INTRODUCTION

Given rapid urbanisation all over the world, peat is likely to become one of the soil foundations for development. That is why it is important to understand the characteristics and structure embedded inside peat, because these play a vital role in its tensile strength. This information is necessary for geotechnical engineers and developers to help them understand foundation laying of buildings. In this research, the focus was more on characteristics that provide tensile strength for peat. Peat is known for its low shear strength and tensile strength, thus developers tend to permanently remove it, rather than working on peat as a foundation for construction. This research will also help to provide further information on stabilising peat for geotechnical engineers.

Peat originates from inhibited decomposition of various plant materials in a waterlogged environment of marshes, bogs and swamps (Asadi et al. 2010).

ABSTRACT

Knowing peat characteristics and its microstructure is of grave importance to agriculturists, engineers and developers. This paper aimed to determine the degree of humification of tropical peat in the state of Sarawak, Malaysia. The peat under study was extracted from Sarawak and the degree of humification was determined based on its physical properties. Data was collected using seven parameters based on the American Society for Testing and Materials (ASTM) and British Standard (BS) method while peat assessment was done using the scanning electron microscope (SEM). The micrograph of peat shows colloidal granular particles with no visible hollow cellular connections. Our findings show that the peat index properties reflect the effect of decomposition and influence of fabric composition on its geotechnical properties. The degree of humification was successfully identified as H7. This implies that the peat sample is highly decomposed in the subsurface. Further research using X-Ray diffraction should be able to correlate the degree of humification with the shear strength of the peat to obtain a better understanding of peat’s microstructure.

Keywords: SEM, microstructure, peat, humification
Natural peats that are formed by complex humification processes from plant residues are important reservoirs of refractory organic carbon in aquatic environments. Peat also has high organic content as it is a result of full decomposition of plant remains. The organic materials range from woody coarse-fibres (fibrous) to fine-fibres (hemic) and amorphous (sapric). The materials depend highly on the parent plant, environmental condition and degree of decomposition (Gylland et al. 2013). The high rainfall and hot temperature of Southeast Asia allows for peat deposits to form and decompose rapidly. Then, there is also the influence of penetrating air and the combination of immense heat with humidity (Huat et al. 2013). Besides, microbes, for instance, fungi, bacteria and microflora, hasten the breakdown of plant remains in aerobic conditions while the accumulation of plant remains intensifies during anaerobic conditions (Pastor et al. 2017). When oxygen is reduced in a water-saturated environment, an anaerobic condition prevails. Temperature, acidity and nitrogen level also affect the rate of decomposition (Kazemian et al. 2011). As studies on microstructure and decomposition effects are limited, good data is not available for the study of peat settlement and strength behaviour.

Due to its high content of humic substances, natural peats exhibit favourable chemical-physical properties enabling its useful application in various areas, for example, wastewater treatment, pollution monitoring, fuel production, and soil fertilising. Past research has established that the ability of humic substances to bind heavy metal ions can be attributed to its high content of oxygen that contains functional groups such as carboxyl, phenol, hydroxyl, enol and structures of carbonyl (Xiao et al. 2017). Humic substances are classified according to their solubility in water as humic acids, fulvic acids and humin. The fractions with a high porous level exhibit a surface area that is very large. The pores available for the internal surface are useful in the adsorption process (Mutalib et al. 1991). Due to its heterogeneity and natural variety, chemical attributes of peat can vary widely among peat deposits. The characterisation of isolated peat samples and its manifold effects is still a challenging task in environmental analytical chemistry as it requires efficient combinations of powerful chemical and spectroscopic methodologies. Further, peat is composed mostly of humus which can generate a lot of methane gas (CH₄), which is a contributor to greenhouse gases that are considered a major cause of global warming. The emission from peat to the atmosphere is dependent on the rates of methane production and consumption and the ability of plants and soil to act as a medium that transports the gas to the surface (Lulie et al. 2005).

Our study on soil index properties and microstructure of decomposed peat was conducted in the laboratory. Soil index properties involve moisture content, particle density, pH, loss on ignition, and organic and fibre content test. The microstructure of Sarawak peat samples and its properties were studied through scanning electron microscope (SEM). A multi-method concept is an important prerequisite for a reliable assessment of beneficial peat effects on the environment.
MATERIALS AND METHODS

Site Description
On Monday, 6th March 2017 at 10.00 am in the morning, the samples were retrieved from Kampung Meranek, Kota Samarahan, Sarawak. The weather condition during the extraction of the samples was sunny and the coordinates for the extraction point was 1°25'37"N, 110°27'33"E. The area where the peat was extracted was surrounded by a pineapple plantation.

Soil Sampling
An auger was used to extract the sample peat from 2m depth. An in-situ Von Post Scale test was conducted by squeezing the peat to determine the scale of humification. Subsequent to extraction of the peat, samples were kept in hard plastic bags that were completely sealed to retain the moisture of the soil and to avoid any external contamination that might affect soil properties.

Laboratory Analysis

Moisture Content
This analysis was based on BS 1377: Part 2 1990. An empty crucible was weighed and labelled w3. Then the soil specimen was also weighed at an approximate weight of 20g and placed into an empty crucible labelled w1. The crucible that was filled with the soil specimen was placed in an oven set at 105°C and this was labelled as w2. The specimen was dried in the oven for a night. The procedure was repeated three times to collect the average percentage moisture content. Finally, the percentage of moisture content was calculated using the following equation:

\[ w\% = \left[ \frac{(w_1 - w_2)}{(w_2 - w_3)} \right] \times 100\% \]  

where
\[ w_1 = \text{weight of empty crucible + saturated soil (g)} \]
\[ w_2 = \text{weight of empty crucible + oven dried soil (g)} \]
\[ w_3 = \text{weight of empty crucible} \]

Moisture content of undisturbed peat sample:

<table>
<thead>
<tr>
<th>Time placed in an oven</th>
<th>14.05 pm</th>
<th>6 March 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time taken out of an oven</td>
<td>14.15 pm</td>
<td>7 March 2017</td>
</tr>
<tr>
<td>Total time in an oven</td>
<td>24 h and 10 min</td>
<td></td>
</tr>
</tbody>
</table>
Moisture content:
1<sup>st</sup> Attempt: 1220%
2<sup>nd</sup> Attempt: 1131.25%
3<sup>rd</sup> Attempt: 1058.82%
Average: 1136.69%

**Particle Density**

Particle density was determined by referring to BS1377: 1990 Test 2. Particle density is the ratio of a unit of dry soil sample to a unit of water. A small pycnometer was used for this analysis. The formula below was used to calculate the particle density of the soil.

\[
G_s = \frac{\left( M_2 - M_1 \right)}{\left( M_4 - M_1 \right) - \left( M_3 - M_2 \right)}
\]  

where

\( m_1 \) = mass of pycnometer + stopper (g)
\( m_2 \) = mass of pycnometer + stopper + dry soil (g)
\( m_3 \) = mass of pycnometer + stopper + soil with water (g)
\( m_4 \) = mass of pycnometer + stopper when full of water (g)

Particle Density Data:

-Density of Kerosene = 810 kg/m<sup>3</sup> = 0.81 mg/m<sup>3</sup>

<table>
<thead>
<tr>
<th>Pycnometer number</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of bottle + peat + kerosene (m&lt;sub&gt;3&lt;/sub&gt;)(g)</td>
<td>75</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>Mass of bottle + peat (m&lt;sub&gt;2&lt;/sub&gt;)(g)</td>
<td>49</td>
<td>49</td>
<td>49</td>
</tr>
<tr>
<td>Mass of bottle full of kerosene (m&lt;sub&gt;4&lt;/sub&gt;)(g)</td>
<td>70</td>
<td>71</td>
<td>71</td>
</tr>
<tr>
<td>Mass of bottle (m&lt;sub&gt;1&lt;/sub&gt;)(g)</td>
<td>31</td>
<td>32</td>
<td>31</td>
</tr>
<tr>
<td>Mass of peat (m&lt;sub&gt;2&lt;/sub&gt;-m&lt;sub&gt;1&lt;/sub&gt;)(g)</td>
<td>18</td>
<td>17</td>
<td>18</td>
</tr>
<tr>
<td>Mass of kerosene in full bottle (m&lt;sub&gt;4&lt;/sub&gt;-m&lt;sub&gt;1&lt;/sub&gt;)(g)</td>
<td>39</td>
<td>39</td>
<td>40</td>
</tr>
<tr>
<td>Mass of kerosene used (m&lt;sub&gt;3&lt;/sub&gt;-m&lt;sub&gt;2&lt;/sub&gt;)(g)</td>
<td>26</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Volume of peat particles ( \frac{(m_4 - m_1)}{(m_2 - m_1)} )</td>
<td>13</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>Particle density, ( G_s ) (mg/m&lt;sup&gt;3&lt;/sup&gt;)</td>
<td>1.38</td>
<td>1.31</td>
<td>1.29</td>
</tr>
</tbody>
</table>

Particle density \( G_s \) = 1.33
**Loss on Ignition**
The loss on ignition of peat can be determined by the percentage of oven dried mass. The calculation of loss on ignition can be retrieved by applying this formula:

\[ N\% = \left[\frac{(m_2 - m_3)}{(m_2 - m_1)}\right] \times 100\% \quad (3) \]

where
\[ m_1 = \text{mass of crucible (g)} \]
\[ m_2 = \text{mass of crucible and dry soil (g)} \]
\[ m_3 = \text{mass of crucible and dry soil after ignition (g)} \]

**Organic Content**
The analysis was based on BS 1377: 1990 Test 3. The percentage of organic content was calculated using this formula:

\[ OC\% = 1 - 1.04(C-N) \quad (4) \]

where
\[ C = 1 \text{ for } 4400^\circ \text{ or } 1.04 \text{ for } 5500^\circ \text{ temperature} \]
\[ N = \text{ignition loss} \]

Loss on ignition and organic content of dried peat sample
Mass of crucible after 1 h in furnace
\[ m_{1a} = 38.97 \text{ g} \quad m_{1b} = 35.98 \text{ g} \quad m_{1c} = 39.95 \text{ g} \]

Mass of crucible and dried oven sample
\[ m_{2a} = 46.34 \text{ g} \quad m_{2b} = 42.53 \text{ g} \quad m_{2c} = 46.22 \text{ g} \]

Mass of crucible and sample after 5 h in furnace
\[ m_{3a} = 39.62 \text{ g} \quad m_{3b} = 36.38 \text{ g} \quad m_{3c} = 40.56 \text{ g} \]

Loss on ignition:
1\text{st} attempt: 91.18\%
2\text{nd} attempt: 93.89\%
3\text{rd} attempt: 90.27\%
Average: 91.78\% & Organic content: 91.27\%

**Fibre Content**
The fibre content can be determined from the dry weight of the fibres retained on the 150µm sieve. Approximately about 100g of soil specimen was placed into a sieve and soaked into the water for 24 h and washed until all the soil particles passed through the sieve. The sample specimen was then kept in the oven for one night and weighed. The fibre content was calculated by applying this formula.

\[ \text{Fibre Content } nt = \left[\frac{(M_2 - M_1)}{100}\right] \times 100\% \quad (5) \]
where
\( m_1 \) = mass of 150 µm sieve
\( m_2 \) = mass of 150 µm sieve + retained soil

Mass of 150 µm sieve
\( m_{1a} = 30.1 \text{ g} \)
\( m_{1b} = 30.1 \text{ g} \)
\( m_{1c} = 30.1 \text{ g} \)

Mass of 150 µm sieve + retained soil
\( m_{2a} = 35.8 \text{ g} \)
\( m_{2b} = 35.8 \text{ g} \)
\( m_{2c} = 35.8 \text{ g} \)

Fibre content
1\(^{st}\) attempt: 5.7%
2\(^{nd}\) attempt: 5.7%
3\(^{rd}\) attempt: 5.7%
Average: 5.7%

**Bulk Density**

For determination of bulk density of soil samples, the simplest method is to measure volume and mass or weight.

\[
P_\beta = \frac{M}{V_a}
\]

where \( P_\beta \) is bulk density \((\text{g/cm}^3)\), \( M \) is mass \((\text{g})\), and \( V_a \) is the bulk volume including both solid and pore volume \((\text{cm}^3)\). If mass \( M \) is measured using dry peat sample, \( P_\beta \) is the bulk dry density while bulk wet density is determined by the mass of the peat sample at a water saturated state.

**Peat pH Value**

Peat is naturally acidic, and this test proved that it is acidic in its natural state. The data was extracted on site by submerging the pH meter into the subsoil to retrieve the readings.

**Microstructure Analysis**

The peat samples were first air dried at room temperature for approximately two weeks. This was to prevent the organic material from crumbling when exposed to drying in the oven at a high temperature. Then, the air-dried sample was smashed using a rubber hammer and kept in an airtight polythene bag. Next, the sample was sprinkled on 5 mm aluminium stubs, and overlaid with double-sided carbon tape as a form of adhesive to attach the sample to the stubs. The sample was coated with a thin layer of gold in a sputtering diode system for 10 min to allow repulsion of the scattered electron that hits the surface of the sample when it is placed into the SEM.
RESULTS AND DISCUSSION

Peat Properties
The scale of humification for the retrieved peat sample was H7 which can be categorised as sapric type of peat, as it contained less than 33% of fibre content and its capacity to trap water was small compared to fibric or hemic type of peat. Furthermore, it had low permeability, compressibility and friction angle while its coefficient of earth pressure increased at rest. Table 1 gives the moisture content, loss of ignition, organic content, fibre content, bulk density, particle density and pH values as 1136.69%, 91.78% 91.27% 5.7% 1.15 mg/m³, 1.33, and pH 3.57, respectively.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Von post degree of humification</td>
<td>H7</td>
</tr>
<tr>
<td>Moisture content</td>
<td>1136.69%</td>
</tr>
<tr>
<td>Loss on ignition (LOI)</td>
<td>91.78%</td>
</tr>
<tr>
<td>Organic content</td>
<td>91.27%</td>
</tr>
<tr>
<td>Fibre content</td>
<td>5.7%</td>
</tr>
<tr>
<td>Bulk density</td>
<td>1.15 mg/m³</td>
</tr>
<tr>
<td>Particle density</td>
<td>1.33</td>
</tr>
<tr>
<td>pH</td>
<td>3.57</td>
</tr>
</tbody>
</table>

Moisture Content
Moisture content of the peat samples was not affected or influenced by the surrounding environment. The results are presented in Table 2 which shows that the average moisture content for the peat samples is 1136.69% which is more than 200%. Thus, the peat samples can be categorised as sapric peat.

<table>
<thead>
<tr>
<th>Sample number</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content, %</td>
<td>1220</td>
<td>1131.25</td>
<td>1058.82</td>
</tr>
<tr>
<td>Average moisture, %</td>
<td></td>
<td>1136.69</td>
<td></td>
</tr>
</tbody>
</table>
**Loss on Ignition (LOI) and Organic Content**

The above two tests were done after conducting a moisture content test because dried samples are needed to conduct these two tests. The results are shown in Table 3. The samples collected from the study area (Kampung Meranek) possessed a high organic content range of above 75%. The LOI percentage depends on the capability of a soil sample to ignite when it is exposed to high temperatures. Certain peat samples can easily ignite when exposed to high temperatures and tend to lose a lot of their mass in this manner.

<table>
<thead>
<tr>
<th>Sample number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss on ignition, %</td>
<td>91.18</td>
<td>93.89</td>
<td>90.27</td>
<td>91.78</td>
</tr>
<tr>
<td>Organic content, %</td>
<td>90.27</td>
<td>93.65</td>
<td>89.88</td>
<td>91.27</td>
</tr>
</tbody>
</table>

**Fibre Content**

The fibre content test was only 5.7% indicating that that soil samples did not contain much fibre. As this result is rated below 33%, this peat sample is considered a sapric type of peat. It is also known that this type of peat has organic matter composition ranging from medium to high.

**Bulk Density**

The bulk density value of 1.15 mg/m$^3$ had been obtained during soil sample retrieval. When the bulk density obtained ranges between 0.8 and 1.2 mg/m$^3$, it is categorised as a typical bulk density of peat.

**Particle Density**

The data collected for particle density test are shown in Table 4. The average value for particle density was 1.33 while the range for the density of the peat particle from Samarahan, Sarawak peat was from 1.07 to 1.63.

<table>
<thead>
<tr>
<th>Sample number</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle density, G$_s$ (mg/m$^3$)</td>
<td>1.38</td>
<td>1.31</td>
<td>1.29</td>
</tr>
<tr>
<td>Average value, G$_s$</td>
<td></td>
<td></td>
<td>1.33</td>
</tr>
</tbody>
</table>
**pH Value**

An average pH value of 3.57 was obtained. Table 5 shows that the values settled between the range of pH 3.56 to pH 3.58 which is an average pH value for Sarawak peat.

<table>
<thead>
<tr>
<th>pH Test number</th>
<th>pH value, pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.57</td>
</tr>
<tr>
<td>2</td>
<td>3.58</td>
</tr>
<tr>
<td>3</td>
<td>3.56</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>3.57</strong></td>
</tr>
</tbody>
</table>

**Microstructure Study and Analysis**

Scanning electron microscope (SEM) is an electron microscope that is able to capture and observe an image of a sample by scanning its surface with a focused beam of electrons. The electrons tend to interact with the atoms in the sample. It will then form a raster scan pattern, and the position of the beam will be combined with the signal detected to produce the image. SEM can reach a resolution of better than 1 nanometre. The specimen can be observed in a high or low vacuum condition, or even in wet conditions under multiple pressure. The micrograph magnification range is from x100µ to x 500µ.

The images were taken at various micrograph magnifications of the microstructures (Figures 1, 2, 3). The microstructure is homogeneous non-crystalline micro-particles that are colloidal in structure and jelly-like in texture. Figures 2, 4 and 5 show that peat is slightly compact, and it can be observed in Figures 4, 5 and 6 that the particles have a honeycomb and poriferous structure. This condition shows peat to be spongy and fragile and can rupture due to the void which can be exploited for an increase in water retention. This is attributed to its composition of fibric organic content that has more porous space. The colloidal structure in Figures 7 and 8 do not indicate any intra-assemblage pore space, but surfaces seem to be bonded by pore water. The colloidal microstructure in peat indicates a highly humified granular material that ranges from H7 to H10 in the Von-Post classification. Organic colloids are very small in size (less than 2 µm) because it is formed from humified peat with less fibre. It is a product of secondary synthesis of peat and is chemically active due to its small size and high electrical charge. Furthermore, no hollow perforated cellular structure was found in the SEM micrographs. The intra-particle space in peat was reduced, and the water storage capacity was hindered because only water can fill the inter-particle voids. Moreover, the moisture content in peat is lower than that of fibrous peat. The fibrous peat can store water within the hollow cellular fibres and in the inter
Figure 1: SEM peat sample, Kg. Meranek
Figure 2: SEM micrograph, honeycomb

Figure 3: Inter-assemblage pores
Figure 4: Poriferous cellular particle

Figure 5: Honeycomb structure
Figure 6: Poriferous structure

Figure 7: Colloids structure
Figure 8: Dimpled colloid structure
particle voids between the fibres. This will cause the peat particle to become more gelatinous and compact with a relatively high particle density.

**CONCLUSIONS**

It can be concluded that the samples were dominated by highly decomposed organic contents using the soil index properties and SEM. The particle density of 1.33 is higher than the other types of peat, and the decrease in water content shows a reduction in fibrosity. The SEM micrograph of the fibrous peat showed a hollow cellular structure which had disintegrated into a colloidal texture. Hence, the gelatinous, compact texture of peat resulted in non-availability for water storage in the intra-particle arrangement. Therefore, this peat had a high void ratio where its compressibility can be assumed to be as high as its void spaces. This research makes a contribution to areas of soil sciences and agricultural engineering as it provides enhanced understanding of peat characteristics. It is suggested that future studies use techniques such as the X-Ray Diffraction (XRD) to improve the accuracy of the current work.

**Conflict of Interest**

The authors declare that there is no conflict of interests regarding the publication of this paper.

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This research did not receive any funds.

**REFERENCES**


