Strength of Soft Soil Stabilized Using Lime-POFA Mixtures

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Abstract This paper presents the study on the strength of Malaysian soft soil stabilized using mixing of lime and palm oil fly ash (Lime-POFA). Palm Oil Fly Ash (POFA) additives used in this study is a finely product from waste product from the process of burning palm oil fiber and described as a by-product of thermal power plants where palm oil fiber shell, and empty fruit bunches was burnt at temperatures ranging from 800 to 1,000 °C until it is in fly ash condition. According to ASTM C618, the POFA used in this study has been tested and classified as Class-F fly ash accordingly to ASTM C618 because POFA describe as siliceous and aluminous materials that possess little or no cementitious value. In that condition, POFA need to combines with small quantities of lime for pozzolanic reaction. The samples of soft soil classified as slightly sandy CLAY of intermediate plasticity has been used in this study. The optimum of 3 % hydrated lime used in this study as an active additive to the various percentage mixtures of POFA for the pozzolanic reaction. The first objective of this study is to determine the optimum proportion of POFA to be mixed with 3 % lime to stabilize the clay soil based on the compressive strength at 0, 14 and 28 days of curing periods. The second objective is to determine the strength development of clay soil stabilized at the optimum percentage of POFA mixed with 3 % lime at 0, 14 and 28 days of curing periods. This study involved in unconfined compression strength to determine the strength of stabilized clay soil. The development of compressive strength of soil stabilized using (Lime-POFA) were compared to the compressive strength of unstabilized soil. The result shows, the 6 % POFA mixed with 3 % Lime was the suitable proportion in term of strength and strength development and can be used as additives to stabilize clay soil.

Keywords Soil stabilization · Compressive strength · Lime · Palm oil fly ash

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R. Hassan et al. (eds.), *InCIEC 2013*, DOI: 10.1007/978-981-4585-02-6_43,

1 Introduction

Soft soil considered as a problematic soil to the geotechnical engineer's and causes major problems at any construction such as subgrade problems due to the undesirable engineering properties. Commonly, soft soils are known to have low strength, high compressibility and the water contents are also known to be high at almost to its liquid limits. Moreover, soft soil has brought problems because the behavior is unpredictable. Soft soil has the shear strength of less than 25 kPa and it is a mineral combination of hydrous aluminium, silicates, quartz, feldspar, carbonate, oxides, hydroxides, and organic materials [3]. Soft soil usually found in coastal area or river area and the thickness is different depending on that area. The soft soil in Malaysia usually found in coastal area at west coast of Peninsular Malaysia. The thickness of soft clay soil strata in West Coast of Peninsular Malaysia is (5–35 m) and (3–20 m) thick at East Coast of Peninsular Malaysia [1].

The soil modification, stabilization, or both can be classified in group of soil improvement. Soil modification is an addition an active additives such as lime and cement to soil to change its index properties, while soil stabilization is the treatment of soils to improve the texture, increase strength, increase the CBR value and reduce shrink-swell characteristics such that they become totally suitable for construction for a long term. Both techniques introduced many years ago and the main purpose to render the soils capable of meeting the requirements of the specific engineering projects [9]. The techniques of soil stabilization and soil improvement using lime and/or cement are well established and were published by many researches [7]. The optimum lime content for stabilize the Malaysian cohesive soils was recorded between 3 and 6 % [8]. There's an alternative technologies which more sustainable, environmentally friendly and economical. Fly ash stabilization exhibit increased and enhanced both the unconfined compressive strength and the CBR values substantially as well as durability in terms of water resistance, swelling, shrinkage modulus of elasticity and has the potential to offer an alternative for soft subgrade improvement of highway construction [6, 11, 12]. Recently, it has been found that appropriate chemical stabilization can improve undesirable characteristics of such soil [10].

Fly ash is one of the wastes products from manufacturing industry. Generally, fly ash considered as pozzolana, which is not cementitious itself. It has an ability to combine with Ca-rich materials such as lime, cement, etc. to form cementitious ones; e.g. calcium silicate hydrate (CSH), calcium aluminate hydrate (CAH), calcite ($CaCO_3$), etc. among soil particles due to the hydration and long-term pozzolanic reaction [10]. Soft clay is pozzolanic in nature and require the presence of lime that released by the cement to initiate the pozzolanic reaction [13]. The mixture of 9 % cement and 3 % fly ash gives the best result of strength to stabilize the expensive soils [2]. Previous study shows palm oil fly ash has good pozzolanic properties as a cement substitute [3]. The fly ash stabilization increased both the unconfined compressive strength and the CBR values substantially and has the potential to offer an alternative for soft subgrade improvement of highway construction [12].

The aim of this study is to show the use of palm oil fly ash (POFA) as an additive to stabilize a soft soil. This is an experimental study to determine the concentration percentage POFA mixed with 3 % Lime as an additive based on compressive strength and the development of compressive strength at 0, 14 and 28 days of curing periods. The result shows that the 6 % POFA mixed with 3 % Lime was giving the highest strength and considered the suitable proportion to stabilize slightly sandy CLAY of high plasticity and can be used as additives to clay soil.

2 Materials

2.1 Soft Soil Sample

The soft soil samples are collected from Kampung Sijangkang, Selangor, Malaysia and collected in disturbed and undisturbed samples at 2 m from ground level was in grey colour. The samples were tightly sealed and wrapped with plastic after collecting to maintain the original moisture contents before transported, stored at room temperature and testing in the laboratory. The samples were tested for physical and engineering properties in natural state (considered as undisturbed samples) and remolded samples (considered as disturbed samples). The samples were tested for physical properties based on BS 1377: Part 2: 1990.

2.2 Palm Oil Fly Ash

Palm Oil Fly Ash (POFA) additives used in this study was from waste product from the process of burning palm oil fiber or oil palm fiber (OPF). POFA described as a by-product of thermal power plants where palm oil fiber (OPF), shell, and empty fruit bunches was burnt at temperatures ranging from 800 to 1,000 °C until it is in fly ash condition. Previous study shows POFA has good pozzolanic properties that were used as cement substitute [3]. This POFA obtained from Sg. Tengi Palm Oil Factory at Kuala Kubu Bharu, Selangor, Malaysia.

2.3 Lime

Lime was also used widely to stabilize weak fly ash to reduce settlement and to increase bearing capacity. Hydrated lime [$Ca(OH_2)$] was used in this study act as an main active additive to the POFA for the pozzolanic reaction. Hydrated lime was available widely in Malaysia and was provided from Geotechnical Laboratory of Faculty of Civil Engineering UiTM Shah Alam. Fly ashes containing sufficient

Table 1 Details of sample

Specimens	Lime (%)	POFA (%)
Soil (Undisturbed)	–	–
Soil (Remolded)	–	–
Soil + 3Lime	3	2
Soil + 3Lime + 2POFA	3	4
Soil + 3Lime + 4POFA	3	6
Soil + 3Lime + 6POFA	3	8

lime content and reactive silica develop good strength on addition of water while fly ashes containing only reactive silica with insufficient lime content will improve their strength only with the addition of the hydrated lime.

2.4 Sample Preparation and Testing

This study involved two soil samples considered as control. The first undisturbed samples were prepared accordingly to natural state of water content and the second disturbed samples were remolded samples prepared based on optimum moisture content at maximum dry density. The additives consisted of 3 % lime as main activator mixed with various percentages of POFA (2, 4, 6 and 8 %) shown in Table 1. The soil was stabilized based on the dry unit weight of the clay soil.

The laboratory testing was conducted to determine the physical properties of clay soil and POFA such as particle size distribution, specific gravity, atterberg limit, moisture content, compaction characteristic and natural moisture content. All the entire testing based on BS 1377:1990. The mixtures are compacted at maximum dry density, optimum moisture content and molded into cylindrical specimens of 38 mm diameter and 76 mm high based on BS 1377-7:1990 [4] for unconfined compressive strength (UCS) test. The specimen samples wrapped and placed at room temperature condition to protect from loss of moisture content. The samples were cured for 0, 14 and 28 days before being tested. The curing time has a significant effect on unconfined compressive strength [13] and to allow the reaction between soil and additive Lime-POFA to take place, to form a homogeneous mixture, and to strengthen the clay soils particles.

3 Materials Properties

3.1 Clay Soil Properties

The sample of soil had been tested for physical properties and the result shown in Table 2. Based on the properties result of soil sample, it shows in the natural state

Table 2 The physical properties of clay soil sample

Properties	Values
Natural moisture content, w (%)	75
Specific gravity (Gs)	2.65
Plastic limit (%)	24.96
Liquid limit (%)	48.77
Plastic index (%)	23.81
Compaction characteristics	
Optimum moisture content (%)	20
Maximum dry density (%)	14
Particle size distribution	
Gravel (%)	0
Sand (%)	8.18
Fine/Silt (%)	80.60
Clay (%)	11.22
D_{60}	0.036
D_{30}	0.013
D_{10}	0.001
Coefficient of uniformity (C_u)	27.95
Coefficient of curvature (C_c)	3.88
Classification	Slightly sandy CLAY of intermediate plasticity

Table 3 The chemical constituent of soft soil sample

Element	Concentration (%)
SiO_2	63.02
Al_2O_3	17.27
Fe_2O_3	3.59
CaO	0.15
K_2O	2.05
Na_2O	0.21
MgO	1.03
SO_3	0.67
L.O.I	–

the natural water content of soil much higher is about 75 % and the specific gravity of 2.65. The soils sample covered about 8.18 % sand size, 80.60 % of fine or silt size and 11.22 % clay size. The plastic limit and liquid limit are 24.96 and 48.77 % respectively. Meanwhile the plastic index is about 23.81 %. Based on the results properties, the soft soil samples classified as slightly sandy CLAY of intermediate plasticity.

The chemical constituent result for Sijangkang soft soil are presented in Table 3. It shows that, the soft soil samples having pozzolanic properties due to the percentage composition for major constituent components such as silicon dioxide (SiO_2), alumina oxide (Al_2O_3) and iron oxide (Fe_2O_3).

Table 4 The physical properties of palm oil fly ash (POFA)

Properties	Values
Specific gravity (Gs)	1.66
Particle size distribution	
Sand (%)	0.06
Fine/Silt (%)	99.94
Clay (%)	0
Classification (ASTM C618)	Class-F fly ash

Table 5 The chemical properties of palm oil fly ash (POFA)

Element	Concentration (%)
SiO_2	69.01
Al_2O_3	5.41
Fe_2O_3	4.18
CaO	5.58
K_2O	8.76
Na_2O	0.14
MgO	3.07
SO_3	0.06

3.2 Palm Oil Fly Ash Properties

The palm oil fly ash (POFA) had been tested for physical properties and the result shown in Table 4. The specific gravity POFA is about 1.66 and considered as light materials.

Table 5 shows the chemical composition result for palm oil fly ash (POFA). Based on ASTM C618 for classification of fly ash, the palm oil fly ash (POFA) classified as Class-F fly ash because the total combination percentage composition for major constituent components such as silicon dioxide (SiO_2), aluminina oxide (Al_2O_3) and iron oxide (Fe_2O_3) more than 70 %. This class-F POFA describe as siliceous and aluminous materials that possess little or no cementitious value consist a little quantity of Calcium Carbonate or free lime (CaO) lower than 10 %. Furthermore the class-F POFA considered as non self-cementing ash because having pozzolanic properties and no or small quantities of self-cementing properties sources of calcium and magnesium ions.

3.3 Lime

The hydrated lime [$Ca(OH_2)$] were used as a an active additive to the POFA for the pozzolanic reaction to improve some engineering properties of the clays. The chemical properties of hydrated lime listed in Table 6.

Table 6 Properties of hydrated lime [5]

Element	Concentration (%)
SiO_2	20.63
Al_2O_3	5.87
Fe_2O_3	2.52
CaO	63.55
K_2O	0.63
Na_2O	0.85
MgO	2.79
SO_3	1.62
L.O.I	1.54

4 Results and Discussion

The laboratory testing was carried out to achieve the aim and objective of study. This part shows the result of this study.

4.1 The Compressive Strength of Clay Soil Stabilized with Lime-POFA Mixtures at 0, 14 and 28 days of Curing Periods

Table 7 presents the compressive strength of clay soil stabilized using mixtures of Lime-POFA at curing periods of 0, 14 and 28 days. The clays soil samples in natural state (undisturbed samples) shows the lowest in compressive strength compared to the control sample (remolded sample) and stabilized clays with mixtures of Lime-POFA. However, most stabilize soil samples shows increment in compressive strength at curing periods.

Meanwhile, Fig. 1 illustrated the pattern of compressive strength of clay soil stabilized with various mixtures of Lime-POFA at 0, 14 and 28 days of curing periods. It can be seen the compressive strength of clays soil stabilized with various mixtures of Lime-POFA shows the better results in terms of increments of compressive strength at curing periods compared to unstabilized clay soil sample (control) and clay stabilized with 3 % of lime. However, it can be seen the best combination of 3 % Lime mixed with 6 % POFA (3 % Lime + 6 % POFA) was giving the highest result of compressive strength to stabilize clay soil at all curing periods compared to unstabilized clay soil and other mixtures. This happened due to the highly active silica content of POFA and clay soil were react with lime for pozzolanic reaction to form calcium aluminium hydrate (CAH) and calcium silicate hydrate (CSH) to bind the soil particle and thus increasing the soil strength.

Table 7 The compressive strength result of clay soil stabilized with Lime-POFA mixtures at curing periods

Samples	Compressive strength (kPa)		
	0 day	14 days	28 days
CLAY (Undisturbed)	26.3	29.9	37
CLAY (Remolded)	470.5	522.5	578
Clay + 3 % Lime	497.5	592.5	629.3
Clay + 3 % Lime + 2 % POFA	567.1	678.7	675.2
Clay + 3 % Lime + 4 % POFA	597.3	838.4	889.4
Clay + 3 % Lime + 6 %POFA	682	947.6	949.1
Clay + 3 % Lime + 8 % POFA	521.1	591.3	597.5
Clay + 3 % Lime + 10 % POFA	477.2	499.4	582.1

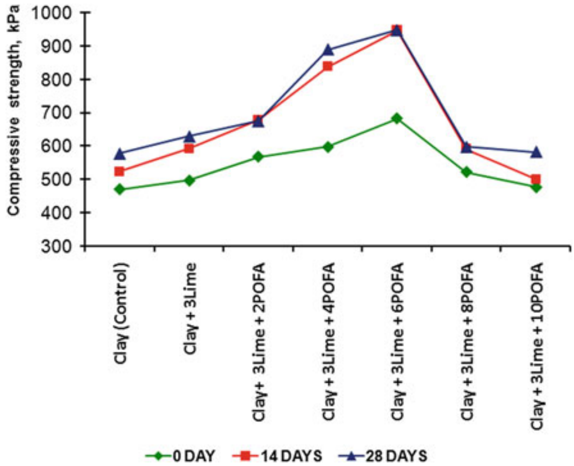
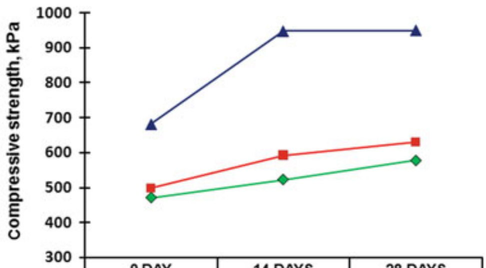


Fig. 1 Graph of clay soil stabilized various Lime-POFA mixtures versus compressive strength at 0, 14 and 28 days of curing periods

4.2 The Development of Compressive Strength of Clay Soil Stabilized with Optimum of Lime-POFA Mixtures

The unconfined compressive strength testing was performed on the clay soil stabilized at optimum mixtures about (3 % Lime + 6 % POFA) at curing periods of 0, 14 and 28 days. The results of development of compressive strength of clay soil stabilized with optimum mixtures of (3 % Lime + 6 % POFA) presented in Fig. 2 with respect to the curing periods at 0, 14 and 28 days. The result was compared to the unstabilized clay soil (control) and clay stabilized with 3 % Lime only. It was observed, the increment on compressive strength for clay soil stabilized with (3 % Lime) and (3 % Lime + 6 % POFA) respected to curing time compared to the unstabilized clay soil (control). However, the result shows that the compressive strength of clay soil stabilized with optimum mixtures of (3 % Lime + 6 % POFA) was giving the highest and best result compared to stabilize with 3 % of



	0 DAY	14 DAYS	28 DAYS
CLAY (CONTROL)	470.5	522.5	578
CLAY+3% LIME	497.5	592.5	629.3
CLAY+3% LIME+6%POFA	682	947.6	949.1

Fig. 2 Graph of clay soil stabilized various Lime-POFA mixtures versus compressive strength at 0, 14 and 28 days of curing periods

lime only. It can be noticed that the strength of stabilized clay soil increased with curing periods from 0 up to 28 days. This stabilization process increase the strength might be beyond to 28 days of compressive strength result until the process is stable and fully stabilized. However, the result for clay stabilized with (3 % Lime + 6 % POFA) shows a constant strength at 14–28 days and might be fully stabilized. The curing time process in stabilization process has a significant effect on compressive strength [14] and indicates that the strength of clay soil stabilization is depending on the presence of Lime and/or POFA because the pozzolanic reaction and the cementation process.

5 Conclusion

Based on the study the following conclusion is made:

1. The Sijangkang soft soil can be classified as sandy CLAY of high plasticity soils. The suitable concentration percentage mixing of Lime-POFA was determined about 6 % POFA mix with 3 % Lime (3 % Lime-6 % POFA) to stabilize the sandy CLAY of high plasticity soils was giving the highest compressive strength. This Class-F POFA used in combination of mixing with 3 % Lime for pozzolanic reaction and the strength increase up to 947.6 kPa.
2. The clay soil stabilized using combination of 3 % Lime-6 % POFA mixtures considered effective to enhance clay soil strength for long periods and. It shows combination mixing of 3 % Lime-6 % POFA were increased the compressive strength of the clay soil until 28 days and this strength will get higher might be beyond to 28 days.
3. This will reduce the construction cost and solving disposal problems and towards the green The use of WPSA will reduced the construction cost, time and will solving the disposal of waste byproduct problems towards green environmentally.

Acknowledgments The author would like to express an acknowledgement to the Research Management Institute, UiTM Shah Alam for providing Excellent Fund (RIF) 600-RMI/DANA 5/3/RIF (115/2012) to complete this study and also to Faculty of Civil Engineering, UiTM Shah Alam, Malaysia, and for providing the facilities such as the geotechnical laboratory and advanced geotechnical laboratory to accomplish this study. The author also wishes to acknowledge cooperation given by laboratory technician and the undergraduate student from Faculty of Civil engineering, UiTM Shah Alam for this study.

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