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GEOTECHNICAL ASSESSMENT OF PALM OIL FUEL ASH (POFA) MIXED WITH GRANITE RESIDUAL SOIL FOR HYDRAULIC BARRIER PURPOSES

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Abstract: This paper assesses the geotechnical properties of granite residual soil treated with palm oil fuel ash (POFA), a waste from the palm oil factory for the purposes of hydraulic barrier in landfills. Granite residual soil treated with up to 40% palm oil fuel ash (by dry weight of the soil) was compacted using standard proctor compactive effort at the optimum moisture content. Index properties, hydraulic conductivity (*k*), volumetric shrinkage strain (*VSS*) and unconfined compressive strength (*UCS*) tests were carried out. Results showed that the index properties of samples met the minimum requirement for it to be used ass a liner. The maximum dry density and optimum moisture content decreased and increased respectively. The influence of POFA treatment on the geotechnical properties generally showed an improvement with up to 15% POFA which gave the acceptable results with regards to its usability as a hydraulic barrier material in landfill.

Keywords: *Granite residual soil, hydraulic conductivity, palm oil fuel ash, unconfined compressive strength, volumetric shrinkage.*

1.0 Introduction

In the near future, landfilling will continue to be the best option because incineration is not a viable method for wide variety of waste and it may lead to air pollution problems which will leave ash residue that will still require disposal in a landfill (Qian *et al*., 2002). An important part of the landfill is the liner otherwise known as the hydraulic barrier, which has the primary aim of limiting the infiltration of solid waste leachate into ground water or surface water. Compacted natural soils are widely used as hydraulic barrier in waste containment system. Daniel and Benson (1990) stated that compacted clay liner should have a maximum hydraulic conductivity of 1×10^{-7} cm/s. The stated maximum hydraulic conductivity also conforms to the one stated by American

Environmental Protection Agency (EPA, 1989). Other criteria to be considered in the design and construction compacted clay liner are shear strength and volumetric strain of the compacted soil (Daniel and Benson, 1990; Osinubi *et al*., 2006)

In this era of sustainable development, scholarly investigations into the use of waste materials are on the forefront especially with the beneficial reuse of most waste materials. Several researchers have carried out enormous studies by incorporating waste material into the liner systems such as rice husk ash, groundnut shell ash, bagasse ash, blast furnace slag, cement kiln dust, scrap tires and steel slag (Oriola and Moses, 2011; Younu and Sreedeep, 2012). Palm oil fuel ash (POFA) has been produced from a burning process for boiler fuel in palm oil mill. Malaysia has been one of the largest producers of palm oil with around 41% of the total world supply in years 2009– 2010 (Chandara *et al*., 2010). Owing to this reason, there is an increase in the quantity of POFA produced and thus creating large environmental load. Granite residual soils formed in the tropics due to favourable condition for intense weathering, the formation of granite residual soil is so rapid due to availability of high amount of rainfall and changes in temperature which are the major factors that influence the formation of this soil. Therefore, the likelihood of using granite residual soil and POFA as a composite material should significantly reduce environmental load pose by POFA. A number of studies have been carried out on the effect of POFA ranging from 5 – 30% on different types of soils to be used for liner purposes (Nik Daud and Muhammed, 2014a; Brown *et al*., 2011; Mohamed et al., 2007). However beyond 30% POFA content no studies have been done to check its effect on these soils. Therefore, the objective of this study is to evaluate geotechnical properties granite residual soil mixed with palm oil fuel ash (POFA) at the optimum moisture content relevant to hydraulic barrier design in landfill.

2.0 Materials and Methods

2.1 Materials

The granite residual soil used in this study was obtained from Hulu Langat, in Selangor State of Malaysia. The details of the sample location and sampling procedure for the granite residual soil and POFA have been stated in (Nik Daud and Muhammed, 2014a; 2014b). Figure 1 (a) and (b) shows the picture of borrow pit of the granite residual soil and disposal practice of POFA around the milling factory, respectively. The dominant mineral and the chemical composition of the soil and POFA respectively were obtained in an earlier study (Nik Daud and Muhammed, 2014a). The air-dried granite residual soil sample passing through sieve number 4.75mm aperture mixed with 5, 10, 15, 20, 30, and 40% POFA by weight of dry soil were used in this study.

(a) (b)

Figure 1: (a) Granite residual soil from Hulu Langat, Selangor (b) Disposal practice of POFA around the factories

2.2 Methods

2.2.1 Index Properties

Laboratory tests were conducted to determine the index properties of the natural granite residual soil sample and granite residual soil – POFA mixture sample in accordance with British Standard (BS1377, 1990).

2.2.2 Mechanical Properties

The mechanical tests carried out include compaction (standard proctor effort), hydraulic conductivity, volumetric shrinkage and unconfined compressive strength. All tests were carried out in accordance with British Standard (BS1377, 1990).

3.0 Results and Discussion

3.1 Index Properties

The index properties and compaction characteristics of soil and soil – POFA mixture is shown in Table 1. The specific gravity of soil – POFA mixture show a decrease in value which relates to the specific gravity of POFA. The physical properties of POFA showed the specific gravity value is 2.22 and specific surface area is 5720 cm^2/g. Fineness is a very important property of a material to be used as partial replacement of cement, which is measured through the specific surface area of the particles. The value obtained in this study is in line with values obtained by other studies for supplementary cementing material (Brown *et al*., 2011). The effects of POFA content on the Atterberg limits (liquid limit, plastic limit, and plasticity index) are shown in Table 1. The Atterberg limits for both natural soil and soil – POFA mixture were obtained using the Cassagrande method. The results showed a general across the parameters with addition of palm oil fuel ash. According to Qian *et al*. (2002) the liquid limit and plasticity index of a soil liner should be at least 20% and ≥ 7% respectively because low hydraulic conductivity is attributed to higher liquid limit and plasticity indices. Therefore the soil and soil – POFA mixture meets these criteria. The soil was classified as low plasticity clay CL under the Unified Soil Classification System (USCS). The particle size distribution of the soil and POFA shows 53.13% and 38.74% passed through No. 200 sieve (75μm) respectively which represents the fine portion. The particle composition of a soil which is determined from the particle size distribution plays a vital role in the hydraulic conductivity of the soil, which is the principal factor to be considered as a hydraulic barrier (Taha and Kabir, 2005). Recommendations have been made that a liner material should have fine content of greater or equal to 20 – 30%, therefore this material meets this criteria (Rowe *et al*., 1995; Daniel and Koerner, 1993).

Table 1: Index properties of the soil and soil mixed POFA samples used in the study

Properties	**Granite Residual Soil*	**5% POFA*	***10% POFA*	***15% POFA*	*20% POFA*	*30% POFA*	*40% POFA*	**** Standard*
Moisture content, %	27.51	-	-	-	-	-	-	-
Specific Gravity	2.63	2.58	2.55	2.53	2.09	1.98	1.95	-
Liquid limit %	50	48	44	41	60.2	60.3	62.7	≥ 7
Plastic limit %	29.89	28.06	27.56	24.82	46.8	45.1	48.3	-
Plasticity index %	20.11	19.94	16.44	16.18	16.7	16.4	15.4	≥ 20
Linear Shrinkage%	9.30	8.79	7.82	6.89	16.7	16.4	15.4	
Percentage passing No. 200 sieve	53.13	-	-	-	-	-	-	30
MDD, Mg/m^3	1.61	1.59	1.59	1.58	1.43	1.39	1.34	-
OMC, %	20.05	23.0	24.0	23.5	36	33	29	-

* Nik Daud and Muhammed, 2014a; ** Nik Daud and Muhammed, 2014b; ***Benson *et al*., 1994

3.2 Compaction Characteristics

The effect of POFA on the maximum dry density (MDD) and optimum moisture content (OMC) of the granite residual soil – POFA mixtures are shown in Table 1. The MDD generally decreased with higher POFA content. This was attributed to the fact that POFA has lower specific gravity (2.22) when compared with granite residual soil (2.63). On the other hand, the increase in OMC was attributed to the increase in fine content because of the inclusion of POFA with larger surface area that needed more water to react. A similar pattern was obtained when wastes which have less specific gravity when compared with the soil were used as additive on various types of soils (Nik Daud and Muhammed, 2014a; Moses and Afolayan, 2011).

3.3 *Hydraulic Conductivity*

The variation in hydraulic conductivity with different percentages POFA content using standard proctor compactive effort is shown in Figure 2. There was a gradual decrease and subsequent slight increase in the hydraulic conductivity values obtained. The lowest hydraulic conductivity value of 8.1 x 10^{-10} m/s was obtained at 20% POFA, which conforms to the minimum values stated for liner material (Daniel and Wu, 1993). The initial decrease in hydraulic conductivity was due to the decrease in pore spaces as the fines from the POFA filled the voids thus reducing water flow. It could also be due to cation exchange reactions between POFA and the soil (Asavapisit *et al*., 2003; Phani Kumar and Sharma, 2004). On the other hand, the increase in hydraulic conductivity could be due to the presence of excess POFA that would have changed the soil matrix leading to increased flocculation. This was similar to the result obtained when bagasse ash was used as admixture to lateritic soil (Eberemu, 2013).

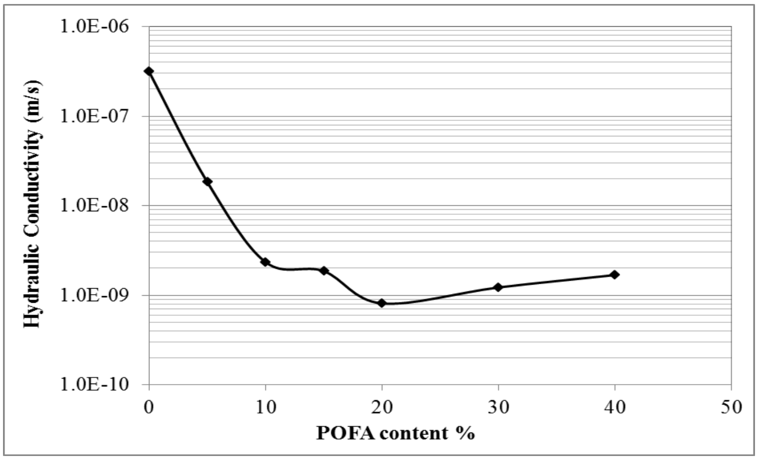

Figure 2: Variation of hydraulic conductivity with POFA content

3.4 *Unconfined Compressive Strength (UCS)*

Daniel and Wu (1993) suggested that the minimum strength of a soil to be used as compacted soil liners should be 200 kN/m^2. The variation of unconfined compressive strength for different percentages of POFA using standard proctor compactive effort is shown in Figure 3. There was an initial increase in shear strength values and subsequent decrease. The increase in strength with higher POFA up to 15% can likely be attributed to the formations of cementitious product such as hydrated calcium silicate gel (C-S-H) and calcium aluminates gel (C-A-H). The pozzolanic reaction and cementitious material hydration that coats and binds the soil particles to produce stronger matrices (Amadi *et al*., 2012) . However, the increasing percentage of POFA beyond 15% showed decrease in strength. This is because the increasing additive material in a large amount has overcome soil weight thereby lowering the reaction rate at the right side of the graph (Mohamed *et al*., 2007). Lack of adequate strength may lead to failure of the liner to carry the expected load imposed on it by the waste.

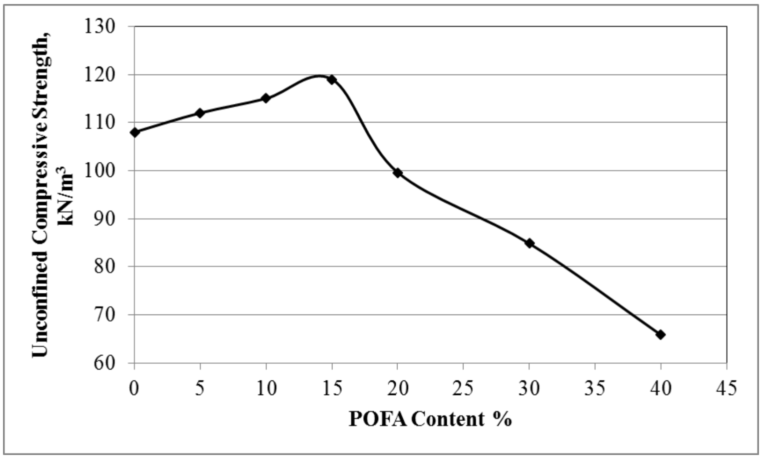

Figure 3: Variation of unconfined compressive strength (UCS) with POFA content

3.5 Volumetric Shrinkage Strain (VSS)

Daniel and Wu (1993) suggested that cracking is not likely to occur in soil liners when compacted cylinders of the same soil undergo volumetric shrinkage strain (VSS) of less than 4% upon drying. The variation of volumetric shrinkage strain different percentage POFA using standard proctor compactive is shown in Figure 4. Generally, there was a general decrease in VSS up to 10% POFA and a subsequent was recorded increase with higher percentage of POFA. The initial decrease might be attributed the pozzolanic input of POFA while on the other hand the increase in VSS may occur as a result the higher OMC recorded for corresponding higher POFA content that resulted in more fines with larger surface area present in the soil mixture. The mixture required more water for reaction that led to increased shrinkage during drying. This also could be attributed to physico-chemical reactions (i.e. ion exchange) taking place within the soil POFA mixture (Osinubi *et al*., 2006).

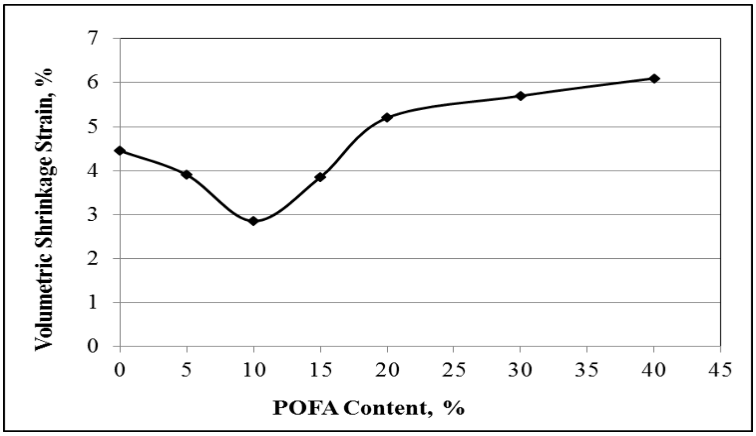

Figure 4. Variation of volumetric shrinkage strain (VSS) with POFA content

4.0 Conclusions

Granite residual soil was mixed with up to 40% POFA using standard proctor compactive effort at the optimum moisture content (OMC), to ascertain its suitability to be used as hydraulic barrier in landfill showed general improvement in properties tested. The index properties of the granite residual soil–POFA content satisfy the basic requirement for a liner. The soil possesses adequate quantity of fines along with good plasticity characteristics required to achieve hydraulic conductivity, while the MDD and OMC decreased and increased respectively with higher POFA content. All mechanical tests carried out showed improved properties up 15% POFA, however beyond 15% POFA there was no satisfactory result with regards to usage as a liner material. In addition, the use of POFA as additives in soil would help in reducing the environmental nuisance caused by the POFA being generated from palm oil production.

5.0 Acknowledgements

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