Journal of Applied Sciences

ISSN 1812-5654

science alert

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Journal of Applied Sciences 15 (7): 1006-1012, 2015
ISSN 1812-5654

RESEARCH ARTICLE **OPEN ACCESS**

DOI: 10.3923/jas.2015.1006.1012

Application of Gypsum and Fly Ash as Additives in Stabilization of Tropical Peat Soil

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ARTICLE INFO
Article History:
Received: February 25, 2015
Accepted: June 12, 2015

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ABSTRACT
The demand for land in conjunction to infrastructure development is become crucial and expensive. In the near future, a problematic soil such as peat is becoming a final alternative. In crucial cases, peat land cannot be avoided and has been hosted for engineering structures (e.g., road, highway, railway and bridge). Peat soil is well established of its downgraded characteristics, highly compressibility and low in shear strength. This study aimed to investigate effect of fly ash and gypsum on the mechanical properties of peat soil. Fly Ash (FA) is a by-product material that is generated from the burning of coal in thermal power plants. In this study, gypsum was prepared chemically in the laboratory to simulate residue from Neutralization Underflow Process (NUF). For the first batch of samples, the peat samples were initially treated with Synthetic Gypsum (SG) in the ranges between 0 and 20% of sample dried weight (SG treated soil). In a second batch, the peat samples were prepared with 10% FA and then mixed thoroughly with different amounts of SG contents (0, 5, 10 and 20%) (10FA-SG treated soil). The results showed that soil treated with mixture of 10% FA and SG indicated lower liquid limit values than the SG treated soil. In compaction tests, the maximum dry density of both increased in both SG treated soil and FA-SG treated soil. The permeability of SG treated soil increased with the increases in SG contents. Similarly, occurred to permeability of FA-SG treated soil however, its values are lower than the soil treated without FA. Shear strength of SG treated showed decreased with increasing amount of SG content. In contrast, the FA-SG treated soil exhibited higher strength if compared to that of SG treated soil. The result suggested that the application of FA and SG mixture is more effective in stabilization in mechanical strength and densification of peat soil than the use of SG only.

Key words: Fly ash, gypsum, mechanical characteristics, compaction, shear strength

INTRODUCTION

Tropical peat soil covers 2.7 million ha of Malaysia (Mutalib *et al*., 1991). Most of the peat land areas have been developed for agriculture purposes mainly for palm oil plantation. Malaysia itself contributes to 90% of world's oil palm stock (Wetlands International, 2010). The coverage of peat soil is quite extensive; utilization of marginal soil has been required as population and demands for new infrastructures sites are arising (Huat *et al*., 2005). At present, peat land is being gradually transformed into sites for infrastructure developments.

Peat soil comprises of high organic and natural water contents up to more than 70 and 400%, respectively. It forms in waterlogged area, where lack of oxygen prevents natural microorganisms from decomposing the dead plant material (Badv and Sayadin, 2012). It occurs as extremely soft, unconsolidated surficial deposits and can be a thick layer beneath other surficial deposits (Huat, 2006). Peat soil exhibits unique geotechnical behaviour as compared to that of inorganic soils which made up of soil particles (Deboucha *et al*., 2008).

As a result of high compressibility and low strength, development of peat soils has encountered several engineering failures associated with surface subsidence and uneven settlement. This area is generally discomfort and difficult to access to the sites and change chemically and biologically with time (Huat *et al*., 2005). Jarret (1995) regarded this soft soil is susceptible to massive and long term settlement as even under moderate loading. Deboucha *et al.* (2008) reported that the shear strength of peat soil is very low of between 5 and 20 kPa. Hence, peat soils are considered problematic soil and unsuitable for supporting foundation in natural state (Yamaguchi *et al*., 1992; Duraisamy *et al*., 2009). It is a common practice to remove and replace peat soil with other soil. Nevertheless, the cost will higher as the peat layers get deeper and economically limited to shallow zone. Stabilization technique of chemical admixture can be performed through mixing of additives to allow flocculation (aggregation) and to form chemical bonding between particles (Edil *et al*., 2006; Huat *et al*., 2005). Increase in effective size in clay aggregation and inter-particle bonding contribute to the stability and strength of the treated soil.

Some common additives used in improving the mechanical strength of soil are cement, lime and fly ash. Cement is widely applied in stabilizing clay and soft soils (Axelsson *et al*., 2002; Lorenzo and Bergado, 2004). Use of lime can enhance the shear strength and reduce significantly the water absorption (NLA., 2004; Eren and Filiz, 2009). Fly ash with high calcium shows a significant amount of tobermorite that leading to the formation of a denser and more stable structure of the clay samples. It is well established that the application of chemical admixture has been successfully improved the mechanical strength of stabilized peat soil as concluded by many studies (Huat *et al*., 2005; Kolay and Romali, 2006; Deboucha *et al*., 2008; Islam and Hashim, 2010; Kazemian *et al*., 2011). Fly ash has been widely used in brick and rammed earth studies (Kayali, 2005; Brooks, 2009; Cristelo *et al*., 2012). The usages of fly ash as additive have also been examined by Zia and Fox (2000) and Edil *et al.* (2006). Kolay and Pui (2010) examined the potential usage of gypsum and fly ash in stabilization of peat soil. They found that both additive industrial by products can improve the unconfined compressive strength with the increase of curing periods. Application of recycled gypsum in the stabilized soft clay was performed by Kamei *at al.* (2013) in order to improve its shear strength. This study indicated the potential use of gypsum in increasing the unconfined shear strength of the treated soil.

The conventional materials such as cement and lime become expensive, now-a-days have increased the cost of soil stabilization. In environmental aspect, the production of these materials has associated with high energy consumption and the release of attributed greenhouse gases (Worrell *et al*., 2001; Pandian *et al*., 2002; Klee, 2008). As the environmental regulations get tougher and more restricted, alternative materials that offer economically effective should be explored. The amount of waste originated from daily activities, production and industries continues to increase rapidly as population growing (Abdul Kadir and Mohajerani, 2011). Therefore, the utilization of the industrial by-products can enhance the value added of particular waste and can also minimize the cost in terms of waste disposal and management. In this study, fly ash and gypsum were used as additive materials in stabilization of peat soil. The use of waste materials is attractive because of their relatively cheaper, compared with cement and lime as well promoting sustainable construction (Ahmed, 2014). Their effect on some mechanical characteristic such as Atterberg limit, hydraulic conductivity, compaction and shear strength were examined in this study.

MATERIALS AND METHODS

Based soil and additive materials: Based soil used was peat soil that was collected from Tanjung Sepat district, Sepang Selangor (N 2°40’41”, E 101° 35’31”). The samples were taken at depth below 1 m from ground surface at which water level ranged between 0.5 and 0.8 m. The soil was characterized by its high water content, spongy fabric and strong odour of rotten organic matters. Based on field observation, the soil was dark brown in colour and very acidic with average pH of 3.2. The organic and natural water contents were high of 95.6-97.4 and 77-560%, respectively. The liquid limit of peat soil was between 144 and 184%. Most of peat soil lacks of plastic limit characteristic. The scale of humification of peat sample was categorized as H_4 according to Von Post classification. This category was attributed to the facts that peat presents with distinct plant fibres and water with muddy brown colour when peat sample was squeezed. Little plant characters were identified due to its pasty in nature. Similar previous results were also stated that organic content of peat soil ranged between 88.6 and 99.1%. Fly ash samples were collected from nearby thermal power station at Kapar, Selangor. It is classified as Class F, non-plastic and whitish grey. Gypsum waste might be produced from manufacturing process, construction and demolition activities. In general, it consists of calcium sulphate dehydrate ($CaSO_4 \bullet 2H_2O$). In this study, gypsum was synthetically produced in the laboratory to simulate waste produced from neutralization underflow process or also known as NUF. This residue is rich in magnesium as a result of sulphuric acid neutralization on minerals of calcium, magnesium and aluminium to produce sulphate minerals (WorleyParson, 2008; Vaisey, 2012). Summary of the basic characteristics of peat soil, fly ash and synthetic gypsum used in this study is shown in Table 1. The SEM images of peat soil treated with fly ash and synthetic gypsum is shown in Fig. 1. Fly ash particles found to be filling the spaces between soil particles while bridging of chemical bindings formed by gypsum and clay particles (Fig. 1b). The crystal of gypsum seen as an elongate shape that interlocked

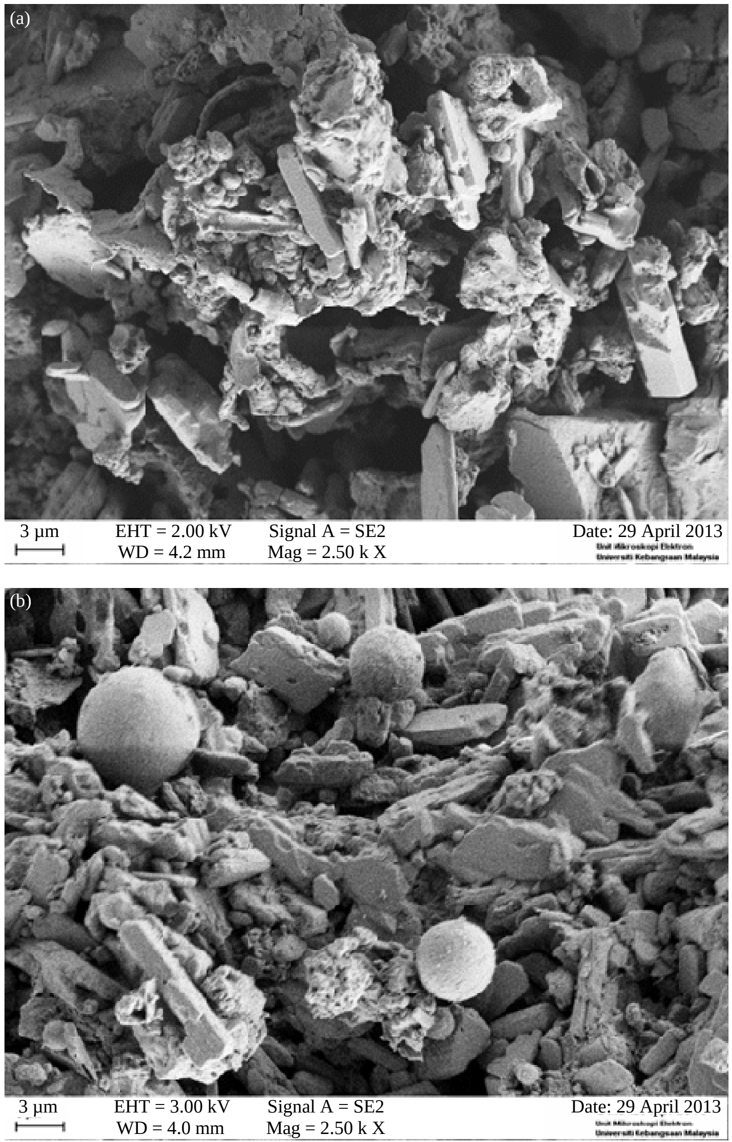

Fig. 1(a-b): Scanning electron microscope photographs of at 2.5 K magnification (a) Peat soil treated with synthetic gypsum (seen as elongate shapes) and (b) Peat soil treated with 10% fly ash (sphere shape) and synthetic gypsum

Table 1: Summary of basic characterization of peat and additive materials

Material properties	Peat	Fly ash	Gypsum
Natural moisture content, w (%)	77-96	0.1	39.7
Organic content (%)	95.6	-	-
Humification class	H_4	-	-
pH	3.2	12.5	8.8
Specific gravity (G_s)	1.3	2.2	2.0
Liquid limit, w_L (%)	144-184	-	-
Permeability, k ($\times 10^{-5}$) (m sec^{-1})	4.9	-	-
Compaction test			
Maximum dry density, ρ_{dmax} (g cm^{-3})	0.54	-	-
Optimum moisture content, w_{opt} (%)	86.5	-	-
Shear strength, C_u (kPa)	10-13	-	-

with few voids (Camarini and de Milito, 2011). Particle size distribution curves for fly ash and synthetic gypsum are presented in Fig. 2. It is clearly seen that fly ash is dominated by silt size while, synthetic gypsum constitutes of silt and very fine sand.

Sample preparation of treated peat soil: Prior to preparation of treated samples, peat samples were openly air dried under room temperature and soil any aggregate form was broken down manually by hand. The samples were sieved through 2 mm mesh size. The used additives of Fly Ash (FA) and Synthetic Gypsum (SG) were oven dried for overnight before cold down to room temperature and kept in desiccator. The treated samples were prepared by dry mixing between peat sample and different percentages of SG ranged between 0 and 20% of dried weight of base soil. This first batch was

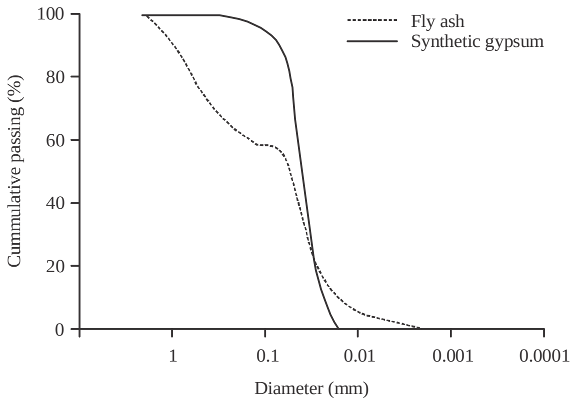

Fig. 2: Particle size distribution of additive materials used

labelled as SG treated soil. A second batch of treated samples had initially prepared between peat samples with 10% of FA before different amount of SG were added (10 FA-SG treated soil). This second batch aimed to examine the effect SG contents at specific amount of FA on the geotechnical parameters of treated peat soil. Both treated samples were kept in airtight containers prior to further testing. All the treated samples experienced a week curing period before particular parameters such as permeability and mechanical strength tests.

Geotechnical testing of treated soils: Consistency index of liquid limit, w_L was determined by using the Casagrande cup techniques. This technique equipped with a cup and a grooving tool. This test is used to classify a particular soil and to estimate its moisture content at which the shear strength is virtually zero (Dias and Alves, 2009). A groove was cut at the middle of the soil paste and is subjected to shallow drop of the cup. The value of plastic limit, w_P was determined from 3 mm in diameter of soil thread with sign of crumbles. After of each test, sample was collected to determine the moisture content. Difference between w_L and w_P is the plasticity index, I_P.

The objective of compaction is to densify the soil mass by bringing down the air voids. By compaction of the soil, particles will re-arrange to gain more surface contact by reducing the inter-particle voids (Rahman *et al*., 2013). Compaction tests were carried out using the standard Proctor 2.5 kg (or BS light) compaction effort in order to determine the values of maximum dry density, ρ_{dmax} and optimum water content, w_{opt}. Sample was compacted in three equal layers using a rammer where each layer experienced 27 blows that were evenly distributed over the mould area. The tests were repeated for samples with higher water contents. Compaction curves were delineated to achieve the values of ρ_{dmax} and w_{opt}.

The permeability and shear strength of the treated soil samples were determined using the falling permeameter methods and quick undrained tests. Preparation of samples for both tests was obtained from the standard compaction procedures. Each sample was equally compacted in three layers in compaction mould. The samples were extruded from the mould and sealed for predetermined curing period before testing. For quick undrained tests, a set of three samples of 38 mm diameter by 76 mm high sample was used. These samples were subjected confining stresses of 140, 280 and 420 kPa prior to shearing. The samples were sheared at strain rate of 1.52 mm min^{-1}. Shearing of the samples was performed until the samples failed. A further explanation of the methods adopted to determine the geotechnical characteristics of the treated samples were referred to the British Standard Institution 1377 (1990a-d) Part 2, 4, 5 and 7.

RESULTS AND DISCUSSION

Effect on liquid limit: The values of liquid limit, w_L for the treated peat soil synthetic gypsum (SG treated soil) and 10% fly ash and different amount of synthetic gypsum (10 FA-SG treated soil) are shown in Fig. 3. For SG treated soil, the values of w_L gradually reduced from 144-123% at 20% of SG content. As, 10% of FA was added to the peat soil, the value of w_L generally dropped to 134% if compared to that of peat soil without FA. A similar picture was seen for the liquid limit, w_L values of the 10 FA-SG treated soil and the was located slightly below the line of the SG treated soil (Fig. 3). It is clear that the addition of SG has decreased the values of liquid limit, w_L and combination of SG and FA will further reduce the w_L value in treated peat soil. Several previous studies also mentioned a similar trend of the influence of fly ash in reducing the liquid limit value of treated soil (Geliga and Ismail, 2010; Yadu *et al*., 2011; Vukicevic *et al*., 2013; Saravanan *et al*., 2013). The influences of SG content on both treated soils are indicated by strong correlation values as shown in Fig. 3.

Effect on compaction and permeability: The results of the effect of added SG contents on the maximum dry density, ρ_{dmax} and optimum water content, w_{opt} are shown in Fig. 4. From Fig. 4a, the increase in SG contents has increased the values of maximum dry density, ρ_{dmax} of both treated SG treated and 10FA-SG treated soils. Meanwhile for the addition of SG has decreased the optimum water content, w_{opt} values for both treated soils (Fig. 4b).

The results suggested that the increase in ρ_{dmax} and decrease in w_{opt} were not significantly affected by the presence of 10% fly ash. It is clearly seen that further addition of SG more than 5% has decreased the w_{opt}. A similar result was also exhibited by 10 FA-SG treated soils up to 5% of SG content. An addition of 10% FA content has brought down the value w_{opt} and then value levelled off up to 20% SG content. Therefore, as the added SG contents were increased, the amount of water to achieve the maximum dry density was apparently reduced.

The effect of SG and 10 FA-SG content on permeability, k is shown in Fig. 5. For untreated peat soil (0% SG), the k value was 4.90×10^{-5} m sec^{-1}. As, the contents of SG were increased, the permeability also gradually increased up to 1.01×10^{-4} m sec^{-1}. For the 10 FA-SG treated soil, the presence of fly ash has lowered the value of permeability to

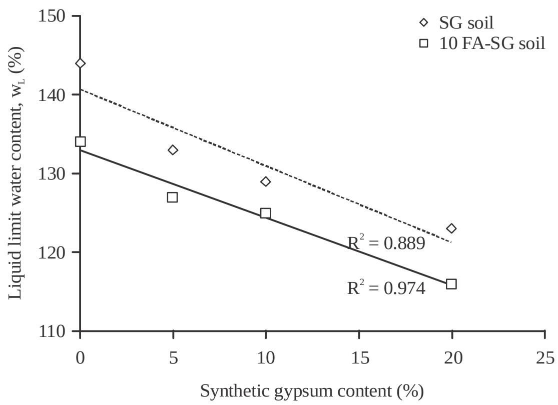

Fig. 3: Atterberg limit, w values against synthetic gypsum contents for SG and 10 FA-SG soils

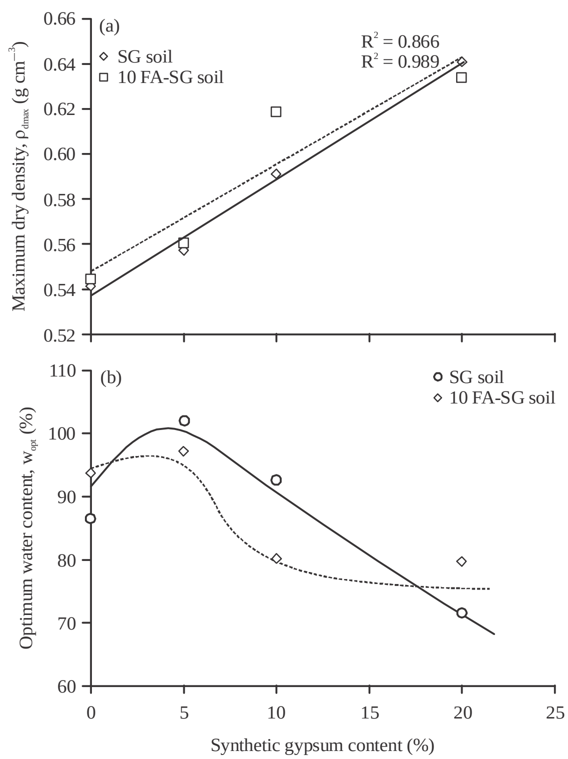

Fig. 4(a-b): (a) Maximum dry density, ρ_{dmax} values and (b) Optimum water content, w_{opt} against synthetic gypsum contents for SG and 10 FA-SG soils

1.96×10^{-5} m sec^{-1} for sample 10% FA with 0% SG if, compared to that of SG sample without SG content. By further addition of the SG contents, the k values were increased from 2.42×10^{-5}-5.94×10^{-5} m sec^{-1} for 10 FA-SG treated soil (Fig. 5). The k values for SG treated soil were seen higher than that of 10 FA-SG treated soil.

The increase of k values in both treated soils was possibly caused by the high content of calcium (Ca^{2+}) and magnesium (Mg^{2+}) in SG used in this study. These cations are responsible in the flocculation of clay particles in the studied soil.

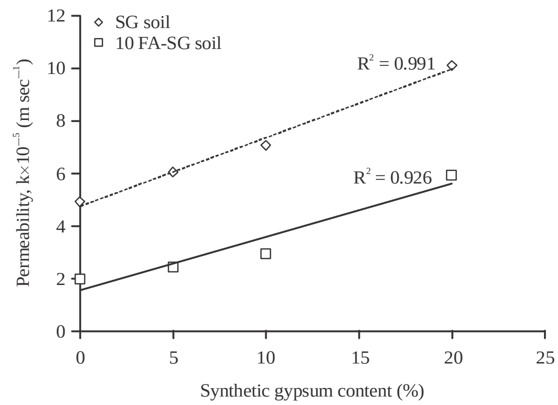

Fig. 5: Permeability of SG and 10 FA-SG soils

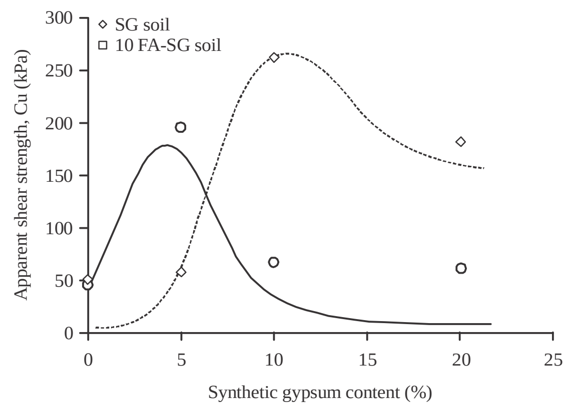

Fig. 6: Shear strength against synthetic gypsum contents of SG and 10 FA-SG soils

Flocculation may contribute to larger soil particles with bigger inter-particle voids (Fig. 1). Therefore, by increasing the amount of SG, the permeability of treated peat also increased significantly as shown in Fig. 5. The higher value of k for SG treated soil than 10 FA-SG treated soil attributable to presence of fly ash that it occupies the voids hence, reduce the permeability of 10 FA-SG treated soil. Since, the amount of FA was limited to 10%, further increased in SG subsequently increase the permeability of 10 FA-SG treated soil.

Effect on shear strength: All samples were tested after a week of curing. The effect of SG and 10% FA-SG contents on the strength of treated peat soil is illustrated by the apparent shear strength, C_u is shown Fig. 6. The untreated peat soil (SG soil) is represented by lower C_u value of 47 kPa. A low C_u value was also seen for peat soil treated with 10% of FA (10 FA-SG soil). It seemed that presence of 10% FA in treated peat soil did not significantly change the strength of peat soil (C_u equal 50 kPa). However, as SG content was added up to 5% in SG soil, the C_u value climbed up from 47-195 kPa. This value dropped back to 67 kPa (10% FA) and 61 kPa when the SG content used in the peat soil was 20%. In contrast, the C_u value for sample 10 FA-SG soil increased to 58 kPa (5% FA) and then climbed significantly to 261 kPa as SG content of 10% before the value decreased to below 181 kPa at 20% of SG content. It also noticed that higher shear strength was achieved for the samples treated with fly ash and gypsum.

The results indicated that the improvement of the C_u values is much dependant on the amount of SG used in SG treated soil. In SG treated soil, 5% of SG was the optimum content whereas, for samples with the presence of 10% FA (10 FA-SG treated soil), the amount of SG should not be in excess of 10%. The increase in C_u value was due to the reaction between gypsum and soil particles that responsible in inter-particles binding and bridging. Aggregation of clay particles may be attributable to increase in shear strength. Using of gypsum as a cementation agent can alter the behaviour of soil to more cohesion (Hughes and Glendinning, 2004). Ahmed *et al*. (2011) also found that the amount of gypsum corresponded to the increase in the shear strength of fine grain soil. However, excessive presence of gypsum has attributed to the formation of weak inter-particle binding as stated by Kolay and Pui (2010). A combination of fly ash and gypsum additives in treatment of peat soil (as in 10 FA-SG soil) achieved higher maximum C_u value if, compared to that of SG soil. Higher shear strength was the result of blend of chemical bonding created from both fly ash and gypsum present in the treated soil (Moseley, 1993). However, further addition of gypsum in 10 FA-SG soils has weaken the strength of the treated peat soil possibly related to formation of weakly bonding with more porous soil as fly ash used was limited to 10%.

CONCLUSION

From the results of this study, the application of fly ash and gypsum as additive materials can improve the geotechnical characteristics peat soil. The consistency index of liquid limit of peat soil was decreased apparently especially with the presence of fly ash and gypsum. The compaction behaviour of treated peat soil exhibited higher maximum dry density with lesser optimum water content as the amount of additive materials used were increased, yet the presence of fly ash did not significantly affect the value of the maximum dry density. In contrast, the permeability of treated soils increased with the increase of SG contents. It clearly showed the fly ash can lower the permeability of treated peat soil if compared to that of samples treated solely with gypsum. In terms of shear strength, the amount of gypsum used should be not in excess as further addition has contributed to the reduction in soil shear strength.

ACKNOWLEDGMENTS

The authors would like to thank, Universiti Kebangsaan Malaysia for the financial support under the research grants PIP-2013-004. The authors would also like to express their gratitude to the laboratory staffs at the School of Environmental and Natural Resource Sciences, Faculty of Science and Technology, UKM for sample preparation and testing.

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