Enhancing Soft Clay Properties Treated with Palm Oil Fuel Ash (POFA) and Lime

Nur Amalina Mohd Hizam, Muzamir Hasan,
Abdulmajeed Ali Alhokabi and Muhammad Syamsul Imran Zaini

December 25, 2020

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Nur Amalina Mohd Hizam
College of Engineering
Department of Civil Engineering
University Malaysia Pahang Pahang, Malaysia
nuramalinahzm@gmail.com

Assoc. Prof. Ts. Dr. Muzamir Hasan
College of Engineering
Department of Civil Engineering
University Malaysia Pahang
Pahang, Malaysia
muzamir@ump.edu.my

Abdulmajeed Ali Al-hokabi
College of Engineering
Department of Civil Engineering
University Malaysia Pahang
Pahang, Malaysia
alhokabi93@gmail.com

Muhammad Syamsul Imran Zaini
College of Engineering
Department of Civil Engineering
University Malaysia Pahang
Pahang, Malaysia
Syamsulimran94@ gmail.com

Abstract—Malaysia is one of the largest palm oil producers in the world, palm oil fuel ash is produced also in huge quantities. The unavoidable produced waste should be exploited as an economically effective product, which can contribute to generating new income for a project such as soil stabilization which is the most economical way to improve the properties of soil. Therefore, POFA is the unwanted material in the form of ash from burning palm oil fibers. This paper presents the utilization of POFA with the addition of lime as an additive mixture to stabilize kaolin, the results of the basic physical properties, standard compaction test, and unconfined compression test by admixture method of kaolin, quicklime, and POFA standardized with ASTM & BS standards. The effect on the compressive strength result of the kaolin with the admixture of lime, POFA, or both. It indicates that the reason behind the increment in the strength of kaolin is the pozzolanic reaction and cementation process which occur due to the high silica content of POFA and clay soil that was reacted with lime. The results presented that the optimal percentage of lime and POFA combination was attained 4% of lime and 2% of POFA. In conclusion, the highest shear strength achieved was 77.26 kPA while the improvement of undrained shear strength obtained was 37.31 kPa which shows apparent enhancement on soil strength.

Keywords—Soil Stabilization; POFA; lime; waste; UCT; Compressive strength

1. INTRODUCTION

Problematic soil issues that arise can be cured by improving ground techniques such as soil stabilization[1][2]. Generally, soil stabilization is a method of improving soil properties by blending and mixing other materials. Improvements include increasing the dry unit weight, bearing capabilities, and other waste materials to strengthen road surfaces and other geotechnical

applications[3][4], to solve this issue, engineers adapted new methods which combine the enhancement of soil properties as well as utilizing waste and reducing the contamination.
POFA is a waste material generated in power plants as a result of the combustion of palm oil industry waste for the generation of electricity. The position of POFA to open area which triggering environmental contamination issues[5]. Besides, POFA containing high pozzolanic characteristics which known as a siliceous or silica-aluminous material that will finely divide in the presence of moisture, and chemically react with calcium hydroxide at ordinary temperatures to form compounds having cementitious material[6] [7], when dumped abundantly which caused to the unwanted effects to our environmental sustainability. By using lime and palm oil fuel ash can contribute to managing the waste to a better sustainable environment, as well as improve the engineering properties and strength of the soft soils.
This research focuses on the study of the effectiveness of POFA and lime in soft clay stabilization in terms of basic physical properties as specific gravity and Attreberg limit as well as soil strength properties of undrained shear strength. kaolin S300 was used because of its low strength and high settlement in the presence of water, the behavior of the soil is also unpredictable. To stabilize the soft soil by the addition of quicklime to modify the properties of the soil, the improvement was observed based on different percentages of POFA. The compressive strength of kaolin that mixed with 4% lime and 6% POFA showed the highest and the best result compared to other mixed percentages, they showed better results in terms of increments of compressive strength with the lowest percentage of POFA and lowest percentage of lime.

2. MATERIALS

Kaolin
The kaolin powder grade S300 was used in this project, kaolin clay could be easily dispersed in water and capable of increasing strength in the plastic formation and extrusion operations. Kaolin has a minimal shrink-swell capacity and low cation exchange capacity[4]. It is easy to absorb water and will shrink as water is drawn away. This kind of clayey soil contains clay minerals that have the possibility of swelling and shrinkage under transforming water content [3].

Lime
Lime is commonly used for stabilization purposes which are familiarized many years ago and the main driving goal to render the soils capable to meet the requirements of the specific engineering project, lime also provides an economical way of soil stabilization[9][10]. Lime modification defines a growth in strength brought by cation exchange capacity rather than the cementing effect brought by pozzolanic reaction [11].

POFA
POFA is a pozzolanic material which has the properties of cement. Based on ASTM C618 for classification of POFA classified as Class-F fly ash because of the total combination percentage composition for major constituent components such as silicon dioxide (SiO_2), aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3) more than 70%. This Class-F POFA describes as siliceous and aluminous materials that possess little or no cementitious value consist of a little quantity of Calcium Carbonate or free lime (CaO) lower than 10%[12]. Furthermore, the Class-F POFA considered as not self-cementing ash because having pozzolanic properties and no or small quantities of self-cementing properties sources of calcium and magnesium ions[13].

Figure 1: POFA collected at Kilang Sawit LCSB Lepar, Gambang, Pahang.

3. METHODOLOGY

This research methodology was basically to determine the basic physical and shear strength properties of the soil which is in this experiment kaolin as soft clay and when it is substituted with different percentages of lime and POFA. The flow of works is conducted and demonstrated with standard laboratory tests procedure and data analysis methods, according to British Standard (BS)and American Society of Testing Material (ASTM) as shown in table 1 below.
Constant composition of Kaolin added with lime (4% and 6%) then three different contents of POFA (2%, 4%, and 6%) were mixed together respectively. 7 total samples had been conducted including on Kaolin sample only for UCT and SPT. The samples were prepared in a container of 100 mm height with 50 mm diameter and allowed for curing at least under 24 hours before testing. This study involved an unconfined compression strength to investigate the strength of stabilized soil as shown in Table 2.

Table 1. Summary tests and standards

Material	Test Name	Standard
POFA	Specific Gravity Test	BS 1377: Part 2: 1990: 8
	Liquid Limit Plastic Limit	BS 1377: Part 2: 1990: 4 BS 1377: Part 2: 1990: 5
Kaolin	Specific Gravity Test	BS 1377: Part 2: 1990: 8
	Liquid Limit Plastic Limit	BS 1377: Part 2: 1990: 4 BS 1377: Part 2: 1990: 5
Lime	Specific Gravity Test	BS 1377: Part 2: 1990: 8
	Liquid Limit Plastic Limit	BS 1377: Part 2: 1990: 4 BS 1377: Part 2: 1990: 5
The mixture of POFA, Kaolin & Lime	Standard Compaction Test	BS 1377: Part 4: 1990: 3.3
	Unconfined Compression Test	ASTM D 2434

Table 2. Proportion Percentage of quicklime and POFA & Kaolin.

Kaolin (%)	Lime (%)	POFA (%)
100	0	0
94	4	2
92	4	4
90	4	6
92	6	2
90	6	4
88	6	6

Standard Proctor compaction test is conducted to determine the relationship between the moisture content of soil and its dry density. In this test, 984 cm3 compaction mold and 2.5kg rammer for BS light manual compaction test is used. Three layers are compacted layer by layer with the free-fall hammer distanced from 30cm above the soil. The graph of dry unit weight versus moisture content is plotted according to the results. The maximum dry unit weight of the soil sample and corresponding moisture content is determined. The test is conducted on both kaolin only and kaolin with various percentages of POFA and lime. Figure 2 shows the process of compaction of the sample in mold

Figure 2: Process of standard Compaction Test (Compacting, Oven Dry)

The compressive strength of the soil samples is determined under an unconfined compression test. This test is the simplest laboratory test in determining the strength of soil samples [8]. In this test, axial loading is applied onto the specimen, with the absence of lateral confining pressures. In this study, a constant composition of kaolin added with quicklime (4% and 6%), and three different contents of POFA (2%,4%, and 6%) were mixed respectively. There were Seven total samples as shown in table 2, that had been conducted including the kaolin sample as the control sample. The samples were prepared in a cylinder of 100 mm height with 50 mm diameter and allowed for curing at least for 24 hours before testing. This study involved an unconfined compression strength to investigate the strength of stabilized soil.

The compressive strength of clay soil stabilized using mixtures of lime and POFA at the curing period at least under 24 hours. The sample that is mixed and stabilizes by lime and POFA shows improvement compared to kaolin samples only. Meanwhile, figure (2) shows the pattern of the unconfined compression test of kaolin mixed with different percentages of lime and POFA. The compressive strength of clay soils that mixed with 4% lime and 6% POFA shows the highest and the best result compared to other mixed percentages. Its show better results in term of increments of compressive strength with the lowest percentage of

POFA and lowest percentage of lime. The effect on compressive strength results indicates the kaolin depending on the presence of lime or POFA because of the pozzolanic reaction and cementation process. The result shows the second-best is Kaolin mixed with 6% lime and 2% POFA. This happens due to the highly active silica content of POFA and clay soil that reacted with lime for pozzolanic reaction to form calcium aluminum hydrate (CAH) and calcium silicate hydrate (CHS) to bind the soil particles and thus increasing the soil strength.

Figure 3: Unconfined Compression Test

4. RESULTS AND DISCUSSION

Physical properties of the sample

The soil sample taken was carried out with physical properties experiments such as Specific gravity, plasticity index which showed medium plasticity as plastic Limit, w_p (%) was 30.8 while liquid Limit, w_L (%) was 41.3 and optimum moisture content to classify the type of soil used before conducting the main experiment.

Table 3. The specific gravity of lime and POFA & Kaolin.

Sample	Specific Gravity, Gs
Kaolin	2.71
Lime	2.36
POFA	2.06

Standard Proctor Compaction Test

This testing was to determine the maximum dry density and optimum moisture content of the mixture sample with the stabilizer. The obtained result can be used for determining the relationship between the compaction of water content and the dry unit weight of the sample that was tested. The compaction was examined with kaolin with admixtures stabilized soil. The result of kaolin alone and with admixture. The comparison of various combinations between POFA and lime within or less than 20% replacement in the kaolin. The test conducted using a mold with a volume of 984 cm3 and compacted every three layers with 25 blows using rammer dropped. The ratio varies with percentages based on the type of soil, water ratio, chemical effect, the material used, and method of preparation.

The testing for stabilized soils was done by giving a constant trend for all mixture samples prepared for the stabilization reaction to take place. The treatment of the sample with POFA and lime content changed the optimum moisture content and maximum dry density values of the samples.

Figure 4 shows that compaction curves of the original soil sample and stabilized by POFA and lime with using different proportions percentage or less than 20% replacement ratio such as (lime 4% + POFA 2%), (lime 4% + POFA 4%), (lime 4% + POFA 6%), (lime 6% + POFA 2%), (lime 6% + POFA 4%), (lime 6% + POFA 6%). Figure 4 shows the optimum moisture content and maximum dry density for the Kaolin only and the replacement sample result. The test sample was carefully prepared by maintaining uniform density and moisture content, to ensure a fair assessment of the effects of the admixture on the mechanical properties. It can be observed that the control sample have the highest dry density with a maximum of 1.59 kg/m3 and the lowest water content of 17.43 whereas (lime 4% + POFA 6%) showed the lowest dry density of 1.49 kg/m^3, the highest optimum water content has appeared in the sample of (lime 4% + POFA 2%). From the pattern of the graph, it can be observed that the effect of POFA and lime replacement decrease the maximum dry density. Despite the decreasing of the dry density, there is an improvement as compared with the original sample, as the decrease of dry density will eventually reduce the volume and void ratio resulting in more compact soil. However, the higher lime and POFA content give lower optimum moisture content while higher POFA content gives a higher optimum moisture content.

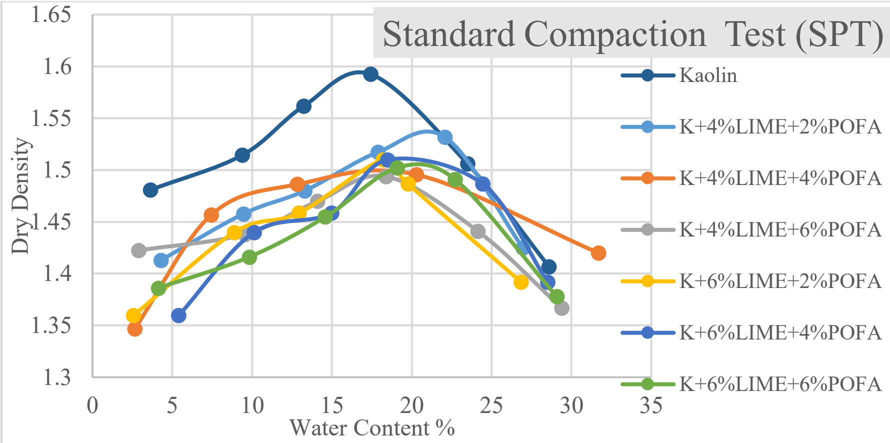

Figure 4: Standard Compaction test curve graph for tested samples.

Based on the result, the increases of POFA and lime within the replacement of kaolin, the dry density decreases, and optimum moisture content increases. When lime is added to the kaolin with the presence of water instant reaction occurred as cation exchange occurs and clay particles flocculate together. Based on overall observation, it can be determined that the optimum moisture content and maximum dry density of the sample are dependants more on POFA rather than lime. When clay soil is dry or at low moisture content the texture is stiff and difficult for the particles to pack together. As the water content in the soil increases the water start to lubricant, then the particles of the soil begin to move closer under a given amount of compaction and increased workability. The water starts occupying the air void and thus a gradual increase in dry density but as more water is added the volume of air content reaches a minimum volume in soil and reaches optimum moisture content. Therefore, the sample will be flooded with water. By the adding of lime and POFA where POFA acts as a binder that flocculates the soil and lime and increases in density compare to the original sample. Hence, when the density increases the more stable the soil.

Unconfined Compression Test

Shear strength of soft clay stabilized with lime and POFA was measured by carrying out the Unconfined Compression Test (UCT). Kaolin which acts as the controlled sample for the test. There are seven specimens were prepared and tested. The shear strengths of kaolin mixed with lime and POFA were shown higher results compare to the kaolin only. Figure (5), (6), and (7) below shows shear strength, the average unconfined compressive stress of the kaolin mixed with various percentages of POFA and Lime as well as the improvement of shear strength compared to the control sample. Based on Figure 5, the results showed that 4% lime with 2% POFA mixed with kaolin is higher which is at 77.26 kPa of unconfined shear strength value compare to other percentages of lime and POFA. Figure 6, it can be observed that the compressive stress increases with lime & POFA content, and the optimum percent is 4% L and 2% POFA. Which is 154.51 kPa. This increase is due to the pozzolanic reactions (the released silica and alumina in POFA react with the calcium from the lime to form cement) within the lime–soil mixtures, which result in strength gain over time. At 6% L, there is a decrease in compressive stress due to the reduction in one compound of the pozzolanic reaction (alumina in the soil) which proves what is reported by (Alrubaye, 2016) and Khalid, 2013[4][14]. The improvement in the cohesion and angle of internal friction values may be due to the pozzolanic activity and self-cementitious characteristics of the combination of the lime–soil mix.

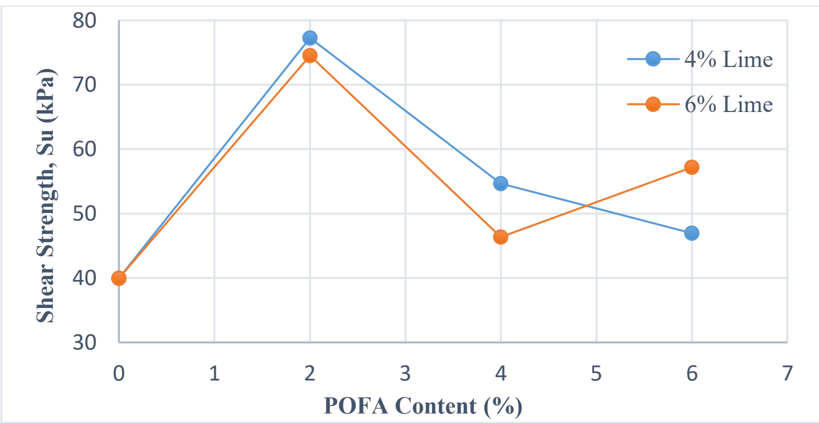

Figure 6: Shear Strength graph for kaolin mixed with various percentages of lime and POFA.

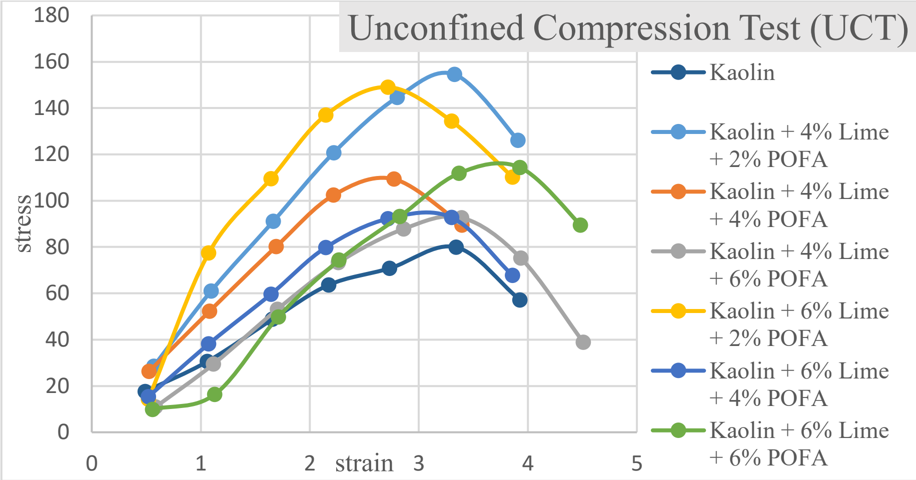

Figure 5: Stress-Strain curves of kaolin mixed with various percentages of lime and POFA.

To conclude, the improvement of shear strength in the treated samples is obvious, Figure 7 shows the comparison between the control samples which showed as the zero-Lime content, where the highest improvement of shear is about 37.31 kPa over the control sample, which is considered as double strength of the original untreated sample.

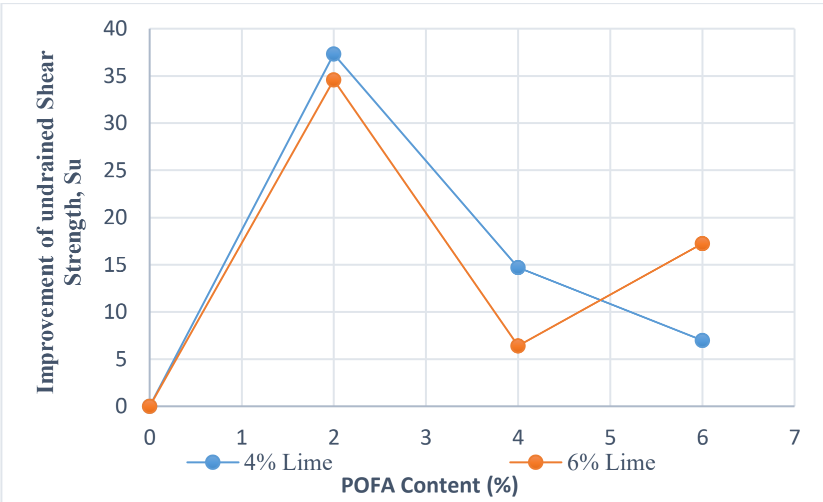

Figure 7: The improvement of Shear Strength (S_u) for kaolin mixed with various percentages of lime and POFA.

Conclusion

To summarize the outcomes of this paper, the soft soil which has very weak properties can be enhanced by adding chemicals or any type of materials which contain siliceous compounds as POFA, that can initiate the pozzolanic reaction, from this project it can be noticed that the maximum dry density of soil decreases due to flocculation and causes aggregation between the particles by occupying larger space and the decreasing of density is due to the replacement of soil particles with lower specific gravity. The increase of POFA or lime leads to a decrease in maximum dry density because of its low specific gravity than clay. The optimum moisture content increases as a result of the high POFA water absorption, therefore with the increases of POFA the optimum moisture content also increases. Other than that, as the lime content increases the optimum moisture content increases due to flocculation of clay particles with lime and reduction of the void For the compression test, lime content and POFA content helped to improve the shear strength of the mixture depending on the existence of percentage of lime and POFA. The results presented that the optimal percentage of lime and POFA combination was attained at 4% of lime and 2% of POFA. The highest shear strength achieved was 77.26 kPA while the improvement of undrained shear strength obtained was 37.31 kPa. Therefore, the objectives of this research are achieved. In conclusion, the replacement of POFA and lime admixtures can be used for soft soil stabilization are depending on their percentage

Acknowledgment

The authors would like to acknowledge the Universiti Malaysia Pahang (UMP) and Hokoku Engineering (Japan) for financing this research through the UMP Matching Grant RDU202701, Short Term Grant RDU190344; and International Grant UIC201503 respectively. The cooperation given by all parties involved in this research is greatly acknowledged

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