SHEAR STRENGTH STABILIZATION USING BURNED SLUDGE ASH

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Abstract- This research studied the potential use of burned sludge ash to improve the shear strength parameters of clayey soils. The sludge ash was obtained by burning the sludge at 550 °C. Two types of clay soils were used in this study and the initial physical properties such as Atterberg's limit, gradation, compaction parameters were determined. The selection of the soils was based on plasticity index and clay fraction. The sludge ash was mixed with the soil at different percentages by dry weight of the soil at 2.5% increment. Standard Direct shear test (ASTM-D3080) was conducted on specimen mixed with sludge ash. The results showed that the increase in the sludge ash up to 7.5% will increase both the cohesion and angle of internal friction. Further increase of the sludge ash will reduce both the angle of internal friction and the cohesion in the two soils. However highly plastic clay soil (CH) shows a higher increase in the percentages of the shear strength parameters than low plastic soil (CL) for the same percentages of the burned sludge. The result of this research implies that sludge ash can be used to stabilize the soil and further reduce the environmental hazard associated with this material.

Keywords- Soil, Sludge Ash, Shear Strength, Cohesion, Clay

I. INTRODUCTION

The properties of soil play an important role for built structures. However, shear strength parameters for clayey soil can be a challenge for these sustainable structures. These parameters are susceptible to any water content change which resulted in most of the cases in significant reduction of the shear strength values. In addition to that, clayey soil is well known to have high compressibility and expansive properties, which causes major defects in any structure overlaying on such soil. Engineers all over the world used many materials with clayey soil to reduce its expansive properties and increase its shear strength. This technique is known as soil stabilization.

The problems with expansive soil have been reported in many previous literatures (Al-Rawas et al., 2005; Gong et al., 2015; Adem and Vanapalli, 2016). It is reported in the literature that this potential for swelling of the soil can be reduced or in many cases eliminated if treated with different materials such as waste cermic, cement kiln dust and waste shredded rubber (Hombirao and Rakaraddi, 2014; Ismail, 2013, Sabat, 2012). Soil stabilization has been used in the past as a mean to improve the engineering properties. Geotechnical engineers often used this technology to overcome and reduce many soil engineering problems especially for places with highly expansive soil.

Soil stabilization or improvement of engineering properties of soil for economic, safe and long lasting structures drew a lot of interest among the researchers in recent years. These studies are mostly focused on using waste materials as a stabilizing agent. Hombirao and Rakaraddi (2014) studied the possibility of using the shredded rubber tire chips for soil stabilization. The

waste materials used for soil stabilization are shredded rubber tyre (Hombirao and Rakaraddi, 2014), plastic waste (Mallikarjuna and Mani, 2016), metal casting industry waste (Joe and Rajesh, 2015), cement kiln dust (Ismail, 2013), red mud (Pandey and Jawaid, 2015; Dharavath et al., 2014), copper slag (Venkatasuresh and Anthakumar, 2016), brick dust (Sachin et al., 2014), ceramic dust (Sabat, 2012), fly ash (Karthik et al., 2014). Even though several materials were tried as a means to stabilize the soil, majority of them are chemical in nature and poor in terms of biological degradation.

Sewage sludge is an organic waste generated during the wastewater treatment. It has been used in the past as a soil stabilizing material (Theodoratos et al., 2000; Xenidis et al., 2001). Burned sewage sludge ash has also been used for soil stabilization. A research conducted of using sludge ash with the clay soil showed that the addition of this waste increased the unconfined compressive strength and reduce and eliminate the expansive properties of the slay soil (Al-Sharif and Attom, 2013; Al-Sharif and Attom, 2000). However, the use of burned sludge ash for the improvement of shear strength properties has never been explored in the past.

Important factors for consideration of stabilizing agents are abundance, availability, cost and easiness to obtain and can be found everywhere. Sewage sludge is available in huge quantities and is likely to be more available in the near future with the expansion in wastewater treatment plants associated with the rapid urbanization throughout the world. The incineration technology of sewage sludge enables not only the production of stable ashes, but also the total thermal destruction of organic pollutants and the concentration of organic pollutants (Vehlow, 1997). In addition to that it solve the environmental problems associated with this huge amount of such waste.

The objective of this research is to evaluate the effect of using burned sludge on improvement of shear

strength. Laboratory based experiments were conducted to achieve the objective.

II. DETAILS EXPERIMENTAL

2.1. Materials and Procedures

Two types of soil were selected and the initial physical properties were determined such as Atterberg's limits, gradation, compaction parameters (maximum dry density and optimum water content), specific gravity, and mineralogical composition. All soil physical properties were obtained in accordance with ASTM (American Standard for Testing and Materials) standard procedures. The selection was based on the difference in soil classification according to the unified classification system. Table 1 shows the initial physical and mineralogical composition of the soils used in this research.

The sludge ash was obtained from a public wastewater treatment plant and air dried. The sludge ash was obtained by burning the air dried sludge at 550 ^{o}C. The constituents and the typical range of the elements concentration in sludge ash is presented in Table 2. It is clear from this table that the sludge ash consists of silicon, calcium and iron in addition to other minerals. Then, the obtained sludge ash was mixed with the two types of soils at different percentages namely; 2.5%, 5%, 7.5%, 10% and 12.5% by dry weight of the soil. Three identical samples were remolded at each percent. All soil samples were remolded at 95% relative compaction and optimum moisture content. The shear strength parameters such as cohesion and angle of internal friction were determined using standard direct shear test (ASTM-D3080).

Table1: Soil initial properties

Soil No.	Soil_I	Soil_II
Liquid Limit (%)	79	47
Plastic Limit	26	23
Plasticity Index	53	24
γ_{dmax}(kN/m^3)	13.8	15.6
W_{op} (%)	34	21
Sand (%)	11	26
Silt (%)	25	30
Clay (%)	64	44
Activity	86	55
Specific Gravity Gs	2.7	2.6
Kaolinite (%)	18.2	29.3
Illite (%)	33.2	37.7
Montmorillonite (%)	14.1	7.6
Chlorite (%)	16.3	6.2
Classification (USCS)	CH	CL

Table 2: Range of element concentration in the sludge ash (Wegman and Young 1988)

Element	Oxide	Element	Oxides
Silicon (Si)	SiO_2	5.6-25.7	14.4-57.7
Calcium (Ca)	CaO	1.4-42.9	8.9-36.9
Iron (Fe)	Fe_2O_3	1.0-16.4	2.6-24.4
Aluminum (Al)	Al_2O_3	1.1-8.5	4.6-22.1
Magnesium (Mg)	MgO	0.6-1.9	0.8-2.2
Sodium (Na)	Na_2O	0.1-0.8	0.1-0.7
Potassium (K)	K_2O	0.3-1.6	0.07-0.7
Phosphorus (P)	P_2O_5	1.2-4.4	3.9-15.4
Sulfur (S)	SO_3	0.3-1.2	0.01-3.4
Carbon (C)		0.6-2.2	-

2.2. Direct Shear Test

Direct shear test (ASTM-D3080) was conducted on samples from the two soils mixed with sludge ash at different percentages with 2.5% increment mainly; 2.5%, 5.0%, 7.5%, 10.0%, and 12.5% by dry weight of the soil. All samples were remolded at predetermined dry density and water content. In this test, three identical samples from each parentage were prepared in the standard direct shear box. The three samples were sheared separately at different normal loads. The shear stress vs strain readings were recorded throughout the shearing process and plotted. From this plot, the maximum shear stress was determined under each normal load. After obtaining the maximum shear stress, another figure was plotted namely maximum shear stress vs normal load. A straight line was plotted between the points of maximum shear and normal load. The slope of this line (failure envelop line) is the angle of internal friction and the intersection of this line with the y-axis is the cohesion of the soil. This test was conducted on the two types of soils at five different percentages.

III. RESULTS AND DISCUSSION

3.1. The effect of sludge ash on the cohesion of the soil

Fig. 1 depicts the effect of the addition of the sludge ash on the cohesion parameter of the two soils. It is clear from this figure that the addition of the sludge ash increased the cohesion of the two soils up to 7.5% and for the two soils. Further addition of sludge ash resulted in decreasing the cohesion. 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 7.5% of sludge ash in the soils may be due the increase of none-cohesive property of the sludge ash in the soil. This implies that 7.5% of the sludge ash in the soil is the optimum value that form cementation bond. It is also noticed that the highly plastic clay (CH soil) affected more than low plastic clay (CL soil).

3.2. The effect of sludge ash on the angle of internal friction of the soil

Fig. 2 shows the effect of adding sludge ash on the angle of internal friction of the soil. The angle of internal friction increased as the percentage of the sludge ash increased. The highest increase in the value of angle of internal friction takes place at 7.5 % of sludge ash. The angle of internal friction decreased when the percentages of sludge ash higher than 7.5%. This implies that the optimum value of burned sludge to increase the angle of internal friction in the soil is 7.5% by dry weight of the soil. This is attributed to the fact that the highest dry density for the two soils were obtained at the addition of 7.5% of sludge as. At this percentage the two soils experienced the highest value of maximum dry density. Also it was noticed that the increase of the angle of internal friction in the highly plastic soil is more than low plastic soil.

3.3. Percent increase in the shear strength parameters and shear strength due to the addition of sludge ash

Figs. 3 and 4 Show the percentages increase in shear strength parameters for soil 1 and soil 2 due to the addition of 7.5% of sludge ash to the soils respectively. Fig. 3 depicts the percentage increased in cohesion for soil 1 and soil 2. It is clear from this figure that the cohesion increase as high as 33.3% for soil 1 and 27.3% for soil 2. This indicates that the sludge as can be used as a soil stabilizing agent to increase the cohesion and therefore improve the engineering performance of the soil.

Fig 3 shows the percentages increase in the angle of internal friction due for soil 1 and soil 2 due to the addition of sludge ash to the soil. This figure implies that the addition of 7.5% of the sludge ash by dry weight of the soil will increase the angle of internal friction. The angle of internal friction increased as high as 30% and 24% for soil 1 and soil 2, respectively.

As a result of increasing the shear strength parameters, the shear strength of the soil will therefore increase. The shear strength of the soil can be calculated using the following equation:

$$\tau = C+\sigma \tan\Phi$$

where:
τ : shear strength of the soil
C: cohesion of the soil
σ : normal load
Φ : angle of internal friction

The maximum value of cohesion and internal friction in Fig. 1 and Fig. 2 (at 7.5% of sludge ash) are used to calculate the shear strength of the soil at 55 kPa normal load (σ).

The results of this calculation are used to find the percentage increased in shear strength due to addition of burned sludge. Fig. 5 shows the percent increase in shear strength due to 7.5% percent addition of sludge ash. The shear strength increased significantly for the two soils especially for highly plastic clay soil (CH soil). The percentages increased as high as 50 % for soil 1 and 35% for soil 2. These values are consistent with earlier finding with regard to cohesion and angle of internal friction.

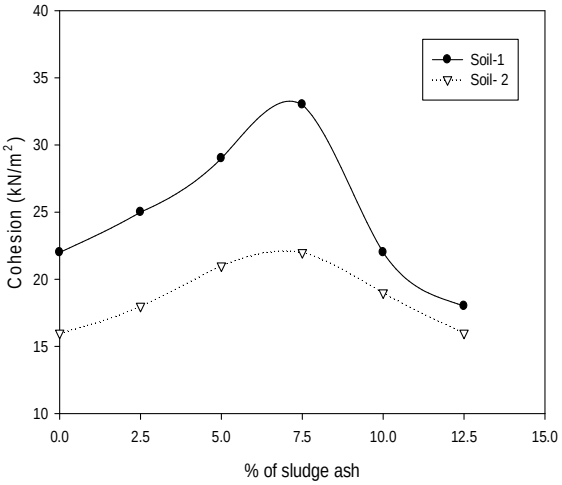


Fig.1. The effect of the sludge ash on the cohesion of the soils.

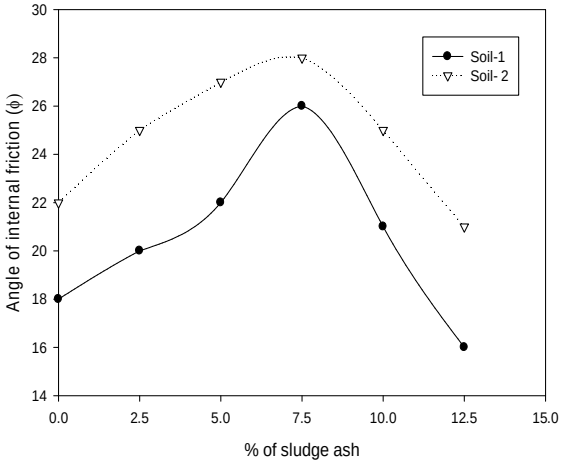


Fig.2. The effect of the sludge ash on the angle of internal friction of the two soils.

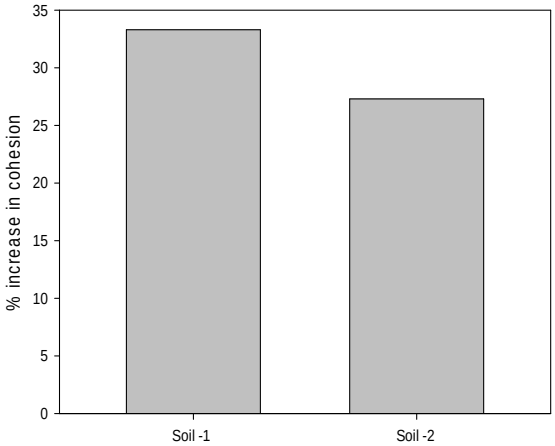


Fig.3. Percent increase in the cohesion for soil-1 and soil-2 due to the addition of sludge ash at 7.5%.

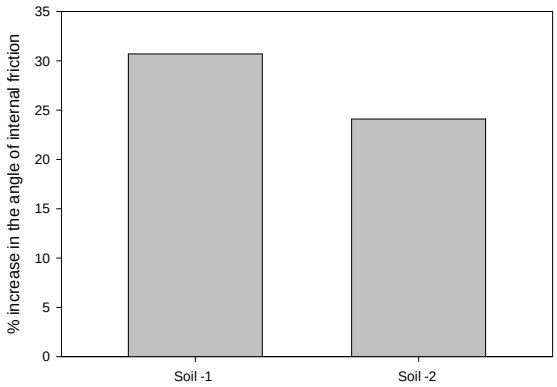


Fig.4. Percent increase in angle of internal friction for soil-1 and soil-2 due to the addition of sludge ash at 7.5%.

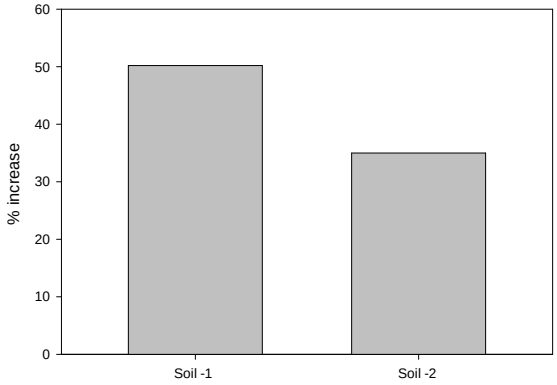


Fig.5. Percent increase in shear strength of the two soils due to the addition of sludge ash at 7.5%.

CONCLUSIONS

Based on the direct shear test results of adding sludge ash on two types of clayey soils, the following conclusions may be drawn out :

1. The increase of the percentage sludge ash up to 7.5% in the soil increased both the cohesion and the angle of internal friction of the soil.
2. Further increase in the percentage of sludge ash in the soil would reduce both the cohesion and the angle of internal friction of the soil.
3. As a result, shear strength increased in the same trend of shear strength parameter.
4. It was also noticed that the shear strength parameters have increased in highly plastic soil (CH) more than low plastic soil (CL) due ot addition of sludge ash.

REFERENCES

[1] Sabat, A. K., "Stabilization of Expansive Soil Using Waste Ceramic Dust", The Electronic Journal of Geotechnical Engineering, vol. 17, pp 3915-3926.

[2] Sachin N. Bhavsar, Hiral B. Joshi, Priyanka k. Shrof and Ankit J. Patel. (2014). Effect of Burnt Brick Dust on Engineering Properties on Expansive Soil. International Journal of Research in Engineering and Technology, 3(4), 433-441.

[3] Al-Rawas, A.A., Hago, A.W., and Al-Sarmi, H., (2005) "Effect of lime, cement and Sarooj (artificial pozzolan) on the swelling potential of an expansive soil from Oman". Building and Environment, 40(5): 681-687.

[4] Gong, B., Cheng, Z., Tong, J., Liu, J., and Liu, M., (2015) "Field test study on expansive soil canal of middle route of South to North Water Diversion Project". Japanese Geotechnical Society Special Publication, 2

[5] Adem, H.H., Vanapalli, S.K., 2016. "Heave Prediction in a Natural Unsaturated Expansive Soil Deposit Under a Lightly Loaded Structure". Geotechnical and Geological Engineering, 34(4), 1181-1192.

[6] Theodoratos, P., Moirou, A., Xenidis, A., and Paspaliaris, I., (2000), The use of municipal sewage sludge for the stabilization of soil contaminated by mining activities. Journal of Hazardous Material, 77(1-3): 177-191.

[7] Xenidis, A., Stouraiti, C., and Moirou, A., 2001. The effectivemenss of municipal sewage sludge application on the stabilization of Pb, Zn, and Cd in a soil contaminated from mining activities. Journal of Environmental Science and Health Part A., Toxic and Hazardous Substances in Environmental Engineering, 36(6): 971-986.

[8] Al-Sharif, M.M., and Attom, M.F., (2000), The Use of Burned Sludge as a New Soil Stabilizing Agent. Environmental and Pipeline Engineering.

[9] Al-Sharif, M.M., and Attom, M.F., (2014), A geoenvironmental application of burned wastewater sludge ash in soil stabilization. Environmental Earth Science, 71(5): 2453-2463.

[10] Vehlow, J., (1997), Modern Strategies in waste incineration, Technology and Environment, 1: 60-74.

[11] Hombirao, G.S., and Rakaraddi, P.G., (2014), Soil Stabilization Using Waste Shredded Rubber Tyre Chips. IOSR Journal of Mechanical and Civil Engineering, 11(1): 20-27.

[12] Mallikarjuna, V., and Mani, T.B., 2016, Soil Stabilization using Plastic Waste. International Journal of Research in Engineering and Technology, 5(5): 391-394.

[13] Joe, M.A., and Rajesh, A.M., 2015. Soil Stabilization using Industrial Waste and Lime. International Journal of Scientific Research Engineering and Technology, 4(7): 799-805.

[14] Venkatasuresh, P., and Anthakumar, S., (2016), A Study on the Effect of Copper Slag and Lime Treated Clay. International Conference on Engineering Innovations and Solutions, 72-76.

[15] Karthik, S., Ashok Kumar, E., Gowtham, P., Elango, G., Gokul, D., and Thangaraj, S., (2014). Soil Stabilization by using Fly Ash. IOSR Journal of Mechanical and Civil Engineering, 10(6): 20-25.

[16] Pandey, P.K., and Jawaid, A., (2015), Siol Improvement using Red Mud and Flyash. GJESR Research, 1(12): 7-9.

[17] Ismail, H., (2013), Cement Kiln Dust Chemical Stabilization of Expansive Soil Exposed at El-Kawther Quarter, Sohag Region, Egypt. International Journal of Geosciences, 4(10): 1416-1424.

[18] Dharavath, K.D.K., and Kulshreshtha, M., (2014). Evaluation of Characteristic Properties of Red Mud for Possible Use as a Geotechnical Material in Civil Construction. International Journal of Advances in Engineering and Technology, 7(3):1053-1057

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