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Comparative study of peat properties in Johore Malaysia

Norhaliza Wahab[1], Mohd Khaidir Abu Talib[2,*], Nur J. Latifah[1], Aziman Madun[2] and Faizal Pakir[2]

[1]Research Centre of Soft Soil, Universiti Tun Hussein Onn Malaysia, Johor, Malaysia
[2]Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Johor, Malaysia
[*]Corresponding author: khaidir@uthm.edu.my

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Abstract

In its natural condition, peat contains an excessive organic content of more than 75%, which is very challenging for any construction with high water content, random fiber arrangement, and low shear strength. It is necessary to define the properties of peat as preliminary work before any construction is established. Thus, the main objective of this paper was to compare the index properties, including the physical, chemical, and engineering properties of all three types of Johore peat. The method applied to investigate the index properties involved oven-dried, chemical solution, x-ray radiation, and compressive strength. As a result, Johore peat graded the ranges from H3 to H8 in the South-West region, whereas the Fibric recorded high fiber contents compared to other types. All the peat types were poor in strength due to the low clay mineral and high carbon content. The peat was very spongy due to its loose structure, odour, and reddish to dark brown colour produced by an organic component capable of maintaining a high-water capacity and acidity within its body. The Fibric demonstrated a spongy texture compared to Hemic and Sapric, as shown in the Scanning Electron Microscope analysis. Generally, the index properties result for Fibric, Hemic, and Sapric depended on the fiber components contained in the peat, based on its scale, arrangement, and quantity.

Keywords: Johore peat, Fibric peat, Hemic peat, Sapric peat, Decomposition, Index properties

1. Introduction

Johore is located in Southern Malaysia, and it is the nearest state to Singapore. Johore has recorded the third most significant area of peat distribution in Peninsular Malaysia, with a total area of 143,974 ha [1]. Peat in the Johore regions is mainly monopolized by agricultural activities such as palm oil, pineapples, bananas, and others plantation that could contribute to local and global economic development. The combination of water and temperature technically influences peat formation. Peat originates from plants and signifies the different phases of the humidification system in which the structure of the plant can be defined [1]. Under anaerobic conditions, peat is formed from layers of compressed plant material, leading to a shortage of oxygen that affects peat formation [2]. According to [3, 4], the peat soil consists of a high content of the fibrous organic matter, formed by the partial decomposition and disintegration of mosses, sedges, trees, and other plants growing in peatland areas due to the insufficient amount of oxygen that has accumulated over thousands of years. Based on [5], peat or organic soil is highly diversified due to the decomposition of organic matter, such as dead animal shells, plant remains, leaves, trunks, roots, and other materials. Peat has complex textures and physical structures. Even under normal saturated conditions, tiny bubbles (gases) will still be trapped in the peat body [6].

The composition of the peat varies from one area to another due to factors such as the temperature, origin fiber, and humidity [7]. According to their types, the construction purposes of peat characterizations are essential to be analyzed in the future. Based on the declaration from [5,8], the characteristics and properties of the peat, including the degree of peat decomposition, colour, water content, and organic content, are essential. All these aspects need to be extracted in the complete description to make work more accessible in the future. Oxygen, moisture content, mineral content, and organic content are essential in peat formation that specifically affects the index properties, which can distinguish the type of peat (Fibric, Hemic, and Sapric). Once it has changed, all the physical, structural, and engineering properties will also change [6] as its types also will also change. Hence, this paper represents the data and illustrates the comparison of geotechnical properties of Johore peat, including all three types of peat that is Fibric, Hemic, and Sapric.

2. Materials and methods

Highly distributed peat was identifiable in the South-West Johore area, as shown in Figure 1. Thus, three location of study areas were selected around these areas due to the high distribution of peat in Johore state, and at the same time, it consisted of three types of peat that met the purpose of this study. The sampling of peat specimens was carried out at Kampung Medan Sari, Pontian- 1°28'24.2"N 103°26'35.4"E (Fibric); Kampung Parit Nipah- 1º 55’11” N, 103º 10’36” E (Hemic); and Ayer Baloi, Pontian- 1° 37’58.69” E, 103º 23’44.31” E (Sapric). These sites were located about 79.8, 12.5 and 55.2 Km from Universiti Tun Hussein Onn Malaysia (UTHM) respectively. The peat specimen was excavated below the groundwater table to obtain disturbed and undisturbed soil specimens. For undisturbed soil, it was acquired by injecting the PVC-sized 50 mm diameter and 200 mm height into the soil. Then, it was carefully taken out to the surface, sealed with wax, and wrapped with an aluminum sheet to minimize the disturbance, and later it was stored in a plastic container. Meanwhile, the disturbed peat (obtained from the excessive peat during the digging) was kept in the plastic bag to conduct the properties test.

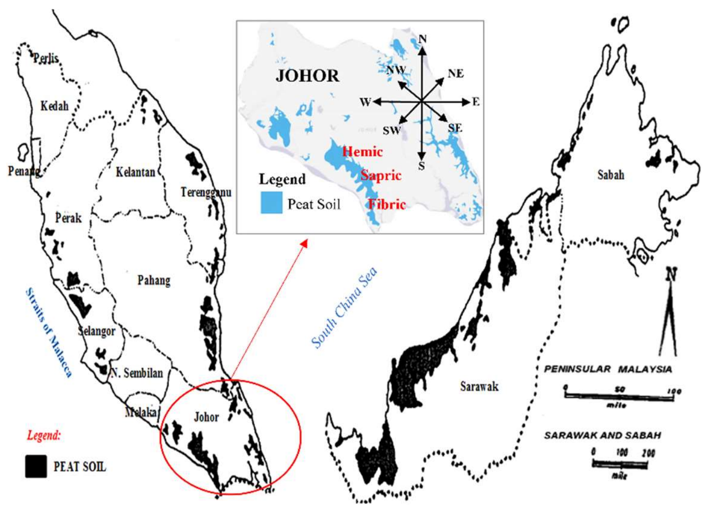

Figure 1 Distribution peat in Johore state [9].

2.1 Experimental materials and methods

Experimental methods were conducted where the field identification and index properties were vital in understanding the characteristic of peat before projecting any construction on it. Most of the common field identifications involved in peat recognition were the peat sampler, Von Post identification, and Vane Shear test. Apart from that, the laboratory test was generally measured using unit weight, water content (BS 1377: Part 2: 1990, Clause 3.0), organic content (BS 1377: Part 3: 1990, Clause 4.0/ American Society for Testing and Materials (ASTM) D2974), fiber content (ASTM, D 1997 - 91 (2001)), specific gravity (BS 1377: Part 2: 1990, Clause 8.3), liquid limit (BS 1377: Part 2: 1990, Clause 4.3), pH (ASTM - D 2976), Scanning Electron Microscope (SEM), Energy Dispersive X-Ray Spectroscopy (EDX), and Unconfined Compressive Strength test (ASTM, D2166).

To comprehend the texture of the peat layer by respecting 0.5m for each connector, the specifically designated tool, named peat sampler, was used. The peat sampler was designed to be cohesionless with the blade, rod connector, and a handle to make the peat specimen easier to extract and bring out the samples onto the surface, as shown in Figure 2A. The peat sampler was inserted into the ground at 0.5m depth each and rotated anticlockwise to obtain peat texture. This procedure was repeated by adding a rod length of 0.5 m until the texture of the soil was found in the clayey soil.

Figure 2B shows the Vane Shear tools used to determine the strength in the field. The tools were assembled and injected into the peat ground. It then was set with the ‘zero’ value. After that, the handle rotated anticlockwise until it became loose. The strength value was then obtained and recorded. The Von Post was the identification test applied through the squeezing method to govern the range of the degree of humification (H1- H10) and the analyses of the result during and after squeezing.

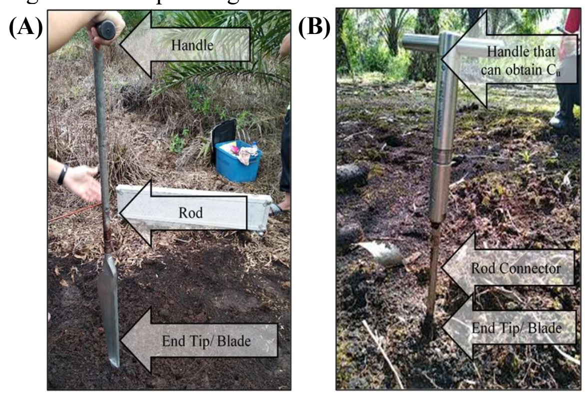

Figure 2 Field test method, in which (A) Peat Sampler, and (B) Vane Shear.

The unit weight and the water content were usually carried out in tandem. The can was filled with the natural peat in the volume, and weight was determined to obtain the unit weight. After the unit weight was obtained, the specimen in the can was incinerated at 105±5°C in the oven, drying about 24 h. The organic content was attained by igniting the dry peat that passed 0.425 mm in the controlled muffle furnace at 440°C- 900°C or until there was no mass change as described in the BS 1377: Part 3: 1990. This test was suitable for measuring organic matter with more than 10% organic matter [1]. It was predicted that after four (4) h of readings that the main test to identify the peat types in the laboratory was the fiber content. Fiber content was conducted by applying some chemical solution named sodium hexametaphosphate $(NaPO_3)_6$ to segregate the peat fiber and hydrochloric acid (HCI) to assist and remove the excess carbon in the peat bodies. The peat fiber was placed onto an opening sieving size of 150 µm; it allowed the tap water to flow on it to remove the unnecessary particles until the colour of the water was clear. The fiber retained on the sieving was then placed on the filter paper. The last step involved the specimen which was dried in the oven at 105°C for about 24 h to verify its constant mass.

The specific gravity data were obtained by removing air bubbles in the peat bodies using a desiccator. The 10 g of peat passing 2 mm was placed in the 50 mL density of a small pycnometer bottle soaked together in kerosene. Kerosene was used to replace the water (1.00 g/cm^3) because the density of kerosene was lower than the water, 0.81g/cm^3. Thus, the specimen was immersed in the kerosene solution to assist and avoid the chemical interaction between the peat particles. The cone penetrometer method was the most applicable method to attain the liquid limit result of peat soil due to the presence of the peat fiber. The passing peat soil on sieving sized 0.425 mm was mixed in distilled water to form the homogenous pasty texture. The texture was then placed in the cylindrical metal cup with the measurement of 50 mm diameter and 40 mm height to undergo the cone penetration. The angle of the cone dimension was 30º±1. The penetrated samples underwent the oven-dried at 105°C for about 24 h to obtain their water content. Hence, the cone penetration versus water content could be projected.

The pH meter was used to measure the pH value of the peat specimen. The pH meter was calibrating with 4.0, 7.0, and 10.0 buffer solution to check the accuracy of the apparatus before doing the test on the peat samples. The pH was then placed in the ready peat specimen submerged in water after 5 h with the soil and water ratio of 1:5. The chemical properties testing to analyze the microstructure of peat arrangement was known as SEM Besides, observing and analyzing the chemical mineral was identified as Energy EDX The Hitachi variable pressure (VP)-SEM SU 1510 machine was used to analyze the fiber structure and arrangement; and, consequently, acquire the chemical element. The peat specimen passed 150 mm sieving and was coated with gold material by a high vacuum evaporation machine (FISON SEM Coating System) before being placed into the machine chamber. The magnified scale selected on the SEM image was X2000, and 3 points/spectra were chosen to analyze the chemical element from EDX.

The strength of undisturbed natural peat-sized 50 mm diameter and 100 mm height was obtained by testing the samples on Unconfined Compressive Strength (UCS). The 15% of maximum axial strain was recorded or depended on the first engagement as the maximum load attained per unit area as directed in ASTM 2166.

3. Results and discussion

The results of the index properties are tabulated in Table 1 to compare the purposes. The properties showed that the results were within the range of previous research with minimum differences. Based on the Von Post characterization, the Fibric was identified as (H3) and slightly decomposed with the release of muddy brown water, but there was no peat passes between the fingers. The plant remained still identifiable, and no amorphous material was present. For Hemic, it was recognized as (H5) where it was a moderately decomposed peat as also recognized [10]. When squeezed, about one-third of the peat escaped between the fingers. The decomposed material structure was more distinct than before squeezing. Meanwhile, for Sapric, a very highly decomposed peat with a large quantity of amorphous material was categorized as (H8). About two-thirds of the peat escaped between the fingers. A small amount of pasty water might be released as well. In comparison, the texture of peat was different from each other due to the degree of decomposition of organic material. Moreover, the influence of plant types and the effect on the environment also led to the peat's different textures.

Table 1 Index properties of Johore peat.

Soil identification test	Fibric	Hemic	Sapric
Depth GWT (m)	0.7	0.8	0.6
Von Post Classification	H3	H5	H8
Unit weight, γ (kN/m^3)	9.22	11.12	11.2
Water content, w (%)	938.32	848.68	610.07
Liquid limit, LL (%)	419	370	188
Fibre content, Fc (%)	72.32	49.53	28.03
Loss of Ignition, LOI (%)	97.59	95.73	94.93
Ash (%)	2.41	4.27	5.07
Specific gravity, Gs (mg/m^3)	1.21	1.33	1.47
pH	3.29	3.26	3.61
UCS (kPa)	14.71	11.33	9.28
Vane shear, Vs (kPa)	19 - 28	14-22	13 - 22
Past Researcher	[19, 20]	[21, 22]	[23, 24]

Table 2 shows the distinguished peat textures by respecting their types obtained from peat sampler tools. The depth represented by the layer of peat from the surface before meeting the clayed soil was different between Fibric, Hemic, and Sapric which were recorded at 1.5 m, 4.0 m, and 1.5 m, respectively. The peat texture was loose, partly containing organic material such as twigs, leaves, branches, and others. At a certain depth, it could be seen there was a presence of tree trunk shown in the organic material which did not fully decompose. Simultaneously, from the peat sampler, the groundwater table (GWT) could be identified as Fibric was found at 0.7 m, Hemic found at 0.8 m, and Sapric was identified at a depth of 0.6 m. According to the observation conducted by [11], the results obtained showed that the peat colour was commonly dark reddish-brown to black. It had an organic odour due to the aerobic and anaerobic processes with the aid of water and oxygen. The depth, colour, and texture of the peat were affected by the decomposition rate and the nutrient content of the plant [12].

Table 2 Texture of peat from peat sampler.

Depth (m)	Fibric	Hemic	Sapric
0-0.5			
0.5-1.0			
1.0- 1.5			
1.5- 2.0			
2.0-2.5			
2.5- 3.0			
3.0- 3.5			
3.5- 4.0			
4.0- 4.5			
4.5- 5.0			

Naturally, peat had a very high-water content compared to other soil due to its natural state. The explanation for the high-water holding ability was due to the structure of the peat which was formed by the coarse organic particles that degraded from time to time. From the data analysis, the percentage of water content and liquid limit for Fibric recorded the highest rate compared to Hemic and Sapric. The water contents for Fibric, Hemic, and Sapric were recorded at 938.32, 848.68, and 610.07%, respectively. Besides, for liquid limit, the results obtained were 419, 370, and 188%. These two properties were associated with the ability of peat to absorb high water capacity in their bodies. The fibrous peat was identified with higher water content and liquid limit. According to [13,14], the most critical features of peat were about storing water in their hollow and having very loose structure (coarse organic particles) in a considerable amount.

Generally, the unit weight of the peat was lower than the mineral soil. It also varied among peat types; in practice, fibrous peat recorded lower unit weight than the hemic and sapric peat. As a result, Fibric, Hemic, and Sapric recorded 9.22, 11.12, and 11.2 kN/m^3 respectively, where the fibric peat was the lowest and nearest to the unit weight of water (9.81 kN/m^3). It was observed that the water content was increasing, and the unit weight was reduced due to the presence of gas. According to [15,16], the unit weight was related to the percentage of water content and inorganic material, attributed to the degree of saturation or gas content.

Based on the results obtained, Sapric recorded a higher specific gravity of approximately 1.47 mg/m^3 followed by Hemic of 1.33 mg/m^3 and the lowest was Fibric attaining 1.21 mg/m^3. The differences in results were observed to be influenced by the degree of decomposition and the organic constituents such as cellulose and lignin. Corresponding to a statement from [3,16], the specific gravity of peat was significantly affected by the percentage of the organic component and its composition.

The fiber content indicated significant comparative data recorded 72.32, 49.53, and 28.03% for Fibric, Hemic, and Sapric, respectively. Technically, the result obtained could distinguish the peat type based on ASTM 2007. The fiber content which was less than 33% was known as sapric, in 33- 66% was known as hemic, and more than 66% was known as fibric. Generally, the fiber content was affected by the degree of decomposition of plant types and organic matters and the environmental condition. According to [17], the environmental condition influenced the peat types.

More than 75% of the organic content has been recorded for all types of peat, indicating that all specimens are classified as peat soil. As a result, the ash contents recorded by Fibric, Hemic, and Sapric were 2.41%, 4.27%, and 5.07%, which, as stated by ASTM D2974, was graded as medium ash peat (5% < ash< 15%). It was observed that the least decomposed peat appeared to have a low organic content due to the presence of organic material. Based on [5,18], peat has been graded as an organic soil with more than 75% formed and affected by various plant types, temperature, humidity, and location [9].

3.1 Chemical properties

Determination of pH value for peat soil was important for further research into the stabilization of peat soil. pH was established as one of the chemical properties. The pH value of all the nature peat samples for Fibric, Hemic, and Sapric recorded the pH less than 4.5. Similarly [25], also classified Sapric peat as acidic. According to ASTM D2976, it was a highly acidic peat. From the pH meter analysis, Fibric, Hemic, and Sapric recorded 3.29, 3.26, and 3.61, respectively and the Sapric peat was the highest. Based on [26,27], peat acidity varied depending on the degree of degradation of the organic material, the types of plants, the climate and temperature, the microbial activity, and the peat specimen's origin.

The electron micrographs and some parts of the chemical element of peat samples from several areas of Johore representing three forms of peat are shown in Figure 3. The morphology analysis obtained through SEM analysis exposed that all the peat types were observed with different structural formations. Raw peat technically looked similar to the plate or sheet shape like clay type structure [28]. The fibric illustrated the fiber membrane more significantly with the flaky shape plate structure, larger fiber fragments, and porous (Figure 3A) with a carbon content of 75.22% and clay mineral (SiO_2+ Al_2O_3+ Fe_2O_3) recorded 0.85%. In comparison, the hemic peat (Figure 3B) was spotted in random arrangement which was still in loose formation. The presence of fiber cellulose capillary was still visible, with carbon content estimated at 68.67%, with the clay mineral being 0.73%. Figure 3C shows the texture of the sapric peat with almost no presentation of large fragments or plate-like features, which presumably indicated that macropores did not exist with carbon content, and the clay mineral of sapric peat was recorded at 64.21% and 5.87%, respectively. It was revealed [29,30] that peat in coarse condition (fibric and hemic peat) retained a high volume of water in their membrane but with minimal strength due to the woody and porous structure condition. According to [23] statement, certain part of the sapric peat could be in a dense state, whereas the fiber particles were tightly attached to others. In conclusion, it could be noticed that all types of peat had a deficient clay mineral (less than 70% according to ASTM C618) with dominant carbon content. The carbon content of Fibric was the highest compared to Hemic and Sapric peat; and for clay mineral content, the highest was recorded by sapric peat. This argument was confirmed by [29,30] and claimed that the carbon content of peat was very high where the combination of the element clay mineral was deficient, which identified that this type of soil was not great as the foundation on it due to its features of being loose, spongy and brittle [9].

3.2 Engineering properties

The results of Vane Shear and UCS for all the natural peat types are shown in Table 3, Figure 4 shows the pattern of the UCS graph for the entire natural peat that continuously increased up to 15% of the strains, except for the Fibric 1, Hemic 2, and Sapric 1, which dropped slightly. It might be affected by the presence of fibrous material, such as a trunk, which could not be prevented during the field sampling.

All the results of the UCS performed in the laboratory were in the range of the vane shear field test data according to the Equation 1:

$$C_u = q_u / 2 \tag{1}$$

where C_u = Undrained shear strength, and q_u = Unconfined compressive strength

The vane shear results showed that the Fibric peat recorded the highest strength than Hemic and Sapric and recorded 19-28 kPa, 14-22 kPa, and 13-22 kPa, respectively. Overall, UCS data for all peat types were between 9.28- 14.71 kPa, as shown in (Table 3). In comparison, Fibric recorded the highest strength, which was 14.71 kPa, followed by a Hemic which recorded 11.33 kPa, and Sapric recorded the lowest at 9.28 kPa. The effect of the fragment size (degree of decomposition) is the key to the strength. From the observation, the lowest decomposed peat recorded the highest strength among the others, and maybe it acted as reinforcement [16]. According to [13], the natural condition of the peat typically consisted of decaying organic fragments of plants and water with virtually no measurable strength.

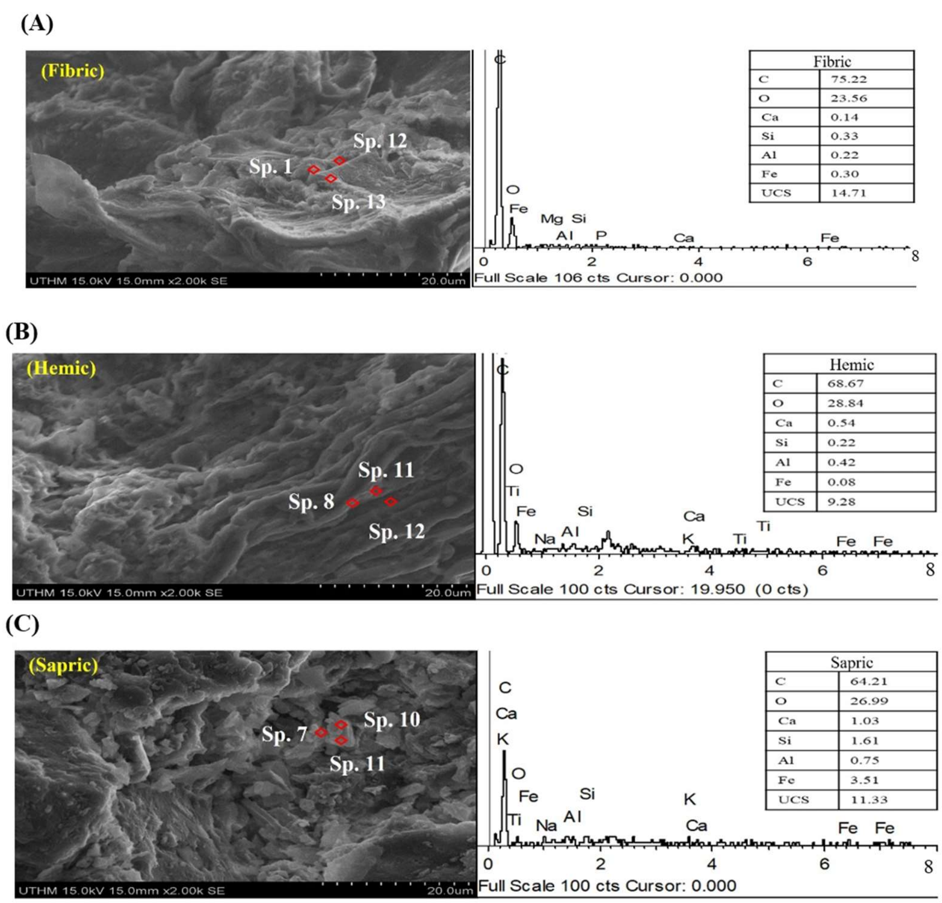

Figure 3 Chemical properties (SEM/ EDX) result of Johore peat, in which (A) Fibric, (B) Hemic, and (C)Sapric.

Table 3 Unconfined compressive strength of Johore peat.

Peat Sample	UCS (kPa)	Vane Shear (kPa)
Fibric	14.71	19- 28
Hemic	11.33	14- 22
Sapric	9.28	13- 22

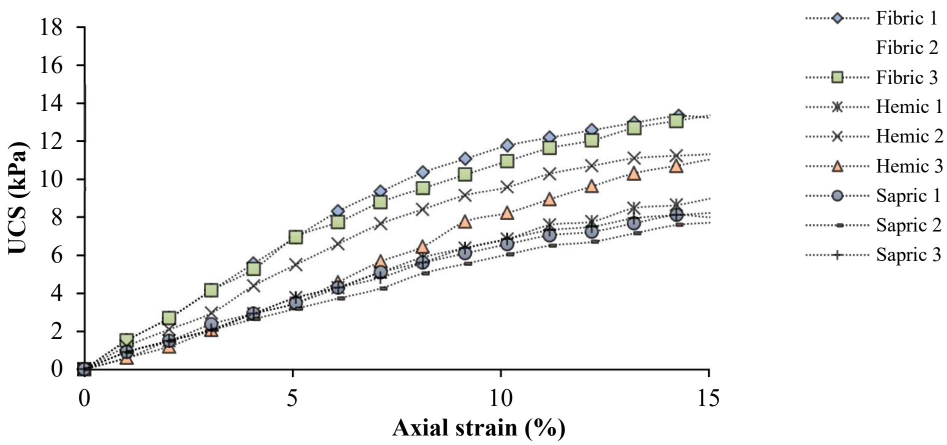

Figure 4 Unconfined compressive strength (UCS) of Johore peat.

4. Conclusion

Based on the observation, the higher decomposed peat attended to record the refined texture of peat (depending on the period of organic decomposition and plant disintegration); lower fiber content (loose structure); the lower water contents (less void space); the lower liquid limit (liquid state could be in transition to the plastic state); the higher unit weight (the soil arrangement more packed or less void), and the higher specific gravity (as, the higher organic constituents and lower specific gravity). The significant result obtained in this study was related to the organic content and pH value. The organic content for all the three types of peat had a recorded pass of over 75% and recorded more than 90%. The organic peat in Southwest Johore areas was very high due to the presence of organic material. At the same time, the pH values for all peat types were classified as highly acidic, which was less than 4.5 due to the presence of humic acid. The Fibric structure of the SEM result showed that its fiber membrane was distinctly porous and hollow with a flaky-shaped plate structure compared to Hemic and Sapric. However, the fiber arrangement for all the peat types still behaved arbitrarily where the EDX analysis showed that all the types of peat recorded inadequate clay minerals with dominant carbon content. In comparison, the carbon content of Fibric was the highest, relative to Hemic and Sapric, while the Sapric was the highest regarding to clay minerals. The UCS showed that the Fibric peat had high strength compared to Hemic and Sapric. This was certainly attributable to the existence of a large hollow fiber structure that acted as reinforcement.

As a recommendation, more studies on peat soil at a different location should be carried out in order to increase the locational factors representing the natural characteristics of the peat properties.

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