UNIVERSITI MALAYSIA SARAWAK
UNIMAS

Faculty of Engineering

ELECTRICAL RESISTIVITY FOR HYDRATION OF SEDIMENTED GYPSUM SLURRY

Colin Chong Ka Liang

Bachelor of Engineering with Honours
(Civil Engineering)

UNIVERSITI MALAYSIA SARAWAK

Grade: ____________

Please tick (√)

Final Year Project Report ☑

Masters ☐

PhD ☐

DECLARATION OF ORIGINAL WORK

This declaration is made on 14th June 2019.

Students' Declaration:

I, COLIN CHONG KA LIANG (51553), from FACULTY OF ENGIEERING hereby declare that the work entitled, ELECTRICAL RESISTIVITY FOR HYDRATION OF SEDIMENTED GYPSUM SLURRY is my original work. I have not copied from any other students' work or from any other sources except where due reference or acknowledgement is made explicitly in the text, nor has any part been written for me by another person.

14th June 2019 Colin

Date submitted COLIN CHONG KA LIANG (51553)

Supervisor's Declaration:

I, DR. ALSIDQI HASAN hereby certifies that the work entitled, ELECTRICAL RESISTIVITY FOR HYDRATION OF SEDIMENTED GYPSUM SLURRY was prepared by the above named student, and was submitted to the "FACULTY" as a partial KNS 4254 Final Year Project fulfilment for the conferment of BACHELOR OF ENGINEERING WITH HONOURS (CIVIL ENGINEERING), and the aforementioned work, to the best of my knowledge, is the said students' work

Received for examination by: ______________________

(DR. ALSIDQI HASAN) Date: 14th June 2019

I declare this Project/Thesis is classified as (Please tick (√)):

☐ **CONFIDENTIAL** (Contains confidential information under the Official Secret Act 1972)*

☐ **RESTRICTED** (Contains restricted information as specified by the organisation where research was done) *

☑ **OPEN ACCESS**

Validation of Project/Thesis

I therefore duly affirmed with free consent and willingness declared that this said Project/Thesis shall be placed officially in the Centre for Academic Information Services with the abide interest and rights as follows:

- This Project/Thesis is the sole legal property of Universiti Malaysia Sarawak (UNIMAS).
- The Centre for Academic Information Services has the lawful right to make copies for the purpose of academic and research only and not for other purpose.
- The Centre for Academic Information Services has the lawful right to digitise the content to for the Local Content Database.
- The Centre for Academic Information Services has the lawful right to make copies of the Project/Thesis for academic exchange between Higher Learning Institute.
- No dispute or any claim shall arise from the student itself neither third party on this Project/Thesis once it becomes sole property of UNIMAS.
- This Project/Thesis or any material, data and information related to it shall not be distributed, published or disclosed to any party by the student except with UNIMAS permission.

Student's signature: Colin

(14th JUNE 2019)

Supervisor's signature:

(14th JUNE 2019)

Current Address:
DEPT. OF CIVIL ENGINEERING, FACULTY OF ENGINEERING, 94300 KOTA SAMARAHAN, SARAWAK

Notes: * If the Report is **CONFIDENTIAL** or **RESTRICTED**, please attach together as annexure a letter from the organisation with the period and reasons of confidentiality and restriction.

ELECTRICAL RESISTIVITY FOR HYDRATION OF SEDIMENTED GYPSUM SLURRY

COLIN CHONG KA LIANG

A dissertation submitted in partial fulfilment
of the requirement for the degree of
Bachelor of Engineering with Honours
(Civil Engineering)

Faculty of Engineering
Universiti Malaysia Sarawak

2019

ACKNOWLEDGEMENTS

First and foremost, I would like to express my sincere gratitude to my supervisor, Dr. Alsidqi Hasan of Universiti Malaysia Sarawak from Civil Engineering department for his continuous support and guidance in completing throughout this thesis. His guidance helped me in all the time of research and writing of this thesis. A special word of appreciation goes to my family members for their encouragement, support and love throughout my life. I gratefully acknowledge my fellow friends and coursemates for their help and making my time more interesting. Finally, I would like to extend my gratitude to all the caring people that I enjoyed interacting with throughout my study.

ABSTRACT

The phenomenon of Flue Gas Desulfurization process increasingly produces gypsum waste as by-product requires better design and construction of impoundment, which is used as storage for the waste. The knowledge of sedimented gypsum slurry's geotechnical properties is therefore vital in solving the problem. This project presents the experimental results to correlate the electrical resistivity of gypsum slurry to its water content and curing time. The electrical resistivity tests are performed on six samples of gypsum slurry with different water to gypsum ratio and the reading of resistivities are recorded at curing time predetermined, as per the ASTM standards. The analysis of results reveals that resistivity of the gypsum is solely dependent on its water content and the resistivity falls as the water content rises. The correlation developed and relationship found between electrical resistivity of gypsum slurry and its water content is then hoped to be extended with its strength behaviour.

TABLE OF CONTENTS

Chapter 1 **Introduction**

Chapter 2 **Literature Review**

Chapter 3 Methodology

Chapter 4 Results and Discussion

Chapter 5 Conclusion

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF ABBREVIATIONS

AC	-	Alternating Current
ACCA	-	American Coal Ash Association
ASTM	-	American Society of Testing and Materials
BFB	-	Bubbling Fluidized Bed
CFB	-	Circulating Fluidized Bed
CFBC	-	Circulating Fluidized Bed Combustion
CoPS	-	Centre of Research Excellence Construction on Peat Soil
CST	-	Constant Separation Traversing
DC	-	Direct Current
ERCP	-	Electrical Resistivity Cone Probe
ERT	-	Electrical Resistivity Tomography
FB	-	Fluidized Bed
FBC	-	Fluidized Bed Combustion
FGD	-	Flue Gas Desulfurization
ICOLD	-	International Commission on Large Dams
IPPs	-	Independent Power Producers
MCS	-	Mineral Commodity Summaries
NPS	-	National Park Service
SEM	-	Scanning Electron Microscope
SGP	-	Siam Gypsum Plaster
SMRT	-	Soil Moisture, Resistivity and Temperature
TNB	-	Tenaga Nasional Berhad
US	-	United States
USCOLD	-	United States Committee on Large Dams
VES	-	Vertical Electrical Sounding
1D	-	One-Dimensional

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Gypsum is a sulfate mineral which is normally found in layered sedimentary rocks associated with anhydrate, calcite, sulfur, dolomite and halite. Gypsum is an evaporite mineral and it is formed as a product of hydration of anhydrate. It is composed of calcium sulfate dihydrate, $CaSO_4 \cdot 2H_2O$. Besides from being an abundant mineral, synthetic gypsum can also be found as by-product of flue gas desulfurization utilized in power plant combusting coal.

Gypsum can be used in a wide range of functions, prominently as the most common mineral binders. Products made from gypsum are environmentally friendly materials. Gypsum-based products are mainly comprising calcium sulphate, which occurs as three forms of compounds, namely dihydrate ($CaSO_4 \cdot 2H_2O$), hemihydrate ($CaSO_4 \cdot 0.5H_2O$) and anhydrate ($CaSO_4$). The pH value of gypsum is neutral, which is different from lime and cement-based materials. The white colour of gypsum makes its products desirable for decorative purposes. Due to the lower temperature (135 to 180° C) required by gypsum in calcination processes, the fuel consumption is lower and the CO2 emissions from gypsum production are small as compared to lime and cement. Accelerated curing is also not required by gypsum products due to the rapid setting and hardening. Gypsum products are light and have outstanding mould ability, resistant to fire and sound, despite having low resistance to water.

As a building material, numerous advantages are offered by gypsum. Gypsum is used in manufacturing fire-resistant interiors such as ceiling panels, dry wallboards and flooring panels (Greene, 2009; Sampson, 2011). They are non-toxic and highly heat-insulated materials. In place of cellular block of concrete, ceramic and other relevant products, blocks and panels of gypsum are used as internal walls and partitions. In internal plasters, gypsum can replace cement and lime.

As chemical by-products, synthetic gypsum is widely used in the manufacture of gypsum. In whole or in part, replacement of natural gypsum by synthetic gypsum as drywalls, cement mixtures and plasters based on gypsum is common. The increase in the utilization of waste that contains gypsum reduces the landfill load.

Synthetic gypsum products, which usually contain a great percentage of calcium sulphate in industrial waste, are used to substitute natural gypsum totally or partially. Over 50 types of gypsum waste are available and majority of these can be regarded as natural gypsum replacements. Phosphorgypsum, flue gas desulphurization (FGD) gypsum and borogypsum are the most common by-products. Synthetic gypsum is usually composed of calcium sulfate dihydrate, hemihydrate calcium sulfate and anhydrate. The following are basic chemical reactions for the production of synthetic gypsum:

FGD gypsum: $CaCO_3 + SO_2 + 2H_2O \rightarrow CaSO_4\cdot 2H_2O + CO_2$ (1.1)

Phosphorgypsum: $Ca_5F(PO_4)_3 + H_2SO_4 \rightarrow 5CaSO_4 + HF + 3H_3PO_4$ (1.2)

Borogypsum: $2CaO\cdot 3B_2O_3 5\cdot H_2O + 2H_2SO_4 + 6H_2O \rightarrow 2CaSO_4\cdot 2H_2O + 6H_3BO_3$ (1.3)

The total quantity of calcium sulfate components varies in weight between 80 and 98%. Other components of synthetic gypsum may include initial raw and silica. Synthetic gypsum requires that impurities be removed or neutralized. It is unlikely in removing all the destructive impurities inside the crystals of calcium sulfate. Phosphorgypsum is one of the examples for industrial waste that containing gypsums with high level of radioactivity. Synthetic gypsum is segregated in many manufacturing processes as sludges. Before being transported, they need to be dried out, which demands extra energy.

For FGD gypsum, it is one of the by-products from flue gas desulfurization (FGD) process. Flue gas desulfurization (FGD) is the first and most traditional method of reducing sulfur dioxide in coal energy production. The flue gas is freed of sulfur dioxide through the FGD scrubbing process after coal combustion has occurred. When coal is combusted, the sulfur in the coal reacts with oxygen in the air and forms sulfur dioxide that leaves the flue gas combustion system. The sulfur dioxide-containing flue gas is an acid gas; alkaline materials such as calcareous slurries or lime are therefore used to remove sulfur as the gas passes through the scrubber system. The following equation illustrates the chemical reaction in the scrubber system.

$$CaCO_3 + SO_2 \rightarrow CaSO_3 + CO_2 \qquad (1.4)$$

Previously, the by-product produced from FGD scrubbing process was calcium sulfite (CaSO3) sludge that offered nothing useful. As the technology progressed, however, it was found that oxidization of the sludge is possible to make it becomes merchantable gypsum product.

$$CaSO_3 + \frac{1}{2}O_2 + 2H_2O \rightarrow CaSO_4 \cdot 2H_2O \qquad (1.5)$$

According to the American Coal Ash Association (ACAA 2007), more than 30.2 million tons of FGD scrubber by-products were produced in the United States in 2006, of which just over 10.6 million tons were used at an utilization rate of 35%. FGD gypsum was the most widely used FGD material with most of it utilized in manufacturing gypsum wallboard. In 2014, only 49% of FGD gypsum made in the US, or approximately 16.8 million tons can be used, mainly in wallboard production. (ACAA, 2015). These statistics have clearly shown that the production frequency of synthetic gypsum is greater than its utilization frequency, despite its potential in becoming marketable products.

The by-products from FGD process are then needed to be temporarily or permanently stored in surface impoundment. Power plant usually flushed its liquid waste to the surface impoundment units or known as wet ponds which store the waste. After the process of settling out, comparatively clear water is then left for discharging to surface water or recirculating back to the plant. Proper design of impoundment is required to cater the increased production gypsum slurry waste from FGD process.

In Malaysia, there are two coal - fired power plants in Kapar and Jaamanjung owned by Tenaga Nasional Berhad (TNB) and two other coal - fired power plants in Tanjong Bin and Jimah owned by independent power producers (IPPs) (Oh et al., 2010). As referred to the Table 1.1; in year 2003, about 12% of energy mix in Malaysia was contributed by coal, while in year 2008 about 30% or 14,200 MW of total energy generation was contributed by coal while in year 2013, it is expected to increase up to 42%

or 17,600 MW (Mohamed & Lee, 2006; Oh et al., 2010). Therefore, the amount of by-products which contain sulfur is expected to rise intensely over the next few years.

Table 1.1 Energy mix in Malaysia from year 1980 – 2003 (Abdul-Rahman, 2003).

Source of energy	1980 (%)	1990 (%)	2000 (%)	2003 (%)
Oil	87.9	71.4	53.1	
Natural Gas	7.5	15.7	37.1	71.06.0
Hydro	4.1	5.3	4.4	10.0
Coal	0.5	7.6	5.4	11.9
Biomass	-	-	-	1.1

Undoubtedly, the strength behaviour and geotechnical characteristics of sedimented gypsum slurry need to be studied and understood thoroughly for proper design of impoundment. Considering soils, an accurate understanding of the water content of unsaturated soils is essential for understanding the geotechnical properties and behaviour of natural and engineered earth structures. Seasonal changes in the water content of the soil can cause significant seasonal changes in the pore pressure, which affects the soil strength, making the water content an important factor when considering the stability and long - term serviceability of engineered earth structures such as containers (Gunn et al., 2009; Toll et al., 2011). However, changes in the water content of clay soils can lead to cyclical shrinkage and swelling processes, which can adversely affect the engineering properties and behaviour of these soils, which are known to contribute to slope failures (Smethurst et al., 2006). In-situ monitoring of the water content of engineered earth structures is therefore urgently required.

Water content probes provide valuable information on a small volume, which is within a cubic centimeter of the soil. These techniques, however, are destructive and offer measurements on a point scale that make it sensitive to the disturbance of the soil itself during installation with limited spatial resolution (Robinson et al., 2008). Furthermore, measurement of water content in the vicinity of these probes may not be representative for heterogeneous soils, and moisture along fissures cannot be accurately measured, which may lead to significant errors (Sass, 2005). The measurements also relate to the time and location of the probe and installation process, which cannot be repeated at the same place, prohibiting a reliable monitoring of the evolution of moisture.

The Electrical Resistivity Tomography (ERT) method has recently emerged as an alternative method for quantifying the water content of the soil on different scales. The technique offers non - invasive measurements for a large volume. The soil resistivity is particularly sensitive to changes in the water content. Many researchers have indicated a proxy relationship between resistivity and water content.

According to Stephenson and Hepburn (1955), the soil in and around Perth consists majority of sand. The sandy soils' electrical resistivity is mainly dependent on the quantity and continuity of porous fluid (Yoon & Park, 2001). Fukue *et al.* (1999) obtained about 105 ohm-m of electric resistivity for dry sands. Another study reported electric resistivity values for silicates between 1010 and 1014 Ohm-m (Munoz-Castelblanco et al., 2012). In addition, the dry sand shows a considerable drop in electrical resistivity as water content increases. Even as the water content increases slightly from 2.5 to 5%, there is a reduction factor of 60 for the electrical resistivity of the sand.

1.2 Problem Statement

The soil's electric resistivity is determined by measuring the soil's resistance. This is achieved by measuring the voltage at a known current level across a pair of electrodes. Measured resistance, however, is not an exclusive property of material. Its value is directly proportional to the length and inversely proportional to the cross-sectional area of the material. The theory of electric resistivity in the soil is based on the Ohm's law.

Depending on the configuration of electrode and current, there are various types of systems for electrical resistivity measurement. The polarization effect is minimized in a four-electrode arrangement since the generation of heat from measuring electrodes is minor which prevent accumulation of ions in the electrodes (Campanella & Davies, 1997). Compared to two-electrode system, the advantages of four-electrode system are highlighted by the other studies (Abu- Hassanein, 1994; Yan *et al.*, 2012).

Circular four-probe resistivity cells and Miller soil box are the two common methods for measuring electrical resistivity of soil in laboratories (Fowles, 1980; Kalinski & Kelly, 1993). Various modifications have been made by researchers to the basic structure to meet specific requirements. By modifying the soil box from Fowles' (1980) study, Sreedeep et al. (2004) manufactured an original soil resistivity box for testing. Another new electrical resistivity probe has been developed by Munoz- Castelblanco *et al.* (2012) to study how electrical resistivity of loess samples is influenced by changes in water content by subjecting them to controlled wetting and drying.

However, unlike other types of soils, such as sand and clay, which have been used as media in a number of studies to determine the relationship between their water content and electrical resistivity, a very limited number of studies have been found to correlate the electrical resistivity of gypsum slurry with its water content. There is also lack of geotechnical data available for gypsum. For this reason, an experimental set-up is proposed in this study to investigate the relationship between electrical resistivity of gypsum slurry and its water content or water to gypsum ratio.

1.3 Aim & Objective

This research is aimed at examining the relationship between electrical resistivity of sedimented gypsum slurry and its water content. This project's objectives are:

i) To study the relationship between the electrical resistivity of hydration for calcium sulfate hemihydrate and the water content used and curing time;

ii) To evaluate the electrical resistivity of the gypsum samples using American Society of Testing and Material (ASTM) standard test.

1.4 Significance of Study

This study is significant in establishing the relationship between the electrical resistivity of gypsum slurry and its water content, which is possible to be correlated to its strength behaviour. The knowledge of strength behaviour of gypsum slurry is important in order to improve the design and construction of the impoundment used as storage of gypsum slurry. Thus, the result of this study is hoped to be referred by interested researchers and engineers in future who want to further develop the relevant study.

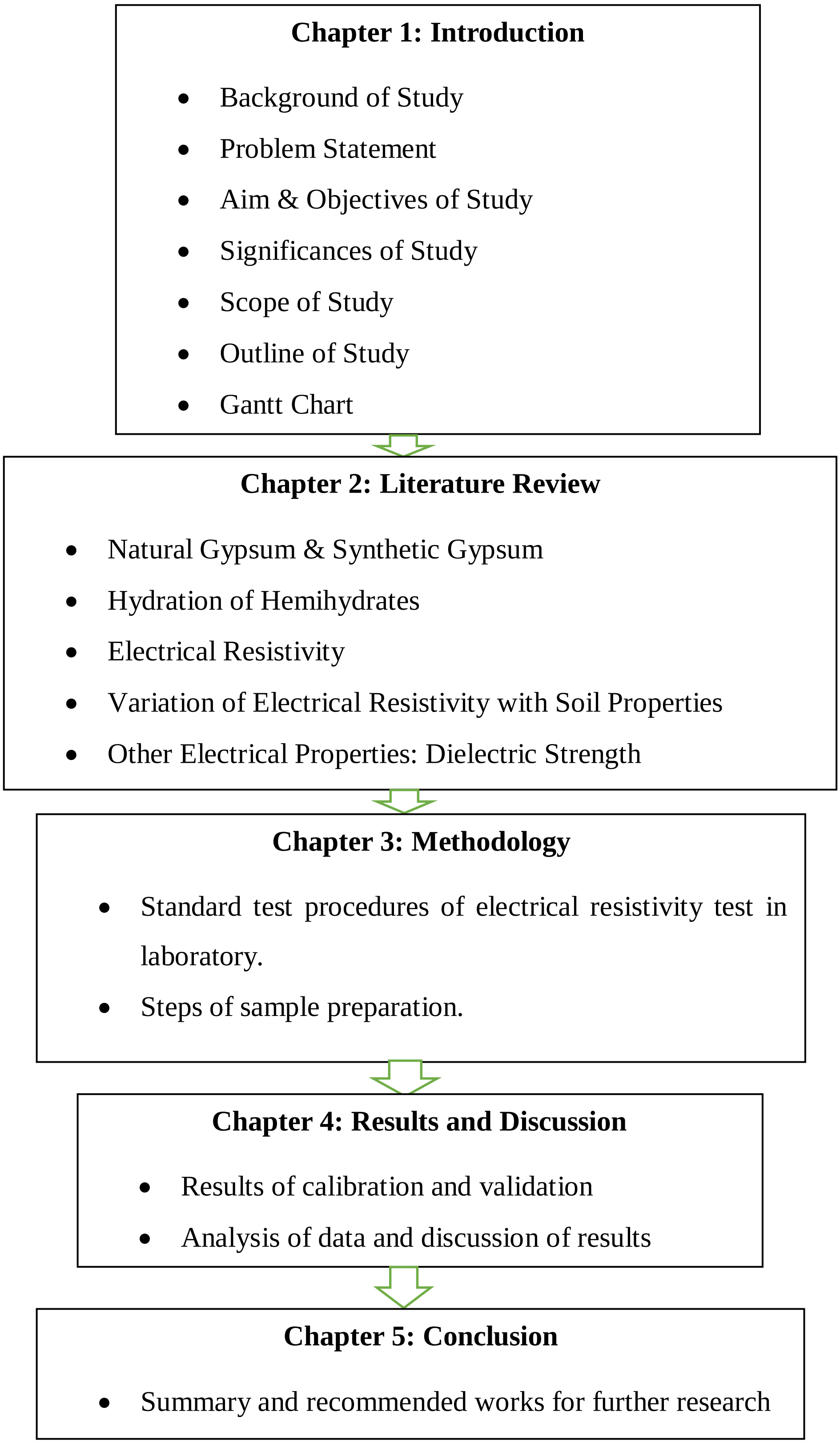
1.5 Scope of Study

This study is limited to preparation of six samples of gypsum with different water content, which ranges from the loosest state to the just workable state, and curing time. The gypsum used is produced by Siam Gypsum Plaster (SGP) Ltd. The gypsum samples are prepared in a customized Miler soil box. Electrical resistivities of these samples are then tested according to American Society for Testing and Materials (ASTM) Standard, G57-95a.

This study scope covers the application of the same low amount of voltage and current through the gypsum samples contained in the soil box. The readings of the resulting electrical resistivity are obtained by the two electrodes, which are parts of a resistivity cell connected to a multimeter for automated recording of results. The trend of electrical resistivity of sample for the duration of the experiment is observed. The experiments and tests are carried out in UNIMAS's CoPS Laboratory.

1.6 Outline of Study

There are five chapters in this project report. Following this introductory chapter, Chapter 2 presents the literature review and the theoretical background for the works included in this study. The classification of gypsum, process of flue gas desulfurization (FGD) and hydration of hemihydrates, and the basis for electrical resistivity measurement in laboratory. Chapter 3 describes the methodology which includes the fabrication of soil box, steps in preparing gypsum slurry samples and test procedures for electrical resistivity test in laboratory. Chapter 4 presents and discusses the results obtained from this study. The relationship between electrical resistivity and water content of gypsum slurry is also explored in this chapter. Finally, Chapter 5 summarises the results of this study and provides conclusions and offers recommended works for further research. The chapter sequence is depicted in Figure 1.1.



Chapter 1: Introduction

- Background of Study
- Problem Statement
- Aim & Objectives of Study
- Significances of Study
- Scope of Study
- Outline of Study
- Gantt Chart

Chapter 2: Literature Review

- Natural Gypsum & Synthetic Gypsum
- Hydration of Hemihydrates
- Electrical Resistivity
- Variation of Electrical Resistivity with Soil Properties
- Other Electrical Properties: Dielectric Strength

Chapter 3: Methodology

- Standard test procedures of electrical resistivity test in laboratory.
- Steps of sample preparation.

Chapter 4: Results and Discussion

- Results of calibration and validation
- Analysis of data and discussion of results

Chapter 5: Conclusion

- Summary and recommended works for further research

Figure 1.1: Organization chart of report

1.7 Time Plan

The schedule or time plan for the activities of this project is represented by using the Gantt chart, as depicted in Table 1.2 and 1.3. This project is required to be completed within 2 semesters of study, which is about 28 weeks. Most of the activities that need to be done are allocated to weeks of lecture within these 2 semesters.

The study of this project focuses mainly on the laboratory work in CoPS Laboratory. The preliminary laboratory work, which is aimed to determine the range of water content to be used in this project is planned to be carried out during the first semester of the final year, which is on the year 2018. The main laboratory test which is conducted to measure electrical resistivity of gypsum samples with different water content and curing time is proposed to be performed on the year 2019. The allocation of time for electrical resistivity test has taken the time required for repetition into consideration.

For report writing, the tasks are proposed to be finished within 2 semesters. Chapter 1, 2 and 3 which make up the Final Year Project 1 are planned to be completed during the first semester on the year 2018. Since the main body of Chapter 4 and 5 are according to the results obtained from laboratory tests, they are planned to be finished during the second semester on the year 2019. After compiling all the 5 chapters, they are to be handed in as Final Year Project 2 Report.

Table 1.2 Final Year Project’s Gantt Chart on the year 2018.

Event/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Year 2018														
FYP 1 Report														
Chapter 1: Introduction									■	■				
Chapter 2: Literature Review	■	■	■	■	■	■	■	■						
Chapter 3: Methodology										■	■			
FYP 1 Presentation												■		
Correction of FYP 1 Report													■	
Submission of FYP 1														■

Table 1.3 Final Year Project’s Gantt Chart on the year 2019.

Event/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Year 2019														
Laboratory Test														
Electrical Resistivity Test	🟦	🟦	🟦											
FYP 2 Report														
Chapter 4: Result and Discussion				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			
Chapter 5: Conclusion and Recommendations									🟦	🟦	🟦			
FYP 2 Draft Submission												🟦		
Correction of FYP 2 Report													🟦	
Submission of FYP 2														🟦

CHAPTER 2

LITERATURE REVIEW

2.1 Natural Gypsum and Synthetic Gypsum

Gypsum, or chemically known as calcium sulfate dihydrate, is a non-toxic mineral that contains calcium, sulfur bound to oxygen, and water. It has various uses to mankind, fauna, flora, and the environment. Besides from being used in manufacturing gypsum board, there are a lot of ways in which gypsum can be utilised, for instances as turbid water additive, soil additive, colour additive for drugs and cosmetics, and to create surgical and orthopaedic casts.

There are 2 categories of gypsum, namely natural gypsum and synthetic gypsum. Formations of sedimentary rock is the source of natural gypsum and can be found in more than 85 countries. Some of the biggest reserves of gypsum with fine quality are in Mexico and The United States. Synthetic gypsum, which is chemically nearly identical to mined natural mined gypsum, exists as by product of various industrial process.

Figure 2.1 shows the natural gypsum, which is normally used in producing binders. Attributing to sedimentary rocks, it is a soft mineral with grey or no colour and a humidity ranged from 8% to 10%. A denser modified gypsum, gypseous stone is made up of gypsum and clayey and sandy stone and it is commonly used in producing gypsum binders

Reserves of gypsum are considered to be large and its deposits are widely distributed. Based on U.S. Mineral Commodity data (MCS, 2015), a total of 246 million