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SOFT SOIL STABILIZATION USING SEWAGE SLUDGE ASH

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ABSTRACT

This study investigate on the potential of using sewage sludge ash to improve the shear strength parameters of soft soil. The sludge ash was obtained by burning the sludge for 1 hour at 800 °C. In this research, the following laboratory tests were conducted on the soft soil which are sieve analysis, standard proctor compaction, specific gravity, Atterberg limit and direct shear test. Two curing times were used for the untreated soils and treated soils with sludge ash which are 7 days and 14 days. The sludge ash was mixed with the soil at different percentages by weight of the soil at 2%, 4% 8% and 16%. The results showed that the increment in the sludge ash up to 8% increase both shear strength parameters which are cohesion and friction angle at 7 days curing time. Further increment of the sludge ash resulting decreases the cohesion values. The outcomes were observed present a better performance of the shear strength parameters at 7 days curing time. The findings of this research indicate that sludge ash can be applied to stabilize the soft soil and further diminish the environmental hazard associated with this material.

Keywords: sewage sludge ash, shear strength, soft soil, stabilization.

INTRODUCTION

Due to ongoing industrialization and increasing of living standard, the amount of sewage sludge produce all over the world also increase day by day. According to statistic, about 3 million metric tons of sewage sludge was produced annually in Malaysia and it is expected to increase to 7 million ton by the year 2020 (IWK, 2010). In Taiwan, Ministry of Interior reported that 180000 m^3 was produced daily (Ing *et al*., 2006). Sewage sludge can be defined as a waste material generate from sewage treatment plant that contain harmful element to the environment. Usually, deposited in landfill is the most popular method used to dispose sewage sludge. For country with limited land space, ocean disposal was chosen as one of the method to dispose sewage sludge. However, landfill and ocean disposal is not consider as a sustainable disposal method due to the leachate release by the sewage sludge that might create another environmental issue. Moreover, due to stringent rules set by the government, some country do not allowed wastewater treatment company to dispose sewage sludge in landfill. To overcome leachate related problem, some country incinerate the sewage sludge prior deposited it in landfill. Incineration of sewage sludge at high temperature not only change the properties of sewage sludge to inert ash, it can also reduce the mass and volume of the sewage sludge ash. Studies shows, incineration reduce the mass and volume of sewage sludge up to 70 and 90 percent respectively (Ciaran *et al*., 2015, Perez *et al*., 2014). However, incineration is just a temporary solution to reduce the volume of sewage sludge. The amount of sewage sludge ash still increasing by the year due to urbanization and industrialization.

In order to solve these problem, simple 3R rule: Reuse, Reduce and Recycle can be implemented. For the past few years, a lot of research have been conducted to reuse sewage sludge ash as part of the soil stabilization materials. From the research, it shows that sewage sludge and sewage sludge ash has a huge potential to be utilized as soil stabilization materials. For example, study conducted by Deng *et al*. (2016) shows that sewage sludge ash are good material to stabilize the engineering properties of soft cohesive subgrade soil. Besides, investigation conducted by Munjed and Mousa (2013) found that, 7.5 percent of burned sludge (by dry weight of soil) has increase the maximum dry density and unconfined compressive strength of the stabilize soil. Some studies used the mix of sludge ash and cement to stabilize the soil. The ratio of sludge ash/cement (3:1) produce the best improvement and the most efficient treatment to increase the soil strength with additional 2 percent of nano-silicon dioxide (Deng *et al*., 2016). Based on good findings by the previous researches, this study was conducted to investigate the feasibility of using local wastewater sludge ash to improve the engineering properties of soft soil.

EXPERIMENTAL WORK

In this study, sewage sludge sample was collected from local wastewater treatment plant located in Cheras, Kuala Lumpur. To produce sewage sludge ash, the air dried sewage sludge sample was incinerated in electric furnace at 800ºC for 1 hour. The ash then was grounded into fine particles to pass through a #200 sieve. Chemical analysis test using X-ray fluorescence (XRF) technique was then carried out to examine the chemical properties of sewage sludge ash. The sample of soil mixture were prepared by adding 0%, 2%, 4%, 8% and 16% (in weight percentage) of sewage sludge ash to soft soil. In order to understand the influences of sewage sludge ash on the strength of soft soil, few experiment such as Direct Shear Test (Shear Box Test), Unconfined Compressive Strength Test and Compaction Test were carried out on these samples.

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Figure-1. Sewage sludge samples before incinerated.

Figure-2. Sewage sludge samples were incinerated for 1 hour in an electric furnace.

RESULTS AND DISCUSSIONS

Properties of materials

Table-1 shows the result of XRF chemical analysis for sewage sludge ash. It can be seen that the sewage sludge ash primarily contain of iron oxide (Fe_2O_3), carbon dioxide (CO_2), phosphorus pentoxide (P_2O_5), sulphur trioxide (SO_3), silicon dioxide (SiO_2) and potassium oxide (K_2O), where these components made 95% of SSA. Iron oxide and silicon dioxide are two main oxides in pozzolanic reactions. Sulphur trioxide is normally used to retard quick setting in cement and phosphorus pentoxide is the element that will control the quality of cement in construction industry (Kartini *et al.*, 2015). Besides, phosphorus element also can be utilized as fertilizer in agricultural industry.

Sieve analysis test

Sieve analysis test was conducted to determine the percentage of different grain size distribution and to obtain classification of soil such as gravel, sand and fine particles. The test was carried out by applied ASTM D422. The experiment results obtained then were plotted in a semi-log graph to get the trend of curve as shown in Figure-3. Table-2 shows the summarize result of particle size distribution of soil sample.

Table-1. Results of XRF analysis for sewage sludge ash.

Component	%
Fe_2O_3	68.0
CO_2	16.2
P_2O_5	3.42
SO_3	3.31
SiO_2	2.14
K_2O	2.00
Na_2O	1.93
Al_2O_3	0.936
Cl	0.815
CaO	0.591
Cr_2O_3	0.150
MgO	0.123
ZnO	0.105
TiO_2	0.0904
As_2O_3	0.0609
NiO	0.0297
ZrO_2	0.0217
MnO	0.0216
CuO	0.0209
Br	0.0094
SrO	0.0033

Table-2. Grain size classification and grading of soil samples.

Sample No.	Clay (%)	Medium and fine sand %	Gravel (%)	C_u	C_c	Grading
1	4.67	93.87	1.54	2.98	1.20	Fine sand (silt)

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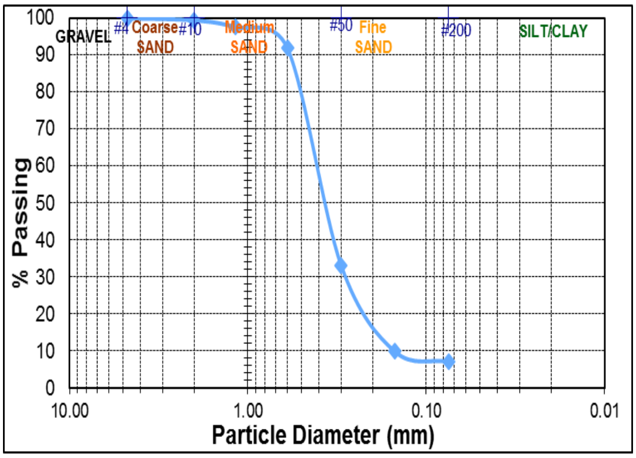

Figure-3. Curve plotting in the semi-log graph.

Atterberg limit test

Atterberg limit test was carried out to determine plastic limit (PL) and liquid limit (LL) of soil based on ASTM D4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. Besides that, plasticity index of soil also was measured to classify the soil. Atterberg limit test results of the soft soil samples are summarized shown in Table-3.

The results of the liquid limit (LL) was found to be 36.07%. The plastic limit (PL) was 26% and the plasticity index (PI) was 10%. The liquid limit is always greater than the plastic limit and the liquid limit represents in low rate in coarse granular soils. Plasticity was found to be low-plastic representing fine sandy soil. Liquid and plastic limit of soft soil are important criteria for classification objective. There are significant differences in the liquid limits, plastic limits and plasticity index resulting from the Atterberg reduction test. Determination of moisture content plays an important and fundamental role in determining the values of liquid and plastic limits.

Table-3. Atterberg limits test results.

Liquid limit (LL)	**Plastic limit** (PL)	**Plasticity index** (PI)	**Classification**
36.07%	26.00%	10.00%	Clay - Low Plasticity

Specific gravity

Specific gravity is a vital parameter for the classification of soils where it is according to void ratio porosity. According to the previous studies, specific gravity for soft soil value falls between 2.4 and 2.9. In this study, the result of specific gravity test shows that the soil samples can be classified as a clay soil.

Table-4. Summary of specific gravity results.

Sample No.	**Specific gravity**	**Average specific gravity**	**Classification**
1	2.451	2.422	clay soil
2	2.392		

Compaction test

Compaction test is a process of re-arranging the soil particles using different amount of compaction effort and moisture content. From the test, the optimum moisture content and the maximum dry density of soil sample were determined. In this study, the results of the moisture content and dry density were obtained for 7 and 14 days curing time of untreated soft soil and treated soft soil using different percentage of sewage sludge ash (SSA): 0%, 2%, 4%, 8%, and 16% (by weight).

Table-5. Summary of optimum moisture content results.

Sample	**Optimum moisture content** (%) (7 days)	**Optimum moisture content** (%) (14 days)
0% SSA	16.81	17.17
2% SSA	14.50	17.07
4% SSA	17.82	21.66
8% SSA	17.24	17.68
16% SSA	14.54	14.46

Table-6. Summary of maximum dry density results.

Sample	**Maximum dry density** (7 days)	**Maximum dry density** (14 days)
0% SSA	1.83	1.88
2% SSA	1.81	1.83
4% SSA	1.76	1.83
8% SSA	1.84	1.87
16% SSA	1.87	1.75

From the results shown in Table-5, the range of optimum moisture content for 7 days and 14 days curing time were varies from 14.50% to 17.82% and 14.46% to 21.66% respectively. It was found that the water affects the fine-grained soil more than the coarse-grained soil. Coarse soil contains larger voids which drain more quickly than fine soil. When the coarse soil above the ground-water table, it does not retain large quantities of water. It was observed that all samples are fine grains where they have higher percentage of moisture contents. In addition, the fine soil granules (soft soil) have more water absorption with the increment of sewage sludge ash (SSA)

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ratio due to SSA elements which absorb more water (Deng *et al.,* 2016).

Sewage sludge ash particles were characterized as small and irregular in shape. When compared with untreated soil, sewage sludge ash was larger in specific surface area and smaller in specific weight. Table-6 shows the result of maximum dry density for treated and untreated soft soil samples. It can be seen that the dry density of the treated soil samples decreased when small amounts of fine sewage sludge ash particles were added. However, when more sewage sludge ash was added to the soil, the dry density value increased. For 14 days curing time, this value was significantly drop when the amount of sewage sludge ash was increased from 8% to 16%. This result was attributed to either sewage sludge ash becoming clods or filling pores among soil particles. Hence, fewer small pores between soil and sewage sludge ash particles existed. Therefore, the moisture content of the treated soil with sewage sludge ash samples reduced when added with a small amount of SSA (2%), compared with untreated soil. In the case of having 4% and 8% sewage sludge ash, moisture contents were even higher than the untreated soil for both curing time (7 and 14 days). At 16% sewage sludge ash content, the ash absorbed more water and mixed well with the soil to form clods. Therefore, a slight increase in dry density in 7 days curing time and a reduction in water content of the mixture were produced. The results shall be supported findings by Huan *et al.*, (2012) whereas the percentage of sewage sludge ash increased in the treated soil, the increment of optimum moisture content shall be obtained. While, the maximum dry density decreased as the percentage of sewage sludge ash increases until reach at minimum value.

Direct shear box test

The shear strength parameter of soil sample obtained by conducting the direct shear box test for 7 days and 14 days curing time for treated and untreated soft soil using different percentage of sewage sludge ash (SSA): 0%, 2%, 4%, 8%, and 16% (by weight).

Table-7. Shear Strength of soil.

Sample	Maximum shear strength (τ)		Cohesion		Angle of friction (Ø)	
Curing	7 days	14 days	7 days	14 days	7 days	14 days
0% SSA	186.99	172.22	28	50	81.1	78.9
2% SSA	188.89	183.61	31	40	81.1	80.2
4% SSA	190.56	191.11	24	40	81.6	80.7
8% SAA	196.39	193.61	38	25	81.1	81.5
16% SSA	196.22	203.89	20	25	82.3	82.2

Results in Table-7 depicts the effect of the addition of the sewage sludge ash on the cohesion parameter of the soil samples. It can be seen that, for 7 days curing time, the addition of sewage sludge ash has increased the cohesion of the soil samples up to 8% of SSA. Further addition of sewage sludge ash resulted in decreasing the cohesion value. The increase of the cohesion may be attributed to the minerals such as CaO, MgO and K_2O that form cementation bonds with the minerals of the clay resulted in a higher cohesion. The reduction of the cohesion after 8% SSA in the soils may be due the increase of none-cohesive property of the sewage sludge ash in the soil. This implies that 8% SSA in the soil is the optimum value that form cementation bond. However, at 14 days curing time, the cohesion of the soil was decreased significantly with increasing amount of sewage sludge ash. It is may be due to the increment of the none cohesive constituent in the mix exceed the cohesive ones thus decreases as the percentage of SSA above 7.5%. Besides that, the maximum cohesion reached at maximum curing day where the hydration processes in the mixture lead reduction in volumetric changes.

For the result of angle of internal friction, the value was increased as the percentage of the sewage sludge ash increased for both curing time. The highest value of angle of internal friction takes place at 16% of sewage sludge ash. This implies that the optimum value of sewage sludge ash to increase the angle of internal friction in the soil is 16% by dry weight of the soil. This is attributed to the fact that the highest dry density for the treated soil samples were obtained at the addition of 16% of sewage sludge ash.

These results shall be supported by finding from study conducted by Munjed and Mousa (2013) where the cohesion values increases as the percentage of SSA increases until reach at minimum value and lose in strength with ratio by weight more than 7.5% of SSA. The increment of cohesion is due to the mineral composition of the sewage sludge ash. Similarly, the angle of friction increases as the percentage of sewage sludge ash increases by weight ratio. The increment in main shear parameters; cohesion and friction angle lead to increase the shear strength of soft soil.

Unconfined compressive strength (UCS) test

Table-8 shows the result of unconfined compressive strength test for untreated and treated soil sample for 7 and 14 days curing time. Overall, it can be seen that the treated soil with sewage sludge ash have better strength compared to untreated soil. The increased

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strength for treated soil sample with various percentage of sewage sludge ash ranged between 0.2 to 0.6 times higher compared to untreated soil. When cured for 14 days, the strength increased by 0.1 to 0.3 times higher to the original soil. It is interesting to notice that the increment in strength of 14 days curing time is a bit lower compared to 7 days curing time. The increment of percentage of sewage sludge ash lead the higher wetness absorption took place thus resulting in less moisture content and as more water is need, the loss

in strength of soft soil occur. Besides that, the hydraulic conductivity was reached at lowest value as the curing day increases.

Table-8. Unconfined compressive strength.

Curing period (days)		**Curing period** (days)	
7		**14**	
SSA (%)	UCS (kPa)	SSA (%)	UCS (kPa)
0	222	0	257
2	243	2	213
4	365	4	308
8	278	8	248
16	323	16	332

CONCLUSIONS

To sum up, two main shear strength parameters influence the shear capacity of soil. The cohesion strength increases as sewage sludge ash increases up to 8% and decreases beyond 16%. On the other hand, the angle of friction also increases with addition of SSA to all soil samples. In general, it can be concluded that the optimum dosage of SSA to be added is 8% by weight as the parameters reach at peak values. In addition, SSA increases the shear strength of soft soil by 10%. Besides that, the sewage sludge ash stabilized soil properties with improved curing time until reach at minimum value. The highest values of unconfined compressive strength obtained from the treated samples were with 4% and 16% sewage sludge ash. Furthermore, the highest maximum dry density was obtained with 16% of sewage sludge ash. It can be said that the hydration process as indication of soil permeability is another factor influence the strength of soil. Therefore, SSA is an effective soil stabilizer to improve soft soil properties.

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