PERFORMANCE OF CEMENT COLUMN STABILIZATION BY PALM OIL FUEL ASH (POFA) AND PALM OIL FIBRE (POF)

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ABSTRACT: *As far as soil stabilization are concerned, this research was conducted to study the performance of Cement Column Stabilization by Palm Oil Fuel Ash (POFA) and Palm Oil Fibre (POF). As a matter of fact, clay soil possesses weak physical and mechanical properties hence soil stabilizers are mixed in the soil to increase its strength. The waste products for the soil stabilization were Palm Oil Fuel Ash (POFA) and Palm Oil Fibre (POF). POFA or POF was mixed in ratios of (0%, 10%, 20%, 30% and 40%) with cement with ratios of (40%, 30%, 20%, 10% and 0%) and 60 % of soft soil. The mixtures were tested for pH test and Direct Shear Box test in order to determine its relative chemical properties and mechanical properties respectively. For compaction test of soil and POFA or POF-cement was mixed with ratios of (0%, 5%, 10%, 15%, and 20%). The soil samples with 0 % of POFA or POF had a maximum dry density of 1.821 g/cm^3 whereby 5% of POFA and POF were 1.637 g/cm^3 and 1.543 g/cm^3 respectively. The optimum percentage of the maximum shear strength for POFA-cement and POF-cement mixes were up to 30 % and 20% respectively. The shear strength showed an increase from the 7 to 14 days in all the sample mixes.*

Keywords: Cement, POFA, POF, Compaction, Direct Shear Box, Shear Strength

1. INTRODUCTION

Soil exist in diverse natures in the Earth Strata, each with unique characteristics such as color, texture, structural bonding, and mineral content. A typical soil consists of a mixture of about 50% solids (45% mineral and 5% organic matter), 25% air and 25% water approximately. Soil can be categorized and differentiated into various types based on the particle size distribution. Malaysia is known to have a tropical climate, with around 27°C average yearly temperature and an everlasting high humidity. Hence as a result of its climate, the soil in Malaysia possesses weak properties of around 70% of the 5,000 km of the shoreline with a thickness between 20 m to 40 m of soft soil [1,2]. The most common deformities in soft soils are their high compressibility, low compressive strength, and the ability to swell when water content rises. Thus, these qualities are the reasons for soil to be categorized as problematic soil. There are techniques that can be employed to change or improve the existing soil bearing capacity, which is the most convenient method of soft soil modification is to supplement the soft soil with stronger materials during backfilling [3].

One of the most efficient and popular soil stabilizing techniques, deep mixing columns (DMCs) is attracting an increasing number of countries for its cost-effective approach with many technical and environmental advantages including immediate application, removal of off-site disposal, high ground strength, and impeding of biodegradation [4,5]. Therefore, to achieve soil stabilization for strength and stiffness of the soft soil, the addition of adequate amount and appropriate stabilizers or binders are needed. Cement and/or lime are the most frequently used soil stabilizers, however, they are not always economical, particularly in locations where resources are limited. In this research, the study about]. the usage of Palm Oil Fuel Ash (POFA) and Palm Oil Fibre (POF) as supplementary cementing material in cement columns is carried out. All preliminary test has been conducted to exploit the use of POF and POFA as a stabilizing agent. In Malaysia, the palm oil industry is considered as the most important agro mills. POFA is a waste product that is produced from the burning of palm oil plant residuals and about 5% of ash is produced as waste [6-9]. The usage of POF and POFA as the admixture, it is expected to cut the cost in addition to promoting a more environmentally friendly and ecological stabilizing product. Since the rapid increase in the palm oil industry, the ash produced had become a large impact on the environment. In this research, POFA and POF have been used as a pozzolanic material and furthermore as a substitution of cement to create cementitious properties.

Pozzolans are characterized as a siliceous and aluminous material where the particles respond with calcium hydroxide from the cement to create cementitious properties. The usage of pozzolanic material in cement would reduce the negative environmental impact and landfill volume for waste disposal. In addition, acts as a binder between soft soil and cement. It has been found that with the proper ratio and procedures, the unstable soil was significantly improved. There are three major factors that affect the activity of pozzolans which are the finesse of its particle, the degree of amorphousness of its structure and the SiO2, Al203, and Fe203 content [10]. Palm Oil Fuel Ash (POFA) is a pozzolanic material that has a high percentage of silicon dioxide and high potential to be used as a cement replacement material. Pozzolanic reactions occur when Si and Al combine with Ca, resulting in cementitious mixes called Calcium Silicate Hydrates (CSH) and Calcium Aluminate Hydrates (CAH) [11],

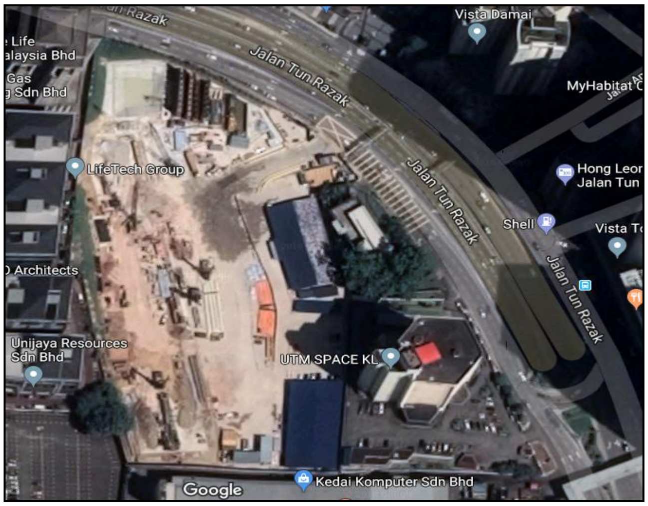

Fig (1) Location of soil sample collected at Ampang Park, Jalan Tun Razak, Kuala Lumpur, Malaysia.

2. EXPERIMENTAL PROGRAM

The preliminary study's methodology was separated into two parts ultimately to conclude the physical properties and the mechanical properties of the soil sample retrieved from Ampang Park, Jalan Tun Razak, Kuala Lumpur, Malaysia, and location of sample collection is shown in Fig 1. All the laboratory experiment will follow the standard method according to ASTM [12-18]. Four preliminary tests i.e. Moisture Content determination test to obtain the natural water content of the soil, Sieve Analysis test to determine the particle size and grading of soil, Atterberg Limit test to obtain the plasticity index and Pycnometer test to obtain the specific gravity were conducted. Secondly, the mechanical tests i.e. compaction test to obtain the maximum dry density and maximum optimum moisture content and Direct Shear Box test to obtain the shear strength results to compare with the POFA or POF-cement stabilized with soil were also conducted and pH test was conducted to check if the additives are chemically reactive and its alkalinity/acidity.

For Compaction test, the mixture of POFA and soil were (0%-100%, 95%-5%, 90%-10%, 85%-15% & 80%-20%) whereby for Direct Shear test, the mixture of POFA or POF-cement were (40%-0%, 30%-10%, 20%-20%, 10%-30% & 0%-40%) replacement of 60% soft soil were adopted to enhance the properties of the weak soil. Soil stabilization is a method of basically altering the chemical properties of the soil by the addition of admixture or stabilizer with water to improve the physical properties, mechanical properties, and strength of the soil.

Table 1 shows the chemical composition of POFA. Table 2 shows the chemical composition of POF that was used in this study. Table 3 shows all the Proportion percentages of POFA or POF mixed with soil for the Compaction test and Table 4 shows the Proportion percentage of cement and POFA or POF mixed with soil for the Direct Shear Box test.

TABLE 1: CHEMICAL COMPOSITION OF POFA

Composition	Percentage, %
Silicon Dioxide, SiO_2	52.35
Aluminum Oxide, Al_2O_3	6.27
Iron Oxide, Fe_2O_3	11.72
Calcium Oxide, CaO	11.72
Magnesium Oxide, MgO	-
Sulfur Trioxide, SO_3	1.50
Potassium Oxide, K_2O	15.72
Manganese Oxide, MnO	0.11
Loss on ignition	10.1

TABLE 2: CHEMICAL COMPOSITION OF POF

Constituent	MPOB/UKM
Extractives	3.323
Acid-insoluble lignin	20.917
Ash-free acid-insoluble	-
Ash	-
Hot-water soluble	-
1 % NaOH soluble	-
Holocellulose	62.785
Cellulose	39.405
Hemicellulose	23.380

TABLE 3: PROPORTION PERCENTAGE OF POFA OR POF MIXED WITH SOIL FOR COMPACTION TEST

% of soil	% POFA	% of water	No of sample (1 day)
100	0	30	2
95	5	30	2
90	10	30	2
85	15	30	2
80	20	30	2

TABLE 4: PROPORTION PERCENTAGE OF CEMENT AND POFA OR POF MIXED WITH SOIL FOR DIRECT SHEAR BOX TEST

% of soil	% POFA	% of cement	% of water	7 days	14 days
60	40	0	30	3	3
60	30	10	30	3	3
60	20	20	30	3	3
60	10	30	30	3	3
60	0	40	30	3	3

3. RESULTS AND DISCUSSION

A. Physical Properties of Soil Sample

With the soil sample, four types of physical properties tests were conducted such as particle size distribution, plasticity index, optimum moisture content, and specific gravity to categorize the type of soil used prior to carrying out the main tests. As a result of the physical test of the soil, the soil was classified as Fine-Grained soil. Table 5 showcases the Summary results of the Physical properties of the soil.

TABLE 5. SUMMARY RESULTS OF THE PHYSICAL PROPERTIES OF SOIL

Type of Tests	Source of Sample	Soil Sample
Moisture Content Determination Test	Natural Moisture Content, w (%)	20.4
Particle Sieve Analysis Test	Fines (%)	55.6
	Sands (%)	44.4
	Gravel (%)	0
Atterberg Limit Test	Liquid Limit (LL)	37.3
	Plastic Limit (PL)	30.8
	Plasticity Index (PI)	6.5
Water Pycnometer Test	Specific Gravity, G_S	2.24

B. Compaction Test

A compaction test was conducted to determine the optimum moisture content (wopt) and maximum dry unit weight (γd, max) of the soil sample retrieved and the stabilized soil which was exposed to a particular compaction force by the standard proctor (SP) compaction test. The results obtained can be used for concluding the relationship between the compaction of moisture content and the resultant dry unit weight of the sample that was tested. Hence, the compaction efforts were studied with an original soft soil sample and with admixtures stabilized soil. Therefore, results were obtained for the original soft soil with and without additive. The comparison of different combinations between POFA and soil within the 40% replacement in soft soil. Followed the standard test procedure [17] was implemented and the soil was compacted into a 104 mm in diameter mold in three equal layers with 25 blows dropped from the height of 300 mm with total compaction energy of 600 kN-m/m3. The ratio differs with percentage according to the type of soil, water ratio, chemical effect, the material used, and method of preparation.

TABLE 6. SUMMARY OF TEST RESULTS OF VARYING PERCENTAGE OF POFA

Soil + Additive, %	Optimum Moisture Content, %	Maximum Dry Density, g/m³
100 % Soil, 0 % POFA	19.2	1.820
95 % Soil, 5 % POFA	24.5	1.637
90 % Soil, 10 % POFA	24.4	1.656
85 % Soil, 15 % POFA	24.1	1.626
80 % Soil, 20 % POFA	22.1	1.549

TABLE 7. SUMMARY OF TEST RESULTS OF VARYING PERCENTAGE OF POF

Soil + Additive, %	Optimum Moisture Content, %	Maximum Dry Density, g/m³
100 % Soil, 0 % POF	19.2	1.820
95 % Soil, 5 % POF	21.2	1.543
90 % Soil, 10 % POF	32.5	1.380
85 % Soil, 15 % POF	38.7	1.182
80 % Soil, 20 % POF	37.9	1.204

Fig 2 and Fig 3 presents the compaction curves of the soil original sample and stabilized by POFA or POF with varying proportions of 40% replacement ratio such as (soil 100% + POFA or POF 0%), (soil 95% + POFA or POF 5%), (soil 90% + POFA or POF 10%), (soil 85% + POFA or POF 15%) and (soil 80% + POFA or POF 20%). Table 6 and Table 7 displays the optimum moisture content and maximum dry density for the original fine-grained soil and 40% replacement sample result.

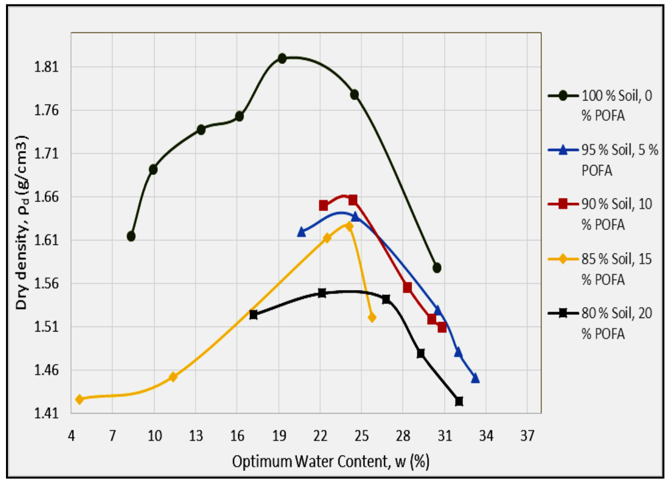

Fig (2) Comparison of Varying Percentage of POFA for Dry Density against Moisture Content

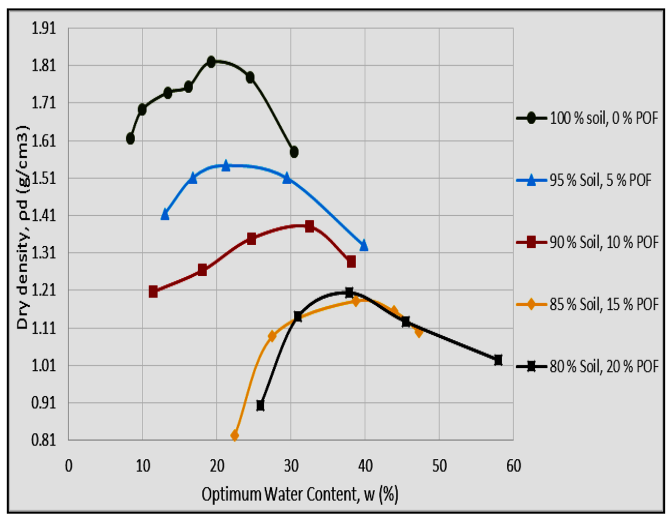

Fig (3) Comparison of Varying Percentage of POF for Dry Density against Moisture Content

These test samples were cautiously mixed and prepared by keeping constant density, moisture content, and curing time so as to make sure a reasonable valuation of the effects of the additives on the mechanical properties.

The treatment of samples with soil and POFA or POF content altered the maximum dry density and optimum moisture content values of the samples. Fig 2 shows that the effect of POFA replacement on the soft soil decreases in maximum dry density. Fig 3 shows that the effect of POF replacement on the soft soil decreases in maximum dry density further. The effect of varying percentage of additive on the maximum dry density (MDD) and optimum moisture content (OMC) of the soil, POFA, and POF mixtures for 7 and 14 days are shown in Table 6 and Table 7 respectively. The maximum dry density obtained was in the range of 1.820 g/cm3 for 100% soil and 0 % POFA or POF mixtures and lowest density was about 1.549 g/cm3 for 80% soil and 20% POFA mixture

whereas 1.204 g/cm3 for 80% soil and 20% POF mixture. This difference of density is mainly due to the modification of the gradation of soil mixes. The reduction of the maximum dry density with an increasing percentage of POFA and POF is largely due to the lower specific gravity and unit weight of the POFA and POF in comparison with soil and the instant formation of cemented material by hydration that decreases the density of soil. Furthermore, the reduction in dry density with increasing fine ash content is due to the change of gradation of soil mixes. Optimum moisture content acts as lubrication on the soil then the particles of the soil start moving closer under a given amount of compaction effort and hence enhancing the workability of the soil.

POFA also acts as a binder between soils which flocculate and causes aggregation between the particles and gives a lower density due to replacement of soil particles with lower specific gravity material such as POFA and POF. The increase of POFA or POF leads to a decrease in maximum dry density because of its low specific gravity. Although POFA has a lower specific gravity compared to clay but still considerably higher than POF which has a very low specific gravity. Therefore, the value of maximum dry density (MDD) will be manipulated by POF rather than POFA.

The optimum moisture content increases with the increase of POFA or POF. But the absorption of water in POF is higher compared to POFA and clay soil due to the fact that fiber would absorb water also and stores it in its pores.

C. Direct Shear Box Test

This experiment was conducted with reference to [13] in order to determine the shear strength of a soil sample with varying percentages of POFA, POF, and Cement. The results for the shear strength was achieved by carrying out the direct shear box for curing periods of 7 days and 14 days, in the treated soft soil (60%) with the Palm Oil Fuel Ash (POFA), Palm Oil Fibre (POF) and Cement mixes by varying percentages of 0%, 10%, 20%, 30%, and 40% (by weight).

TABLE 8. SHEAR STRENGTH OF SOIL WITH POFA AND CEMENT MIXED (7 DAYS)

Test No	% POF	% of Cement	c	(Ø)	Average Max Shear Strength (τ) (kN/m^2)
1	**0**	**40**	11.46	86.2	142.52
2	**10**	**30**	0.92	86.9	167.78
3	**20**	**20**	8.92	87.0	182.75
4	**30**	**10**	21.23	87.0	194.06
5	**40**	**0**	16.18	86.6	169.96

TABLE 9. SHEAR STRENGTH OF SOIL WITH POFA AND CEMENT MIXED (14 DAYS)

Test No	% POFA	% of Cement	c	(Ø)	Average Max Shear Strength (τ) (kN/m^2)
1	**0**	**40**	3.35	86.7	159.05
2	**10**	**30**	10.23	86.6	165.33
3	**20**	**20**	15.95	86.8	177.42
4	**30**	**10**	14.49	86.0	145.87
5	**40**	**0**	24.42	84.6	120.66

TABLE 10. SHEAR STRENGTH OF SOIL WITH POF AND CEMENT MIXED (7 DAYS)

Test No	% POFA	% Cement	c	(Ø)	Average Max Shear Strength (τ) (KN/m^2)
1	**0**	**40**	11.46	86.0	142.52
2	**10**	**30**	14.40	86.4	158.14
3	**20**	**20**	16.11	86.7	171.34
4	**30**	**10**	13.33	85.9	139.53
5	**40**	**0**	23.19	83.9	108.41

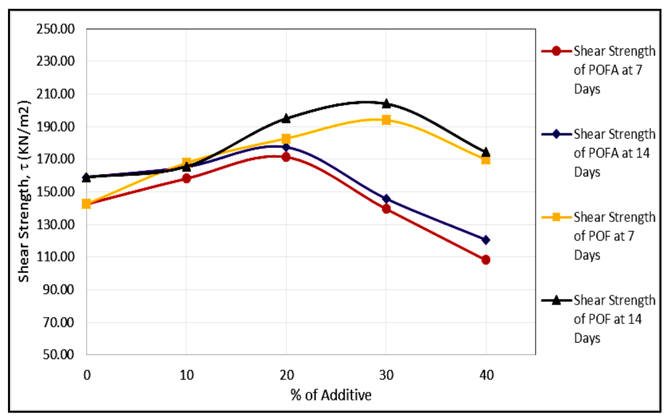

Fig (4) Comparison of Maximum Shear Strength of Soil-POFA and POF with Cement mixes

From Fig 4, it can be concluded that POFA reached maximum Shear Strength up to 20 % whereby POF reached maximum Shear Strength up to 30 % additive but upon further addition, a decrease was observed. However, we can deduce that POF for 14 curing days showed a greater increase of shear strength encountered on the shearing plane compared to 7 curing days POF and POFA mixes which means that the soil strength increases gradually. The maximum Shear Strength of POF obtained was 204.05 kN/m2 for 30 % POF and 10 % Cement after 14 days whereas POFA achieved a maximum shear strength of 177.42 kN/m2 for 60 % soil, 20 % POFA and 20 % Cement after 14 days.

POF was observed to have gain shear strength due to the occurrence of pozzolanic reaction due to the presence of cement and the Palm Oil Fibers (POF) also acts toward interlocking particles and grouping of particles in a unitary well-organized matrix hence the strength properties of soil was increased further compared to POFA.

POFA days were seen to gain even more shear strength due to the occurrence of pozzolanic reaction with soil through the hydration process of POFA where the presence of Calcium Aluminate hydrates and calcium silicate hydrates behaves as a binder and ultimately rises the soil's shear strength.

4. CONCLUSIONS

The physical test conducted with soil concluded that the soil was fine-grained soil as the percentage of fine soil (Silt and Clay) was greater than 50% (55.6 %) and that of sand was lesser than 50% (44.4 %). Furthermore, the results acquired from tests, this soil was categorized as low plasticity silt or organic with a liquid limit lower than 50, according to the Unified Soil Classification System (USCS).

The optimum percentage of Palm Oil Fuel Ash (POFA) was 60% soil, 20% POFA, and 20% Cement as the maximum shear strength achieved was 171.34 kN/m2 for 7 days and 177.42 kN/m2 for 14 days. This means that the shear strength increases gradually. Hence we can conclude that pozzolanic reaction with soil through the hydration process of POFA shows the presence of calcium silicate hydrates and Calcium Aluminate hydrates behaves as a binder and ultimately rises the soil's shear strength. Whereby the optimum percentage for Palm Oil Fibre (POF) was 60% soil, 30% POF and 1 % Cement mixture as the maximum shear strength gain was 194.06 kN/m2 for 7 days and 204.05 kN/m2 for 14 days. This increase in shear strength was attributed to the pozzolanic reaction due to the presence of cement and POF also acts toward interlocking particles and grouping of particles in a unitary well-organized matrix hence the strength properties of soil was increased further compared to POFA.

Eventually, we found out that the shear strength was improved upon the addition of POFA or POF with cement. For the conventional cement column (i.e. 60% soil and 40% Cement) the maximum shear strength achieved was 149.52 kN/m2 and 159.05 kN/m2 for 7 days and 14 days respectively. However, it can be concluded that POFA and POF showed a greater gain in shear strength after the curing days.

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