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Improvement of Compaction Properties of Laterite-Geopolymer Mixtures in Landfill Soil Liner

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Abstract: *In the landfill, lining systems play an essential function in providing a barrier between the waste and the environment. Soil liners are used in the liner system to reduce leachate infiltration and prevent ground pollution. It is essential to compact the layer properly to achieve low hydraulic conductivity of 1x 10-9 m/s. The purpose of this study is to investigate the optimum content of geopolymer mixed in laterite soil in designing a modified soil liner. Geopolymer binder consists of palm oil boiler ash as source material and sodium hydroxide mixed with sodium silicate as an alkaline solution. Laboratory work involved physical properties test and compaction characteristics of the modified mixture. The percentage of geopolymer in the mix varies between 0, 10, 15, and 20% of lateritic soil dry weight. The results obtained imply that the laterites soil mixed with geopolymer gives a plasticity index ranging from 10 to 19%, with specific gravity ranging from 2.43 to 2.62; the maximum dry density (MDD) varies from 1.71 Mg/m3 to 2.19Mg/m3, and the optimum moisture content (OMC) ranges from 13.58% to 16.38%. The conclusion reached based on compaction characteristics is compacted geopolymers are compatible with lateritic soils. Soil strength of laterite with 15% of geopolymer mixture is the best mix design to be used as a modified soil liner in a landfill. From the result, geopolymer could be the alternative material in enhancing the soil liner properties.*

Keywords: landfill liners, geopolymer, laterite soil, palm oil boiler ash

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1. Introduction

Rapid development in urbanization and industrialization generates a huge quantity of municipal solid waste. The increasing amount of solid waste becomes more hazardous and resulting pollution affecting human, soil, and groundwater. One of the crucial problems in dealing with municipal waste is landfill leachate. Leachate is a liquid form consists of toxic chemicals produced by wastes in a combination of the degradation of the organic fraction with percolating rainwater (Anitha et al., 2017). One of the traditional and preferred methods of disposing municipal waste efficiently and economically is dumping the waste into a sanitary landfill. The main and the based of sanitary landfill were known as compacted soil liner. The compacted soil liner must achieve the hydraulic conductivity of $1x10^{-9}$ m/s to prevent the leachate infiltration into the soil and groundwater. A strong soil bond is provided by compaction, which is an important part of the construction process. The bonding strength of the soil is determined by its strength, moisture content and performance, both while building the foundation and after its lining is constructed.

2. Literature Review

Soil liner is the initial structure of a sanitary landfill known as compacted soil liner. The soil is compacted at desired strength to prevent leachate infiltration into the soil and groundwater (Atiqah et. al., 2018). Daniel and Benson (1990) stated that compacted soil liner should have a maximum hydraulic conductivity of $1.0x10^{-9}$ m/s. Soil liners common materials used are compacted clay liners, geosynthetic clay liners, and composite liners. Clay liner is naturally soil with low hydraulic conductivity (Craig H. et al., 2018). However, if clay soil is not locally available as a liner material, the clay soil needs to be imported from any other site, and the project's cost will increase (Yamusa et al., 2017).

The study was conducted using laterite soil due to the abundance and ease of availability of the material as an alternative to replace clay as a soil liner. Lateritic soils are economically convenient in road construction because they are cheaper than other materials that can achieve comparable strength with them and are more available than those materials. According to Mustapha et al., (2012), laterites' geotechnical characteristics and field performance are influenced considerably by their degree of weathering, morphological characteristics, chemical and mineral compositions. Laterite soils consist of soil grain with high hydraulic conductivity (Nik et al., 2016). Thus, modification of soils to improve their engineering properties becomes necessary.

In soil liner, compaction is one of the works required to improve the strength of the soil. The compaction work can result in the reduction of shrinkage potential, subsidence, and low hydraulic conductivity. Many researchers have extensively studied various materials to improve soil strength by chemical modification. Geopolymer is one of the popular chemicals to increase soil strength in ground improvement techniques as a green material with many advantages, such as low cost, high strength, the durability of weathering, and a friendly environment (Zainudin et al., 2021; Wisam Dheyab et al., 2019; Nik et al., 2015; Latifi et al., 2014).

Geopolymer was introduced in 1972 by Joseph Davidovits; a technology of advanced alternative materials in enhancing the properties which contain silica-alumina as a source material added to an alkaline solution. Geopolymer is categorized as a chemical stabilization technique in enhancing soil properties, and it is more dependent on the reaction between chemical additives and soil particles used to increase soil strength and workability. There are some common raw materials used in geopolymer, such as metakaolin, fly ash, slag, bottom ash, volcanic ash, and rice husk ash (Lemougna et al., 2011; Papa.E et al., 2014). According to Van Jaarsveld et al. (2000) study, the SiO_2 and Al_2O_3 in the ash provide a rich source of Si and Al atoms as a source of aluminosilicate materials for producing geopolymers. Cristelo et al., (2012), study the effectiveness of alkaline activation of low-calcium fly ash to improve residual granitic soils to be used on rammed-earth construction. The results show the compressive strength increases significantly as an optimum value for the activator: solids ratio and the alkali concentration. According to Nik et.al. (2016), fly ash -geopolymer produces a strong network that binds the soil grains in the compaction test. Moreover, Fasihnikoutalab et al., (2017), have been researched utilizing the alkaline activation of olivine to form a geopolymeric gel to increase soil strength.

The use of geopolymer materials as soils stabilizers has widely studied, and the results of such past studies which indicate that geopolymers could be used as an effective soil stabilizer have encouraged the researcher to investigate more source for alternative material depending on the properties and application.

In this era of sustainable development, study into waste materials is essential, especially with the beneficial reuse of most waste materials into the liner systems. Boiler ash is a waste product from the coal industry. Usage of boiler ash in producing the geopolymer binder as additives in soil liner is an economical and eco-friendly solution. The geopolymer source material, palm oil boiler ash, included high percent SiO_2 and Al_2O_3, which is the most necessary composition for geopolymer production (Zainuddin et al., 2021). An attempt was made to study the suitability of amended soil liner with geopolymer as an additive. Amended soil was prepared using locally available lateritic soil and boiler ash. Geopolymer is one of the popular chemicals to increase soil strength in ground improvement techniques as a green material with many advantages, such as low cost, high strength, the durability of weathering, and a friendly environment. The study investigates the compaction parameter of different geopolymer percentage and improves the characteristic of laterite soil for the soil liner application.

3. Material

3.1 Soil

This soil was collected from Johor, Malaysia. The chosen soil in this study which is laterite soil with reddish color was collected at the depth of 1.5 to 2m under the ground. The soil was washed, and oven dried at 105 ºC before it was mixed with geopolymer as additive material in laterite soil. Physical properties test performed on soil and amended soil at different mixed proportion are according to British Standard BS 1377: Part 2:1990. Atterberg Limit test, particle density test, shrinkage test and compaction test were carried out to investigate the properties in laterite soil.

3.2 Geopolymer Paste

Soil stabilization refers to the alteration of origin soil properties using physical stabilization and chemical stabilization to enhance, and to improve the soil strength and physical nature of native soil particles (Ayyappan et al., 2017). Attempts were made to effectively improve the properties of laterite by treating the soil with new materials as additives in soil stabilization known as geopolymer. In this paper, the geopolymer chosen as alternative material was mixed in origin soil to achieve the desired effect. The primary attraction of this material is the source material used is from industrial waste and the production of this materials is relatively low cost. In the preparation of geopolymer, Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) were added to distilled water to obtain alkaline solution as shown in Figure 1. Then, the alkaline solution was added to palm oil boiler ash and mixed to form the geopolymer binder. Palm oil boiler ash was chosen as a source material of geopolymer due to the higher content of silica and alumina which are the most required composition to produce geopolymer (Yahya et al., 2015; Lopez et al., 2015). The mixture of palm oil boiler ash and alkaline solution produces geopolymer binder as shown in Figure 2. Geopolymer was added to soil in 0, 5, 10, 15 and 20% of dry weight of laterite soil respectively and experimental properties were determined.

Figure 1: Alkaline Solution Preparation


Figure 2: Geopolymer Paste

4. Result and Discussion

This section presents the result from basic physical properties and compaction that have been done. Three types of tests have been carried out in determining physical properties and one compaction test using British Standard Light (*BSL*) according to BS 1377: Part 4: 1990. Table 1 shows the physical properties test for laterite soil on particle density test, pH value test, and shrinkage limit test. Meanwhile, Table 2 shows the chemical composition of laterite soil and palm oil boiler ash from the X-Ray Florence test *(XRF).* The palm oil boiler ash as geopolymer source material contained SiO_2 and Al_2O_3 about 44 to 55%, which is the most required composition to produce geopolymer (Benson et al., 1990, Yahya et al., 2015, Zainuddin et al., 2021).

Table 1: Physical properties of laterite soil

Soil Description	LS-P
Specific Gravity	2.62
pH value	6.49
Shrinkage Limit	11.49

Table 2: Chemical composition of laterite soil and palm oil boiler ash

Oxides	SiO_2	Al_2O_3	CaO	Fe_2O_3	Na_2O	MgO	P_2O_5	K_2O
Laterite Soil	56.0	30.3	0.381	9.54	-	-	-	0.290
Palm Oil Boiler Ash	43.9	4.55	13.1	4.11	-	3.27	2.45	12.5

4.1 Liquid Limit *(LL)*

According to the British Standard procedure on the Atterberg test, to ensure the consistency of the soil and to ensure proper blending of soil with geopolymer, the soil is oven dried and sieved through a 4.75 mm sieve. In this experimental test, the cone penetrometer method was chosen to determine the liquid limit of samples. Cone penetrometer was used because the reading of the cone penetration is less subjective, more precise than the reading of the length of the contact when the two halves of sample come together during the Casagrande method (Zainuddin et al., 2017). The geopolymer was added to laterite soil at design mixed proportions of 0, 5, 10, 15, and 20% of geopolymer.

Figure 3: Laterite mix with geopolymer mixed before experimental tests conduct.

As shown in Figure 4, the result shows the effect of varying percentages of geopolymer on the liquid limit *(LL)* in laterite soil. The liquid limit decreased from 0, 5, and 10% of mixture proportion at 48, 45, and 39% of the liquid limit, respectively. The result with decreased liquid limit is due to a reduction in the specific surface area of soil. Meanwhile, the liquid limit with 15% and 20% of geopolymer slightly increased resulted in 40% and 44% respectively. According to O'Sullivan & Paul (2002), liners with a liquid limit of < 90% is required to prevent the leakage of leachate from the landfill. The result shows that the liquid limit for all mixture is suitable for liner materials.

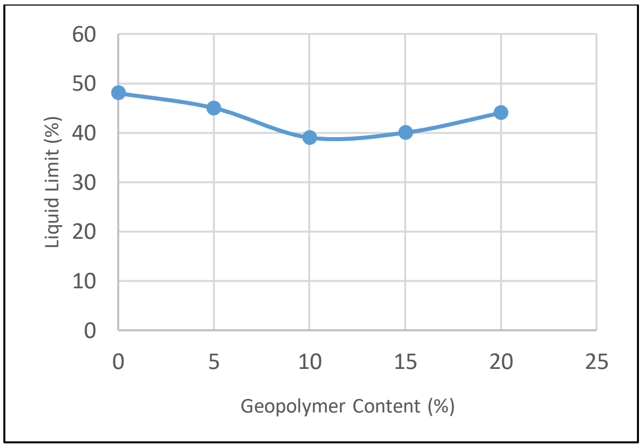

Figure 4: Liquid Limit of Laterite soil with different percentage of Geopolymer

4.2 Plastic Limit *(PL)*

Figure 5: Plastic Limit test

The plastic limit is the water content at which the soil can just be rolled out in a thread of 1/8 inch in diameter. The plastic limit (*PL*) is the minimum water content at which soil is considered to behave in a 'plastic' manner, that is capable of being moulded. About 20g of sample was taken from the soil paste and placed on a mixing plate. A thread of soil is at its plastic limit when it begins to crumble when rolled to a diameter of 3 mm. Figure 5 shows how the Plastic Limit test is conducted. This result shows the plastic limit for mixed samples with geopolymer slightly increases from 29% to 32% at 0% and 5% of geopolymer and decreases at 10% geopolymer, giving 24% of the plastic limit. However, there are increment at sample 15% and 20% of geopolymer at 28% and 34% as shown in Figure 6.

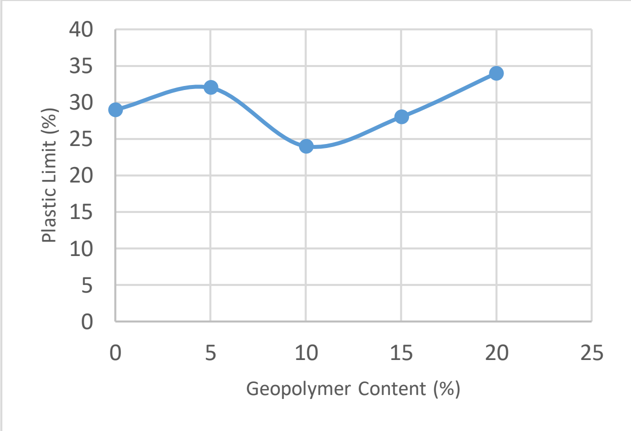

Figure 6: Plastic Limit of Laterite-Geopolymer Mix

4.3. Plasticity Index *(PI)*

The results of the plasticity index for the laterite soil and laterite soil-geopolymer were shown in Figure 7. The plasticity index results from 19, 13, 15, 12, and 10%, as the percentage of geopolymer increased. The measured values of the liquid limit and the plastic index for the laterite soil are 48% and 29%. Thus, the plasticity index is 19%. The obtained plasticity index for laterite soil with geopolymer samples met the plasticity index criteria minimum of 7-10% for liner utilization, as Eberemu, A. O et al., (2013) recommended. In Figure 7, a significant reduction in plasticity index can be observed as the percent of geopolymer increases. The addition of geopolymer to the laterite soil reduces its plasticity index steadily. Therefore, the mixture design can be adopted and used as a potential material in liner requirements. This fact indicates that the use of less costly geopolymer can reduce the requirement to treat laterite.

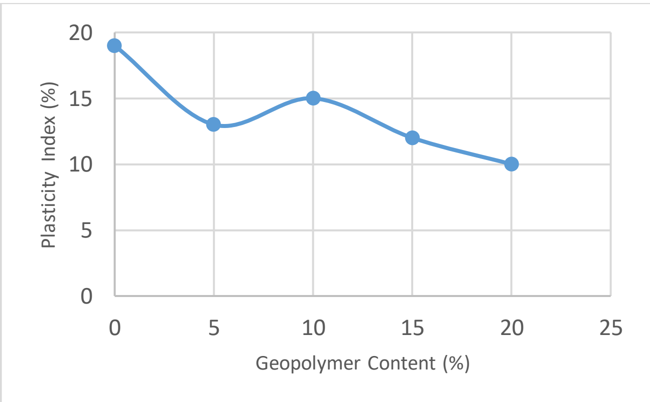

Figure 7: Plasticity Index of Laterite-Geopolymer Mix

4.3 Compaction Test

As shown in Figure 8, the standard proctor test was conducted in this study to determine the maximum dry density (*MDD*) and optimum moisture content (*OMC*). Five samples at different percentages of geopolymer (0, 5, 10, 15, and 20%) were compacted, as shown in Figure 9. Before the compaction test was conducted, the percentage of water required was added and mixed until a uniform consistency was achieved (Ahmad, F. H et al., 2017). Then, the soil sample was dynamically compacted with a release of a steel hammer with a weight of 2.5 kg and 27 blows per each of three layers, falling freely 300 m with a 50 mm diameter of rammer. The samples were trimmed to remove the excess soil, molded, and weighed after compactions were done.

Figure 8: Standard Proctor test

Figure 9: Compaction sample of various percentage of soil-geopolymer

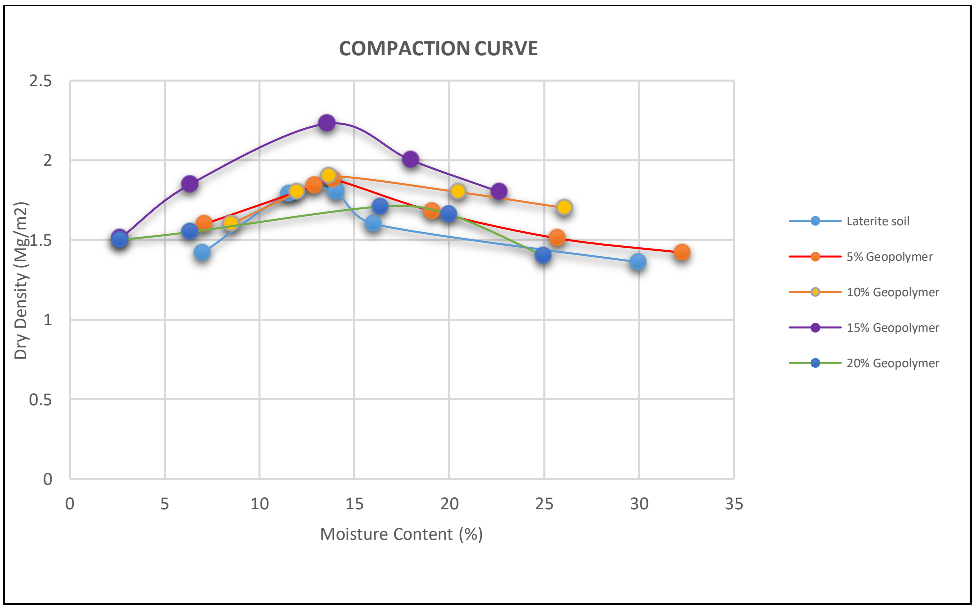

Figure 10: Compaction Curve of various of Laterite-Geopolymer Mix

The compaction graph was produced by drawing the compaction curve through the measured data. The peak point on the compaction curve shown in Figure 10 refers to the maximum dry density (*MDD*), and the corresponding water content is the optimum moisture content (*OMC*). At a percentage of 0% soil-geopolymer, a maximum dry density of 1.80 Mg/m^3 at 14.07% optimum moisture content was obtained. An increment in maximum dry density (*MDD*) occurs at the beginning of soil-geopolymer at 5%, 10%, and 15% of geopolymer added. At this stage, the packing of the soil particles from effect of compaction test reduced the soil voids as they were filled by the geopolymer binder. The addition of geopolymer at 5% and 10% showed increasing maximum dry densities of 1.88 Mg/m^3 and 1.90 Mg/m^3 and decreasing optimum moisture contents at 13.88% and 13.70% respectively. A drastic increase in the maximum dry density gives 2.19 Mg/m^3 and decreased optimum moisture content at 13.58% for 15% of geopolymer in soil, giving positive geopolymerization reactions. The bonding created by alkaline solution and the subsequent isomorphous substitution of silica (*SI*) has increased the packing between the grains (Asyraf et al., 2018). This result is supported by Nik et al., (2015) in their study on using fly ash geopolymer. In her result, geopolymer added in laterite soil resulted in an increment in dry density due to the action of alkaline attack, which changed the soil mineral. Meanwhile, a maximum dry density (*MDD*) reduction at the maximum percentage of geopolymer occurs. This result indicates that the 20% of geopolymer content in the laterite soil mixture was over the amount of water and cannot hold it in, and the gradation of the soil needed to be improved. The structure of silica-alumina in geopolymerization was broken due to increased moisture content and the rapid reaction between geopolymer and soil, leading to the loss of soil particle bonding. This study shows that the optimum and peak reaction achieved at 15% of geopolymer gives the best maximum dry density with low optimum moisture content. This result is in good agreement with the Noushini et al., (2016) study of the behavior in laterite soil with sodium silicate-liquid stabilizer. The result obtained from this shows the increasing maximum dry density and decreased optimum moisture content as an increasing percentage of geopolymer were added to the soil. The compaction test results proved that the presence of a geopolymer in the soil gave a strong relationship between moisture content and maximum dry density and shows the compaction curve of tested samples is suitable for the application of soil liner.

5. Conclusion

This paper determines the effect of geopolymers as additives in the laterite soil to improve the soil strength in landfill soil liner application. Palm oil boiler ash as industrial waste material combined with an alkaline solution to form a geopolymer binder has a beneficial effect on compaction by improving the laterite soil properties. The index properties of laterite and geopolymer mixtures give a plasticity index ranging from 10 to 19%, which meets the essential requirement for a soil liner. Maximum dry density (*MDD*) and optimum moisture content (*OMC*) are essential properties for field compaction control and estimating the value of hydraulic conductivity. A various percentage of geopolymer showed a significant improvement of soil strength than plain laterite soil in the compaction test. The soil strength of maximum dry density (*MDD*) increased with the increasing percentage of geopolymer content. At 15% geopolymer content, the mixtures gave a suitable compaction parameter leading to the high strength of soil properties with maximum dry density at 2.19Mg/m^3 at 13.58% of optimum moisture content. Thus, the mixtures of geopolymer-based palm oil boiler ash and laterite soil may be a potential by-product as an alternative to soil treatment in geotechnical applications that minimize porosity and potentially reduce hydraulic conductivity of 1.0x 10^{-9} m/s. It can be concluded based on the results obtained that geopolymer can be effectively used as a soil liner since it could produce considerable improvements in the properties to be more economical.

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