Shear strength of food packaging plastic wastes as liner material

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Abstract. The demand uses of plastic are increasing day by day leading to the various outsized amount of plastic waste producees across the world. Therefore, a proper discarding of the plastic wastes without causing any environmental risk has become a real challenge. The reuse of plastic to a beneficial product is one of the sustainable options which can secure the environment and prevent the plastic discarded to the landfill or incinerated. In this study, laboratory test was conducted to analyse the potential of recycle plastic waste as liner material in engineering application. The plastic waste was fabricated as 2mm plastic sheet liner and the geotechnical behaviors namely shear strength was analysed and compared with the commercialized liner which known as the geomembrane. Results of shear analysis showed the cohesion between the fabricated plastic waste liner (FPWL) meet the reference value for cohesion ranging 10-24 kPa. However, for internal friction most of the FPWL samples did not meet the reference value for internal friction ranging between 25-35o. This shows that plastic waste has a good shear strength and meet with global factor which feasible as alternative liner material in engineering application.

1. Introduction

Liner system is a significant element of modern landfill and was began in the 1970s with the use of engineered liner system [1]. Above and beyond, landfill liner system is the most crucial element as a barrier against interpenetration of contaminated leachate into ground. To meet the performance as a liner, several types of composite liner system have been developed over the last 35 years [2]. However, the qualification as a barrier to water flow in geotechnical liner systems requires the dependent on the shear strength at the interface between the different material [3] as well as the proof of long-term low water permeability and long term high internal shear strength [4].

The liner systems necessity tolerates the possibly applied stresses without being affected in its function during and after construction phase. The shear resistance among soil body and geosynthetics has proven to be the biggest encounter in landfill design [5]. Shear stresses that are created by putting the geosynthetic composite systems on landfill slanted base and surfaces are of a noteworthy concern.
The stability of these liner structures is governed by the shear strength of each material layer and the different interfaces between the contact layers in the structure [5]. The interface shear strength is an imperative focus with respect to the landfill stability in which it shears strength depends on cohesion ($c$) and internal friction ($\phi$) ranging between 10-24 kPa and 25-35$^\circ$ [2].

In applied design, liner system for waste containment generally include composite liners be made up of geomembrane (GMs) lie beneath by a low permeability soil layer either geosynthetic clay liner (GCL) or compacted clay liner (CCL) or both [7, 8]. Geomembranes are manmade, low-penetrability membrane liners or thin sheet barriers used to control a fluid's migration [9]. Besides, GMs material is a very stable polyolefin, chemically inert and long-lasting, making landfills generally waterproof [10]. Minimize the diffusive and advective exodus of contaminants in either a liquid or vapour state into surrounding environment through base liners and final covers is the main role of a GMs [11, 12, 13].

The waste plastic is one of the most prominent due to the perfect characteristics of these polymers such as corrosion resistance, high strength, low density, and user-friendly design, plastic usage has become much greater than aluminium or other metals [14]. Therefore, reuse of plastic wastes plays a significant role in sustainable solid waste management to assist save uses of natural resources, reduce environmental pollution as well as save and recycle procedures of energy production [15].

The objective of this paper is to study the geotechnical behaviour namely shear strength of various plastic wastes liner derived from plastic waste as well as to understand the causal factor of normal stress on the interface shear behaviour as landfill liner system component. A high-fidelity evaluation of the shear strength leads to maximal storage height as well as safer slope.

2. Methodology

2.1 Geomembrane Liner

Commercialized smooth surface high-density polyethylene (HDPE) geomembrane supplied by GTEK Resources Sdn. Bhd. as shown in Figure 1 (i) was used as a control liner sample in this study. The commercialized HDPE geomembrane with 2mm thickness normally used in waste management, water, civil engineering sectors as well as essential in protecting soils from contamination in applications as critical as the landfills.

![Figure 1. (i) Commercialized HDPE geomembrane sample, (ii) bakery plastic waste (BPW) and (iii) junk food plastic waste (JFPW).](image)

2.2 Plastic Waste Liner

Two types of plastic waste, namely, bakery plastic waste (BPW) and junk food plastic waste (JFPW) as shown in Figure 1 (ii) and (iii) were obtained from municipal solid waste around the area of Permatang Pauh and Seberang Jaya Pulau Pinang. This study limited to this type of plastic because according to [16], bread appeared both in the daily and weekly consumed foods. However, these foods were eaten by more individuals on weekly. As Malaysia’s lifestyles becoming more erudition and modernization,
people lean more to western snack food, especially junk food. According to [17], 44% of consumers globally ate junk food in the last 30 days. This showed that plastic waste from these food packaging was one of the contributions in solid waste stream. The chosen plastic wastes were fabricated to 2mm thickness through hot pressing technique.

2.3 Clay Liner
Clay is a current conventional practice for bottom landfill liner material due its higher impermeable characteristic. Compacted clay is located directly below the liner forms an additional barrier to prevent leachate from leaving the landfill and entering the environment as well as helps to prevent the escape of landfill gas. Clay sample known as kaolin clay (KC) with grade S300 was purchased from Kaolin (M) Sdn. Bhd. The clay can be categorized as Intermediate Plasticity Clay (CL) with Optimum Moisture Content (OMC) of 16.46% at Liquid Limit (LL) of 35% as well as Maximum Dry Density (MDD) of 1.69 Mg/m$^3$.

2.4 Sludge Liner
In this study, the potential of sludge as a liner material is also investigated. The sludge (S) was obtained using grab sampling method from Kulim Hi-Tech Water Treatment Plant (KH-TWTP) located at Sungai Petani, Kedah in which the treatment plant generates 227,000 m$^3$ per day of treated water. According to Syarikat Air Darul Aman (SADA) Sdn. Bhd., the sources of raw is from Muda Dam through Muda River. Based on the previous analysis (unpublished), the sludge has a Liquid Limit (LL) of 50% while the Optimum Moisture Content (OMC) obtained is 43.57 % and the Maximum Dry Density (MDD) is 1.2 Mg/m$^3$ in which this sludge can be classified as a High Plasticity Clay (CH).

2.5 Direct shear test
In The shear analysis is conducted according to ASTM D5321. The shear strength between soil/soil, geomembrane/sludge (GMs/S), geomembrane/kaolin clay (GMs/KC), fabricated liner (bakery plastic)/sludge (BPW/S), fabricated liner (bakery plastic)/kaolin clay (BPW/KC), fabricated liner (junk food plastic)/sludge (JFPW/S) and fabricated liner (junk food plastic)/kaolin clay (JFPW/KC) is conducted using direct shear box test.

Each liner sample is cut into dimension of 60 mm x 60 mm area according to the direct shear box mould. The liner sample is placed on top of compacted soil sample filled at the bottom frame of the mould. The upper frame was carefully placed and secured with bolt clipped. The compacted soil sample was carefully placed at upper frame and covered by load head. The sample then sheared at normal stresses equal to 55, 110 and 164 kPa applied above the loading head with a constant shear displacement rate of 1mm/min without soaking the sample in water. Each liner sample is repeated triplicate and average data for shear displacement, vertical displacement and shear force are recorded during the experiment.

3. Result and Discussion
3.1 Direct shear test on soil/soil interface
The independent soil sample tests were carried out under three normal stresses (55, 110 and 164 kPa) at a constant displacement rate of 1mm/min to understand the soil shear behaviour. The shear stress versus displacement and shear stress at failure versus normal stress curves for independent clay sample are shown in Figure 2 (i) and (ii). There is an initial increased in shear stress as soon as start. It also showed a rapid increment in shear stress as the increasing the displacement as it followed by a failure of shear stress with further deformation.

The shear stress vs displacement for sludge sample are shown in Figure 3 (i) while the shear stress at failure versus normal stress curves for independent sludge sample are shown in Figure 3 (ii). As expected for independent sludge sample it showed similar trends with clay sample which there is an initial increasing on shear stress as soon as it starts. Furthermore, the rapid increment on shear stress with increasing on displacement showed almost similar trends for the three applied normal stresses.
Figure 2. (i) shear stress versus displacement and (ii) shear stress at failure versus normal stress for independent clay sample.

Figure 3. (i) shear stress versus displacement and (ii) shear stress at failure versus normal stress for independent sludge sample.

At the end of the test, the obtained shear strength parameter for clay sample in which depends on cohesion ($c$) and internal friction ($\phi$) is 34 kPa and 20° respectively. However, the cohesion ($c$) for sludge sample is 14 kPa which is lower compare with clay sample but have high internal friction ($\phi$) of 25° which slightly high compare to clay sample. This showed that the friction among particles for alum sludge is high compare with kaolin clay.

3.2 Direct shear test on different liner/soil interface

The most adopted strength in which shear strength depends on both shear strength parameter known as cohesion ($c$) and internal friction ($\phi$) have been considered. Figure 4 (i) shows the interface shear stress-displacement curves for interfaces of clay. This showed evident that with increasing normal stress lead on increment the peak of shear stress. However, from Figure 4 (ii) shows the shear stress-normal stress interfaces for GMs/KC sample under normal stress of 55 kPa, 110kPa and 164 kPa lead to 0 kPa for cohesion which is far beyond reaching global factor range for cohesion ($c$). This showed that the smooth GMs did not have good shearing strength which supported by [18] as to improve the shear strength at the GMs-soil interface is by using textured GMs instead of smooth GMs.

The similar trends of shear stress-displacement for initial rapid increment as soon as the displacement start as well as increase in shear stress with increase displacement found in Figure 5 (i) for BPW/KC interface and Figure 6 (i) for JFPW/KC interface. The peak shear stresses starting to occur at displacement of 1.0 mm for BPW/KC at normal stress of 164 kPa. Besides, the shear stress-normal stress interfaces for BPW/KC cohesion is 30 kPa which showed higher $c$ value compare with JFPW/KC (0 kPa) and GMs/KC (0 kPa). This showed that the textured surface has improving the shear strength
instead of non-textured surface.

**Figure 4.** (i) shear stress-displacement curves and (ii) shear stress-normal stress for GMs/KC sample.

**Figure 5.** (i) shear stress-displacement curves and (ii) shear stress-normal stress for BPW/KC sample.

**Figure 6.** (i) shear stress-displacement curves and (ii) shear stress-normal stress for JFPW/KC sample.

Figure 7 (i) shows the shear analysis between shear stress in conjunction with displacement while Figure 7 (ii) shows the relationship between shear stress at failure with normal stress. For normal stress of 164 kPa, the highest peak shear stresses occur at displacement of 0.6 mm. Besides, the cohesion for GMs/S is 44 kPa which is the highest cohesion for liner sample-sludge interfaces. However, the nearest
cohesion to GMs/S obtained from BPW/S interfaces (30 kPa) as shown in Figure 8 (ii). Furthermore, it was found that from the shear analysis in Figure 9 (ii), the cohesion for JFPW/S is 0 kPa. It is subjected to strain from the shear test and development of friction between soil and liner sample.

**Figure 7.** (i) shear stress-displacement curves and (ii) shear stress-normal stress for GMs/S sample.

**Figure 8.** (i) shear stress-displacement curves and (ii) shear stress-normal stress for BPW/S sample.

**Figure 9.** (i) shear stress-displacement curves and (ii) shear stress-normal stress for JFPW/S sample.
Table 1 shows summary of shear strength parameter in this study with another researcher. Based on the reported data in Table 1, the cohesion value for kaolin clay in this study is in between 32-52 kPa which meets up with other researcher studies. However, the sludge sample in this have the highest value for cohesion (14 kPa) compared with other studies stated in Table 1. The JFPW/S and JFPW/KC both have the same friction angle similar with GMs/KC which consistent with the values reported by [24, 25] meets up with the results in this study well but higher than those reported by [23, 20, 22, 26]. Furthermore, a GMs/S in this study resulted in a higher apparent adhesion compare with BPW and JFPW liner as well as other liner reported by [23, 20, 22, 24, 25, 26].

| No  | Description                             | Soil Parameter | Liner Parameter |
|-----|-----------------------------------------|----------------|-----------------|
| 1   | Kaolin Clay                            | c (kPa) 34.0 | GMs/S 44.0       |
| 2   | Sludge                                 | $\phi$ (°) 20.0 | GMs/KC 18.0     |
| 3   | Clay                                    |               | BPW/S 30.0      |
| 4   | Sand                                    |               | BPW/KC 30.0     |
| 5   | Sand:Bentonite (100:5)                  |               | JFPW/S 20.0     |
| 6   | Sand:Bentonite (100:10)                 |               | JFPW/KC 20.0    |
| 7   | Alum Water Treatment Residue            |               | Geomembrane (HDPE) – clay 0.28 | 22  |
| 8   | Alum residue from the Ballymore Eustace works | 0 28.44 | Geomembrane/Compacted clay liner 0.28 | 26  |
| 9   | Alum residue from the Clareville works  | 0 42.0        | Textured HDPE – compacted clay 0.28 | 22  |
| 10  | Alum residue from the Leixlip works     | 0 44.0        |                 |
| 11  | Compacted Clay Liner                    |               | Geotextile and Geomembrane HDPE smooth surface (Type 1) – as installed condition 1.8 | 27  |
| 12  | Highly Weathered Granite Soil (Native soil) | 25.0 46.7  | Geotextile and Geomembrane HDPE smooth surface (Type 1) – saturated condition 0.28 | 28  |
| 13  | Compacted Clay Liner-Sand Bentonite mix (100:10) | 51.9 37.1 | Compacted clay liner-sand bentonite mix 0.28 | 29  |
|     |                                         |               | Native soil and Geotextile – as installed condition 0.28 | 30  |

Reference:
1. This study
2. (19)
3. (20)
4. (21)
5. (22)
6. (23)
7. (24, 25)
8. (26)
9. (19)
10. (20)
11. (21)
12. (22)
13. (23)
14. (24, 25)
15. (26)
16. (27)
17. (19)
4. Conclusion
This study showed the shear strength behaviour of the component which typically utilized in liner system with the interface interaction mechanisms depend on normal stress. Finding of this paper found that from the shear analysis, the cohesion for GMs/S, BPW/S and BPW/KC were 44 kPa, 30 kPa and 30 kPa respectively which meets and exceed the global factor for cohesion ranging 10-24 kPa. Besides, it was found that the internal friction in between and exceed the reference value (25-35°) is GMs/KC, JFPW/KC and JFPW/S which successfully meets up with the results in this study well.

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