Chapter 6

Physical and Geotechnical Properties of Tropical Peat and Its Stabilization

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Additional information is available at the end of the chapter

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Abstract

The chapter presents the physical and engineering properties of tropical peat treated with various types of stabilizers. Quick lime (QL), fly ash (FA), and ordinary Portland cement (OPC) were used as stabilizers. The amounts of QL, FA, and OPC added with the peat samples are in the range of 2–8, 5–20, and 5–20%, respectively. Various physical or index and engineering tests have been conducted to characterize the peat samples. Unconfined compressive strength (UCS) tests were conducted on original and treated peat samples cured for 7, 14, and 28 days. The results show that the UCS value increases with the increase of all stabilizers used and with curing period. The UCS tests were also conducted on the peat samples with the combination of QL and FA to study the combined effects of the stabilizers. The present study established different correlations between physical and engineering properties of original peat and UCS results on treated peat samples with different types of stabilizers. Geotechnical engineers can refer to these correlations to determine the bearing capacity of treated peat. In addition, scanning electron microscope (SEM) studies were conducted on original and treated peat samples to investigate the microstructure of the samples.

Keywords: tropical peat, characterization, stabilization

1. Introduction

Peat or organic soil is highly heterogeneous formed due to the decomposition of organic matter such as plant remains, leaves, trunks, roots, and so on. Peat can be found anywhere in the world except in barren and arctic regions which cover about 5–8% of land area [1]. Tropical peats cover about 8–11% of the area in Malaysia, Indonesia, Brazil, Uganda, Zambia, Zambia, Venezuela, and Zaire. The department of irrigation and drainage in Sarawak mentioned that there are about 2.7 million hectares of peat land in Malaysia (i.e., 8% of the total land area). Among them, about 1.66 million hectares, that is, 63%, are located in deltas and coastal plains of Sarawak. Most of the year, this peat land area is waterlogged [2]. Peat has typical characteristics, which include high natural moisture content, high compressibility and water-holding capacity, low specific gravity, low bearing capacity, and medium-to-low permeability [3].

Hence, characterization and improvement of peat is necessary to construct any type of infrastructure on it. This is a major problem for infrastructure development as the geotechnical properties of peat soils are lower than mineral soils. However, due to rapid industrialization and population growth, it has become necessary to have infrastructure facilities and road construction everywhere, including in the peat land area. Prior case histories show that several construction methods such as the displacement method, the replacement method, the stage loading and surface reinforcement method, the pile-supported embankment method, the light weight fill raft method, the deep in-situ chemical stabilization method, and the thermal precompression method have been employed in Sarawak [4, 5]. It is observed that some of the projects were technically successful, while others had excessive settlement and failure problems after completion of the project.

Another major problem in Sarawak is the large quantity of fly ash (FA) production from coal-fired thermal power plants. The burning of coal resulted in over 4.2–13 million tons of coal ash as a by-product from 2000 to 2005 in Malaysia mostly disposed into ash pond or lagoon, which is a challenge for the environment [6, 7]. Therefore, it is necessary to increase the use of this FA in order to avoid increasing disposal costs and environmental impact. Due to its pozzolanic nature, fly ash can be effectively used in a variety of construction applications. However, there is a legitimate concern with respect to the potential release of toxic contaminants associated with the use of such wastes. Hence, it is believed that small percentages of fly ash (FA) can be used with peat for stabilization purposes in civil engineering applications. However, Kolay and Singh [7] discussed the impacts of toxic contaminants on the environment. Also FA uses in soil treatment, as conditioners or filler material for low-lying wastelands, in refuse dumps reclamation, and construction or geotechnical secondary raw materials [8, 9] has increased their potential geo-environmental impact. Therefore, the use of FA provides economic benefits by reducing disposal costs and negative environmental effects through engineering applications.

The stabilization of clay and soft soils has been studied by several researchers using cement [10–17]; fly ash [18–21]; and lime [22–25]. Few researchers focused on the stabilization of mineral soil such as clay, silty clay, and dispersive soil by different types of stabilizers. However, geotechnical engineers do face challenges due to inadequate basic tropical peat soil data for construction projects. There are only a few studies [11, 26–29] that have discussed the stabilization of highly organic soil or peat soil. It is difficult to determine the physical or index properties of peat soils due to high water content and variability. Aminur et al. [2] provided a comparison result of physical and geotechnical properties of organic and peat soils. Correlations between various index properties are also useful for peat soil when compared with mineral soils. Previous researchers established the relationship between physical and geotechnical properties with different types of peats [11, 30]. The morphological properties of clay, silty clay, and organic soil have been discussed by several researchers [2, 31]. Most of the researchers focused on soft clay for morphological microstructure investigation and very few studies are available on peat [2, 24, 32].

As FA is a recent issue in Malaysia, there are limited studies available on waste FA utilization. Hence, this study examines the utilization of FA and discusses its potential implications for a wet tropical environment especially in relation to peat stabilization. Therefore, the present study focused on the utilization of the waste FA along with quick lime (QL) and ordinary Portland cement (OPC) for peat stabilization purposes. Furthermore, a few correlations were established from physical and geotechnical properties of the original peat. Geotechnical engineers can use these correlations to determine properties of peat, where geotechnical data are not available.

2. Experimental procedure

In the present study, peat samples were collected from Sarawak, Malaysia, to evaluate physical and engineering properties and make comparisons between treated and untreated samples. The peats were sun dried, sieved through specific sieves, then oven dried at 60°C, and used for different physical and engineering property tests. Commercially available OPC and QL and locally available FA were used as stabilizers. The mixing of the peat and stabilizers can be accomplished using different types of modern equipment in the real field.

The moisture contents of the peat samples were measured by drying the sample in an oven at 105°C for 24 h according to BS 1377 [33]. The degree of decomposition is usually assessed using the Von Post scale, where there is 10 degree of humification (from H1 to H10) in the Von Post system. The peat sample was squeezed in the hand to perform the degree of decomposition test. The color and fluid that is released between the fingers is observed and the pressed residue remains in hand after squeezing is measured as the degree of decomposition. The loss on ignition (LOI) tests were carried out as a percentage of oven-dried mass according to ASTM D2974 [34]. The LOI method was used to determine the organic content (OC) of the peat samples.

The specific gravity (G_s) of the peat samples was determined in accordance with BS 1377 [33]. For accuracy, the average G_s value was obtained from the result of three tests. The fiber content (FC) was measured according to ASTM D1997–91 [35]. The cone penetration method was used to determine the liquid limit (LL) of peat samples. The LL tests were conducted as per the guidelines of BS1377 [33]. The pH tests were conducted in accordance with BS 1377 [33].

Standard Proctor tests were conducted according to BS 1377 [33] to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the peat samples. The unconfined compressive strength (UCS) tests were conducted to determine the shear strength parameters of the peat and stabilizers. The UCS tests were performed according to the guidelines provided in ASTM D2166 [36]. Sample sizes of 50 mm in diameter and 100 mm in height were used in this study. The UCS tests were conducted after the curing period of 7, 14, and 28 days. Due to heterogeneity of peat and FA sample, a minimum of three samples were tested with each percentage of stabilizer and average result is presented. SEM micrographs were conducted to study the morphology of peat, FA and treated peat samples. The SEM tests were performed by using the instrument JEOL, Japan, with model number JSM-6701F.

3. Results and discussion

Table 1 shows the physical and engineering properties of the various peat samples collected from Sarawak, Malaysia. The chemical composition of FA is shown in **Table 2**. The results show that the FA used in this study falls in the category of Class F ash according to ASTM C 618 [37].

3.1. Physical and engineering properties

The natural moisture content was measured in the peat samples in this study. Generally, peats have high natural water content. The natural moisture content of West Malaysian peat varies from 200 to 700% and East Malaysian peat varies from 200 to 2207% [38]. The natural moisture content of peat samples is presented in **Table 1**. **Table 1** shows that the moisture contents of the peat soil samples are very high; this may be attributed to the fact that peat soils have high FC and hence it is able to absorb more water. The degree of decomposition is usually assessed by

Properties	**Sample**				
	M_1	**M_2**	**M_3**	**M_4**	**M_5**
Moisture content (%)	587.20	620.20	496.30	360.70	605.60
Degree of decomposition	H4	H3	H5	H6	H7
Fiber content (%)	65.93	65.00	62.50	61.40	31.98
Loss on ignition (%)	96.12	85.67	78.75	67.88	44.74
Organic content (%)	95.96	85.10	77.90	66.60	42.53
Liquid limit (%)	150.00	78.00	75.00	73.00	69.00
Specific gravity (G_s)	1.17	1.45	1.78	1.64	1.82
pH	3.85	4.05	4.53	5.15	6.18
UCS (kPa)	28.56	31.28	40.38	38.3	43.28

Table 1. Physical and engineering properties of peat samples.

Oxide	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**P_2O_5**	**SO_3**	**TiO_2**	**LOI**
(%)	59.40	24.40	7.60	1.71	2.22	0.23	3.91	0.23	0.17	0.15	0.85

Table 2. Chemical composition of FA.

Von Post scale and there is 10° of humification (from H1 to H10) in the Von Post system. The results show that all samples fall into the category of H3–H7, according to the Von Post scale.

The FC of different peat samples is also presented in **Table 1**. The results show that sample M_1 has higher FC than the other samples and sample M_5 has lowest FC. This may be attributed to the fact that the M_5 sample was more decomposed than the other samples. It is also observed that M_1–M_4 samples fall within the hemic peat soil group and M_5 sample falls within the sapric peat soil group [39]. The results of LOI and OC show that the sample M_4 and the sample M_5 have lower than 75% OC and so can be categorized as highly organic. The remaining samples can be categorized as peat soil. This may be attributed to the fact that the M_5 sample has lower FC and the M_1 sample has higher FC than the other samples.

The cone penetration method was used to determine the LL of the peat samples. The results show that LL value is higher for the M_1 sample as this sample contains more FC and therefore it has high water absorption capacity. Cheng et al. [40] also stated that organic contents are the primary contributors in increasing Atterberg limits and compressibility. The G_s results of the peat samples are also presented in **Table 1**. It can be seen that sample M_5 has a higher G_s value due to its lower FC value. Den Haan [41] also observed that the specific gravity in organic or peat is affected by the organic constituents of cellulose and lignin which have lower G_s values. Typical G_s values of the peat in West Malaysia are in the range of 1.38–1.70 and East Malaysia are of 1.07–1.63 [38].

The pH results show that the M_1 sample has a lower pH value than other peat samples and sample M_5 has a higher pH value. In present study, standard Proctor tests were performed to determine the compaction characteristics of the peat soil samples. The compaction results of the peat soil samples are also presented in **Figure 1**.

Sample M_5 shows an MDD value of 8.47 kN/m^3 and an OMC value of 55.50%. It can also be observed that this is the maximum dry density and minimum moisture content as compared to the other samples. This may be attributed to the fact that sample M_5 has lower FC and as a result it has lower water absorption capacity and higher dry density than the other samples.

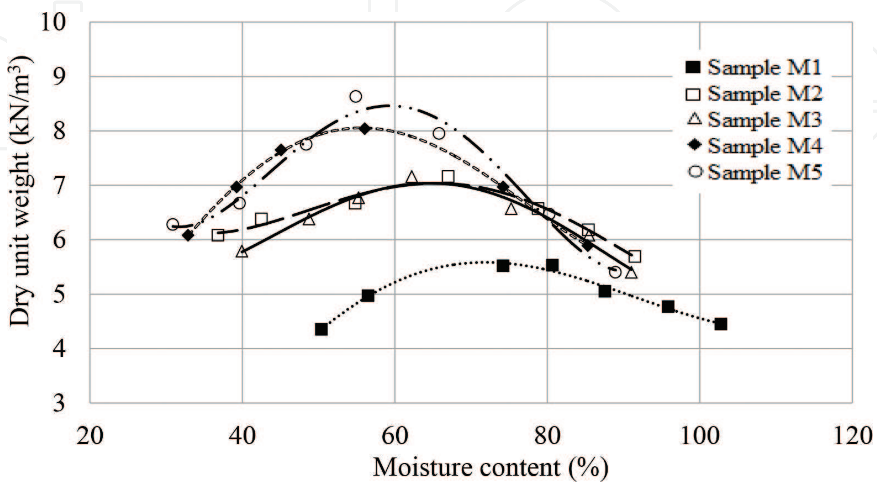

Figure 1. Compaction characteristics of peat samples.

3.2. Engineering properties of stabilized peat

The UCS tests were conducted on the original peat and treated samples with different percentages of stabilizers. The sample M_1 was chosen for the UCS tests in this study as it was the worst among all the samples. The UCS results obtained from QL, FA, and OPC stabilizers are shown in **Figure 2**. The results show that the UCS value increases with the increase of FA and curing period. The results increased up to 6% of QL with the curing period and decreased beyond this percentage. A similar trend of UCS results of lime-treated peat soil samples was reported by Kok and Kassim [22] and Aminur et al. [23]. The results also show that the UCS value increased with the increases of the OPC percentage and the curing period. The increase in strength is much more predominant with a higher percentage (20%) of OPC added to the untreated peat samples. It can be attributed to the formation of calcium silicate hydrate (CSH). The pozzolanic reactions that initiate during the curing process, which lead to calcium silicate hydrate cementitious product formation, are as follows.

$$2Ca_3SiO_5 + 7H_2O \rightarrow 3(CaO)_2(SiO_2)_4(H_2O) + 3Ca(OH)_2 \quad (1)$$

The hydration process begins in the mixer and continues until it reaches its ultimate strength. The hydration also depends on the quality and quantities of the cementitious materials as well as the environmental temperature and the sample's moisture. Furthermore, organic matters vary significantly in their chemical composition. Organic matters also significantly influence the soil reactivity [42]. The major components of the organic matter in peat include humic acid, fulvic acid, lignin, and molecular weight.

Class F FA is not a self-cementing material; therefore, a set of UCS tests was also undertaken with the combination of QL and FA. The UCS results obtained from laboratory experiments are shown in **Figure 2**. The results show that UCS increases with the increase of QL and FA and also with the curing period. The maximum strength was obtained from 28 days of the curing period. After the addition of 6% QL, the UCS value decreases up to 28 days of the curing period and after this successively increases. This may be attributed to the fact that the reaction rate of QL and FA with peat is very slow and the CSH formation take place after

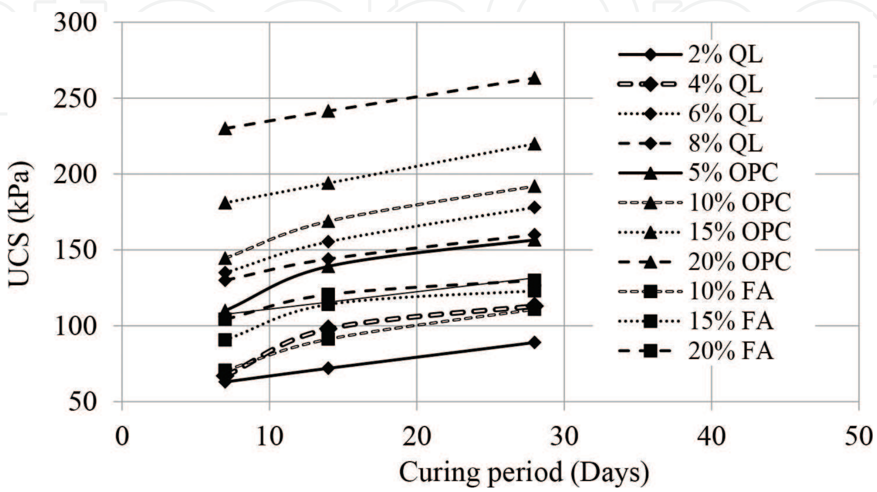

Figure 2. UCS values of treated peat with QL, FA, and OPC after 7, 14, and 28 days curing periods.

certain curing time. The results also show that approximately 70% of UCS was obtained from the combination of 6% QL and 20% FA when compared with 20% OPC. Similar results from FA- and QL-treated peat have been observed by Kolay et al. [43]. Silica and alumina present in fly ash and clay minerals greatly increased pH, which make them available for reaction with the calcium from lime and fly ash to form cementitious hydrates, calcium aluminate hydrate (CAH), and CSH. However, the formation of these calcium aluminosilicate hydrates is mainly responsible for the high strength. A wide variety of hydrate forms could be generated, depending on the quantity and type of lime or FA, soil characteristics, curing time, and temperature.

3.3. Correlation between physical and engineering properties

As the correlation between physical and engineering properties is very useful to determine any unknown properties of peat, various correlations were established in this study. The correlations of the basic physical and geotechnical properties are shown in **Figures 3** and **4**. **Figure 3** shows that MDD decreases with the increases of liquid limit (LL) and optimum moisture contents (OMC). This may be attributed to the fact that higher FC had higher water absorption capacity; as a result, MDD decreased with the increases of LL and OMC. The correlations are presented in **Figure 3**. The results show that the data are too scanty as only five samples were investigated in this study. However, the authors have established these relationships only to study the fundamental behavior of the peat rather than real-field applications.

The correlations between FC, G_s, and OC are shown in **Figure 4**. The figure shows that the value of FC increases with the increase of OC. The correlation in **Figure 4** shows that the R^2 value is 0.984. **Figure 4** also shows the correlation between G_s and OC where G_s decreased with the increase of the OC value. This may be attributed to the fact that higher OC had higher FC and consequently density was lower. Den Haan [41] stated that peat contains higher organic substances and hence the physical properties of the peat may be affected by the organic substances. Previous researchers also observed a similar trend between G_s and OC relation [41].

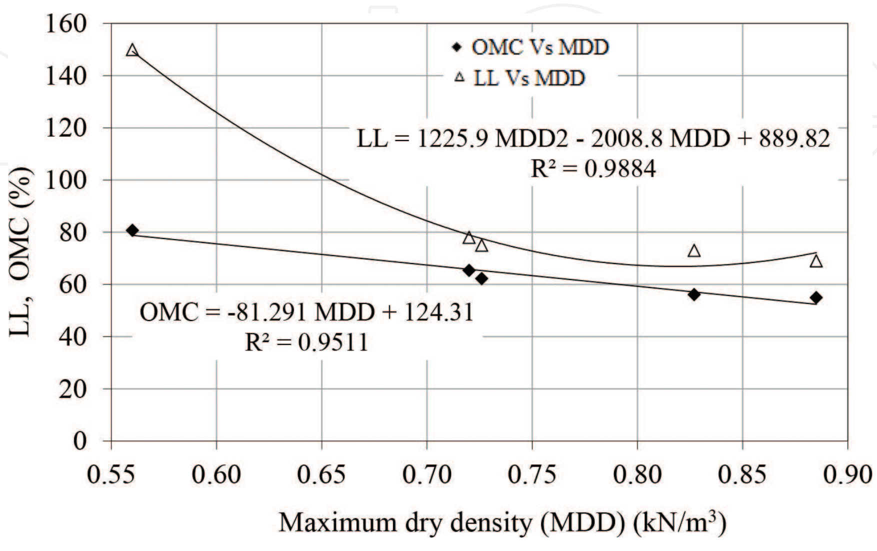

Figure 3. Correlation between LL, OMC, and MDD of the peat.

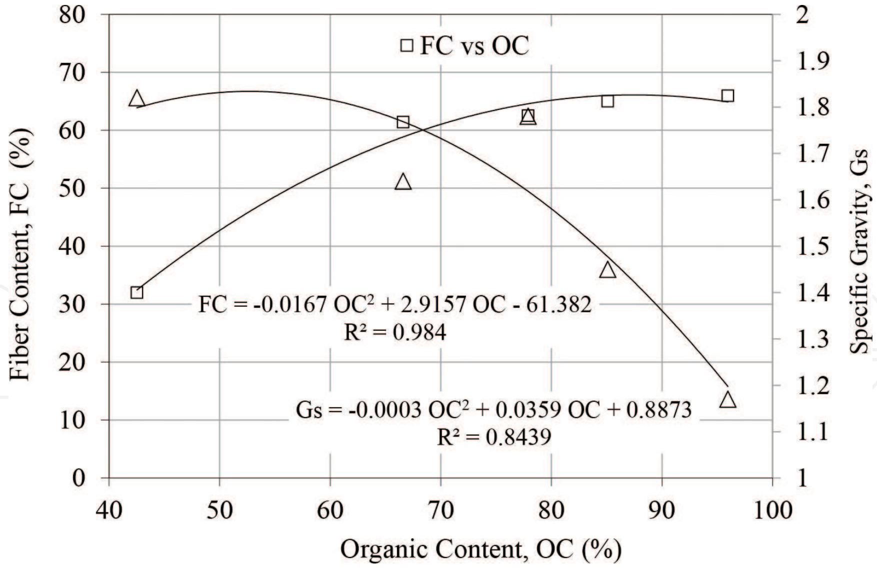

Figure 4. Correlation between FC, G_s, and OC of the peat.

The correlations between UCS values for 28 days of the curing period and different percentages of stabilizers were established. **Figure 2** shows that UCS value increased with the increases of FA and QL percentages. Geotechnical engineers can refer to these correlations in order to comprehend the ultimate strength of treated peat where the geotechnical data are not readily available. The relationships between UCS and stabilizers are shown in Eqs. (2–4). The R^2 values for FA- and OPC-treated peat soil are 0.88 and 0.99, respectively.

$$UCS = 1.14 \times FA\ (\%) + 99.66 \tag{2}$$

$$UCS = 1.58 \times OPC\ (\%) + 219.13 \tag{3}$$

$$UCS = 1.98 \times FA\ (\%) + 123.67\ (20\%FA\ \text{and}\ 6\%QL) \tag{4}$$

3.4. Morphological characteristics

The SEM tests were conducted on peat, FA, and stabilized peat samples to investigate the microstructure. Aminur et al. [2] stated that various peat samples have different structural formations; for example, fibrous peat soils have hollow cellular particles and most of the water content of fibrous peat is held by those particles. Cheng et al. [40] also discussed the microstructure of the peat. Mesri and Ajlouni [1] also observed that peat particles can be bend, permeable and compressible and consist of fibers, fragments of long streams, and thin leaves.

Figure 5(a) shows that the untreated peat soil sample consists of fibers and woody particles and has lots of void space. **Figure 5(b)** shows the FA mainly consists of spherical particles with

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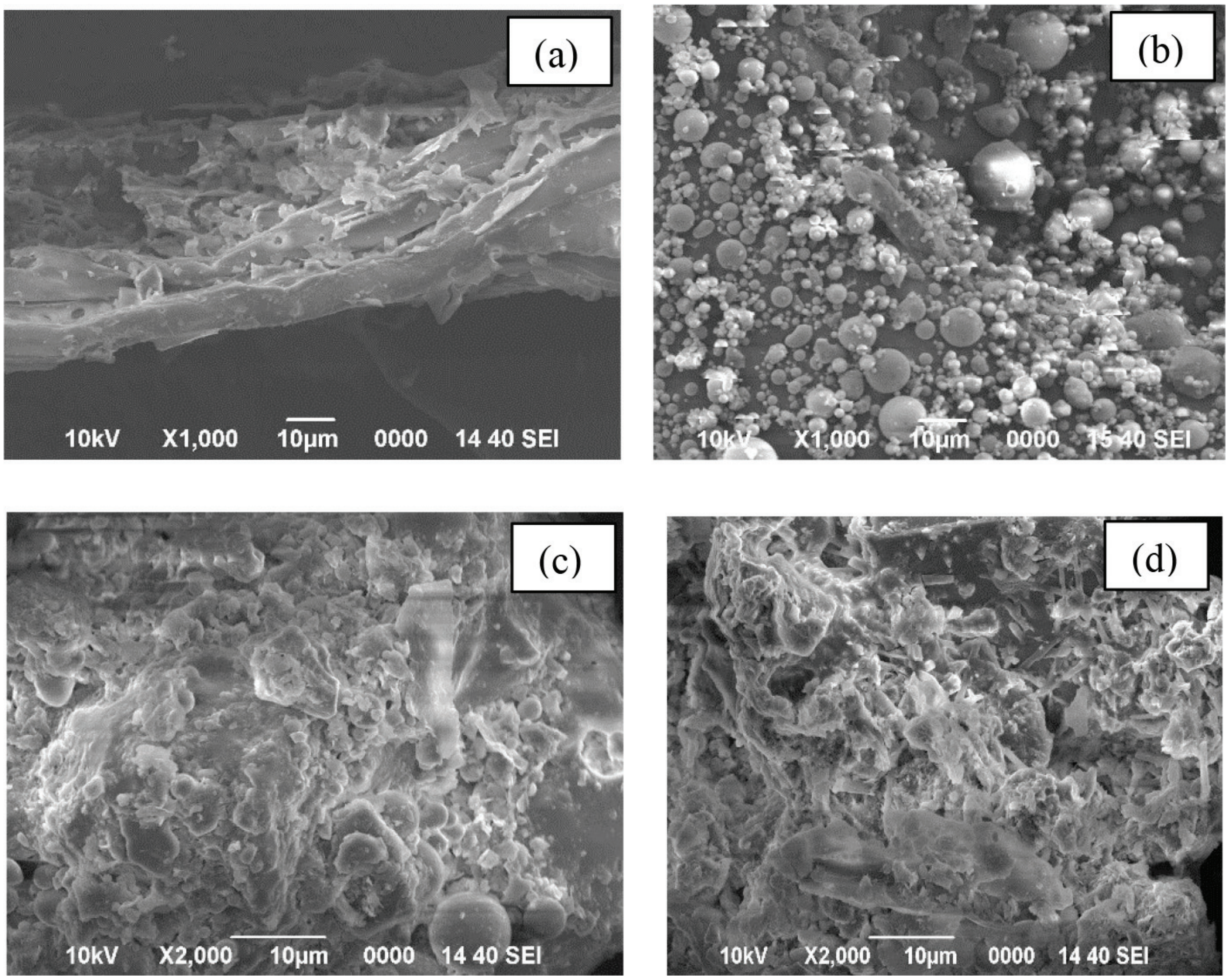

Figure 5. SEM images of (a) peat, (b) FA, (c) peat + FA, (d) peat + OPC.

some irregular shapes. **Figure 5(c)** and **(d)** shows that the internal formation of FA- and OPC-treated peat was changed significantly due to new mineralogical formation.

It is also observed that FA-treated peat soil particles are strongly bonded and have increased shear strength. It also observed from the UCS results that the shear strength increases with the addition of stabilizer and over the course of curing periods. Therefore, the internal mineralogical formation improved when compared with untreated samples. The results show that the mineralogical internal formations of FA-treated peat were also improved. The needle-like particles were formed and the particles are tightly packed and strongly bonded in OPC-treated peat sample. This may be due to the fact that the CSH formation with OPC had significantly improved. Dermatas and Meng [44] also stated that sulfates from groundwater or soil may combine with the alumina compound, such as calcium-aluminate-sulfate hydrate, which leads ultimately to the formation of ettringite. However, the contribution of ettringite and the other cementitious treatment products to the resulting strength increases. As a result, shear strength of the peat soil can be improved by using waste FA and OPC and also a combination of FA + QL stabilizer.

4. Conclusions

The present study investigates the effects of different types of stabilizers on tropical peat samples. Laboratory experimental results show that M_4 and M_5 samples are organic soils and the remaining samples are peat. According to the ASTM standard and based on the Von Post scale, it can be observed that the M_2 sample is sapric, the M_5 sample is fibric, and the remaining samples are hemic peat. The UCS values of treated peat increased with the increment of stabilizer and curing period. Comparing the performance of the stabilizers, OPC is the best stabilizer, although moderate shear strength is achieved from FA + QL stabilizer which is also cheaper than OPC stabilizer. Relationships between physical and geotechnical properties were established in this study to investigate fundamental behavior rather than field applications of peat. However, more data is required for establishing strong relationships between physical and engineering properties for real-field applications. The SEM results show that untreated peat samples contain with fibers and are more porous than treated peat samples. In the case of untreated FA samples, the FA particles are spherical, broken, and some are of irregular shapes. The needle-like particles were also observed in the OPC-treated peat samples and the particles are also tightly packed and strongly bonded compared to the FA-treated peat samples. The study shows that the geotechnical properties of peat can be improved by using QL, FA, and OPC. Therefore, geotechnical engineers can use waste FA and commercially available QL and OPC for peat stabilization purposes.

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