International Journal of the Physical Sciences Vol. 6(8), pp. 1988-1996, 18 April, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.192
ISSN 1992 - 1950 ©2011 Academic Journals

Full Length Research Paper

State of an art review of peat: General perspective

Bujang B. K. Huat[1], Sina Kazemian[2]*, Arun Prasad[3] and Maassoumeh Barghchi[2]

[1]Department of Civil Engineering, University Putra Malaysia, Serdang, Selangor, Malaysia.
[2]Department of Civil Engineering, Bojnourd Branch, Islamic Azad University, Bojnourd, Iran.
[3]Department of Civil Engineering, Banaras Hindu University, Varanasi, India.

Accepted 24 March, 2011

Peat can be defined as the accumulation of 100% pure organic material which contains at least 65% organic matter or less than 35% mineral content. The distribution of peat deposits is extensive. It constituents 5 to 8% of the earth land surface and nearly 60% of the wetlands of the world are peat. The composition of peat differs from location to location. This is due to the reasons such as the origin fibre, climate and humidity. Physical properties of peat are greatly dependent to a large degree on porosity and pore-size distribution. These in turn are related to particle-size distribution. Both the particle size and structure and the resulting porosity of peat are controlled primarily by the degree of decomposition. With increasing decomposition, the size of organic particles decreases, resulting in smaller pores and more dry material per unit volume. Generally, the texture of peat is considered coarse when compared with clay. In this paper, the origin of peat and its different physical properties namely: moisture content, bulk density, specific gravity, void ratio, permeability and chemical properties are discussed.

Key words: Peat, humification, physical properties, chemical properties.

INTRODUCTION

Peat is a type of soft soil with high content of fibrous organic matters. Peat can also be defined as the accumulation of 100% pure organic material which contains at least 65% organic matter or less than 35% mineral content (Muhamad et al., 2010). Huat (2004) has reported that the content of peat differs from location to location and the factors responsible for this are origin fibre, temperature, climate and humidity to name a few. Decomposition (humification) is a process of decrease of organic matter that causes the disappearance of the peat structure and changing the primary chemical composition of the peat. The organic contents are essentially remains of plants whose rate of decay is slower than the rate of accumulation. Generally, the deposit is found in thick layers on limited areas. Basically, peat is predominantly made up of entirely of plant remains such as leaves and stem. It is produced by the incomplete decomposition and disintegration of sedges, trees, mosses and other plants growing in wet place and marshes in the condition of lack of oxygen. Therefore, the color of peat usually is dark brown or black and with a distinctive odor (Craig, 1992). Since the main component is organic matter, peat is very spongy, highly compressible and combustible in characteristic (Roy, 2004). This characteristic also makes peat pose its own distinctive geotechnical properties compared with the other inorganic soils like clay and sandy soils which are made up only by the soil particles (Deboucha et al., 2008).

In agricultural use, fens and raised bogs need to be drained to adjust the water and air in the soil to meet up with the conditions of cultivated or pasture plants. Due to the removal of water from the upper peat by drainage and subsequently by oxidation, leads to compaction and thereby subsidence of the surface. The release of CO_2 and N_2O is increased due to the drainage of peat but the release of CH_4 decreases. The rates of release depend on factors such as level of groundwater and burning CO_2, the temperature of peat, but gases like CH_4 and N_2O are also released. During the process of peat extraction, the green house gas (GHG) sink function of the peat land is lost. The emissions of these gases also occur while preparing the surface for removal of vegetation and ditching, extraction of peat and its storage and transportation, and also due to the combustion and

*Corresponding author. E-mail: sina.kazemian@gmail.com.

Table 1. Physical properties of peat based on location (Huat, 2004).

Soil deposits	Natural water content (ω_o, %)	Unit weight, γ (kN/m^3)	Specific gravity (G_s)	Organic content (%)
Fibrous peat, Quebec	370-450	8.7-10.4	-	-
Fibrous peat Antoniny, Poland	310-450	10.5-11.1	-	65-85
Fibrous peat, Co. Offaly Ireland	865-1400	10.2-11.3	-	98-99
Amorphous peat, Cork, Ireland	450	10.2	-	80
Cranberry bog peat, Massachusetts	759-946	10.1-10.4	-	60-77
Austria	200-800	9.8-13.0	-	-
Japan	334-1320	-	-	20-98
Italy	200-300	10.2-14.3	-	70-80
USA	178-600	-	-	-
Canada	223-1040	-	-	17-80
Hokkaido	115-1150	9.5-11.2	-	20-98
West Malaysia	200-700	8.3-11.5	1.38-1.70	65-97
East Malaysia	200-2207	8.0-12.0	-	76-98
Central Kalimantan	467-1224	8.0-14.0	1.50-1.77	41-99

after-treatment of the cutaway area. Combustion accounts for more than 90% of the greenhouse gas emissions. Sometimes the plant fibers are visible but in the advanced stages of decomposition, they may not be evident. Peat will ultimately be converted into lignite coal over geologic periods of time provided favorable conditions prevail. Also, the fresher the peat, the more fibrous material it contains and as far as engineering is concerned, the more fibrous the peat, the higher is the shear strength, voids ratio and water content. In fact, the property of the peat is greatly dependent on the formation of peat deposits. This means that peat at different location will have different properties (Table 1). Commonly, the classification of peat is developed based on fiber content, organic content, and ash content. Decomposition is the breakdown process of the plant remains by the soil micro flora, bacteria and fungi in the aerobic decay. In this procedure, as mentioned earlier, there is disappearance of the peat structure and change in the primary chemical composition of peat. At the end, carbon dioxide and water are the products of the decomposition process.

The degree of decomposition varies throughout peat since some plants or some parts of the plants are more resistant than others. Also, the degree of decomposition of peat depends on a combination of conditions, such as the chemistry of the water supply, the temperature of the region, aeration and the biochemical stability of the peat-forming plant (Lishtvan, 1981).

Distribution of peat area

Asadi et al. (2009) has reported that peat deposits are found when the conditions are favorable for their accumulation and formation. The distribution of peat deposits is extensive and can be found in many countries throughout the world. The peat land consists of nearly 5 to 8% of the earth land surface and nearly 60% of the wetland of the world is peat. While the areas occupied by the tropical peat land is about 30 million hectares and two third of that are in South East Asia. In Indonesia, the peat covers about 26 million hectares of the country land area. In Japan, peat is widely distributed through Hokkaido with approximately 2,000 km^2 which equals to 6% of the flat area of the island (Figure 1). In Malaysia, peat has been classified as one of the major soil group. Peat covers approximately 8% of the land or 3 million hectares. Among these lands, 6,300 hectares of the peat lands are found in Pontian, Batu Pahat and Muar in West Johore (Yulindasari,

Figure 1. Tropical peat land of Southeast Asia (Huat, 2004).

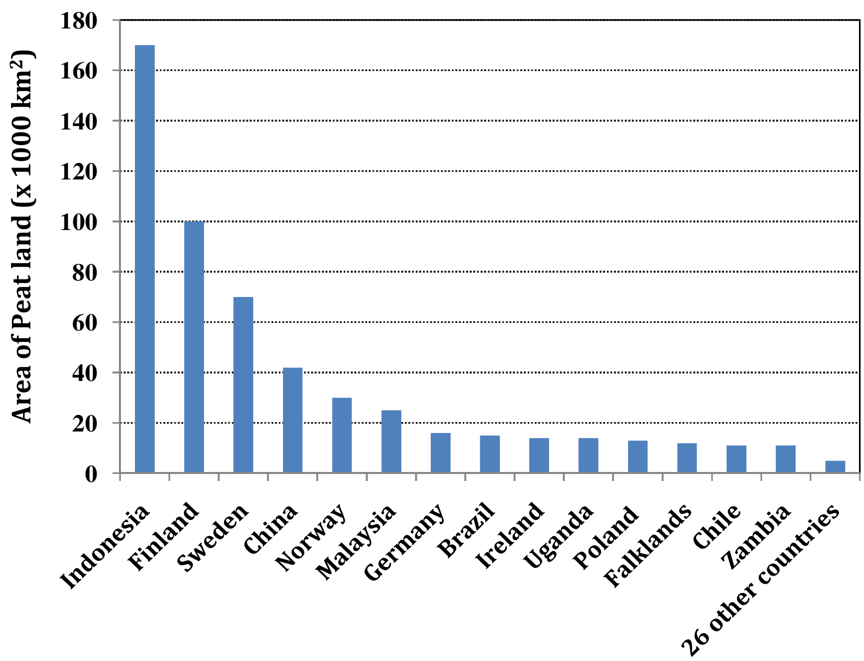

Figure 2. The area of Peatlands in some countries of the world (Mesri and Ajlouni, 2007).

2006). The state that covers the largest area of peat land in Malaysia is Sarawak which is about 13% of the state area or 1.66 million hectares (Said and Taib, 2009). The two countries that have the largest areas of peat are Canada and Russia, at 170 and 150 million hectares respectively.

In US, peat covers a total area of 30 million hectares and can be found in 42 states (Mesri and Ajlouni, 2007). Figure 2 shows the area of peat lands in some countries of the world.

Peat classification

Generally, physical, chemical and physico-chemical properties of peat such as texture, organic content, minerals

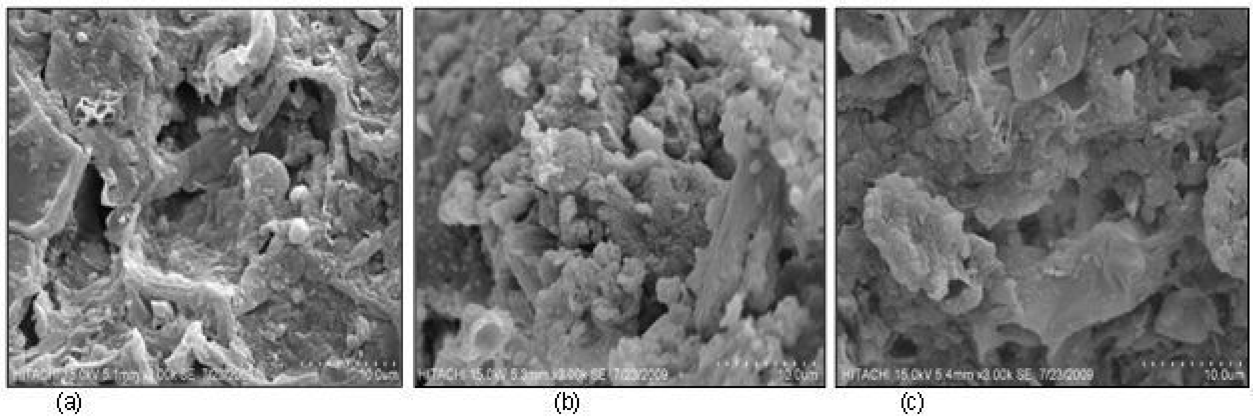

Figure 3. Scanning electron micrograph of peats: (a) fibrous, (b) sapric and (c) hemic.

content, pH, color, water content and degree of decomposition could serve as a basis for its classification. Other classifications may be based on the origin of peat and the field conditions during deposition. Most of the time, peats are classified on the basis of the constituent plants rather based on their texture and composition (Davis, 1997). Degree of decomposition is usually assessed by using von Post (1992) scale. von Post scale is a classification system which is based on a number of factors such as botanical composition, degree of humification, and the color of peat water after squeezing. In this classification system, there are ten degrees of decomposition ranging from H_1 (very fibrous) to H_{10} (very few fibers), which represent the state of decomposition/decay of the organic plant remains. Higher the number in von Post scale, higher is the degree of decomposition. The degree of decomposition is determined to be ten degree based on the appearance of soil water coming out upon squeezing the soil in the hand. Peats near the surface fall into the H_3 and H_4 categories, but with increasing depth it would be classified as H_5 to H_7.

According to the American society for testing and materials (ASTM) standard (ASTM, 1990) peat classification has been narrowed to only three classes based on fiber content, ash content and acidity of soil. In fiber content classification, peat is divided in to three groups: (i) fibric (fibrous; least decomposed with more than 67% fiber content), (ii) hemic (semi-fibrous; intermediate decomposed) and (iii) sapric (amorphous; most decomposed with less than 33% fiber content). Fibrous peat has a high organic and fiber content, with a low degree of humification. It consists of undecomposed fibrous organic materials, is easily identifiable and extremely acidic. Sapric peat contains highly decomposed materials. The original plant fibers have mostly disappeared and the water-holding capacity is generally less than that of either fibrous or hemic peat. It is generally very dark grey to black in colour and is quite stable in its physical properties. Compared with fibrous peat deposits, sapric peat deposits are likely to exist at lower void ratios and display lower permeability, lower compressibility, a lower friction angle and a higher coefficient of earth pressure at rest. Hemic peat have properties intermediate between fibrous and sapric peats. Figure 3 shows the scanning electron micrograph (SEM) of fibrous, hemic and sapric peats. According to the classification of von Post (1922) and ASTM (1990) classification from fiber content view point, the groups H_1 to H_4 containing more than 66% fibers are called fibrous peat. The Hemic peat is the groups H_5 to H_7 and consists of 33 to 66% fibers. The last three groups that is, H_8 to H_{10} having less than 33% of fibers is sapric peat.

In general, ASTM D4427 (1990) emphasized that peat be grouped into two categories; amorphous and fibrous peat. Peat with fiber content of less than 20% is classified as amorphous peat. Most of the particles present in amorphous peat are of colloidal size that is, less than 2 µm and the particle surface is surrounded by the absorbed pore water. The other classifications of soils inASTM (1990) are based on their ash content and organic content. In this classification, a soil is classified as peat if the organic content is more than 75% and ash content is less than 25%. The ash content is obtained by igniting peat (dry ash) at a temperature of 750°C or chemical oxidation (wet ash) using hydrogen peroxide (H_2O_2) or sodium hypochlorite (NaOCl) (Wüst et al., 2003). In Peninsular Malaysia, the ash content and organic content of peat are at an average of 3.55 and 96.45% respectively. These show that peat has very high content of organic matter and indicate the loss of ignition value exceeding 90% (Islam and Hashim, 2008a, b).

Fiber content is a further method used to classify peat. Fiber content is measured by using wet sieving process. The fiber collected from the sieves was oven-dried, weighed and then compared to the oven-dry weight of the

Table 2. Classification of peat in ASTM according to fiber content, ash content and acidity (ASTM, 1990).

Classification of peat based on ASTM standard	
Fiber Content (ASTM D1997)	Fibric: Peat with greater than 67% fibers. Hemic: Peat with between 33% and 67% fibers. Sapric: Peat with less than 33% fibers.
Ash Content (ASTM D2974)	Low ash: Peat with less than 5% ash. Medium ash: Peat with between 5% and 15% ash. High ash: Peat with more than 15% ash.
Acidity (ASTM D2976)	Highly acidic: Peat with a pH less than 4.5. Moderate acidic: Peat with a pH between 4.5 and 5.5. Slightly acidic: Peat with a pH greater than 5.5 and less than 7. Basic: Peat with a pH equal or greater than 7.

original sample (Boelter, 1968). Fibers may be fine (woody or non- woody) or coarse (woody). Table 2 shows the other classification of peat mentioned in ASTM according to fiber content (ASTM D1997), ash content (ASTM D2974) and acidity (ASTM D2976). Figure 4 shows the muffle furnace for finding the ash content in soils.

Physical characteristics of peat

There are a few unique physical properties of peat which should be taken into account when discussing it. Hobbs (1986) stated that the physical characteristics such as colour, degree of humification, water content and organic contents should be included in a full description of peat.

They are influenced by main component of the formation such as mineral content, organic content, moisture and air. When one of these components changes, it will result in the changes of the whole physical properties of peat. The variation in the characteristics of peat is very large both horizontally and vertically. The variability is a result of the differences in climate, water level, aging and the quantity of inorganic soils deposited during peat accumulation. Thus, this variability makes peat possess a very wide range of physical properties such as color, texture, density, specific gravity and water content. Boelter (1968) reported that the physical properties of peat are highly affected by the porosity and the distribution of the pore-size. Both these parameters are related to grain size distribution. The degree of decomposition affects the porosity of peat and the porosity is controlled by both the particle size and structure of peat. With an increase in the decomposition, the particle size of organic matters decreases. These results in more dry material per unit volume and smaller pores (Boelter, 1968).

Generally, the texture of peat is considered coarse when compared with clay. This is related to the particle size and compressibility behavior of peat which is the geotechnical properties of peat (Gofar, 2006).

Water content

One of the important and most variable properties of peat is its water content. The value of water content depends on the origin, degree of decomposition and the chemical composition of peat. Naturally, peat has very high natural water content due to its natural water-holding capacity. The high natural water holding capacity is because of the soil structure characterized by organic coarse particles (fibers) which can hold a considerable amount of water since the soil fibers are very loose and hollow. The high water content is also because peat has low bulk density and low bearing capacity as results of high buoyancy and high pore volume. Ajlouni (2000), and Ajlouni and Mesri (2009) emphasized that the water content of peat may range from 200 to 2000% which is quite different from that for clay and silt deposits which rarely exceed 200%. Water content of fibrous peat generally is very high. It is because fibrous peat holds a considerable amount of water as its organic coarse particles are generally very loose and the organic particles itself are hollow and largely full of water. In West Malaysia, the water content ranges from 200 to 700% (Huat, 2004).

Bulk density

The bulk density (unit weight) of peat is both low and variable compared to mineral soils. The average bulk density of fibrous peat is around the unit weight of water (9.81 kN/m^3). Huat (2004) found that a range of 8.3 to 11.5 kN/m^3 is common for unit weight of fibrous peat in Peninsular Malaysia. Unit weight of the peat will be affected by the water content of peat; as the water content increase, the unit weight will show a sharp reduction, water content about 500%, the unit weight ranges from 10 to 13 kN/m^3 (Jarret, 1995; Kazemian et al., 2009a). Similar with the specific gravity, the bulk density of peat depends on the structure and degree of decomposition. Bulk density of peat is usually smaller than the mineral soils due to the lower specific gravity of the solids found and the higher water holding capacity in peat and the presence of gas. Bulk density is equal to the mass of material per unit bulk volume. It can be used not only as a measure of decomposition, but also for converting water and nutrient content measured on a weight-per-unit-weight basis to the more useful volume-per-unit-volume or weight-per-unit-volume. When peat materials are dried, their volume reduces considerably. Therefore, to make sure the bulk density is representing the field condition, it must be calculated on the basis of the wet bulk volume. If bulk densities are measured using a reduced volume, they will be too high and volumetric water contents calculated with these values will also be too high (Boelter, 1968).

Specific gravity

Specific gravity of peat is greatly affected by its composition and percentage of inorganic component. It is related to the degree of decomposition and mineral content of peat. Higher specific gravity indicates a higher degree of decomposition and higher mineral content. For peat with an organic content of 75% and greater, the specific gravity is in the range from 1.3 to 1.8 with an average of 1.5 (Davis, 1997; Ajlouni, 2000). The bulk density for the top 0.3 m of peat is low and varies from 0.1 to 0.2 g/cm^3 in peat of Peninsular Malaysia and Sarawak (MARDI, 2009). In fact, above 600% water content, both the specific gravity and water content do not greatly influence bulk density. On the other hand, low influence is attributed to higher degree of saturation or gas content (Hobbs, 1986; Bell, 2000). Peats frequently are not saturated and may be buoyant under water due to the presence of gas. Except at low water contents (less than 500%) with high mineral contents, the average bulk density of peats often is slightly lower than that of water.

Void ratio

Generally, peat has higher void ratio compared toinorganic soils and it indicates that peat has high compressibility capacity. The natural void ratio commonly ranges from 5 to 15 and it is reported around 25 for fibrous peat by Hanrahan (1954). Peat will shrink when it gets dry and the shrinkage could reach 50% of the initial volume. However, the dried peat will not swell up upon re-saturation due to the incapability of dried peat to absorb water as much as initial condition; only 33 to 55% of the water can be reabsorbed (Mochtar, 1997).

Permeability

Permeability plays a vital role in the properties of peat because it controls the rate of consolidation and increase in the shear strength of the soil (Hobbs, 1986). The permeability of the peat is dependent on the void ratio, mineral content, degree of decomposition, chemistry, and the presence of gas. The degree of permeability is determined by applying a hydraulic pressure difference across a sample of fibrous peat soil, which is fully saturated, and measuring the consequent rate of flow of water. The coefficient of permeability is expressed in terms of velocity and Darcy’s law is used to determine the flow of water through fibrous peat soil (Wong, 2005; Wong et al., 2008). Peats have very high void ratios because peat particles are large and porous. Due to their large pore sizes and large void ratios, only clean sand displays permeability higher than those of fibrous peats. Therefore, high initial permeability is one of the distinctive characteristic of fibrous peats (Lea and Brawner, 1963). A range of permeability coefficient of 10^{-5} to 10^{-8} m/s was obtained from previous studies (Colley, 1950; Miyakawa, 1960). Constant head permeability and Rowe cells consolidation have been used to determine the vertical and horizontal coefficient of permeability of fibrous peat.

Mesri et al. (1997) have carried out permeability measurements during the secondary compression stage through oedometer tests on Middleton peat. According to this study, a typical void ratio is 12. During consolidation, the permeability of peat will decrease drastically after dissipation of measurable excess pore water pressure (Dhowian and Edil, 1980). Research on Portage fibrous peat shows the peat initially has a relatively high permeability comparable to fine sand or silty sand; however, as compression proceeds and void ratio decreases rapidly, permeability is greatly reduced (about 10,000 fold) to a value comparable to that of clay. These findings agree with Mesri et al. (1997) findings that stated the initial permeability of peat is typically 100 to 1000 times the initial permeability of soft clay and silt deposits. Also, at a given void ratio, the horizontal coefficient of permeability is higher than its vertical coefficient of permeability. This also indicates that horizontal coefficient of consolidation of Portage peat is greater than its vertical coefficient of consolidation (Gofar, 2006).

The hydraulic conductivity of peat is also controlled by density (or degree of consolidation) and extent of decomposition but these factors always change with time so resulting in a change in hydraulic conductivity. At its natural state, peat can have a hydraulic conductivity as high as sand which is about 10^{-5} to 10^{-4} m/s. The finding also showed that the rate of decrease of hydraulic conductivity with decreasing void ratio is usually higher than that in clays (Edil, 2003).

The large decrease in hydraulic conductivity under continuous compression indicated that large strain theory of consolidation may be appropriate for high water content fibrous peat (Gofar, 2006; Lan, 1992).

Chemical characteristics of peat

The chemical properties of peat are affected by the chemical composition of peat's components, the environment in which they were deposited and the extent of decomposition. The chemical characteristics of peats include chemical composition, cation exchange capacity (CEC) and acidity. Primarily, the peat is made up by carbon, hydrogen, oxygen and small amount of nitrogen. The percentage of carbon (C), oxygen (O), hydrogen (H) and nitrogen (N) are in the ranges of 40 to 60%, 20 to 40%, 4 to 6% and 0 to 5% respectively (Chynoweth, 1983; Schelkoph and Hasset, 1983; Andriesse, 1988; Katase et al., 1991). The compositions of peat are different with locations as its content is greatly depending on temperature and degree of decomposition (Deboucha et al., 2008). Normally a higher temperature will enchance the higher rate of biochemical degradation and cause the higher degree of decomposition furthermore, the high decomposition rate in peat cause to decrease the carbon rate in the decomposed peat (Ajlouni, 2000). Generally, peats are in an acidic condition and the pH value often lies between 4 to 7 (Lea, 1956). West Malaysia peats have very low pH values ranging from 3.0 to 4.5, in some cases where sulphide materials are found within the profile, pH values can be below 3.0 (MARDI, 2009). The acidity of peat is decreasing with depth and the decrease may be large near the bottom layer depending on the type of the underlying soil (Waksman, 1942; Muttalib et al., 1991; Ajlouni, 2000; Kazemian et al., 2009a, b, c, d, e; Kazemian et al., 2010a, b).

Peats have high cataion exchange capacity (CEC). The main exchangeable sites are the functional acid groups which is named humic acids. The most common exchangeable cations in peats are Ca^{2+}, Mg^{3+}, Al^{3+}, K^+, Na^+, $(NH_4)^+$. Aho (1986) found that, the CEC will increase with an increase in pH value and the exchangeable cation concentration. Among the peats, the CEC for fibrous peat is larger than others. The property of CEC is very important if the peat is used as a waste water treatment agent (Ajlouni, 2000). The submerged organic component of peat is not totally inert. It undergoes extreme slow decomposition that produces the methane and less amounts of nitrogen, carbon dioxide and hydrogen sulphide. Physical properties measured and field performance related to compression and water flow are affected by gas content. However, the gas content is hard to determine due to unavailable of recognized method. Muskeg Engineering Handbook (1969) reported a gas content of 5 to 10% of the total volume of peat.

Conclusions

Peat is defined as the accumulation of 100% pure organic material which contains at least 65% organic matter or less than 35% mineral content. The decomposition (humification) is the loss of organic matter that causes the disappearance of the peat structure and changing the primary chemical composition of the peat.
The organic contents are essentially remains of plants whose rate of accumulation is faster than the rate of decay. Since the main component is organic matter, peat is very spongy, highly compressible and combustible in characteristic. This characteristic also makes peat pose its own distinctive geotechnical properties compared with the other inorganic soils like clay and sandy soils which are made up only by the soil particles. von Post scale is a classification system which is based on a number of factors such as botanical composition, degree of humification and the colour of peat water after squeezing. In this classification system, there are ten degrees of decomposition ranging from H_1 (very fibrous) to H_{10} (very few fibers), which represent the state of decomposition/decay of the organic plant remains. According to the American Society for Testing and Materials (ASTM) standard (ASTM, 1990) peat classification has been narrowed to only three classes based on fiber content, ash content and acidity of soil.

Physical properties of peat are greatly dependent to a large degree on porosity and pore-size distribution. These in turn are related to particle-size distribution. Both the particle size and structure and the resulting porosity of peat are controlled primarily by the degree of decomposition. With increasing decomposition, the size of organic particles decreases, resulting in smaller pores and more dry material per unit volume. Naturally, peat has very high natural water content due to its natural water-holding capacity. The high natural water holding capacity is because of the soil structure characterized by organic coarse particles (fibers) which can hold a considerable amount of water since the soil fibers are very loose and hollow. It has been emphasized that the water content of peat may range from 200 to 2000% which is quite different from that for clay and silt deposits which rarely exceed 200%. The bulk density of peat is both low and variable compared to mineral soils. The average bulk density of fibrous peat is around the unit weight of water (9.81 kN/m^3). For peat with an organic content of 75% and greater, the specific gravity is in the range from 1.3 to 1.8 with an average of 1.5. The natural void ratio commonly ranges from 5 to 15 and it is around 25 for fibrous peat. Peat will shrink when it gets dry and the shrinkage could reach 50% of the initial volume.

Permeability plays a vital role in the properties of peat because it controls the rate of consolidation and increase in the shear strength of the soil. A range of permeability coefficient of 10.5 to 10.8 m/s was obtained from previous studies. The chemical properties of peat are affected by the chemical composition of peat's components, the environment in which they were deposited and the extent of decomposition. Generally, peats are in an acidic condition and the pH value often lies between 4 and 7. Peats have high cation exchange capacity (CEC). The main exchangeable sites are the functional acid groups which is named humic acids. The most common exchangeable cations in peats are Ca^{2+}, Mg^{3+}, Al^{3+}, K^{+}, Na^{+}, $(NH_4)^{+}$. The CEC will increase with an increase in pH value and the exchangeable cation concentration. Among the peats, the CEC for fibrous peat is larger than others (Moayedi et al., 2011a, b).

ACKNOWLEDGMENT

The authors wish to express their gratitude to the Ministry of Science, Technology and Innovation, Malaysia (Project No. 03-01-04-SF0889) for the financial support to the research group.

REFERENCES

Aho M (1986). The ion exchange and adsorption properties of sphagnum peat under acidic conditions, Research report No. 24, University of Jyväskylä. ISBN 951-679-533-1, ISSN 0357-346X.
Ajlouni MA (2000). Geotechnical properties of peat and related engineering problems. PhD Dissertation, University of Illinois at Urbana-Champaign. 15-189.
Andriesse JP (1988). Nature and Management of Tropical Peat Soils. 1st ed. Rome: FAO. Food Agricult. Organization, 1-165.
Asadi A, Huat B, Hanafi M, Mohamed T, Shariatmadari N (2009). Role of organic matter on electroosmotic properties and ionic modification of organic soils, Geosci. J., 13(2): 175-181.
Bell FG (2000). Engineering Properties of Soils and Rocks, Malden, MA, Blackwell Science. 1st ed., pp 1-496.
Boelter DH (1968). Important physical properties of peat materials. Proceedings of the Third International Peat Congress. Quebec, Canada. 150-156.
Chynoweth DP (1983). A novel process for biogasification of peat. Proc. Int. Symp. Peat Util., Bemidji, Minnesota, pp. 159-171.
Colley BE (1950). Construction of highways over peat and muck areas. Am. Highway, 29(1): 3-7.
Craig RF (1992). Soil Mechanics. 5th Edition, London: Chapman & Hall.
Davis JH (1997). The peat deposits of florida their occurrence, development and uses, Florida Geological Survey. Geol. Bull., 3.
Deboucha S, Hashim R, Alwi A (2008). Engineering properties of stabilized tropical peat soils. J. Geotech. Eng., 13E: 1-9.
Dhowian AW, Edil TB (1980). Consolidation behavior of peats. Geotech. Testing J., 3(3): 105-114.
Edil TB (2003). Recent advances in geotechnical characterization and construction over peats and organic soils. 2nd International Conferences in Soft Soil Engineering and Technology, Putrajaya (Malaysia). 1-16.
Gofar N (2006). Determination of coefficient of rate of horizontal consolidation of peat soil. Master Dissertation, Universiti Teknologi Malaysia, Malaysia. 36-172.
Hanrahan ET (1954). An investigation of some physical properties of peat. Géotechnique, 4(2): 108-123.
Hobbs NB (1986). Mire morphology and the properties and behavior of some British and foreign peats. Q. I. Eng. Geol., 19(1): 7-80.
Huat BBK (2004). Organic and Peat Soils Engineering. University Putra Malaysia Press Serdang, Malaysia.
Islam MS, Hashim R (2008a). Use of machintosh probe test for field investigation in peat soil. Proceeding of the International Conference, May 26-27, Best Western Premeier Seri Pacific Kuala Lumpur, Malaysia, pp 27.
Islam S, Hashim R (2008b). Engineering properties of peat soils in peninsular Malaysia. J. Appl. Sci., 8(22).
Jarret PM (1995). Site investigation for organic soils and peat soil. JKR Document, Institute Kerja Raya Malaysia.4-16.
Katase T, Hirotya S, Naoi M, Yamamoto K, Sumida H (1991). A comparison of phenolic constituents in peat soils between subfrigid area, Japan and tropical areas of peninsular Malaysia and Thailand. In: Tropical Peat, Aminuddin B.Y. (Ed.). MARDI, Malaysia, ISBN: 9679361276, pp. 57-65.
Kazemian S, Huat BBK (2009a). Compressibility characteristics of fibrous tropical peat reinforced with cement column, Electronic J. Geotech. Eng., 14E: 1-8.
Kazemian S, Huat BBK (2009a). Assement and comparison of grouting and injection method in geotechnical engineering. Euro. J. Sci. Res., pp.234-247.
Kazemian S, Huat BBK (2009b). Compressibility characteristics of fibrous tropical peat reinforced with cement column, Electronic J. Geotechnical Eng., 14C.
Kazemian S, Asadi A, Huat BBK (2009c). Laboratory study on geotechnical properties of tropical peat soils, Int. J. Geotechnics Environ., 1: 69-79.
Kazemian S, Prasad A, Ghiasi V, Huat BBK (2009d). Experimental study of engineering behavior of fibrous peat soil reinforced by cement column. In C. F. Leung, J. Chu, & R. F. Shen, Ground Improvement Technologies and Case Histories (ISGI09), Singapore, Research Publishing Service, 533-541.
Kazemian S, Prasad A, Asadi A, Huat BBK (2009e). Settlement problems in peat due to their high compressibility and possible solution using cement columns. In C. Shen-en, A. D. de Leon, A. M. Dolhon, M. J. Drerup, & K. Parfitt, Forensic Engineering 2009: pathology of the built environment : Proc. of the Fifth Congress on Forensic Engineering, November 11-14, 2009, Washington, USA, pp 3: 255-265.
Kazemian S, Prasad A, Huat BBK, Ali TAM, Aznieta FN (2010a). Effect of cement, sodium silicate, kaolinite and water on the viscosity of the grout, Sci. Res. Essays J., 5(22): 3434-3442.
Kazemian S, Huat BBK, Prasad A, Barghchi M (2010b). A review of stabilization of soft soils by injection of chemical grouting. Aust. J. Basic Appl. Sci., 4(12): 5862-5868.
Lan IT (1992). A model for one-dimensional compression of peat. PhD Dissertation, University of Wisconsin, Madison, USA.
Lea FM (1956). In the Chemistry of Cement and Concrete, ed. Lea and Desch, London: Edwar Arnold Ltd.
Lea N, Brawner CO (1963). Highway design and construction over peat deposits in the lower British Colombia, Highw. Res. Rec., 7: 1–32.
Malaysian Agricultural Research and Development Institute, MARDI (2009). Extent and Characteristic of Peat Soil. Agric. Res. Dev. Inst., pp. 3-25.
Mesri G, Ajlouni M (2007). Engineering properties of fibrous peats. J. Geotech. Geoenviron. Eng., 133(7): 850-866.
Mesri G, Stark TD, Ajlouni MA, Chen CS (1997). Secondary compression of peat with or without surcharging. J. Geotech. Geoeviron. Engr., 123(5):411-421.
Miyakawa J (1960). Soils engineering research on peats alluvia. Reports 1-3. Civil Engineering Research Institute, Hokkaido Development Bureau Bulletin No. 20.
Mochtar NE (1997). Perbedaan Perilaku Teknis Tanah Lempung dan Tanah Gambut (Peat Soil), Jurnal Geoteknik (In Malay), Himpunan Ahli Teknik Tanah Indonesia, 3(1): 16-34.
Moayedi H, Asadi A, Huat BBK, Moayedi F (2011a). Zeta Potential of Tropical Soil in Presence of Polyvinyl Alcohol, Int. J. ElectrochemSci., 6 (5): 1294-1306.
Moayedi H, Asadi A, Huat BBK, Moayedi F (2011b). Optimizing Stabilizers Enhanced Electrokinetic Environment to Improve Physicochemical Properties of Highly Organic Soil, Int. J. Electrochem. Sci., 6 (5): 1277-1293.
Muhamad IS, Gandaseca S, Ahmed OH, Majid NMA (2010). Comparison of selected chemical properties of peat swamp soil before and after timber harvesting. Am. J. Environ. Sci., 6(2):

164-167.
Muskeg Engineering Handbook (1969). University of Toronto Press.
Muttalib A, Lim JS, Wong MH, Koonvai L (1991). Characterization, distribution, and utilization of peat in Malaysia. In Proceedings of the International Symposium on Tropical Peatland, ed. Aminuddid, Kuching, Sarawak, pp. 7-16.
Said JM, Taib SNL (2009). Peat stabilization with carbide lime. UNIMAS E- J. Civil Eng., 1: 1.
Schelkoph GM, Hasset DJ (1983). A comparative study of preparation and analytical methods for peat, Testing of Peat and Organic Soils. ASTM STP 820, pp. 99-110.
von Post L (1922). Sveriges geologiska undersoknings torvinventering och nagre av dess hittills vunna resultat, Sr. Mosskulturfor, 1: 1–27.
Waksman SA (1942). The peats of New Jersey and their utilization. New Jersey Department of Conservation and Development. Geol. Ser. Bull., 55: 1-87.
Wong LS (2005). Laboratory evaluation of horizontal coefficient of consolidation c_h of fibrous peat soil, Master Dissertation, Universiti Teknologi Malaysia, Malaysia.
Wong LS, Hashim R, Ali FH (2008). Strength and Permeability of Stabilized Peat Soil. J. Appl. Sci., 8(17): 1-5.
Wust RAJ, Bustin RM, Lavkulich LM (2003). New classification systems for tropical organic-rich deposits based on studies of the tasek bera basin, Malaysia. Elsevier Sci. B.V., pp. 133-163.
Yulindasari I (2006). Compressibility characteristics of fibrous peat soil. Master Dissertation, Universiti Teknologi Malaysia, Malaysia.