ENHANCEMENT OF KAOLINITE USING SUPERABSORBENT POLYMER (SAP) AS EARTH GROUNDING MATERIAL

TEH CHEE YEE

B. ENG (HONS.) CIVIL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

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TEH CHEE YEE

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ABSTRAK

Sistem pembumian berfungsi sebagai perlindungan kilat dalam kilang perindustrian dan loji kuasa. Salah satu parameter utama untuk mengenal pasti prestasi sistem pembumian adalah kerintangan tanah tempatan. Kaolinit mempunyai keplastikan dan pengekalan air yang lebih rendah daripada air bentonit. Oleh itu, Superabsorbent Polymer (SAP), bahan dengan penyerapan cecair yang tinggi dan keupayaan pengekalan cecair ditambah dalam kaolinit untuk meningkatkan prestasi kaolinit dalam keplastikan dan kerintangan. Objektif utama kajian ini adalah untuk menentukan peningkatan dalam ciri keplastikan kaolinit dan mewujudkan ciri serapan air lengkung dengan penambahan SAP dalam pelbagai peratusan ke kaolinit. Kajian ini juga membandingkan kerintangan kaolinit dalam pelbagai peratusan SAP. Tiga jenis sampel kaolinit yang digunakan dalam kajian ini ialah S300, Speswhite dan FMC dengan campuran 10% SAP untuk menentukan ciri-ciri keplastikan. Had keplastikan untuk S300, Speswhite dan FMC dengan tambahan 10% SAP adalah 150.38%, 141.45% dan 275.30%. Indeks keplastikan untuk S300, Speswhite dan FMC dengan 10% daripada SAP adalah 13.10%, 19.40% dan 30.60%. Kerintangan S300, Speswhite dan FMC dengan tambahan 10% SAP adalah 130 Ω.m, 17 Ω.m dan 21 Ω.m. kerintangan ini adalah lebih tinggi daripada kerintangan bentonit dan Marconite, iaitu 6.2 Ω.m dan 0.38 Ω.m.

ABSTRACT

Earth grounding system serves as lightning-protection in industrial and power plants. One of the major parameters to determine the performance of the grounding system is the resistivity of local soil. Kaolinite has lower plasticity and lower retention of water as compared to bentonite. Thus, Superabsorbent Polymer (SAP), a material with high absorption and retention capacity of fluids is added to kaolinite to improve the performance of kaolinite in plasticity and resistivity. The main objectives of the study were to determine the improvement in the plasticity characteristic of kaolinite and establish soil-water characteristics curve (SWCC) by addition of SAP at varying percentage. This study also compare the resistivity of kaolinite at varying percentage of SAP. Three kaolinite samples are used in this study which are S300, Speswhite and FMC with the mixture 10% of SAP to determine the plasticity characteristic. The plastic limit for S300, Speswhite and FMC with addition of 10% SAP are 150.38%, 141.45% and 275.30%. The plasticity index for S300, Speswhite and FMC with 10% of SAP are 13.10%, 19.40% and 30.60% respectively. The resistivity of S300, Speswhite and FMC with 10% SAP are 130 Ω.m, 17 Ω.m and 21 Ω.m respectively. These resistivity are higher than resistivity of bentonite and Marconite, which are 6.2 Ω.m and 0.38 Ω.m.

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Ω.m	Ohm meter

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
BS	British Standard
BET	Brunauer-Emmett-Teller
CEC	Cation Exchange Capacity
IEEE	Institute of Electrical and Electronics Engineers
SAP	Superabsorbent polymer
SWCC	Soil-Water Characteristic Curves

CHAPTER 1

INTRODUCTION

1.1 Background

Earth grounding system serves as lightning-protection in industrial and power plants (Liu et al., 2001). When grounding system is under fault, the system will separate the fault current to the earth by providing low resistivity path to decrease the earth potential rise at the local grounding system (Desmedt et al., 2001). Electrical conduction in rocks and soil can be divided into electronic conduction and ionic conduction where electronic conduction is the transfer of charges through a solid while ionic conduction is the transfer of ionic charges in a polar liquid such as rainwater (Laver et al., 2001). However, the current transmission is limited by the earth's resistance (PolyPhaser, 2010). Thus, it is vital to study the ground or the nature around the grounding system.

One of the major parameters to determine the performance of the grounding system is the resistivity of local soil (Dhrmadasa, 2011). Resistivity of soil varies with soil type, moisture content, temperature (Switzer, 1995), porosity, size of soil particles and so on (Fukue et al., 1999). Moisture content of soil helps the grounding electrode to disperse electrical current (Switzer, 1995). Site with low soil resistivity could install standard ground electrode system but site with high soil resistivity needs to increase the amount or diameter of grounding conductors or drive the ground electrodes deeper to achieve required ground electrode resistance. Normally, it is difficult to achieve the desired ground electrode resistance with the mentioned solutions. In these cases, ground enhancement materials or backfill material are used to enhance the grounding system to attain the required ground electrode resistance (Dale et al. 2017). A good ground enhancement material should provide low earth resistance over a long period with little variation of resistivity value (Gomes et al., 2010).

Bentonite is one of the suitable example of backfill material in decreasing and maintaining the low grounding resistance of electrodes (Lim et al., 2015) for a long time due to its high water absorption and retention tendency (Lim et al.,2013). It is a natural material that is composed predominantly of the clay mineral smectite which able to swell when in contact with free water (Keto, 2004). Bentonite is hydrate where it acts as drying agent to draw moisture from surrounding environment into its structure and holds the water chemically (Jones, 1980). According to research by Fukue et al. (1999), the resistivity for bentonite is high when water content is low. However, when the water content in bentonite is more than 40%, the resistivity is as low as 3Ωm. In Malaysia, it was reported that bentonite only deposited in several areas of Sabah such as in in Segama, Sepagaya, Mansuli and Andrassy (Samsuri, 2006). According to Malaysian Minerals Yearbook 2010, there are three bentonite processing plants in Malaysia which located one each in Perak, Johor and Selangor but the all the raw bentonite are imported. In 2010, Malaysia had imported 73,269 tonnes of bentonite mostly from India, China, USA, Australia and Germany which cost up to RM61,203,000.

Kaolinite is another type of clay which deposited in Malaysia at the state of Perak, Johor, Kelantan, Selangor, Pahang and Sarawak and around 112 million tons of kaolin have been discovered throughout the country (Baioumy et al., 2012). According to Malaysian Minerals Yearbook 2010, kaolin production in that year had increased to 530,331 tonnes from 487,632 tonnes recorded in the previous year mainly from Perak. However, kaolinite has lower plasticity behavior than bentonite. According to research by Horpibulsuk et al. (2011), bentonite has very high plasticity index which 175% is but the plasticity index for kaolin is very low which is 22%. Another study also shows that bentonite has 91.8% of plasticity index but kaolin only has 15.5% of plasticity index (Imai, 1980). Besides that, bentonite has higher optimum water content compare to kaolin due to bentonite's high sportive force from its surface electrical charges (Fattah et al., 2016). Fattah et al. (2016) state that bentonite has optimum water content up to 37% but kaolin only has 19.5% of optimum water content.

Superabsorbent polymer (SAP) is a hydrogel with three-dimensional polymer networks that expand when absorb water (Mudiyanselage et al., 2008). SAP is apply widely in several sector such as enhanced oil recovery, mine waste treatment, sludge dehydration, strengthening of concrete and soil amelioration (Gao, 2003). Gao states that

SAP improve the soil quality for plant growth by absorbing water from rainfall or irrigation and releasing it slowly. SAP able to absorb more than hundred times of water than its own weight rapidly and retain water well even at high temperature and pressure (Guan et al., 2017).

In this study, 10% of SAP are mixed with the kaolinite clay to increase the water absorption and retention behavior. Plasticity and water suction behavior of enhanced kaolinite are studied and compared with kaolinite without and with 5% SAP and bentonite. Several tests such as liquid limit, plastic limit, shrinkage limit, specific gravity, swelling index, specific surface area, loss of ignition and cation exchange capacity are carried out to determine the improvement of plasticity of kaolinite at varying percentage of SAP and soil-water characteristics curves (SWCC) are established to study the water suction behavior of kaolinite. Lastly, resistivity of kaolinite at varying percentage of SAP is determined by four point probe method and compared with bentonite which normally use as earth grounding enhancement material.

1.2 Problem Statement

Bentonite is used as earth grounding backfill material to retain the moisture content of soil and to improve grounding effectiveness by lowering the soil resistivity. However, bentonite is only deposited in several areas at east of Sabah such as in Segama, Segapaya, Mansuli and Andrassy. All the bentonites used in Malaysia are imported from foreign country. A study on replacement of bentonite to kaolinite as earth grounding backfill material is carry out as the high availability of kaolinite in Malaysia such as in the states of Perak, Johor, Kelantan, Selangor, Pahang and Sarawak. But, kaolinite has lower plasticity and resistivity than bentonite. The most significant property of bentonite is its high water absorption and retention capacity. It can absorb up to hundred times of water of its own weight. Thus, superabsorbent polymer (SAP) may be added to the kaolinite to improve its plasticity and resistivity behavior by absorbing and retaining more water.

1.3 Research Objectives

The purpose of this study is to determine the effect of superabsorbent polymer (SAP) on the water absorption, plasticity and resistivity behavior of kaolinite:

1. To determine the improvement in the plasticity characteristic of kaolinite by addition of SAP at varying percentage.

2. To establish soil-water characteristics curve (SWCC) of kaolinite with addition of SAP at varying percentage.

3. To compare the resistivity of kaolinite at varying percentage of SAP.

1.4 Scope of Study

In this study, three kaolinite samples are used which are S300, Speswhite and FMC. The plasticity characteristic of these three kaolinites with 10% of superabsorbent polymer (SAP) is determined and compared with kaolinites with 5% SAP and without SAP, bentonite without SAP and macronite without SAP. Besides, soil-water characteristic curve (SWCC) of kaolinite with addition of SAP at varying percentage is established by using chilled mirror dew point method. Furthermore, a comparison on the resistivity of kaolinite at varying percentage of SAP is carried out by using four point probe method. Resistivity of bentonite is determined as a standard reference.

1.5 Significance of research

In this study, there will be some significant where addition of superabsorbent polymer (SAP) can improve the water absorption and retention, plasticity and resistivity characteristics of kaolinite. These improvement is important in replacement of bentonite which commonly used in geotechnical application with kaolinite.

1.6 Thesis overview

Chapter 2 present the overview of other research related to the study which include earth grounding system, clays, superabsorbent polymer (SAP) and soil water characteristic curve. Earth grounding system is explained on its importance and how the factors affecting soil resistivity influence the grounding resistivity. This chapter also overview about clays which function as backfill materials in earth grounding system. Clays that mention in this chapter include bentonite, kaolinite and macronite. Origin, structure, properties and applications of these clays are discussed. Furthermore, mechanisms of water absorption of SAP in modifying the plasticity and resistivity of kaolinite is explained. Formation, characteristics and uses of SAP also have been studied.

Lastly, soil water characteristic curve (SWCC) is presented in this chapter to illustrate the relation between soil water content and soil suction.

Chapter 3 present the experimental methodologies of this study which include the selection of materials such as S300, Speswhite and FMC, preparation of SAP and soil samples, physical properties, chemical property and resistivity of kaolinites when added 10% of SAP into the soil samples. Physical properties of modified kaolinite that to be determined include liquid limit (BS 1337: Part 2 1990: 4.3), plastic limit (BS 1377: Part 2: 1990: 5.3), shrinkage limit (ASTM D4943-08), specific gravity (BS 1377: Part2: 1990:8.3), swelling index (IS: 2720 (Part 40) 1977), specific surface area (ISO 9277:2010, DIN ISO 9227: 2013), loss of ignition (BS1377: Part 3: 1990: 4.3) and soil water characteristics curve (ASTM C387-99) while cation exchange capacity (ASTM D6836-07) is the chemical property to be determined. Lastly, resistivity test will be conducted by using four point probe method (ASTM G57) to determine and compare the resistance of bentonite and modified kaolinites which contain 5% and 10% of SAP.

Chapter 4 presents the results obtained from the laboratory tests. The results are compared and discussed by using 3 types of kaolinite added with 10% of SAP each. Besides, all the physical properties such as liquid limit, plastic limit, shrinkage limit, specific gravity, swelling index, specific surface area, loss of ignition and soil water characteristics curve, chemical property such as cation exchange capacity and resistivity are compared and explained with kaolinites without adding SAP, kaolinites added with 5% of SAP, bentonite and macronite. For example, the plastic limit for kaolinite with 10% of SAP is higher than kaolinite without SAP and 5% of SAP because addition of SAP improve the water absorption ability of kaolinites.

Chapter 5 present the conclusion of this study which include results and discussions, any important findings and recommendations should be made for next research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will explain the earth grounding system in term of its importance and resistance. Besides, formation and application of bentonite and kaolinite clays are explained and their properties are compared. In this chapter, mechanisms, characteristic and usage of superabsorbent polymer (SAP) that affecting the plasticity of clay is also discussed. Lastly, soil water characteristic curve (SWCC) is explained to understand and compare the effect different content of SAP on three types of kaolinites.

2.2 Earth Grounding System

2.2.1 Importance of Earth Grounding System

The main purpose of earth grounding system is to minimize possible transient overvoltage (Adegboyega et al., 2011). When ground fault occur on transmission line, electrical or telecommunication towers around the fault are probable to gain high potentials to ground. Greatest danger to humans and animals may occurs when the tower reaches peak voltage (Endrenyil, 1967). Earth grounding system is needed so that the persons working in or around electrical or telecommunication towers are safe. Earth grounding system also able to decrease destruction to equipment in towers from lighting and thus decrease the disturbance to power system operations (Ahmeda, 2012). The grounding network resistance for power substation must be in 5 Ohm or less and for large station, the grounding resistance should be lower for satisfactory lightning protection (IEEE Std 142, 2007). Hence, inspection on tower potential conditions and protective effects of various transmission line grounding should be done timely (Endrenyil, 1967). Earth grounding system functions to separate fault currents aroused internally, externally or by unbalance faults into the earth. Besides, all electric and electronic device can make up a large-scale system by referring to the extended grounding systems. (Menter et al., 1994). Ground electrode such as metal plate, metal pipe or metal conductor is driven into numerous places of earth to make electrical grounding connection. Normally, the ground electrode are made from copper, aluminum, mild steel or galvanized iron (Adegboyega et al., 2011).

2.2.2 Earth Grounding Resistance

Earth grounding resistance of the electrical or telecommunication tower should be effectively improved so that the lighting endure level and power supply reliability can be improved and at the same time the transmission line lighting trip-out rate and accident rate can be decreased (Feng et al., 2011).When lighting stroke to a tower, the high current will flows into ground through the tower footing and increase the soil ionization and thermal effects. This will decrease the ground resistance of the tower base (Harid et al., 2012). Normally, location with high transmission line tower grounding resistance has strong lighting activity. Terrain at this area is more complicated, soil resistivity is higher and the transport is not convenience (Feng et al., 2011). Earthing resistance of an electrode are affected by neighboring soil composition, soil temperature, soil moisture content, depth of electrode and severely soil resistivity (Adegboyega et al., 2011).

Soil resistivity is different from soil to soil due to different physical composition, moisture content, dissolved salt, particle size distribution and etc. (Parmar, 2011). Soil resistivity, ρ is measured in Ohm meters (Ω.m) corresponding to a 1 m^2 cylindrical cross sectional area and 1 m length. Soil resistivity shows how the soil conducts electric currents. Lower earth electrode resistance is needed for lower soil resistivity (Kižlo et al., 2009). All soils conduct electrical current but mostly have high resistivity or low electrical conductivity (Igboama et al., 2011). Table 2.1 shows the soil resistivity and earthing resistance required for different type of soil. Stoney soil has the highest soil resistivity which is 30000 Ω.m and Marconite has the lowest soil resistivity which is 0.001 Ω.m.

Table 2.1 Soil resistivity and earthing resistance required for different type of soil

Type of soil	Soil resistivity (Ω.m)
Farming soil loamy and clay soils	100
Sandy clay soil	150
Moist sandy soil	300
Concrete 1:5	400
Moist gravel	500
Dry sandy soil	1000
Dry gravel	1000
Stoney soil	30 000
Rock	107
Bentonite	3
Marconite	0.001

Source: Igboama et al. (2011)

Soil resistivity has most influence by moisture content of soil. The soil's moisture content is important because it helps chemicals in the soil that surround ground conductors carry the electrical current. (Slovick, 2017)Flow of electricity in the soil is greatly electrolytic as it is affected by the transport of ions dissolved in moisture (Kižlo et al., 2009). The soil resistivity should be low to avoid back flashover of lighting transmission line and to keep the ground potential rise in safety tolerance limits (Harid et al., 2012). Table 2.2 shows the effect of moisture content on soil resistivity. From the table, it is clearly shows that increasing of moisture content decrease the soil resistivity for top soil, sandy loam and silica based sand.

Table 2.2 Effect of moisture content on soil resistivity

Moisture content by weight, %	Resistivity, Ω.m		
	Top soil	Sandy loam	Silica based sand
0	10000000	10000000	-
2.5	2500	150	3000000
5	1650	430	50000
10	530	185	2100
15	210	105	630
20	120	63	290
30	100	42	-

Source: Harid et al. (2012)

Desired grounding resistance can be achieved by connecting a number of individual electrodes instead of using single low grounding resistance electrodes (IEEE Std 142, 2007). However, it is very difficult to get the expected grounding resistance by increasing the grid conductors as it may cost highly. In order to solve this problem, the soil surrounding electrodes should be modified by using conductive backfills. Bentonite is one of the popular backfill material. By adding bentonite, grounding resistance may decrease up to 36% per rod (Kostic et al., 1999). According to IEEE Std 142-2007, ground resistance for large substations, transmission lines, or generating stations should not exceed 1 ohm while ground resistance for industrial plant substations and buildings and large commercial installations should be in 1 ohm to 5 ohm.

2.2.3 Grounding Enhancement Material

Nowadays, ground enhancing material or conductance-enhancement material is practice widely to decrease earth resistance due to high materials cost of earth conductors and limited space (Gomes et al., 2014). Ground enhancing material is usually termed as backfill materials. This material is laid inside the trench and the grounding electrode is installed. By this way, the soil resistivity surrounding the electrode is decreased to desired value and thus results in decreasing of grounding resistance value (Androvitsaneas et al., 2012). A good backfill material provide and maintain lower earth resistance than background soil for a long time and non-reactive with electrode (Gomes et al., 2014).

One of the most common backfill material is bentonite. Bentonite has well conductive property, high water absorption and retention as well as sticky property to most of the types of surface that it touches (Lim et al., 2013). However, bentonite must in wet condition to give low soil resistivity as bentonite move ions via ionic conduction in solution only. When bentonite loses moisture, its resistivity will increase (Switzer. 1995).

Marconite is a synthetic earth grounding material solely produced by James Durrans Group. It is an impure form of graphite that mix with cement to form an earth electrode backfill medium (Moore, 2000). According to James Durrans Group, Marconite is chemically inert and contains low sulphate and chloride, thus allow it to mix with all conventional types of cement. Marconite has 0.001 Ωm of resistivity and increse to 0.19 Ωm when mixed with cement.

Ground Enhancement Material (GEM) from ERICO is another alternative for backfill material(Switzer. 1995). Switzer states that GEM has more advantages over bentonite. GEM is maintanenece free as it is chemically stable and does not corrode ground electrode due to its low content of sulfate and chloride. According to ERICO, GEM powder provide resistivity less than 0.02 Ωm and this resistance is conctant throughout the life of grounding system once it is set.

Other material such as metal oxide, a waste product of steel industry is also proven as good backfill material. It possesses criteria of good backfill material (Lim et al., 2013) and less than 1% of corrosion on Galvanized Iron electrodes after more than two years in contact (Gomes et al., 2014). Natural material such as paddy dust or rice hulls and coco peat also can be used as earth grounding material. Janahitagama, a village in Western Province in Sri Lanka has apply rice hulls and coco peat as earth conductive material in three lightning protection towers each (Kumarasinghe, 2008). Kumarasinghe states that coco peat behave better as it can store higher moisture content. Another research by Jasni et al. (2010) shows that coconut coir peat and paddy dust do decrease the grounding resistance values but comparing to planting-clay soil and bentonite, their grounding resistance is higher. According to Eduful et al. (2009), palm kernel oil cake is another environmentally and economically friendly organic material that gives low resistance in effective resistance area. However, this material only suitable to the area relatively close to the earth electrode (Eduful et al., 2009)

2.3 Clay

Clays are fine-grained minerals which less than 2μm. Clays form naturally by crystallization in moisture condition on earth's surface and they are very abundant where they are main component of almost all sedimentary rocks which known as shales. Clays have unique properties such as cation exchange capabilities, plastic behavior when wet but harden when dry or fired, catalytic abilities, swelling behavior, and low permeability due to their distinct crystal structures (Guggenheim, 1995). These crystal structured are formed by planar arrangements of SiO4 structural units and many structural hydroxyls and water (Schulze, 2005).

2.3.1 Bentonite

Bentonite is a natural clay which form by years of volcanic action (Tu et al., 2006). It is formed by in situ devitrification of volcanic ash in water environment such as seawater, alkaline lakes or fresh water during or after deposition which contains highly colloidal and plastic montmorillonite clay mineral (Zuber et al., 2010). Bentonite is noncorrosive, stable (Tu et. al., 2006), high cation exchange capacity, high bonding capacity, high plasticity and high propensity of reaction with organic compounds (Lim et al., 2013). When hydrated with water, bentonite is alkaline with 8 to 10 pH. Besides, bentonite has high water absorption capability as it is hydrophilic which strongly hydrated by water. Its volume will be enlarge to several times of original volume when water is absorbed by diffusion or capillary suction (Lim et al., 2013). According to Sridharan et al. (1999) and Mehyar et al. (2005), the water absorption of bentonite and kaolinite from different places is shown as Table 2.3.

Table 2.3 Water absorption of bentonite and kaolinite from different places

Clay Type	Origin	Water Absorption (%)
Bentonite	Q'a Al Azraq, Jordan	207
Bentonite	Bulgaria	115
Bentonite	Indonesia	115
Bentonite	England	115
Fine Bentonite	USA	115
Bentonite	Kolar, India	292
Fine kaolinite	Bangalore, India	53.0
Fine kaolinite	Shimoga, India	47.1

Bentonite also has high capability to retain water for long period depending on temperature and atmospheric pressure (Lim et al., 2013). In addition, bentonite has thixotropy property where it perform like liquid when load apply by stirring or shaking and setting back to gel when standing (Teplitskiy et al., 2005). By adding bentonite, grounding resistance may decrease up to 36% per rod. Moreover, bentonite resistivity will become relatively low. At 300% moisture content, the resistivity is 2.5 Ω.m. Bentonite is suitable to be grounding backfill material especially in karst and sandy soils due to its good conductive properties, water absorption and retention abilities and surface adhesive (Kostic et. al., 1999).

Not only act as backfill material, bentonite also useful in supporting fluids. For example, bentonite is used sustain the sides of panel excavations for diaphragm walls in order to avoid runoff of fluid into the ground where the fluid pressure can withstand external pressure from soil and groundwater. Besides, bentonite also applies in other construction such as bored piles with big diameter, cut-off walls below ground and tunneling machines excavation. Its main function is to act as a barrier (Ball et al., 2006). Applications of bentonite not only limited in civil engineering but it is used widely in other field. Multitude uses of bentonite include drilling muds, foundry bonds, cat litter, ceramics, detergents, fertilizer, food additive, paint, paper, pharmaceuticals, sealants, water clarification and so on. (Murray, 2007)

2.3.2 Kaolinite

Name of kaolin was originated from Kauling or Gaoling, a village of Kiangsi province in China. Mining of this clay was first developed in the 11th century from the granitic hilly region near the Kauling village (Chen et al., 1997). This mining operated until 1964 before the clay is totally depleted (Haq et al., 2008). Kaolinite also deposited in Malaysia at the state of Perak, Johor, Kelantan, Selangor, Pahang and Sarawak. 12 million tons of kaolin have been discovered at these location. 341,223 tons of Kaolin is produced in 2007 and increased to 587,508 tons in 2006 (Baioumy et al., 2012).

Kaolinite is the most general kaolin mineral. Kaolins are rocks containing mainly one of the kaolin group minerals such as kaolinite, halloysite, dickite and nacrtie. Usually, kaolins are formed by alteration of Al silicate from feldspar mineral in comfortably high temperature and damp ambience (Murray, 1999). Primary kaolins are the aluminosilicate altered in situ by weathering, hydrothermal or sometimes by volcanic processes while secondary kaolins are sedimentary rock deposited in fresh or brackish water environment (Bloodworth et al., 1993).

Structure of kaolinite is the combination of one layer of octahedral sheet and one layer of octahedral sheet. This 1:1 layers are electrically neutral and stacked one above the other by hydrogen bonding (Schulze, 2005). According to Murray (2007), the structure of kaolinite is as shown in Figure 2.1.

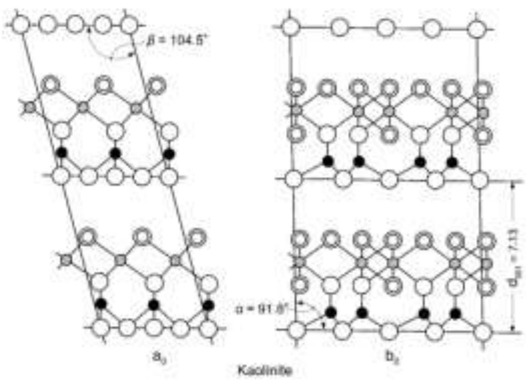

Figure 2.1 Diagrammatic sketch of the structure of kaolinite

Normally, the color of kaolinite is white or almost while. Kaolinite has minimal layer charge and low base exchange capacity as it has few substitution in structural lattice. Comparing to bentonite, kaolinite lower surface area. With minimal layer charge and low surface area properties, kaolinite also has low absorption capacity (Murray, 2000). Kaolinite is relatively pure kaolin with 1.5 Mohs scale of hardness. Its softness and non-abrasiveness is suitable in industrial applications as it provide minimal wear and tear when in contact with equipment. By adding some chemical dispersant to negate the edge charges due to broken bond, kaolinite will disperse easily in water as it is hydrophilic. Thus, in water-based and paper-coating formulations, kaolinite will be added (Murray, 1997). Murray had summarize some comparison of kaolin (kaolinite) and smectite (bentonite) as shown in table 2.3.2.1.

Table 2.4 Properties of kaolin (kaolinite) and smectite (bentonite)

Kaolin	**Smectite**
1:1 layer	2:1 layer
White or near white	Tan, olive, green, white
Little substitution	Octahedral and tetrahedral substitution
Minimal layer charge	High layer charge
Low base exchange capacity	High base exchange capacity
Pseudo- hexagonal flakes	Thin flakes and laths
Low surface area	Very high surface area
Very low absorption capacity	High absorption capacity
Low viscosity	Very high viscosity

2.3.3 Marconite

James Durrans and Sons Limited (2012) stated that Marconite is a synthetic earthing material that is specially manufactured for excellent electrical properties. Marconite is granular, dark grey in colour and dust free. It is a carbon by-product from oil refining. Marconite is expensive. Thus it only apply to small-scale applications such as electromagnetic shielding and anti-static flooring (Tuan et al., 2008). According to Thorne & Derrick UK, Marconite can conduct electricity without water. Unlike other traditional earthing materials such as Bentonite which conduct electricity through moving charged ions in the presence of water or salts, Marconite does not suffer effects from drying out. Marconite is a carbonaceous aggregate that replace normal aggregate in concrete mixing. It is more or less a conductive concrete with low resistivity Marconite has average 0.001 ohm-meter resistivity but when mixed with concrete, the resistivity can increase to 0.19 ohm-meter. Marconite cause little corrosion and able to perform well under hot weathers and rocky soils (Famous et al. 2015).

In the past year within UK, Marconite is used widely in latest power generation plants and rail engineers that does not require maintenance. Marconite is also use by worldwide. For example, Malaysia use Marconite in mass transit systems and Middle East apply Marconite in solar power farms (ETS, 2013). Figure 2.2 shows the Marconite installation in grounding system.

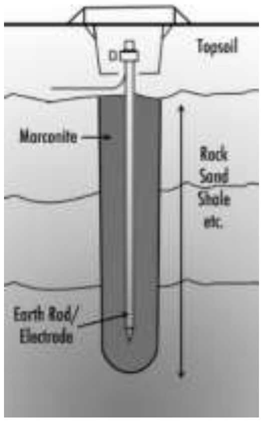

Figure 2.2 Marconite installation in grounding system

2.4 Superabsorbent Polymer (SAP)

Superabsorbent polymers (SAPs) or hydrogels are materials that can absorb and hold huge amounts of fluids without dissolving in water. Basically, they can absorb up to 15 times of fluids of their dried weight via osmotic pressure under load or without loud condition such as water, electrolyte solution, urine, brines, sweat, and blood. SAPs have loose cross-links and flexible polymer chains in 3-dimensional that carry dissociated and ionic functional groups (Kiatkamjornwong, 2007).

Mechanisms of water absorption of SAP can be categorized into physical and chemical absorption. Physical absorption can be further divided into several mechanisms. For example, for crystal structure such as silica gel and anhydrous inorganic salts, their structures are changed reversibly while for macro-porous structure such as soft polyurethane sponge, the water is absorbed via capillary force. There is also some combination of mechanisms such as absorption of water by capillary force is combined with hydration of functional groups (Zohuriaan-Mehr et al., 2008). Polymer backbone in SAP is hydrophilic which carboxylic acid groups (–COOH) that is water loving. Hydration or hydrogen bonds formation is occurred when water is added to SAP (Elliott, 2004). In chemical absorption mechanisms, the nature chemical absorbers such as metal hydrides are converted via chemical reaction to absorb water (Zohuriaan-Mehr et al., 2008). Free energy between the chain networks of SAP and external solvent and the electrostatic repulsion give impetus to swelling behavior of SAP while elastic retractile response or elastic swelling of the SAP chain networks inhibit the SAP to swell. These three forces balance the water absorption in SAP (Mohan et al., 2006).

SAP is non-toxic, hydrophilic, biocompatible and has high swelling capacity in aqueous situation. Thus it is suitable for numerous field such as agriculture and horticulture, health, bioengineering, pharmaceutical, drug delivery, food industry, and other advanced technologies (Mohan et al., 2006). SAP is apply in construction to cure ultra-high performance concrete (Mechtcherine, 2012) and to self-heal concrete with crack width less than 50 to 100 micrometer (Shaikh, 2017). SAP also provide internal water resources to concrete as internal curing agent after the concrete settling. At the same time, SAP gives extra voids in the concrete mass to improve the concrete workability (Al-Nasra et al., 2013). According to Bhagat et al.(2016) SAP can be used in agriculture to reduce the water required by the crops and decrease the watering rate for crops at arid and desert areas. SAP is also ideal in water absorbing applications such as baby nappies and adults incontinence pads to absorb and retain large volume of aqueous solutions (Elliott, 2004). In oil and gas industry, SAP is used to avoid drilling fluids from diffusing into different layers in swellable packers and to enhance the oil extraction in oil recovery (Terhart, 2016).

2.5 Soil Water Characteristic Curve (SWCC)

Water content and its energy state characterized the water status in soil. The two principles form of energy are kinetic energy and potential energy (Or et. al., 2003). However, the kinetic energy is negligible as the water movement in soils is relatively slow. Difference in potential energy of water in soil tend to move from higher potential energy to lower potential energy until equilibrium (Hartmann, 1996). When water flow, larger pores in soil will drain first and the remaining pores will hold water more tenaciously. In this condition, the water in pores is under suction or negative hydrostatic pressure (Atkinson et. al., 2016).

Soil-water characteristic curve (SWCC) shows the relationship between water content and soil suction, where the water content is the water quantity contained in the pores of the soil (Fredlund, 1994) and the soil suction or partial vapor pressure of soil water is the free energy state of soil water (Padilla et.al., 2005). Padilla also states that water content in soil can be express in gravimetric water content, volumetric water content or degree of saturation while soil suction can be presented in matric suction or osmotic suction.

There are several methods to measure soil suction such as equilibration of small soil samples over salt solutions of known osmotic suction until water content are fixed, thermocouple psychrometry and measurement of water activity(Ebrahimi-Birang et.al., 2007). However, the first method may consume weeks to months to get final result while the second method is limited to suction of range -0.2MPa to -8.0 MPa (Gee et. al., 1992). Water activity meter is the device used to measure the water activity in the range of 0.1 to 1.0 (Gee et. al., 1992). Later, water activity meter is modified to dew-point Water PotentiaMeter (WP4), chilled-mirror dew-point psychrometer or chilled-mirror hygrometer to avoid the consequence of the temperature fluctuation of the surrounding on the suction (Ebrahimi-Birang et. al., 2007). Figure 2.3 shows a schematic diagram of a dew-point Water PotentiaMeter, WP4. The device consists of a mirror and photodetector cell, a temperature sensor, a fan and a sealed chamber.

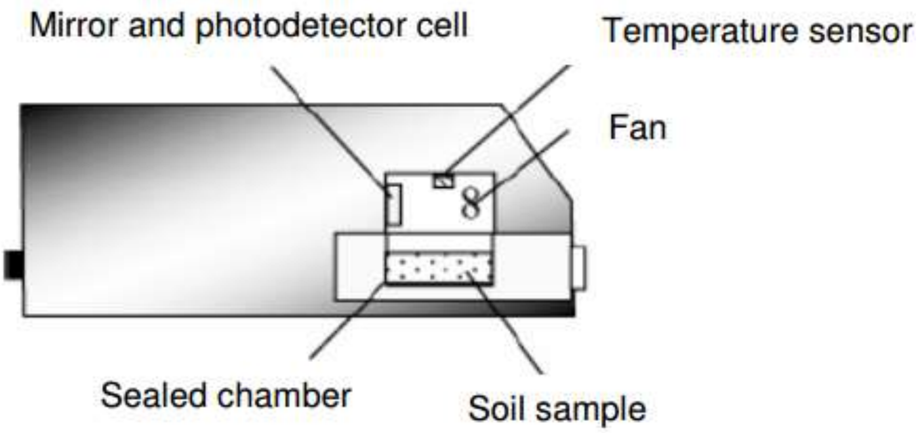

Figure 2.3 Schematic diagram of a dew-point Water PotentiaMeter, WP4

Headspace of the sealed block chamber equilibrate the water potential of air in the chamber and the water potential or suction of the sample while chamber fan helps to accelerate the equilibration. The headspace vapour pressure is measured and the saturation vapour pressure is computed when water potential stable. In-built software will calculate the total suction of the soil specimen (in MPa and pF units) and show on the

LCD panel of the WP4 along with the specimen temperature detected by the temperature sensor (Thakur et al., 2006).

SWCC is affected by initial water content and stress state but the effects decrease when suction increases (Zhou et. al., 2003). Other factor such as soil mineral composition, pore structure, soil body of contractility, and consolidation pressure also affected the characteristic curve directly or indirectly (Xu et al., 2013).According to research by Tripathy and others (2014), SWCC using chilled- mirror dew-point method is not affected by compaction factor. Compacted or uncompacted soil does not influence the relationship between water content and soil suction plot. Besides, dry unit weight of soil has not much influence on SWCC (Thakur et. al., 2006).

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this study, several experiments are carried out to determine the physical properties, chemical property and resistivity of soil. Kaolinites added with 10% of superabsorbent polymer (SAP) are used as the soil samples. Physical properties of soil to be determined include liquid limit, plastic limit, shrinkage limit, specific gravity, swelling index, specific surface area and loss of ignition while cation-exchange capacity (CEC) is the chemical property of soil to be investigated. Besides, soil-water characteristic curve (SWCC) is also obtained to show the relation of water content and soil suction.

3.2 Selection of Material

3.2.1 Clay

Three types of kaolinites are tested throughout the study which include FMC, S300 and Speswhite. These kaolinite soils are readily available in Malaysia and thus the price is lower compare to bentonite soil.

3.2.2 Superabsorbent Polymer (SAP)

The superabsorbent polymer (SAP) is purchased from Daiso Japan.

3.3 Soil Sample Preparation

Superabsorbent polymer (SAP) is blended into small pieces and oven dry for 24 hours at 60℃. Smash the SAP into powder form and add to the kaolinites. 10% of SAP is added and mix uniformly with kaolinites. These soil samples are kept in sealed plastic bag and to be used for all the experiments. Figure 3.1(a) shows the SAP before oven drying and Figure 3.1(b) shows SAP after oven drying at 60˚c.

Figure 3.1(a) Superabsorbent polymer before oven drying

Figure 3.1(b) Superabsorbent polymer after oven drying at 60˚c

3.4 Physical Properties of Kaolinite

3.4.1 Liquid Limit, LL

Liquid limit of a soil is the empirically established moisture content in percentage of the weight of oven-dried soil at which change of consistency of soil from plastic to liquid state. Liquid limit test is carried out with cone penetration method according to BS 1337: Part 2 1990: 4.3.

3.4.2 Plastic Limit, PL

Liquid limit of a soil is the empirically established moisture content in percentage of the weight of oven-dried soil at which change of consistency of soil from semisolid to plastic state. It is the moisture content at which the soil just begin to crumble when rolling into a 3mm diameter thread on a ground glass plate. Plastic limit test is carried out according to BS 1377: Part 2: 1990: 5.3.

3.4.3 Shrinkage Limit

Shrinkage limit is the water content of soil when the soil is just saturated where the volume of water just exactly to fill all the pores of soil. Below shrinkage limit, reduction of water content will not affect the volume of soil. Swell- shrink test is conducted according to ASTM D4943-08. Figure 3.2 shows the soil samples S300, FMC and Speswhite with addition of 10% SAP after air dry. Shrinkage limit of soil is calculated with the following equation:

$$\text{Shrinkage limit } = \mathrm{W} - \left(\frac{\mathrm{V} - \mathrm{V_s}}{\mathrm{W_s}}\right) \text{ x } 100\% \tag{3.1}$$

Where W = Moisture Content of wet soil sample

V = Volume of wet soil sample

V_s = Volume of dry sample

W_s = Weight of oven dried soil sample

Figure 3.2 Shrinkage limit test for S300, FMC and Speswhite with addition of 10% SAP

3.4.4 Specific Gravity

Specific gravity or particle density of soil is the ratio of the weight of the given volume of soil sample to the weight of an equal volume of water. This test is carry out according to BS 1377: Part2: 1990:8.3. The specific gravity of soil is calculated using the following equation:

$$G_s = \frac{w_2 - w_1}{(w_4 - w_1) - (w_3 - w_2)} \qquad 3.2$$

Where w_1 = mass of density bottle + stopper

w_2 = mass of density bottle + stopper + dry soil

w_3 = mass of density bottle + stopper + dry soil + distilled water

w_4 = mass of density bottle + stopper + distilled water

3.4.5 Swelling Index

Free swelling index is the increase in volume of soil when submerged in water without any restrictions. Free swelling index of soil is determined with free swelling method proposed by Holtz and Gibbs (1956).

Firstly, pour 10g of oven dried soil sample each into a 100ml measuring cylinder. The measuring cylinders are filled with distilled water until the 100ml mark of measuring cylinder. The soil-water mixture is left for swelling under controlled laboratory conditions so that the soil sample can gain equilibrium state of volume without any additional changes in the volume of soils. Figure 3.3 shows the swelling index test for S300, Speswhite and FMC with addition of 10% SAP. The final volume of the soils in each measuring cylinder is measured and the free swelling index of soil sample is calculated according the following equation:

$$\text{Free Swell Index (\%)} = \frac{V_1 - V_0}{V_0} \text{ x } 100\% \qquad 3.3$$

Where V_1 = Soil volume after swelling, cm^3

V_0 = Volume of dry soil, $10cm^3$

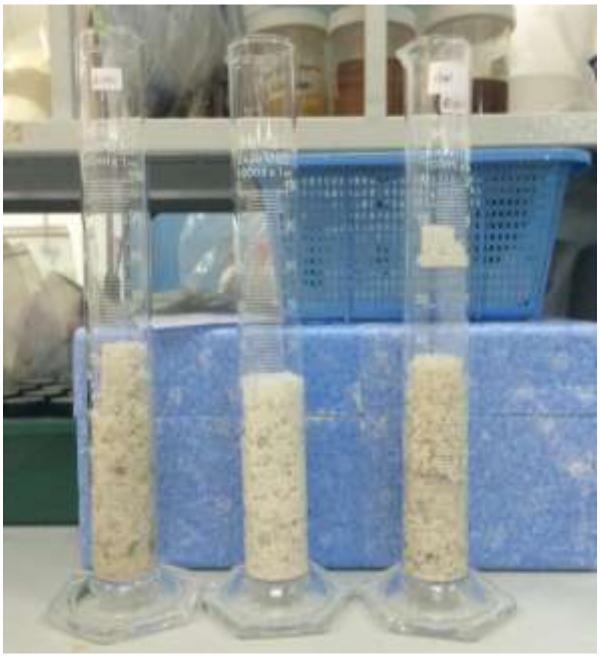

Figure 3.3 Swelling index for S300, Speswhite and FMC with addition of 10% SAP

3.4.6 Specific Surface Area

Specific surface area is the surface area of a soil over its mass or volume. Brunauer-Emmett-Teller (BET) method (ISO 9277:2010, DIN ISO 9227: 2013) is the most common and standardized method used to determine the specific surface area of soil.

Before the test started, the BET analyzer has to be warm up for at least 30 minutes. Firstly, fill the nanomaterials in the instrument specific glass holder and weight on a microbalance. Place 5g of soil sample in the instrument and heat up for at least 18 hours at 250 °C. Weight the soil sample again after the sample is cooled down to determine the possible mass losses. Next, the sample is place in the BET measurement unit for BET analysis. The soil sample will be cooled down to 77k which is the boiling point of liquid nitrogen. Lastly, nitrogen is injected under several pressures to determine the displacement of nitrogen gas for specific surface calculation.

3.4.7 Loss of Ignition

Loss of ignition test is carried out to identify the organic content in a soil sample by measuring the mass loss of soil when heated at high temperature. This test is done according to BS1377: Part 3: 1990: 4.3. The loss of ignition or organic content of soil is calculated as the following equation:

$$\text{Loss of ignition } (\%) = \left(\frac{m_1 - m_2}{m_1 - m_c}\right) \text{ x } 100\% \qquad 3.4$$

Where m_1 = Mass of crucible and oven-dry soil sample (g)

m_2 = Mass of crucible and soil sample after ignition (g)

m_c = Mass of crucible (g)

3.5 Chemical Property

3.5.1 Cation-Exchange Capacity (CEC)

Cation exchange capacity (CEC) is the ability of soil to hold exchangeable positively charged ions. Soils contain higher clay fraction or organic matter tend to have higher CEC. CEC is tested by ammonium acetate method at pH7 according to ASTM C387-99.

3.6 Soil-Water Characteristic Curve (SWCC)

Soil-water characteristic curve (SWCC) shows the relationship between water content contained within the pores of soil and suction of soil. SWCC is plotted by chilled mirror dew point method according to ASTM D6836-07.

Firstly, 10 samples are prepared with 5g of soil mix with various water content from 0.1mL to 1.0mL. These samples are sealed in plastic bags to prevent evaporation of water and allow to equilibrate for 1 week. When the samples are ready to be tested, half fill the sample cups with samples. Make sure that the bottom surface of sample cups are fully covered by the samples. Figure 3.4 shows the device WP4C Dewpoint PotentiaMeter. WP4C Dewpoint PotentiaMeter is the device used to get the suction value of soil. The measurement also can be done when the device shows the $T_s - T_b$ value is

25.0. Next, place the sample cup in the drawer of WP4C and slide the drawer into the device. Turn the knob to left and wait until the data can be read and record the obtained suction value. Lastly, get water content of soil from its wet soil mass and dry soil mass. SWCC is plotted with soil suction value and soil water content.

Figure 3.4 WP4C Potential dew meter

3.7 Soil Resistivity

There are several methods to test for soil resistivity and one of the popular method is Wenner 4 Probe Test. This Wenner 4 Probe Test method (ASTM G57) was developed by Dr. Frank Wenner of the U.S. Bureau of Standards in year 1915 (Hurricane, 2013). Four electrodes are used in this method where two for current injection and two for voltage measurement. The device used to carry out the test is Nilsson Soil Resistance Meter Model 400. This device is shown in Figure 3.5. The soil resistivity is calculated as following equation:

$$\rho = 2\pi AR \qquad 3.5$$

Where ρ = average soil resistivity to a depth equal to A (ohm-cm)

A = probe spacing (cm)

R = soil resistivity measuring equipment’s reading (Ohm)

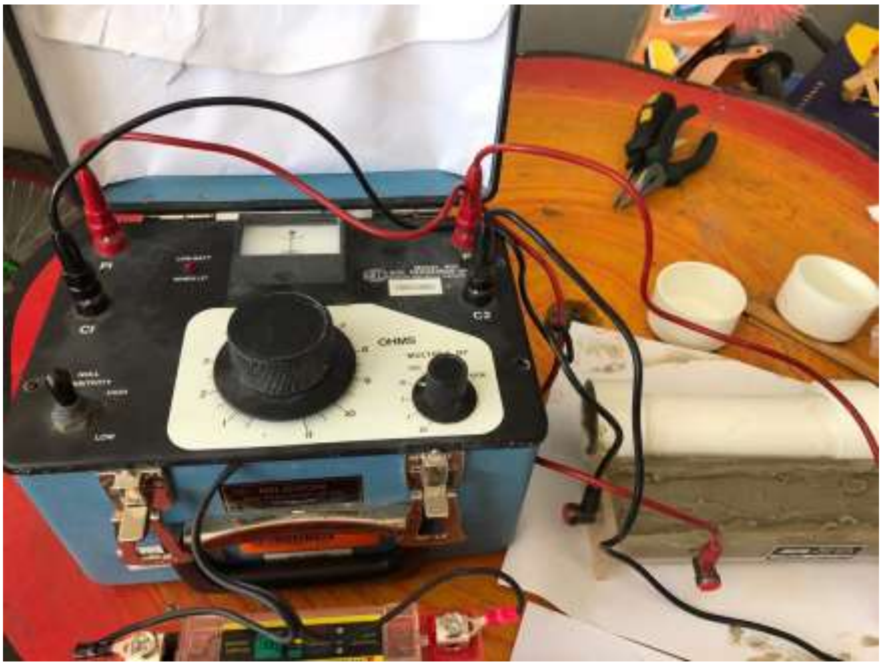

Figure 3.5 Nilsson Soil Resistance Meter Model 400

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter will discuss on all the results obtained from the laboratory test for 3 types of soil sample which are S300, Speswhite and FMC. These three samples are added with 10% of SAP and their properties are determined. These properties include Atterberg limit (liquid limit, plastic limit and shrinkage limit), specific gravity, swelling index, specific surface area, cation exchange capacity, loss of ignition and soil resistivity. Besides, soil water characteristic curve is plotted.

4.2 Physical properties

4.2.1 Liquid Limit

From cone penetration test, the liquid limit for S300, Speswhite and FMC with addition of 10% SAP are 460%, 495% and 500% respectively. From previous study, S300 has 41% of liquid limit and 83.85% with addition of 5% SAP. Meanwhile for Speswhite and FMC, the liquid limit with 5% SAP and without SAP are 51.4%, 96.11%, 80%, and 120% respectively. This clearly shows that addition of SAP has increase the liquid limit of kaolinite and the liquid limit increase with increasing proportion of SAP. For example, S300 with 10% SAP has increase its liquid limit by 1022% comparing to S300 without SAP. The liquid limit for S300 is lowest for 3 types SAP content follow by Speswhite and FMC. Higher liquid limit indicates stronger water absorption as surface charge between negative charge on clay surface and dipolar of water molecules increases (Sen, 2014). The liquid limit for bentonite is 437%. Addition of 10% SAP in kaolinite has achieved the desire liquid limit.

4.2.2 Plastic Limit

The plastic limit for S300, Speswhite and FMC with addition of 10% SAP are 150.38%, 141.45% and 275.30% respectively while the plastic limit are 48.79%, 37.8% and 64.87% respectively when added with 5% SAP. Plastic limit are the lowest for pure kaolinite where 27.9% for S300, follow by 32% for Speswhite and 49.4% for FMC. The plastic limit soil samples with 5% and 10% SAP increases according to the sequences of Speswhite, S300 and lastly FMC. Plastic limit for soil samples with 5% SAP is the lowest. Bentonite has 63% of plastic limit. S300 and Speswhite with 10% SAP and FMC with 5% and 10% SAP has higher plastic limit than bentonite. Plasticity of clay can be measured using Atterberg plasticity method in terms of its plasticity index, where plasticity index is the different between liquid limit and plastic limit. Increasing of plasticity index indicates increasing of plasticity of soil (Hall, 1923). The plasticity index for S300, Speswhite and FMC are 13.10%, 19.40% and 30.60% respectively while the plasticity index are 35.06%, 58.31% and 55.13% respectively when added with 5% SAP. The plasticity index of S300, Speswhite and FMC further increase to 309.62%, 353.55% and 224.70% respectively when added with 10% SAP. The plasticity index of bentonite is highest which is 374%.

4.2.3 Shrinkage Limit

Figure 4.1 shows the shrinkage plot for S300 with addition of 10% SAP.

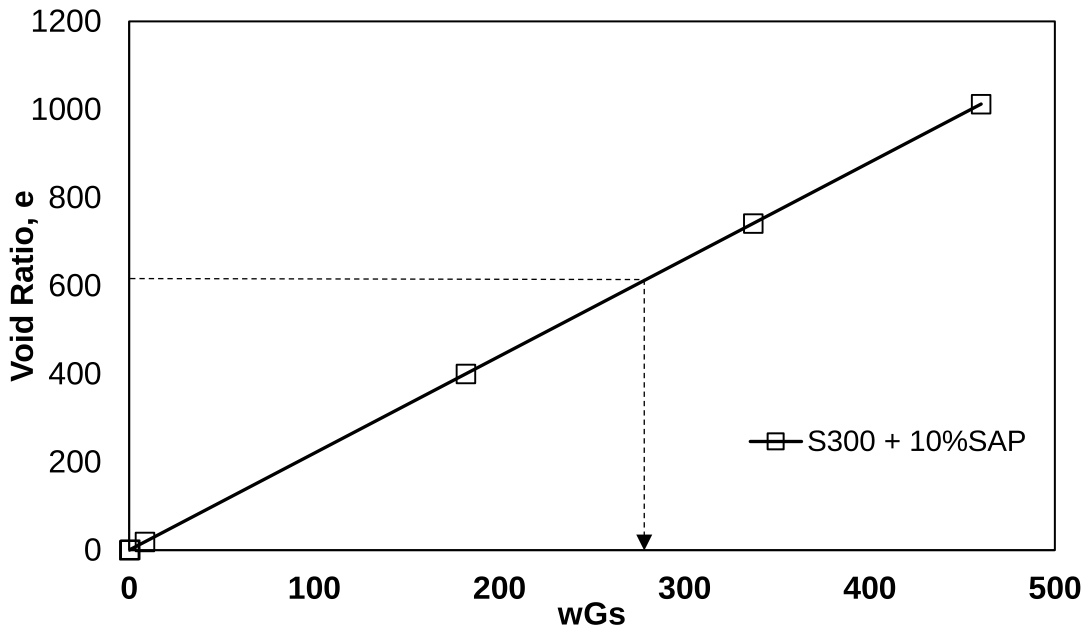

Figure 4.1 Shrinkage plot for S300 with addition of 10% SAP

Void ratio increase with increase of wGs. The void ratio and shrinkage limit for S300 with 10% of SAP are 615.38 and 280%. Comparing to S300 and S300 with 5% SAP, which shrinkage limit are 38.5% and 40.0%, shrinkage limit of S300 with 10% SAP has increase greatly.

Figure 4.2 shows the shrinkage plot for Speswhite with addition of 10% SAP. Void ratio increase with increase of wGs. The void ratio and shrinkage limit for Speswhite with 10% of SAP are 500 and 235% while shrinkage limit for Spswhite and Speswhite with 5% SAP are 36.5% and 38.0%.

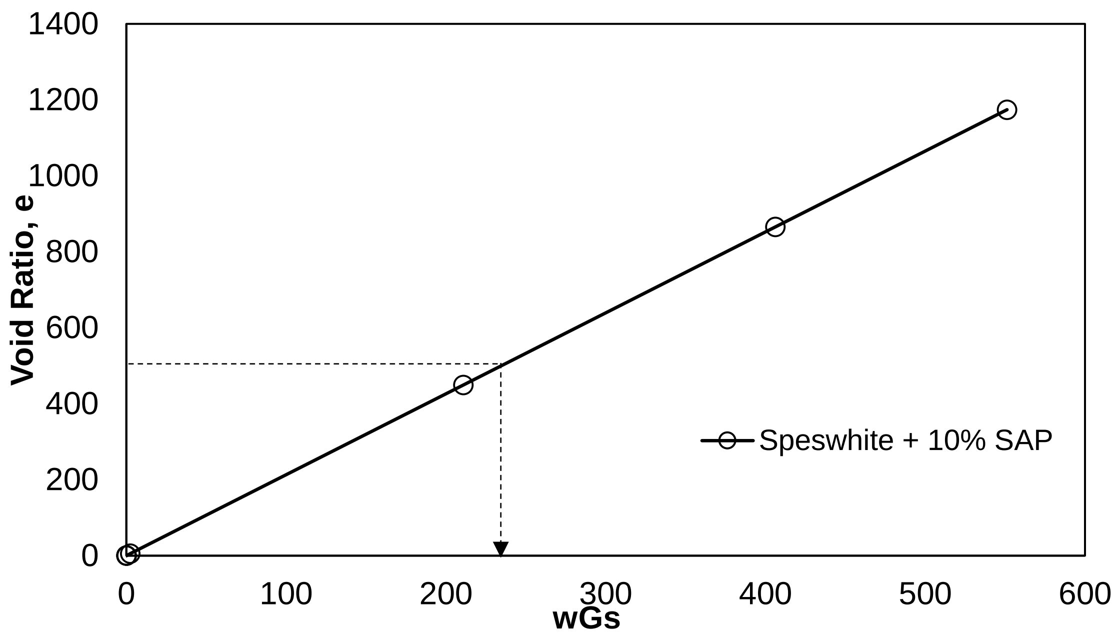

Figure 4.2 Shrinkage plot for Speswhite with addition of 10% SAP.

Figure 4.3 shows the shrinkage plot for FMC with addition of 10% SAP.

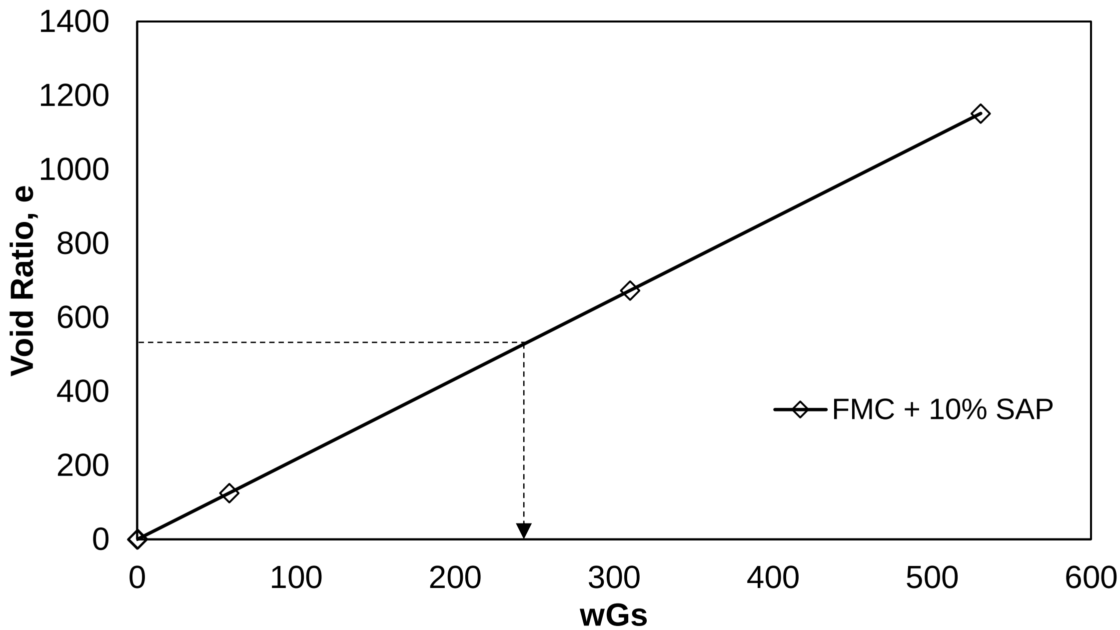

Figure 4.3 Shrinkage plot for FMC with addition of 10% SAP.

Void ratio increase with increase of wGs. The void ratio of FMC with 10% SAP is 526.63 and the shrinkage is limit for FMC with 10% of SAP is 241%, which is greater than shrinkage limit of FMC and FMC. Shrinkage limit for FMC 64.71%.

4.2.4 Specific Gravity

The specific gravity of kaolinites decrease when the proportion of SAP in kaolinite increase. When 5% of SAP is added to the kaolinite, the specific gravities are 2.70, 2.54 and 2.33 respectively for S300, Speswhite and FMC but the specific gravity decrease to 2.20, 2.13 and 2.17 respectively when the SAP added increase to 10%. The specific gravity for both pure S300 and FMC are 2.62 while specific gravity for pure Speswhite is 2.61. Bentonite shows the high specific gravity which is 2.80 while Marconite has lowest specific gravity which is 1.69. Specific gravity is closely related to mineralogy or chemical composition (Oyediran et. al., 2011), weathering history, where specific gravity increase with increasing of degree of weathering (Tuncer et.al, 1977) and appropriateness of soil as construction material, where soil with higher specific gravity gives higher strength for roads and foundations (Prakash et.al, 2002).

4.2.5 Swelling Index

S300, Speswhite and FMC have 1%, 0% and 10% of swelling index respectively and increase to 70%, 100% and 80% respectively with addition of 5% SAP. The swelling index increase greatly after adding 10% of SAP. The S300 with 10% SAP has 500% of swelling index while the swelling index of Speswhite with 10% SAP and FMC with 10% SAP are 440% and 470%. According to IS 1948, S300 and Speswhite without SAP have swelling index below 10% show that both of them have low degree of expansion. S300 and Speswhite with 5% SAP and FMC without SAP and with 5% SAP have medium degree of expansion as they have swelling indexes of 50% to 100%. S300, Speswhite and FMC with 10% SAP have swelling indexes above 200%. They are soils with very high degree of expansion. The major disadvantage of this method is crude as measuring 10cm^3 of soil is not easy depending on personal judgement. It is normal to quantify 10cm^3 of soil volume is equal to 10g of soil but this does not include consideration of density variation (Asuri et al., 2016). Holtz and Gibbs, 1956 stated that more than 100% of soil free swelling will cause lightly loaded structure damage but less than 50% of soil free swelling will not show significant volume changes. However, Dawson, 1953 reported that some Texas clays with free swelling values around 50% showed wide expansion as a result of extreme climate and expansion characters of the soil (Abdel, 2008).

4.2.6 BET Surface Area

BET surface area of S300 and Speswhite increase with addition of 5% SAP and 10%SAP. However, the BET surface area of FMC with 10% SAP decrease compare to FMC with 5% SAP. When S300 added with 5% SAP, the BET surface area is 1.4529 m^2/g and increase by 27.59% when added with 10% SAP. Meanwhile, pure Speswhite has 7.8 m^2/g of BET surface area and increase to 9.6513 m^2/g and 11.2916 m^2/g when added with 5% and 10% SAP. However, FMC with 5% SAP shows 9.6431 m^2/g of BET surface area but the BET surface area decrease by 8.56% for FMC with 10% SAP. On the other hand, Bentonite shows the greatest BET surface area comparing to all kaolinite with and without SAP. Bentonite has 676 m^2/g of BET surface area. Usually, nitrogen gas is for Brunauer-Emmett-Teller (BET) surface area analysis (Pennell, 2016). However, nitrogen does not penetrate the interlayer surfaces of soils and thus only external surfaces of soils are measured (Carter et al., 1986). Several assumption is made in determining the free surface area by BET method. For example, BET test only involve physical adsorption, the surface area of soil remain the same during adsorption process and the adsorbate in the soil does not form solution (Chiou, 1990)

4.2.7 Loss on Ignition (LOI)

LOI is the most common method to measure the soil organic matter content. The results show significant increases of loss on ignition with addition of SAP. Before applying SAP, the LOI of S300 is 0.0007%. After added with 5% of SAP, the LOI increase to 0.00785% and the LOI further increase to 8.722% when added with 10% SAP. While for Speswhite, the LOI before adding SAP and after adding 5% and 10% SAP are 0.086%, 0.022% and 9.128% respectively. On the other hand, LOI for pure FMC is 0.112% and the LOI increase to 0.056% and 9.572% when put in 5% and 10% SAP. Increase of soil organic matter indicates increase of water holding capacity of soil (Murphy, 2015). Soil organic matter also affect the cation exchange capacity of soil depending on the soil texture and pH range (Krull et. al, 2009). The results is affected by ignition temperature and heating time (Brix, 2008). Too low ignition temperature and too short burning time may not convert the organic matter completely into CO_2 but too high ignition temperature and too long heating time may convert, inorganic compounds such as carbonates and sulphate into CO_2 and SO_2.

4.2.8 Particle size distribution

Bentonite has 96.4 % of particle size that less than 2 μm. This shows that Bentonite is a clay. Figure below shows the particle size distribution graph of Marconite. It is uniformly graded soil as most of the soil are the same size which is greater than 0.6mm but smaller than 3.35mm. D_{10} , D_{30} and D_{60} Marconite are 0.7mm, 0.93mm and 1.60mm respectively while the uniformity coefficient, Cu is 2.29 and the coefficient of gradation, Cc is 0.77.

4.3 Chemical Property

4.3.1 Cation-Exchange Capacity (CEC)

Cation exchange capacity (CEC) is a soil particle's ability to react with positively charged molecules such as nutrients, water, herbicides and other soil amendments (Goldy, 2011). CEC occurs when bonds around the crystal edges broken, substitute within lattice, and the hydrogen of exposed surface hydroxyls that may be replaced (Ma et al., 1999). The most common exchangeable cations in clay materials are Calcium (Ca^{++}), Magnesium (Mg^{++}), Hydrogen (H^{+}), Potassium (K^{+}), Ammonium (NH_4^{+}) and Sodium (Na^{+}) (Grim, 1953). Low CEC indicates that not much positively charged molecules are able to react with soil particle while high CEC shows that huge number of molecules can react with soil particle (Goldy, 2011). The CEC for S300, Speswhite and FMC with 10% of SAP are 460 meq/100g, 523.6 meq/100g and 344.1 meq/100g respectively. This shows great increase of CEC comparing to kaolinites with 5% SAP and without SAP. For example, S300 with 5% of SAP has 10.12 meq/100g of total CEC while S300 without SAP has only 1.80 meq/100g of total CEC. In all soil samples, the composition of Sodium ion is the highest. Bentonite has 90.31 meq/100g of total CEC.

Table 4.1 Properties of S300, Speswhite, FMC, Bentonite and Marconite with varying percentage of SAP

Properties	**S300**			**Speswhite**			**FMC**			**Bentonite**	**Marconite**
	Without SAP	**With 5% SAP**	**With 10% SAP**	**Without SAP**	**With 5% SAP**	**With 10% SAP**	**Without SAP**	**With 5% SAP**	**With 10% SAP**	**Without SAP**	**Without SAP**
Physical Properties											
Liquid limit (%)	41.00	83.85	460.00	51.40	96.11	495.00	80.00	120.00	500.00	437.00	-
Plastic limit (%)	27.90	48.79	150.38	32.00	37.80	141.45	49.40	64.87	275.30	63.00	-
Shrinkage limit (%)	38.50	40.00	280.00	26.50	38.00	235.00	64.71	-	241.00	12.20	-
Specific gravity	2.62	2.70	2.20	2.61	2.54	2.13	2.62	2.33	2.17	2.80	1.69
Swelling Index (%)	1	70	500	0	100	440	10	80	470	-	-
BET Surface Area (m^2/g)	-	1.4529	1.8537	7.80	9.6513	11.2916	-	9.6431	8.8176	19.77	-
Loss on ignition (%)	0.0007	0.00785	8.722	0.0860	0.02200	9.128	0.1120	0.0560	9.572	-	-
Initial water content (%)	-	-	1.13	-	-	0.83	1.011	1.678	2.68	-	0.05
Particle size distriction	-	-	-	-	-	-	-	-	-	< 2 µm: 96.4 %	< 63 µm: 1.36%
Chemical Property											
Cation exchange capacity (meq/100g)	Na: 0.15 K: 0.12 Mg: 0.05 Ca:0.482	Na: 9.73 K: 0.14 Mg: 0.04 Ca:0.192	Na: 456.4 K: 1.6 Mg: 2.0 Ca: <0.5	Na: 1.06 K: 0.37 Mg: 0.66 Ca: 1.09	Na:18.30 K: 2.68 Mg: 0.07 Ca:0.867	Na: 506.8 K: 2.0 Mg: 14.8 Ca: <0.5	Na:0.44 K: 0.21 Mg:0.06 Ca: 0.734	Na:14.73 K: 0.59 Mg: 0.62 Ca: 2.256	Na: 342.8 K: 1.2 Mg: <0.1 Ca: <0.5	Na:51.24 K: 1.40 Mg: 9.43 Ca: 28.24	-
Total CEC (meq/100g)	0.81	10.10	460.0	3.19	21.92	523.6	1.45	20.90	344.1	90.31	

4.4 Soil Water Characteristic Curve

Figures 4.4 shows the soil water characteristic curve for soil sample S300 without and with 5% and 10% SAP.

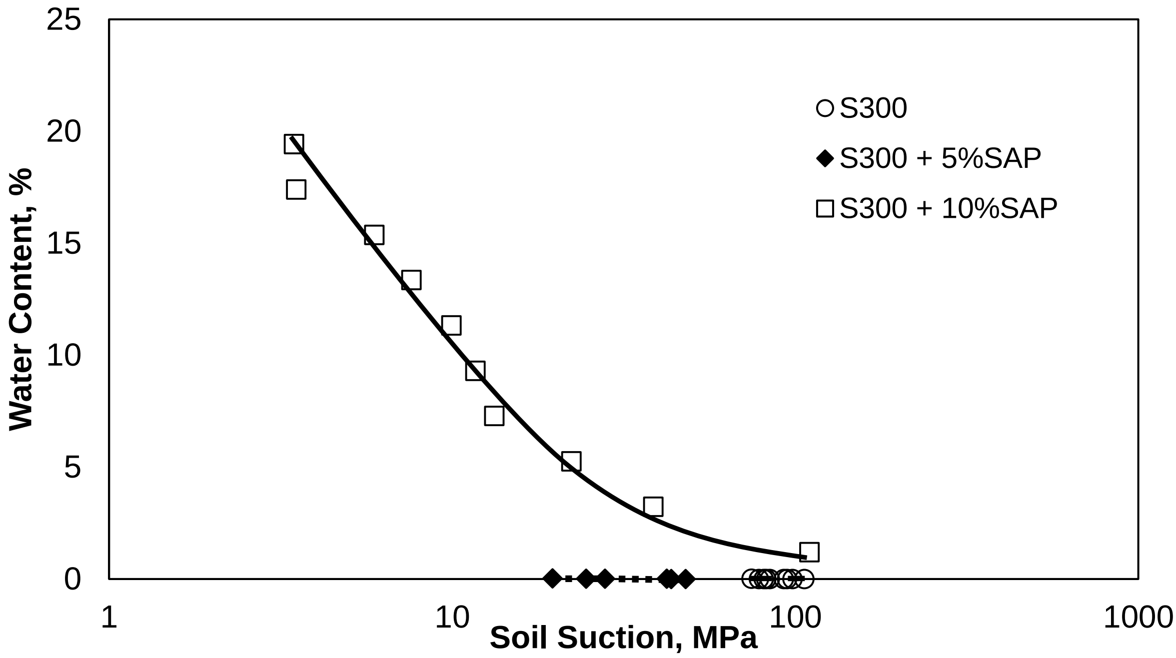

Figure 4.4 Soil water characteristic curve for S300

S300 with 0% and 5% SAP do not show change in water content with increasing of soil suction but water content for S300 with 10% SAP decrease dramatically with increase of soil suction. The soil suction of S300 with 10% SAP varied between 3.93MPa to 109.99MPa corresponding to water content changes from 21.46% to 1.21%.

Figures 4.5 shows the soil water characteristic curve for soil sample Speswhite without and with 5% and 10% SAP. Based on the analysis, the water content for all soil samples decrease with increase of soil suction. The water content of 3 Speswhite samples decrease with increase of soil suction. At soil suction below 5.64MPa, water content of Speswhite with 10% SAP is higher Speswhite with 5% SAP but the water content of Speswhite with 5% SAP is higher Speswhite with 10% SAP above 5.64MPa soil suction. Water content for pure Speswhite is the lowest.

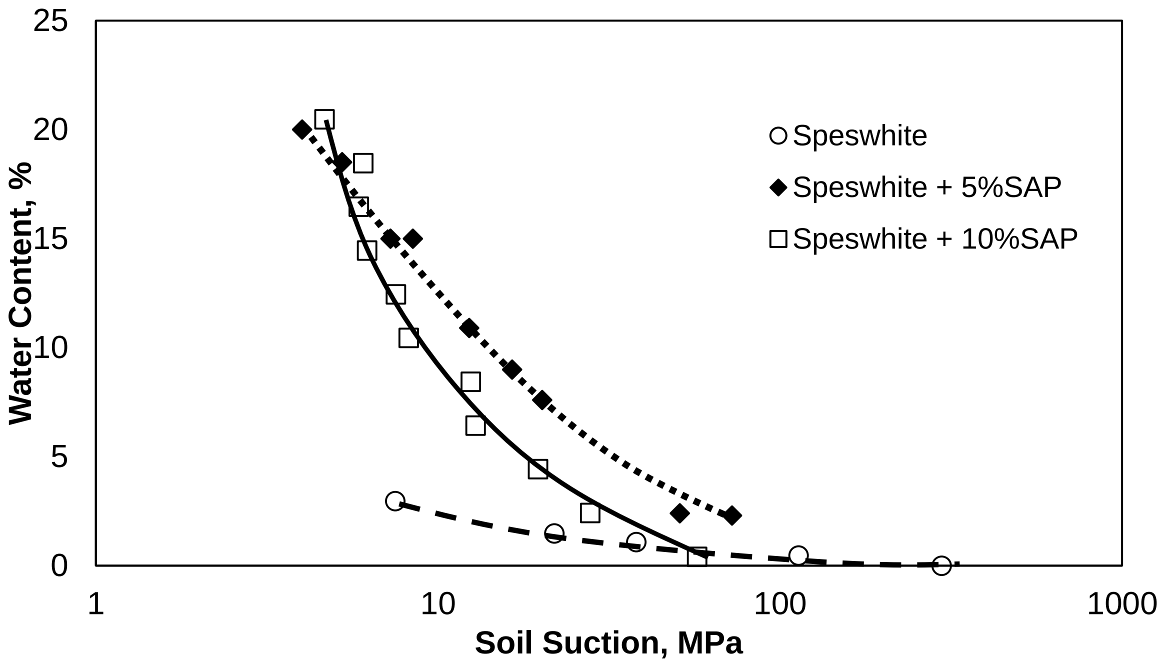

Figure 4.5 Soil water characteristic curve for Speswhite

Figures 4.6 shows the soil water characteristic curve for soil sample FMC without and with 5% and 10% SAP.

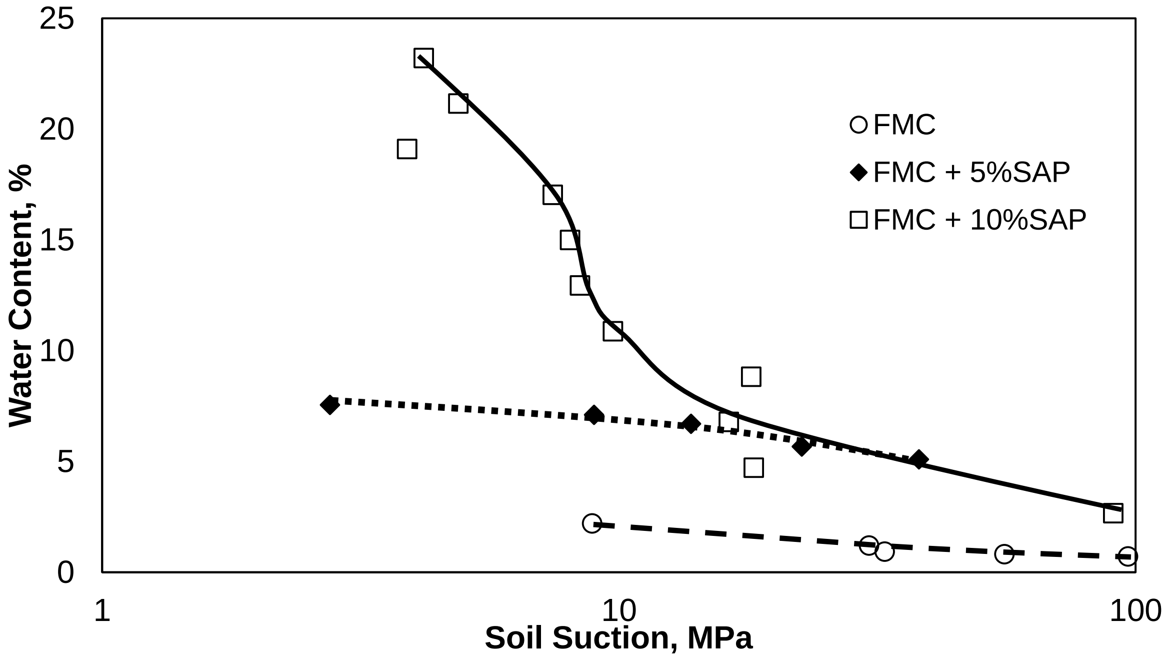

Figure 4.6 Soil water characteristic curve for FMC

Based on the analysis, the water content for all soil samples decrease with increase of soil suction. The water content of 3 FMC samples decrease with increase of soil suction. At all soil suction, water content of FMC with 10% SAP is higher than FMC with 5% SAP and pure FMC except at soil suction above 27.8MPa the water content of FMC with 5% SAP is slightly higher FMC with 10% SAP.

4.5 Soil Resistivity

The soil resistivity of various soil samples are as shown in Table 4.2.

Table 4.2 Soil resistivity of various soil samples

Soil	**Soil Resistivity (Ω.m)**
S300	140
S300 + 5% SAP	130
S300 + 10% SAP	27
Speswhite	20
Speswhite + 5% SAP	26
Speswhite + 10% SAP	17
FMC	110
FMC + 5% SAP	110
FMC + 10% SAP	21
Bentonite	6.2
Marconite	0.38

From the result obtained, addition 5% of SAP has slightly decrease the soil resistivity of S300 and further decrease when 10% of SAP is added. The soil resistivity of S300, S300 with 5% SAP and S300 with 10% SAP are 140 **Ω**.m, 130 **Ω**.m and 27 **Ω**.m respectively. Soil resistivity of Speswhite is 20 **Ω**.m and increase to 26 **Ω**.m when added with 5% SAP but decrease to 17 **Ω**.m when added with 10% SAP. FMC and FMC with 5% SAP have same soil resistivity which is 110 **Ω**.m. The soil resistivity drop to 21 **Ω**.m when added with 10% SAP. S300 has highest soil resistivity follow by FMC and Speswhite. Overall, addition of SAP has decrease the soil resistivity of kaolinite. However, comparing to bentonite with 6.2 **Ω**.m and Marconite with 0.38 **Ω**.m soil resistivity, the desired resistivity for kaolinites are not achieved. According to IEEE Std 142-2007, Marconite is suitable as backfill material for large substations, transmission lines, or generating stations which grounding resistance should not exceed 1 **Ω**.m while bentonite is suitable for industrial plant substations and buildings and large commercial installations which grounding resistance should be in 1 **Ω**.m to 5 **Ω**.m. All the kaolinite samples do not meet the requirement for grounding resistance.

CHAPTER 5

CONCLUSION

5.1 Conclusion

The objectives of study are achieved. Based on the study, it can be conclude that:

i. The plasticity index for S300, Speswhite and FMC are 13.10%, 19.40% and 30.60% respectively while the plasticity index are 35.06%, 58.31% and 55.13% respectively when added with 5% SAP. The plasticity index of S300, Speswhite and FMC further increase to 309.62%, 353.55% and 224.70% respectively when added with 10% SAP. Addition of 5% and 10% of SAP in S300 increase the plasticity index by 167.63% 2263.51% while the plasticity index of Speswhite increase by 163.85% and 1499.77% with addition of 5% and 10% 0f SAP. FMC with 5% and 10% SAP increase their plastic limit by 80.16% and 634.31%. However, all of the plasticity index of kaolinites with or without SAP have lower plastic index than bentonite. The plasticity index of bentonite is highest, which is 374%.

ii. Soil-water characteristics curve (SWCC) of kaolinite with addition of SAP at varying percentage is established. The water content for all soil samples decrease with increase of soil suction except S300 with 0% and 5% SAP do not show change in water content with increasing of soil suction. S300 with 10% SAP shows obvious reduction in water content with increase of soil suction comparing to S300 with 0% and 5% SAP. For pure Speswhite, the water content is lowest for all soil suction. On the other hand, at soil suction below 5.64MPa, water content of Speswhite with 10% SAP is higher Speswhite with 5% SAP but the water content of Speswhite with 5% SAP is higher Speswhite with 10% SAP above 5.64Mpa soil suction. At all soil suction, water content of FMC with 10%

SAP is higher FMC with 5% SAP and pure FMC except at soil suction above 27.8MPa the water content of FMC with 5% SAP is slightly higher FMC with 10% SAP.

iii. Addition of SAP has decrease the soil resistivity of kaolinites. S300 has highest soil resistivity follow by FMC and Speswhite. Addition 5% of SAP has slightly decrease the soil resistivity of S300 and further decrease when 10% of SAP is added. The soil resistivity of S300, S300 with 5% SAP and S300 with 10% SAP are 140 Ω.m, 130 Ω.m and 27 Ω.m respectively. Soil resistivity of Speswhite is 20 Ω.m and increase to 26 Ω.m when added with 5% SAP but decrease to 17 Ω.m when added with 10% SAP. FMC and FMC with 5% SAP have same soil resistivity which is 110 Ω.m. The soil resistivity drop to 21 Ω.m when added with 10% SAP. Overall, addition of SAP has decrease the soil resistivity of kaolinite. However, comparing to bentonite with 6.2 Ω.m and Marconite with 0.38 Ω.m soil resistivity, the desired resistivity for kaolinites are not achieved. According to IEEE Std 142-2007, Marconite is suitable as backfill material for large substations, transmission lines, or generating stations which grounding resistance should not exceed 1 Ω.m while bentonite is suitable for industrial plant substations and buildings and large commercial installations which grounding resistance should be in 1 Ω.m to 5 Ω.m. All the kaolinite samples do not meet the requirement for grounding resistance.

5.2 Recommendations

1. Increase the percentage of SAP to 15%, 20% and so on in order to further enhance the properties of kaolinites.
2. Crushing the SAP into smaller and regular shape in order to increase the result accuracy.
3. Modification of SAP to improve its absorbency, gel strength, and absorption rate.

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