Stabilisation of soft soil using palm oil fuel ash and palm oil fibre

S Y Lim1* and M S Shakri2*
Faculty of Engineering and the Built Environment, SEGi University, MALAYSIA

*1sawyin.94@gmail.com
*2shakrishariff@segi.edu.my

Abstract. Development requires new findings and innovative science to support. This research aims to study the simulation of soft ground improvement by comparing the soil strength after mixing with pozzolanic and fibrous additive such as Palm Oil Fuel Ash (POFA) and Palm Oil Fibre (POF) were chosen due to its redundancy found as industrial waste material. The soft soil sample collected was added with 0%, 5%, 10%, 15% and 20% percentage of additives by weight respectively. The soil sample used was from the soil that passed through sieve size of 0.425 mm.

The data and analysis show that POF treated soil has a higher optimum moisture content and greater shear strength than the POFA treated soil.

1. Introduction
Malaysia is located around the equator line (4.2105° N, 101.9758° E) [1], hot and humid are the usual temperature throughout the year with an average rainfall of 250 cm per annum and average temperature of 27 °C [2]. Peninsular Malaysia is surrounded by the Malacca Strait, Singapore Strait and South China Sea. Hence, the soils are mostly contaminated by water, sandy, clay and silt are commonly found around Malaysia and the weak bearing capacity is non-negligible. Weak soil has the characteristic of high nutritional value that benefits for the plantation and agricultural industry [3]. On the other side, weak soil has relatively lower shear strength and capability to withstand axial load from the structure. Accommodating 32.2 million over people of population [4], Malaysia holds 0.42% of population around the world in the size of 330,803 km² of land (95 people per km²) [5]. This reflects that Malaysia is experiencing a rapid growth in population, the demand in residential area, food supply and job opportunity will gradually increase in a direct proportional relation. Gross Domestic Products (GDP) per capita in 2016 is 9502.57 USD. In order to ensure the supply is in pace with the demand, constructing sufficient number of infrastructures and housings will be required.

Importing enormous amount of material is required to build up a functional structure. Meanwhile, with the rising on transportation cost and the damage that cause by cement, a sustainable replacement that able to provide the same function is crucial to be discovered. Reason being of choosing these additives is because Malaysia palm oil industry is empowered and enforced by the law of Malaysian Palm Oil Board (MPOB) Act 1998, Act 582 under section 5 (a) regarding the waste management from the refinery process [6] [7] [8]. Exporting 39% of the palm oil around the world [9] [10], Malaysia is having redundant amount of waste derived from manufacturing and refining palm oil products. Palm Oil Fibre Ash (POFA) is a waste produced by palm oil mill that has a function of increasing the soil strength and treats the ground [11] [12]. POFA can provide pozzolanic reaction that produces a cementitious property that decrease the permeability of soil and eventually increase the bearing capacity of soil [11]. This study investigated the
difference of mixing POFA and unburned palm oil fibres (POF) with clay soil in order to maximise the outcome of ground improvement [1][2].

2. Experimental Program

2.1 Material Selected

The natural soil samples were collected from Ampang Park MRT construction site at Jalan Tun Razak, Kuala Lumpur as shown in Figure 1. The soil was collected from the excavation of 65 m below ground level (-30.0 m mean sea level) of soil for construction of diaphragm wall. The POF and POFA were collected from Tenaga Sulpom Sdn Bhd at Dengkil, it is a power station that burns the POF to generate energy using Electro Static Precipitator (ESP). POFA is the end product of combustion of POF and shown in Figure 2. Summary of the chemical composition of POFA has been presented in Table 1. While for natural soft soil also has been used as a second layer of direct shear test. It has been used to study the effects between samples of mixture with natural of soil.

Table 1. Chemical composition of POFA

| Component                | %    |
|--------------------------|------|
| Silica (SiO$_2$)         | 40-60|
| Alumina (Al$_2$O$_3$)    | 20-30|
| Iron Oxide (Fe$_2$O$_3$) | 4-10 |
| Calcium Oxide (CaO)      | 5-30 |
| Magnesium Oxide (MgO)    | 1-6  |
| Sulphur Trioxide (SO$_3$)| 0-2  |
| Sodium Oxide (Na$_2$O)   | 0-2  |
| Potassium Oxide (K$_2$O) | 0-4  |
| Loss on Ignition (LOI)   | 0-3  |

Figure 1. Soft soil sample collected at Ampang Park MRT construction site at Jalan Tun Razak, Kuala Lumpur.
2.2 Experimental Test
Four preliminary tests were carried out to identify the physical properties along with one chemical property test onto each sample prepared. 25% of water content was added onto all POFA added soil sample and a moisture content of 25% was applied onto all POF added soil sample for direct shear box test. The mechanical properties of the modified samples of POF and POFA were identified using compaction test and direct shear box test. The three major property tests involved were chemical test, physical test and mechanical test. The chemical test involved was pH test. The physical tests to identify the physical properties of the 100% natural soils were moisture content test, sieve analysis, water pycnometer test and Atterberg limit test. The major tests carried out were compaction test and direct shear box test to study the engineering of the modified sample. The list of tests in accordance to the standard reference was shown in Table 2. The soil was modified by adding 0%, 5%, 10%, 15% and 20% of the additive by weight into the soil [21].

| Property   | Name of Test                  | Standard Reference |
|------------|-------------------------------|--------------------|
| Chemical   | pH Test [14]                  | ASTM D4972, 2013   |
|            | Moisture Content Test [15]    | ASTM D2216, 2017   |
|            | Sieve Analysis [16]           | ASTM D 422, 2017   |
|            | Water Pycnometer Test [17]    | ASTM D854, 2000    |
|            | Atterberg Limit Test [18]     | ASTM D 2487, 2011  |
|            | Compaction Test [19]          | ASTM D 698, 2017   |
| Mechanical | Direct Shear Box Test [20]    | ASTM D 3080, 2017  |

3 Results and Analysis
Table 3 shows the physical properties of 100% natural soil collected from project location without adding any additives. It has high moisture content. The sieve analysis shows that this sample had more than 50% of fine soil which classified as weak soil. This soil shows specific gravity of 2.24 using pycnometer water test and it was classified as organic soil. Atterberg limit test shows that this soil was classified under organic soil as shown in Figure 3. Organic soil consists of two types such as organic silt and organic clay. Hence, the physical properties of soil show that this was a fine and weak organic soil.
Table 3. Summary of Physical Properties of 100% Natural Soil Sample

| Physical Properties of Soil | Moisture Content | Coarse % (> 0.075 mm) | Fine % (< 0.075 mm) | Specific Gravity | Plastic Limit | Plasticity index |
|-----------------------------|------------------|------------------------|---------------------|------------------|---------------|-----------------|
|                             | 20.40%           | 44.44%                 | 55.56%              | 2.24             | 30.8          | 6.45            |
| Atterberg Limit             |                  |                        |                     |                  |               |                 |
| Liquid Limit                | 37.25            |                        |                     |                  |               |                 |

Figure 3. Plasticity Chart of Soil Sample.

The chemical property of this soil sample shows alkaline pH value in the range of 8 to 10. This phenomenon was highly influenced by the bentonite slurry and cement used at the construction site. As for the compaction test to identify the mechanical properties of the samples as shown in Table 4 and Figure 4 show that soil had the highest maximum dry density whereas it had the lowest optimum moisture content same as the 5% POFA. As the percentage of additive increases the maximum dry density decreases that shows that the additives were very light weight, especially POF with maximum dry density as low as 1181.91 kg/m³ at 10% POF. The 15% POF shows the highest value of optimum moisture content for all of the samples mentioned above. This shows that POF had a lighter mass than POFA and was able to contain more water than POFA. Hence, POF is a better ground improvement material for high water table soil condition. The other mechanical test of direct shear box test to identify the shear strength of samples shows a sign of all modified samples had greater shear strength than the 100% soil sample. POF modified soil shows greater shear strength in general compared to POFA modified soil. The highest shear strength was given out by 14 curing days of 20% POF modified soil. The fibrous arrangement of POF modified soil can be concluded as having greater shear strength than having powdery ash arrangement soil sample.

POF is a very light mass material as compared with POFA proven using the compaction test as it had generally smaller value of maximum dry density. It was a fibrous material composed by the empty fruit bunch of palm oil after extracting the oil. The composition of how each strand holds onto each other helps to trap the soil and increase the angle of friction in between the soil and the fibre. This was a bonus for a
fine soil with low plasticity index that can hardly bind together and easily crunched. On the other hand, due to its strong bond in between each strand, it was hard to manage and control the POF into the desired amount and size, more preparation work needs to be done before turning into a useful material that could solve the challenges on point.

Table 4. Summary of chemical properties and mechanical properties of 100% soil, modified soil with POF and modified soil with POFA

| Additive | %  | pH Value | OMC, % | MDD, kg/m³ | 7 Days | 14 Days |
|----------|----|----------|--------|------------|--------|---------|
| Soil     | 100| 8.03     | 17.6   | 1845.33    |        | 14.89   |
| POF      | 5  | 8.69     | 21.23  | 1525.87    | 21.83  | 30.51   |
|          | 10 | 9.03     | 24.68  | 1348.83    | 26.08  | 34.23   |
|          | 15 | 9.42     | 38.72  | 1181.91    | 27.63  | 37.31   |
| POFA     | 5  | 9.04     | 17.6   | 1629.44    | 19.81  | 26.94   |
|          | 10 | 9.25     | 25.14  | 1656.43    | 24.82  | 28.86   |
|          | 15 | 9.43     | 24.37  | 1683.37    | 27.51  | 30.05   |
|          | 20 | 9.76     | 19.88  | 1607.91    | 28.63  | 31.66   |

**Figure 4.** Shear strength of each modified soil versus the percentage of additive.

POFA is a material obtained after the combustion of POF. The purpose of this combustion was to generate electricity using the biomass fuel concept. There are two types of waste produced by this process which were dry ash and wet ash. Dry ash was the material obtained in this research due to its property that was similar as cement as it bonds with the elements in soil to produce a stronger combination with
the help of water. Many researches need to be done before the human nation totally replace cement with other waste material product. POFA is one of the materials that have the highest similarity to cement. POFA is a powdery ash form product that can easily be handled and transported; it can easily be spread by using the tools. However, the other side of POFA was too hazardous as it could easily escape into the air by just being influenced by the air movement. Any personnel who handled it require putting on personal protection equipment to prevent any side effect caused by it.

4 Conclusion

The main reason behind all these works was to create a better future by using waste material by managing the waste and for a sustainable development considering the cost, transportation, suitability, and reliability innovative creation. Hence POF and POFA were chosen to take part in this research due to the redundant waste found all over Malaysia.

Firstly, the physical property tests proved that this soil sample was exposed to moist area, weak and fine organic soil with low plasticity. Secondly, POFA is a pozzolan that work well with the existence of water to allow pozzolanic happen and it does not perform as good as POF at 30% of moisture content during sample preparation. The following objective was to justify the engineering comparison between the soils treated with POF and POFA. It is a non-hazardous produce and bio-degradable environmentally friendly waste material. The transportation could be another challenge as well as it was not as easy to handle as ash.

To conclude, analysing the results obtained throughout the tests, POF was a better additive to treat soil with high ground water table as it has a higher optimum moisture content and can produce higher shear strength due to its fibrous arrangement. POFA was a weaker option in terms of shear strength and optimum moisture content but it could obtain a higher maximum dry density that could be useful to support the trench of the soil. Also, POFA was considered as a recycle material as it was used to burn as an energy source before this that makes it more useful than POF which was produced immediately from the extraction of palm oil.

References

[1] Google Map (2017) *Malaysia coordinates - Google Search*. Retrieved from https://www.google.com/search. Accessed on 10 Feb 2019.
[2] Nur Amira (2017) *Rainfall in Malaysia 2008-2015 | OR Technologies Malaysia - Data. Analytics Insight*. Retrieved from http://www.orttechnologies.net/blog/posts/rainfall-in-malaysia-2008-2015/. Accessed on 10 Feb 2019.
[3] Manan (2017) *Malaysia Inflation Rate | 1973-2017 | Data | Chart | Calendar | Forecast*. Retrieved from https://tradingeconomics.com/malaysia/inflation-cpi. Accessed on 10 Feb 2019.
[4] United Nation (2017) *Malaysia Population (2017, 2018) - Worldometers*. Retrieved from http://www.worldometers.info/world-population/malaysia-population/. Accessed on 10 Feb 2019.
[5] Worldometer *Malaysia Population (2017, 2018) - Worldometers*. Retrieved from http://www.worldometers.info/world-population/malaysia-population/. Accessed on 10 Feb 2019.
[6] MPOB *Malaysian Palm Oil Board Act 1998*, (January), 2017. Retrieved from http://www.agc.gov.my/Akta/Vol. 12/Act 582.pdf. p. 1–56. Accessed on 10 Feb 2019.
[7] MPOB *Number &amp; Capacities of Palm Oil Sectors 2017*. Retrieved from http://bepi.mpob.gov.my/index.php/en/statistics/sectoral-status/179-sectoral-status2017/803-number-a-capacities-of-palm-oil-sectors-2017.html. Accessed on 10 Feb 2019.
[8] Sreekala M S Kumaran M G and Thomas S 1997 *Oil Palm Fibers: Morphology, Chemical Composition, Surface Modification and Mechanical Properties*. *J. App. Polym. Sci.* **66**, p. 821-835.
[9] Idrees A *Malaysian Palm Oil Industry 2017*. Retrieved from
http://mpoc.org.my/Malaysian_Palm_Oil_Industry.aspx. Accessed on 10 Feb 2019.

[10] Bateni F (2015) Stabilization Mechanisms of Oil Palm Empty Fruit Bunch (Opefb) Fibre Reinforced Silty Sand. Retrieved from http://eprints.usm.my/15643/1/STABILIZATION_MECHANISMS_OF_OIL_PALM_EMPT Y_FRUIT_BUNCH_(OPEFB)_FIBRE_REINFORCED_SILTY_SAND.pdf. Accessed on 10 Feb 2019.

[11] Amzar Y F and Suwandi A K (2006) The Suitability of POFA (Palm Oil Fuel Ash) Treated Clay Soil For Linear Material in Sanitary Landfil, Environmental technology, Sanitary engineering. Retrieved from http://eprints.uthm.edu.my/1947/1/THE_SUITABILITY_OF_POFA_YULIA_FITRI_AMZAR.pdf. Accessed on 10 Feb 2019.

[12] Federick M Lea (2015) Cement Building Material. Retrieved from https://www.britannica.com/technology/cement-building-material#Article-History. Accessed on 10 Feb 2019.

[13] Amzar Y F and Suwandi A K (2006) The Suitability of POFA (Palm Oil Fuel Ash) Treated Clay Soil For Linear Material in Sanitary Landfill Environmental technology, Sanitary engineering.

[14] ASTM D 4972 Standard Test for pH Value of Soil.

[15] ASTM D 2216 Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass.

[16] ASTM D 422 Standard Test Method for Particle-Size Analysis of Soil.

[17] ASTM D 854 Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer.

[18] ASTM D 2487 Standard Practice for Classification of Soils for Engineering Purposes (USCS).

[19] ASTM D 698 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort.

[20] ASTM D 3080 Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Condition.

[21] Megat Johari M A Zayed A M Muhamad Bunnori N and Ariffin K S 2012 Construction Building Material