AMENDED LATERITE SOIL WITH FLY ASH AS LANDFILL LINER

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ABSTRACT

Here in Malaysia, which has a daily generation of more than 30,000 tonnes of municipal solid waste (MSW), disposes of approximately 95% of MSW directly into landfills. Landfills are the final destinations of the majority of waste generated in most urban areas. A liquid that permeated through waste and contains heavy minerals and suspended materials are defined as landfill leachate (Yamusa, *et. al.*, 2019). Compacted natural soils are often used as liner materials in engineered landfills to minimize the environmental impacts attributed to landfills by preventing the migration of leachate and landfill gases into the environment and groundwater (Lee, 2019). Lining systems for waste containment facilities can be enhanced if they are constructed with reactive materials, that is, materials that retard movement of solutes, promote biodegradation, or reduce chemical conversion (Chakradhar & Katoch, 2016). Three objectives were set for this research which includes determining the physical properties of laterite soil, optimum percentage of fly ash to be added into laterite soil, and identifying the permeability of amended laterite soil with fly ash as a suitable landfill liner. This study is an attempt to assess the use of coal ash (fly ash) mixing with abundant soils (laterite soils) as potential landfill liners. In this study, physical properties and compaction of soils will be conducted to identify the soil profiles of the laterite soil. 15%, 20%, and 30% of fly ash will be used to assist in strengthening the soil. This study will broaden the research of materials being used as a landfill liner and give a bigger option for landfill operators to have more information about the use of material such as a mixture of laterite soil and fly ash. As result, the physical properties of laterite soil are 21% and 27% of moisture content based on samples 1 and 2. At the same time, its liquid limit is 42% and 55%, plastic limit of 31% and 36%, plasticity index of 11 and 19 while the particle size distribution is classified as sandy clay (SC) and poorly graded for both the samples. Laterite soil location 1 with 20% amended fly ash has the highest dry density of 1.87 mg/m3 compared to location 2 with 20% amended fly ash of 1.64 mg/m^3. As for consolidation test, location 1 with 20% amended fly ash has permeability value of 2.564×10^{-10} cm/s while location 2 has value of 3.391×10^{-10} cm/s which has surpassed the requirement of $< 1 \times 10^{-7}$ cm/s.

Keywords: *Consolidation test, fly ash, landfill liner, laterite soil, permeability*

INTRODUCTION

Waste management is becoming a problem for the citizens in Malaysia ever since the population has begun growing. Due to the rapid growth of the Malaysian population, the numbers of municipal solid waste (MSW) that was produced are only ascending. Landfills have become one of the best solutions to our problems since it is much more economical and can be easily maintained. Malaysia, which has a daily generation of more than 30,000 tonnes of MSW, disposes of approximately 95% of MSW directly into landfills. As we all know, the waste generates leachate that is contaminated and toxic which is harmful to the environment and us if it is not properly treated. Therefore, it is important to create the best design of landfill not just to sustain the load from the waste but also to

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prevent the leachate from infiltrating deeper into the ground. However, researchers have found that the landfill lining system has only about 10 - 30 years of lifespan duration. When liners fail, a variety of compounds whose concentration may be above the acceptable level spread into the environment. Natural clay is often fractured and cracked or loses its grip strength, a mechanism called diffusion will move organic chemicals like benzene through a three-foot thick clay landfill liner in approximately five years and some chemicals can degrade clay. According to Rubinos & Spagnoli (2018), several wastes were identified as technically suitable to be used in landfill barriers. This will also increase the usage of waste products as alternative landfill liners and cover materials. To achieve an effective soil lining system, a minimum criterion of 30% fine content is required to fulfill the hydraulic conductivity requirement of $\leq 1 \times 10^{-}$ m/s as specified by most regulatory agencies and researchers (Yamusa, *et. al.,* 2020).

With the reference to journals relating to 'The use of Laterite soil or Marine soil as landfill liner', the research gap has been identified as the basis for this research. This includes fly ash and laterite soil as research material. As for methodology, it would be basic soil testing, compaction test, and consolidation test. Since this is a pilot test, this research aims to close the research gap and to find a better liner material as a substitute or an alternative option for different circumstances. These materials will be mixed at a certain ratio and be tested to identify the soil profiles. The test also covers the shear strength and permeability of the mixed soil. The test results will be compared to the standards to determine the usability of the mixed materials or to be tested at a different ratio of both the mixed materials.

LITERATURE REVIEW

Landfilling remains the most preferred solid waste disposal method globally. Once in the landfill, solid waste starts to decompose and generates leachate. Generally, low permeable materials such as compacted clay liner (CCL) and geosynthetic clay liner (GCL) can function as landfill liners. GCL has become more promising compared to compacted clay liner due to several advantages such as cost, handling, availability, transport, and installation. GCL contains bentonite (in powder or granular form) that swells and becomes impermeable upon complete hydration. However, CCLs are expected to provide adequate hydraulic performance when proper design and construction steps are maintained.

The characteristics of laterites from all around the world have been studied extensively during the last two decades. Laterite soils are widely used as a construction material in Malaysia and many other nations across the world. Laterites are commonly used in the building of roads, dams, airfields, embankments, foundations, and landfill tops because they provide excellent load resistance and infiltration prevention. However, particularly in the case of the Malaysian scenario, the findings of this research have not been well presented; it would have been easier to anticipate individual soil attributes if the important information about the soil had been known.

Based on the research, the hydraulic conductivity of lateritic soil was determined to be 4.969 10^{-7} cm/s when penetrated with heavy metal polluted leachate. According to other similar research in different places such as Vellore, TN, India, the lateritic soil that was utilized to simulate field soil was gathered at a depth of 1m from ground level. It was non-plastic and clayey silt with symbol NP according to the Unified Soil Classification System (USCS) classification system (Thankam, *et. al*., 2017). Moreover, soil mixing with fly ash or a combination of bentonite and fly ash after compaction also has been used for the bottom liner of waste landfills. For the case of a mixture of soil and fly ash, the previous studies showed that plasticity index, hydraulic conductivity, and swelling property of soil samples mixed with fly ash reduced along with the increase of dry density and strength when the fly ash content in the mixture increases (Lan, *et. al.*, 2019).

According to Oluremi, *et. al*. (2019), lateritic soil classified was treated with up to 10 percent waste wood ash (WWA). Compaction was carried out using four energies, namely, reduced British Standard light (BSL), West African Standard, and British Standard heavy, on samples, which were then examined for hydraulic conductivity, volumetric shrinkage, and unconfined compressive strength as major criteria for use as a liner and the development of acceptable zones. Specimens with 4% WWA content compacted with a minimum BSL energy satisfied the maximum hydraulic conductivity (k) value of 1×10^{-9} m/s, maximum volumetric shrinkage strain of 4%. With the evidence shown by Oluremi, we have enough evidence to prove that laterite soil has the potential to be a landfill liner with conditions of adding admixtures into the soil. It is also proven that a mixture that has 15% or greater than 15% of soil replaced by fly ash combined with bentonite (with the ratio between fly ash and bentonite is 4:1) can have the value of hydraulic conductivity (less than 1×10^{-9} m/s) satisfies Vietnamese standard for bottom liner (Lan, *et. al*., 2019).

Laterite soil amended with fly ash has a great potential to be used as a landfill liner with a percentage of 15% or greater than 15% of fly ash amendment and will have a satisfactory hydraulic conductivity value (Lan, *et. al*., 2019). In addition, fly ash offers the absorption of heavy metal present in landfill leachates, where it will be a major requirement as landfill lining (Deka & Sekharan, 2017).

This paper will be highlighting the use of lateritic soil stabilized with a certain percentage of fly ash. It was based on the research gap evaluated from the past research. The materials used were found to produce low hydraulic conductivity and it was suitable as landfill liners.

METHODOLOGY

An experimental test will be conducted on laterite soil samples obtained from Hulu Langat, Malaysia. The use of laterite soil can improve the shear strength of the liner (Prakash & Poulose, 2016). Soil samples have been extracted from 2 nearby locations that are within 5 kilometers range to be used for testing. Fly ash has been acquired from a nearby power station as an admixture for laterite soil. According to Chakradhar & Katoch (2016), fly ash is one potential material for constructing reactive liners that contains a modest amount of residual organic carbon, which is a sorbent of volatile organic chemicals (VOCs).

Basic soil tests such as moisture content, Atterberg limit, particle size distribution (PSD), and shrinkage limit test were used to find the physical properties of the soil. Atterberg limit includes a liquid limit and plastic limit test to tabulate the data as well as classification of soil by using USCS from the data acquired from the above-mentioned experiments.

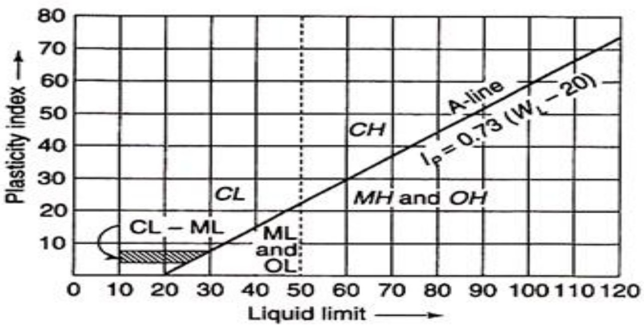

Figure 1: A-Chart

Major division			Group symbol	Typical name	Classification criteria	
Coarse-grained soils (More than 50% retained on No. 200 ASTM sieve)	Gravels 50% or more of coarse fraction retained on No. 4 ASTM sieve	Clean gravels	GW	Well-graded gravels and gravel-sand mixtures, little or no fines.		$U = D_{60}/D_{10}$ greater than 4 $C_c = D^2_{30} \cdot (D_{60} \times D_{20})$ between 1 and 3.
			GP	Poorly-graded gravels and gravel-sand mixtures, little or no fines.	Classification on the basis of percentage of fines. Less than 5% passing No. 200 ASTM sieve—GW, GP, SW, SP. More than 12% passing No. 200 ASTM sieve— GM, GC, SM, SC. 5% to 12% passing No. 200 ASTM sieve—Border-line classification requiring use of dual symbols.	Not meeting both criteria for GW.
		Gravels with fines	GM	Silty gravels, gravel-sand-silt mixtures.		Atterberg limits plot below *A*-line or plasticity index less than 4.
			GC	Clayey gravels, gravel-sand-clay mixtures.		Atterberg limits plot above *A*-line or plasticity index less than 4.
	Sands More than 50% of coarse fraction passes No. 4 ASTM sieve	Clean sands	SW	Well-graded sands and gravelly sands, little or no fines.		*U* greater than 6 C_c between 1 and 3.
			SP	Poorly-graded sands and gravelly sands, little or no fines.		Not meeting both criteria for SW.
		Sands with fines	SM	Silty sands, and-silt mixtures.		Atterberg limits plot below *A*-line or plasticity index less than 4.
			SC	Clayey sands, sand-clay mixtures.		Atterberg limits plot above *A*-line or plasticity index greater than 7.
Fine-grained soils (50% or more passes No. 200 ASTM Sieve)	Silts and Clays (Liquid limit 50% or less)		ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands.	Check Plasticity Chart	
			CL	Inorganic clays or low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.		
			OL	Organic silts and organic silty clays of low plasticity.		
	Silts and clays (Liquid limit greater than 50%)		MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts.		
			CH	Inorganic clays of high plasticity, fat clays.		
			OH	Organic clays of medium to high plasticity.		
Highly organic clays			P_t	Peat, muck and other highly organic soils.	Fibrous organic matter, will char, burn, or glow. Readily identified by colour, odour, spongy feel, and fibrous texture.	

Figure 2: USCS Classification Table

The proctor compaction test is a laboratory method of experimentally determining the optimal moisture content at which a given soil type will become most dense and achieve its maximum dry density. Therefore, to find the optimum dry density of the amended laterite soil with fly ash, we will refer to the analysis results from the compaction test. Consolidation test was conducted using the highest dry density value from each sample as well as a controlled sample for value benchmarking.

Table 1: Summary of the method used

Type of test	Objective
Moisture content	The moisture content test is used to determine the amount and percentage of moisture in soils.
Liquid limit and plastic limit	To determine the liquid limit, plastic limit, and plasticity index for the soil profiling and to produce an acceptable range of data.
Shrinkage limit	The test is to determine the percentage of shrinkage limit.
Particle size distribution	To determine the particle-size distribution curve for a given soil sample and to determine the coefficient of uniformity (Cu) and coefficient of concavity (Cc) of soil.
Compaction test	To determine the dry unit weight of the sample soil.
Consolidation test	To determine the coefficient of permeability (k) and settlement over time.

RESULTS AND DISCUSSION

Basic Soil Test

Basic soil test which includes moisture content, Atterberg limit, shrinkage limit, and PSD has been conducted on lateritic soil for its physical properties. The results have found that location 2 has a higher percentage of moisture content for moisture content compared to location 1. As for the Atterberg limit, location 2 has a slightly higher reading for LL, PL, and PI than location 1.

Table 2: Summary of Moisture Content and Atterberg Limit

	Location 1	Location 2
Moisture Content (%)	21.35	21.37
Liquid Limit (%)	42	55
Plastic Limit (%)	31	36
Plasticity Index	11	19

Particle Size Distribution (PSD) & Soil Classification

PSD will segregate between the percentages of particle size in a 50g of soil sample. Soil distribution has been summarized in Table 3 below with as well as the values of Cu and Cc for USCS classification. Both laterite soil samples are classified as sandy-clay (SC) and poorly graded (SP) under USCS standards as summarized in the table below. From Table 4, it is shown that the average of both LL and PI from both locations is greater than 30% for LL value and 15% for PI. For attaining the lowest permeability, liner material should contain a minimum of 20-30% fines and less than 30% gravel, and LL should be greater than 30% and PI should be greater than 15%. Also, the percentage of clay should be greater than 25% (Nair & Issac, 2016).

Table 3: Summary of Particle Size Distribution

Soil	Soil Group				Particle Size (μm)			Soil Gradation	
	Gravel	Sand	Silt	Clay	D_{10}	D_{30}	D_{60}	Cu	Cc
	%								
L1a	23	66	5	6	0.02	250	525	2.1	5952.4
L1b	21	68	7	4	0.015	500	1180	2.4	14124.3
L2a	8	85	5	2	0.006	500	1180	2.4	35310.7
L2b	8	78	10	4	150	450	800	1.8	1.7

Table 4: Soil Classification

	F_{200} (63_{um}>)	F_4(5mm>)	Atterberg Limit			Soil Classification
	(%)	(%)	LL	PL	PI	(>50% Passing 2mm, Sands)
L1	6	94	42	31	11	SP, SC
L2	4	96	55	36	19	SP, SC

Maximum Dry Density

An intensive compaction experiment is carried out by applying the method detailed in 3.3 of chapter 3 to find out the dry density of the controlled sample from both Location 1 and Location 2. With the help of controlled sample results, we can estimate the amount of water content to be added to the amended samples. Laterite soils for both locations will be amended with 15%, 20%, and 30% of fly ash to find out the highest dry density of the soil mixture for consolidation test use.

As shown in figure 4, the density of location 2 has been increased with the help of fly ash, which increased the value of dry density of location 2 from 1.53 mg/m^3 to 1.64 mg/m^3 that accounts for 7% of increment to the soil sample. The results found that 20% is also the most efficient additive percentage for the soil sample. However, the dry density of location 1 with 20% amended soil is higher than location 2 which is 1.64 mg/m^3 rather than 1.87 mg/m^3. Therefore, 20% amended fly ash with laterite soil is used as a sample for consolidation test.

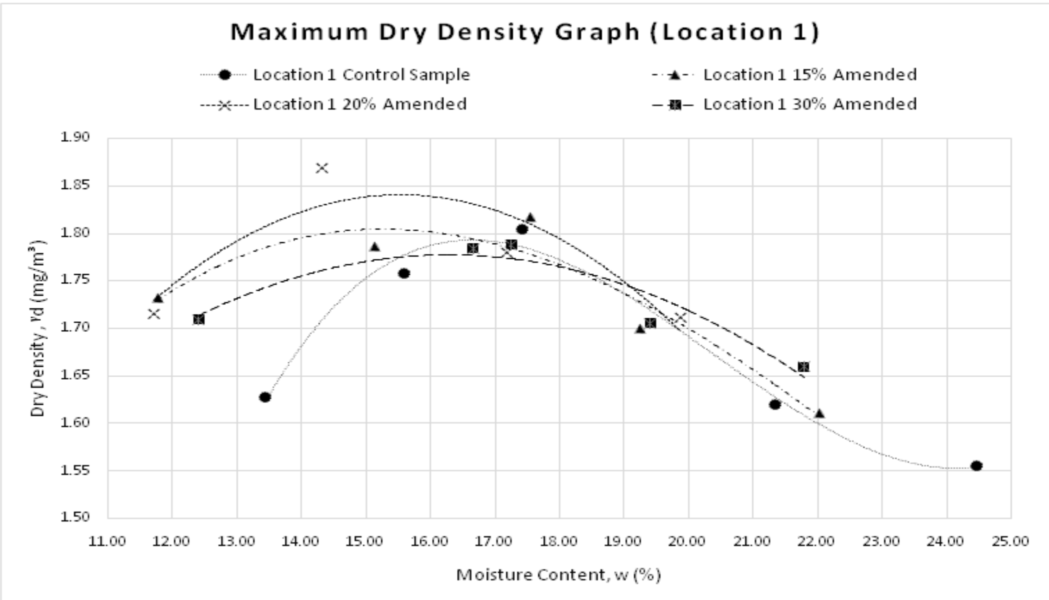

Figure 3: Summary of compaction test for location 1 (Control sample,15%,20% & 30% fly ash)

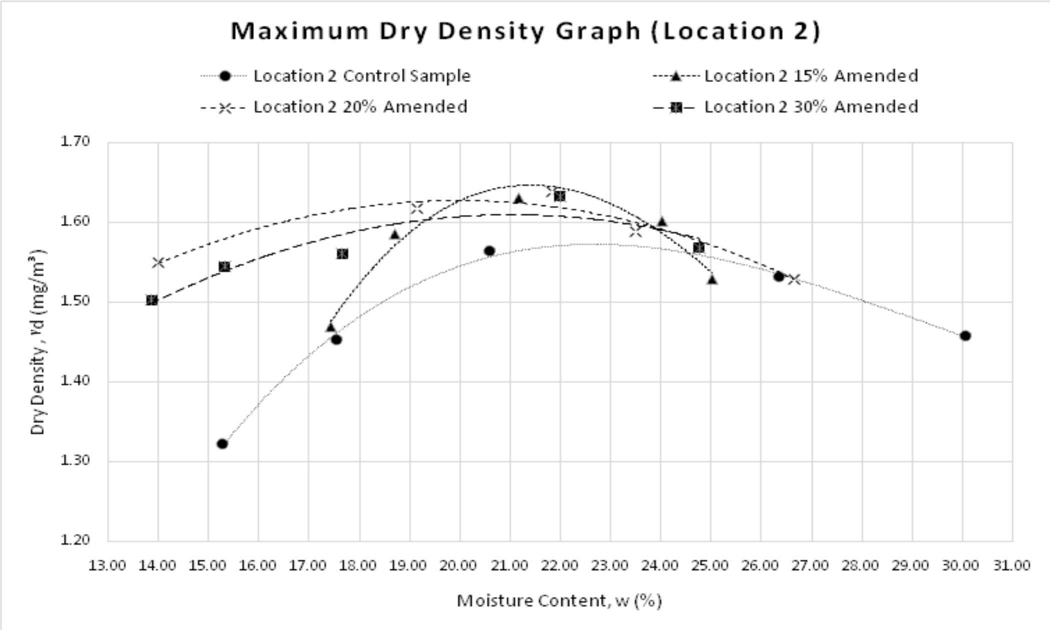

Figure 4: Summary of compaction test for location 2 (Control sample,15%,20% & 30% fly ash)

Table 5: Summary of Maximum Dry Density for Sample 1 and 2

	Location 1 (mg/m^3)	Location 2 (mg/m^3)
Control Sample	1.80	1.53
Amended 15% Fly Ash	1.82	1.63
Amended 20% Fly Ash	1.87	1.64
Amended 30% Fly Ash	1.79	1.63

Permeability of Soil

In the consolidation experiment, we aim to determine the optimum percentage of fly ash to be added to laterite soil as well as identifying the permeability of the amended soil to be used as a suitable landfill liner. Therefore, we will expect to achieve the two objectives with the results and data. Additional data such as settlement level can be found in this test, and it will be included as a reference to find the permeability of the soil.

Both location 1 and location 2 optimum dry density are used as control samples. The values will be used to compare with the highest dry density fly ash amended soil samples for their permeability and the suitability of being used as a landfill liner. Value of settlement will be obtained from the consolidation test recorded from weight pressured on soil sample over time. The value will then be used to find the permeability of soil (K). Loads of 2, 4, 6, and 8kg pressure are used for this purpose.

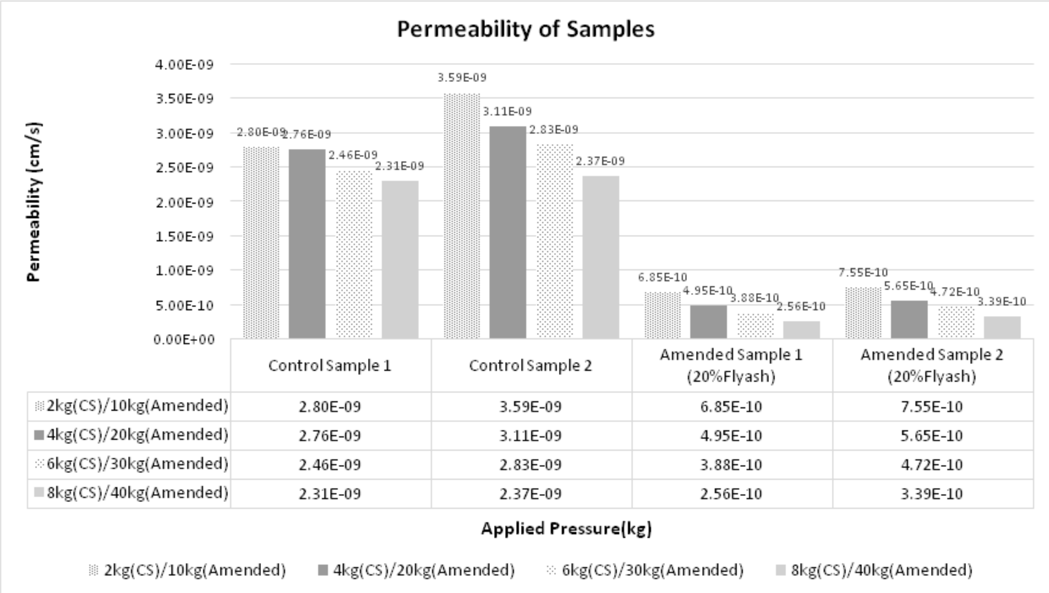

Figure 5: Summary of Permeability for Sample 1 and Sample 2.

Both location control samples are also used as a benchmark to find out any improvements on the amended soil. The results have found that the permeability of both the amended soil has a higher value than their controlled sample ones. The value for location 1 is 2.306 x10^{-11} m/sec and location 2 is 2.370 x 10^{-11} m/sec while the amended location 1 is 2.564 x 10^{-12} m/sec and location 2 amended soil is 3.391 x 10^{-12} m/sec. Figure 5, also shows that the hydraulic conductivity of the samples was decreased with the increase of the load. This is also proven by Mishra & Ravindra in 2015.

CONCLUSION

As the population in Malaysia is growing, it is important to keep our environment safe from pollution from the expansion of landfills. It is important to choose the right material to be used as a landfill liner to prevent seepage of leachates into the environment. Therefore, one of our main objectives is to find abundant material to achieve the standards for landfill liner use.

Concurrently, all our objectives are targeted to contribute more information for varieties of materials that can be used as landfill liners that might help in saving the cost of operating the site. This chapter will be concluded based on our objectives set and recommendations to be given.

The first objective is to determine the physical properties of the laterite soil by conducting the Atterberg limit, particle size distribution, and shrinkage of the laterite soil. From the result of the Atterberg limit and PSD, the soil has been classified as SP and SC by using USCS standards. At the same time, the physical properties of the laterite soil are tabulated in detail including LL, PL, PI, PSD, dry density, and permeability.

The second objective is to determine the optimum percentage of fly ash to be added into laterite soil as landfill liner is done with compaction tests with controlled samples with 15%, 20% and 30% amended laterite soil with fly ash for both the location of the sample. From the experiment result, it is found that 20% additive has the highest dry density for both the laterite soil sample. Therefore, 20% is the optimum percentage of fly ash to be added to the laterite soil to achieve its maximum potential as a landfill liner. Further testing with a consolidation experiment has been conducted to prove that the optimum fly ash percentage indeed improved the efficiency of permeability compared to the original controlled sample.

The last objective is to identify the permeability of amended laterite soil with fly ash as a suitable landfill liner and have identified results surpassing the requirement of k $\leq 1.00 \times 10^{-7}$ cm/s. From the consolidation experiment, it is found that location 1 and 2 is already sufficient for the requirement of landfill liner permeability, the permeability value of location 1 is 2.306×10^{-9} cm/s while location 2 is 2.370×10^{-9} cm/s.

In conclusion, all three of the objectives have been achieved and 20% of fly ash is proved to be effective in strengthening the soil to be used for landfill liner purposes.

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