SHRINKAGE BEHAVIOUR OF KAOLIN ENHANCED WITH SUPERABSORBENT POLYMER

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ABSTRAK

Jumlah pelupusan sampah yang banyak ke tapak pelupusan setiap hari boleh menyebabkan masalah alam sekitar ke tapak pelupusan sampah. Tanah liat boleh menjadi salah satu penyelesaian masalah alam sekitar yang boleh digunakan untuk aplikasi geo-alam sekitar seperti halangan tanah liat, halangan tambak dan boleh bertindak sebagai rawatan dan kawalan sisa. Kaolinite mempunyai keplastikan yang lebih rendah selain ia ada di dalam negara dan mempunyai kos yang lebih rendah berbanding beberapa jenis tanah liat seperti bentonit, illite dan montmorillonite. Tingkah laku kaolinit pengecutan akan dikaji dengan menggunakan Ujian Clod. Peningkatan Super Penyerap Polimer (SAP) dapat membantu meningkatkan prestasi susunan pengecutan kaolinit kerana ia mempunyai penjerapan tinggi dan pengekalan cecair. Objektif kajian ini adalah untuk menguji tindak balas pengecutan kaolinit yang dipertingkatkan dengan SAP dan untuk mendapatkan lengkung pengecutan nisbah kekosongan berbanding kandungan air menggunakan Ujian Clod.

ABSTRACT

Huge amount of waste disposal to landfill every single day can cause environmental problem to landfill. Clay can be one of the solution the environmental problem which it can be used for geo-environmental application such as clay barriers, landfill barriers and can act as treatment and waste control. Kaolinite has lower plasticity besides it is locally available and has lower cost compared to a few other types of clay such as bentonite, illite and montmorillonite. Shrinkage behaviour of kaolinite will be studied by applying Clod Test. Enhancement of Super Absorbent Polymer (SAP) can help to improve the performance of shrinkage behaviour of kaolinite as it has high adsorption and retention of fluids. The objectives of this study are to test the shrinkage behaviour of kaolinite enhanced with SAP and to obtain shrinkage curve of void ratio versus water content using Clod Test.

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CHAPTER 1

INTRODUCTION

1.1 Background

Waste water are generated daily in form of solid, sludge, liquid or gas (Bouzza & Van Impe, 1998). Increasing in number of population for a developing country in Malaysia will inevitable produce more wastes that need to be disposed. Disposal of these wastes need to be carried out in a proper way to ensure the safety of the environment. One of the methods of waste disposal is by permanent disposal at landfill sites (Ayomoha et al., 2008). A proper landfill should be able to contained waste at the same time preventing the migration of pollutants into the environment. In order to obtain the best waste disposal practices, waste characterization must be undertaken prior to designing a landfill.

Landfill is built up with layers of solid waste and covered with soil or bottom liner to prevent ground water pollution. A landfill is designed in order to minimize public health and environment impacts. The main feature of sanitary landfill is that a liner is designed at the bottom of landfill (Baghci, 2004). According to Qian et al., (2002), liner system in landfill acts as a barrier against the advective and diffusive transport of leachate. In addition, in addition liner system in landfill consist of multiple barrier and drainage layers (Qian et al., 2002). Clayey soils are widely used as liner material for landfills. Clayey soil is used to liner material due to its low hydraulic conductivity (k) and sorptive properties (Owies and Khera, 1998). In some cases, geosynthetic clay liners (GCL) containing bentonite and geotextile are used (Sharma and Reddy, 2004). Furthermore, the use of natural soil containing kaolinite minerals is a cheaper alternative.

Clay exhibit swelling and shrinkage behaviour when objected to wetting and drying process (Hsai-Yang and Daniels, 2006). In landfills, clay liners received water when in contact with groundwater or stormwater that infiltrate into the landfill which in turn caused the liners to swell. Upon drying, soil containing clay mineral undergoes shrinkage process and reduction in volume with water content changes. Shrinkage behaviour of clays can cause damage to structures built on or with clays (Sivapullaiah et al., 1986). During the dry periods, clayey soil will shrink and form cracks (Sivapulliah et al., 1986). Significant shrinkage and excessive formation of crack cause problem to the landfill. Thus, shrinkage behaviour is important for long-term assessment of engineering behaviour of clays. It is very important to determine the shrinkage behaviour of soil. Studies relating to shrinkage behaviour of soil have been shown to be useful in assessment of stability of clay barriers (Tang et al., 2008). In order to determine the shrinkage characteristic of clay soil, volume measurement of soil during dying is required. Generally, duplicate soil specimens are prepared and tested in the laboratory for this purpose. However, this process is tedious and time consuming (Head, 2006).

Bentonite is one of the suitable example of backfill materials 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 chemical (Jones, 1980). In Malaysia, it was reported that bentonite only deposited in several areas of Sabah such as in Segama, Sepagaya, Mansuli and Andrassy (Samsuri,2006). According to Malaysia minerals Yearbook 2010, there are three bentonite processing plants in Malaysia which located one each in Perak, Johor, Selangor but all are raw bentonite are imported. In 2010, Malaysia imported 73,269 tonnes of bentonite mostly from india, Chin, 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 increased to 530,331 tonnes from 487,632 tonnes recorded in the previous year mainly in Perak. However, kaolinite has lower plasticity behaviour than bentonite. According to research by Horpibulsuk et al., (2011), bentonite has very high plasticity index which 175% but the plasticity index for kaolin is very low which is 22%. Another study also showed that bentonite has 91.8% 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 chargers. It is also stated that bentonite has optimum water content up to 37% but kaolin only has 19.5% of optimum water content (Fattah et al., 2016).

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

Literature suggested that, the use of several soil parameters can be used to establish the soil shrinkage characteristic curve according to Chertkov, (2000). By using parameters such as water content and specific gravity, the entire shrinkage curves at any given water content can be establish for a given soil. Various researchers in the past have proposed models such as ModGG model, ModC model, OH model, TD model, Gea model, Bea model, Kea model, MM2 model and MM1 model can be used to establish the soil shrinkage characteristic curve (Cornelis et al., 2006). As the shrinkage curve of soils is generally nonlinear in nature, a number of equations are used to establish the entire shrinkage curve. A model proposed by Kim et al., (1992) however, uses a simple equation which combined an exponential and linear functions which gave best fits to experimental data (Cornelis et al., 2006).

In this study, clod test is used to measure the volume change of soil during drying from initial saturated condition under zero applied stress. The use of glue as a coating agent enable the volume of soil samples to be measured. Multiple samples are prepared at various water content to establish the shrinkage curve. In order to improve plasticity, the soil will be enhanced with SAP. The result obtained experimentally will later compared with the curve establish using Kea model.

1.2 Problem statement

Clay soils are generally used as liner material of landfill in purpose to prevent the waste water from infiltrating groundwater and cause pollution to environment. Bentonite is commonly used as landfill liner due to high water absorption ability. Bentonite only can be deposited in several area in Malaysia and need be imported from other country compared to kaolinite that has higher availability in Malaysia. However, kaolinite has lower plasticity compared to bentonite. Thus, a study of enhancement of Superabsorbent Polymer which can absorb and retain more water to kaolinite will be carried out.

1.3 Research objective

Based on the problem statement, several objectives are expected to be achieved throughout this study. The objectives are:

i. To study the properties of kaolinite with enhancement of Superabsorbent Polymer.
ii. To establish shrinkage curve of kaolinite with enhancement of Superabsorbent Polymer using Clod Test.

1.4 Scope of study

In this study, two kaolinite samples are used which are S300 and FMC. The properties of S300 and FMC is determined with addition 10% of Superabsorbent Polymer. The volume channge of S300 and FMC with addition 5% and 10% of superabsorbent polymer are measured experimentally from initially saturated slurry condition under zero applied stress using Clod Test. A shrinkage model which is Kea model will then be used to establish the entire shrinkage curve for both soils.

1.5 Significant of study

In this study, there will be some significant where addition of Superabsorbent Polymer (SAP) can improve water absorption and retention, plasticity and volume change of kaolinite. The improvement is important in replacement of bentonite to which commonly used in geotechnical application with kaolinite.

1.6 Thesis overview

Chapter 2 present the overview research related to the study which include briefly explanation on linear system applied on landfill. Follow with brief explanation on clay liner as a liner material on landfill site. Explanation about minerals group which are kaolinite, illite and montmorillonite contains in clay is presented. This chapter also discuss about the interaction of between water and clay minerals, followed by the shrinkage behaviour of the soil samples. Next, the modification mechanisms of water absorption which is Superabsorbent Polymer that can improve plasticity and volume change of kaolinite will be briefly explained. Then, the volume measurement to determine the shrinkage characteristic of kaolinite. Lastly, this chapter will briefly explain about the proposed model to establish the shrinkage curve of kaolinite.

Chapter 3 present the experimental methodologies of this study which include the selection of materials which are s300 and FMC, preparation of superabsorbent Polymer (SAP) and soil samples, physical and chemical properties of kaolinite with addition of 10% SAP. 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, shrinkage behaviour in terms of its volume change will be determined using Clod test that will be briefly explained the methodology in this chapter.

Chapter 4 presents the results obtained from the laboratory tests. The results of properties of S300 and FMC with enhancement of 10% SAP will be discussed by comparing the properties of S300 and FMC from previous study. The physical properties which are liquid limit, plastic limit, shrinkage limit, specific gravity, swelling index, specific surface area, loss of ignition, chemical property such as cation exchange capacity and volume change are compared and explained with kaolinites without adding SAP, kaolinites added with 5% of SAP. 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 can improve the water absorption ability of kaolinites.

Chapter 5 present the findings conclusion of this study which include result and discussion, important findings and recommendations should be made for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will explain and review past research efforts related with the measuring of the shrinkage characteristic of kaolinite. Other than that, in this chapter also explain briefly on waste disposal, landfill, clay minerals. Substantial literature has been studied on shrinkage behaviour, volume measurement and model. Besides that, application of bentonite and kaolinite are explained and their properties are compared. Mechanism, characteristic and usage of Superabsorbent Polymer (SAP) that affect the plasticity of clay also will be discussed.

2.2 Waste disposal

Waste can be classified into mineral, industrial, hazardous and municipal solid waste. Basically, organic waste contains minerals which originated from living organisms. Municipal waste produced from the residential, commercial and institutional sources. The composition of the municipal waste is affluence from the society and economic status of the country (Kreith, 1994).

Most of the solid waste disposal sites in Malaysia are either open or dumps or controlled tipping. There is limited area to placing the waste for the site of control tipping. The pollution levels from these sites are expected to be high especially the contamination of soil, air, surface and underground water. All these pollutions can give effects to human being (Theng et al., 2004). The materials used in landfill design are very important to research in order to meet several design criteria that are acceptable to the public. Impermeable clay soils can avoid the seepage of landfill leachate, thus make it more often to establish the landfill sites. In UK, several large sites receiving municipal households waste from London have been sited on Oxford clay (J. Martin and Stephens, 2006).

2.3 Landfill (liner system)

Landfill can be classified into three classes based on the types of waste that are hazardous waste, designated waste and municipal waste (Williams, 2006). However, landfill used nowadays is dealing with municipal waste which is designed and operated to minimize environmental impacts. Modern landfills are highly engineered containment systems, designed to minimize the impact of solid waste on the environment and human health. In modern landfills, the waste is contained by a liner system. The primary purpose of the liner system is to isolate the landfill contents from the environment and therefore, to protect the soil and ground water from pollution originating in the landfill (Kerry et al., 2005).

Landfill liners are designed and constructed to create barrier between the waste and the environment and to drain the leachate to collection and treatment facilities. There are different types of materials that have been used to construct the landfill liners and final cover fall into three categories that are clayey soil, synthetic membranes or other artificial manufactured materials and amended soil or other mixtures (Baghchi, 2004). Landfill liner also can prevent the uncontrolled release of leachate into the environment.

2.3.1 Clay liner

Normally landfills come with a cover barrier that includes a compacted clay liner. However, this barrier encounters numerous problems especially those related to the in situ implementation and the differential settlement. This can cause stress in the clay layer that leads to the development of cracks. It is necessary to maintain the physical and mechanical characteristic of clayey soil and its waterproofing properties at required level such as permeability of the soil is lower 10^{-9} m/s (Camp et al., 2010). The liner components are very important to study before design the landfill. Clay is used to protect the ground water from landfill contaminants and can only allow water to penetrate at a rate of less than 1.2 inches per year specified by regulations. Besides, clays compacted at higher moisture contents are more effective barriers to contaminants compare that compacted at lower moisture contents (Kerry et al., 2005).

According to Owis and Khera, generally clays acting on reducing hydraulic conductivity of soil used in the construction of liners and slurry walls for containment of new or existing waste disposal facilities. In general, typical type of clay liners is the soil which can be classified as clay with high plasticity, clay with low plasticity, and sandy clay. In liner construction clay is wet-of-optimum and the field moisture content is typical higher than the shrinkage and plastic limits. Clay with low plasticity index and high shrinkage limit is preferable (Koerner and Daniel, 1997).

According to Bagchi, clay that used in the construction of compacted clay liner should have the following specifications that are liquid limit is between 20 percent to 30 percent, plasticity index is between 10 percent and 20 percent and clay friction is 0.002 mm or less.

2.4 Clays

Fined-grained soils, such as fine silts and clays, are usually found in deeper water. This is due to the fact that as currents dissipate only fine-grained soils are carried further into a deposition basin or deepwater flow channel. Sands without silts or clays are also susceptible to grain flows but occur only locally in areas with relatively steep slopes (Middleton, 2006). A soil considered as a fine-grained soil when the soil passes 50 percent or more by weight of the particles finer than the No. 200 sieve (Naresh, 2006).

Commonly, clayey soil used as lining non-hazardous waste landfills barrier. According to Bagchi 2004, clay can be defined as the soil is made up of millions of tiny particles, that has particles equal to or finer than 0.002 mm. Clay is a particle that having size below 2μm and can feel that it is slightly abrasive but not gritty and also feel greasy (Whitlow, 2001).

The surface of clay soil is said to be surface active which means that much happen on their surface. The surface of the clay soils can absorb and hold water, organic compound, toxic ions and also plant nutrients ion (Singer and Munns,2006). Some clay is more prone to loss of strength due to sensitivity. Theses clays are relatively strong in their natural, undisturbed state but can quickly change to a liquid mass when disturbed (Sultan et al., 2004).

2.4.1 Clay minerals

Clay minerals are complex aluminium silicates composed of two basic units that are silica tetrahedron and alumina octahedron. Each tetrahedron unit consists of four oxygen atoms surrounding a silicon atom meanwhile the octahedral unit consists of six hydroxyls surrounding an aluminium atom. There are three important clay minerals that are kaolinite, illite and montmorillonite (Das, 2006).

Kaolinite be likely to develop in areas that having relatively high precipitation but good drainage that enables the leaching of Magnesium (Mg), Calcium (Ca) and Ferrum (Fe) cations (Mitchell and Soga, 2011). The kaolinite group are known as 1:1 clay minerals because they consist of repeating layers of one silica tetrahedron sheet and one alumina octahedron sheet. They consist of several layers of the basic layer is about 0.72 nm thick that extends indefinitely in the other two directions. These basic layers are held together by strong hydrogen bonds between hydroxyls of octahedral sheet and the oxygen of the tetrahedral sheet (Robert et al., 2011).

Illite group has 2:1 structure due to its minerals composed sheet and one alumina sheet in between. The illite interlayer’s bonded together with a potassium ion. The potassium ion (K+) are strongly bonds the layers together because the diameter of K+ atom is almost exactly same with the diameter of hexagonal hole in the silica sheet thus it’s just fills the hole. Besides there is some isomorphous substitution of aluminium for silicon in the silica sheet (Robert et al., 2011).

In montmorillonite group, these minerals composed of two silica sheets and one alumina sheet in between. Thus, it also called as 2:1 clay minerals same as illite group.

A single layer form by the tips of the silica share oxygen and hydroxyls with the alumina sheet. The layer thickness of each is about 0.96 nm and the layers extend indefinitely in the order two directions (Robert et al., 2011). The dominant clay mineral in most bentonite is montmorillonite. Bentonite is the entire layers of volcanic ash that converted into white, sticky and highly expensive clay by chemical weathering (Handu and Spangler,2007).

2.4.2 Interaction between water and clay minerals

A fine-textured soil tends to absorb much water. It becomes plastic and sticky when wet while when dry it becomes tight, compact and cohesive. Water basically will give effect on soil behaviour. Fine grained soils are strongly influenced by the presence of water especially the clay soil (Robert et al., 2011). In general, water molecule is electrically natural. Water molecule has two separate centres of charge which are positive and negative. Electrically neutral of water molecule makes it attract electrostatically to the crystal surface of clay. Besides that, water molecule held to the clay crystal by hydrogen bonding due to attraction of hydrogen water to the oxygen atoms or hydroxyl molecules on the surface of the clay. The presence of negative charge of clay surface attract cations in water. Cations also contribute to attract water since all cations are hydrated to some extent depends on the ion.

Kaolinite as the largest clay mineral crystal has a thickness roughly 1 µm while montmorillonite as the smallest clay mineral only a few nanometres. The smaller the particles, the larger the specific surface. The higher active surfaces cause the montmorillonite has higher plasticity, more swelling and shrinkage and larger volume change due to loading compared to kaolinite (Robert et al., 2011).

2.4.3 Bentonite

Bentonite is a natural clay which form by years of volcanic action (Tu et al., 2006). It is formed 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 non-corrosive, stable (Tu et al., 2006), high cation exchange capacity, high plasticity and high propensity of reaction with organic compounds (Lim et aal., 2013). When hydrated with water, bentonite is alkaline with 8 to 10 pH. Besides that, bentonite also has high water absorption capability as it is hydropolic which strongly hydrated by water. Its volume will be enlarged to several times of original volume when water is absorbed by diffusion or capillary suction (Lim et al., 2013). Bentonite also has high capability to retain water for long period depending on temperature and atmospheric pressure (Lim et al., 2013).

Not only act as landfill liner, bentonite also useful in supporting fluids. Bentonite is used to sustain the sides of panel excavation wall in order to avoid runoff of fluid into the ground where the fluid pressure can withstand external pressure from soil and groundwater. Bentonite also applies in other construction such as bore piles with big diameter, cut-off walls below ground and tunnelling machines excavation. Its main function is act as a barrier (Ball et al., 2006). Applications of bentonite not only limited in Civil Engineering but it is used widely in others field. Multitude uses of bentonite include drilling muds, foundry bonds, cat litter, ceramics, detergents, fertilizers, food additive, paint, paper, pharmaceutical, sealants, water clarification (Murray,2007).

2.4.4 Kaolinite

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

Normally, the colour of kaolinite is white or almost white. Kaolinite has minimal layer charge and low base exchange capacity as it has few substitutions in structural lattice. Comparing to bentonite, kaolinite has lower surface area. With minimal layer charge and low surface area properties, kaolinite also has lower 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 application as it provides minimal wear and tear when in contact with equipment. By adding some chemical dispersant to negate the edge charge 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).

Kaolinite is the common mineral that has been used for industrial application because of their physical and chemical properties has determined it is used as industrial minerals. Previous study of traditional and new applications of kaolin, smectite and palygorskite: a general overview, a relatively low viscosity at high solid concentrations is important characteristic of some kaolin which particularly important in paper coating and paint applications. The use of kaolin is for coating paper so the properties that are important to the manufacturer are dispersion, viscosity (both low and high shear), brightness, whiteness, gloss, smoothness, adhesive demand, film strength, ink receptivity and print quality (Murray,2000).

In the research of influence of kaolinite clay on the chloride diffusion property of cement-based materials, it shows that the objective if this study is to investigate the effect of kaolin clay on the workability, strength and chloride diffusion coefficient of cement-based mixtures (i.e. cement, mortar and concrete). The effects of addition amount and dispersion method on the porosity characteristics of cement paste with 1% of clay addition, the porosity in the cement paste has a reduction of 18.48% whereas the average, medium and mode pore diameter have reduction of 20.64%,43.36% and 56.84% respectively (Fan et al., 2014). It shows that clay also can be applied as cement-based improvement.

Other research shows that kaolinite also can be applied in geo-environmental application. Even though kaolinite has lower plasticity compared to bentonite that used as landfill barrier, Modified kaolinite can be used as removal for organic pollutant in a very low concentration.

2.5 Superabsorbent polymer

Superabsorbent polymers (SAP) 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).

Superabsorbent polymer has widely used in industrial because the properties of the superabsorbent polymer itself suitable to improve soil properties. Superabsorbent polymer can absorb up until 100% of water that applied in agriculture application. Superabsorbent polymer has been applied in agriculture as soil conditioner and nutrient carrier which some properties of superabsorbent polymer help in enhancing the soil structure for example the complete elucidation of the swelling profile exhibit by a given superabsorbent polymer assures better applicability and adequate responses in specific situation (Giulherme et al., 2015). Other than that, in agriculture and horticultural industry, the application of SAP is in the form of seed additives, seed coatings, root dips. The superabsorbent polymer is helpful in arid and semiarid since the superabsorbent polymer can ease the burden of water shortage (Zohuriaan-Mehr & Kabiri, 2008). Superabsorbent polymer also can be applied to influence the soil water retention, seed germination and plant survivals for rocky slope eco-engineering (Yang et al., 2014).

Besides that, SAP also widely used in agriculture since it is environmentally friendly towards soil. Superabsorbent polymers are a class of polymers that are able to absorb large amount of water, typically more than traditional absorbent material. SAP has been used as soil additives to increase the water retention of soils which can replace peat, the traditional moisture retention aid for soil (Brave & Nnadi, 2011). In other research study, it clearly shows that addition of SAP can improve the soil water-holding capacity and allow soil hold much more water as SAP increase soil water content. However, the benefit of SAP to plant growth might be limited (Xi et al., 2104).

Superabsorbent polymer also used to be applied in plain concrete which a study to investigate the use of superabsorbent polymer in plain concrete is done. Both concrete and plant has similarity I terms of the need of continuous water supply. Water is an essential ingredient needed for the hydration process in the fresh concrete and for the curing process in the hardened concrete at its early stages. Excessive amount of water added in fresh concrete improves the concrete workability in general, reduces the concrete strength and increase the drying shrinkage of the hardened concrete. Small amount of SAP will give negligible effect on the concrete performance while excessive amount of SAP will leave the concrete with large amounts of voids, which in return reduces the concrete strength and durability (Al-Nasra & Daoud, 2013).

2.6 Shrinkage behaviour

During shrinkage water will moves from inner side of soil to outside surface. During conventional shrinkage test, the external load is zero and the dead weight of the clay can be considered negligible (Sivapulliah et al., 1986). Change in void ratio with change of in water content for an expansive soil as a result of desiccation and water absorption provides an understanding of shrinkage behaviour (Hanafy, 1991). As the water content decrease, the capillary stress in the void spaces will increase due to increased surface tension of soil. Thus, increase of surface tension tends to pull adjacent soil particles close together which cause the overall volume of soil decrease. As the water content at which there is no further volume decrease with further evaporation of porewater is called as shrinkage limit (Sivapulliah et al., 1986). Water content continuously decrease when the capillary stress continued to increase which continue to reduce overall volume until no further volume reduction occurs at the degree of moisture content is still 100%.

The characteristic that can affecting the percentage of shrinkage in clay soil are the kind clay minerals, the mode of geological deposition, the depositional environment which determines the particle arrangement and overburden pressure; and the degree of the weathering (Yong and Warketin, 1966). In situation where there is a gradual decrease in water content upon drying, the air entry value of the soil is indistinct and the shrinkage curve must be used in conjunction with the soil-water characteristic curve to determine the correct air-entry value of the soil (Frelund and Raharjo, 1993). As the volume changes resulting from the shrinkage of clays are often large enough to damage the buildings and highway pavements. The shrinkage cracks can occur when the capillary pressure exceed the tensile strength of soil caused by evaporation from the surface in dry climates and lowering of the groundwater table (Robert et al., 2011).

2.7 Soil shrinkage characteristic curve (SSCC)

Soil shrinkage characteristic curve (SSCC) can use to express the changes in bulk volume due to relation between the changes in water content in soil and the void ratio (Cornelis et al., 2006). This curve involved the relation between void ratio and moisture ratio of soil. The figure below shown the schematic that present the soil shrinkage characteristic curve of non-structured soil and a well-structured soil.

The subscript associate with the moisture ratio and void ratio are denote for S, N, and Z respectively (1) structural, (2) normal or basic, (3) residual and (4) zero shrinkage. The progressive drying of natural soils contains different phases of shrinkage which are structural shrinkage, normal shrinkage and residual shrinkage. During the structural shrinkage a few large, stable pores are emptied and the decrease in volume of the soil is less than the volume of water lost. Then the volume decreased and equal to the volume of water lost during the normal shrinkage phase. Upon further drying, the slope of the shrinkage curves changed and air enters the voids at the start of residual shrinkage or at the shrinkage limit (Tripathy et al., 2002).

To study the volume stability of soil, it is important to identify the shrinkage limit of soil. There are many techniques can be applied to determine the soil shrinkage characteristic curve which can be experimentally by volume measurement and theoretically by referring current available models.

2.7.1 Clod test

There are a few of experimental techniques that can be used to measure volume change of soil such as rubber-ballon method, wax method, clod test and others. Clod test procedure was found to be very effective in developing the experimental shrinkage curve. Clod test has been used as one of the common techniques to characterize expansive soil in united states. It produces the relationship between the soil volume and water content as soil dries out under a free confining condition (Perko et al., 2000). For such free stress and drying condition, the test is sometimes referred to as the "free shrinkage" test. Since soil clods either collected from the field or prepared in the laboratory are directly used for the test, it is commonly called the “Clod test” in literature.

The soil volume-water content relationship established from the Clod test is a constitutive or characteristic function of a particular expansive soil and is important for several geotechnical applications. Such a relationship can be used as a quantitative basis for heave or shrinking prediction for construction on expansive soils or as a quantitative basis for clarifying for expansive soil (Krosley, 2000).

Encasement method using molten wax requires duplicate soil specimens to be tested to establish the entire shrinkage path (Lairitzen, 1948; Ward et al., 1965; ASTM D4943-08). On the other hand, Clod test using Methyl ethyl ketone (MEK) saran or PVAc as encasement eliminates the need of multiple specimens and only single specimen is required to establish the entire shrinkage path (Krosley et al., 2003). In Clod tests, encased soils are allowed to dry under free unconfined condition. The volume is measured by utilising Archimedes principle (by weighing the soil specimen first in air and under liquid of known density) (Nelson and Miler, 1992). Alternatively, a water-based glue (PVAc) as encasement material proposed by Krosley et al., 2003 which can improve the testing time as compared to MEK saran due to improvement of vapour permeability of the glue. The glue is non-hazardous and easily available.

2.7.2 Kea model

Soil shrinkage characteristic curve can be determined from currently empirical models. There are nine models that can be used to describe SSCC which are Gea model, MM1 model, MM2 model, Kea model, TD model, OH model, Bea model, ModC model and ModGG model (Cornelis et al., 2006). All models expressed in terms of void ratio as function and moisture ratio. The term of void ratio correspondingly as the volume of voids and the moisture ratio correspondingly as the volume of water over the volume of solids.

Kea model is proposed by Kim et al., (1992) which combined an exponential and linear function to best fit shrinkage data points. Kea model consists of three parameters and restricted to the representation of the normal shrinkage by a linear function and by expressing the zero and residual shrinkage by an inverse exponential function which gradually approaches to a certain denominator value as the moisture ratio decreases (Kim et al.,). The model is currently used in the soil-water and solute transport computer simulation model SWAP (Cornelis et al., 2006).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will discuss on the selection of materials and the several experiments carried out to achieve research objectives which are to determine the physical and chemical properties and shrinkage value of kaolinite. Physical properties to be experimented are liquid limit, plastic limit, shrinkage limit, specific gravity, swelling index, specific surface area and loss of ignition while the chemical property of kaolinite to be determined is cation-exchange capacity (CEC). In order to obtain shrinkage curve which is show relation of void ratio and moisture content, Clod test is carried out. As an improvement, 5% and 10% of Superabsorbent polymer added to kaolinite.

3.2 Selection of materials

3.2.1 Clay

Clay used in this study is kaolinite. The two types of kaolinite experimented are S300 and FMC. Kaolinite soil is high availability in Malaysia while bentonite need to be imported from foreign country. In terms of cost, kaolinite is way reasonable compared to bentonite.

3.2.2 Superabsorbent polymer (SAP)

Kaolinite has low plasticity and it unable to absorb larger amount of water compared to bentonite. In a way of improvement to kaolinite properties, Superabsorbent polymer enhanced to kaolinite due to its ability to absorb and retain huge amount of water. According to Yaacob et al., 2015, superabsorbent polymer can be prepared experimentally in laboratory using graft-polymerization method. However, for this study superabsorbent polymer is purchased from Daiso Japan.

3.3 Physical properties of kaolinite

3.3.1 Liquid limit,LL

Liquid limit of soil is the moisture content of oven-dried soil in terms of its percentage of weight which established when the change of soil from plastic to liquid state is constant. The liquid limit is defined as the moisture content at which soil begins to behave as a liquid material and begins to flow. Liquid limit test is carried out with cone penetration method according to BS 1337: Part 2 1990: 4.3.

3.3.2 Plastic limit, PL

Plastic limit of soil is established when moisture content of oven-dried soil at its semisolid state change to plastic state consistently. Continuing from the Liquid limit test, the soil samples that become dry, the moisture content is taken when the dry soil sample turn to plastic. Liquid limit test conducted following BS 1377: Part 2: 1990: 5.3.

3.3.3 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 and FMC with addition of 5% and 10% SAP after air dry. Shrinkage limit of soil is calculated with the following equation:

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

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

3.3.4 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:

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

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

3.3.5 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 and FMC with addition of 5% and 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:

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

Where, V_1 = Soil volume after swelling, cm^3

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

3.3.6 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.

3.3.7 Loss in 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:

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

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)

3.4 Chemical properties

3.4.1 Cation-exchange capacity

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.

3.5 Soil shrinkage characteristic curve (SSCC)

Clod test is conducted as the volume measurement test. The test is to determine the shrinkage characteristic curve of kaolinite. Clod test is slightly different from wax method in term of the coating material which for wax method the coating material used is wax while for Clod test the coating material used is glue. The procedure applied for the experiment is same which is following the ASTM designation of D4943-08.

3.6 Modelling the soil shrinkage characteristic curve

The model that used to refer in describing the soil shrinkage characteristic curve of kaolinite is Kea model. The model is proposed by Kim et al., (1992). The theory behind the model is restricted to the representation of the normal shrinkage by a linear function, and by expressing the zero and residual shrinkage by an inverse exponential function which gradually approaches to a certain denominator value as the moisture ratio decrease (Cornelis et al., 2006). This procedure will describe the soil shrinkage characteristic curve that is expressed in terms of void ratio as a function of the moisture ratio. Below is how Kea model was written:

$$e = e^{\circ} \exp(-\beta\partial) + \varphi\vartheta$$

Where, e° = initial void ratio

β = slope parameter depending on the air entry value

∂ = moisture ratio

φ = slope of saturation line

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter will discuss on all results obtained from the laboratory tests for two types of kaolin which are s300 and FMC. The samples are added with 5% and 10% of SAP and their properties are determined. The properties include Atterbeg limit (liquid limit, plastic limit and shrinkage limit), specific gravity, swelling index, specific surface area, cation exchange capacity, loss of ignition and shrinkage volume. Besides, shrinkage curved is plotted.

4.2 Physical properties

4.2.1 Liquid limit, LL

From cone penetration test, liquid limit for both s300 and FMC with addition of 10% SAP are 460% and 500% respectively. From previous study, s300 has 41% of liquid limit without addition of SAP while 83.85% with addition of 5% SAP. FMC has 80% of liquid limit without addition of SAP while 120% with addition of 5% SAP. Liquid limit of S300 and FMC with 10% SAP increase compared to 5% SAP. This shows that with the increasing of SAP proportion, the liquid limit of kaolinite increase. The liquid limit for s300 is lower than FMC. Higher liquid limit indicates stronger water absorption as surface charge between negative charge on clay surface and dipolar of water molecules increase (Sen,2014). Addition of 10% SAP in kaolinite has achieve the desire liquid limit.

4.2.2 Plastic limit, PL

The plastic limit for S300 and FMC with addition of 10% SAP are 150.38% and 275.30% respectively while the plastic limit are 48.79% and 64.87% respectively when added with 5% SAP. Kaolinite has lower plastic limit \ where 27.9% for S300 and 49.4% for FMC. The plastic limit soil samples with 5% and 10% SAP increases according to the sequences of S300 and followed by FMC. Plastic limit for soil samples with 5% SAP is the lowest. Bentonite has 63% of plastic limit. S300 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 and FMC are 13.10% and 30.60% respectively while the plasticity index are 35.06% and 55.13% respectively when added with 5% SAP. The plasticity index of S300 and FMC further increase to 309.62% and 224.70% respectively when added with 10% SAP. The plasticity index of bentonite is highest which is 374%.

4.2.3 Shrinkage limit

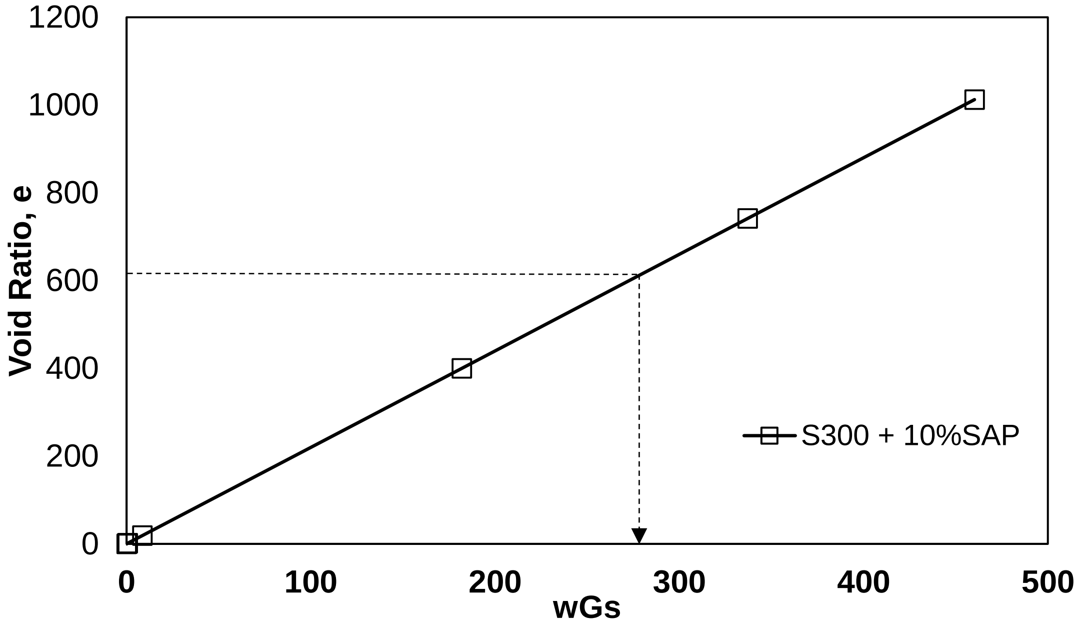

Figure 4.1 Shrinkage plot for S300 with addition of 10% SAP.

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.

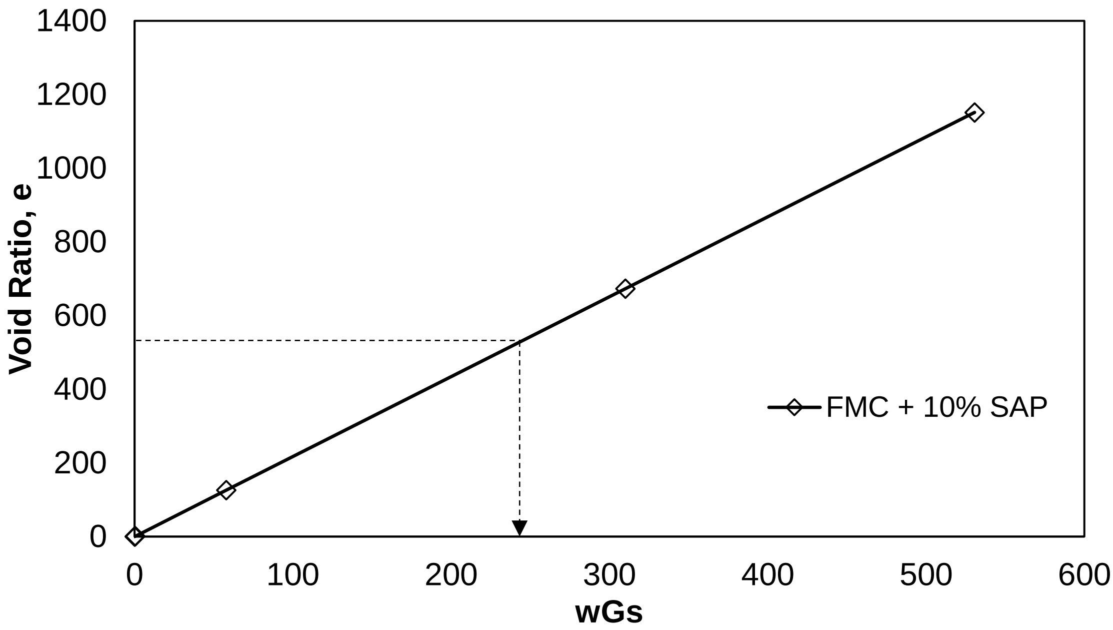

Figure 4.2 Shrinkage plot for FMC with addition of 10% SAP.

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 and 2.33 respectively for S300 and FMC but the specific gravity decrease to 2.20 and 2.17 respectively when the SAP added increase to 10%. The specific gravity for both pure S300 and FMC are 2.62. Bentonite shows the high specific gravity which is 2.80. 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 and FMC have 1%, 0% and 10% of swelling index respectively and increase to 70% 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 FMC with 10% SAP is 470%. According to IS 1948, S300 without SAP has swelling index below 10% show that both of them have low degree of expansion. S300 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 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 Surface area

BET surface area of S300 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. 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 in ignition

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. 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 properties

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.

Properties	S300			FMC			Bentonite
	Without SAP	**With 5% SAP**	**With 10% SAP**	**Without SAP**	**With 5% SAP**	**With 10% SAP**	**Without SAP**
Physical Properties							
Liquid limit (%)	41.00	83.85	460.00	80.00	120.00	500.00	437.00
Plastic limit (%)	27.90	48.79	150.38	49.40	64.87	275.30	63.00
Shrinkage limit (%)	38.50	40.00	280.00	64.71	-	241.00	12.20
Specific gravity	2.62	2.70	2.20	2.62	2.33	2.17	2.80
Swelling Index (%)	1	70	500	10	80	470	-
BET Surface Area (m^2/g)	1.8765	1.4529	1.8537	-	9.6431	8.8176	19.77
Loss on ignition (%)	0.0007	0.00785	8.722	0.1120	0.0560	9.572	-
Initial water content (%)	1.223	1.0	1.13	1.011	1.678	2.68	-
Particle size distriction	97	-	-	99	-	-	< 2 µm: 96.4 %
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: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	1.45	20.90	344.1	90.31

Table 4.1 Properties of S300,FMC and Bentonite with varries percentage of SAP

4.4 Soil Shrinkage characteristic curve

Based on the experimental data obtained, the shrinkage curve of kaolinite soil that has been established, the points data is continuously with the saturated line in early stage. However, some parts inaccurate at the last due to experimental error. There is some difficulties to get the best fit data at air dry because of the loss water content happen.

From previous study for bentonite soil, the points data of experimental clod test is continuously with the saturated line. It shows that clod test is suitable to measure shrinkage characteristic of bentonite.

CHAPTER 5

CONCLUSION

5.1 Introduction

This chapter will conclude the result of the whole research study. At the end of the study, it can be concluded that:

5.2 Conclusion

The plasticity index for S300 and FMC are 13.10% and 30.60% respectively while the plasticity index are 35.06% and 55.13% respectively when added with 5% SAP. The plasticity index of S300 and FMC further increase to 309.62% 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%. 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%.

Based on shrinkage curve, it observed that Kea model is not suitable for determination of shrinkage characteristic curve for kaolinite soil. Kea model cant not replicate exactly as experimented curve by clod test. Kea model is more suitable to use for bentonite soil as it can replicate more likely as experimented shrinkage characteristic curve. It can be concluded that Kea model can be used for both kaolinite and bentonite but with some limtations.

Addition of SAP has decrease the volume of kaolinites. S300 has highest volume compare to FMC. Addition 5% of SAP has slightly decrease the soil volume of S300 and

FMC while further decrease when 10% of SAP is added. Overall, addition of SAP has decrease the soil volume of kaolinite.

5.3 Recommendation

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.

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