MICROSTRUCTURAL CHARACTERISTIC OF LATERITIC AND MARINE CLAY SOIL TREATED WITH LIME AND CEMENT

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**SCHOOL OF CIVIL ENGINEERING
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ABSTRAK

Keadaan tanah akan selalu berubah sebagai reaksi terhadap cuaca, komposisi, dan usia. Sebagai hasil daripada perubahan tersebut, ia boleh menyumbang kepada keadaan tanah yang baik atau tidak baik. Asas tanah yang baik diperlukan untuk asas pembinaan yang kukuh. Tanah Laterit dan tanah liat laut, yang digunakan sebagai sampel tanah untuk penyelidikan ini, adalah contoh tanah yang lemah. Ia dianggap tidak sesuai kerana kehadiran kandungan kelembapan yang tinggi. Bekerja dengan tanah liat laut sangat sukar kerana kesannya yang kuat terhadap kandungan lembapan. Kualiti fizikal tanah mempengaruhi kekuatan dan kestabilannya. Tanah dengan kapasiti dan struktur tinggi lebih stabil. Ketika datang ke tanah, campuran adalah bahan yang dilaksanakan untuk meningkatkan ciri, struktur, dan kapasitas tanah. Untuk bahan campuran penstabil, simen dan kapur dipilih. Ujian Proctor Standard adalah ujian pemadatan yang akan menentukan kesan bahan penstabil ini terhadap proses pemadatan terhadap hasil ketumpatan dan kelembapannya. Kesan simen dan kapur banyak tertumpu pada kandungan lembapan. Komposisi simen dan kapur yang lebih tinggi memberikan kandungan kelembapan yang lebih rendah untuk mencapai ketumpatan kering maksimum, sementara kapur dihasilkan dari penggunaan kandungan kelembapan yang ada untuk melakukan reaksi pozzolanic. Tindak balas mengubah struktur mikro tanah yang dirawat. Secara teorinya, kedua-dua agen penstabil terdiri daripada hasil tindak balas yang serupa. Penyelidikan dan penemuan ini akan menyumbang kepada pengetahuan tambahan untuk memahami mekanisme penstabilan bahan.

ABSTRACT

Soil conditions will always vary as a reaction to weather, composition, and age. As a result of such changes, it may contribute to either the favourable or unfavourable state of the soil. A good ground foundation is required for a solid construction foundation. Lateritic soil and marine clay soil used as soil samples for this investigation are examples of weak soil. It is considered unsuitable due to the visible presence of high moisture content. It often occurs as a slurry, including a considerable amount of expandable clay minerals. Working with marine clay soil is extremely difficult owing to its strong impact on moisture content. The physical qualities of the soil influence its strength and stability. Soil with a high capacity and structure is more stable. When it comes to soil, an admixture is a substance implemented to enhance soil characteristics, structure, and ability. For the stabilizing admixture materials, cement and lime were selected. Standard Proctor test is a compaction test that will determine the effects of these stabilizing materials toward the compaction process for their density and moisture content results. The effects of cement and lime are majorly focused on the moisture content. Higher cement and lime composition give less moisture content to achieve maximum dry density, while lime results from using up an existing moisture content to perform the pozzolanic reaction. The reaction alters the microstructure of the treated soil. Theoretically, both stabilizing agents consist of the same reaction outcomes. This research and findings will contribute to extra knowledge on understanding the mechanism of stabilizing materials.

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LIST OF ABBREVIATIONS

USM	Universiti Sains Malaysia
UCT	Unconfined Compression Test
XRF	X-ray Fluorescence
XRD	X-ray Diffraction
SEM	Scanning electron microscope
OPC	Ordinary Portland cement
PC	Portland cement
CKD	Cement Kiln Dust
CSH	Calcium silicates hydrates
CAH	Calcium aluminates hydrates
CASH	Calcium aluminium silicate hydrate
Ca2+	Calcium ions
Na+	Sodium ions
K+	Potassium ions
SiO2	Silicon dioxide
Al2O3	Aluminium oxide
Fe2O3	Ferric oxide
CaO	Oxocalcium

LIST OF SYMBOLS

kPa	kiloPascal
kg	kilogram
g	gram
m^3	Meter cube
mm	Millimetre
µm	Micrometre
Mg/m^3	Milligram per meter cubic
%	Percentage
C	Cement treated sample
K	Kiln dust treated sample

CHAPTER 1

INTRODUCTION

1.1 Research Background

Soil refers to the outmost layer in the earth's crust that supports earth life. Soil is among of important aspects to be concerned in any construction project. To show how important thus the soil is the construction project, soil investigations are the first step needed to be done. Geotechnical investigations examine the properties, composition, and condition from the top layer soil to the bottom of needed soil depth. This includes an examination of soil strength, soil layer, and groundwater. This step is a must to understand soil behaviour, the strength to withstand a load of an object, and how that soil is affected for any further construction on it.

A geotechnical investigation will help the engineer plan and determine the foundation system for each construction building that suits soil conditions and estimates the cost for those solutions. Soil strength and stability depend on its physical characteristics. Soil with good capability and structure is more stable for construction that requires a good foundation, to begin with. On the other hand, removing large amounts of topsoil or fill it may cause a large increase in cost for that project. Thus, the solution to overcome this soil problem is by using admixture.

When it comes to soil, the admixture is a compound used to enhance soil qualities, improve soil structure, and improve soil capacity. Mechanical stabilization, chemical stabilization, thermal stabilization, and electrical stability are some ways to improve the soil. Chemical additions are a common method for stabilizing soils by improving their natural qualities (Buddhima Indraratna et al., 2015).

Chemical additives such as lime, asphalt, and fly ash increase the characteristics of the soil, leading to a stronger platform infrastructure. After acquiring a soil sample, the composition of the stabilizers and the right doses to increase the soil qualities to particular defined levels may be obtained using appropriate laboratory mix design procedures. Soil minerals are divided into three size types: clay, silt, and sand. The percentage of particles in these size groupings is referred to as soil texture. The use of admixture in the soil might result in changes in the structure of soil components.

Lime is an inorganic mineral that contains calcium and is composed mostly of oxides and hydroxides, most notably calcium oxide or calcium hydroxide. Lime comes from its early usage as a building mortar, and it appears to stick or adhere. The rocks and minerals from which these products are generated, which are often limestone or chalk, are mostly calcium carbonate. They are meant to minimise permeability, minimise shrinkage, promote better strength, and contribute to strong composites since they are water reducers. They can be chemically changed by being cut, crushed, or pulverised.

Cement is also another binding agent, which is a substance used in construction that sets, hardens, and adhering to other materials in order to bind them together. When cement is exposed to moisture, it begins to set, activating a sequence of hydration chemical processes. Mineral hydrates solidify and harden as the components slowly hydrate. The interconnecting of the hydrates provides the strength of cement. Proper curing needs to keep the sufficient moisture content for hydration reactions during the setting and hardening phases. In terms of soil, using cement and lime as an additive can change the adsorbed layer's structure and provides pozzolanic action.

1.2 Problem Statement

Weather, composition, and time will always cause changes in soil conditions. As a result of such changes, it may contribute to the excellent or bad state of the soil. A good ground site is needed for a good construction foundation. The performance of the soil is therefore highly emphasized. Soil minerals are divided into three groups of size which are the clay, silt, and sand. In any construction project, especially for road pavement, soil condition problems always cause difficulties in providing a solid construction foundation. This soil layer for foundation refers to the subgrade layer, which is the lowest layer in road construction.

Civil engineering construction projects, especially highway projects, built on problem soils, including soft soils, expansive soils, and other soil types, require some soil stabilization (Anand et al., 2015). From light vehicles to heavily loaded trucks that always move on the road give a continuous load that distributes from the upper layer to the bottom layer of road pavement. Some of the soil has an adequate load-bearing capacity, but some have a low load-bearing capacity (Pandey et al., 2017).

The Department of Public Works has extensive expertise in working with this problematic soil over the years as the key technical agency responsible for executing construction programs for the Government of Malaysia (N O Mohamad et al., 2016). Soil conditions will always change due to weather, content, and time. Facing problems such as floods is difficult and will always be faced when the rainy season arrives. The water scours and erodes the underside of the road surface in this case.

In this experiment, lateritic soil and marine clay soil used as soil samples are among the weak soil. Typical laterites are claylike and porous, while marine clay is soft soil. Due to the obvious presence of high moisture content, this type of soil is undesirable and typically occurs as a slurry with a significant percentage of expandable clay minerals. It is highly challenging to work with marine clay soil due to its great influence on moisture content. It swells when the moisture increased and shrinks when it decreased (Pakir et al., 2014).

1.3 Objectives

This study will focus on several objectives that will lead to new findings to resolve the problem of weak soil for construction purposes;

1. To determine the physical characteristic of marine clay.
2. To determine the optimum percentage of cement and lime admixture for marine clay improvement.
3. To describe the changes in the mineralogy of the marine clay before and after cement stabilization.

1.4 Scope of work

The main objective of this study is to examine the competency of the cement and lime admixture. Various percentages of lime admixture will be used on different soil samples. Those different percentages of lime admixture used in soil samples will measure the additives' ability to achieve soil stabilization. The improved soil will be examined by its shear strength, permeability, and compressibility.

1.5 Dissertation Outline

The structure of this dissertation is divided into the following five chapters:

Chapter 1: Description of the problem statement, the purpose of the study and the nature of the work.

Chapter 2: An overview of the literature on the effect of lime, cement and soil samples.

Chapter 3: Methodology

Chapter 4: An analysis of results obtained

Chapter 5: Conclusions and recommendation

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Foundation is one of the most crucial parts of construction planning. Flaws in the foundation of a building can cause serious troubles for occupants and the environment, such as fatality and building destruction. In terms of road construction, the subgrade is a foundation to any pavement works. A solid subgrade condition results in the excellent pavement.

Generally, this soil type has different issues due to its low strength, high compressibility, and a high degree of volumetric changes. Clay is the among soil types that engineers and soil experts are most concerned about. The clay easily reacts with the presence of water. Commonly, the moisture content of the soil is likely to rise if the soil itself has been in contact with rains, flooding, overflowing sewage pipes, or if the area is surrounded by construction systems or road pavements by minimizing surface evaporation where water cannot dry out.

In this chapter, a comprehensive review with an overview of the major factors used to stabilize problem soil is given. This additive will help in stabilizing soil to meet the needs of a good subgrade. The additive for this study will be lime. Those soil will be stabilized with different percentages of lime. To see how efficiently a soil changes from or moves, several tests on those stabilized soil need to be done for measuring their soil shear strength, permeability when reacting with water, and compressibility.

2.2 Marine Clay

Marine clay is a form of clay found in coastal locations all over the world. The colour of marine clay is grey. Marine clay can also be found on the ocean floor and the beach. Typically, marine clay contains a larger proportion of organic materials.

Clay particles will self-assemble into a variety of configurations, each with a different set of properties. Based on Myint et al. (2015) research that has done site investigation works, which identify the place of Singapore marine clay that taken from Changi, Singapore by borehole method. A geophysical seismic reflection survey was used to coordinate marine site investigation work. Boreholes were drilled in areas of dense marine clay as well as in other areas to assess the marine clay profile. Because of the project's large size and differences in the underlying soil profile, underwater boreholes were dug using offshore jack-up pontoons. The figure below represents the geological profile along Y 1000, which runs parallel to the runway's middle line (Arulrajah & Bo, 2008).

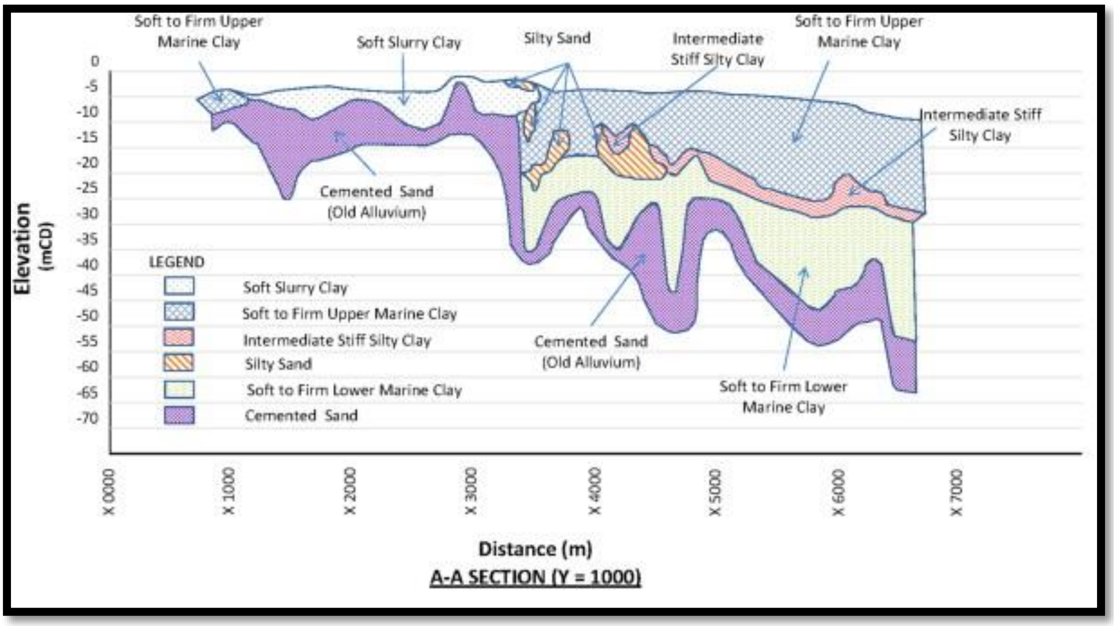

Figure 2.1: Clay profile of Changi (Aruljalah & Bo, 2008)

From the figure, we can find out that different place and depth gives a different clay characteristic.

In general, marine clay comprises clay, silt, and a lower proportion of microscopic particle size sand. S. Basack and R. D. Purkayastha (2009) laboratory test results showed that the grain size distribution on marine clay samples collected from India's east coast was 14% sand, 27 % silt, and 59 % clay by weight (Basack & Purkayastha, 2009). The grain size distribution graph is illustrated in the figure below.

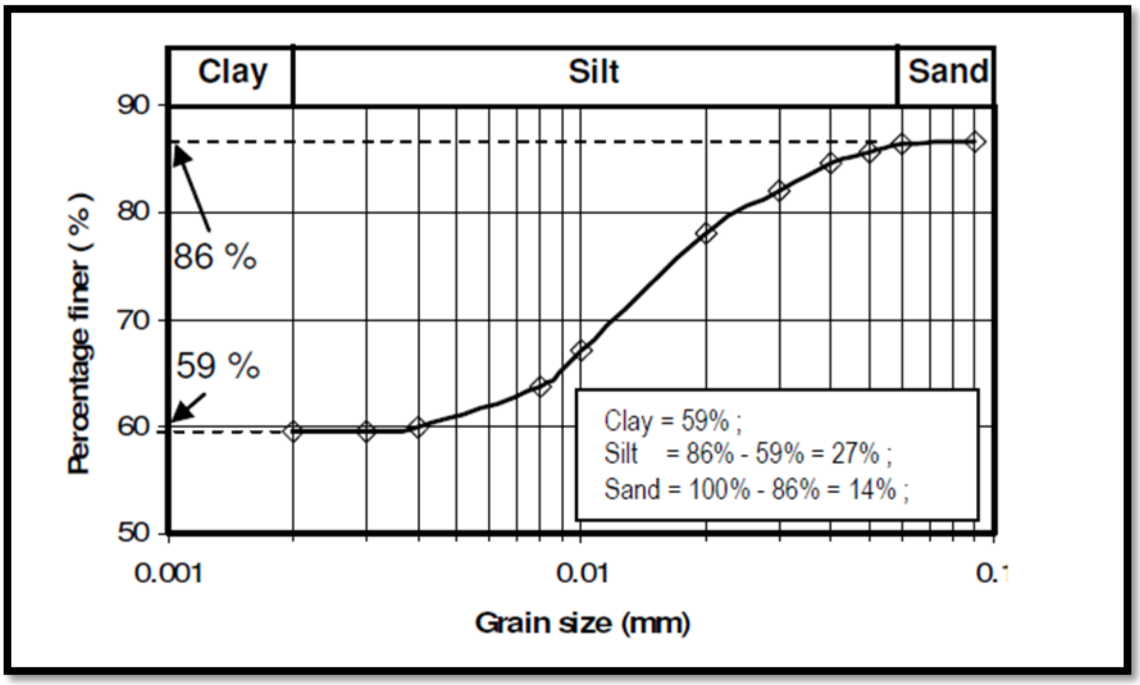

Figure 2.2: Grain size distribution (Aruljalah & Bo, 2008)

According to the graph, marine clay has a larger proportion of clay than silt and sand. Fine-grain particles also cause water absorption. Mechanical qualities like compatibility, stability compatibility, cracking, swelling, shrinkage, and mass are affected by soil moisture content (K. Terzaghi, 1943). The soil moisture content is also an essential parameter in water balancing testing, slope stabilization studies, and the performance evaluation of different geotechnical constructions such as pavements, foundations, earthen dams, and retaining walls (Susha Lekshmi et al., 2014).

A mineralogical study of Indian marine clays was undertaken. The samples obtained for testing suggest that these sediments of marine clay samples were deposited with high moisture content, ranging from 53% to 74%. This is due to the presence of high swelling clay minerals such as vermiculite, smectite, and chlorite, which have an expandable diffuse double layer, resulting in an increase in repulsive forces between constituent particles and a flocculated arrangement (Rajasekaran et al., 1998).

Yunus et al. (2015) from Universiti Teknologi Malaysia conduct a study in Malaysia to investigate the efficacy of marine clay when treated with lime. This test measures the strength and compressibility of the treated marine clay (Yunus et al., 2015). The marine clay was collected at Nusajaya, Gelang Patah, Johor, Malaysia. The presence of marine clay in Nusajaya's Iskandar Malaysia Region has necessitated complex solutions in the creation of structures and roadways. Alternatively, soil treatment is advised to enhance the strength of the inappropriate material to meet structural foundation requirements as well as building performance standards.

It was excavated from the seabed off the southern coast of Nusajaya, where a port project is being developed. The earth was thrown on the property's other side. It was a dark grey colour, and dredging had greatly disturbed it. It was then kept in oil tanks and transported to the laboratory. The findings of the index study and chemical composition on untreated marine clay collected in Nusajaya are shown in Tables 2.1 and 2.2.

Table 2.1: Physical properties of MArine Clay (Yunus et al., 2015)

Physical Properties of Marine Clay from Nusajaya, Johor, Malaysia	Values
Specific Gravity	2.62
Liquid Limit, LL (%)	58
Plastic Limit, PL (%)	36
Plasticity Index, PI	22
Maximum dry density (kg/m3)	1600
Optimum moisture content (%)	21

Table 2.2: Chemical composition of Nusajaya Marine clay (Yunus et al., 2015)

Chemical formula	Sio2	Al2O3	Fe2O3	K2O	SO3	TiO2	MgO	Cl	Na2O	ZrO2
Concentration (%)	36.8	13.3	2.61	2.4	1.47	0.66	0.35	0.32	0.26	0.20

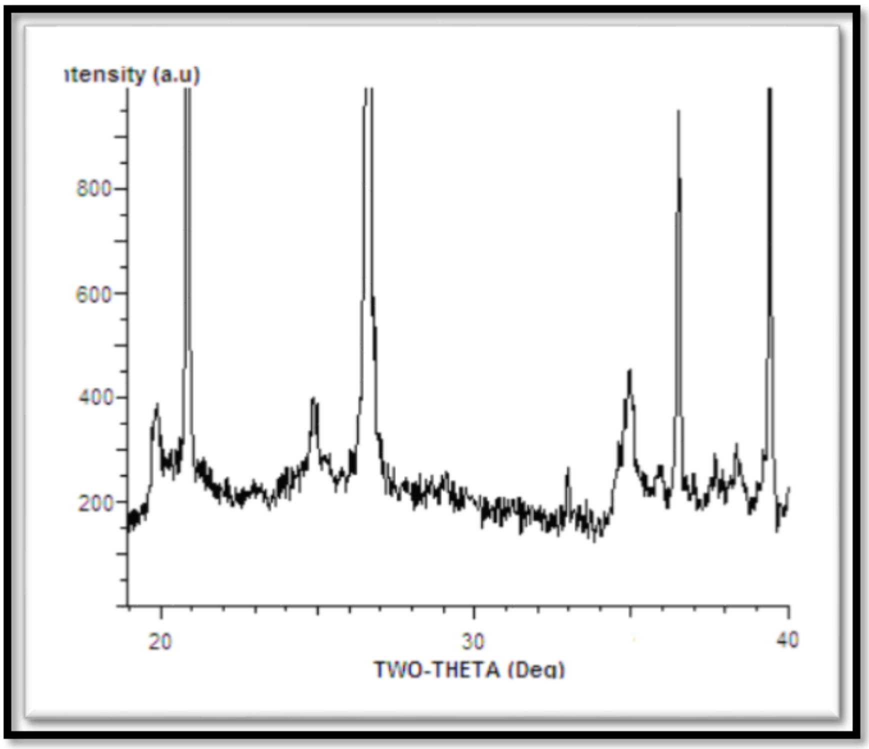

Figure 2.3: X-Ray Diffraction pattern of Marine Clay (Yunus et al., 2015)

The physical characteristics of untreated and treated lime stabilized marine clays were investigated in this thesis. Marine clay is categorized as MH, which stands for high silt, according to the plasticity table. Because the Marine Clay has a Plastic Index (PI) value greater than 10, it is perfect for lime stabilization. The Standard Proctor Compaction Test yielded mean dry density and optimum moisture content of 1.55 Mg/m^3 and 21.20 %, respectively, and a specific gravity of 2.62. The Unconfined Compression Test (UCT) demonstrated that intensity rise is less significant after 7 days. This is because of the modification stage. However, after 28 days of curing, the condition of the treated soils increases rapidly. This phenomenon might be related to the stabilization process. Overall, this research shows that when lime is given to soils, the interactions between lime and clay particles change the soil's characteristics, enhancing the compression and shear strength of the soil and making marine clay more stable.

2.3 Laterite Soil

Lateritic soils are essential soils that are found in tropical and subtropical climates (Tzu-Hsing Ko, 2009). Laterite soil is a red colour soil that is rich in iron and aluminium. Laterite is one of the most well-known and commonly used construction materials in the industry. Moreover, it is successfully used as a renewable construction material in various civil and building construction projects such as foundations, filling soil, and road construction projects for road layers.

In general, Jabatan Kerja Raya also emphasized that numerous standard specifications, such as Atterberg limits, plasticity index, gradation analysis, and compaction test, must be considered before accepting any soil filling. Table 2.3 shows the physical parameters of the laterite soil sample obtained from Universiti Teknologi Malaysia, while Figure 2.4 shows the particle size distribution (Marto et al., 2013).

Table 2.3: Physical properties of laterite soil (Marto et al., 2013)

Engineering and Physical Properties (Laterite)	Values
Specific Gravity	2.69
Liquid Limit, LL (%)	75
Plastic Limit, PL (%)	41
Plasticity Index, PI	34
BS Classification	MH
Maximum dry density (Mg/m3)	1.31
Optimum moisture content (%)	34

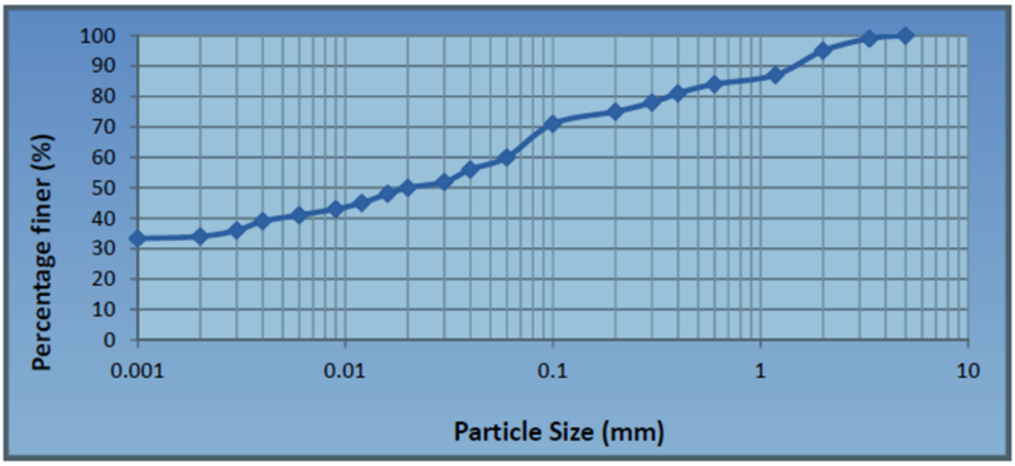

Figure 2.4: Grain size distribution graph (Marto et al., 2013)

According to table 2.3, laterite soils have a liquid limit of 75% and a plastic limit of 41%, respectively. It is critical to detect the soil sample value during construction applications of soil, such as liquid limits testing, because a high value in liquid limit testing typically indicates high compressibility and shrinkage or swelling potential. The plasticity index quantifies the range of water content in which the soil shows plastic qualities. According to the British Soil Classification, this sample is MH, which means that it contains fine silt and has high plasticity.

2.4 Stabilizing Agent

Soil stabilization is described as chemical or physical treatments that increase or improve a soil's stability for engineering purposes (Fátima Arroyo Torralvo et al., 2017). This stabilizing compound is commonly used for poor soil or any need for augmentation for long-term use.

Mechanical stabilization and chemical stabilization are the two primary kinds of soil stability. Mechanical stabilization is modifying the grading of soil by mixing it with soils of varying degrees. This enables the creation of a compacted soil mass. Chemical stabilization, on the other hand, refers to the modification of soil characteristics by the addition of chemically active substances. Understanding the material qualities of the mixture as well as the results after mixing is critical in soil stabilization. Furthermore, it is critical to understand how the material will function following stabilization (Anjan Patel, 2019).

Cement, lime, fly ash, and blast furnace slags are common stabilizing agents that have been used in many projects. This occurs due to the effectiveness of the previous project and already know the results and the characteristic features of the stabilizing agent.

2.5 Cement

A cement is a binding agent, which is a substance used in building to bind things together due to the cement abilities that harden and stick to other materials when mixed together. This cement is one of the major stabilizing agents used in construction.

One of the situations that demanded the use of stabilizing chemicals was to improve soil strength and repair weak soil. The most significant role of cement reactivity is its interaction with water, which may be found in every soil. This is one of the reasons why cement is so commonly used in construction. Ordinary Portland cement is a readily available and inexpensive substance.

When cement reacts with dirt, it produces a cementitious reaction. A small proportion of cement is often applied, but it is enough to improve soil engineering qualities and clay cation exchange. Cement-stabilized soils have enhanced qualities such as decreased cohesion (Plasticity), decreased volume expansion or compressibility, and increased strength (Makusa, 2012).

2.6 Lime

Lime is a calcium-containing inorganic mineral that is predominantly made of oxides and hydroxide, most often calcium oxide or calcium hydroxide. The name lime comes from its early usage as construction mortar and means "sticking" or "adhering." The rocks and minerals that these products are formed from, often limestone or chalk, are predominantly calcium carbonate. They can be sliced, crushed, or pulverized, and their chemical properties can be adjusted.

In most cases, the effect of lime on clay soil plasticity is instantaneous, with the calcium ions from the lime cause a decrease in plasticity and the soils becoming more friable and readily handled. Clay particles flocculate to form aggregates (Raheem et al., 2010). When lime dissolves in water, the calcium ions (Ca2+) and hydroxyls (OH) separate, releasing divalent calcium ions for interaction with cations in the clay particles' distributed double layer. The pore water's cation exchange and higher ionic concentration cause a contraction of the diffuse double layer, flocculation, particle agglomeration, and a practically immediate drop in plasticity index (PI) and better workability (Amadi & Okeiyi, 2017).

Another outcome of lime dissolution is an elevation in the pH of the soil–water–lime combination caused by an increase in hydroxyl ion concentration. The silica and alumina associated with clay particles become soluble when the pH rises. Thus, the lime generates calcium and an appropriate chemical environment, while the soil offers the silica and alumina ions required to make cementitious compounds such as calcium-alumina silicates. These clay silicates and clay aluminates link to or gel with the clay particles, further improving the soil. This reaction is time-dependent in the sense that the faster the clay combines with the lime and the stronger the reaction, the more a specimen can cure (Amadi & Okeiyi, 2017).

2.7 Moisture Content

In soil, moisture contents play an important role in determining the workability and performance of soil. For example, the clay swells when exposed to high moisture levels, whereas it shrinks and hardens when exposed to low moisture levels. This is because the pores between clay particles lose moisture, causing soil particles to pack together. According to Mendes & Toll (2016) study on the influence of initial water content on the mechanical behaviour of unsaturated sandy clay soil, soil samples that had been dried down to a certain water content had higher strength than samples that had been compacted at that water content; samples that had been wetted to achieve that water content had a lower strength (Mendes & Toll, 2016).

2.8 Microstructural changes when soil treated with stabilizing agents

The microstructure of a material is the extremely small scale structure that may be identified when the substance is exposed by a higher magnification optical microscope. Nowadays, various methods are available to researchers to assess changes in microstructure, one of which is the X-ray approach, such as X-ray fluorescence (XRF), X-ray Diffraction (XRD), or scanning electron microscope (SEM).

Yoobanpot et al. (2017) conducted research in which they compared the usage of cement kiln dust to increase the unconfined compressive strength of soft Bangkok clay to standard Portland cement (OPC). The fundamental purpose of the research is to evaluate the strength of stabilized clay utilizing cementitious materials as stabilizers, such as regular Portland cement and cement kiln dust. Each reaction product was investigated using X-ray diffraction (XRD), and changes in the microstructures of the stabilized clay were seen using a scanning electron microscope. Bangkok is built on a soft layer of marine clay ground, often known as "soft Bangkok clay," and is located on the Chao-Phraya delta river plain. Clay enhancement procedures can improve soft clay's unfavourable properties, such as poor shear strength and high compressibility, for building applications (Yoobanpot et al., 2017).

The deep mixing approach uses an in-situ mechanism for combining soft clay and stabilizer to generate a clay mixing column that transmits the weight to the deep hardened clay layer. The most often used stabilizer for deep mixing is ordinary Portland cement (OPC), which is well recognized for its improved clay strength. When cement and water are mixed with clay, primary and secondary hydration reaction products are generated, impacting the enhanced clay cement qualities. The major products are calcium silicates hydrates (CSH), calcium aluminates hydrates (CAH), and lime. After curing, the secondary products of the pozzolanic interaction between lime and clay minerals, clay silica and clay alumina, were continually created as CSH and CAH. As a result of both reaction materials, the clay grew denser, heavier, and harder, resulting in an increase in treated clay strength after curing.

The chemical composition of the clay was determined using an X-Ray Fluorescence (XRF) examination, which revealed the major components of the clay to be SiO2, Al2O3, and Fe2O3. A SEM image of typical Portland cement (OPC) particles in figure 2.5 revealed that they have a rough surface, sharp edges, and are not consistently produced. The compositions of cement kiln dust are mostly CaO and SiO2, with Al2O3 and Fe2O3 that are identical to those found in ordinary Portland cement. The CaO and SiO2 concentrations of CKD are lower than those of Portland cement.

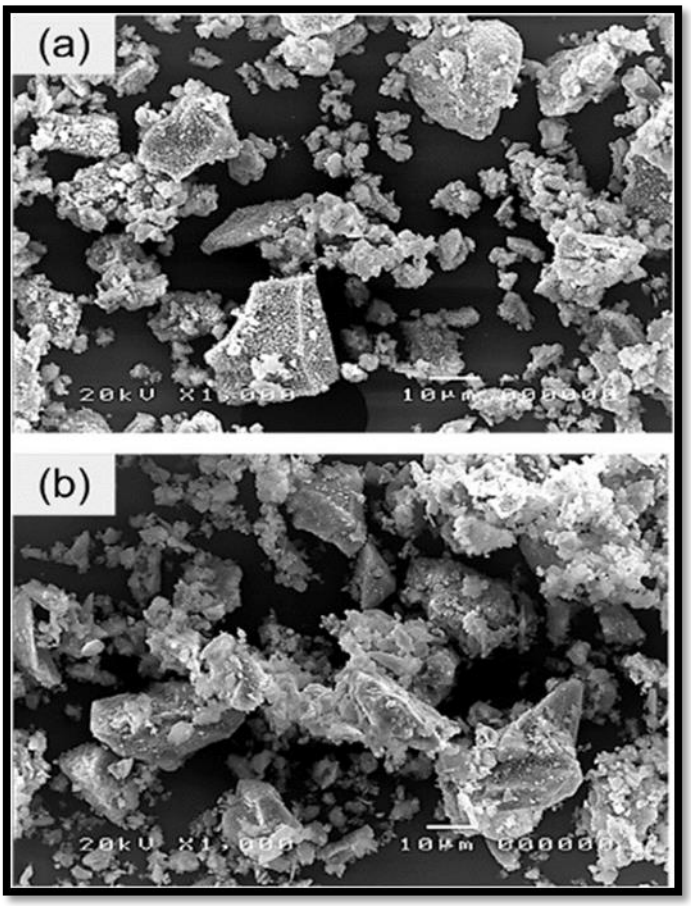

Figure 2.5: Scanning electron microscope of (a) OPC and (b) CKD

The base clay was blended with ordinary Portland cement and cement kiln dust stabilizer to enhance the unconfined compressive strength of the soft Bangkok clay. One clay sample was combined with 10% standard Portland cement, while another clay sample was combined with 10% cement kiln dust. According to the findings, the unconfined compressive strength of C10 was 317 kPa after three days and swiftly climbed to 508 kPa and 837 kPa after seven and twenty-eight days, respectively. The unconfined compressive strength progressively rose to 915 kPa after 90 days. The intensity characteristics of C10 were discovered to rapidly grow in the short term (3 days and 7 days), to consistently grow at 28 days, and to barely rise in the long term (90 days). The UCSs for K10 on curing days 3, 7, 28, and 90 were 265, 398, 675, and 706 kPa, respectively. The UCS developments for the K10 and C10 were identical. K10, on the other hand, has significantly lower unconfined compressive strengths than C10.

Figure 2.6(a) shows the XRD analysis of treated clay, C10 at 3, 7, 28, and 90 days for treated clay relative to basal clay. After three days, new reflections of calcium silicate hydrate (CSH), calcium hydroxide (CH,), and ettringite phases may be detected in stabilized clay. Furthermore, the remaining un-hydrated reactant generated tricalcium silicate (C3S) and dicalcium silicate (C2S). The reflection of the CSH level grew significantly at 3 and 7 days, gradually at 28 days, and slowly at 90 days, according to the X-ray diffraction trend, which is compatible with the UCS growth curve. The number of new ettringite reflections formed at 3, 7, 28, and 90 days grew with time, similar to how CSH grew.

Figure 2.6(b) shows the X-ray diffraction pattern of the K10 sample. The CSH and CH products produced were found to be similar to those found in the C10 investigation, but no ettringite was identified. With curing time, the growth of CSH strength for K10 tends to grow. The CSH rate progressively rises during the brief healing phase of 3 to 7 days, with a steady rise at 28 days, and only gradually rises in the long run, i.e., 90 days. The montmorillonite reflectivity, like C10, diminished with increasing time. CSH may be formed when montmorillonite combines with cement kiln dust.

Furthermore, the lack of ettringite crystals resulted in lower strength than cement. The cement kiln dust just combination, on the other hand, was revealed to have the same reaction products as the typical Portland cement mixture, which might lead to an increase in strength in the stabilized clay. Therefore, cement kiln dust has been proposed as a cementitious material for soft clay improvement.

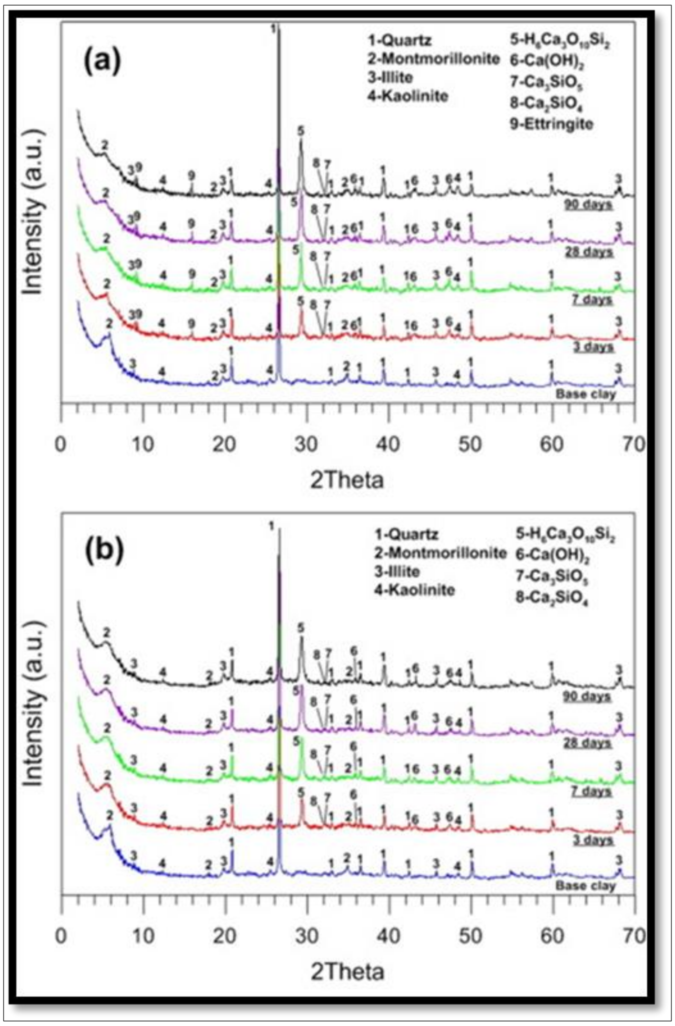

Figure 2.6: The X-Ray Diffraction pattern of soil sample with (a) OPC and (b) CKD

SEM is a scanning electron microscope used to investigate the microstructure of clay after it has been modified with cementitious ingredients. The methodology was utilized to examine changes in the microstructure of the stabilized clay after the unconfined compressive strength test. The finding of C10 in Figure 2.7(a) demonstrates that the primary hydration reaction products of OPC stabilized clay are CSH and ettringite, which was corroborated by the X-ray diffraction study and was coated on the clay surface in the early phases of 3 and 7 days. CSH fabrics were spread on clay particles and filled the pore space between the clay particles, resulting in a denser clay structure. According to Bahmani et al. (2016), the hydration products affecting clay denser and stiffer after the cement was added to soft clay.

Figure 2.7(b) displays changes in the microstructure of cement kiln dust stabilized clay. X-ray diffraction study revealed CSH to be the primary hydration reaction agent. At the beginning stages of 3 days and 7 days, CSH fabric was formed cover with a clay surface and confined in pore space of clay particle, resulting in clay denser. The needle-like ettringite, on the other hand, was not apparent in the SEM micrograph and was not recognized in the X-ray diffraction investigation. Clay bonding was affected by the constant creation of CSH throughout time, resulting in enhanced clay strength at 28 days. CSH growth was heterogeneous and spread across the clay surface for 90 days, resulting in increasing intensity with curing time.

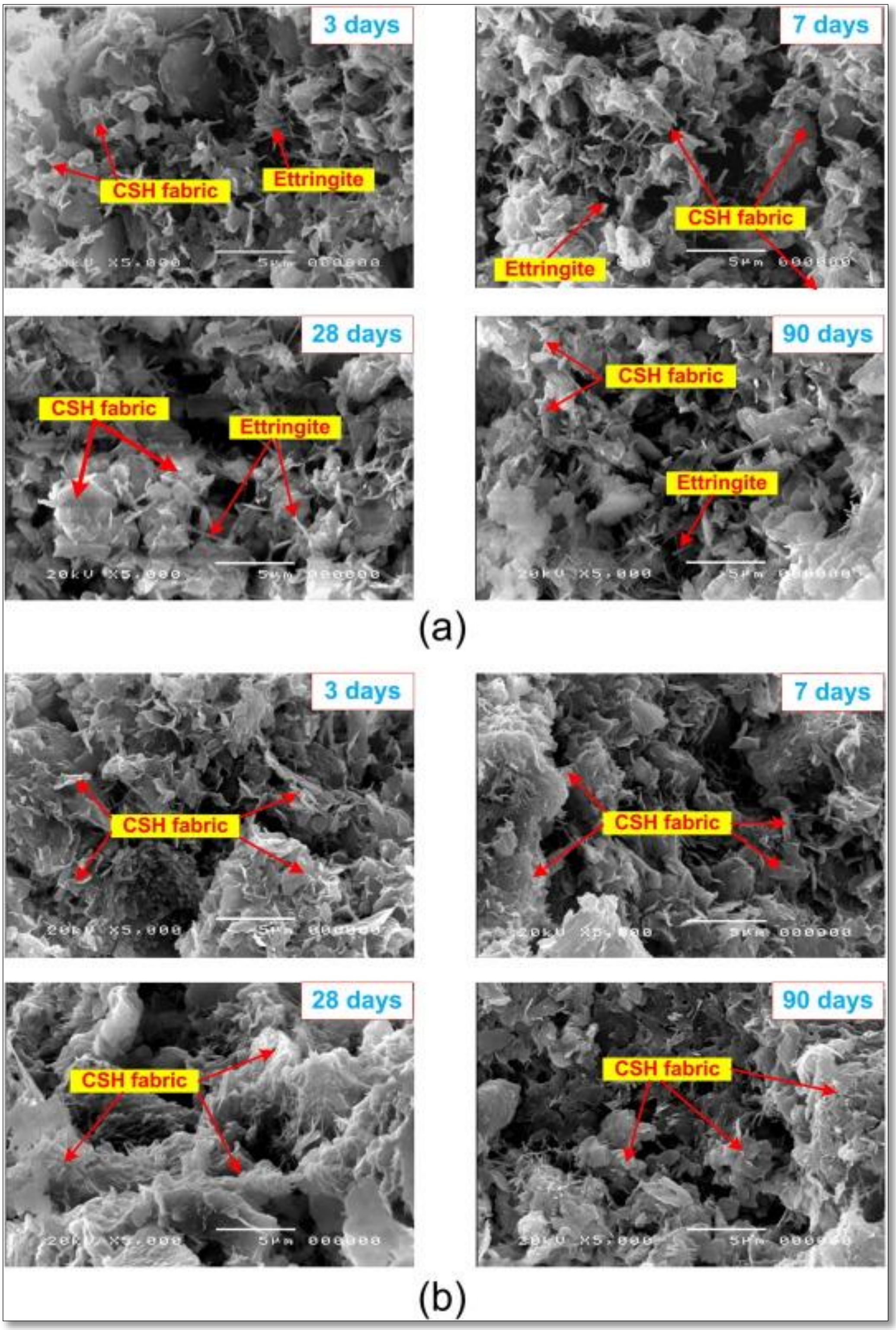

Figure 2.7: SEM of soil sample with (a) OPC and (b) CKD

The microstructure difference between cement kiln dust and OPC stabilized clay was studied. While the addition of cement kiln dust enhanced clay consistency, this was