MECHANICAL PERFORMANCE EVALUATION OF IMPROVED SOILS USING COMPOUND STABILIZER AND FIBRE REINFORCEMENT

by

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LIST OF ABREVIATIONS

Abbreviation	*Description*
ABS	Acrylonitrile Butadiene Styrene
ADVDPC	Advanced Pressure/Volume Controller
ANOVA	Analysis of Variance
CBR	California Bearing Ratio
CE	Compactive Energy
CL	Cement and Lime Content
CLR	Cement, Lime and RHA Content
CU	Consolidated Undrained
EFB	Empty Fruit Bunch
GLM	General Linear Model
MDD	Maximum Dry Density
MEK	Methyl Ethyl Ketone
MH	High plasticity silt
OMC	Optimum Moisture Content
OPC	Ordinary Portland Cement
OPEFB	Oil Palm Empty Fruit Bunch
PI	Plasticity Index
RHA	Rice Husk Ash
SC	Clayey Sand
SM	Silty Sand
UCS	Unconfined Compressive Strength
USCS	Unified Soil Classification System

LIST OF SYMBOLS

Symbol	*Description*
Gs	Specific gravity
Gs_{CLR}	Specific gravity of CLR
I_B	Brittleness index
d_{50}	Main particle diameter
q_p	Peak deviator stress
q_r	Residual deviator stress
q_u	Unconfined compressive strength
γ_d	Dry unit weight
d_f	Diameter of fibre
l_f	Length of fibre
σ_1'	Effective major principal stress
R^2	Coefficient of determination
σ_3'	Effective minor principal stress
σ_N	Nominal confining stress level
σ_c	Unconfined compressive strength
η/CLR_w	Voids-CLR ratio
CLR_w	Percent by weight of CLR content
h_i	Initial thickness
Δh	Changes in thickness at a given time
C_V	Volumetric cement content
$(\sigma_c)_d$	Unconfined compressive strength at age of d days
$(\sigma_c)_{d0}$	Unconfined compressive strength at age of d_0 days
p_c	Pre-consolidation pressure
c_s	Swelling index

c_c	Compression index
Δu	Pore pressure changes
$\Delta \sigma_3$	Cell pressures changes
c'	Effective cohesion
φ'	Friction angle
σ'	Effective principal stress
τ	Shear stress at failure
P	Mean of the maximum and minimum principal stresses
q	Deviator stress
E	Modulus of elasticity
S	Swell index
η	Porosity
t	Curing time period
u	Pore-water pressure
B	Saturation factor
M	Slope of critical state line
υ	Specific volumes
e	Void ratio
Γ	Value of υ corresponding to $p' = 1.0$ kN/m^2
λ	Regarded on soil constants

PENILAIAN PRESTASI MEKANIKAL TANAH YANG DIPERBAIKI MENGGUNAKAN PENSTABIL KOMPAUN DAN PENGUKUHAN FIBRE

ABSTRAK

Pembinaan struktur-struktur kejuruteraan awam di atas tanah yang lembut atau lemah adalah sukar tanpa penstabil tanah disebabkan kekuatan ricih yang rendah dan kebolehmampatan yang tinggi. Masalah penggunaan penstabil biasa termasuk kos pengeluaran yang tinggi, peningkatan pengeluaran gas rumah hijau daripada pengeluaran simen dan kapur serta aplikasi ke atas jenis tanah yang terhad. Dalam kajian ini, keberkesanan CLR (campuran simen, kapur dan abu sekam padi), CL (campuran simen dan kapur), gentian OPEFB (tandan kosong kelapa sawit) dan OPEFB-CLR ke atas ciri-ciri geoteknikal tanah yang bermasalah telah dinilai dan disiasat. Objektif utama penyelidikan ini ialah untuk mengkaji kekuatan, ubah bentuk dan ciri-ciri pemadatan tanah terawat CLR dan tanah terawat gentian CLR sebagai satu bahan pengukuhan untuk tanah yang lemah, lembut atau bermasalah. Ini dicapai dengan mengkaji perubahan dalam tanah terawat dan tanah tidak terawat menggunakan taburan saiz butiran, had Atterberg, keupayaan pemadatan (ujian proktor standard), oedometer, nisbah galas california, kekuatan mampatan tak terkurung dan ujian tiga paksi terkukuh tak tersalir (CU). Untuk menilai kesan taburan rawak OPEFB bersalut gentian ke atas tanah terawat, satu siri ujian tiga paksi CU telah dijalankan. Gentian yang disalut dengan Akrilonitril Butadiena Stirena (ABS) memberi perlindungan yang memuaskan terhadap biodegradasi gentian OPEFB. Selain itu, ujian tiga paksi CU juga dijalankan untuk menilai pengaruh optimum OPEFB bersalut gentian ke atas perilaku kekuatan tegasan–terikan tanah terawat dengan kandungan CLR 10% dan 12.5% pada 7 dan 28 hari pengawetan. Daripada keputusan yang diperolehi, ciri-ciri geoteknikal untuk kedua-

dua jenis tanah yang dikaji (SM & MH) menunjukkan peningkatan yang ketara dengan penambahan kandungan CLR dan masa pengawetan. Puncak kekuatan, ketegaran dan kerapuhan terutama untuk tanah SM meningkat dengan ketara di mana perilaku tanah berubah dari mulur ke tegar. Oleh itu, penilaian struktur-struktur bumi yang diperbuat daripada bahan berkenaan amat diperlukan. Model matematik dengan korelasi yang tinggi untuk kedua-dua tanah (SM & MH) terawat dengan CLR dicapai untuk menganggar kekuatan mampatan tak terkurung (qu), tegasan sisihan puncak, kejelekitan tanah c' dan sudut geseran berkesan φ'. OPEFB bersalut gentian optimum untuk tanah SM telah dianggarkan sebanyak panjang gentian = 40 mm dan kandungan gentian = 0.5% daripada berat. Spesimen terawat gentian-CLR-SM telah menunjukkan perilaku yang mulur dan kegagalan terikan paksi serta tegasan sisihan selepas puncak untuk spesimen terawat gentian-CLR-SM adalah lebih tinggi berbanding dengan spesimen terawat CLR-SM. Maka, rawatan tanah dengan menggunakan gentian-CLR adalah dicadangkan untuk struktur-struktur bumi. Keputusan juga telah membuktikan bahawa RHA boleh meningkatkan kekuatan ricih campuran tanah dan CLR dengan ketara serta mengurangkan kos dan masalah alam sekitar disebabakan oleh bahan tambahan simen dan kapur.

MECHANICAL PERFORMANCE EVALUATION OF IMPROVED SOILS USING COMPOUND STABILIZER AND FIBRE REINFORCEMENT

ABSTRACT

Construction of civil engineering structures on weak or soft soil is difficult without any soil improvement due to their poor shear strength and high compressibility. The problems of utilization of common stabilizers are such as: high cost of production, increment in greenhouse gases emissions followed by the cement and lime production and application on only a certain type of soils. In this study, effectiveness of CLR (Cement-Lime-Rice husk ash admixture), CL (Cement-Lime admixture), OPEFB fibre (Oil Palm Empty Fruit Bunch) and OPEFB-CLR on geotechnical properties of problematic soils was evaluated and investigated. The primary objective of this research was to study the strength, deformation and compaction characteristics of CLR treated soils and fibre-CLR treated soils as a reinforced material on weak, soft or problematic soils. This was achieved by studying the changes induced in treated and untreated soils using grain size distribution, atterberg limits, compaction ability (standard proctor test), oedometer, california bearing ratio (CBR), unconfined compressive strength and consolidated-undrained triaxial (CU). To evaluate the effects of random distribution of OPEFB coated fibres on treated soil a series of triaxial CU test were carried out. The fibres coated with Acrylonitrile Butadiene Styrene (ABS) provide acceptable protection against the biodegradability of the OPEFB fibre. In addition, CU triaxial test was also conducted to evaluate the influence of optimum OPEFB coated fibre on the stress–strain–strength behaviour of treated soil with 10% and 12.5% CLR contents at 7 and 28 days of curing. From the results, geotechnical properties of both studied soils (SM & MH) were found to improve significantly by the addition of CLR content and

increasing curing time. Peak of strength, stiffness and brittleness especially in SM soil were increased significantly while soil behaviour changes from ductile to rigid. Thus, assessment of any related earth structure made of such material is required. Mathematical model with strong correlation for both stabilized soil (SM & MH) with CLR is achieved to estimate the unconfined compressive strength (q_u), peak deviator stress effective (q_p), cohesion c′ and effective friction φ′. Optimum OPEFB coated fibre for SM soil was estimated at fibre length = 40 mm and fibre content = 0.5% by weight. The fibre-CLR-SM treated specimens have demonstrated a ductile behaviour and both the failure axial strain and post-peak deviator stress of the fibre-CLR-SM treated specimens were greater than those of the CLR-SM specimens. Therefore, soil treatment with fibre-CLR is recommended for earth structures. Results have shown that the RHA can significantly increase the shear strength of soil-CLR mixture as well as reduce the cost and environmental disadvantages of cement and lime additives.

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Soil has been used as a base material in various engineering infrastructures such as retaining walls, pavements, water ways, irrigation and drainage networks, protective barrier and embankments. Particular attention has been turn to the chemical stabilization or mechanical compaction of natural problematic soils in order to enhance soil physicochemical properties such as increasing the strength and cohesion (McDowell, 1959, Sherwood, 1993, Kolias et al., 2005). However, the economic aspect of soil stabilization projects limits the application of mechanical approach. Regarding to the chemical stabilization viewpoint, several additives such as cement, lime, polymers and asphalt have been utilized as stabilizers are quite common (Rawas et al. 2005, Chen and Lin, 2009,(Billong et al., 2009),(Tastan et al., 2011). Cement and lime are the most common additives amongst the mentioned materials that positive by affect soil performance and these effects have been widely documented (McDowell, 1959, Osula, 1996, Lo and Wardani, 2002, Sariosseiri and Muhunthan, 2009, Joel and Agbede, 2011, Schanaid et al., 2011,(Dash and Hussain, 2012). Cement and lime significantly decrease the swell potential, plasticity index (PI), increase the modulus of elasticity (E_s), durability index (I_d) brittle index (I_B) and shear strength of soils (τ) (Lo and Wardani, 2002, Sharma et al., 2008,(Kalantari et al., 2011, Jongpradist et al., 2011, Consoli et al., 2011a).

Application of pozzolanic stabilizers such as; slag, fly ash, foundry slag and rich husk ash in soils stabilization have been investigated. Pozzolanic stabilizers can bind soil particles together and reduce water absorption by clay particles (Kaniraj and Havanagi 1999, Miller and Azad 2000,(Ansary et al., 2007), Moon et al. 2009). Generally, usefulness and selection of chemical and pozzolanic stabilizers depends on the field conditions, mechanic behaviour of treated soil and type of soil.

In recent years, many investigations have been conducted on the solution of environmental and economic problems due to chemical stabilizers applications. Using the waste natural material is one of the most effective approaches in soil improvement as a green method. Agricultural activities provide various waste natural materials such as bran and husk. Paddy farms are composited of 5–8% of bran, 72% of rice and 20–22% of husk on an average by weight, that cause to generate rice husk ash (RHA) as an alternative additive to eliminate the chemical additives problems. Rice husk ash (RHA) can be used as a pozzolanic material (87–97% of SiO_2) with cement or lime in soil stabilization and lead to reduce cement and lime consumption in soil stabilization and improve the soil engineering properties (Sharma et al., 2008, Eberemu, 2011), Khandaker et al., 2011, Zain et al., 2011). It must be noted that, the different amount of chemical additives and curing time are also significant variable parameters which render different reactions for treated soils (Puppala et al. 2005,(Consoli et al., 2009a). By consideration on past investigations, it was found that no treated soil with the combination of cement-lime and RHA (CLR) has been utilized yet.

Both, soil stabilization and soil reinforcement are employed to improvement soil geotechnical properties. Reinforced and stabilized soils are composite materials that result from the optimization and combination of properties of individual materials. There are conventional geosynthetics for soil reinforcement, such as geotextile, geogrid and strips, but using fibre for different geotechnical purposes has been recommended in recent years (Zornberg, 2002, Latha and Murthy, 2007, Chauhan et al., 2008,(Ahmad et al., 2010). All last investigations have presented that addition of randomly distributed fibres caused significant improvement in the strength and ductility of the soil. Furthermore, utilization of randomly distributed fibres to improve the ductility of cement-stabilized soils has been reported by some researchers. (Tang et al., 2007) and (Consoli et al., 2009b), reported that residual shear strength and peak of shear strength of fibre-cement-treated soil comparing to cement-treated soil, increased and brittle behaviour of treated soil changed to ductile behaviour.

1.2 Problem statement

Increased costs associated with the utilization of high quality materials have led to the need for local soils to be used in geotechnical and highway construction. However, high water content and low workability of these soils often pose difficulties for construction projects. Construction of civil engineering structures on weak or soft soil is difficult without any soil improvement due to their poor shear strength and high compressibility. Cement and lime are the most common additives amongst the mentioned materials that positively affect the soil performance and the selection of a particular additive depends on costs, benefits, availability, and practicality of its application. The problems of utilization of these stabilizers are such as: high cost of production, increment in greenhouse gases emissions followed by the cement and lime production and the application on only a certain type of soils. According to former studies, researchers have always been trying to find a solution for environmental and economical problems of utilizing common chemical stabilizations (cement and lime). The means of finding an alternative material as a combination with common chemical stabilizers that on one hand leads to improve a function; such as improve the bearing capacity of layers in highway, railroad, and airport constructions, as foundation for light structures, as backfill for retaining walls, and as lateral support in excavations and trenches, while on the other hand, to some extent causing negative effects on the environment. Another problem in utilizing stabilizers with some soils is the increased in brittleness which requires further studies to find the solutions. Moreover, limited studies have been carried out for the influence of natural fibre inclusion on the mechanical behaviour of treated soils.

1.3 Objectives of the research

The main objective forming the basis of this research is to study the strength, deformation and compaction characteristics of CLR treated soils and fibre-CLR treated soils as a reinforced material on problematic soils. Also, the following specific objectives are considered

1- To investigate of the mechanical and deformability properties of CLR treated soils

2- To determine the effect of RHA on engineering properties of Soil-CLR

3- To develop model on the basis of results for stabilized soil with CLR content and curing time

4- To evaluate the effect of OPEFB fibre distribution on soil strength and concentration on fibre-CLR-soil behaviours

1.4 Scope of the research

The present study was carried out at Universiti Sains Malaysia (USM), School of Civil Engineering. Tests were performed on two types of soils. First silty sand soil (SM) was collected from Matang Kerat Telunjuk, Bandar Baharu in Kedah and second soil (MH) was collected from Nibong Tebal, USM Engineering campus. Combination of 25% cement, 50% lime and 25% rice husk ash as the best mixture was selected for this investigation. The percentages of the additives of CLR and CL varied from 2.5 to 15% by dry unit weight of the soil and the curing times of 3, 7, 28 and 60 days were examined. The effect of different CLR and CL quantities was evaluated on both treated and untreated soils using grain size distribution, Atterberg limits, compact ability (standard proctor test), oedometer, california bearing ratio (CBR), unconfined compressive strength and consolidated-undrained triaxial (CU). To evaluate the effects of randomly distributed of OPEFB coated fibres on SM soil a series of Triaxial CU test were carried out. The specimens were prepared at dry unit weight = 16 kN/m^3 with different fibre lengths (20 mm, 40 mm and 60 mm) and different fibre contents (0.25% and 0.5% by the weight). In addition, CU triaxial test at different confining pressures (50 kPa, 100 kPa and 250 kPa) was conducted to evaluate the influence of optimum OPEFB coated fibre (fibre length = 40 mm, fibre content = 0.5% by weight) on the stress–strain–strength behaviour of SM treated with 10% and 12.5% CLR contents at 7 and 28 days of curing.

1.5 Organization of thesis

This study is divided into five chapters, including the introduction, literature review, experimental programs and methods, results and discussion, and conclusions and recommendations. Chapter one presents a summary of the research, consisting of background of the research, problem statement, objective of the study, scope of the research, and thesis organization. Chapter two deals with background and a general literature review of the topic. It includes the performance of different stabilizations on soil engineering properties including lime, cement (Portland), rice husk ash, fly ash, cement-lime-fly ash combination, fibres, emulsified asphalt and polymers. Moreover, discussion on the critical state framework is presented in this chapter. Chapter three presents the methodology of the study and a summary of the experimental tests programs. Results and discussion are presented in Chapter Four and finally, the conclusion of the study and recommendations for future program studies are presented in Chapter five.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the performance of a number of widely used traditional and non-traditional stabilizers in geotechnical engineering projects such as: lime, cement, rice husk ash, fly ash, cement-lime-fly ash admixture, fibre reinforcement, polymer, salt and emulsified asphalt is discussed and compared. It is followed by discussion of stress path and critical state behaviour of the soils.

2.2 Traditional stabilizers

2.2.1 Lime stabilization

Lime which is gained by burning lime stone ($CaCO_3$) is an old and popular additive. It has been used in modern geotechnical engineering to improve soil properties since 1924 (McCaustland, 1925). Today, clay soil stabilization with lime is used widely in the world to the some geotechnical engineering applications improvement such as; improvement of subgrades and subbases in road, airport and railroad construction, backfill for bridge, embankments, slopes stability, retaining walls, soil foundation (Anon, 1990;(Bell, 1996);(Consoli et al., 2009a, Dash and Hussain, 2012). The major lime additives mostly used in constructions are; Calcitic quick lime [CaO], dolomitic quick lime [CaO MgO], hydrated high calcium lime [$Ca(OH)_2$] and monohydrated dolomitic lime [$Ca(OH)_2$ MgO]. Quicklime is produced by heating limestone to about 850^{o}C and driving off carbon dioxide through reactions such as the following:

$$CaCO_3 + heat \rightarrow CaO + CO_2 \quad (2\text{-}1)$$

The construction activities are simplified by lime treated of soil in three ways: First, lime by reduction in plasticity index leads to soil workability increase. Second, it simplifies compaction of very wet soils (increases the optimum moisture content and decreases the maximum dry density) and improve the soil properties and strength parameters (Chen and Lin, 2009).

Immediately, after mixing lime with soil particles, when the water exists, cation exchange and flocculation-agglomeration are the main reactions. During these reactions, the monovalent cations are replaced by the calcium ions. As a result changes occur in plasticity index, workability and strength (Mitchell and Soga, 2005). As reported by Mitchell and Soga (2005), the pH of combination of soil and lime increases up to 12.4 after mixed with water and caused to the dissolution of silica (SiO_2) and alumina (Al_2O_3) from the soil. The strength of soils treated with lime is dependent primarily on the dissolved Al_2O_3 and SiO_2 in pozzolanic reactions as follows (Consoli et al., 2011a).

$$Ca(OH)_2 + SiO_2 \rightarrow CaO\text{-}SiO_2\text{-}H_2O \quad (2\text{-}2)$$

$$Ca(OH)_2 + Al_2O_3 \rightarrow CaO\text{-}Al_2O_3\text{-}H_2O \quad (2\text{-}3)$$

Instead $CaO\text{-}SiO_2$ and $CaO\text{-}Al_2O_3$ is produced as a result of lime reacting with carbon dioxide. The pozzolanic reactions are time and temperature dependent and might continue for a long time till the pH remains 12.4.

2.2.1.1 Lime content

The cation exchange, pozzolanic reaction and carbonation are the lime reaction after mix with soil. Cation exchange takes place immediately when lime is added to soil and lead to produces free Ca++ ions and caused to increase the pH of the soil–lime. The solubility of silica and alumina present is increased in pH above 12.4 in the clay minerals (Bell, 1996). The alumina and silica then react with the Ca++ to form aluminates and calcium silicates and calcium silicates become hydrates. This pozzolanic reaction is temperature dependent (Thompson, 1967).

2.2.1.2 Lime treatment advantages

Soil treatment with lime can be attributed by production of new cementing materials due to the pozzolanic reactions and leads to larger size particles by aggregation (Narasimha and Rajasekaren, 1996;(Bell, 1996, Sakr et al., 2009). Throughout these years, the effect of lime on the stabilization process has been examined by many investigators who have tested various soils with different mixtures of lime. The results obtained have shown that either quicklime or hydrated lime can be used for soil stabilization depending on the soil type and environmental conditions. For instance, according to Greaves (1996), quicklime is more widely used in Britain than hydrated lime, because of it denser state, less dusty nature, and also due to its hydration and evaporation reactions which makes it more effective when dealing with high moisture content soils. As reported by investigators, many engineering properties of problematic soils can improve by treatment with lime such as; decreasing plasticity index, swell potential and maximum dry density, increasing the California Bearing Ratio (CBR), increase of modulus of elasticity, strength, durability and permeability (Osinubi, 1998, Alhassan, 2008a, Sakr et al., 2009, Dash and Hussain, 2012). Increase in strength and durability is a long time stabilization which happens during and after curing.

2.2.1.3 Lime effect on compaction characteristics

Lime treatment increase the optimum moisture content (%) and decrease maximum dry unit weight (kN/m³). As an example, Figure 2.1 presented the result of lime treatment of clay soil in compaction characteristics (Bell, 1996).

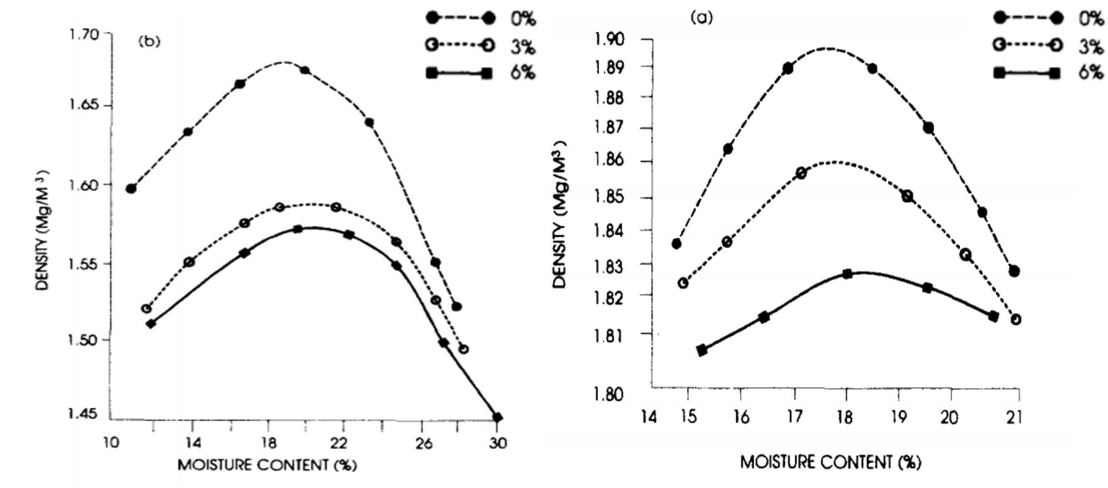

Figure 2.1: Compaction curves of two clay samples containing 0, 3 and 6% lime (Bell, 1996)

2.2.1.4 Lime effect on shear strength behaviour

Flocculation-agglomeration reaction following lime treatment leads to an immediate increase in strength and workability improvement. It should be considered that long term increase in strength is due to pozzolanic reactions. The soil strength

(UCS at failure) variation of lime content is shown in Figure 2.2; it can be observed that with increase in lime content soil strength is increased. But, with additional increase in lime content, the soil strength is reduced. This reduction in strength is recommended by Bell (1996), because lime has neither appreciable friction nor cohesion and excess quantity worked as a lubricant between soil particles.

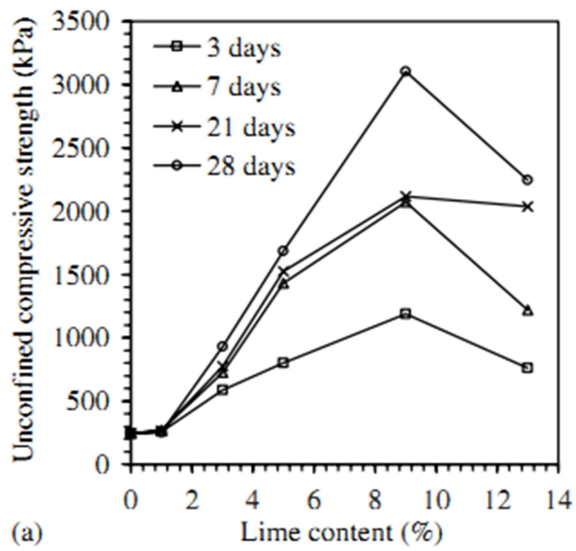

Figure 2.2: Variation in unconfined compressive strength with lime content (Dash and Hussain, 2012)

From Figure 2.2, unconfined compressive strength increased by increasing the curing time. The effect of lime treated and curing time on soil strength and modulus of elasticity by Saker (2009) is presented in Figure 2.3.

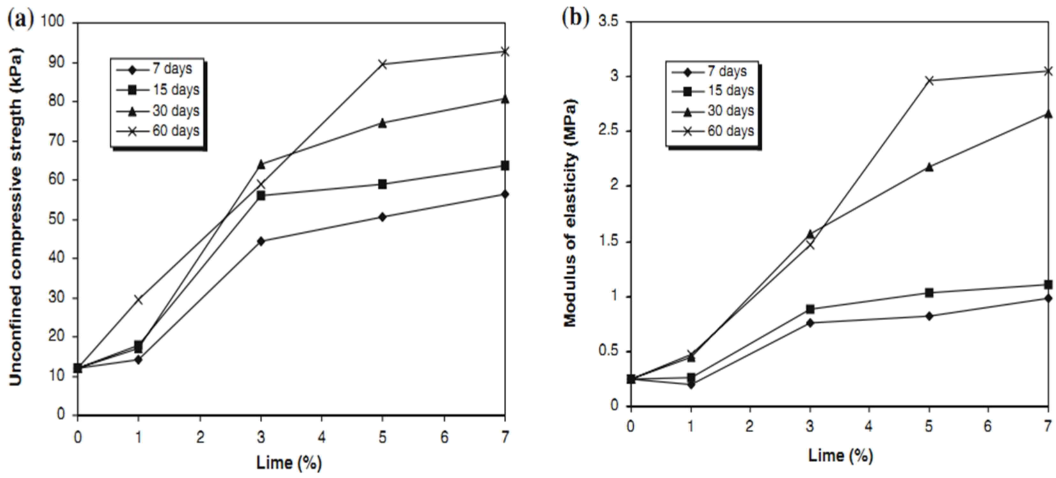

Figure 2.3: Effects of lime percent on (a) unconfined compressive strength, (b) stress-strain modulus of elasticity (Sakr et al., 2009)

To find out the cohesion and modulus of elasticity of lime treated soils based on unconfined compressive strength. Thompson (1996) suggested the following equations:

$$c = 9.3 + 0.292 \times \sigma_c \tag{2-4}$$

$$E = 9.98 + 0.1235 \times \sigma_c \tag{2-5}$$

where: σ_c: Unconfined compressive strength (psi)

2.2.1.5 Lime effect on swell potential

Relationship between swell time and swell (%) for expansive soil is shown in Figure 2.4 for different lime content. It can be observed that swell (%) decreased significantly with lime content of expansive soil increase. The swell, is defined as follow equation:

$$S = \frac{\Delta h}{h_i} \times 100 \quad (2\text{-}6)$$

where:

Δh: increase in thickness at a given time

h_i: initial thickness of the specimen

S: swell (%)

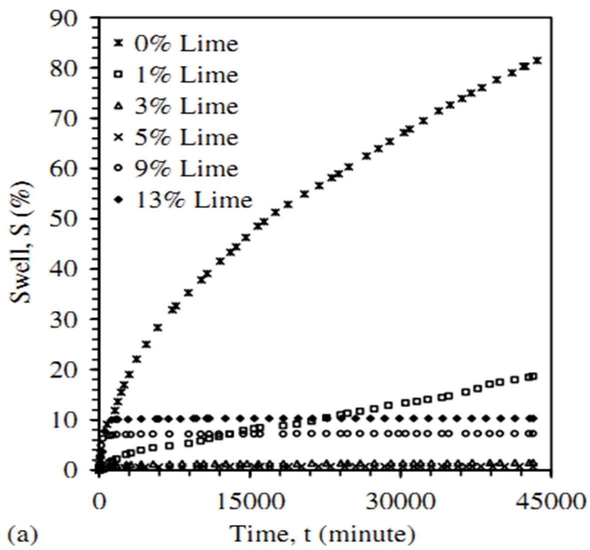

Figure 2.4: Swell-time responses of lime-treated for expansive soil (Dash and Hussain, 2012)

This result is attributed the formation of a cementation skeleton and leads to decreased thickness of the double layer and the swelling as well.

2.2.1.6 Lime quantity

Depending on properties of the material needing to treatment and the degree of stabilization, the amount of lime required may vary. Commonly, 2-3% (lime) by dry weight of the soil for modification and 5-10% for stabilization and more for pozzolanic reactions is sufficient (Das 1990; Maher et al. 2005).

Different methods have been suggested to determine the lime quantity required for soil stabilization; for instance, the following relation was suggested by Hilt and Davidson (1960):

$$Optimum\ content = \frac{\%\ of\ Clay}{35} + 1.25 \tag{2-7}$$

Eades and Grim (1966) suggested that the smallest quantity of lime needed to stabilize a soil must be able to maintain a pH of at all 12.4. The U.S. Army Corps of Engineers manuals have also suggestions and guidelines to measure the lime content required for soil stabilization and modification. But, additional laboratory tests should be conducted to determine the optimum lime amount.

2.2.1.7 Lime suitability

There have been good results when mixing clay soils with lime spectacularly those with moderate to high plasticity index (PI > 15). But these fine effects fade away in silts because in order to pozzolanic reactions take place, aluminates and silicates are needed which is not sufficient in silts. So, to stabilize granular and silt materials, pozzolanic admixtures are needed to be used in addition to lime (like fly ash) (Jauberthie et al., 2010). Berube *et al*. (1990) reported the results of a series of tests conducted on range of soil minerals treated with lime. The results show that siliceous minerals react more with lime than iron or magnesium silicates such as chlorite that can reduce the efficiency of lime treatment. Furthermore, the solubility of the minerals would be expected to increase with decreasing particle size and decreasing degree of crystallinity because of a greater specific surface and less resistant crystal structure.

As suggested by Little (1995), soils classified by Unified Soil Classification System (USCS) as MH, SM, CH, SC, SW-SC, CL, GC, SM-SC, SP-SC, GM-GC, and GP-GC can be stabilized by lime treatment. Hence, lime is suitable to be mixed with plastic fines and other marginal bases that contain noticeable quantity of material passing sieve number 40. Moreover, soils with sulfate concentration less than 7000 to 8000 (ppm) can be stabilized with lime (Harris et al. 2006).

2.2.1.8 Lime quality analysis

The appropriate and adequate amount of lime should be determined before stabilization process commerce. Available lime content (ALC) test is commonly performed on lime to determine a quality of lime for stabilization. The available lime content either quicklime or hydrated lime is determined based on BS6463: Part 2. The present of calcium oxide or calcium hydroxide is made by shaking them with a solution of sucrose. The solution is titrated against standard hydrochloride acid after the residue has been filtered off. Phenolphthalein is used as indicator in the titration. The formulae for indicator to be used are as follow;

$$\text{Percentage available lime (as CaO)} = 2.8045\ V / M \quad (2\text{-}8)$$

$$\text{Percentage available lime (as } Ca(OH)_2\text{)} = 3.705\ V / M \quad (2\text{-}9)$$

Where:

V = the titration (mL)

M = mass of sample (mg)

The available lime content in terms of equivalent CaO should be more than 60% and the available $Ca(OH)_2$ content is must be more than 80% for lime stabilization.

2.2.2 Cement stabilization

Soil stabilization with cement has a long history and the effects of cement treatment on wide range of soils performance have been documented widely (Mitchell, 1976;(Sariosseiri and Muhunthan, 2009, Chen and Wang, 2006, Schnaid et al., 2001, Rahman, 1987). Chemical reactions in cement treatment and lime treatment are the same and it can be used for stabilization and modification as well. Pervious investigations have shown that coarse soils and clayey soils with low PI index at pH > 5.3 are more appropriate (Currin et al., 1976;(Osula, 1996).

2.2.2.1 Cement content

The addition of cement to soil produced primary and secondary cementatious compounds duo to addition of cement of the soil (Pakbaz and Alipour, 2012). The primary cementation compounds are formed by a hydration reaction and comprised of hydrated calcium silicates (C_2SH_x, $C_3S_2H_x$), calcium aluminates (C_3AH_x, C_4AH_x), and hydrated lime Ca $(OH)_2$.. Thus, due to hydration reaction, hydrated calcium aluminates, hydrated calcium silicates, hydrated lime and hydrated calcium aluminium silicates are formed (Horpibulsuk et al., 2011). The hydration reaction would take place rapidly and is responsible to improve the properties of the treated soil in short term. The secondary reaction in the stabilization process is pozzolanic reaction between the silica and alumina and hydrated lime of clay minerals as a cementing compounds and leads to the formation of additional calcium silicate hydrates and calcium aluminate hydrates (Chew et al., 2004).

2.2.2.2 Cement treatment advantages

Significant alterations achieved by cement stabilization are: reduction in plasticity index (PI), maximum dry density and swell potential (%), increase in modulus of elasticity, strength, California Bearing Ratio (CBR), brittle index (I_B) and increase in optimum moisture content of treated soil (Osula, 1996, Yin et al., 2006, Sariosseiri and Muhunthan, 2009, Consoli et al., 2010, Consoli et al., 2011c, Joel and Agbede, 2011).

2.2.2.3 Cement effect on compaction characteristics

The effect of cement treatment on optimum moisture content (%) and maximum dry unit weight (kN/m^3) of studied soils determined by Sariosseiri and Muhunthanand (2009) are presented in Figure 2.5. from the results it is concluded that optimum water content increased by increasing cement content by weight but maximum dry unit weight decreased. The reduction in dry density is related to the change of particles size and specific gravity of the soils after mixing with cement.

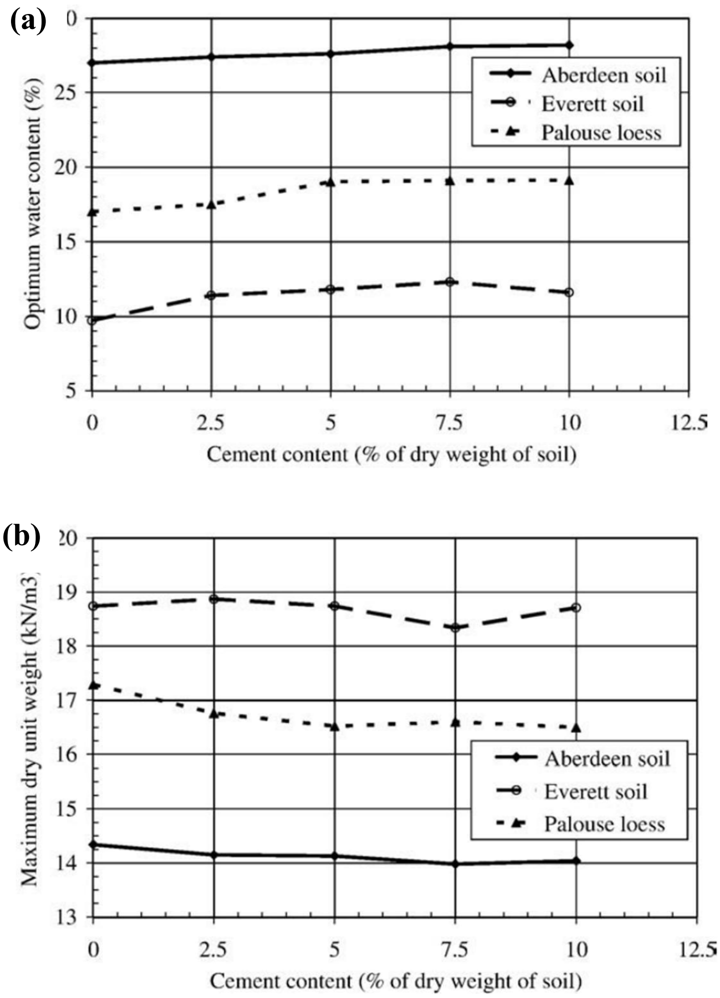

Figure 2.5: Effect of cement treatment on (a) optimum water content (b) maximum dry density (Sariosseiri and Muhunthan, 2009)

2.2.2.4 Cement effect on shear strength behaviour

The result of cement content on unconfined compressive strength for clayey sand (SC) soil at different dry density after 7 days curing is shown in Figure 2.6. It can be seen that the strength of soil treated with cement increased significantly. Results of this investigation showed that unconfined compressive strength increases with increase in different dry density, too.

It must be noted that the delay between mixing and compaction during sample preparation leads to significant reduction in strength of cement treated soils.

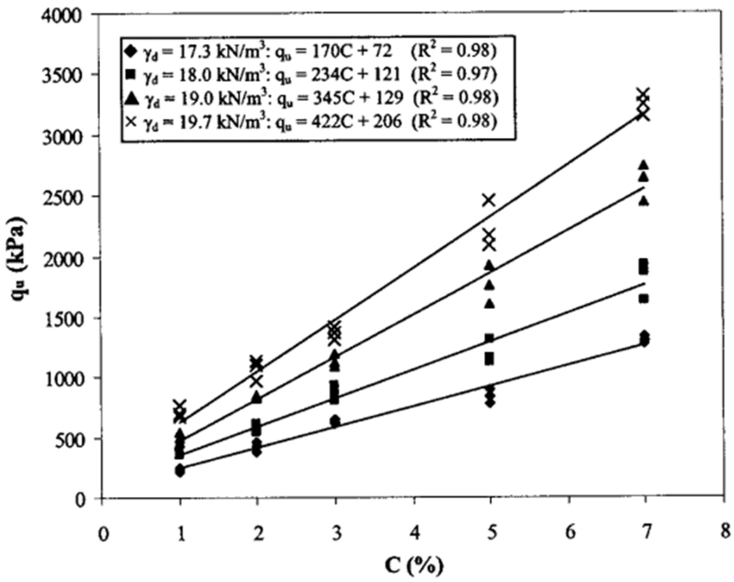

Figure 2.6: Variation of unconfined compression strength of clayey sand (SC) soil with cement and different dry density (Consoli et al., 2007)

The relationship between unconfined compressive strength and porosity for clayey sand (SC) soil and cement content was presented by Consoli et al. (2007) as follow:

$$q(kPa) = 2.20 \times 10^{6} \left[\frac{\eta}{(C_V)^{0.28}} \right]^{-2.22} \qquad (2\text{-}10)$$

Where:

q (kPa) : Unconfined compressive strength

C_V: Volumetric cement content

η = porosity

The effect of cement treatment and effect of curing on silt soil strength by Jauberthie et al. (2010) is presented and soil strength improvement due to curing time and cement content is significant as shown in Figure 2.7

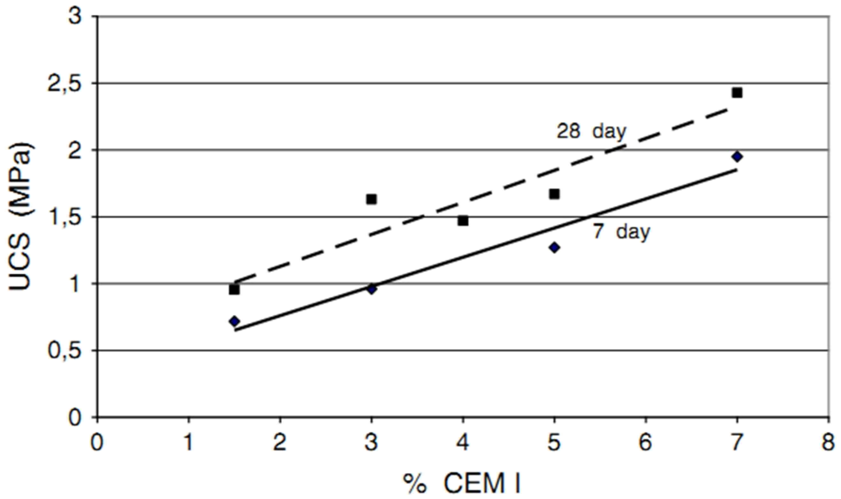

Figure 2.7: UCS test results of cement stabilised silt at 7 and 28 days (Jauberthie et al., 2010)

In 1976, Mitchell presented the relationship between unconfined compressive strength, cement content and curing time as following equation:

$$(\sigma_c)_d = (\sigma_c)_{d_0} + K \log\left(\frac{d}{d_0}\right) \qquad (2\text{-}11)$$

Where:

$(\sigma_c)_d$: Unconfined compressive strength at age of d days

$(\sigma_c)_{d0}$: Unconfined compressive strength at age of d_0 days

K = 10C for fine-grained soils, and K = 70C for coarse-grained soils (C: percent of cement content by weight).

2.2.2.5 Cement effect on modulus of elasticity

The effect of cement treatment on modulus of elasticity for soaked and unsoaked conditions is shown in Figure 2.8 by Sariosseiri and Muhunthan (2009). It can be seen that modulus of elasticity increased significantly by increasing cement content by weight.

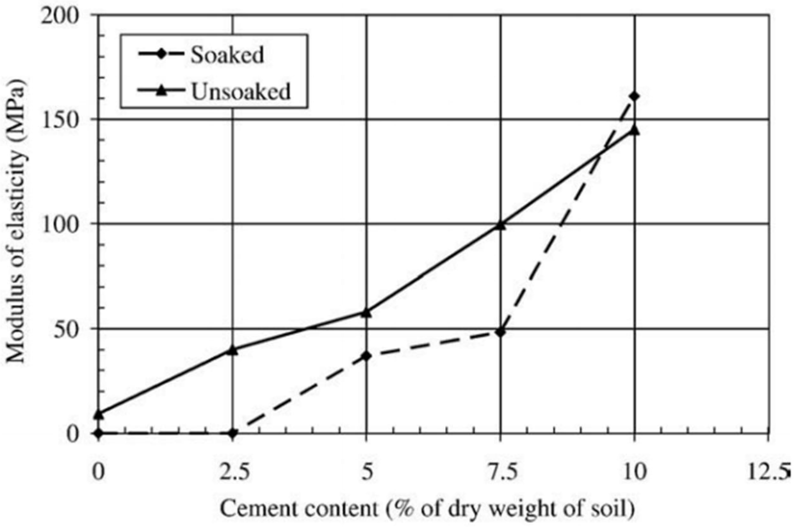

Figure 2.8: Effect of cement treatment on modulus of elasticity for soaked and unsoaked samples (Sariosseiri and Muhunthan, 2009)

2.2.2.6 Cement effect on effective cohesion

Figure 2.9 compares the evolution of the cohesion of the treated soil by cement in time (days). The treated soil with cement content comparing to untreated soil shows a significant enhance in soil cohesion.

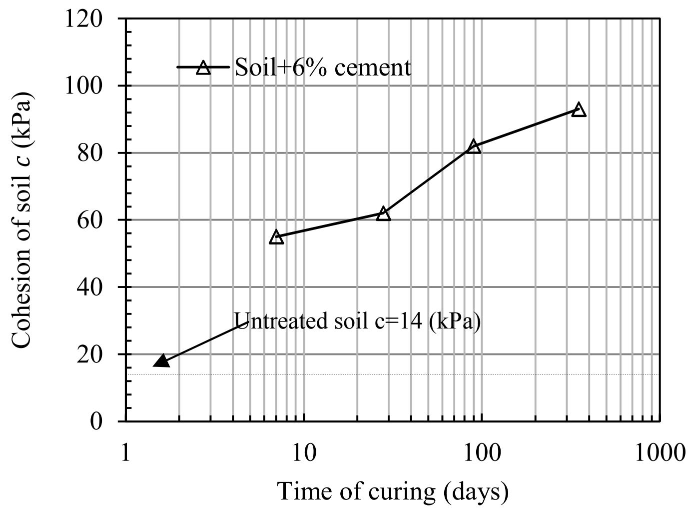

Figure 2.9: Evolution of cohesion of soil treated with cement at different curing time (Okyay and Dias, 2010)

The value of the cohesion soil treated with cement in first week of curing reached up to 55 kPa. These values are above 90 kPa at 350 days that means soil cohesion has improved more than 6 times.

2.2.2.7 Cement quantity

Usually, the cement amount needed for soil stabilization is about 5% to 10 % of dry soil weight. Although, guidelines have been provided to measure the optimum cement content by U.S. Army Corps of Engineers, but most of manuals and guidelines do not suggest the soils with PI >15 to be treated by cement. To overcome this, small quantity of lime can be added to cement soil.

2.2.3 Rice husk ash

Agricultural activities provide various waste natural materials such as bran and husk. Paddy farms are composited of 5–8% of bran, 72% of rice and 20–22% of husk on an average by weight, that cause to generate rice husk ash (RHA) as an alternative additive to eliminate the chemical additives problems (Basha et al, 2005, Bui and Stroeven, 2005,(Muthadhi and Kothandaraman, 2010). It was estimated that1000 kg of rice grain generated 200 kg of rice husk and burning the rice husk would become about 20% or 40 kg of RHA (Sharma et al., 2008).

Rice husk ash contains high amount of silica (87–97% of SiO_2) and thus can be used as a pozzolanic material in lime and cement mixture. Rice husk ash cannot be used alone for stabilization of soil because of lack of cementitious properties. During last few decades, different investigations on RHA performance in soil stabilization have shown that RHA can be considered as a pozzolan promising material with cement or lime as it can improve the problematic soil engineering properties. It improved strength and durability properties, reduced materials costs (Jha and Gill, 2006, Nair et al., 2006, Alhassan, 2008b, Sharma et al., 2008, Muthadhi and Kothandaraman, 2010, Eberemu, 2011) and also reduce cement and lime consumption in soil stabilization and concrete technology as well (Khandaker et al., 2011, Zain et al., 2011). Figure 2.10 shows the effect of RHA on UCS and CBR of clay-lime blends. It can be seen that, both unconfined compressive strength and CBR increased with increasing lime content for given RHA content. Using RHA as a supplementary cementitious material leads to reduction in greenhouse gases (carbon dioxide) emissions following by the cement and lime production (Metha, 1997, Zhang and Malhotra, 1996, Cordeiro et al., 2009). Besides, it is figured out that carbon remained in the ash is trapped in the soil or concrete and will not distribute in atmosphere which is environmentally so momentous (Metha, 1997).

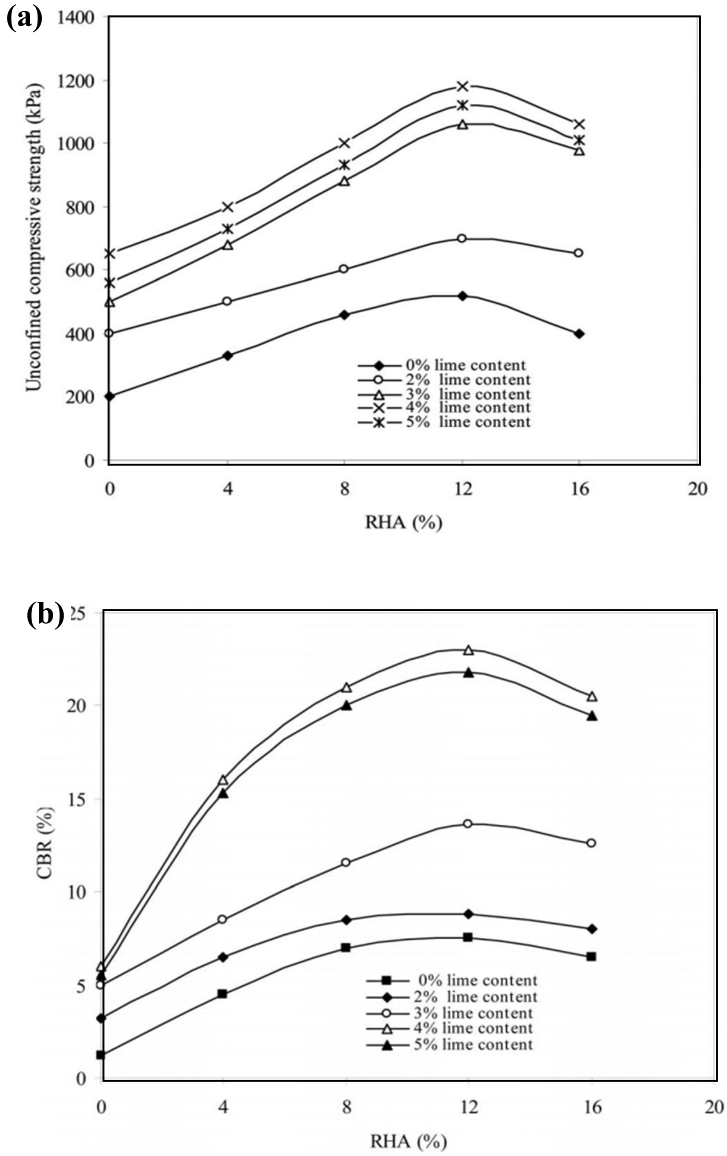

Figure 2.10: (a) Effect of RHA on UCS of clay-lime blends, (b) Effect of RHA on CBR of clay-lime blends (Sharma et al., 2008)

2.2.3.1 Rice husk ash content

Rice husk ash contains a high amount of SiO_2 in amorphous which makes it a pozzolanic. Rice husk ash as a pozzolanic material can be mixed with lime and cement for soil stabilization (Payá et al. 2001). Pozzolana is a siliceous or aluminous material and can be used alone for stabilization. However, rive husk ash (pozzolana)