixtures, the UCS value was obtained as the average of three UCS tests and should not deviate by more than 10% from the mean strength.

3.3 Microstructural Analysis

The microstructural evolution of the hydrated lime and bagasse ash treated soil samples was investigated using scanning electron microscope analysis. The treated soil samples collected from fracture portion of the UCS tests after 28 days of curing at a controlled temperature of 25°C were utilised to carry out the microstructural analysis, while the similar tests were conducted on the untreated soil after the UCS tests without any curing.

It is noted that SEM analysis was performed on the samples without coating and scanned using a high revolution scanning microscope (ZEISS EVO LS 15) at an accelerating voltage of 15 kV. Prior to testing, both untreated and treated soil samples were dried in an oven at a temperature of 40°C for 24 hours. Several SEM images at different magnifications were captured in order to evaluate the sample microstructural change as well as examine the formation of cementitious compounds of the stabilised soils.

4 RESULTS AND DISCUSSION

4.1 Influence of Additive Content on Stress and Strain Relationship of Expansive Soil

The influence of different contents of combination of bagasse ash (BA) and hydrated lime (L) on stress and strain relationship of expansive soil after 28 days of curing is presented in Figure 5. As can be seen in Figure 5, compared with untreated soil, the peak strength increased considerably and the stabilised soils also showed a remarkable stiffness and brittleness when the combined additive content increased from 0% to 25%. Referring to Figure 5, for example, the introduction of 25% combined hydrated lime-bagasse ash into soils produced a significant increase in the failure strength by 815% but caused a substantial decrease by 61% in the corresponding peak strain, respectively, when compared to those of untreated soil. However, in comparison with the soil sample treated with 6.25% hydrated lime as shown in Figure 5, the addition of 25% hydrated lime-bagasse ash combination yielded a considerable increase of approximately 58% in the peak strength together with about 81% improvement in the corresponding axial strain. Such improvement indicates that the additions of hydrated lime-bagasse ash combination transformed the behaviour of stabilised soils from brittleness to be more ductile and showed axial strength and strain-hardening characteristics compared to only hydrated lime stabilisation of expansive soil. According to several researchers (Fatahi et al. 2012; Tang et al. 2007), the failure strain for cement/lime treated clayey soil is typically ranging from 0.5% to 0.75% which is significantly less than the corresponding values in this research for lime treated soil with bagasse ash combination. Hence, the failure strain of soil treated with bagasse ash-hydrated lime combination obtained in this investigation ranging from 1.22% to 1.52% could be considered a significant improvement in the ductility of stabilised soils.

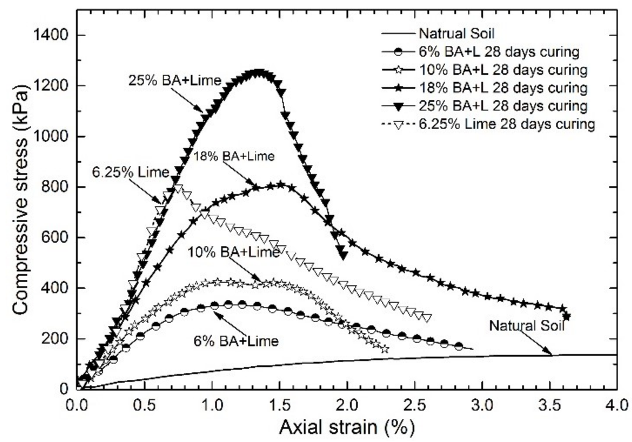


Figure 5. Influence of different additive contents stress and strain relationship of expansive soil after 28 days of curing

Generally, it can be expressed that the addition of hydrated lime, and its combination with bagasse ash into expansive soils results in chemical reactions in forms of cation exchange, pozzolanic reactivity, carbonation, and cementation. During cation exchange, flocculation and agglomeration of clay particles occur, which alter the clay particles to become coarser, stronger and less plastic. Such improved particles can effectively resist the higher compressive stresses applied than those of natural soil. In addition, the cementation process plays a key role in binding the clay particles together and consequently increasing the compressive strength. Results in this investigation are a good agreement with the findings of published research by other researchers (Sharma et al. 2008).

4.2 Influence of Curing Time on the Unconfined Compressive Strength

Figure 6 presents the effects of curing time on the strength development of soils stabilised with 25% bagasse ash-lime combination and only 6.25% hydrated lime as curing time increased from 3 days to 56 days. Referring to Figure 6, the remarkable strength development of lime treated soil samples with bagasse ash combination was observed not only during the first 28 days of curing but also through the subsequent 28 days of curing. However, the significant increase in the compressive strength was found during the only first 28 days of curing for 6.25% hydrated lime alone treated soil as illustrated in Figure 6. Subsequently, when curing time increased beyond 28 days, the compressive strength remained almost unchanged. As clearly observed in Figure 6, the UCS value was more pronounced for combined bagasse ash-hydrated lime stabilised soils than only hydrated lime inclusion to stabilise soils during the investigated curing period. This behaviour corroborates that adding bagasse ash into lime-soil mixtures was more effective than only hydrated lime in enhancing the compressive strength of stabilised soils with the curing time prolonged. It is important to note that the addition of bagasse ash into lime-soil mixtures provides additional pozzolanic materials such as silica (SiO_2), alumina (Al_2O_3), and ferric oxide (Fe_2O_3), which play a key goal in facilitating the higher pozzolanic reactivity and consequently enhancing the higher soil strength in the long-term. This behaviour is consistent with the similar phenomenon reported by other researchers (Kampala & Horpibulsuk 2013) when investigated silty clay stabilised with calcium carbide residue and hydrated lime.

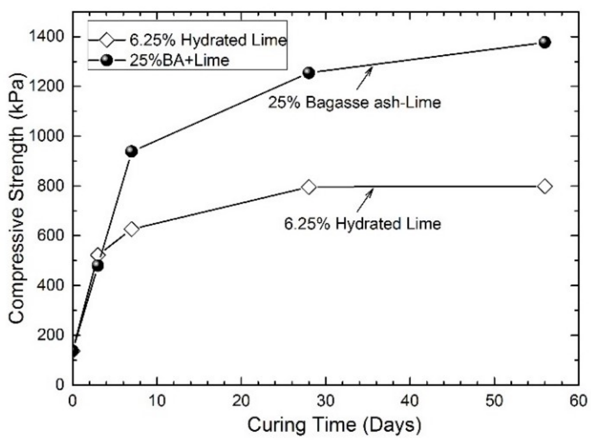
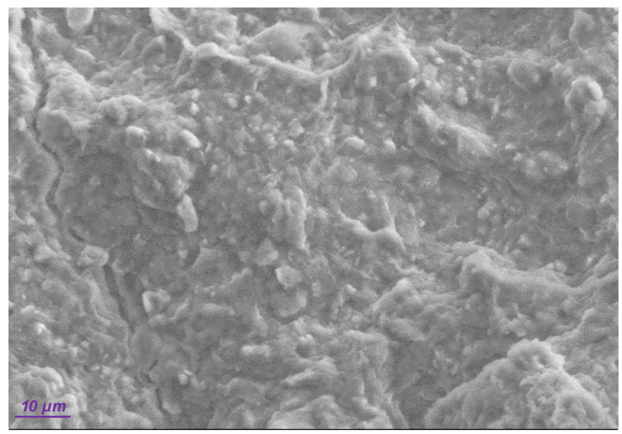


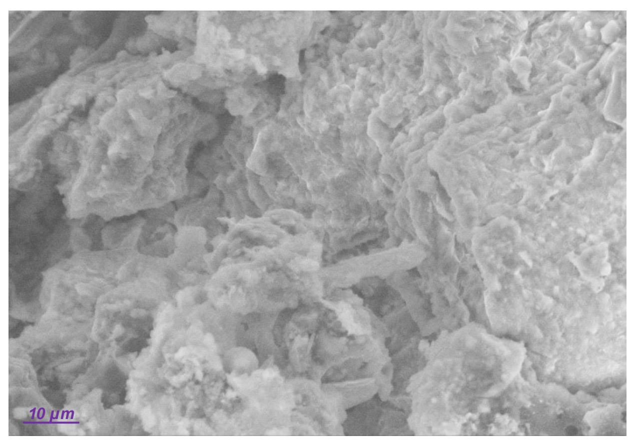
Figure 6. Influence of longer curing time on the UCS of soils treated with 6.25% lime, and 25% bagasse ash-lime

4.3 Influence of Bagasse Ash and Lime Addition on Microstructural Evolution of Treated Soils

Figure 7a and 7b present SEM images of natural soil and 28 days cured soil sample treated with 25% hydrated lime and bagasse ash combination (BAL), respectively, which were used to examine the microstructure development of stabilised soil. It can be noted that the SEM images of selected soil samples were obtained from fracture portions of unconfined compression tests. As observed in Figure 7a, the microstructure of compacted soil without chemical treatment appears to be like wet-state morphology and highly plastic materials that represent the typical type of expansive clay as previously observed by Aiban (2006). However, as can be found in Figure 7b, a combination of hydrated lime and bagasse ash to stabilise expansive soil altered the wet-state condition of untreated soil to be drier and less plastic. In addition, Figure 7b reveals that the cementitious products such as calcium-silicate-hydrate (CSH), calcium-aluminum-hydrate (CAH) or calcium-aluminum-silicate-hydrate (CASH) can be observed in plates-like shape in the pore space of soil samples treated with BAL combination. Such cementitious products resulted from the time-dependent pozzolanic reactivity and accounted for the strength improvement of stabilised soils when curing time extended. Moreover, referring to Figure 7b, the cementitious products attached to the bagasse ash and clay particles chemically treated with hydrated lime. As such formation of cementitious products, the stabilised particles became not only larger than the original clay and bagasse ash particles but also stronger with curing time because of crystallization. In order words, the formation of cementitious products is mainly responsible for the development of particle bonds in the stabilised soil mixtures, promoting the improvement in the soil strength, stiffness and other geotechnical properties of soils stabilised with a combination of bagasse ash and lime.



(a) Natural soil



(b) 25% Bagasse ash and lime combination (BAL)

Figure 7 SEM images of (a) untreated expansive soil and soil treated with 25% BAL (b) after 28 days of curing

5 CONCLUSIONS

In this paper, an experimental investigation, conducted on expansive soils stabilised with different contents of lime and bagasse ash combination, was presented in order to assess the time-dependent strength development and the brittle behaviour of stabilised soils. The key findings of this investigation are summarised as follows:

The unconfined compressive strength (UCS) of treated expansive soil considerably increased with the increase in the combined additive content and the curing time. The strength development of soils treated with bagasse ash and lime combination was certainly more noticeable than that of soils treated with hydrated lime alone. In addition, adding bagasse ash into hydrated lime treated soil mixtures transforms the behaviour of stabilised soils to be more ductile than that treated with only lime. Inspection of the UCS results with longer curing for lime treated soils without and with bagasse ash combination reveals that when curing time increased, the increase in strength of soils stabilised with only lime was more significant during the first 28 days of curing and then it remained almost unchanged with further curing time up to 56 days. Meanwhile, the strength development of lime treated soils with bagasse ash combination showed a continuously increasing trend before and after 28 days of curing, and the compressive strength was certainly higher for hydrated lime treated soils combined with bagasse ash.

SEM analysis of untreated soil and lime treated soil samples combined with bagasse ash inclusion indicates the formation of cementitious products (e.g. CSH, CAH or CASH) as a result of the time-dependent pozzolanic reactions between clay and bagasse ash particles together with hydrated lime inclusion plays a key role in the improvement in the strength and stiffness as well as other geotechnical properties of treated soils.

The utilisation of hydrated lime and bagasse ash combination for expansive soil treatment can be highly effective not only in improving the geotechnical properties of expansive soil but also in curtailing the adverse effects of agricultural waste by-product (e.g. bagasse ash and fibres) on the environment. This experimental assessment has provided a deeper insight into making use of the recycled and cost-effective waste material of bagasse ash for sustainable construction development by means of reduction of conventional stabiliser consumption such as lime or cement, commonly adopted in treatment of expansive soils.

6 ACKNOWLEDGMENTS

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