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Utilization of Kenaf Core Fiber – Marine Clay Mixture as a Landfill Liner Material

Noor Shazreen A. Rahman[a]*, Diana Che Lat[a], Husaini Rosli[b], Siti Nur Aishah Mohd Noor[a] & Roslizayati Razali[a]

[a]*School of Civil Engineering, College of Engineering, UiTM Pasir Gudang, 81750, Johor*
[b]*School of Civil Engineering, College of Engineering, UiTM Shah Alam, 40450, Selangor*

**Corresponding author: noorshazreen@uitm.edu.my*

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ABSTRACT

Nowadays, leachate production is a big concern and causes a serious hazard to the soil and groundwater which causes the subsurface soil to be polluted as a result of the loss of soil quality and environmental pollution. This study aims to study the potential of using kenaf core fiber and marine clay mixtures as improved landfill liner material. Relevant laboratory tests such as atterberg limit test, specific gravity test, and particle size distribution were performed to examine basic geotechnical properties of marine clay soil collected from Batu Kawan, Penang. Besides that, compaction test and hydraulic conductivity test were carried out for soil mixed with kenaf core fiber to determine the strength and permeability characteristics. The results found that the marine clay has significantly adequate physical properties to be used as a landfill liner. The permeability test for marine clay soil inclusion of kenaf core fibre indicated that the hydraulic conductivity of the samples admixture for 0%, 4%, 8%, and 12% ranged between 6.68×10^{-9} and 1.57×10^{-8} m/s. Compaction of marine clay mix kenaf core fibre samples resulted in maximum dry density, ρ_{dmax} that ranged between 0.936 and 1.595 g/cm^3 and optimum moisture content, w_{opt} that ranged between 19.8% and 24%. Hence the inclusion of kenaf core fiber in marine clay soil improves the maximum dry density value, decrease permeability of marine clay and could be potentially used for landfill liner material.

Keywords: landfill liner, marine clay soil, kenaf core fiber, compaction, hydraulic conductivity

INTRODUCTION

Leachate is created by landfills that contain vast quantities of organic and non-organic contaminants as water percolates. A complicated organic wastewater called landfill leachate will be generated in the sanitary landfilling process. Waste penetrates precipitates from the solid waste and leaches the constituents out of the decomposed waste when going through the landfill. Municipal landfill leachate represents a common environmental burden and poses a significant threat to surface water and groundwater, due to the existence of toxic substances such as heavy metals, organic contaminants, and ammonia nitrogen. It must be appropriately disposed to avoid ecotoxicity and damage to the environment. Based on the study by (Sachin et al. 2019), they concluded that the groundwater quality is deteriorated gradually around their study area due to leaching of landfill leachate and is not safe for drinking purposes as most of the physico-chemical parameter values exceed the permissible limit of drinking water standard prescribed by WHO & BIS. Results showed that groundwater is gradually changed from good to fair water quality which is very near to landfill site that can be threatened soon.

According to (Zhiyong Han et al. 2016), the groundwater contamination appeared in the initial landfill stage after five years and peaked some years afterward. After 25 years, the groundwater contamination was very low at selected landfills. To meet strict quality standards for direct discharge into water bodies or sewer system, various sustainable approaches and technologies have been proposed and tested to treat highly polluted leachates. According to (Hongwei et al. 2020), there are a lot of things influenced the selection of the appropriate treatment technology for landfill leachate problem. They suggested a combination of two or more physical-chemical treatments to maximize the removal of recalcitrant organic compounds from stabilized leachates, while a combination of biological and physical-chemical treatments is required to achieve an effective removal of chemical oxygen demand (COD) and Ammonium-Nitrogen (NH_4^+-N). Based on a study by (Chunying et al. 2021), the up-to-date spectroscopic techniques for landfill leachate characterization and advanced oxidation treatment techniques are highlighted. An understanding of the physiochemical characteristics and environmental behaviors of landfill leachate is essential for its effective treatment. Many research studies conducted in developing countries have focused on phytoremediation/constructed wetlands and adsorption methods as efficient methods in terms of their cost and removal capacities that can remediate a wide range of pollutants. According to (Prabuddhi et al.

2022), beneficial uses of landfill leachate for commercial and industrial applications can be an assurance of the sustainable management of leachate.

Nevertheless, the main component of the landfill liner system is the clay liner or Compacted Clay Liner CCL. According to (Emmanuel et al. 2020), the hydraulic conductivity $\leq 1\times10^{-9}$ m/s and thickness standards (0.6–1.5 m) of the Compacted Clay Liner should be satisfied. Also, similarly with the Malaysian Ministry of Housing and Local Government (MHLGM) supports the use of earthen liners in landfills as long as they fulfill the minimal standards of long-term stability, minimum thickness (50 cm), permeability $\leq 1\times10^{-8}$ m/s, and fines content (8%) stated in (Yachiyo Engineering Co. LTD, 2004). The soil liner effect from uncontrolled leachate landfills is given adverse consequences to the geotechnical properties of soil in the liner layer of the dumpsite especially hydraulic conductivity properties. An efficient liner layer system of the dumpsite is essential to prevent leachate from spreading past the landfill site. According to (Emmanuel et al. 2020) when marine clay is compacted, it typically results in increased densification, improved bearing capacity, and acceptable strength. As a result, in addition to its low permeability and excellent attenuation capacity, as well as the economic attraction of employing the natural geomaterial for liner application, these favourable compaction qualities may increase the usage of marine clay as a compacted soil liner in engineered landfills. In this case, compacted natural marine clay might be utilized to make landfill bottom liner materials.

Hence, to increase the soil improvement of marine clay soil as a landfill liner, a natural fiber which is kenaf core fiber is adequate. Kenaf is one of the natural fiber which is a hydrophilic fiber and tends to absorb water, because of its nature which is rich in cellulose making it hydrophilic. Landfill leachate contains pollutants that penetrate waste and contaminants such as organic and inorganic compounds, heavy metals, total dissolved solids and color with or without odour. (Mojiri et al. 2016a 2017) However, the most harmful contaminant is heavy metals that have high concentrations that come from the weaknesses and irregularities in the segregation of hazardous waste by the plant before disposal to landfill (Chuangcham et al. 2008; Edokpayi et al. 2018). In a recent study, Kenaf can be a cleaning solution for contaminated soil because it has a potential to absorb heavy metal such as nickel and copper (Hasfalina et al. 2010). Furthermore, it is also been demonstrated to be an excellent absorbent material which open porosity cell systems on short kenaf core fibers are extremely absorbent whereas the core pith appears to be the greatest absorbent substance, capable of retaining up to 20 times its weight (Sreenivasan et al. 2013). Moreover, the previous research also proves that the influence by moisture absorption on mechanical properties of kenaf shows that the highest value of diffusion coefficient is 7.140×10^{-10} m/s (Mishra et al. 2021).

According to (Ferdous & Hossain 2017) the natural fiber like kenaf are unbreakable, maintenance-free, durable, fire retardant and water-resistant, acid- and alkali-resistant, less abrasive, less expensive, with low thermal conductivity and stronger than wood. Batchiar and Hamdan, 2009 and Ahmad et al. (2011) said that kenaf is an alternative to synthetic polymers given the low price and green materials that can be recycled, renewed and biodegradable. Compare to synthetic fiber, kenaf fibre can provide higher density resulting in lightweight and eco-friendly materials (Rozyanty & Syed Zhafer 2019). Natural fiber composites were discovered to be cheaper, lighter, and had strength qualities equivalent to glass fiber reinforced polypropylene fiber composites, as well as being nearly twice as stiff. Thus, it is adequate to enhance the performance of clay soil for clay landfill liner using the kenaf fibre to increase the properties in terms of strength, hydraulic conductivity and it is expected to prolong the performance lifespan of landfill and overcome the leachate problem to the environment.

MATERIAL AND METHOD

SAMPLE COLLECTION AND PREPARATION

Marine clay soil used in this research was collected at Batu Kawan, Penang. The soil was collected using a shovel about 0.5 meters depth below ground level. Marine clay soil samples are prepared based on Clause 7 (Preparation of Disturbed Samples for testing) specified in BS1377: Part1: 1990. The soil in the metal tray was oven-dried at temperatures between 105°C – 110°C for 24 hours. The dry soil was abrasion into the fine-grain soil by an abrasion machine with 11 metal balls for 30 minutes and keep stored in a plastic airtight container and can be used for all the experiments. The natural fiber for this research is kenaf core. According to Shahar et al. (2019), the kenaf core fiber is extracted using three different methods or approaches which are hand harvest and retting, applying a decorticator machine, and whole stalks harvesters. For this research, the kenaf core fiber as shown in Figure 1 is provided by Syarikat Ecovet Pet Sdn. Bhd. with the random size of kenaf core fiber.

FIGURE 1. Kenaf core fibre

EXPERIMENTAL PROCEDURES

For the marine clay soil, the physical properties test was conducted namely the Atterberg limit test, particle size distribution test and particle density test. The liquid limit test was conducted using cone penetrometer whilst the plastic limit was determined by rolling the soil thread into a 3 mm diameter without crumbling. The plasticity index, Ip is defined as the difference between the liquid limit and the plastic limit. Atterberg Limit test was referred to BS 1377 : Part 2 : 1990 : 4.3 & 5.3. The specific gravity of the marine clay samples was established by using the pycnometer bottle method which referred to BS 1377: Part 2: 1990: 8.3. The particle size distribution of the dry sieve and hydrometer test were carried out to determine the particle size of marine clay soil. The standard procedure for this test is referred to BS 1377: Part 2: 1990: 9.3 and 9.5.

For the kenaf core fiber mix with marine clay soil, four different samples were tested with various quantities of fiber mix in the soil those were 0%, 4%, 8%, and 12%. The laboratory test involved is the standard proctor compaction test and falling head test. Compaction characteristic tests were performed using a 2.5 kg standard proctor. The sample was compacted in three equal layers using a rammer where each layer required 27 blows that were evenly distributed over the mold area. This test is referred to BS 1377: Part 4: 1990: 3.3. The maximum dry density, ρ_{dmax}, and optimum moisture content, w_{opt} can be obtained from the compaction curve. The permeability test was performed using a falling head permeameter method. It was conducted by referring to British Standard BS1377: Part 5: 1990: 5.5. The compaction test and falling head test were repeated for the soil admixture with different percentage of kenaf core fiber.

RESULTS AND DISCUSSION

PHYSICAL PROPERTIES OF MARINE CLAY SOIL

The physical properties tests of marine clay soil were conducted which are Atterberg limit test, specific gravity test, and particle size distribution. As shown in Table 1, the marine clay soil recorded a liquid limit of 49.31%, a plastic limit of 28.8%, and a plasticity index of 20.51%. Referring to the Technical Reference Document for Liquid Manure Storage Structures Compacted Clay Liners, CGRM, (Iners 2007) the samples have adequate liquid limits and plasticity index based on the liquid limit value of ≥30% and plasticity index ≥20%. Moreover, the plasticity index for this marine clay sample which is 20.51% fulfilled the plasticity index criterion of ≥7% for liner usage suggested by Yong et al. (2019).

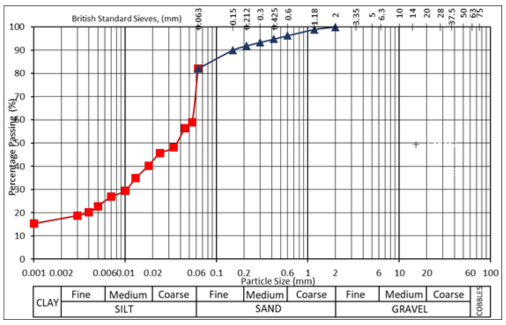

FIGURE 2. Particle size distribution curve of Marine Clay Soil

From Table 1 and Figure 2, the marine clay soil sample is dominated by silt (65.01%), followed by sand (17.89%), and clay (17.03%). Hence, from this result, the fine particle percentage which is including silt and clay is 82% and complied with the permissible potential use as a landfill liner material by referred to the Ministry of Housing and Local Government, Malaysia (MHLGM) requirement of fine content ≥8%. Moreover, according to Emmanuel et al. (2020) through their literature review study about the potential of marine soil as a bottom liner, the clay fraction should be ≥10% to be used as a landfill liner soil. Thus, from this result, the clay fraction is adequate as a landfill liner. The particle density test of the sample is 2.61 Mg/m^3. This value is acceptable to utilize as a landfill liner by referring to the previous research did by Rahman et al. (2013), Ojuri (2015) and Yong et al. (2019). The value of particle density for the typical clay is between 2.6-2.8. Hence, this marine clay has a low hydraulic conductivity which is suitable to be utilized as a landfill soil liner.

TABLE 1. Summary of marine clay soil characteristics

Material Properties	Value
Attreberg Limit (%)	49.31
Liquid Limit, W_L	28.80
Plastic Limit, W_p	20.51
Plasticity Index, I_p	
Particle Size Distribution (%)	
Sand	17.89
Silt	65.09
Clay	17.03
Soil Description	Slightly sandy SILT of intermediate plasticity
Specific Gravity (Mg/m^3)	2.61

COMPACTION OF MARINE CLAY SOIL MIX KENAF CORE FIBRE

Compaction is defined as a mechanical process that brings about an increase in soil density, with a consequent reduction of air-voids volume, but with no change in the volume of water. In landfill liner, the compaction properties which is compacted clay liner landfill is important as a seepage-free barrier constructed of a cohesive soil that is compacted to increase its maximum dry density and homogeneity. The aim is to reduce porosity and decrease soil permeability. Four samples were tested with different quantities of kenaf core fiber mix in marine clay soil. The results of the maximum dry density, ρ_{dmax}, and optimum moisture content, w_{opt} as shown in Figure 3 illustrates the compaction curves of the marine clay sample.

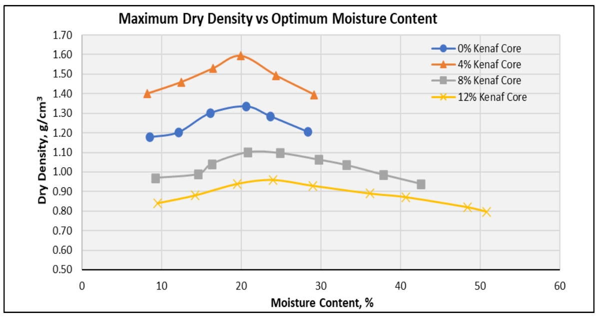

FIGURE 3. Compaction curve of marine clay soil mix kenaf core fiber

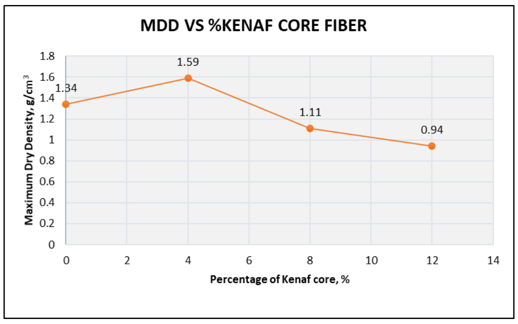

FIGURE 4. Maximum Dry Density vs % kenaf core fiber inclusion

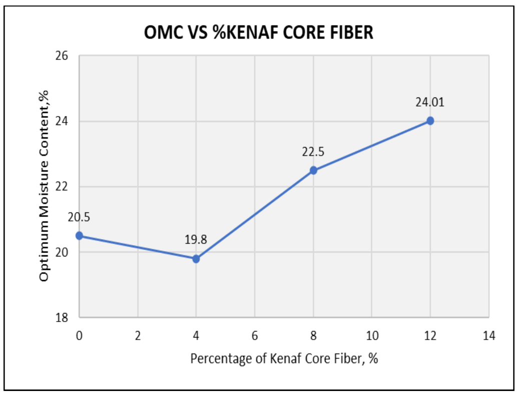

FIGURE 5. Optimum Moisture Content vs % kenaf core fiber inclusion

From the results depicted in Figure 4 and Figure 5, it was found that when the soil is compacted without the mix of kenaf core fiber, it gives optimum moisture content, OMC of 20.5% and a maximum dry density, MDD of 1.34 g/cm^3. When the content of 4% kenaf core fiber is included, the MDD is gradually increased to the 1.59 g/cm^3 and the OMC is gradually decreased to 19.8%. As the percentage of kenaf core mixing reached 8%, the MDD is starting decreasing and lower than the 0% of kenaf core in soil. While the OMC is increasing started at the 8% of kenaf core in soil. The soil mix at lower content of kenaf core fiber which at 4% decrease in MDD is observed. This is owing to the higher density at lower fiber content, which leads to reduce voids with empty spaces occupied by solid particles with higher specific gravity (Mittal & Shukla 2020). Furthermore, the kenaf core fiber's greater water absorption capacity than the surrounding soil is most likely the cause of the rise in moisture content starter at 8% of kenaf core fiber inclusion. Thus, the optimum fiber inclusion in marine soil is 4% since the MDD is higher than other percentage inclusion.

PERMEABILITY OF MARINE CLAY SOIL MIX KENAF CORE FIBRE

The permeability of the material is one of the vital criteria in geotechnical engineering properties in soil especially criteria in landfill soil liner. To comply with the permissible hydraulic conductivity of landfill liner, which the permeability of the sample increased with leachate penetration but remained within the Malaysian statutory requirement of $\leq 10^{-8}$ m/s stated by the regulatory authorities (Emmanuel et al. 2020)

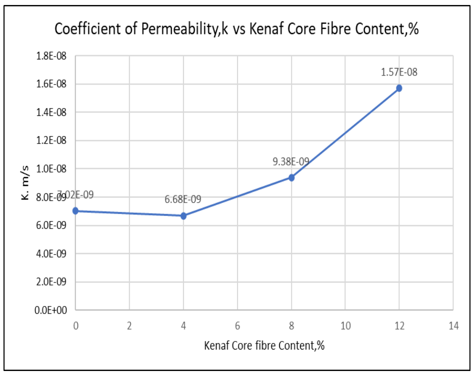

FIGURE 6. K vs % kenaf core fiber inclusion

Based on Figure 6 which the correlation of permeability and quantity of kenaf core fiber, the slight decrease in hydraulic conductivity is seen at 4% which is 6.68 × 10^{-8} m/s, the lowest fiber content should be interpreted to mean that the fiber additions is lower the hydraulic conductivity. The rise in hydraulic conductivity was increased for kenaf fiber inclusion by more than 4%. soil admixture of 12% is the only fiber inclusion in the soil that is not obeyed the standard use in landfill liner permeability which is ≤10-8 m/s. When fiber are added to soil, they attempt to block the pores that were already present in the soil specimen. This is due to the higher density at lower fiber content, which results in fewer gaps with empty spaces occupied by solid particles with higher specific gravity. However, increasing the number of fiber leads to an increase in the number of fiber in unit weight. When the number of fiber in a given volume grows, so does the total contact area between the fiber and soil particles, which might change the granular structure and generate new water flow pathways. Thus, it can be said that interaction between fiber and soil may create an increase in hydraulic conductivity by generating certain pathways for water to escape in the soil matrix and increasing the coefficient permeability of soil admixture. Hence the optimum percentage quantity of kenaf core fiber has the potential to improve the hydraulic conductivity of landfill liner is 4%.

CONCLUSION

Geotechnical characterization of marine clay deposits was investigated for possible use as a liner material. The marine clay samples were classified as slightly sandy SILT of intermediate plasticity. The fraction of the finer is 82.11%, indicating the appreciable quantity of fines that are suitable for achieving the targeted low hydraulic conductivity for liners. The specific gravity of the sample is 2.61 Mg/m3. The maximum dry density for 0% , 4%, 8% and 12% of kenaf core fibre are 1.336 g/cm^3 , 1.595 g/cm^3 , 1.106 g/cm^3 , and 0.936 g/cm^3 respectively, while the optimum moisture content are 20.5%, 19.8%, 22.5% and 24% sequentially. It was found the highest Maximum Dry Density is 1.595 g/cm^3 which is at 4% of kenaf core fiber inclusion. Meanwhile, the permeability for 0% , 4%, 8% and 12% of kenaf core fibre are 7.02×10^{-9} m/s, 6.68×10^{-9} m/s, 9.38×10^{-9} m/s and 1.57×10^{-8} m/s respectively. It was found at 4% of kenaf core inclusion, the permeability is the lowest among other percentage kenaf core fiber. The optimum fiber content for the soils admixture under consideration is required to achieve maximum dry density while retaining acceptable hydraulic conductivity. Hence, from the result, the 4% of kenaf core fiber mix in the soil is adequate and acceptable as an optimum quantity percentage mix with soil and also strength of soil admixture is acceptable to enhance the strength and the durability of the landfill liner criteria.

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DECLARATION OF COMPETING INTEREST

None

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