DETERMINATION OF OPTIMUM MOISTURE CONTENT FOR AGGREGATION OF S300 KAOLIN

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Thesis submitted in fulfilment of the requirements
for the award of the degree of
Bachelor Eng. (Hons.) Civil Engineering

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JUNE 2015

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Specially dedicated to

my beloved grandmother, mother and father

for their love and care

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ABSTRACT

Soil aggregation is the behaviour of groups of soil particles that bind each other together. Generally, soil aggregation is frequently found in agriculture industry as the tillage and re-compaction of soil particles. The best soil aggregation requires optimum moisture content as water is crucial to soil for achieving aggregation. This research was done to determine the soil properties of S300 kaolin and to study the aggregated pore structures of S300 kaolin samples. Besides that, this research is conducted to determine the optimum moisture content for S300 kaolin aggregation. S300 kaolin was used in this research as it is commercially available and easily obtainable. Furthermore, S300 kaolin clay is suitable for this research as double porosity characteristics is able to be created and seen in kaolin. There are five kaolin samples, each with different moisture content, 26%, 28%, 30%, 32%, and 34%. Common soil properties experiments are done to S300 kaolin and Environmental Scanning Electron Microscope (ESEM) machine was used too in order to analyze the double porosity feature in S300 kaolin aggregated samples. This research proves that S300 kaolin clay was purely fine-grained inorganic clay soil with low to medium plasticity, classified using Unified Soil Classification System (USCS). The specific gravity of kaolin is within the range of the standard clay and the permeability also satisfied the standard of clay. Apart from that, results from ESEM machine are shown to prove that 30% of moisture content was the optimum moisture content for aggregation of S300 kaolin. The soil structure for aggregation of S300 kaolin clay shows double porosity characteristics at 30% of moisture content. The results and analysis of this research will contribute to future research of groundwater contamination problems.

ABSTRAK

Agregasi tanah merupakan perilaku tanah yang telah dibajak dan menghasilkan gumpalan-gumpalan, tetapi masih terikat sesama sendiri. Secara umumnya, agregasi tanah sering ditemui dalam industri pertanian ketika tanah dibajak menggunakan mesin atau dengan tenaga manusia, dan dipadatkan lagi. Air sangat penting untuk tanah kerana agregasi tanah yang terbaik memerlukan kadar kelembaban yang optimum. Penyelidikan ini dilakukan untuk menentukan sifat-sifat tanah jenis S300 kaolin dan mempelajari struktur pori tanah S300 kaolin yang diagregat. Selain itu, penyelidikan ini dijalankan untuk mendapat tahu kadar kelembaban yang optimum untuk agregasi S300 kaolin. S300 kaolin digunakan dalam segala eksperimen dalam penyelidikan ini atas sebab tanah jenis kaolin mudah didapati dan tersedia secara komersial. Selanjutnya, S300 kaolin sesuai digunakan kerana kemampuannya untuk mewujudkan ciri porositi berganda. Lima sampel kaolin telah disediakan dalam penyelidikan ini, masing-masing dengan kadar kelembaban yang berbeza, iaitu, 26%, 28%, 30%, 32% dan 34%. Eksperimen-eksperimen untuk menentukan sifat-sifat tanah telah diadakan pada tanah jenis S300 kaolin dan Environmental Scanning Electron Microscope (ESEM) juga digunakan untuk menganalisis ciri porositi berganda pada sampel S300 kaolin yang diagregatkan. Sebagai hasil penyelidikan ini, telah membuktikan bahawa S300 kaolin adalah tanah liat halus yang tak berorganik. S300 kaolin mempunyai keliatan yang rendah ke sederhana, hasil ini diklasifikasikan menggunakan Unified Soil Classification System (USCS). Hasil dari eksperimen dijalankan, gravitasi spesifik kaolin didapati berada dalam lingkungan yang sama dengan standard tanah liat dan kebolehtelapan kaolin turut memenuhi standard tanah liat. Sehubungan itu, keputusan dari eksperimen ESEM membuktikan bahawa tanah dengan kadar kelembapan 30% adalah kandungan kelembapan yang optimum untuk pengagregatan kaolin. Struktur tanah pengagregatan S300 kaolin juga menunjukkan ciri-ciri porositi berganda pada tanah yang mempunyai kadar kelembapan 30%. Dengan itu, keputusan dan analisis kajian ini akan menyumbang kepada penyelidikan masalah pencemaran air bawah tanah pada masa hadapan.

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LIST OF SYMBOLS

%	Percentage
µm	Micrometer
$\emptyset_1$	Primarty Porosity
$\emptyset_2$	Secondary Porosity
$\emptyset_T$	Total Porosity
K_t	Permeability Coefficient
θ_{inter}	Inter-aggregate Porosity
θ_{intra}	Intra-aggregate Porosity
$\theta_{overall}$	Overall Porosity
∑	Sum
°C	Degree Celcius
a	Cross section area of used manometer tube
A	Cross section area of sample in permeameter cell
cm^3	Centimeter cube
g	Gram
Gs	Specific Gravity
h_1	Starting level of manometer tube
h_2	End level of manometer tube
kg	Kilogram
kN/m^3	KiloNewton per meter cube
L	Liter
L	Length of sample
m/s	Meter per second

m^2/g	Meter square per gram
Mg/m^3	Megagram per meter cube
mL	Milliliter
mm	Millimeter
mm^2	Millimeter square
s	Seconds
t	Measured time intervals
V	Volume of sample
W	Required weight of the aggregated soil paste
Y	Unit weight of soil samples

LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
BET	Brunauer, Emmett and Teller
CL	Inorganic Clay with low to medium plasticity
EPA	Environmental Protection Agency
ESEM	Environmental Scanning Electron Microscopy
IMA-NA	Industrial Minerals Association North America
LL	Liquid Limit
LS	Linear Shrinkage
PI	Plasticity Index
PL	Plastic Limit
PSD	Particle Size Distribution
SEM	Scanning Electron Microscopy
SL	Shrinkage Limit
UiTM	Universiti Teknologi MARA
US	United State
USCS	Unified Soil Classification System
ZAV	Zero Air Void

Chapter 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

According to Gringarten (1987), double-porosity behavior is obtained when two different media are involved in the flow process: a higher-permeability medium that produces fluid and a lower-permeability medium that recharges the higher-permeability medium. Double-porosity behavior is typical of fissured reservoirs and multilayered reservoirs with high permeability contrast between layers.

Double-porosity behavior is frequently found in petroleum reservoir engineering, which consists of two types of porosity systems, that is primary porosity, also known as matrix porosity, and secondary porosity, also known as fracture porosity (Ngien, 2012). Double-porosity that has been studied broadly in oil and gas field explain more on rocks fractures and porosity that happen in fissures of rock block (Wilson, R K & Aifantis, 1984).

On the basis of vast experiment studies of double-porosity, the double-porosity concept is found apposite to the soil condition, especially in agricultural top-soils (El-Zein et al., 2006) and compacted soils (Romero et al., 1999). The phenomenon of double-porosity occurs when the two separate pore systems in structure of the soil come about concurrently (Ngien, 2012).

At the same time, ground water that provides irrigation for all the citizens worldwide is exposed to contamination problems by human activities (US Environmental

Protection Agency-EPA, 2002). Contaminated rain water or surface water and liquid hazardous substances are stated to flow through the soil firsthand without any filtration and straight to the ground water ("Groundwater Contamination," 2011). As prevention is better than cure, ground water is subjected for protection from further contamination.

Furthermore, so far little had done research on double-porosity concept soil. Therefore, experimental studies should be carried out to determine the fluid flow in structure of double-porosity soil.

1.2 PROBLEM STATEMENT

Groundwater is very important as it is one of the reachable freshwater that human can obtain. However, groundwater contamination has been an issue due to its difficulties to detect and control (Ngien et al, 2012).

In agriculture industry, pesticides are sprayed to control the pest away from the plants or certain form of animal organisms. The pesticides sprayed will dispersed in all directions and through the porous holes of the soil, seeping into the soil, ending in storing as well as contaminating the ground water. Contaminated ground water is said to be difficult and consume high expenses to clean up (US Environmental Protection Agency-EPA, 2002). Thus, this research is crucial to be done as it contributes in detection of contamination in ground water and to control further contamination.

The research of double-porosity in aggregated soil is feasible to be done as the medium can be easily obtained and reproduced in laboratory. Laboratory testing of soil does not require big amount of money and the materials are easily acquirable as compared to physical experiments on fractured rocks. Moreover, research on double-porosity soil has not yet been vastly studied on (Ngien et al., 2012). This research of determining the optimum moisture content for aggregation of S300 kaolin, in other words, is determining the optimum moisture content for double porosity behavior.

Apart from that, this research will also contribute towards study in the flow of contaminants through double porosity aggregated soil at optimum moisture content. Thus, contributing in solving groundwater contamination.

1.3 OBJECTIVES

i. To determine the soil properties of commercially available S300 kaolin.
ii. To study the aggregated pore structure of S300 kaolin samples.
iii. To determine the optimum moisture content for S300 kaolin aggregation.

1.4 SCOPE OF STUDY

The soil used for this study is S300 kaolin, a clay-typed soil. In this proposed study, the soil will be classified according to the Unified Soil Classification System (USCS). The S300 kaolin clay will be ran through a series of experiments for identification of the properties of soil. The first experiment is liquid limit; it is done using the cone penetrometer method, which requires a cone penetrometer. Secondly is to determine the plastic limit; plastic limit is done with simple moisture content apparatus. Plasticity index will be determined after the experiments of liquid limit and plastic limit are done. A sample of S300 kaolin soil will also be taken for Brunauer, Emmett and Teller (BET) method test to determine the surface area. Particles density and particles size distribution experiments will be carried out too. These tests are done to determine the S300 kaolin soil properties. Besides that, permeability of the clay is determined using Falling Head Permeability. However, the main focus of this study is to determine the optimum moisture content for aggregation of S300 kaolin. Thus, five different moisture content S300 kaolin samples are used, each with 26%, 28%, 30%, 32% and 34% of moisture content respectively. The samples will be aggregated using sieve of size 2 mm. Furthermore, the soil will also undergo Environmental Scanning Electron Microscopy (ESEM) test.

1.5 RESEARCH SIGNIFICANCE

This research paper will provide the results of optimum moisture content for S300 kaolin aggregation and the soil properties of S300 kaolin using USCS classification. The optimum moisture content for aggregation of S300 kaolin will aid researchers in studying the flow of contaminants through aggregated soil. This research is beneficiary to the environment as it contributes towards knowledge for sustainable solutions in groundwater contamination problems.

Chapter 2

LITERATURE REVIEW

2.1 INTRODUCTION

The literature review is the studies on the reading materials related to the title and the objectives of this research. In this chapter, the porosity of rocks and soils will be studied. Besides that, the classification of clay and determination of properties of kaolin clay will be discussed. Moreover, the structure of soil will be explained in detail as well as the effect of water in soil.

2.2 POROSITY

Porosity is defined in the Oxford Dictionary as the ratio of volume of voids or pores to the total volume of the mass, or in simple words the measurement of empty spaces around a material. Porosity is described as the measurement of empty spaces surrounding every object or masses.

According to Department of Petroleum Technology, porosity is said to be the best known physical characteristic of an oil reservoir as it determines the volume of oil and gas present. They added that, in an oil reservoir, the porosity represent the percentage of the total void space within the rock that is available for occupancy by either liquids or gases.

Porosity is usually found in rocks and soils. The porosities involved in both rocks and soils include primary porosity and secondary porosity (Crain, 2014). Based on Figure

2.1, Crain (2014) explained that the figure in a, is intergranular porosity; b, sucrosic porosity; c, moldic porosity; d, matrix porosity; e, vuggy porosity; and f, fracture porosity. For all the types of porosities, only intergranular is under primary porosity and the balance are secondary.

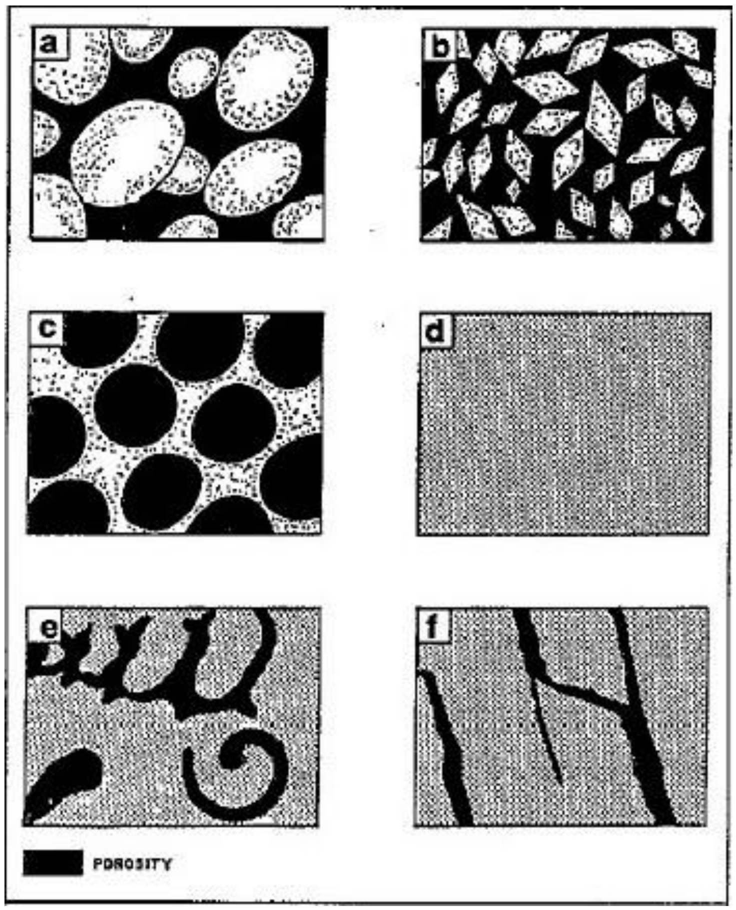


Figure 2.1: Types of Porosity

Source: (Crain, 2014)

2.2.1 Double-porosity

There is no evidence and studies about how double-porosity is created, but double-porosity is said to be present in subsurface media which has two overlapping continuums, for example, agricultural top-soils (El-Zein et al., 2006), rock aquifers (Pao and Lewis, 2002), and compacted soils (Romero et al., 1999).

Barenblatt et al. (1960) first presented the double-porosity concept with overlapping continuum technique. (Warren & Root, 1963) then developed the double-porosity concept and applied it to petroleum and reservoir engineering, due to the nature of oil-bearing formations in igneous rocks.

For rocks studies, Wilson & Aifantis (1986) have conducted experiment on double-porosity with fissured rocks and porous blocks. They said that fissured rocks have fissures that will provide most of the permeability of the fissured rocks, and that permeability is much higher than the permeability of the porous blocks pores. However, the porous blocks porosity is much larger than the porosity of fissures. Therefore, they defined that the storage capacity of the blocks is high and the fissures low, the flow in the fissures is high and the blocks act as feeders to the system of fissures.

However so, double-porosity also occurs naturally in soils, namely agricultural top-soils and compacted soils. In agriculture, the occurrence of double-porosity is due to soil fauna, plant roots, natural soil pipes and cracks as well as fissures (Ngien et al., 2012; Beven and Germann, 1982). The earthworm activities in subsurface media may also contribute to double-porosity in soil (Ngien et al., 2012).

In an aggregated soil, the contaminated groundwater is assumed to infiltrate and saturate all pores. Double-porosity consists of primary porosity and secondary porosity. The primary porosity is made up of intergranular pore spaces, and secondary porosity is formed by fractured voids (Ngien et al., 2012). Ngien (2012) elaborates that the total void space is said to be the summation of primary and secondary porosities, presented in Equation 2.1.

$$\emptyset_1 + \emptyset_2 = \emptyset_T \tag{2.1}$$

where, $\emptyset_1$ represents primary porosity, $\emptyset_2$ represents secondary porosity and $\emptyset_T$ representing the total porosity.

2.3 CLAY

There are different types of soils in this world, such as sand, loam, silt, peat and clay is also included in it (Leineriza, 2011). Classification of soil comes from various sources, for example Unified Soil Classification System (USCS), American Association of State Highway and Transportation Officials (AASHTO) Soil Classification System, or commonly with the textural triangle. USCS and AASHTO Soil Classification System illustrates classification of soil in chart, while textural triangle indicates that soil is categorized into the respective classes according to the percentage of clay, silt or sand. Figures 2.2 to 2.4 show textural triangle, USCS, and AASHTO Soil Classification System.

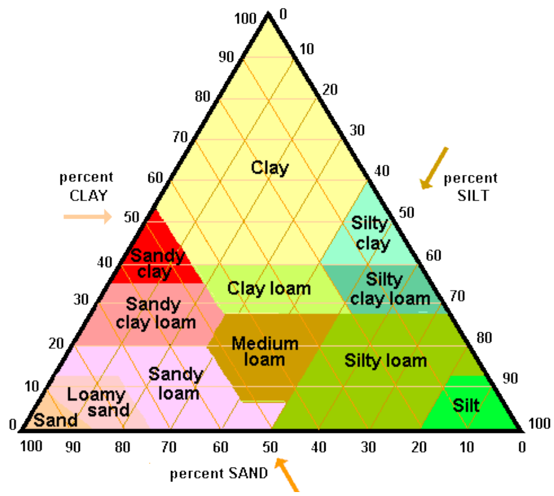


Figure 2.2: The Textural Triangle

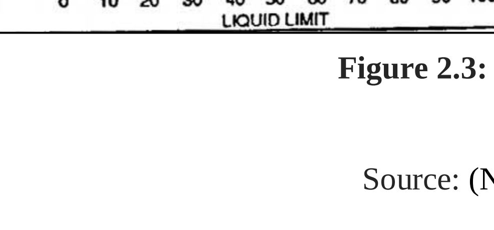
UNIFIED SOIL CLASSIFICATION SYSTEM

Soils are visually classified for engineering purposes by the Unified Soil Classification System. Grain-size analyses and Atterberg Limits tests often are performed on selected samples to aid in classification. The classification system is briefly outlined on this chart. Graphic symbols are used on boring logs presented in this report. For a more detailed description of the system, see "Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)" ASTM Designation: 2488-84 and "Standard Test Method for Classification of Soils for Engineering Purposes" ASTM Designation: 2487-85.

MAJOR DIVISIONS				GRAPHIC SYMBOL	GROUP SYMBOL	TYPICAL NAMES
COARSE-GRAINED SOILS (Less than 50% passes No. 200 sieve)	GRAVELS (50% or less of coarse fraction passes No. 4 sieve)	CLEAN GRAVELS (Less than 5% passes No. 200 sieve)			GW	Well graded gravels, gravel-sand mixtures, or sand-gravel-cobble mixtures
					GP	Poorly graded gravels, gravel-sand mixtures, or sand-gravel-cobble mixtures
		GRAVELS WITH FINES (More than 12% passes No. 200 sieve)	Limits plot below "A" line & hatched zone on plasticity chart		GM	Silty gravels, gravel-sand-silt mixtures
			Limits plot above "A" line & hatched zone on plasticity chart		GC	Clayey gravels, gravel-sand-clay mixtures
	SANDS (50% or more of coarse fraction passes No. 4 sieve)	CLEAN SANDS (Less than 5% passes No. 200 sieve)			SW	Well graded sands, gravelly sands
					SP	Poorly graded sands, gravelly sands
		SANDS WITH FINES (More than 12% passes No. 200 sieve)	Limits plot below "A" line & hatched zone on plasticity chart		SM	Silty sands, sand-silt mixtures
			Limits plot above "A" line & hatched zone on plasticity chart		SC	Clayey sands, sand-clay mixtures
FINE-GRAINED SOILS (50% or more passes No. 200 sieve)	SILTS (Limits plot below "A" line & hatched zone on plasticity chart)	SILTS OF LOW PLASTICITY (Liquid Limit less than 50)			ML	Inorganic silts, clayey silts of low to medium plasticity
		SILTS OF HIGH PLASTICITY (Liquid Limit 50 or more)			MH	Inorganic silts, micaceous or diatomaceous silty soils, elastic silts
	CLAYS (Limits plot above "A" line & hatched zone on plasticity chart)	CLAYS OF LOW PLASTICITY (Liquid Limit less than 50)			CL	Inorganic clays of low to medium plasticity, gravelly, sandy, and silty clays
		CLAYS OF HIGH PLASTICITY (Liquid Limit 50 or more)			CH	Inorganic clays of high plasticity, fat clays, sandy clays of high plasticity
	ORGANIC SILTS AND CLAYS	ORGANIC SILTS AND CLAYS OF LOW PLASTICITY (Liquid Limit less than 50)			OL	Organic silts and clays of low to medium plasticity, sandy organic silts and clays
		ORGANIC SILTS AND CLAYS OF HIGH PLASTICITY (Liquid Limit 50 or more)			OH	Organic silts and clays of high plasticity, sandy organic silts and clays
ORGANIC SOILS		PRIMARILY ORGANIC MATTER (dark in color and organic odor)			PT	Peat

NOTE: Coarse-grained soils with between 5% and 12% passing the No. 200 sieve and fine-grained soils with limits plotting in the hatched zone on the plasticity chart have dual classifications.

PLASTICITY CHART



DEFINITION OF SOIL FRACTIONS

SOIL COMPONENT	PARTICLE SIZE RANGE
Boulders	Above 12 in.
Cobbles	12 in. to 3 in.
Gravel	3 in. to No. 4 sieve
Coarse gravel	3 in. to 3/4 in.
Fine gravel	3/4 in. to No. 4 sieve
Sand	No. 4 to No. 200 sieve
Coarse sand	No. 4 to No. 10 sieve
Medium sand	No. 10 to No. 40 sieve
Fine sand	No. 40 to No. 200 sieve
Fines (silt and clay)	Less than No. 200 sieve

Figure 2.3: USCS Chart

Source: (Nate, 2012)

AASHTO Soil Classification System

Major Divisions	Group	AASHTO symbol	Typical names	Sieve analysis (percent passing)	Atterberg limits
Granual materials (35% or less passing No. 200 sieve)	Group A-1	A-1-a	Stone or gravel fragments	Percent Passing: No. 10 ≤ 50% No. 40 ≤ 30% No. 200 ≤ 15%	PI ≤ 6
		A-1-b	Gravel and sand mixtures	No. 40 ≤ 50% No. 200 ≤ 25%	PI ≤ 6
	Group A-3	A-3	Fine sand that is nonplastic	No. 40 > 50% No. 200 ≤ 10%	PI = 0 (nonplastic)
	Group A-2	A-2-4	Silty gravel and sand	Percent passing No. 200 sieve ≤ 35%	LL ≤ 40 PI ≤ 10
		A-2-5	Silty gravel and sand	Percent passing No. 200 sieve ≤ 35%	LL > 40 PI ≤ 10
		A-2-6	Clayey gravel and sand	Percent passing No. 200 sieve ≤ 35%	LL ≤ 40 PI > 10
		A-2-7	Clayey gravel and sand	Percent passing No. 200 sieve ≤ 35%	LL > 40 PI > 10
Silt-clay materials (More than 35% passing No. 200 sieve)	Group A-4	A-4	Silty soils	Percent passing No. 200 sieve > 35%	LL ≤ 40 PI ≤ 10
	Group A-5	A-5	Silty soils	Percent passing No. 200 sieve > 35%	LL > 40 PI ≤ 10
	Group A-6	A-6	Clayey soils	Percent passing No. 200 sieve > 35%	LL ≤ 40 PI > 10
	Group A-7	A-7-5	Clayey soils	Percent passing No. 200 sieve > 35%	LL > 40 PI ≤ LL − 30 PI > 10
		A-7-6	Clayey soils	Percent passing No. 200 sieve > 35%	LL > 40 PI > LL − 30 PI > 10
Highly organic	Group A-8	A-8	Peat and other highly organic soils	Primarily organic matter, dark in color, and organic odor	

Figure 2.4: AASHTO Soil Classification System Chart

Source: ("Soil Mechanics and Foundations Laboratory Testing," 2014)

Leineriza (2011) proved that clay soil is made up of the smallest particles among other soils. Leineriza (2011) also stated that clay soil holds moisture well, but resist water infiltration which means the permeability is low. Clay soil gives slick and sticky feel when added with moisture and is smooth when dry. The clay soil is easily compacted and handled.

The properties of clay soil categorized the classes or groups of the clay. The clay soils are tested through plasticity, shrinkage, fineness of grain, color, hardness, cohesion, and capacity. It turns out china clays or kaolins are the purest clay.

2.3.1 Kaolin

Kaolin, or china clay, is a hydrated aluminum silicate (Kluwer, 2009). The editors of ("Kaolin Clay," 2015) explained that the history of kaolin started from a hill in China, named Kao-ling, from which it was mined for centuries and it was sent to Europe by a French Jesuit around 1700 as examples of materials used by the Chinese in manufacturing porcelain.

IMA-NA (2011) stated that kaolin clay is distinguished by its fine particle size and color. The small particle size of kaolin scatters light. It contributes to the white color of kaolin, which occurs naturally. However it can be processed to white by removing minerals and other color-bearing compounds.

IMA-NA (2011) discovered that kaolin is used widely in the paper industry as kaolin adds brightness, smoothness and gloss to the paper. The editors of "Kaolin Clay" (2015) also added that kaolin was used in the production of paint, rubber, specialty film, besides being continued to be used as an essential material to produce porcelain.

All in all, the clay soil used in this research to create the double-porosity medium in the experiments is commercially available S300 kaolin. Kaolin has the properties of soil, which comprised of liquid limit, plastic limit, plasticity index, surface area and particles density. Thus, the properties of kaolin soil need to be determined.

2.4 STRUCTURE OF SOIL

Soil structure refers to the arrangement of soil separated into units called soil aggregates. An aggregate is said to possess solids and pore space. Aggregates are mainly dominated by clay particles, but silt and fine sand particles may also be part of an aggregate (ELibrary, 2015)

Aggregates are described by their shape, size and stability. Aggregate types are used most frequently when discussing structure. Figure 2.5 shows the types of soil structure.

Soil aggregation is crucial in soil as aggregation can influence the bulk density, porosity and pore size of the soil. Pores within aggregates are smaller than the pores between aggregates and between single soil particles (ELibrary, 2015). The porosity of pores within aggregates is known as intra-aggregate porosity and the porosity of pores between aggregates is named inter-aggregate porosity. The overall porosity is equal to the sum of intra-aggregate porosity and inter-aggregate porosity (Hillel, 1998), as shown in Equation 2.2.

$$\theta_{overall} = \theta_{intra} + \theta_{inter} \tag{2.2}$$

where $\theta_{overall}$ is the overall porosity, θ_{intra} is the intra-aggregate porosity, and θ_{inter} is the inter-aggregate porosity.

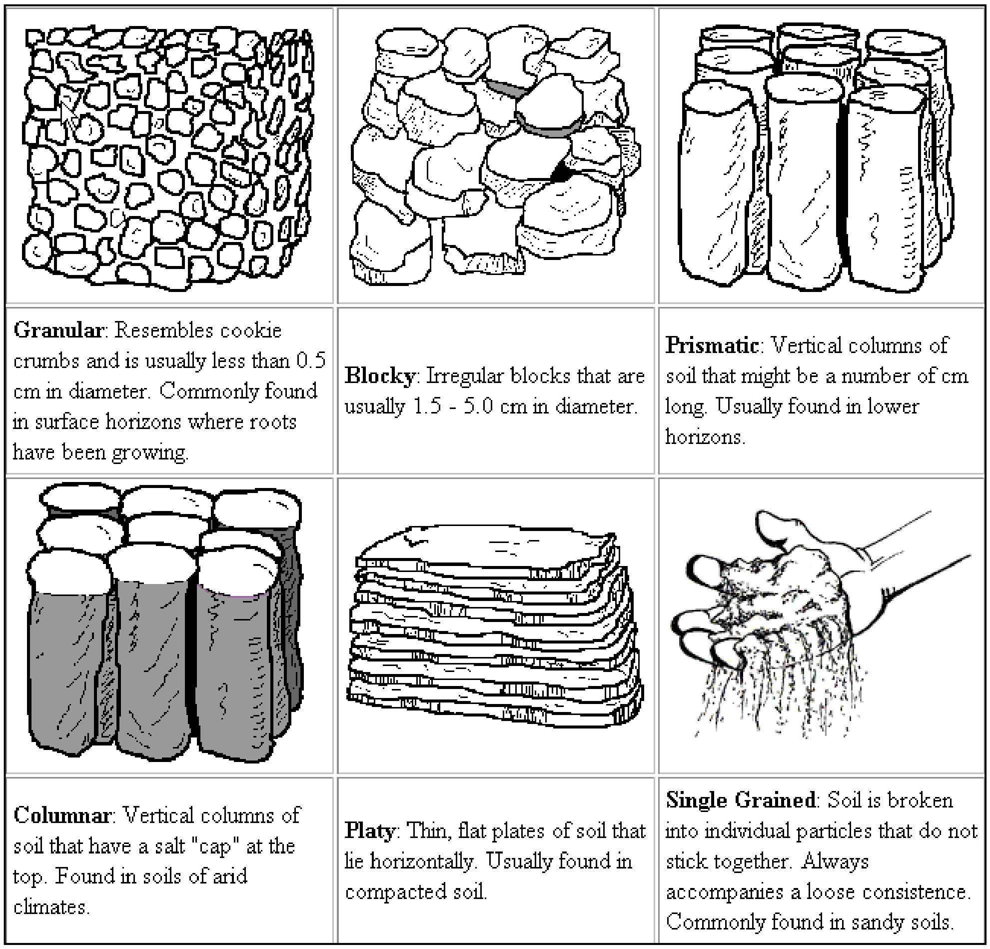


Figure 2.5: Types of Soil Structure

Source: (“Soil Texture and Soil Structure,” 2015)

2.5 EFFECT OF WATER

In accordance to Flury, Flühler, Jury, & Leuenberger (1994), the flow pattern of fluid in soil is inconsistent all the time. The factor of the inconsistency of fluid flow path in soil is due to the soil structure. A well-structured soil or an unstructured soil will enable fluid, such as water to flow through but with variable patterns. Figure 2.6 shows the pathway of water migration.

Figure 2.6: Paths of Water Flow through Soils with Granular, Prismatic, Subangular Blocky, and Platy Structure, respectively

Source: (“Soil Structure,” n.d.)

For well-structured soil, loamy to clayey soils, there are cracks and fissures to allow the water to migrate with a congested pattern (Beven and Germann, 1982; Bouma, 1991). On the other hand, for unstructured soil, sandy soils, the pattern of the water path is far more dispersed (Hillel, 1998). Flury, Flühler, Jury, & Leuenberger (1994) concluded that fluid, water will infiltrate deeper in structured soil, for example structured clayey soil, than in unstructured soil – sandy soil. Thus, water is more likely to infiltrate in structured soil, clay, to groundwater as compared to unstructured soil, sand.

Furthermore, water content in soil is said to be crucial for transporting water and solutes as it can affect not only hydraulic conductivity, but also shrinking and swelling of the soil (Flury et al., 1994). However, fluid water can also move downwards in a rapid speed but low rates of absorption, it is defined as a bypass flow (Radulovich et al., 1992). Bypass flow may contribute to the rate of fluid flow from surface of the soil to groundwater.

Flury, Flühler, Jury, & Leuenberger (1994) added that heavy rain or storm has the potential to devote the rate of contaminants, such as herbicides or pesticides of agriculture, to be leached deep into the soil or groundwater. Therefore, clay soils are more prone to be hazard for groundwater contamination.

Chapter 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

The research methodology involved in this research is based on the experiments and tests conducted to determine the soil properties for S300 kaolin soil. The soil properties, such as the Atterberg limits of S300 kaolin will be identified and classified based on the Unified Soil Classification System (USCS). In addition, method to conduct the experiment to determine particles size distribution, specific gravity, optimum moisture content with maximum dry unit weight, surface area, and permeability is described too. Besides that, sample preparation of S300 kaolin aggregation is explained and ESEM test is introduced in this section.

3.2 MATERIALS

There are different types of soil that can be found in the industry area. The most common soil types found are gravels, sand, clay, and silt. However so, not all of the soil types are able to create double-porosity and not only that, a specific amount of water is needed to create the best double-porosity feature of the soil. According to Ngien (2012), one of the soil that is suitable to create double-porosity medium is commercially available kaolin, specifically S300 kaolin. Therefore, S300 kaolin clay is used immensely in all of the experiments done for this research. As the aim of the research is to determine the optimum moisture content for aggregation of S300 kaolin, thus 26%, 28%, 30%, 32% and 34% of soil moisture content parameters were set for the experiment.

3.2.1 Kaolin

Figure 3.1: S300 Kaolin Clay Powder

Kaolin is a type of fine grained soil. Fine grained soil particles are not visible by human naked eye, totally the opposite of coarse grained soil, such as gravel particles, which can be seen and identified through the naked eye (Suryakanta, 2014). Moreover, according to the Integrated Soil Classification System, soil particles that are finer than 2 μm are classified as clay particles. Hence, S300 kaolin particles are generally marked as clay of fine grained soil.

Kaolin originally is used for making porcelain, which starts in the seventh and eighth centuries, but in this technology era, it can be used to make paint, rubber, cable insulations, fertilizers, medicine and so on. There are different types of kaolin; graded based on their colour, texture and quality. Different grade of kaolin are different from each other. Each type of kaolin has their own properties and characteristics (Ling, Kassim, & Karim, 2011). Therefore, the type of kaolin that is used in this research is S300 kaolin clay, as shown in Figure 3.1.

3.2.2 Water

Figure 3.2: Water

Source: (Harvey, 2013)

Water plays an important role in soil aggregation, such that water is the binder between the particles of soil. Potable water is used in this research for contributing in the experiments of soil properties and for preparing aggregation samples. Potable water is crucial for mixing kaolin to become the required sample for the experiment. In the proposed study, to prepare for aggregated S300 kaolin samples, potable water is used to mix with S300 kaolin powder. Potable water will mixed with S300 kaolin powder in different percentage of moisture content, that are 26%, 28%, 30%, 32% and 34%.

Besides potable water, distilled water is also used in this research. Distilled water is used in experiments where it is to determine soil properties, for example, Atterberg Limit Test, Particle Size Distribution Analysis and Particle Density Test. This is because distilled water is water without contaminants; contaminants such as waste materials, minerals, heavy metals, and others (Williams, 2015). The contaminants of water will affect the results of experiment. Thus, distilled water is used for those experiments.

3.3 SOIL PROPERTIES DETERMINATION

As S300 kaolin is chosen as the experimented material, the properties of this clay-typed soil must be classified and determined. Therefore, the sample soil is classified by running several soil properties experiments.

3.3.1 Atterberg Limits Test

Atterberg define the boundaries of states in term of limits, the limits defined are liquid limit (LL), plastic limit (PL), plasticity index (PI) and shrinkage limit (SL) (*Civil Engineering Laboratory Manual UMP*, 2011). According to Mani (2010), Atterberg limits are a basic measure of the nature of fine-grained soil. Mani (2010) added that these limits are defined to classify and distinguish fine-grained soils, between silts and clays. It can also distinguish between different types of silts and clays.

Atterberg Limits Test is conducted for this research, to determine the soil properties of S300 kaolin clay. LL and PL experiments of Atterberg Limits Test will be carried out except for SL experiments, as the apparatus for SL is scarcely available. The experiment of SL is changed to Linear Shrinkage (LS) experiment, because the apparatus is ready and prepared in campus laboratory. In the study of Atterberg Limits Test, the procedures of conducting the experiments are based on the British Standard (BS1377: Part 2: 1990).

3.3.1.1 Liquid Limit (LL)

LL is the boundary between the liquid and plastic states. Based on *Civil Engineering Laboratory Manual UMP* (2011), LL is determined based on the change of soil consistency from plastic to liquid.

Generally, LL is determined using a cone penetrometer, which is semi-automated, as shown in Figure 3.3. In this research, cone penetrometer is used to determine the LL. Firstly, the cone penetrometer is checked to ensure there are no faulty parts. Zero errors and parallax errors are prevented too, to ensure the accuracy of the results to this experiment. Meanwhile, the S300 kaolin clay soil is sieved through a 425μm sieve by using a sieve machine.

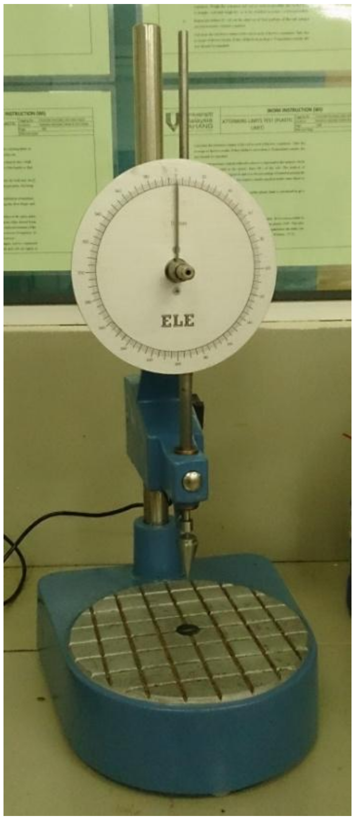


Figure 3.3: Cone Penetrometer

After done sieving, 300g of the soil is taken out and placed on the glass plate. The soil is then added with 20% of distilled water and mixed for about 10 minutes using two laboratory spatulas. Then, a small portion of the mixed soil paste is placed into a metal cup. The soil paste is pushed against the side and edge of the metal cup to avoid the edge of the cup from trapping any air. When the metal cup is fully filled with soil paste, the top surface of the metal cup is smoothed with a spatula. The top level surface of the metal cup must be smoothened to get the best and clear results.

Following that, the metal cup is taken and situated below the cone penetrometer. The cone penetrometer showed the dial reading to the nearest 0.1mm. When the position of the metal cup is fixed under the cone penetrometer, a digital timer, which connected to the cone penetrometer, is pressed and the timer starts to countdown. After 5 seconds, the bid falls onto the metal cup, creating a small hole at the smoothened soil paste.

The dial reading of how deep the bid penetrates is measured manually and the reading is recorded. Two readings are taken for one sample and the readings are recorded as the cone penetration. A small part of the penetrated area of soil paste is then taken out and placed in a container. The container with the soil paste is weighed and oven dried to determine the moisture content.

The procedure is repeated with 40%, 42%, 44%, 46% and 48% of moisture content until the reading of the penetration is between 15mm to 20mm. A graph of moisture content against cone penetration is plotted.

3.3.1.2 Plastic Limit (PL)

PL is defined as the change of soil consistency from crumbly to plastic. According to Mani (2010), PL is the moisture content at which soil behaves like a plastic material. Generally, PL experiment is conducted after the LL experiment. It is because the sample to test for PL experiment is taken from the experiment of LL.

The experiment starts by taking about 20g of the 48% mixed soil paste, which consists of mixture of water and S300 kaolin soil, and placed on the glass plate. The soil paste is then equally distributed into two parts sub-samples at 10g each. Later, each sub-sample of 10g is divided again into four equal small portions.

One of the small portions of soil paste is then taken to be moulded into a long thread with fingers. The purpose of moulding with fingers is to equalize the distribution of moisture content. The portion of soil paste is moulded into a thread of about 6mm diameter at first. Then, the soil paste is further moulded until the diameter of the thread is about 3mm. At this point, the thread-shaped paste will start to crumble and break into a number of short pieces, as shown in Figure 3.4.

Figure 3.4: Short pieces of S300 Kaolin Soil Paste

As the crumbling stage is reached, all the short pieces are gathered and placed into a weighed moisture content container. The container is shut with the lid immediately after the short pieces of soil paste is been placed in. Then, the container with the crumbled soil paste is weighed and oven dried for 24 hours. The procedure is repeated with two other small portions of soil paste.

After 24 hours, the oven dried samples are weighed and the readings are recorded. This is to determine the amount of moisture content. The results of the three sets of soil paste are the difference between the weight of dry soil and wet soil, which means the moisture content of the soil paste. Meanwhile, PL is the average moisture content of the three sets of results and the final result is expressed to the nearest two decimals.

3.3.1.3 Plasticity Index (PI)

When the LL and PL is determined, PI is calculated. PI is defined as the range of water content over which a soil has a plastic consistency (*Civil Engineering Laboratory Manual UMP*, 2011). PI is obtained by calculating the difference between liquid limit and plastic limit, as presented in Equation 3.1.

$$PI = LL - PL \tag{3.1}$$

where PI is the plasticity index, LL is the liquid limit, and PL is the plastic limit.

The value of PI will be reported to the nearest whole number. The result obtained will indicates the water content for soil to reach plastic state.

3.3.1.4 Linear Shrinkage (LS)

LS is the decrease in length of a soil sample when oven-dried, starting with a moisture content of the sample at liquid limit, while shrinkage limit is the water content at which a reduction in water content will not cause decrease in volume of soil mass but increase in water will increase the volume. Hence, the difference between LS and SL is LS measures the decrease of soil sample length whereas SL determines the volume of soil.

LS experiment is conducted to this research as the apparatus of LS is easier to obtain and prepared. LS is done firstly by preparing the apparatus, which is a half circle circular tube with diameter of 26 mm and 160 mm long of length. The tube is greased before placing any content, to prevent the soil paste from sticking to the side of the tube.

Next the soil paste is made, from the results of LL experiment – 38.2% of moisture content mixture. The soil paste is then spread all over the tube. The tube must be fully filled and the surface of the tube is leveled and smoothed, as illustrated in Figure 3.5.

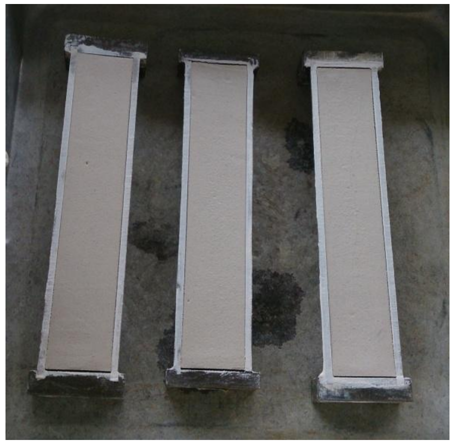


Figure 3.5: Linear Shrinkage Samples

After the soil paste is smoothed across the surface of the tube, the samples are taken to oven dry at temperature of 40°C for at least 24 hours. Following that, the oven is heated up to temperature of 80°C and then 105°C, each for another 24 hours. When the temperature reached 105°C and the samples are left in the oven for 24 hours, the samples are taken out for measurement. Length and wide of the samples are measured and recorded. The results obtained are used for calculating LS. LS is calculated with Equation 3.2.

$$LS = \left[1 - \left(\frac{Length\ of\ oven\ dried\ sample}{Initial\ length\ of\ sample}\right)\right] \times 100 \qquad (3.2)$$

The final result is the average LS of the total number of samples tested. The value is presented in percentage and expressed to the nearest two decimals.

3.3.2 Particle Size Distribution Analysis (PSD)

Fundamentally, Particle Size Distribution Analysis (PSD) is a measurement designed to determine the size and range of a set of particles of a soil sample (Gee & Or, 2002). Soil is a mixture of discrete particles of various shapes and sizes. Therefore, the purpose of particles size distribution analysis is to sort the soil particles according to their sizes. In this research, the PSD test conducted on S300 kaolin is by applying sieve analysis and fine analysis.

Sieve analysis is used to determine the distribution of the larger grain sizes of soil. The soil is passed through a series of sieves with the mesh size reducing progressively, from 5mm to 63μm. For this research, 80g of S300 kaolin is sieved through 5mm, 3.35mm, 1.18mm, 0.6mm, 0.3mm, 0.15mm and 63μm opening sieves. The weight of kaolin retained on each sieve are measured and recorded.

After done with sieve analysis, the kaolin retained on the pan is taken for fine analysis experiment. Fine analysis is done for only fine-grained soil to determine the grain size distribution of material passing through 63μm of sieve (*Civil Engineering Laboratory Manual UMP*, 2011).

Figure 3.6: Hydrometer Bulb

For fine analysis, hydrometer bulb is used, as shown in Figure 3.6. However, before the hydrometer is inserted into the measuring cylinder, the hydrometer is weighed to the nearest 0.1g and is recorded as the volume. A solution of sodium hexametaphosphate is prepared in a 1 liter glass measuring cylinders with ground glass stopper.

The soil from the bottom pan of the sieve is taken and placed into a stirrer cup. 125mL of dispersing agent is added into it, the mixture is stirred and leave for kaolin soil to soak the dispersing agent. Meanwhile, another 125mL of dispersing agent is added into the control cylinder, which is then filled with distilled water to the 1L mark. The reading at the top of the meniscus formed by the hydrometer stem and the control solution is taken. Reading of less than zero is recorded as negative (-) correction while reading between zero to sixty is recorded as positive (+) correction. This reading is called the zero correction. The control cylinder is shaked and the contents are mixed thoroughly. Later, the hydrometer and thermometer is inserted into the control cylinder.

Next, the soil slurry is transferred into a mixer by adding more distilled water into it, making the mixing cup at least half full. The solution is mixed for about two minutes with the stirring machine. After that, the soil slurry is transferred immediately into an empty measuring cylinder and distilled water is added up to the 1L mark. The open end of the cylinder is covered with a stopper securely. The cylinder is turned upside down and back upright for 30 times to ensure thorough mixing.

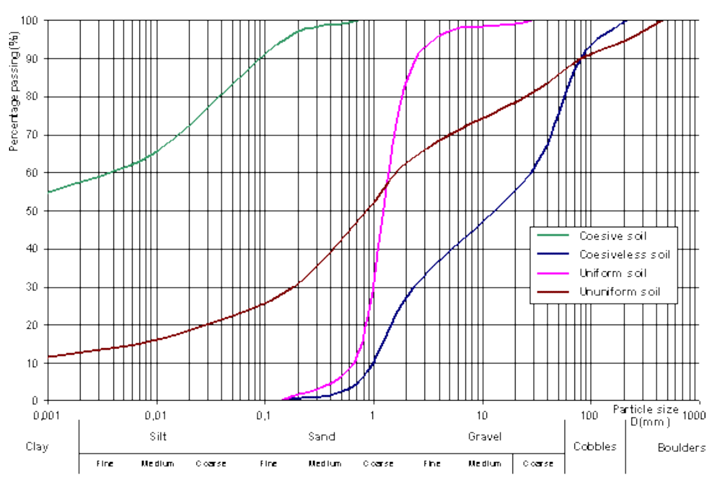


Figure 3.7: Particle Size Distribution Graph

Source: ("Soils for civil engineering purposes Part 2. Classification tests BS1377: Part 2: 1990," 1990)

Then, the cylinder is set down and the stopper is removed from the cylinder. Hydrometer bulb is carefully inserted and stopwatch is started once the hydrometer bulb is inserted. The reading of hydrometer is taken after elapsed time of 0.5, 1, 2, 4, 8, 16, 32, and so on minutes until the value of the hydrometer bulb reading is constant. A particle size distribution graph, as shown in Figure 3.7, is plotted.

3.3.3 Particle Density Test

Particle Density Test starts with preparing the apparatus. For this experiment, four density bottles with stoppers are needed, a vacuum desiccators containing anhydrous silica gel, digital weighing balance, drying oven (105°C – 110°C) and distilled water.

The four density bottle with stopper are dried and weighed with digital weighing balance. The S300 kaolin soil is taken to drying oven for drying purpose and sieved with BS 2mm opening sieve. Kaolin soil is transferred to the density bottle, each about 7g of soil.

The bottles are then weighed with kaolin soil and with the stoppers. After that, distilled water is added in to the density bottle until about half to three-fourth full of each density bottles. The bottles are slightly shaken to remove the air bubbles trapped in the soil and placed in the vacuum desiccators. Take note that the stoppers are placed outside the vacuum desiccators.

The density bottles are left in the desiccators for two hours until no further loss of air is in sight. Next, the density bottles are taken out and placed on a stable table. Distilled water is added in the density bottles until full. The density bottles, full with kaolin soil and distilled water are left at an undisturbed place in room temperature for three hours.

After the three hours, the water level decreases. However, distilled water is added to the density bottles till full again and the stopper is placed on each of the density bottles. They are then taken to the weighing balance for weighing process with no water droplet at the surface or around the density bottles.

Figure 3.8: Particle Density Samples

Later when weighing is done, the kaolin soil and distilled water are removed from all the density bottles. The density bottles are cleaned with acetic acid and refilled with distilled water until full, as shown in Figure 3.8. The bottles are left for three hours again and adding up with distilled water until full after the three hours. The stoppers are placed on the density bottles and the surface of the density bottles are wiped dry before being weighed. The weight of the bottles with stoppers and only distilled water are recorded.

$$Gs = \frac{Weight\ of\ dry\ soil}{(Weight\ of\ water) - (Weight\ of\ soil + Water)} \tag{3.3}$$

The result is calculated with Equation 3.3 and analyzed. The experiment is repeated if the results differed by 0.03 Mg/m^3.

3.3.4 Standard Proctor Test

Based on the principles of standard proctor, the soil is compacted to increase the soil density, as the solid particles are packed together more closely while the air is removed. The soil is said to be totally saturated when the percentage of air voids is zero (*Civil Engineering Laboratory Manual UMP*, 2011). The increase of water content in a saturated soil will results in reduction in dry unit weight. Thus, the relation between the moisture content and dry unit weight for saturated soil is known as the zero air voids line.

In this experiment, the objective is to determine the relationship between the dry unit weight and the moisture content of kaolin soil using standard rammer in Proctor method. Furthermore, the maximum dry density and optimum moisture content of kaolin soil is also determined.

Figure 3.9: Standard Proctor Apparatus

Firstly, 4kg of air-dry S300 kaolin is prepared for this experiment. The apparatus needed are standard compaction mould (with base plate and collar), 3.78kg of rammer, measuring cylinder, large mixing pan, soil mixer, large spoon, and mixing tools. Figure 3.9 illustrate some of the apparatus used. The experiment started with measuring 5% of potable water to be mixed with soil later on.

Secondly, the weight of the compaction mould including the base plate (without the collar) is weighed and recorded. The length of the mould is also measured to check the volume of the mould, which should be $1000cm^3$. The mould is then fixed to the base plate with the collar.

Next, the 4kg air-dried kaolin soil is mixed with 5% of water in the mixer. The mixer is left for about 3 minutes and the mixture is taken to the mould. The mould is filled half full for when it was compacted, it will occupy a little over one third of the height of the mould. 25 blows of free flow hits are then applied to the mixture in the mould and the blows are distributed uniformly over the surface.

The second layer of mixture is filled up to the surface of the mould so that after compaction, the mixture occupies two third of the mould height. 25 blows are given to the mixture again and distributed evenly. The procedure is repeated for the last layer of kaolin soil mixture. After that, the collar is detached from the mould and excess soil mixture is trimmed off by using the straightedge mixing tool.

The whole mould is then detached from the base plate and taken to weigh at the weighing balance. The data is recorded on the data sheet. Following that, the soil mixture is removed from the mould and some kaolin mixture soil samples are taken and put into two moisture content cans to determine the moisture content. The soil samples are put into oven for drying 24 hours and results are recorded the next day.

The procedure is repeated, from measuring the amount of potable water to taking soil samples and put into oven, for five times, each with 10%, 15%, 20%, 25% and 30% of potable water (by the weight of dry soil). The data are recorded and calculated in the data sheet. A graph of dry unit weight against moisture content is plotted.

3.3.5 Falling Head Permeability Test

Falling head permeability test is commonly used for measuring the permeability of soils of intermediate and low permeability (*Civil Engineering Laboratory Manual UMP*, 2011). The experiment is simple where the sample is connected to a standpipe, which provides both the head of water and the means of measuring the quantity of water, flowing through the sample. This experiment can determine the coefficient of permeability of kaolin.

The soil sample of kaolin clay is prepared by using the standard proctor test experiment with optimum amount of moisture content (data obtained from dry unit weight against moisture content graph) and three layers compaction of standard proctor. Before the sample is prepared, the length of the mould is measured, which diameter and height of the mould is determined. The compacted kaolin soil sample is then immersed in water for 24 hours afterwards.

Figure 3.10: Falling Head Sample

The following day, the sample is taken out and fixed with the permeameter cell, as shown in Figure 3.10. After fixing with the permeameter cell, the sample is submerged inside a cylinder filled with de-aired water and connected with a falling head tube. The tube is connected with the manometer.

The experiment is started by opening the manometer tube of diameter 16.17 mm for permeability test. The experiment is timed for 15 minutes and the starting level of the manometer tube is at 1000 mm point. The procedure is then repeated for two more times with manometer tube of diameter 7.33 mm and 8.15 mm. The time is fixed at 15 minutes and the starting point is also fixed at 1000 mm point.

The data and results are recorded in the data sheet. The permeability coefficient, K_t is calculated with Equation 3.4 and analysis is done. The average permeability coefficient is later obtained by dividing the total number of samples.

$$K_t = \frac{3.84 \times a \times L \times \log\left(\frac{h_1}{h_2}\right) \times 0.00001}{A \times t} \tag{3.4}$$

where K_t is permeability (m/s), a is the cross section area of used manometer tube (mm^2), A is the cross section area of sample in permeameter cell (mm^2), t is the measured time interval (s), L is the length of sample (m), h_1 is the starting level of manometer tube (m), and h_2 is the end level of manometer tube (m).

3.3.6 Brunauer, Emmett and Teller Method (BET) Test

Brunauer, Emmett and Teller method (BET) test is used for determining the surface area of solids from nitrogen sorption isotherm at liquid nitrogen temperatures (Naderi, 2015). For this research, a sample of about 5g of S300 kaolin powder is taken to the laboratory of Faculty Biochemical Industry, for the experiment to be conducted.

3.4 SAMPLE PREPARATION

After conducting the test to define the properties of S300 kaolin clay, samples for determination of double porosity (S300 kaolin aggregation) are prepared. First of all, materials needed, such as samples mould (39 mm dia. × 76 mm height), pipe with 39 mm diameter, a ruler, big basin, tapes, 2mm sieve, rubber block, gloves, trays, steel block, steel pole are prepared.

S300 kaolin clay is oven dried for more than 24 hours before being used for preparing sample. After that, the kaolin powder is left to cool at room temperature for 3 hours. Then, the kaolin powder is weighed and mixed with 26% of water. The mixture is mixed for about 5 minutes until the water and the kaolin powder are evenly mixed. Then, the soil paste is packed into sealable bags and placed in a container at room temperature for curing process for at least 24 hours. This procedure is repeated with 28%, 30%, 32%, and 34% of water.

Next the cured kaolin soil paste is taken out and sieved through the 2mm opening sieve. At the same time, make sure that the unused kaolin soil paste is sealed back to its bag to prevent the moisture content from decreasing. The sieved samples, aggregated soil paste, are used to fill up the sample mould; pipe is used to prevent spillage off the mould before compression. The amount of aggregated soil paste needed is obtained using Equation 3.5 to Equation 3.7.

$$Y = 11kN/m^3 \times (1 + m.c.) \tag{3.5}$$

$$V = \pi r^2 h \tag{3.6}$$

$$W = \frac{Y}{V} \tag{3.7}$$

where *Y* is the unit weight of the soil samples, *m.c.* represents the moisture content, *V* is the volume of the sample and *W* is the required weight of the aggregated soil paste.

When the sample mould is fully-filled with aggregated soil paste, the mould is being compressed using a steel block through the pipe to the height where the surface of the steel block meets the surface of the mould. Later, the whole mould is taken to a steel pole, for the samples to be pushed out. A little force is applied to the mould through the steel pole and then the samples are done.

Figure 3.11 shows the completed sample. The aggregated samples are stored in a moisture content tube to prevent the moisture content from decreasing. The samples are used for analysis of ESEM machine.

Figure 3.11: Prepared Aggregated Sample

3.5 SOIL STRUCTURE TEST

3.5.1 Environmental Scanning Electron Microscopy (ESEM)

Figure 3.12: ESEM Machine

Environmental Scanning Electron Microscopy (ESEM) was developed from Scanning Electron Microscopy (SEM) limitations. The advantages of ESEM are permitting consumers to vary the sample environment through a range of pressures, temperatures, and gas compositions. Samples with wet, oily, dirty, or non-conductive, was once banned to undergo SEM test as SEM requires clean, dry and electrically conductive samples only. However, ESEM now permitting all samples, including wet, dirty or oily, to be examined under it. ESEM machine is displayed in Figure 3.12.

In this research, the samples are taken to Universiti Teknologi MARA (UiTM) to conduct ESEM analysis. The kaolin soil paste with 26%, 28%, 30%, 32% and 34% of moisture content is taken to UiTM and the aggregated samples is prepared there.

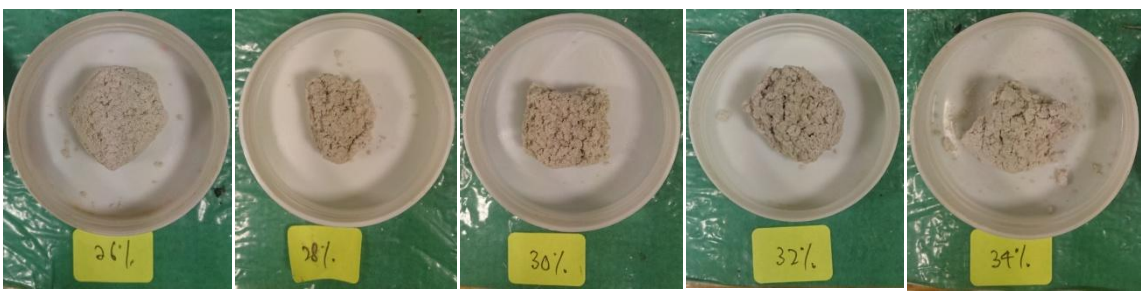


Figure 3.13: Aggregated Kaolin Soil Samples

Figure 3.13 shows the aggregated kaolin soil samples prepared to be taken for ESEM analysis. The aggregated kaolin sample is placed in ESEM machine for analysis and the results are generated through machine linked computer. Analysis of double porosity feature is done through the results.

Chapter 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

In this chapter, the results obtained from laboratory tests carried out in the research methodology were presented. The results will determine the soil properties of S300 kaolin where the Atterberg Limits, PSD, Particle Density, BET, Standard Proctor Test, and Falling Head Permeability Test results will be analyzed and discussed. S300 kaolin soil will be classified based on the Unified Soil Classification System (USCS). Moreover, the aggregated pore structure of S300 kaolin samples will be studied and explained. This will determine the capability of kaolin aggregation in creating double porosity characteristics under optimum moisture content in laboratory. Furthermore, the main objective, optimum moisture content for S300 kaolin aggregation will be discussed and determined.

4.2 SOIL PROPERTIES

Soil properties in geotechnical laboratory and experiments include Atterberg Limit, PSD, Particle Density Test, and BET test. These experiments are commonly used to determine the properties of soil.

4.2.1 Atterberg Limits

This test is done to find the basic information of soil. That information such as PL, LL, PI and LS are determined from this experiment.

Firstly, LL experiment of S300 kaolin soil is done and LL is determined. The results of LL experiment are in Table 4.1.

Table 4.1 Liquid Limit Data

Test Number		**1**		**2**		**3**		**4**	
Moisture content	%	42		44		46		48	
Cone penetration	mm	14.6	15.1	17	17.4	23.9	24.7	28.1	27.2
Average penetration	mm	14.85		17.2		24.3		27.65	
Container No.		**34D**	**46D**	**42D**	**26D**	**23D**	**27C**	**30D**	**47C**
Container weight	g	10.35	10.42	11.05	10.42	9.54	9.78	10.94	10.2
Wet soil + container	g	23.25	23.74	24.52	23.48	26.16	26.4	24.31	21.92
Wet soil, W_w	g	12.9	13.32	13.47	13.06	16.62	16.62	13.37	11.72
Dry soil + container	g	19.75	20.12	20.8	19.86	21.54	21.78	20.52	18.59
Dry soil, W_d	g	9.4	9.7	9.75	9.44	12	12	9.58	8.39
Moisture loss, W_w - W_d	g	3.5	3.62	3.72	3.62	4.62	4.62	3.79	3.33
Moisture content	%	37.23	37.32	38.15	38.35	38.50	38.50	39.56	39.69
AVERAGE MOISTURE CONTENT	%	**37.28**		**38.25**		**38.50**		**39.63**	

$$\text{Moisture Content} = \frac{Moisture\ Loss}{Dry\ Soil} \times 100\%$$

$$= \frac{3.50}{9.40} \times 100\%$$

$$= 37.23\%$$

$$\text{Average Moisture Content} = \frac{\Sigma(Moisture\ Content)}{2}$$

$$= \frac{(37.23+37.32)}{2}$$

$$= \mathbf{37.28\%}$$

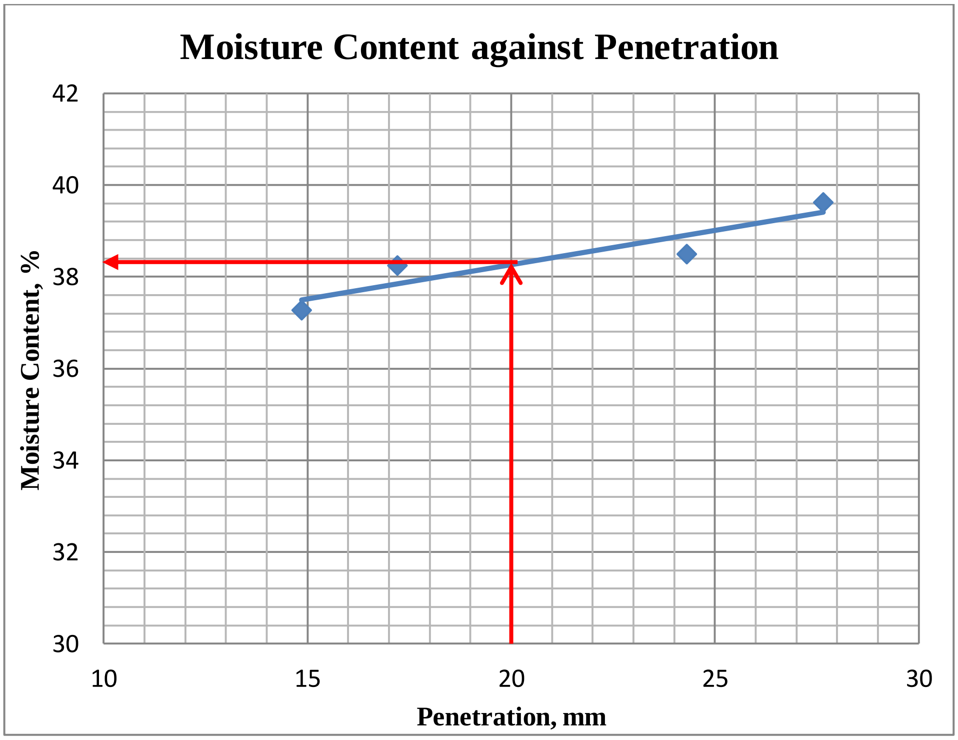


Figure 4.1 Graph of Liquid Limit

From Figure 4.1, the liquid limit obtained is **38.3%**, which is the moisture content corresponding to a cone penetration of 20 mm. Secondly, the data of PL for S300 kaolin soil is also determined and calculated. Table 4.2 shows the PL results.

Table 4.2 Plastic Limit Data

Container No.		**2**	**4**	**6**
Container weight	g	36.48	36.49	36.57
Wet soil + container	g	45.56	46.72	45.31
Wet soil, W_w	g	9.08	10.23	8.74
Dry soil + container	g	43.61	44.5	43.39
Dry soil, W_d	g	7.13	8.01	6.82
Moisture loss, W_w - W_d	g	1.95	2.22	1.92
Moisture content	%	27.35	27.72	28.15
AVERAGE MOISTURE CONTENT	%		**27.74**	

$$\text{Moisture Content} = \frac{Moisture\ Loss}{Dry\ Soil} \times 100\%$$

$$= \frac{1.95}{7.13} \times 100\%$$

$$= 27.35\%$$

$$\text{Average Moisture Content} = \frac{\Sigma(Moisture\ Content)}{Number\ of\ experiments}$$

$$= \frac{(27.35+27.72+28.15)}{3}$$

$$= \mathbf{27.74\%}$$

The data results obtained in Table 4.1 and 4.2 contribute in determining PI. The calculation of PI involves PL and LL, as mentioned in Equation 3.1.

Plasticity Index (PI) = Liquid Limit (LL) – Plastic Limit (PL)
= 38.3% – 27.7%
= **10.6%**

Linear shrinkage experiment was also done to determine the percentage of one dimension shrinkage of kaolin soil. The results for linear shrinkage are as in Table 4.3.

Table 4.3 Linear Shrinkage Data

Container No.		**1**	**2**	**3**
Before shrinking				
Weight of mould	g	165.34	166.37	229.54
Length of inner part	mm	140	141	140
Length of outer part	mm	158	158	152
Inner diameter, ϕ_{inner}	mm	25.9	25.9	26.35
Outer diameter, ϕ_{outer}	mm	31.78	31.75	32.3
After shrinking		**105°C**	**105°C**	**105°C**

Length 1	mm	26-Mar	138	26-Mar	138	26-Mar	137
Diameter 1	mm		26		26		26
Length 2	mm	27-Mar	138	27-Mar	138	27-Mar	138
Diameter 2	mm		26		26		26
Length 3	mm	3-Apr	138	3-Apr	138	3-Apr	138
Diameter 3	mm		26		26		26
LINEAR SHRINKAGE	%	1.43		2.13		1.43	
AVERAGE LINEAR SHRINKAGE	%			**1.66**			

$$\text{Linear Shrinkage} = \left[1 - \left(\frac{Length\ of\ Oven\ Dried\ Sample}{Initial\ Length\ of\ Sample}\right)\right] \times 100$$

$$= \left[1 - \left(\frac{138}{140}\right)\right] \times 100$$

$$= 1.43\%$$

$$\text{Average Linear Shrinkage} = \frac{\Sigma\ (Linear\ Shrinkage)}{Number\ of\ experiments}$$

$$= \frac{(1.43 + 2.13 + 1.43)}{3}$$

$$= \mathbf{1.66\%}$$

Therefore, based on the results obtained, S300 kaolin soil has LL of 38.3% and PL of 27.7%, which contributes to the PI of 10.6%. The LS obtained from the experiment is 1.66%. These results proves that S300 kaolin soil will behaves like plastic material below 27.7% of moisture content and behaves like liquid below 38.3% of moisture content. At 38.3% of liquid limit, the kaolin soil will shrink linearly for 1.66% of the sample in drying oven.

Meanwhile, according to the USCS, with the results obtained in Atterberg limits experiment, S300 kaolin sample is classified as CL, which implies that S300 kaolin is inorganic clay with low to medium plasticity.

4.2.2 Particle Size Distribution Test (PSD)

PSD is crucial and is conducted for every soil research. This test is the index to indicate the particle size in a specific amount of proportions of the soil sample (Shimadzu, 2015). For S300 kaolin soil, the soil had taken for sieving (sieve analysis) and then fine analysis using hydrometer. The results of sieve analysis and fine analysis are shown in Table 4.4 and Table 4.5.

Table 4.4 Data of Sieve Analysis

Sieve Size (mm)	**Mass of Sieve (g)**	**Mass Retained on Sieve (g)**	**Percent Retained (%)**	**Percent Passing (%)**
5	508.86	0	0	100
3.35	540	0	0	100
1.18	430	0	0	100
0.6	490.89	0.4	0.5	99.5
0.3	432.78	1.5	1.875	98.125
0.15	422.89	3.65	4.5625	95.4375
0.063	404.19	23.95	29.9375	70.0625
Pan	368.84	50.5	63.125	8.36
Total		**80**	**100**	

$$\text{Percent Retained} = \frac{Mass\ Retained\ on\ sieve}{Total\ Mass\ of\ Soil} \times 100\%$$

$$= \frac{0.4}{80} \times 100\%$$

$$= 0.5\%$$

$$\text{Percent Passing} = (100 - Percent\ Retained)\%$$

$$= (100 - 0.5)\%$$

$$= \mathbf{99.5\%}$$

Table 4.5 Data of Fine Analysis

Date	Time	Elapse time (t min)	Temperature (T °C)	Reading (Rh')	Rh' + Cm (Rh)	Effective Depth (HR mm)	Viscosity, η (mPa.s)	Particle Diameter (D mm)	Rh' - Ro' (Rd)	% Finer than D (K%)
16 Mac	13:51	0.5	25	1.02025	1.02050	114.28260	0.89100	0.060430759	0.02025	8.36
16 Mac	13:52	1	25.2	1.01975	1.02000	116.24400	0.88728	0.04309613	0.01975	6.203324318
16 Mac	13:53	2	25.1	1.01800	1.01825	123.10890	0.88914	0.031360482	0.01800	5.65366267
16 Mac	13:55	4	25	1.01600	1.01625	130.95450	0.89100	0.022870898	0.01600	5.025477929
16 Mac	13:59	8	25	1.01280	1.01305	143.50746	0.89100	0.016929543	0.01280	4.020382343
16 Mac	14:07	16	25	1.00980	1.01005	155.27586	0.89100	0.012452168	0.00980	3.078105231
16 Mac	14:23	32	25	1.00650	1.00675	168.22110	0.89100	0.0091647	0.00650	2.041600409
16 Mac	14:51	60	25	1.00450	1.00475	176.06670	0.89100	0.006847247	0.00450	1.413415667
16 Mac	15:51	120	25	1.00340	1.00365	180.38178	0.89100	0.004900707	0.00340	1.06791406
16 Mac	17:51	240	25	1.00250	1.00275	183.91230	0.89100	0.003499071	0.00250	0.785230926
17 Mac	13:51	1440	25	1.00075	1.00100	190.77720	0.89100	0.001454906	0.00075	0.235569278
18 Mac	13:51	2880	25	1.00050	1.00075	191.75790	0.89100	0.001031415	0.00050	0.157046185
19 Mac	13:51	4320	25	1.00050	1.00075	191.75790	0.89100	0.000842147	0.00050	0.157046185
23 Mac	10:24	9840	26.4	1.00000	1.00025	193.71930	0.86496	0.000560844	0.00000	0
23 Mac	13:51	10080	25.4	1.00000	1.00025	193.71930	0.87954	0.000554127	0.00000	0
24 Mac	13:51	11520	25	1.00025	1.00050	192.73860	0.89100	0.000517024	0.00025	0.078523093
25 Mac	13:51	12960	23.4	1.00050	1.00075	191.75790	0.92652	0.000486214	0.00050	0.157046185
31 Mac	16:23	21720	26	1.00000	1.00025	193.71930	0.87240	0.000377494	0.00000	0

Referring to the results in Table 4.4 and Table 4.5, the particle-size distribution graph is plotted. The graph is shown in Figure 4.2.

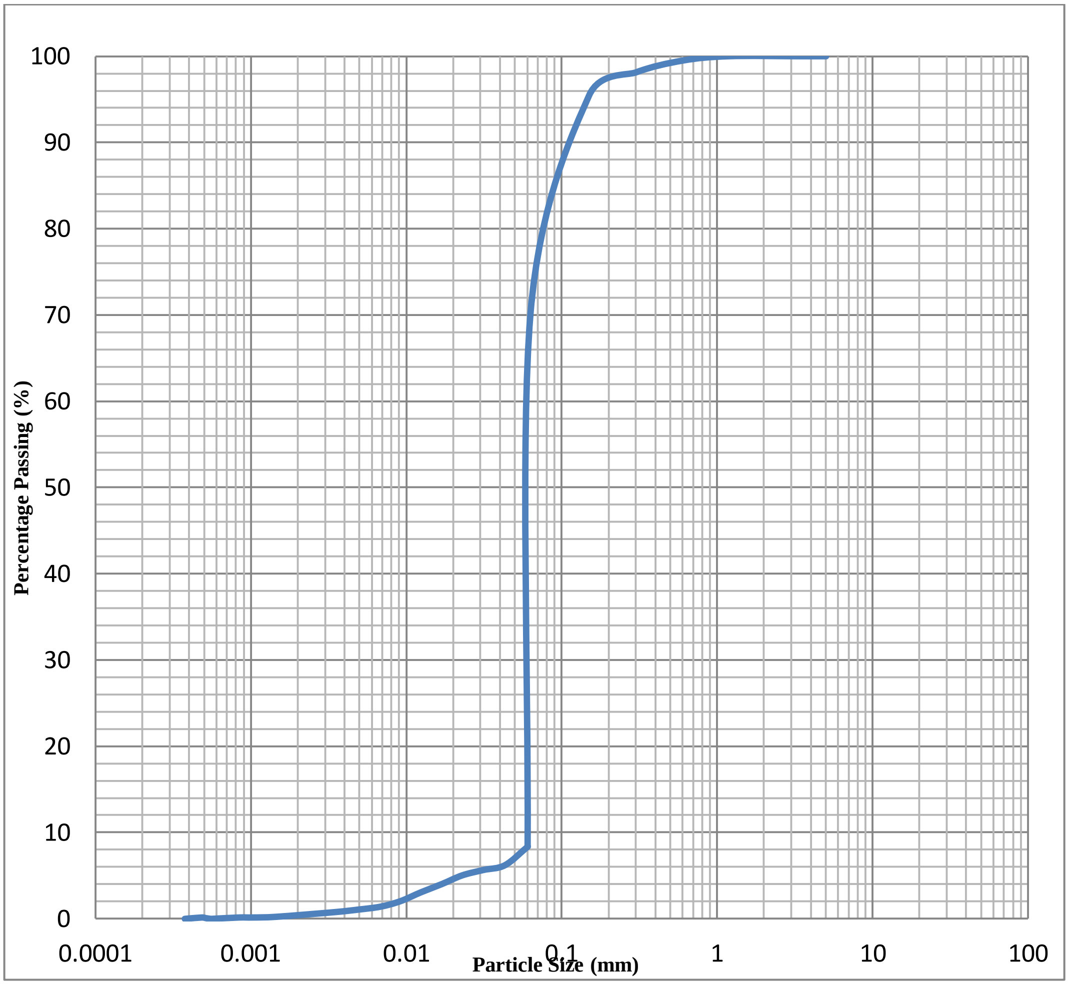


Figure 4.2 Particle-Size Distribution Curve

Based on the curve, the S300 kaolin soil is proven as a fine-grained soil as there is a huge increment during sieve analysis. Kaolin soil is more concentrated at sieve with opening of 63µm and pan. This indicates that the diameter of a kaolin particle is less than 75 micron meter, which fine-grained soil exhibits.

4.2.3 Particle Density Test

Blake (2008) defines that particle density is the density of a solid particle, which a soil sample is made up of a thousand or millions of the solid particle. The density of S300 kaolin soil is determined using particle density test. The result is shown in Table 4.6.

Table 4.6 Results of Particle Density Test

Test No.			**1**	**2**	**3**	**4**
Weight of density bottle		g	30.36	29.87	33.02	31.92
Wight of bottle + Stopper	W_1	g	34.79	34.29	37.48	35.80
Weight of bottle + Stopper + Dry soil	W_2	g	41.83	41.32	44.60	42.83
Weight of bottle + Stopper + Soil + Water	W_3	g	138.95	139.54	142.21	139.26
Weight of bottle + Stopper + Water	W_4	g	134.59	135.19	137.80	134.92
Weight of dry soil	W_2-W_1	g	7.04	7.03	7.12	7.03
Weight of water	W_4-W_1	g	99.80	100.90	100.32	99.12
Weight of soil + Water	W_3-W_2	g	97.12	98.22	97.61	96.43
Specific gravity, G_s			2.63	2.62	2.63	2.61
AVERAGE SPECIFIC GRAVITY				**2.62**		

$$\text{Specific Gravity, Gs} = \frac{(W_2 - W_1)}{(W_4 - W_1) - (W_3 - W_2)}$$

$$= \frac{7.04}{99.80 - 97.12}$$

$$= 2.63$$

$$\text{Average Specific Gravity} = \frac{\Sigma\,(Specific\ Gravity)}{Total\ number\ of\ experiments}$$

$$= \frac{(2.63+2.62+2.63+2.61)}{4}$$

$$= \mathbf{2.62}$$

Table 4.7 Specific Gravity of Common Minerals

Mineral	Formula	Specific Gravity
Biotite	Complex	2.8 – 3.2
Calcite	$CaCO_3$	2.71
Dolomite	$CaMg(CO_3)_2$	2.85
Gypsum	$CaSO_4.2H_2O$	2.3
Quartz	SiO_2	2.65
K Feldspar	$KAlSi_3O_8$	2.54 – 2.57
Na Feldspar	$NaAlSi_2O_8$	2.62 – 2.76
Kaolinite	$Al_2Si_2O_5(OH)_4$	2.61 – 2.66
Muscovite	Varies	2.76 – 3.0
Hematite	Fe_2O_3	5.2 – 5.3
Serpentine	$Mg_3Si_2O_5(OH)_4$	2.5 – 2.6
Illite	Complex	2.6 – 2.86
Montmorillonite	Complex	2.74 – 2.78

Source: (“Soil Mechanics and Foundations Laboratory Testing,” 2014)

Specific density test can be determined accurately from laboratory experiment. Most of the common soils having specific gravity at the range of 2.6 to 2.9 are clayey and silty soil. This aids to the results obtained that the specific gravity of S300 kaolin is 2.62, which falls in the range of 2.61 to 2.66. That range is similar to the mineral of kaolinite, clayey soil. Hence, S300 kaolin is classified under kaolinite, clayey and silty soil.

4.2.4 Brunauer, Emmett and Teller Method (BET)

BET is used for the measure of surface area of a solid particle, thus the surface area of S300 kaolin is 1.3526m^2/g. The results are computer generated and it is obtained from laboratory of Faculty Biochemical Industry.

4.2.5 Standard Proctor Test

Compaction is a process of increasing the bulk density of soil by driving the air out. The proctor compaction test is used to determine the optimum moisture content and the maximum dry density that can achieved with a certain compaction effort. According to *Civil Engineering Laboratory Manual UMP* (2011), the compaction effort used in laboratory test is actually comparable with the compaction force obtained in site or field. Hence, this experiment done can determine the compaction force needed at site. The result of standard compaction test is shown in Table 4.8.

The results obtained from the experiment are calculated. The calculations are as below where the volume of mould is determined, which is 995.79 m^3 and the specific gravity value is taken from the particle density test, which is 2.62. Moreover, the value of water density used in this experiment is 10 kN/m^3.

$$\text{Bulk Density, } \rho = \frac{Mass\ of\ Compacted\ Specimen}{Volume\ of\ Mould} \times 100\%$$

$$= \frac{1420}{995.79} \times 100\%$$

$$= 1.426$$

$$\text{Moisture Content} = \frac{Moisture\ Loss}{Dry\ Soil} \times 100\%$$

$$= \frac{1.80}{44.44} \times 100\%$$

$$= 4.05\%$$

Average Moisture Content $= \frac{\Sigma(Moisture\ Content)}{2}$

$= \frac{(4.05+4.01)}{2}$

= **4.03%**

Dry Density, ρ_d $= \frac{\rho}{(1+w)}$

$= \frac{1.426}{(1+\frac{4.03}{100})}$

= 1.37 g/cm^3

Dry Unit Weight, γ_d $= \frac{\rho_d}{100} \times 1000$

$= \frac{1.37}{100} \times 1000$

= **13.7 kN/m^3**

Unit Weight (zero air void) $= \frac{G\gamma_w}{1+(wG)}$

$= \frac{2.62(10)}{1+\left[\left(\frac{4.03}{100}\right)\times 2.62\right]}$

= **23.70 kN/m^3**

Hence, the graph of dry unit weight against moisture content is plotted. This is to determine the maximum dry unit weight of S300 kaolin soil and the optimum moisture content for kaolin soil. The data is shown in Figure 4.3.

Table 4.8 Data of Standard Proctor Test

WATER CONTENT		**5%**		**10%**		**15%**		**20%**		**25%**		**30%**	
Mass of Mould + Base *(m_1)*	g	4100		4100		4100		4100		4100		4100	
Mass of Mould + Base + Compacted Specimen *(m_2)*	g	5520		5700		5840		5900		5960		5920	
Mass of Compacted Specimen *(m_2-m_1)*	g	1420		1600		1740		1800		1860		1820	
Bulk Density, $\rho = (m_2-m_1)/V$	g/cm^3	1.426008205		1.606769809		1.747362167		1.807616035		1.867869903		1.827700658	
CONTAINER NO.		**59A**	**5A**	**47A**	**51A**	**53A**	**8A**	**57A**	**38A**	**60A**	**52A**	**12A**	**32A**
Container Weight	G	24.00	22.37	25.25	24.40	26.33	23.26	25.04	26.24	25.72	22.05	25.43	28.83
Wet Soil + Container	G	70.24	55.55	52.63	40.68	58.21	42.71	76.07	61.78	58.84	55.86	74.98	81.64
Wet Soil, W_w	G	46.24	33.18	27.38	16.28	31.88	19.45	51.03	35.54	33.12	33.81	49.55	52.81
Dry Soil + Container	G	68.44	54.27	50.52	39.18	54.45	40.46	68.31	56.40	52.72	49.67	64.20	70.29
Dry Soil, W_d	G	44.44	31.90	25.27	14.78	28.12	17.20	43.27	30.16	27.00	27.62	38.77	41.46
Moisture Loss, W_w - W_d	G	1.80	1.28	2.11	1.50	3.76	2.25	7.76	5.38	6.12	6.19	10.78	11.35
Moisture Content	%	4.05	4.01	8.35	10.15	13.37	13.08	17.93	17.84	22.67	22.41	27.81	27.38
Average Moisture Content	%	4.03		9.25		13.23		17.89		22.54		27.59	
Dry Density, $\rho_d = \rho/(1+w)$	g/cm^3	1.37		1.47		1.54		1.53		1.52		1.43	
Dry Density	kg/m^3	1370.746925		1470.736455		1543.247191		1533.358729		1524.306699		1432.475128	
Dry Unit Weight, γ_d	kN/m^3	13.71		14.71		15.43		15.33		15.24		14.32	
Unit Weight (zero air void)	kN/m^3	23.69701319		21.08936046		19.45742215		17.83994363		16.47258656		15.20719819	

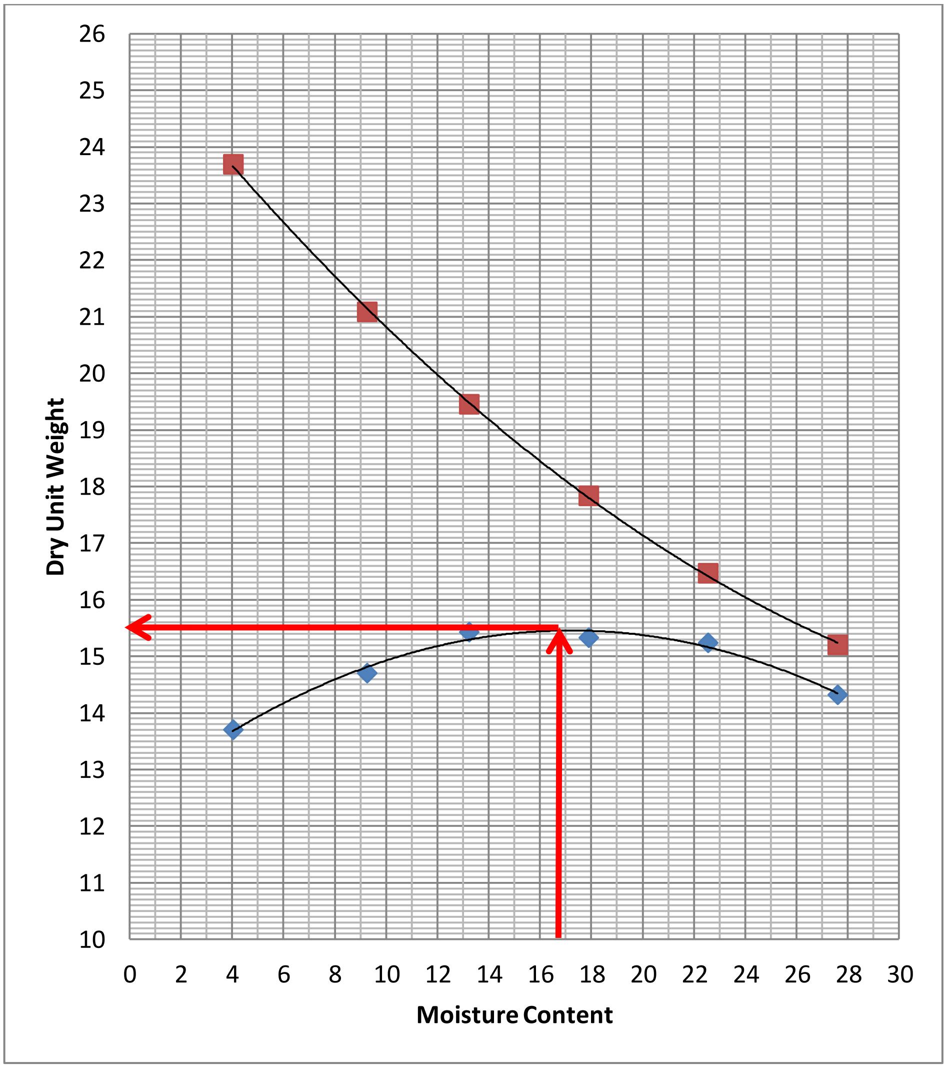


Figure 4.3 Graph of Dry Unit Weight against Moisture Content

According to the graph, the maximum dry unit weight found is 15.48 kN/m^3 and the optimum moisture content for kaolin is 17.1%. Furthermore, the zero air voids (ZAV) line is the combination of moisture and density that produce complete saturation of the soil when there is no air in the void spaces. The ZAV line does not cross the curve but becomes parallel to it.

4.2.6 Falling Head Permeability Test

Falling head permeability test is a measure of the ease in which water can flow through a volume of soil (Tiwari, 2008). Falling head permeability test is done for fine-grained soil, whereas constant head permeability test is done for coarse-grained soil. Tiwari (2008) stated that this test contributes to the estimation of groundwater flow, calculation of seepage through dams, determining the rate of consolidation and settlement of structures, designing of landfill liner, and calculation of the uplift pressure in piping. In this case, falling head permeability test is done to determine the coefficient of permeability in S300 kaolin soil that will aid in double porosity determination. The result is shown in Table 4.9 and Table 4.10.

Table 4.9 Data of Falling Head Permeability Test I

Manometer tube	Diameter, ø (m)	Start level, h_1 (m)	End level, h_{2i} (m)		Average End level h_2 (m)	Time, t (sec)
T1	0.01617	1	0.916	0.920	0.918	900
T2	0.00733	1	0.581	0.591	0.586	900
T3	0.00815	1	0.494	0.503	0.4985	900

Table 4.10 Data of Falling Head Permeability Test II

Manometer tube	h_1/h_2	log h_1/h_2	Radius Manometer Tube, r (m)	Area Manometer Tube, a (m_2)	Permeability Coefficient, K_t
T1	1.0893	0.0372	0.008085	0.00020538	5.39×10^{-12}
T2	1.7065	0.2321	0.003665	0.00004220	6.92×10^{-12}
T3	2.0060	0.3023	0.004075	0.00005217	1.11×10^{-11}

Table 4.9 and Table 4.10 are connected. The diameter of the mould is 0.1 m, length is 0.13 m and the area is 0.00786 m^2. The time is fixed at 900 seconds. The experiment

starts at the level of 1 m of each manometer tube and the end level is determined. These information are required for the calculations. One of the permeability of the kaolin is calculated as shown.

$$K_t = \frac{3.84 \times a \times L \times \log\frac{h_1}{h_2} \times 0.00001}{A \times t}$$

$$= \frac{3.84 \times 0.00020538 \times 0.13 \times 0.0372 \times 0.00001}{7.0695}$$

$$= 5.39 \times 10^{-12} \text{ m/s}$$

$$\text{Average } K_t = \frac{\Sigma\,(K_t)}{Total\ number\ of\ permeability\ test}$$

$$= \frac{(5.39 \times 10^{-12}) + (6.92 \times 10^{-12}) + (1.11 \times 10^{-11})}{3}$$

$$= \mathbf{7.81 \times 10^{-12}\ m/s}$$

The results showed that the permeability of kaolin in different diameter of manometer is almost the same value, with small difference. From the results obtained, the values of permeability coefficient for T1, T2 and T3 are 5.39×10^{-12} m/s, 6.92×10^{-12} m/s, and 1.11×10^{-11} m/s respectively.

Table 4.11 Typical permeability coefficient for different soil type

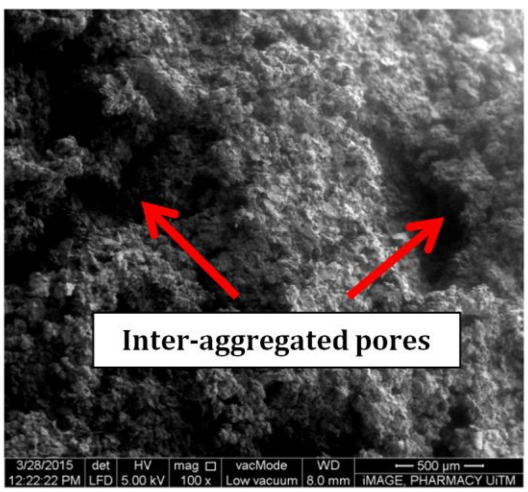
Soil Type	Typical Permeability, k (m/s)
Gravels and Coarse Sand	$> 10^{-1}$
Fine Sand	10^{-1} to 10^{-3}
Silty Sand	10^{-3} to 10^{-5}
Silts	10^{-5} to 10^{-7}
Clay	$< 10^{-7}$

According to Table 4.11, which displayed the different permeability coefficient for different types of soil, S300 kaolin is classified under clay type of soil. This is due to the experiment results obtained that the value permeability coefficient of S300 kaolin is 7.81 × 10^{-12} m/s, which is less than 10^{-7}. Therefore, it is shown that S300 kaolin is a type of clay.

4.3 SOIL STRUCTURE

Soil structure is the result of the spatial arrangement of the solid soil particles and their associated pore space (Jordan, 2013). Jordan (2013) added that aggregation mainly depends on the soil composition and texture, but also strongly influenced by other factors such as biological activity, climate, and geomorphic processes. Due to that soil structure is crucial; soil structure is commonly described in soil studies.

Soil structure was experimented with ESEM machine. The analysis was done at UiTM where the results are illustrated in Figure 4.5 and Figure 4.6.



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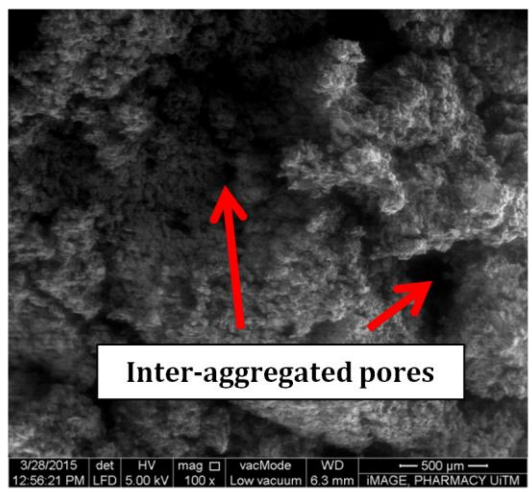

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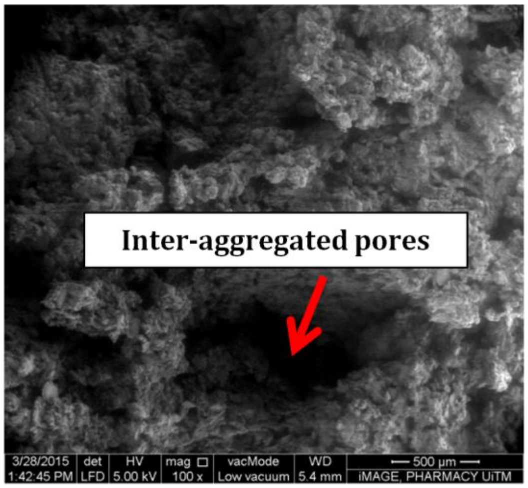

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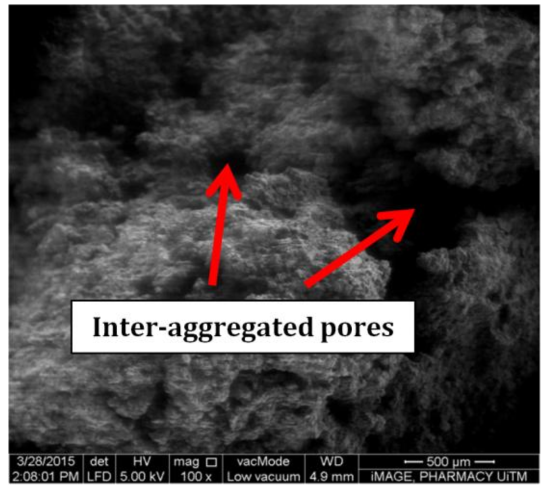

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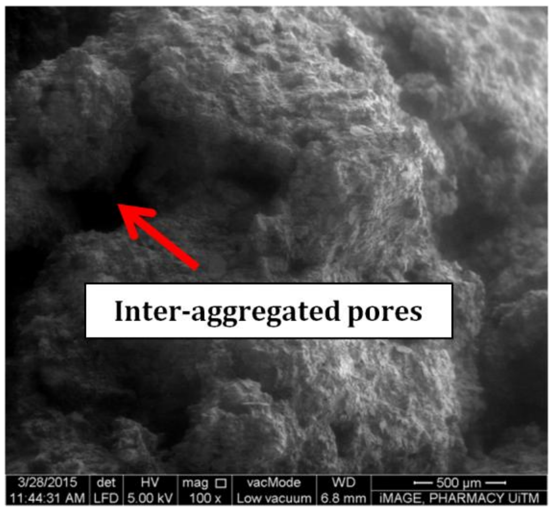

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Figure 4.4 ESEM results on S300 Kaolin samples

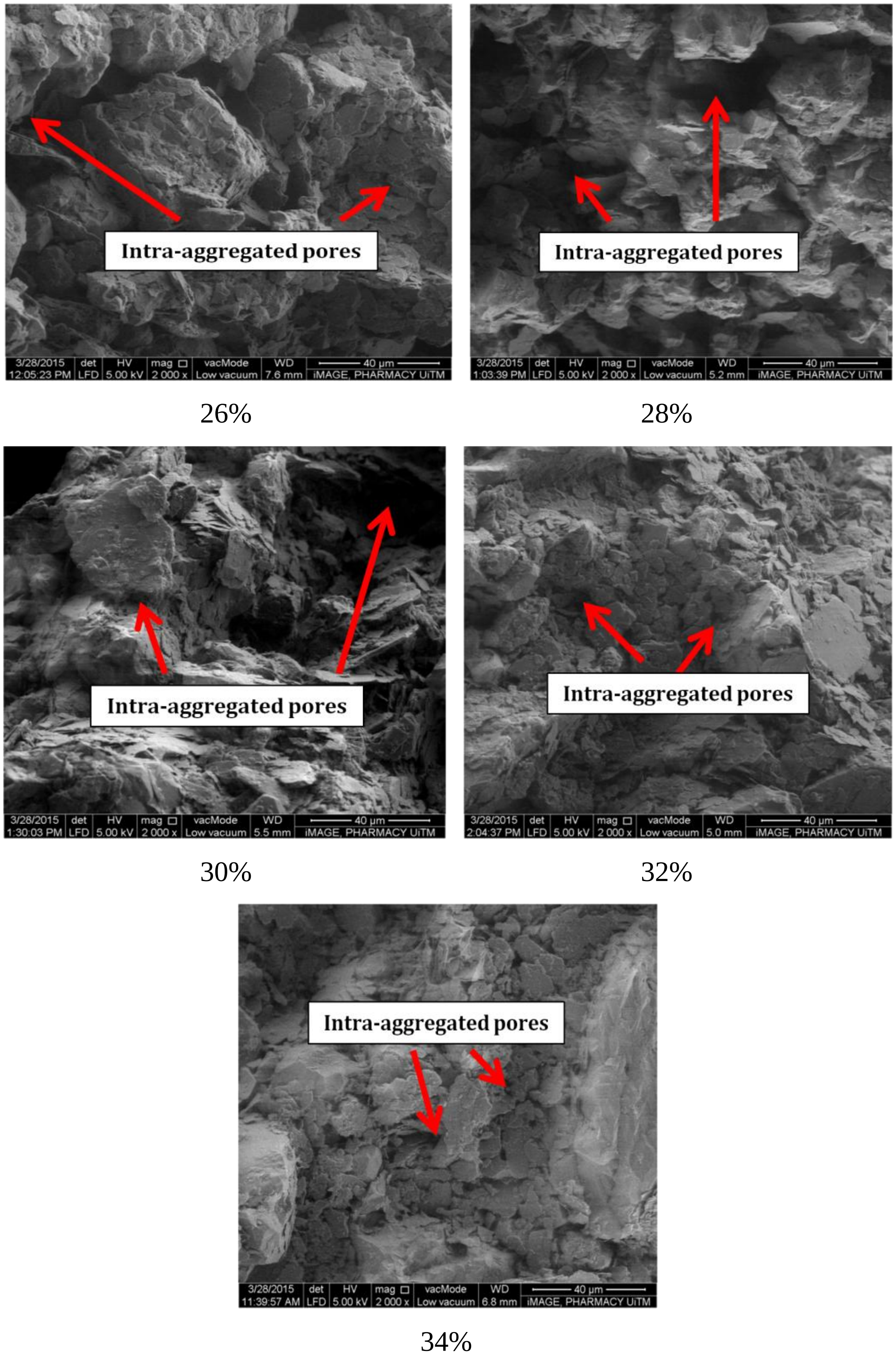

Figure 4.5 ESEM results on single kaolin granule

Figure 4.4 aggregates samples results was magnified under 100-fold of magnification and Figure 4.5 kaolin granules results was magnified under 2000-fold of magnification. Based on the results, the pore size of all the five samples are in different sizes. The samples with moisture content of 28%, 30%, 32% display bigger pore sizes as compared to 26% and 34%. This indicates that S300 kaolin can used to create inter-aggregation porosity under optimum moisture content.

Following to Figure 4.5, the results illustrate that sample with 28% and 30% of moisture content is bigger in pore size than 26%, 32%, and 34%. The pore size of kaolin samples increases when moisture content increases, however it decreases back to smaller size when the moisture content is at 32% and 34%. This clearly proves that optimum moisture content shows the highest porosity of soil.

Double porosity is the combination of inter-aggregate porosity and intra-aggregate porosity. From Figure 4.4 above, it is displayed that kaolin experiencing inter-aggregate porosity where there is different size of pores between the aggregated sample. Meanwhile in Figure 4.5, the figure illustrated that kaolin is also experiencing intra-aggregate porosity at the same time where there is pores between each kaolin granule. This gives the statement that S300 kaolin is able to have double porosity characteristics under specific moisture content.

Based on the results of the images from ESEM machine, the biggest pore size of the sample is under 30% of moisture content. It can be concluded that 30% of moisture content is the optimum moisture content for aggregation of S300 kaolin.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION

This research aims to determine the soil properties of S300 kaolin soil and to determine the optimum moisture content for S300 kaolin aggregation. Hence, this research can be concluded that, the S300 kaolin soil is inorganic clay with low to medium plasticity. The soil properties are shown as S300 kaolin obtained the results of LL at 38.3%, PL at 27.7% and LS at 1.66%. The PI is calculated and the value obtained is 10.56%. By referring to USCS, S300 kaolin soil is classified under the category of CL, which implies inorganic clay with low to medium plasticity.

The results of PSD experiment proves that S300 kaolin soil is a fine-grained soil as the PSD graph shows a major 90 degree drop in the PSD S curve. The PSD S curve is the combination results of sieve analysis and fine analysis. Moreover, the specific gravity value of S300 kaolin obtained from the particle density test is 2.62, which implies that S300 kaolin is under the category of kaolinite, as referring to the standards. The category of kaolinite indicates that S300 kaolin is a clayey and silty soil.

Besides that, the results of standard proctor test shows that maximum dry unit weight acquired is $15.48 kN/m^3$ with the optimum moisture content is 17.1%. The permeability of S300 kaolin obtained is 7.81×10^{-12} m/s, which suits the permeability standard for clay that is $< 10^{-7}$. Hence, this study has displayed that S300 kaolin is a fine-grained clayey soil.

Furthermore, this study conveys that the inter-aggregation and intra-aggregation porosity can be created in S300 kaolin soil samples. The ESEM results illustrated that the inter-aggregation porosity emerged at the pores within kaolin samples. Apart from that, ESEM results displayed the intra-aggregation porosity too. The intra-aggregation porosity is seen between the pores of a single kaolin granule. Thus, from the results of ESEM experiment, 30% of moisture content is determined as the optimum moisture content to achieve best aggregation with double porosity of S300 kaolin.

5.2 RECOMMENDATIONS

This study is done for the purpose of identifying double porosity in soil, specifically in S300 kaolin soil. The results prove that the characteristic of double porosity is able to be created in laboratory using S300 kaolin soil under moisture content of 30%.

However, the experiment can still be improved. The prepared aggregated samples for ESEM experiment are not evenly compressed. The compression applied to the samples causes the upper side of the samples more compacted when compared to the middle or the other side of the sample. This is because the upper side of the samples received direct compaction force from the steel block, while compaction force decreases at the middle part and only a little reaches the other side of the sample. This causes uneven distribution of compaction.

Thus, as a recommendation, the sample that is fully-filled with aggregated soil paste can be compacted using standard proctor theory of 3 layers of compaction. This can eliminate the uneven distribution of compaction in the samples.

In addition, for further research of double-porosity in agriculture industry, it is recommended to conduct a further study on the optimum temperature for double-porosity to be created in aggregation of S300 kaolin. The study can determine the optimum temperature to create double-porosity feature in aggregation of S300 kaolin soil.

In a nutshell, the results and optimum moisture content for aggregation of S300 kaolin will aid researchers in studying the flow of contaminants through aggregated soil. Future research can use this result in finding the sustainable solutions for groundwater contamination.

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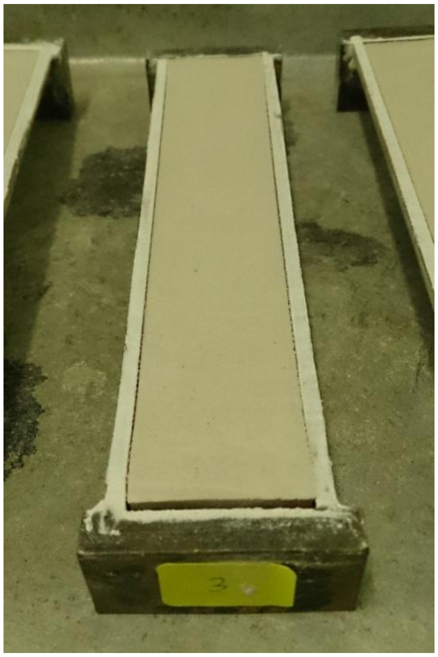
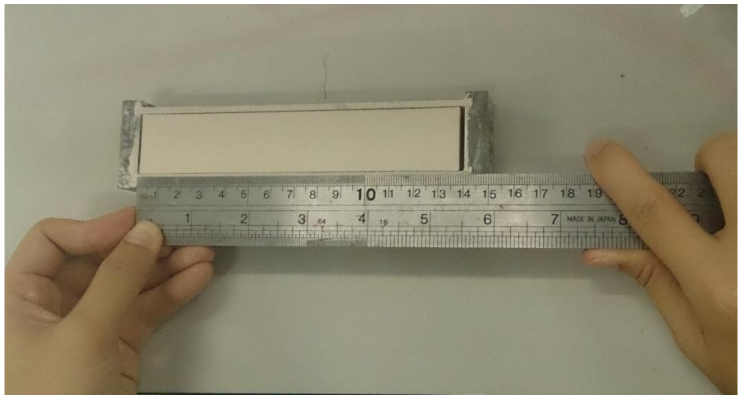
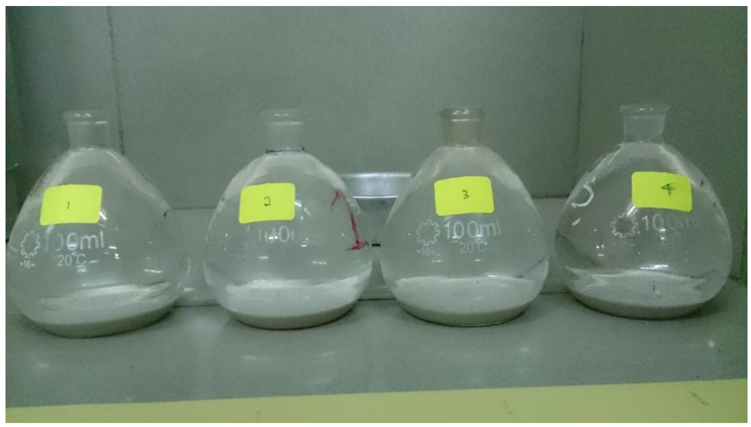
APPENDICES

A Photos of Laboratory Experiments



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