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INVESTIGATIONS ON THE HYDRAULIC CONDUCTIVITY AND PHYSICAL PROPERTIES OF SILT AND SLUDGE AS POTENTIAL LANDFILL CAPPING MATERIAL

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ABSTRACT: Landfills have been the most common methods of municipal solid waste disposal in developing countries. Landfill capping is a containment technology that forms a barrier between the contaminated media and the surface. Presently, the commonest capping materials for landfills are sandy material and laterite soil. The permeability and the strength of the material against slope failure are among the important parameters to be considered. The objective of this research was to study the suitability of silt from Ulu Kinta dam in Malaysia and sludge (domestic wastewater sludge and water treatment sludge) as alternative materials for landfill capping. Both materials have little commercial values in Malaysia to date. The two materials were mixed with varying proportions of pure silt, 20, 40, 60, 80 and 100% of the sludge. Investigations were made on the hydraulic conductivity and physical properties of the mix. The results showed that silt material has a moderate hydraulic conductivity with *k* of value 4.81×10^{-4} cm/s, poor cohesion strength, 7.64 kN/m^2 and good friction angle, 36.2°. Sewage sludge has the best properties among the three materials, good hydraulic conductivity with *k* of 2.07×10^{-6} cm/s, moderate cohesion strength, 8.95 kN/m^2 and very high friction angle of 45.7°. Water treatment sludge's hydraulic conductivity, *k* was 2.9×10^{-6} cm/s which is good, but having poor cohesion strength and friction angle of 6.16 kN/m^2 and 6.1°, respectively. Silt and sludge were also mixed to test whether the method improves the properties of the final product; the result was negative. The use of 100% sewage sludge exhibited better results than others.

Keywords: Silt, Sewage Sludge, Hydraulic Conductivity Landfill Capping

INTRODUCTION

In the last few decades, increasing population growth and industrial development have increased generation of Municipal Solid Waste (MSW). MSW can be defined as the wastes generated from domestic, commercial, industrial, and institutional activities [1].Solid waste landfilling is still the most and suitable way for MSW disposal [2].Although the open landfill sites are the most popular method for solid waste disposal due to their ability to deal with high quantities of solid waste generated [3], landfills contain high toxic and hazardous materials and may cause potential risk to environment. Most of the landfill in developing countries does not have any liners at the base or proper top covers, which results in the potential problems of ground water/surface water contamination due to the leachate generated from the solid waste landfill. Therefore, landfills must be separated away from the surrounding environment. Some environmental aspects for landfilling should be considered such as capping system. The landfill capping system can be used to minimize exposure on the surface of the waste facility, and prevent vertical infiltration of water into wastes that would create contaminated leachate [4].

Several materials can be used for landfill capping system like sand, clay, silt and sludge generated from industrial waste water treatment plants. Capping materials should restrict surface water infiltration into the contaminated subsurface to reduce the potential for contaminants to leach from the site. Covering systems must function with minimum maintenance, promote drainage, minimize erosion of the cover, accommodate settling, and have hydraulic conductivity less than or equal to that of any bottom liner system or natural soil present [5-8]. In humid climates, cover and/or re-vegetation are usually required for erosion protection and infiltration control. The regulations do, however, permit alternative designs if they can achieve erosion and infiltration protection equivalent to an acceptable conventional cover system. This indicates the significance of searching different alternatives to compacted clay-based barriers in arid areas and evaluates their performance under various environmental conditions [9 - 12]. Many laboratory tests are needed to ensure that the materials being considered for each of the landfill cap components are suitable. Landfill instability can be solved by understanding the interface friction properties between all material layers, natural or synthetic.

Most of wastewater treatments processes produce large amount of sludge, which required being disposed. Conventional secondary sewage treatment plants typically generate a primary sludge in the primary sedimentation stage of the treatment and a secondary, biological, sludge in the final sedimentation after the biological process. The characteristics of the secondary sludge vary with the type of biological process and, often, it is mixed with primary sludge before treatment and disposal.

Huge amount of silt is produced daily, especially from siltation of dams. This material is inert and has minimum to no commercial value. The study aimed to find an alternative capping material which has little commercial value, thus saving the cost of landfill capping material without neglecting the strength properties of the landfill capping for safety purposes. In this regard, the performance of silt and sludge as capping materials for landfill in comparison with sand and laterite soil is evaluated. Both are considered as waste materials with no commercial values. Their usefulness as capping material either as an individual or in a mixed form has not been well investigated. The performance in terms of the hydraulic conductivity, shear strength, cohesion and friction angle of silt, sludge and a mixture of the sludge and silt are determined.

MATERIALS AND METHODS

Sampling

The main focus of this study is to find an alternative landfill capping material that uses various soil mixtures; specifically a mixture of silt and sludge. The geotechnical characteristics of the mixture were also compared with other different types of soil. Therefore, silt, sludge, sand and laterite soil were used in this study.

The silt used in this study was obtained from the Perak Water Board (LAP) dam in Ulu Kinta, Perak. The silt is basically sediment transported by the flow of river water into the dam. Approximately 15 kg of silt was taken from piles of excavated silt with a shovel. The sludge was obtained from the Bayan Baru wastewater treatment plant, in Penang and the LAP Jalan Baru water treatment plant, Parit Buntar Perak. Approximately 15 kg of fresh sludge were taken from sludge piles under the dewatering machine.

The sand used in this study had a fine texture and it was purchased from a nearby sand mining quarry. The purpose of the sand in this study is to compare the strength properties of sand with a silt and sludge mixture. The laterite soil used in this study was material that was available locally. It is commonly found in hot and wet tropical regions such as Malaysia. Laterite soil, which is rich in iron and aluminum, develops through an intense and lengthy weathering process of the parent rock. This process influences its soil characteristics and makes it reddish, clayey soil due to iron oxides. The purpose of the laterite soil is to compare the strength and hydraulic conductivity of laterite with the silt and sludge mixture.

Experimental Procedures

In selecting a suitable landfill capping material, there are several important geotechnical characteristics that merit the consideration. Since a landfill should be able to contain waste material, it is very important to ensure that the soil's permeability is able to perform according to the landfill's designed concept. Besides the permeability of the capping material, the geotechnical strength characteristics of the material are also important in order to ensure that the landfill is structurally stable and able to perform according to its design specifications for many years. If this can be achieved, any geotechnical structure failure, such as slope failure, ground depression, deferential settlement and tension crack, can be prevented. Therefore, the main characteristics; permeability and strength of the soil mix material were studied in order to assess the suitability of the landfill capping material.

As a standard of practice in soil mechanics, before any soil characteristic test is conducted, the sample must be classified. The classification of the sample is required in order to choose the suitable soil characteristic test. The classification test starts with sieve analysis, as grain particle-sorting was performed on sand, silt and laterite soil to determine the grain size distribution curve. The sieve analysis test was performed according to the ASTM C136-06 standard test method for sieve analysis of fine and coarse aggregates. Based on the standard sieve analysis, the particle size analysis of finer material that is available in silt and laterite soil was assessed by using a hydrometer test in accordance with the ASTM D422-63 standard.

The changes in water content can also alter the mechanical properties of a clay material. Therefore, the liquid limit test based on the BS 1377 standard and the plastic limit test based on the ASTM D4318 standard were conducted on silt and laterite soil to understand this change in mechanical properties. Based on the information obtained from sieve analysis, liquid limit and plastic limit tests, the soil classification group was determined by using the unified soil classification system (USCS) based on the ASTM D2487 standard of practice for the classification of soils for engineering purposes. The specific gravity of sand, silt and laterite were determined in accordance with the ASTM D854-00 standard test for specific gravity of solids by water pycnometer.

Once the soil had been classified and its characteristics were identified, the permeability and shear tests were conducted. Prior to these assessments, the maximum dry density of the sample was determined. The maximum dry density values of the sample are required in order to ensure that the sample prepared for the permeability and shear tests were able to simulate the actual compacted soil at the site. The sand, silt and laterite maximum dry densities were determined by using the modified proctor test based on the ASTM 1557 standard.

Since the landfill capping material requirement required low permeability of the material, the falling head permeability tests were conducted. The permeability tests were performed on silt, laterite and a sludge-silt mixture of soil. The ratios of the silt and sludge mixture are 0, 20, 40, 60, 80 and 100%. Two types of sludge, as mentioned in the materials and sampling section, were use in this study. In order to assess the strength of the silt and sludge mixture, a direct shear test was conducted based on the ASTM D3080 standard test method for the direct shear test of soils under consolidated drained conditions. The same tests were also conducted on sand, silt and laterite soil for comparison. Based on the tests that were conducted, the alternative landfill capping material capability of various soil mixtures was assessed.

RESULTS AND DISCUSSIONS

Both Table **1** and Fig. **1** show the results of modified proctor test. Table 1 shows the maximum dry unit weight (g/cm^3) ratios for silt, sand and laterite soils. Referring to the graph (Fig. 1), the result of hydraulic conductivity is plotted. The hydraulic conductivity of sludge regarding whether its sewage or water treatment sludge, it is better than the hydraulic conductivity of silt. The mixing ratio of silt to sludge is 0, 20, 40, 60, 80 and 100% of the sludge. As the sludge percentage increases, the hydraulic conductivity drops, which represents a drop in permeability. It is good since the landfill capping requires a low permeability material.

Table 1 Summary result for the modified proctor test

Soil	Laterite	Sand	Silt
Maximumdryunitweight (g/cm^3)	1.80	1.98	1.85

Comparing both water treatment and sewage sludge, the *k* value of sewage sludge has a better advantage. The permeability of sewage sludge is lower than water treatment sludge, which makes it a more ideal material for landfill capping. Laterite soil, which is the currently used capping material has a *k* value of 8.24x10^{-8}cm/s, which none of the combined sludge-silt samples nor did pure sludge could achieve such a low hydraulic conductivity.

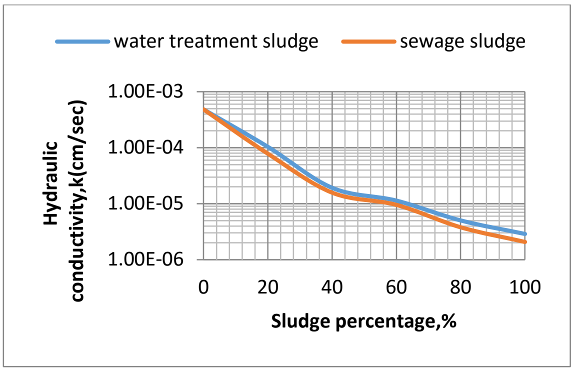

Fig. 1 Hydraulic conductivity at different sludge-silt mixture

The lowest achievable of hydraulic conductivity is 2.07x10^{-6}cm/s by100% sewage sludge, which is still quite a significant difference, compared to the laterite soil. The results of the direct shear test can be referred in tables 2 to 8, which show the value of *c* (cohesion) and *Ø* (soil friction angle) of each soil sample, including the combined sample of silt-sludge of 0, 20, 40, 60, 80 and 100% of the sludge. There is a significant difference between sewage sludge and water treatment sludge. By mixing silt with sewage sludge, it tends to weaken the cohesive strength and friction angle. Whereas, the silt strengthens the cohesive strength and friction angle of the water treatment sludge. The highest strength of all the mixed samples is the pure sewage sludge sample, with a *c* value of8.95 k N/m^2 and a friction angle of45.7°. The friction angle of pure sewage sludge exceeds both laterite and sand material, which means the failure plane is more stable compared to both laterite and sand material; however, the *c* value (cohesion) is lower than both sand and laterite. Laterite has the highest *c* value, 13.72 kN /m^2, whereas sewage sludge's *c* value is 8.95 kN /m^2.The experiment suggests that the best material to replace the current landfill capping material would be 100% pure sewage sludge with no mixed silt in it. Typical values of friction angle for sands and silts are presented in table 3.

Table 2 Cohesion and friction angle of laterite, sand and silt

Soil	Laterite	Sand	Silt
Cohesion, *c* (kN/m^2)	13.72	11.17	7.64
Friction angle, *Ø* (°)	41.9	34.1	36.2

Table 3 Typical values of friction angle for sands and silt [13]

Materials	Friction angle (degres)
Sand, uniform, round grains	27 - 34
Sand, well graded, angular	33 - 54
Sandy gravels	35 - 50
Silty sand	27 - 34
Inorganic silt	27 - 35

Laterite soil with a *k* value of 8.24x10^{-8}cm/s tends to resist water infiltration into the sample, thus enhancing the surface water runoff. The *k* value of silt is 4.81x10^{-4}cm/s; the significant difference of hydraulic conductivity between both samples concludes that silt will not provide surface water runoff as effectively as laterite soil. From the lab tests' results, the hydraulic conductivity of sewage sludge is 2.07x10^{-6}cm/s. Although the hydraulic conductivity of sewage sludge is not as low as the laterite sample, it is sufficient to support surface water runoff as the hydraulic conductivity value of sewage sludge is considered as low permeability.

Table 4 Cohesion and friction angle of sewage sludge-silt mixture

Sewage Sludge (%)	100	80	60	40	20	Silt
c (kN/m^2)	8.95	8.90	8.77	7.88	7.74	7.64
Ø (°)	45.7	43.8	40.0	39.6	37.8	36.2

The hydraulic conductivity of water treatment sludge, *k* is 2.9x10^{-6}cm/s, which is just slightly higher than sewage sludge. Nevertheless, it is considered as low permeability. The permeability level of water treatment sludge would be sufficient to support surface water runoff. In terms of shear strength resistance, referring to Table 2, silt has a *c* value of 7.64 kN/m^2, whereas laterite soil and sand sample has a *c* value of 13.72 kN/m^2 and 11.17 kN/m^2, respectively. This proves that the bond strength of silt is not good at all. Silt is very weak in bond strength; when held in hand it tends to only stick to the hand a little. Whereas the friction angle value, Ø of silt is 36.2°. The friction angle value is in between laterite and sand sample in a sequence of laterite (41.9°) < silt (36.2°) < sand (34.1°). This means that the failure plane of silt is on the acceptable region, and the results are satisfactory.

Table 5 Cohesion and friction angle of water treatment sludge-silt mixture

Water treatment Sludge (%)	100	80	60	40	20	Silt
c (kN/m^2)	6.16	5.21	5.82	6.44	7.02	7.64
Ø (°)	6.1	27.7	30.0	31.5	33.3	36.2

In terms of shear strength resistance, referring to Table 4, sewage sludge has a *c* value of 8.95 kN/m^2. The results proved the fact that sewage sludge does not have good bonding properties. Whereas the friction angle value, Ø of sewage sludge is 45.7°. The friction angle value is higher than laterite and sand sample, which can be arranged in a friction angle sequence of sewage sludge (45.7°) < laterite (41.9°) < sand (34.1°). This means that the failure plane of sewage sludge is better than both laterite and sand sample, which makes sewage sludge a very good material to replace the current landfill capping.

Table 6 Hydraulic conductivity of silt, laterite and sewage sludge

Soil	Silt	Laterite	Failed Sewage sludge
Hydraulicconductivity, *k*(cm/s)	4.81x10^{-4}	8.24x10^{-8}	2.66x10^{-2}

Referring to Table 5, the water treatment sludge has a low *c* value of 6.16 kN/m^2. The difference between the cohesion strength is approximately two times compared to water treatment sludge with laterite and sand sample, proving that the bond strength in water treatment sludge is poor. The friction angle value, Ø of water treatment sludge is 6.1°. The friction angle value is very much lower than laterite and sand sample, 41.9°and 34.1°. Pure water treatment sludge would not be a good option for capping material since both of the cohesion strength and friction angle value is too low compared to laterite and sand sample.

Table 7 Hydraulic conductivity of sewage sludge-silt mixture

Sewage Sludge (%)	100	80	60	40	20	Silt
Hydraulic conductivity,*k* (cm/s)	2.07x 10^{-6}	3.78x 10^{-6}	9.50x 10^{-6}	1.57x 10^{-5}	7.79x 10^{-5}	4.81x 10^{-4}

Table 8 Hydraulic conductivity of water treatment sludge-silt mixture

Water Treatment Sludge (%)	100	80	60	40	20	Silt
Hydraulic conductivity, *k* (cm/s)	2.90x 10^{-6}	5.05x 10^{-6}	1.14x 10^{-5}	1.93x 10^{-5}	1.04x 10^{-4}	4.81x 10^{-4}

CONCLUSION

Based on this study, silt is considered not suitable for landfill capping due to its moderate permeability and low bond strength. Although the bond strength of sewage sludge is not desirable, the hydraulic conductivity and friction angle value show satisfying results. Judging from the strength and permeability properties of the sewage sludge, it can be accepted as the replacement for landfill capping material. The ratios of mixed samples are the same in both types of sludge, which are 0%, 20%, 40%, 60%, 80% and 100% sludge. In the sewage sludge, the hydraulic conductivity, cohesion strength and friction angle in sludge itself is better compared to silt. In the water treatment sludge sample, the hydraulic conductivity shows low permeability, which is good. But its cohesion strength and friction angle have very weak values. By mixing the silt in the water treatment sludge, the cohesion strength increased slightly, whereas the friction angle improved a lot. The hydraulic conductivity of the water treatment sludge increases as silt is added in it. The case is the same with sewage sludge. Among all the samples of the mixture, 100% sewage sludge poses the best and suitable properties for landfill capping usage.

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