# SHEAR STRENGTH BEHAVIOUR AND CRITICAL SHEAR STRESS FOR NESOSILICATES SUBJECTED TO WILDFIRE

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Thesis submitted in fulfillment of the requirements
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# ABSTRAK

Kebakaran boleh mengurangkan kapasiti penyusupan air, menyebabkan tanah tidak menyerap air dan meningkatkan aliran dan hakisan. Kajian ini mengkaji kesan suhu di bawah keadaan semula jadi dan makmal sampel tanah diambil dari lereng bukit di Jalan Gambang. Sampel tanah yang tidak terbakar dan dibakar diperolehi daripada lapangan. Manakala, sampel tanah di bawah keadaan makmal telah dibakar pada tiga suhu iaitu 440˚C, 800˚C dan 1350˚C. Pelbagai ciri tanah telah dikaji, termasuk graviti tentu, had Atterberg, indeks pengembangan dan kandungan bahan organik. Lengkung ciri tanah-air semua sampel tanah juga ditentukan. Lengkung ciri tanah-air telah ditubuhkan menggunakan teknik titik embun sejuk cermin dan teknik osmotik. Kekuatan ricih tanah ditentukan melalui ujian ujian ricih ram dan ujian ricih terus. Keputusan eksperimen menunjukkan bahawa suhu di 440°C, had cecair, kandungan bahan organik dan SWCC dikurangkan dan indeks pengembangan telah dihapuskan. Pemanasan tanah pada 800 dan 1350°C benar-benar dihapuskan had cecair, had plastik, index pengembangan dan kandungan organik tanah yang diuji. Sedutan tanah menurun dengan peningkatan suhu. Dari keseluruhan eksperimen, tanah yang dibakar semula jadi diramalkan telah mengalami kebakaran pada suhu antara 440°C. Keputusan ujian dari ujian ricih ram menunjukkan suhu yang tidak terbakar semulajadi, terbakar semulajadi dan dibakar pada suhu 440˚C menunjukkan hasil yang kekuatan ricih berkurang dengan peningkatan kandungan air. Hasil ujian dari ujian ricih terus menunjukkan kejeleketan berkurang dengan peningkatan kandungan air. Suhu terbakat pada 440°C menunjukkan hasil kenaikan kejeleketan berbanding dibakar 800°C dan 1350°C. Walau bagaimanapun, hasilnya mempengaruhi kandungan air akibat sudut geseran menunjukkan ketidakstabilan pada hasil ujian, hal ini kemungkinan disebabkan oleh peratusan tinggi pecahan pasir dalam spesimen, yang menyebabkan nilai-nilai yang lebih rendah di kejeleketan, maka nilai rendah pada kekuatan ricih.

# ABSTRACT

Fires can reduce soil infiltration capacity, induce soil water repellency and increase runoff and erosion. This study examines the effect of temperature under natural and laboratory condition of soil samples collected from hillside at Jalan Gambang. The unburned and burned soil sample were obtained from site. In addition, the soil samples under laboratory condition were burned at three temperatures, i.e. 440˚C, 800˚C and 1350°C. Various soil properties were studied, including specific gravity, Atterberg limits, swell index and organic matter content. The soil-water characteristic curve (SWCC) of all soil samples were also determined. The SWCC were established using chilled-mirror dew point technique and osmotic technique. The shear strength of soil were determined using vane shear test and direct shear test. Experimental results demonstrated that temperature at 440°C, the liquid limit, organic matter content and SWCC were reduced and the swell index was eliminated. Heating the soil at 800°C and 1350°C completely eliminated the liquid limit, plastic limit, swell potential and organic content of soil tested. The soil suction decrease with increasing temperature. From overall experimental results, the natural burned soil was predicted had experienced a fire at temperature between at 440°C. Results of vane shear test for natural unburned, natural burned and burned temperature at 440˚C shows the result which are shear strength decreases with increasing water content. The result of direct shear test shows cohesion diminished with increasing water content. Burned 440 shows the results of cohesion increase compare to burned 800˚C and 1350˚C. However, the result influence water content due to angle of friction indicate instability might be attributed to high percentage of sand fraction in the specimen, which causes lower values of cohesion, hence lower values of shear strength.

**TABLE OF CONTENT**

# LIST OF TABLES

## LIST OF FIGURES

# LIST OF SYMBOLS

| | |
|---|---|
| Ca | Calcium |
| Fs | Free Swell |
| Gs | Specific Gravity |
| K | Potassium |
| $M_A$ | Mass of Crucible and Soil Sample after Ignition |
| $M_C$ | Mass of Crucible |
| Mg | MagnesiumVolume of Dry Soil |
| Ms | Mass of Crucible and Oven Dried Soil Sample Sodium |
| Na | Sodium |
| $V_0$ | Volume of Dry Soil |
| $V_1$ | Soil Volume after Swelling |
| PEG | Polyethlene Glycol |
| $\tau$ | Nominal Shear Stress |
| F | Shearing Force |
| A | Initial Cross Sectional Area of the Specimen |
| $\sigma$ | Normal Shear Stress |
| N | Normal Vertical Force acting on the Specimen |
| $\tau c$ | Critical Shear Stress |

## LIST OF ABBREVIATIONS

| | |
|---|---|
| ASTM | American Society for Testing Material |
| BS | British Standard |
| FS | Free Swell |
| SWCC | Soil Water characteristics Curve |
| SWRC | Soil Water Retention Curve |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

The global average shows the temperature is increase 0.6˚C in the past three decades and also increased to 0.8˚C in the past century because of human activities (Hansen et al., 2006). Global temperatures have increased by 0.2˚C per decade over the last three decades, possibly leading to an acceleration of the global water cycle with more intense rainfall events, more severe and widespread droughts and regional humidity variations. Regional droughts are also tightly coupled to sea surface temperature variations, and regional water availability variations can explain a significant proportion of the variations in burned area (Williamson et al., 2015). The characteristics of droughts and heat waves will also be altered as anthropogenic warming continues (Tangang et al., 2012). Wildfires can increase runoff and erosion by several orders of magnitude (Diaz-Fierros et al., 1987). Climate, vegetation, and topography of the burnt area control the resilience of the soil system and some fire-induced changes can even be permanent (Certini, 2005). Low to moderate severity fires, such as most of those prescribed in forest management, promote renovation of the dominant vegetation through elimination of undesired species and transient increase of pH and available nutrients. No irreversible ecosystem change occurs, but the enhancement of hydrophobicity can render the soil less able to soak up water and more prone to erosion. Severe fires, such as wildfires, generally have several negative effects on soil (Certini, 2005). They Regional droughts are also stiff to sea surface temperature variations and regional water availability variations can explain an important the proportion of the variations in burned area (Girardin & Wotton, 2009). Climatic changes are involved in global fire variations and also are expected to increase fire season severity over the coming decades (Flannigan et al, 2013). In burned areas, it is very difficult to determine the effect of soil water repellency on surface erosion rates because high severity fires also remove protective layer and expose the mineral soil to rain splash. The removal of the litter layer also reduces the surface roughness and increases the velocity of overland flow, which will further increase the surface erosion rates. In steeper terrain that burned at high severity, the wet table surface soil layer can become saturated, and the increased pore pressures will decrease the shear strength and lead to the downslope movement of soil by mass failure (Debano, 2000). The soil-water characteristics curve (SWCC) can be used to estimate the different of parameter which is used to analyse soil behaviour. In this study, the suction- water content soil water characteristics curve and shear strength of soil were established.

## 1.2 Problem of Statement

Wildfires may produce several changes in the short and long term in the landscape and in the soil system. The magnitude of these changes induced by fire in the components of ecosystems such as water, soil and vegetation are depends on fire properties and environmental factors. The most important impacts on soils in the short term are the reduction of shear strength and vegetation cover which are increases soil erosion. Changes in soil properties affect the SWCC which is important in process-based hydrologic. In this research, the changes in soil properties between burned and unburned soil were investigated. Besides, the differences in SWCC and changes in shear strength of burned and unburned soil were established.

## 1.3 Research Objective

The objective of this study were as follow

I. To determine the properties of soil of unburned and burned soil.

II. To establish the soil water characteristics curve for burned and unburned soil.

III. To determine the shear strength of burned and unburned soil at varying water content.

## 1.4 Scope of Study

In this study, the soil sample obtained from hillside at Jalan Gambang, Kuantan was considered. Sampling of soil samples were obtained at a site affected by wildfire. Burned and unburned soil sampling was obtained from natural slope at Jalan Gambang in Kuantan. Several test were conducted to investigate the properties of unburned and burned soil. In this research, the soil water characteristics curve for burned and unburned soil were determined and the technique were used which are chilled-mirror dew point technique and osmotic technique. In this study shear strength of burned and unburned soil also are determined at varying water content by vane shear test and direct shear test.

## 1.5 Significant of Study

Significance of this study is to understand behaviour and analyse the property of shear strength which is provide soil stability be related the shear failures such as bearing capacity and lateral pressure on earth's retaining structure. The shear strength is most important property to the soil. Shear strength is a term that used in soil mechanics to determine magnitude of the shear stress that a soil can be permanently. Mostly, the shear strength of a soil mass is essentially made up of due to the interlocking of the grains the structural resistance of the movement of the soil is very essential. An other important component is the frictional resistance between the individual soil grains at their contact point on sliding. In this study, the properties of soil were conducted for the first step and follow by determine the soil water characteristics curve. Then, the shear strength also were conducted by vane shear test and direct shear test. Hopefully, the result in this study can be used for future engineer as their guideline.

## 1.6 Thesis Outline

The thesis is divided into five consecutive chapters.

Chapter 2 explains the climate change were effect of fire on properties of soil and soil shear strength. It also presented the previous researches on the effect of fire on properties and its effect on soil-water characteristics curve at different water content.

Chapter 3 explains the research methodology of test were conducted in this research. The test were determined the properties of burned and unburned soil, establishment of soil water characteristics curve and determined the shear strength of burned and unburned soil at varying water content. In this research, every test has a detailed explanations of methodology.

Chapter 4 present the result for every test conducted. Lastly, graph of suction water content soil-water characteristics curve and shear strength were presented in this study.

Chapter 5 explains the conclusion based changes on physical properties of burned and unburned soil. The graph of drying suction water content soil water characteristics for each sample was compared. Also, the conclusion of effect fire on shear strength of burned and unburned soil were analysed.

CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

In this chapter, the previous study of burned soil were discussed. The soil suction, soil suction measurement technique and soil suction controlling were determined. In this study, shear strength measurement by vane shear test and direct shear test were presented. Critical shear stress measurement also discussed.

## 2.2 Climate Change

Climate change is the larger, more complex and more uncertain than any other environmental problem. The sources of greenhouse gas emission are more diffuse than any other environmental problem. The causes and consequences of climate change are very diverse, and those in low- income countries who contribute least to climate change are most vulnerable to its effects. Climate change is also a long-term problem. Some greenhouse gases have an atmospheric life-time measured in tens of thousands of years. The quantities of emissions involved are enormous. In 2000, carbon dioxide emissions itself which are 24 billion metric tons of carbon dioxide (Richard Tol, 2009). Climate change that happens due to natural phenomenon is a consequence of a change in the sun's energy or Earth's orbital cycle (Crowley et al., 2000). Climate change also occurs by increasing amount of carbon dioxide released into the atmosphere due to human activities such as burning of fossil fuels, conversion of natural prairie to farmland and deforestation. Carbon dioxide emission from fossil-fuel burning and industrial processes accelerating around the globe from 1.1% per year for 1990-1999 to 3.3% for 2000-2004 (Raupach et al., 2007). In the past three decades, globe temperature has increased 0.6°C but in the past century, it has increased to 0.8°C (Hansen et al., 2006). Most computer climate models predict that the globe will warm up by 1.5°C to 4.5°C if the carbon dioxide concentration reaches the predicted level of 600 parts per million by the year 2050 (Solomon et al., 2009). Climate change is any long-term significant change in the “average weather” that a given region experiences. Average weather may include average temperature, precipitation and wind patterns. It involves changes in the variability or average state of the atmosphere over durations ranging from decades to millions of years. These changes can be caused by dynamic process on Earth, external forces including variations in sunlight intensity, and more recently by human activities. In detailed, Climate Change means annual temperature of the Earth has swung up and down by several degrees Celsius over the past million years. Temperature records in the past 30 to 50 years have shown warming trends in most places including Malaysia. However, mild climate related disasters are quite frequent to happen lately. These refer to the occurrence of floods and droughts that caused significant socio-economic impacts to the nation while the occurrence of landslides due to excessive rainfall and strong winds happened at the hilly and the latter, at the coastal areas caused minimal damage ( Abdul Rahman, 2009).

### 2.3 Forest Fire

As the global temperature increase with no increasing in rainfall amount will lead to a much drier forest and make fire ignition occur easier (Wotton & Flannigan, 1993). The relationship between meteorological conditions and fire occurrence is well established. Forest fires tend to be more severe when temperature is high and air humidity and fuel moisture are low (Pinol et al., 1998). Fires have an impact on millions of hectares of rainforest, increase deforestation rates by as up to 50% in some regions and cause billions of dollars in damages in the tropics.

Forest fire can be characterized in terms of the cause of ignition, their physical properties, the combustible material present, and the effect of weather on the fire. Global warming may increase the intensity and frequency of droughts in many areas, creating more intense and frequent wildfires. (Flannigan, 2005). Bachmann and Allgower (2000) noted that cause and sustain fire requires fuel, heat and oxygen, also fire behavior is affected by fuel, weather, and topography. In either case, fuel is only one of three components required to predict or characterize fire (Colin Hardy, 2005).

Fire is classified into three criteria according to its severity. The fire is classified as low severity burn if less than two percent of the area is severely burned. The area is classified as moderate severity burned if less than ten percent of the area is severely burned while it is classified as high severity burned if the severely burned area is more than ten percent. Many physical, chemical, mineralogical and biological soil properties can be affected by forest fire (Solera et al., 2011). The energy generated during the ignition and combustion of fuels provides the driving force that is responsible for the changes that occur in the physical, chemical, and biological properties of soils during a fire. The magnitude of change occurring during a fire depends largely upon the level of fire severity, combustion and heat transfer, magnitude and depth of soil heating, proximity of the soil property to the soil surface, and the threshold temperatures at which the different soil properties change (Beyers et al., 2008).

### 2.3.1 Effect of Forest Fire on Properties of Soil

Many physical, chemical, mineralogical and biological soil properties can be affected by forest fire (Solera et al., 2011). Most post-fire stabilization and short-term rehabilitation treatments are used to mitigate the post-fire effects on physical ecosystem components, such as soil, water, and hydrologic processes (Robichaud et al., 2000). Burn severity is a qualitative classification of fire effects on the physical, biological, and ecological characteristics of the burned area, and is generally designated in discrete categories of unburned, low, moderate, and high (Lutes et al., 2006). Scientist predicted the degree or magnitude of nearly all secondary fire effects is directly related to burn severity (Moody et al., 2005).

Climate, vegetation, and topography of the burnt area control the resilience of the soil system, some fire-induced changes can even be permanent. Low to moderate severity fires, such as most of those prescribed in forest management, promote renovation of the dominant vegetation through elimination of undesired species and transient increase of pH and available nutrients. No irreversible ecosystem change occurs, but the enhancement of hydrophobicity can render the soil less able to soak up water and more exposed to erosion. Generally, forest fire have several negative effects on soil. Forest fire cause significant removal of organic matter, deterioration of both structure and porosity, loss of nutrients through volatilisation, leaching and erosion. However, if plants succeed in promptly recolonizing the burnt area, the pre-fire level of most properties can be enhanced (Certini, 2005). Soil properties can experience short-term, long-term, or permanent fire-induced changes, depending chiefly on type of property, severity and frequency of fires, and post-fire climatic conditions (Abdul Rahman, 2009).

Soil fertility can increase after low intensity fires since fire chemically converts nutrients bound in dead plant tissues and the soil surface to more available forms or the fire indirectly increases mineralization rates through its impacts on soil microorganisms (Schoch & Binkley, 1986). Hough (1981) predicted that the concentration of potassium, calcium, and magnesium ions in the soil can increase or be unaffected by fires whereas nitrogen and sulphur often decrease. Although the relationship between fire and soil nutrients is complex because of the interactions among many factors, fire intensity is usually the most critical factor affecting post-fire nutrient dynamics, with greater nutrient losses occurring with higher fire intensity. Fire temperature directly determines the amounts and kinds of nutrients that will be volatilized. For instance, nitrogen begins volatilizing out of organic matter at only 200ºC, whereas calcium must be heated to 1240ºC for vaporization to occur (Neary et al., 1999). High intensity fires can also change the physical characteristics of the soil making it more susceptible to nutrient loss through erosion (Mccoll & Grigal, 1977).

### 2.3.2 Effect of Forest Fire on Soil Shear Strength

Shear strength is a term used in soil mechanics to describe the magnitude of the shear stress that a soil can sustain. The shear resistance of soil is a result of friction and interlocking of particles, and possibly cementation or bonding at particle contacts. Due to interlocking, particulate material may expand or contract in volume as it is subject to shear strains (Kennedy Chibuzor, 2013).

In some environments and soil types rill networks may not develop, and this can be due to several reasons. First, the shear stress exerted by flowing water is several orders of magnitude lower than the force exerted by rainsplash (Hudson, 1995). Once concentrated flow develops, the depth of water may protect the soil surface from rainsplash and erosion rates may be higher in the interrill areas. In other cases rill networks may not develop on water repellent burnt soils due to the interception of overland flow by cracks, burnt-out root holes, and burrows from insects and animals (Booker et al., 1993).

The water infiltrates into the wettable surface until it encounters a water repellent layer (Wells, 1981). As rainfall continues, water fills all available pore space until the wet table soil layer becomes saturated. Because pores cannot drain, pore pressures build up immediately above a water repellent layer. This increased pore pressure reduces intergranular stress among soil particles, and as a result, decreases shear strength in the soil mass and produces a failure zone at the boundary between the wet table and water repellent layers where pore pressures are greatest. Pore pressure continues to increase and shear strength decreases until it is exceeded by the shear stress of gravity acting on the soil mass. When this happens, a failure occurs and a portion of the wet table soil begins to slide downslope. If the soil is coarse textured, initial failure causes a re-orientation of the soil particles in the failure zone and causes them to momentarily lose contact with each other. The loss of intergranular contact further reduces shear strength and extends the failure zone downslope. When most of the soil grains lose contact, a condition develops in which the shearing soil is almost fluid (Debano, 2000).

## 2.4 Nesosilicates

Nesosilicates are silica-alumina oxide having the chemical formula of Al2SiO5 (Anthony et al., 1997). Nesosilicates may exist in three different phases depending upon surrounding temperature and pressure (Bohlen et al., 1991) with mullite as the most stable form (Bradt, 2008). Thus, in the event of wildfire, the changes in the mineral structure of nesosilicates are expected to occur given that wildfire could have a temperature exceeding 400°C. It is anticipated that, these changes would resulted in increased soil erosion problems during heavy rainfall.

## 2.5 Soil Suction

The theoretical concept of soil suction was developed in soil physics regarding the soil water-plant system in the early 1900’s (Buckingham et al., 1907). In soil physics, soil suction is commonly referred to as the free energy state of soil water (Edlefsen & Anderson, 1943). It can be measured in terms of the partial vapour pressure of the soil water (Richards, 1965) and represents the thermodynamic potential pore water relative to free water, where the free water is defined as water with no dissolved solutes. The use of soil suction in explaining the mechanical behavior of unsaturated soils in relation to engineering problems was introduced by Croney & Coleman (1948).

The suction required to remove water from soil above the water table, largely made up of the matric potential, by which water is held in soil pores by capillary action, and the much smaller solute potential, which is the osmotic effect of dissolved salts. Richard (1974) defined soil suction is water potential in soil-water system. Three components of suction that list by Richard (1974) in unsaturated soils is capillarity, adsorption of water on the surface of the clay minerals and osmotic phenomena.

The an understanding of the flow behaviour through unsaturated soils is required for numerous applications in geotechnical and geo-environmental areas. The shear strength of a soil is required for the prediction of the stability of slopes, the bearing capacity of foundation and pressure against earth retaining structures (Fredlund, 1995). Thakur et al (2005) conducted studies on the parameters affecting soil-water characteristics curves of fine grained soils. The results were used to develop soil-water characteristic curves, for these soils and for checking the efficiency of different fitting functions, in high suction ranges. Efforts have also been made to demonstrate the influence of the soil type and dry unit weight on the soil suction. The study brings out the observation that dry unit weight has negligible influence on the soil suction and parameters effecting SWCC.

Soil suction can be defined as the force with which water is held in the pores between the soil particles. It is one of the fundamental properties in explaining the mechanical behaviour of the unsaturated soils. The soil suction is mainly influenced by the pore size and the water content of the soil. The soil suction theory was mainly developed in relation to the soil water-plant system (Fredlund et al., 2012). The coeffiecient of permeability decrease with an increase in soil suction. The shear strength increase with increase in soil suction. The shear strength of a soil is also required for the prediction of the stability of slopes, the bearing capacity of foundation and pressure against earth retaining structure (fredlund et al., 1995).

The moisture diffusivity measurements in unsaturated soils strongly depend on reliable suction measurement techniques. There are many ways to determine the soil suction (Hupan et al., 2010). The soil suction has two components, namely matric suction and osmotic suction. There are different measurement devices available to determine the matric suction component of the soil and total suction of the soil independently (Fredlund & Rahardjo, 1993).

### 2.5.1 Soil Suction Measurement

The measurement of matric suction in the field is a challenging task due to a variety of limitations, laborious procedures, and the cost of currently available methods (Fredlund, 2004). Matric suction measurements are also useful in assessing the strength of an unsaturated soil for slope stability conditions (Fredlund & Rahardjo, 1993). There are different method to measure soil suction. There are different method which use another medium to determine soil suction and direct method. Direct suction measurement technique mainly includes axis transition technique, tensiometer and suction probe. Indirect suction measurement technique are divided into three categories namely, measurement technique of matric suction, osmotic suction and total suction. Indirect osmotic suction measurement technique chiefly included squeezing technique and saturation extract method. Indirect total suction measurement technique include psychrometer technique, relatively humidity sensor, chilled mirror hygrometer technique and non- contact filter paper contact (Hu Pan et al., 2010).

### 2.5.2 Suction Control Technique

Matric suction is the equivalent suction derived from measurement of the partial pressure of the water vapour in equilibrium with the soil water, relative to the partial pressure of the water vapour in equilibrium with a solution with identical composition to that of the soil water. There is various type of apparatus that can measure the matric suction like tensiometer, null-type axis translation apparatus, moisture block, thermal conductivity sensor, filter paper and electrical conductivity sensor. Osmotic suction is the equivalent suction derived from measurement of the partial pressure of the water vapour in equilibrium with a solution with identical composition to that of the soil water, relative to the partial pressure of water vapour in equilibrium with free pure water (Leong et al., 2003).

## 2.6 Effect of Soil Water Retention Curve

The functional relationship between the matric suction of soil and the water content can be described by the soil water retention curve (SWRC) (Hillel et al., 1998). Various physical and chemical properties of soil affect the shape of the SWRC, which are specific to each soil (Botula et al., 2012). The SWRC contains useful information about the water content present in the pores at a given soil suction and the pore size distribution that corresponds to the stress state of the soil (Fredlund et al., 2002). In general, the SWRC provides insights into the soil behavior during adsorption and desorption procedures, where the soil may be close to full saturation at the start of the drying procedure. As the drying proceeds, there is an increase in suction and air begins to enter the soil pores, thereby defining the air entry value for the soil. Above the air entry value, the desorption process stage enters the transition zone where most of the desaturation occurs. This stage is followed by residual suction, where the only water present in the soil is that bound closely to the soil particles (Au et al., 1998).

In addition, there are increased incidents of groundwater contamination, erosion, and contamination of surface waters from points and non-point sources. Besides, the soil water retention relationship, characterized by soil water content and potential are not unique and are affected by a number of environmental and soil factors. Temperature affects soil water retention, however it is generally not critical in moist soils, nor is it in sandy or loamy soils, which are typical in agricultural settings (Taylor et al., 1958). Irregular pore geometry and discontinuity, and variations in texture and mineralogy are the primary soil properties influencing soil water retention. Variability in these soil factors greatly increases the uncertainty of predicting soil water retention values. The reason for relating soil water retention characteristics to soil physical properties is that direct measurements are very time consuming and frequently impractical due to high degree of spatial and temporal variability. Coefficients of variation for commonly measured saturated and unsaturated hydraulic conductivity often exceed 100% (Nielsen et al., 1973).

## 2.7 Shear Strength

Shear strength value of soil need to be determined so that deep analysis and design of geotechnical structure such as retaining wall, dam, highway base and foundation can be preceded. Shear strength parameter can be tested and estimated both directly at site and also in laboratory. Undisturbed soil can be taken from the site straight to laboratory for further investigations (Craig & Tiong, 2004).

The shear strength of a soil mass is the internal resistance per unit area that the soil mass can offer to resist failure and sliding along any inside plane (Das, 2002). It always refers to the resistance along a plane that passes between or along particle surfaces but not through the particle. The mineral composition of soil particles produce materials that have relatively high resistance to compressive and shear forces, and that rarely are fractured or sheared when a soil mass "shears". A plane of resistance passing between or along particle surfaces is weaker than a plane of resistance through the solid particles (McCarthy, 2002).

Soil strength was linked to soil erosion (Torri et al., 1987), soil aggregate detachment (Nearing et al., 1992). Tensile strength of soil has been reported to decrease with increasing water content. Nearing et al. (1991) found that the tensile strength ranged between 0.93 kPa and 3.23 kPa at high water content, which much higher than typical shear stress which is less than 5 Pa that applied in rill erosion. Shainberg et al. (1994) suggested that the binding forces between particles at the soil-water surface much weaker than the tensile force in bulk soil. Soil particle at the interface are not confined, as the soil particles are within the bulk soil. Conventional methods of determining soil strength include cone penetrometer, shear vane and direct shear method. However, these method cannot measure the properties at a soil surface with required resolution and the parameters were not sufficient to explain the mechanical dynamics during soil water erosion.(Zhang et al., 2001)

The shear strength of a soil mass is the internal resistance per unit area that the soil mass can offer to resists failure and sliding along any plane inside it. For most soil mechanics problems, it is sufficient to approximate the shear stress on the failure plane as a linear function of the normal stress. The shear strength of a soil in any direction is the maximum shear stress that can be applied to the soil structure in that direction. When this maximum has been reached, the soil is regarded as having failed, the strength of the soil having been fully mobilized (Murthy, 2008). Stabilization of a soil is commonly assessed in terms of strength gain over a certain period of time (cure).

Thus, the failure plane as described for soil shear is an undulated surface rather than a true plane. As such, the soil shear plane may be visualized as a failure band having a finite thickness rather than a conventional plane surface. Thus, the shear strength and the failure phenomenon of soil are difficult to comprehend in view of the multitude factors known to affect this failure phenomenon. The shear strength of the soil may be attributed to three basic components: (i) resistance due to interlocking of the particles; (ii) adhesion between soil particles called cohesion; and (iii) frictional resistance between the individual soil grains, which may be either of the sliding or rolling frictions or the both. (Wai, 2014).

### 2.7.1 Shear Strength Measurement

There are different method to determine the shear strength parameters of soil. There are divided into two method of test that are laboratory tests and field test. Laboratory tests on specimens taken from representive undisturbed samples. Most common laboratory tests to determine the shear strength parameters are direct shear test and triaxial shear test. Field test divided in several method namely vane shear test, fall cone, static cone penetrometer and standard penetration test. Other laboratory test include direct simple shear test, torsional ring shear test, plain strain triaxial test, laboratory vane shear test and laboratory fall cone test. Many laboratory-based tests have been developed over the years to quantify the shear strength of soil and sediment, including the triaxial and direct shear tests (Terzaghi et al., 1996). For in situ applications, the shear vane is the most reliable and readily-available device for measuring the undrained shear strength of cohesive sediment. It has been used extensively for the analysis of shear strength in soils (Serota et al., 1972).

#### 2.7.1.1 Vane Shear Test

The vane shear test is an in-situ geotechnical testing methods used to estimate the undrained shear strength of fully saturated clays without disturbance. The vane shear test has been one of the most widely used methods for the in-situ determination of the undrained shear strength of soil for many years. Bauer et al. (2007) discussed the capabilities of the vane test by highlighting its theoretical basis, its functioning principle with some operational particularities, and certain applications for investigating the properties of fresh rendering mortar. Laskar et al. (2011) considered the resistances from underneath and above the vane in their study to examine the relationship between torque and rotation speed using a concrete rheometer with the vane geometry. Skempton (1948) reported that the shear strength increases by 10% if the cylindrical shear surface has a diameter that is 5% greater than the width of the blade. Arman et al. (1975) found that the failure surface is circular at the cross section. However, Wilson (1964) noted that the failure surface is not circular but almost square on a plane when the torque reaches its maximum value. Furthermore, the vane configuration, geometry, operating conditions, and material properties are also controversial topics. The vanes applied in tests can have two, three, four, six, or eight blades, and their geometry can be rectangular, triangular, diamond-shaped, or conical (Keentok et al., 1985).

#### 2.7.1.2 Direct Shear Test

At present the direct shear is the most common laboratory tests for determining soil shear strength parameters. Direct shear is widely applied in other countries (Norkus, 2009). An angle of internal friction φ (°) and a cohesion c (kPa) are the shear strength parameters of the Mohr – Coulomb strength criterion. Direct shear test is simple and relatively cheap method for determining the soil shear strength parameters. The construction of apparatus is not complicated, the test is fast to perform, the output data can be relatively easily processed to obtain the necessary parameters. Therefore the direct shear apparatuses are widely applied in an engineering practice and for research aims (Bareither et al., 2008). Despite an attraction of the method, the obtained experience and recognized factors leading to many inaccuracies such as raise a necessity for deeper analysis and subsequent improvements to ensure the more reliable and adequate testing and data processing methods using this technique (Alikonis et al., 1999). The efforts are applied to eliminate and reduce an influence of unexpected factors, which influencing the accuracy of shear strength parameters to be determined (Amsiejus, 2000).

The main mentioned negative factors met in practice of determining strength parameters via the usual direct shear apparatuses can be listed as follow, non-uniform stress and strain distribution in sample, the vertical compressive load applied on the top is not completely transferred to the sample, the actual distribution of normal load on shear plane is unknown, the testing conditions do not imitate a soil sample behavior in ground, one cannot perform the test under the constant volume condition (S. Heng et al., 2010). The distribution of stresses in sample applying the direct shear box depends on: the way of vertical load transmission; the position of the movable part of shear ring; the horizontal displacement of the movable part of the ring, the shape and stiffness of the loading plate; the clearance between the upper and the lower rings of the box ( Amsiejus, 2000). Generally it is assumed that vertical load applied onto the top of shear box specimen is completely transmitted to the soil shear plane. Hence the frictional force mobilized between the specimen and that of the vertical walls of the shear box is not taken into account (Kostkanova et al., 2012).

## 2.8 Critical Shear Stress Measurement

The critical shear stress ( $\tau_c$ ) is defined as the stress at which soil detachment begins or the condition that initiates soil detachment. If the critical stress is higher than the effective stress, the erosion rate is considered zero (Nearing et al., 1989). The critical stress is then determined visually. Visually, τc is determined by measuring the shear stress at failure. Unfortunately, the point of failure is difficult to define, and most definitions are subjective (Hanson et al., 1999). Leonard & Richard (2004) estimated critical shear stress from soil shear strength measured with a shear vane device. They found that there is a linear correlation between critical shear stress and shear strength. Mostafa et al. (2008) studied the effect of sediment specific gravity and liquid limit on the erodibilty of cohesive sediments. Usually non-cohesive soils with coarser particle size have higher friction angle and lower cohesion whereas with lower cohesion, lower critical shear stress is expected (Budhu, 1999).

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# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

The characteristics of soil were tested through laboratory test. The physical properties of unburned and burned soil were conducted by specific gravity, atterberg limit, and free swell test. The organic matter content was determined by loss on ignition test. Soil water characteristic curve of unburned and burned soil were conducted by using osmotic technique Then, shear strength of unburned and burned soil were tested by using vane shear test. In this chapter, all the test conducted were analyzed.

## 3.2 Site Description

Soils for this study were collected from a slope at Jalan Gambang, Kuantan. The fire began on October 2016. The slope is located in the Eastern Belt where andalusite deposits can abundantly be found. According to Hutchison (1983), andalusite deposits in the area extend approximately 50 km radius from Gambang to Sungai Lembing. The slope considered in this study was 315 m in length and a portion of the slope (about 131 m) was affected by wildfire.


Figure 3.1 Map of Gambang showing locality of the burned slope.


Figure 3.2 Map of the slope at Jalan Gambang, Kuantan. Location of the burned and unburned soils are shown.

## 3.3 Selection of Material

The soil sample for unburned and burned soil were taken at the hillside at Jalan Gambang, Kuantan. All the sample were taken to the laboratory in sealed bags.

### 3.4 Properties of Unburned and Burned Soil

The laboratory test included specific gravity test, atterberg limit test, free well test and loss on ignition. All the test followed different standards as shown in table 3.1.

Table 3.1 Standard used for the physical properties of soil test

| **Physical Properties** | **Method** |
|---|---|
| Specific gravity, Gs | Density bottle (small pyconometer) (BS1377:1990:8.3) |
| Liquid limit, LL | Cone penetrometer method (BS1377:part 2:1990:4.3) |
| Plastic limit, PL | (BS1377:part 2:1990:5.3) Standard test method for shrinkage factors of soil by the wax |
| Shrinkage limit, SL | Method (ASTM D 4943-08) |
| Swell Index, Cs | Free swell test (ASTM D4829) |
| **Determination organic matter** | **Method** |
| Loss on ignition | (BS 1377:Part 3:1990:4.3) |

#### 3.4.1 Specific Gravity

The specific gravity test follow BS 1377:Part 2:1990:8.3. The first step was started about 10 g oven dried soil sample that passed 2mm sieve was evacuate to the density bottle. The distilled water The distilled water was combined about half to three-fourth of the density bottle and was placed in the vacuum desiccator. The soil sample was left in the desiccator for at least one hour until no further loss of air was significantly. Then, the distilled water was added until the bottle full and the bottle should left in room temperature for an hour. Then, remove the soil and water from the bottle. The density bottle was refilled with water until full and leave it for an hour. The process was repeated for the same soil sample to take the data of it. The apparatus was set up as shown in figure 3.1. The calculation of specific gravity can be follow as shown in Equation 3.1.

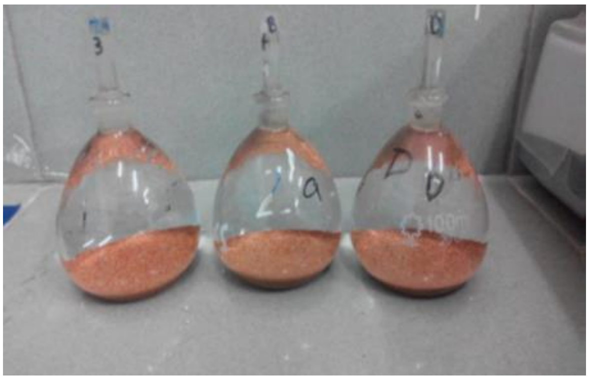

Figure 3.3 Apparatus set up for specific gravity

$$Gs = \frac{(w2 - w1)}{((w4 - w1) - (w3 - w2))} \quad 3.1$$

Where

$w1$ = weight of bottle + stopper

$w2$ = weight of bottle + stopper + dry soil

$w3$ = weight of bottle + stopper + soil+ water

$w4$ = weight of bottle +stopper + water

### 3.4.2 Liquid Limit Test

Liquid limit test was followed the BS 1377: part2 :1990: 4.3. Taken about 250 g of the oven dried soil passing 0.425mm were left air dried for 30 minutes. Distilled water were mixed to the soil sample to form a uniform paste and then moved to the cylindrical cup of cone penetrometer apparatus, ensuring that no air trapped in the sample. Finally the wet soil was level up the top of the cup and placed on the base of the cone penetrometer. The penetrometer was adjusted that the cone points touch the surfaces of the soil paste in the cup. The initial reading was taken. Then, the vertical clamp was release to allow the cone penetrate into soil paste for 5 seconds. After 5 second, the penetration of the cone was recorded. The test was repeated for three times of values of penetration in the range 0f 14 to 28mm. The exact moisture content of each test was determined. The graph of water content versus cone penetration was plotted.

Then, the moisture content corresponding to cone penetration 0f 20mm was taken as liquid limit.

### 3.4.3 Plastic Limit Test

This test was follow the BS1377: Part 2:1990:5.3. The soil in the form paste was rolled out a thread on a flat surface. The plastic limit is defined as the moisture content where the soil paste begin to break apart at diameter 3.2 mm.

### 3.4.4 Shrinkage Limit Test

This test follow the ASTM D4943-08. The sample was mixed with distilled water until it reaches 1.2 times liquid limit test of the soil sample. Weight of empty container was weighed and recorded. The grease was applied on internal of the container and weight again. Then, transfer the soil sample to the cylindrical cup, ensuring that no air was trapped in the soil and the weight was recorded. The soil sample was left air dried until no changes in the soil weight. The dried sample was tied with thread and coated with wax. The weight of dried sample with thread and coated wax were recorded. The graph of void ratio versus water content was plotted. The moisture content corresponding to void ratio of the soil was taken as shrinkage limit of the soil.

Figure 3.4 Apparatus set up for shrinkage limit test

### 3.4.5 Free Swell Test

Free swell test was conducted as follow ASTM D4829. The 10 ml soil sample was poured into a cylinder. Then, distilled water was filled into a cylindrical until it reaches 50 ml. The entrapped air in the cylinder was removed by gentle shaking and stirring with a glass rod. The soil sample was left air dried until no change in its volume. The free swell test can be calculated by using the Equation 3.2.

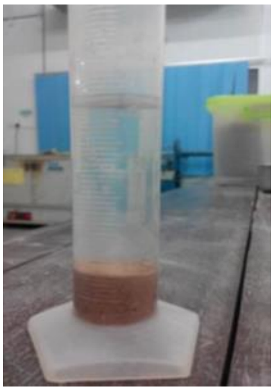

Figure 3.5 The apparatus set up for free swell test

$$\frac{(v_1 - v_0)}{v} \times 100\% \qquad 3.2$$

Where

$v_1$ = Free Swell, %

$v_0$ = Soil Volume after swelling, $cm^3$

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

### 3.4.6 Loss on Ignition

Loss on ignition was follow BS 1377: Part 3: 1990: 4.3. The soil sample was dried until one hour. The soil sample was left in a desiccator for 30 minutes. Then, the sample was combined into the crucible until half full and weight of sample accurately. Before the soil sample was cooled and weigh, it was oven dried until 24 hour. Then, the soil sample was heated in a furnace with 440oC until three hours and follow step cooled it in a desiccator and reweigh. The process was repeated until no further changes in the soil weight. The loss ignition can be determined by using Eq 3.3.

$$\frac{(M_S - M_A)}{(M_S - M_C)} \times 100\% \qquad 3.3$$

Where

$M_S$ = Mass of crucible and oven dried soil sample

$M_A$ = Mass of crucible and soil sample after ignition

$M_C$ = Mass of crucible

## 3.5 Soil Water Retention Curve

Soil water characteristics curve defined as relationship between the volumetric water content and matrix suction. Soil water characteristics curve also represented the relationship between degree of saturation versus suction which is allows for the determination of properties of soil that can be used to determine the shear strength. Water content can be divided in gravimetric water content, volumetric water content and degree of saturation. In this research, gravimetric water content was used. The soil sample was mixed with deionized water with increment of 2%. Soil suction has two components namely matric suction and osmotic suction. In this research, the of total suction was determined by using osmotic method and chilled mirror dew-point technique.

### 3.5.1 Osmotic Technique

The semi-permeable membranes mostly used in the osmotic technique are dialysis membranes used in medicinal field. This technique was used to control the osmotic pressure of culture solutions in biology by Lagerwerff et al. (1961). The soil and distilled water were prepared. The soil specimen is placed in contact with a semi-permeable membrane behind which an aqueous solution of large sized polyethylene glycol (PEG) molecules is circulated. Since water molecules can cross the membrane whereas PEG molecules cannot, an osmotic suction that increases with the PEG concentration is applied to the soil through the semi-permeable membrane. Since water transfer takes place in the liquid phase and ions can cross the semi-permeable membrane freely, the osmotic technique controls the matric suction of a soil and not the osmotic suction. The relationship between osmotic pressure and PEG concentration is well known for molecular weights (PEG 20,000). The soil sample is placed in a tube-shaped semi-permeable membrane and immersed in a PEG solution which is stirred by a magnetic stirrer to maintain its homogeneity. During suction application, PEG solution is circulated behind the semipermeable membrane in contact with a specimen causing water to be extracted or added to the sample to attain a specific matric suction. This will result in change in PEG beaker weight. At suction equilibrium, the recorded weight of the PEG beaker remains unchanged. This indicates that suction equilibrium has been reached in the whole specimen and change in weight can be used to evaluate the change in specimen's water content.

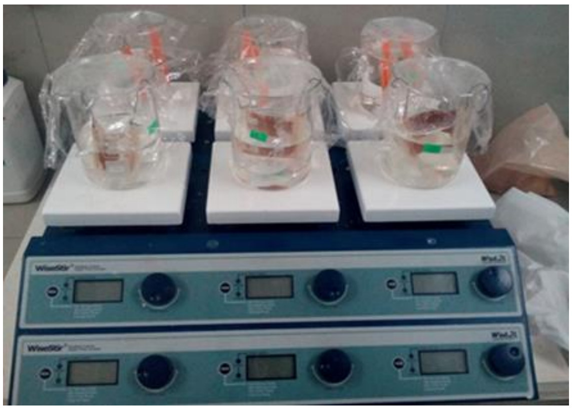

Figure 3.6 Osmotic technique

### 3.5.2 Chilled Mirror Dew-Point Technique

Figure 3.5 shows the chill mirror hygrometer that is used to measure the suction of the polyethylene glycol (PEG) using the dew point technique. The polyethylene sample is filled about half of the capacity of the container and make sure the temperature reading difference is not higher than the device. The device detects the changes of first point when the first condensation happens on the mirror which the mirror temperature is controlled by the thermoelectric cooler. The photo detector cell senses the light that is reflected by the beam of the light directed onto the mirror and into the photo detector cell. The equilibrium time can be reduced by equipped with an internal fan to circulate air inside the sample chamber in the device. Temperature controller is used to set the temperature of the sample in order to measure the relative humidity. The device has the sensitivity of to detect the change of relative humidity to an accuracy of ±0.1%.


Figure 3.7 Chilled mirror dew-point technique

### 3.6 Shear Strength of Unburned and Burned Soil

The shear strength of soil importantly to determine the load on soil. Some of test can be used to obtained the value by using direct shear test, triaxial shear test, vane shear test and unconfined compression test. In this study, vane shear and direct shear test were used. It used to estimated and measured the shear strength of sample without derangement in the specimen.

#### 3.6.1 Vane Shear Test

The shear strength of soil is determined by the Laboratory and Field Vane Shear Tests which is prescribed BS 1377:1975. It is suitable for the determination shear strength of cohesive soils. Based on the results properties of soil, shows that the sample of natural burned, natural unburned and burned 440˚C were categorized as cohesive soil. The test is relatively simple and provide a cost effective way of estimating the soil shear strength. Therefore it is widely used in geotechnical investigation. It consists of a torque head adjustable in height by means of a lead screw rotated by a drive wheel to enable the vane to be lowered into the specimen. The vane diameter, vane size, rod diameter and vane height are in accordance with the IS codes. The test apparatus consists of a four-blade stainless steel vane which is lowered into the mould containing the compacted soil. Generally, the height of the vane is two times its diameter. It is driven by an external torque supplied by an electric motor. The vane should be inserted into the soil to a depth at least two times the height of the vane. The vane rotates at a slow speed of 0.1 per second. It determines the torsional force required to cause a cylindrical surface to be sheared by the vane which is the force then converted to a unit shearing resistance of the cylindrical surface. It is of basic importance that the friction of the vane rod and instrument be accounted, otherwise the friction would be improperly recorded as soil strength. The torque measured at the failure gives the shear strength of the soil at that moisture level. This test is performed on sand compacted with 5, 10 and 15 blows in three layers .The torque is measured using a spring which controls the degree of rotation of the metallic dial. Essentially, the torque is dependent on the degree of rotation of the spring and varies with it. The shear strength of the soil is a function of the torque generated at failure. The calculation of the maximum torque, Tmax and undrained shear strength of soil , S using the Equation 3.4 below.

$$S = \frac{T\max}{\pi(0.5H^2 + D^3)} \qquad 3.4$$

Where

$S$ = Shear Strength

$T\max$ = Maximum torque

$H$ = Height of Vane

$D$ = Diameter of vane

Figure 3.8 Vane shear test

### 3.6.2 Direct Shear Test

The shear strength of soil is determined by the Laboratory and Direct shear Tests which is prescribed ASTM D 3080. Direct shear test is used to determine the shear strength of both cohesive as well as non-cohesive soils. Based on the results properties of soil, shows that the sample of burned at temperature 440˚C, 800˚C and 1350˚C were categorized as non-cohesive soil. The advantage of the direct shear test over other shear tests are the simplicity of equipment used and the ability to test under differing saturation, drainage and consolidation conditions. The test is carried out on a soil sample confined in a metal box of square cross-section which is split horizontally at mid-height. A small clearance is maintained between the two halves of the box. The soil is sheared along a predetermined plane by moving the top half of the box relative to the bottom half. The size of box was used 100 mm x 100 mm. After the soil sample already inserted fully , perforated metal plates and porous stones were placed below and above the sample to allow free drainage. When the sample was dry, solid metal plate were used. A load normal to the plane of shearing can be applied to the soil sample through the lid of the box. Tests on sands can be performed quickly, and usually performed dry as it is found that water does not significantly affect the drained strength. As a vertical normal load is applied to the sample, shear stress was gradually applied horizontally, by causing the two halves of the box to move relative to each other. The shear load was measured together with the corresponding shear displacement. The change of thickness of the sample is also measured. Calculate the nominal shear stress, acting on the specimen as follows.

$$\tau = \frac{F}{A} \qquad 3.5$$

Where

$\tau$ = Nominal shear Stress

$F$ = Shearing force

$A$ = Initial cross sectional area of the specimen

Calculate the normal stress section on the specimen:

$$\sigma_n = \frac{N}{A} \tag{3.6}$$

Where

$\sigma_n$ = Normal shear stress

$N$ = Normal vertical force acting on the specimen

Estimation the friction angle, $\varphi$ for the specimen by assuming the shear stress at failure is the maximum shear stress.

Estimate the friction angle, $\varphi$ by assuming the horizontal plane is the pailure plane.

Figure 3.9 Direct shear test

CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Introduction

In this chapter, there are result of physical and chemical properties presented for test carried out on soil. However, result graph of suction water content soil-water characteristics curve and shear strength were presented in this chapter. All the result were discussed and analysed.

## 4.2 Physical and Chemical Properties

The test that carried out to determine the physical and chemical properties of soil that are specific gravity, atterberg limit, swell potential and organic matter content were analysed.

Table 4.1 Effect temperature on properties of unburned and burned soil at varying temperature

| **Properties** | **Natural unburned** | **Natural burned** | **Burned 440˚C** | **Burned 880˚C** | **Burned 1350˚C** |
|---|---|---|---|---|---|
| Specific Gravity, Gs | 2.65 | 2.58 | 2.69 | 2.63 | 2.60 |
| Liquid limit (%) | 56.4 | 55 | 46.4 | - | - |
| Plastic limit (%) | 29.69 | 37.14 | 32.10 | NP | NP |
| Shrinkage limit (%) | 32 | 40 | 21.40 | - | - |
| Free swell (%) | 5 | 5 | 0 | 0 | 0 |
| Organic matter content (%) | 0.36 | 0.51 | 0.20 | 0 | 0 |

### 4.2.1 Effect of temperature on specific gravity

Table 4.1 shows effect of temperature on specific gravity of unburned and burned soil. Specific gravity of natural burned soil reduced from 2.65 to 2.58. In a study conducted by Young-Suk Song (2007), they suggest that specific gravity for natural burned soil is lower compared to unburned soil. There is shows that burned sample reduced start at 440˚C, 800˚C until 1350˚C. It is contrast with study conducted by Tan et al, (2004) that stated specific gravity reduced rapidly from 100°C to 600°C and does not show significant decrease for interval of 600°C to 1000°C.

### 4.2.2 Effect of Temperature on Liquid Limit

Table 4.1 shows liquid limit for natural burned soil is slightly lower compared to unburned soil. Burned soil at 440° and 800°C, it reduced with increasing temperature until it reached zero at 800°C and 1350 ˚C. The result showed similar pattern with study conducted by Abu-Zreig (2001) which suggest that liquid limit decreased with increasing temperature. However, it in contrast with research conducted by Tan et al. (2004) which stated that liquid limit decreased rapidly at temperature between 100°C to 300°C and does not show significant changes between 400°C to 1000°C.

### 4.2.3 Effect of temperature on Plastic Limit

The effect of temperature on plastic limit is shown in Table 4.1. There is increase in plastic limit of natural burned soil by 25% from unburned soil. At a temperature of 440°C, the plastic limit slightly increased by 2% and 8%, respectively. At temperature 800°C and 1350˚C, the plastic limit reached non-plastic (NP) state. The result contrast with study conducted by Tan et al. (2004) and Abu-Zreig (2001) which suggest that plastic limit reduced as temperature increase until it reached zero at 400°C.

### 4.2.4 Effect of temperature on Shrinkage Limit

From Table 4.1 shows the effect of temperature on shrinkage limit. The shrinkage limit of natural burned soil increased by 25% but it reduced at 440°C by 50%, respectively. The shrinkage limit reached zero at temperature 800°C and 1350˚C.

### 4.2.5 Effect of temperature on Free Swell

The effect of temperature on free swell is shown in Table 4.1. The swell index in both unburned and burned soil samples do not show any significant changes. However, it reduced to zero after burned at 440°C, 800°C and 1350˚C.

### 4.2.6 Effect of Temperature on Organic Content

From the result in Table 4.1, the organic matter increase to 0.51% in natural burned soil from 0.36% in unburned soil which may cause by the ash in natural burned soil sample (Ebel, 2012). At temperature of 400°C, organic matter content reduced compared to the natural burned and burned. However, the temperature increased until it reached zero at 800°C until 1350˚C. According to a review on effects of fire on properties of forest soils conducted by Certini (2005), loss of organic matter is the most intuitive change soils experience during burning.

## 4.3 Drying Suction Water Content SWCC

The suction of the unburned and burned soils at various water content are presented in Fig. 4.1. In this study, total suction were obtained by chilled mirror dew-point technique using Decagon WP4 Potential Meter device. However, the result of water content were obtained by using osmotic technique. The result were produced through both of these test show the relationship between water content with suction.

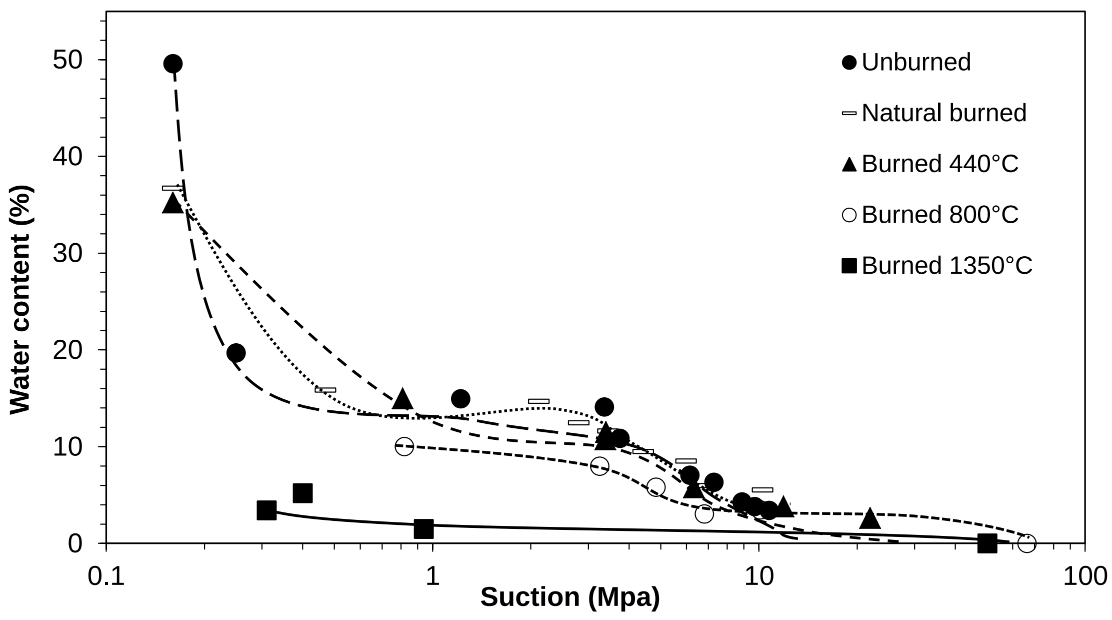


Figure 4.1 Suction Water Content SWCCs of the unburned and burned soil studied

Referring to Fig. 4.1, the suction-water content SWCC of natural burned soil is slightly below that of unburned soil. A study conducted by Alauzis et al. (2004)

measured major declines in organic matter content and soil-water retention resulting from wildfire. At temperature of 440°C, the suction-water content SWCC is higher than natural burned soil sample and which has the value plasticity of the soil. A study conducted by Pachepsky et al. (2002) suggests that water retention increase with increasing plasticity. The suction-water content SWCC start reduced after burned soil at 440°C is reached zero at 800˚C and 1350˚C. Then, it can be proven burned soil at 800°C has lowest suction-water content SWCC due to non-plastic behavior and zero organic matter content. According to Ebel (2012), the primary driver for differences in SWCC in unburned and burned soil is organic matter content.

## 4.4 Effect of Water Content on Shear Strength

The results shear strength of unburned and burned soil are presented in figure 4.2 and figure 4.3. In order to achieve the shear strength, two test had been conducted which were vane shear test and direct shear test. The shear strength for unburned and burned soil were carried out using vane shear test while the direct shear test were conducted to determine shear strength for burned soil at 440˚C, 800˚C and 1350˚C. In this results shows the effect of water content to the shear strength of soil.

### 4.4.1 Shear Strength using Vane Shear Test

Based on the figure 4.2 are shows results of effect water content to the shear strength. The sample natural burned soil and natural unburned were determined by vane shear test. The sample were chosen to be tested using vane shear test because this test suitable for determine shear strength of cohesive soils.

Table 4.2 Table of shear strength for vane shear test

| Sample | | | | | |
|---|---|---|---|---|---|
| **Natural burned** | | **Natural unburned** | | **Burned 440˚C** | |
| **Water content (%)** | **Tmax ($kN/m^2$)** | **Water content (%)** | **Tmax ($kN/m^2$)** | **Water content (%)** | **Tmax ($kN/m^2$)** |
| 5.5 | 25.32 | 3.4 | 21.90 | 2.61 | 27.38 |
| 5.94 | 21.90 | 3.81 | 18.43 | 3.82 | 20.53 |
| 8.48 | 14.37 | 4.29 | 20.53 | 5.79 | 13.69 |
| 9.48 | 10.27 | 6.32 | 16.43 | 10.76 | 10.27 |
| 11.59 | 8.21 | 7.04 | 11.64 | 11.52 | 15.06 |
| 12.45 | 13.69 | 10.86 | 9.58 | 14.98 | 15.06 |
| 14.66 | 15.06 | 14.1 | 15.06 | 35.32 | 13.69 |
| 15.83 | 10.27 | 14.94 | 10.27 | | |
| 36.69 | 8.90 | 19.70 | 13.69 | | |
| | | 49.60 | 3.42 | | |

According to table 4.1, values of shear strength for burned at 440˚C were slightly higher than natural unburned and burned soil. Based on the figure 4.1 shows the results shear strength for burned 440˚C at water content 2.61% most higher than other water content from different sample of soil. However, shear strength of natural burned at water content 49.60% was lower than other water content from different sample.

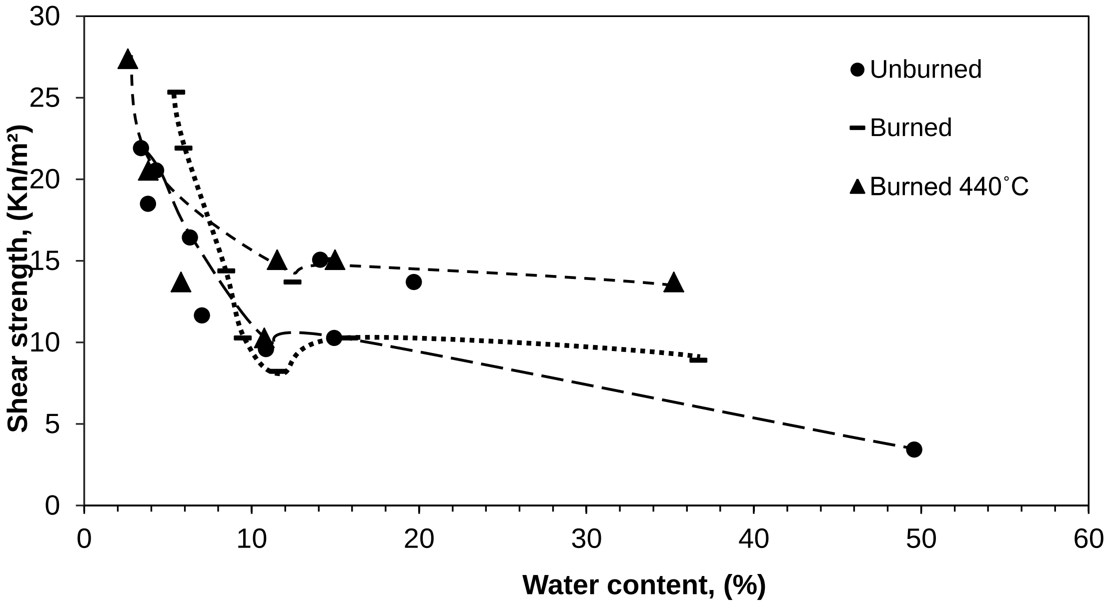


Figure 4.2 Shear strength of the unburned and burned soil studied using vane shear test

Figure 4.2 shows unburned soil were decrease than burned soil and burned at temperature 440˚C The result shows that the increment of water content would lead the shear strength decrease. Kristyna Blahova et al, (2013) define that increament in water content would affect the shear strength decrease. According to (Busscher et al., 2000) highlighted that soil strength varies frequently due to changes in soil moisture condition which affects trafficability of soils quite unexpectedly. However, the result also support by previous study by Fredlund & Rahardjo (1993) define that the suction influences the shear strength of compacted specimens.

### 4.4.2 Shear Strength using Direct Shear Test

The shear strength also can be determined experimentally in the laboratory using a modified direct shear apparatus Based on the figure 4.3 and figure 4.4 are shows the results of cohesion and angle of friction for burned sample in various temperature. The sample burned soil at 440˚C, 800˚C and 1350˚C were determined by direct shear test. The sample were chosen to be tested using direct shear test is to determine the shear strength of both cohesive as well as non-cohesive soils.

Table 4.3 Influence of water content on cohesion and angle of friction

| Sample | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Burned 440˚C** | | | **Burned 880˚C** | | | **Burned 1350˚C** | | |
| **Water content (%)** | **Cohesion, (C)** | **Phi (˚)** | **Water content (%)** | **Cohesion (C)** | **Phi (˚)** | **Water content (%)** | **Cohesion (C)** | **Phi (˚)** |
| 2.61 | 4.65 | 19 | 3.05 | 3.59 | 24 | 1.49 | 2.86 | 20 |
| 3.82 | 3.65 | 22 | 3.46 | 3.81 | 19 | 3.42 | 2.5 | 19 |
| 11.52 | 2.80 | 23 | 5.81 | 3.00 | 20 | 5.18 | 1.15 | 26 |
| 14.98 | 2.51 | 26 | 7.98 | 2.00 | 24 | | | |

According to table 4.3, values of cohesion for burned at 440˚C at water content 2.61% were higher compare to burned soil at temperature 880˚C and 1350˚C. As can be seen in table 4.3 also shows the result of cohesion for burned 1350˚C at water content 1.49% were lower than other water content from different sample of soil. However, the value angle of friction for burned soil at temperature 440˚C and 1350˚C were same at water content 14.98% and 5.18% that are 26˚.

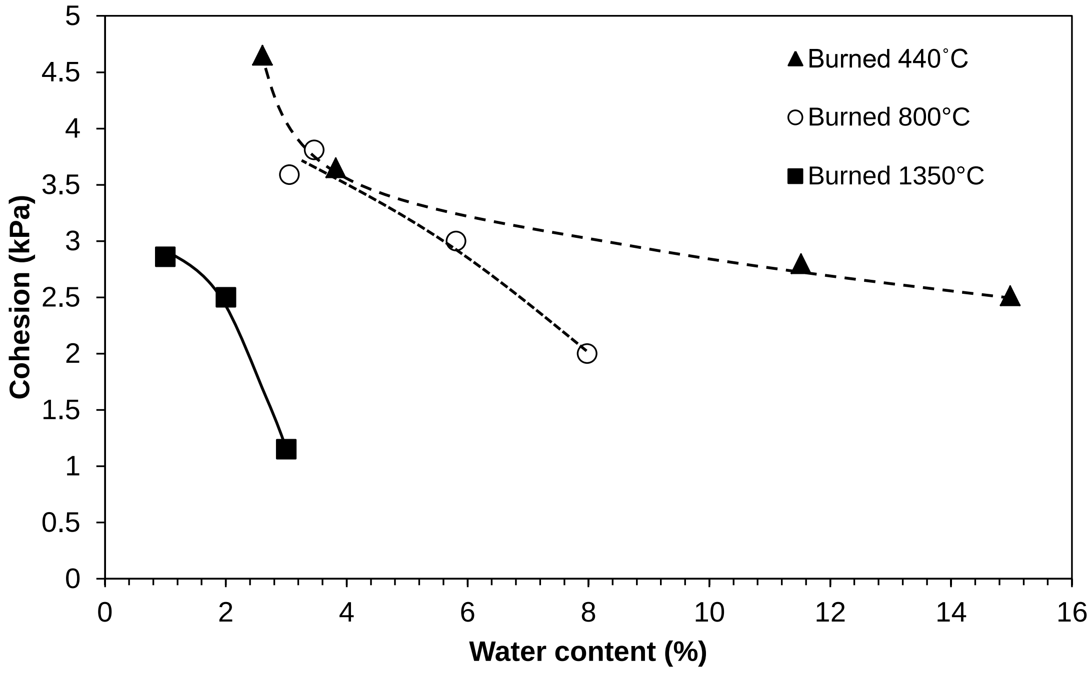


Figure 4.3 Effect of water content on cohesion of the burned soils at different temperature studied

As can be seen figure 4.3 shows the results of cohesion for burned soil at 440˚C were slightly higher than burned soil at 800˚C and 1350˚C. Based on the figure 4.3

shows the results, at burned 440˚C were higher than different sample. But results the cohesion of burned 1350˚C were decrease compared to other different sample. Therefore, the results pointed that the burned 440˚C mostly effect to the water content.

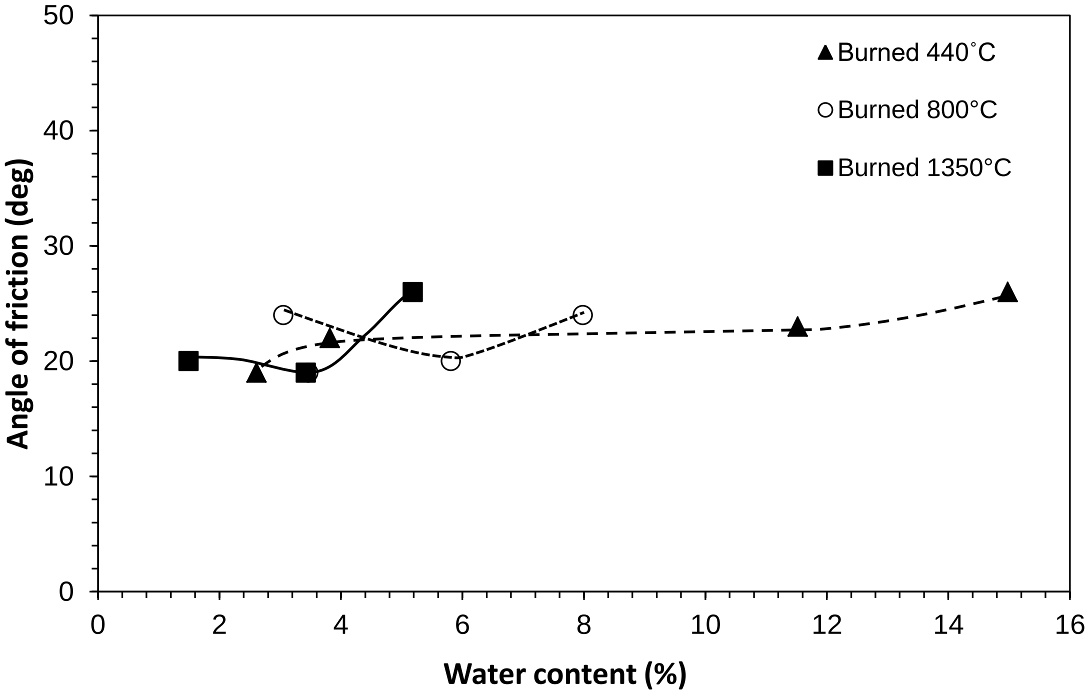


Figure 4.4 Effect of water content on angle of friction of the burned soils at different temperature studied

Based on the result shows that results of angle of friction significant changes in various temperature. Angle of friction for burned soil at 800˚C and 1350˚C were decrease due to water content 3.42% and 3.46% but it could be seen increase after water content 3.42% and 3.46%. Escario & Saez (1986) pointed that the effective friction angle of some soils increases slightly with increasing matric suction. However, for most practical purposes, the effective friction angle may be considered constant for suction values less than 500 kPa, which is often the range of practical interest for geotechnical and geo-environmental engineering . Based on (Blahova et al., 2013) highlited that cohesion was descending with raise of water content. According to the result show the cohesion burned soil at 800˚C diminished from 3.59 $Kn/m^2$ to 2 $Kn/m^2$ compared to burned soil at 1350˚C which are shows the cohesion from 2.86 $Kn/m^2$ decrease to 1.15 $Kn/m^2$. But burned soil at 440 also shows the results cohesion from 4.65 $Kn/m^2$ drop to 2.51 $Kn/m^2$ .

Due to increasing water content the shear strength is expected to decrease. According to Pellet et al, (2013) the friction angle and the cohesion decrease when saturated. This reduction has to be accounted for when conducting stability analyses of rock slopes, dam foundations or underground openings. Also the values of angle of friction differ from expected development, as can be seen in figure 4.3, Mencl et al, (1997) states, that cohesion yields the highest resistance around the plastic limit. Cohesion decreases at water content heading towards the liquid limit and increases towards the shrinkage limit. Apart from moisture conditions, the cause of results, which indicate instability might be attributed to high percentage of sand fraction in the specimen, which causes lower values of cohesion, hence lower values of shear strength. Reason of such drop can also be due to changes in unit weight, which needs to be kept constant during all the tests. Another factor might be the presence of concretion or little gristles on the shear plane, which influences the values obtained from the direct shear tests. (Blahova et al., 2013).

CHAPTER 5

# CONCLUSION

## 5.1 Introduction

The objective of the thesis was to determine the properties and establish the soil water characteristics curve for unburned and burned soil. Soil water characteristics curve of burned and unburned soil was establish using osmotic technique and chilled mirror dew-point technique. However, thesis also to determine shear strength of burned and unburned soil at varying water content which using vane shear test and direct shear test. All the objective were determined following the standard laboratory procedure.

Based on the findings reported in this thesis, the following conclusions were drawn.

1. This study proved that temperature had significant effect on soil properties which consist of specific gravity, Atterberg limits, swell potential, organic matter content and SWCC. However, the changes in these properties were higher when the temperature ranged from 440°C to 1350°C. Experimental results concluded that temperature had a significant effect on soil physical properties.

2. This study concluded that soil water characteristics curve for unburned soil slightly higher than other sample. However, burned soil at temperature at 440˚C were slightly higher than burned soil at temperature 800˚C and 1350˚C. Therefore, it can be concluded effective stress increases the soil strength by controlling matric suction as the water content decreases. Besides, based on in this study proved that the coefficient of permeability

decrease with an increase in soil suction. The shear strength increase with increase in soil suction. In addition, the engineering properties of soil are clearly significant influenced by soil suction.

3. This study highlighted that the shear strength parameters are significantly influenced by moisture conditions. This is proved by the results that already done using vane shear test and direct shear test. Based on the results determine shear strength using vane shear test mostly shows that the shear strength were increase when water content decrease. However, the results of direct shear test shows cohesion diminished with increasing water content. Burned 440 shows the results of cohesion increase compare to burned 800 and 1350. Soil moisture content influences soil failure mechanism machines greatly. Soil moisture content also has a great influence on other soil parameters, this interaction between soil moisture content and other soil parameters is not fully understood. In referenced literature it can be found, that overall shear strength decreases with increasing water content, but results of presented study showed that there is considerable variability in the values obtained from direct shear tests of soil. Such variability can be explained by many factors and it is necessary to provide sufficient number of specimen in order to secure realistic conclusions when dealing with water content and its relation to shear strength of soil.

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