SOIL IMPROVEMENT ON MINING SAND USING PULVERIZED FUEL ASH (PFA) WITH LIME ADDITIVE

by

Aizuddin Faiz Bin Yaacob

Submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering
(Civil Engineering)

JANUARY 2008

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh Perak Darul Ridzuan
Tronoh Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

SOIL IMPROVEMENT ON MINING SAND
USING PULVERIZED FUEL ASH (PFA) WITH LIME ADDITIVE

by

Aizuddin Faiz bin Yaacob

A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

Approved by,

(MS NIRAKU ROSMAWATI AHMAD)
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the reference and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

AIZUDDIN FAIZ BIN YAACOB

ABSTRACT

The state of Perak was famous of a location of tin mines long ago due to the rich of tin contained in soil and rocks especially in Kinta Valley and harvested leaving abandoned tin mines. Pulverized Fuel Ash (PFA) is the byproduct of a coal burning to generate energy from power plant and this byproduct is useful in stabilizing soil under specific condition. This project was carried out to find the highest unconfined compressive strength from the mix between mining sand with PFA and lime as additive. Soil improvement on mining sand could improve the strength carried by the soil. From the experiment of this project, the optimum lime found is 10% lime. The 10% lime then mixed with mining sand and PFA range from 5% until 25% for 5 different percentage mixes. The mixtures then analyzed in term of particle distribution, compaction test and unconfined compression test. For unconfined compression test, the curing periods implemented for the sample mix before tested and the curing periods selected are 7, 14, and 28 days. The sieve analysis for each of the mixtures shows significant improvement on percentage of the silt and clay that is for 3% of raw mining sand to 11% for Mix 5. The standard proctor test conducted shows that the highest maximum dry density could be achieved at 2.1851 Mg/m^3 at Mix 2. The Undrained Shear Strength shows significant increase based on curing period and the increasing percentage of PFA. The highest undrained shear strength occurs at Mix 5 for 28 days curing period that is at 6.675 MPa. This shows that for more percentage of PFA, the strength is increased. The curing period of the mixtures also affect the undrained shear strength. For longer curing period, the undrained shear strength is higher as shown for Mix 3 that is at 305.53 kPa for 7 days while at 3.935 MPa for 28 days of curing.

ACKNOWLEDGEMENT

First and foremost, I would like express my grateful to Allah S.W.T for the completion of this Final Year Project. Special Thanks to my project supervisor, Ms Niraku Rosmawati Ahmad for her guidance, support, patience and commitment in ensuring me to accomplish the project objectives. Special thanks to UTP laboratory technician, Ms Izhatul Imma binti Yusri, Mr Zaini and Mr Johan for his assistance in helping me to complete the project.

I also would like to extend my gratitude to my family and my friends who have given continuous support for me to complete the project.

I as well would like to express a thousand appreciations to other Civil Engineering Lecturers and all my colleagues who involved with this project for all of their helps and guidance throughout the year.

Lastly, a million appreciations to all parties who had contributed directly and indirectly towards the success of this project

Thanks You.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF NOTATIONS

ASTM	American Society for Testing and Materials
AASHTO	American Association of State Highway and Transportation Officials
C_z	Coefficient of gradation
C_u	Uniformity coefficient, ratio of 60% particle size to 10% particle size
D_{10}	The particle-size corresponding to 10% finer and 90% are coarser.
D_{30}	Diameter corresponding to 30% finer
D_{60}	Diameter corresponding to 60% finer
w (%)	Percentage of moisture content
m_w	Mass of wet soil
m_D	Mass of oven dried soil
MIT	Massachusetts Institute of Technology
USDA	U.S. Department of Agriculture
V_s	Volume of the sample
m_s	Mass of the sample
m_w	Mass of the sample submerged in water
ρ_s	Particle density of the soil
m_1	Mass of Pyknometer
m_2	Mass of Pyknometer and soil
m_3	Mass of Pyknometer, soil and water
m_4	Mass of Pyknometer full of water only

m_{mould}	Mass of the sample in the mould
V_m	Volume of the sample in the mould
W_m	Weight of the compacted soil in the mould
γ	Moist unit weight of compaction
γ_d	Dry unit weight
G_s	Specific gravity of soil solids
γ_w	Unit weight of water
e	Void Ratio
S	Degree of Saturation
γ_{zav}	Zero-air-void unit weight
q_u	Unconfined Compression Strength
C_u	Undrained Shear Strength
ϵ	Axial Strain
ΔL	Change in length of the specimen
L_0	Initial length of specimen
σ_1	Axial compressive stress
P	Force applied to specimen
A_0	Initial cross-sectional area of the specimen

CHAPTER 1

INTRODUCTION

1.1. Background

The state of Perak was famous of a location of tin mines long ago due to the rich of tin contained in soil and rocks especially in Kinta Valley. The attraction of the tin mines had caused so many abandoned mines when the mines were harvested during the World War II era. Mining sand was produced from the mining activity at the mining pit or area. From this mining activity, the raw mining materials were excavated from ground using process of spraying pressurized water to the location that has a lot of mining minerals. This process will also crush and excavate the soil particles and creating the mining sand at the mining area due to wash away silt and clay.

In construction, loose soil must be compacted to increase their unit weight in any construction such as dams, highway, embankment, fills and other engineering structures. The top layer of the soil will be removed due to the presence of organic materials such as roots or debris which reduces the soil strength. The top layer then replaced with fill materials and compacted into certain level of compaction. Compaction of soil is defined in general as densification of soil by removal of air which requires mechanical energy. The degree of compaction of a soil is measured in terms of its dry unit weight. Water act as softening agent on the soil particles and added to the soil during compaction. The soil particles will slide to fill voids in the soil during compaction and this will cause the soil to become denser. (Das 2002)

The fill material from the in-situ location or borrow location is identified and submitted to laboratory for testing. The laboratory test usually used to identify the condition of the soil either suitable for the material or not by comparing the parameters tested from the selected fill material location with the standards. The parameters that usually compared for the replacement fill were particle grain size distribution, liquid limit, plastic limit, the maximum dry unit weight of compaction and the optimum moisture content. Laboratory test is performed to ensure the material meets the specification required. Once the result of the fill material is approved, the fill placement is begins based on the optimum moisture-density relationship established.

In most specification for earthwork, the compaction of soil should be achieved a compacted field dry unit weight of 90% to 95% of the maximum dry density (JKR 2007).

Pulverized Fuel Ash (PFA) is also known fly ash. Fly ash is the material extracted from flue gases of a furnace fired with coal. It is non plastic fine silt. Its composition varies according to the nature of coal burned (Rollings and Rollings 1996).

In 9th Malaysia Plan, the consumption of coal for power generation and industrial use is expected to reach 19.0 million tons and 2.2 million tons, respectively, in 2010, due mainly to the commissioning of two new coal-based generation plants in Peninsular Malaysia (RMK–9, 2006). Effort will be continued to enhance the security of supply by exploring the potential of developing local sources, particularly in Sarawak as well as securing long-term supplies from abroad.

1.2. Problem Statement

Sand is widely used as fill material especially in highway construction project. It is cheaper in our country compared to others due to abundant sources. Mining sand was selected at most of construction as soil replacement or fill material in Perak area especially in Ipoh, Seri Iskandar, Batu Gajah and Tronoh. This selection was due to a lot of abandoned tin mines are that contained abundant mining sand at that area (Othman, 2007). But for certain location, the compressive strength of fill material needs to be improved. There are ways to improve the fill material by mixing with the pozzolanic materials such as lime or cement. The alternatives of this type of pozzolanic material should be conducted and by searching from waste material.

At present, the generation of fly ash is far in excess of its utilization. It can be used as an alternative to conventional materials in the construction of geotechnical and geoenvironmental infrastructures (Phani Kumar and Sharma 2004). PFA waste disposal has become an acute problem for many countries due to rapid industrialization and urbanization and the demand of power is increasing day by day. Major part of the power is supplied by thermal power plants where coal is used as fuel and a large quantity of fly ash emerges in the process. Fly ash creates different environmental problems like leaching and dusting and takes huge disposal area. Transforming this waste material into a suitable construction material may minimize the cost of its disposal and in alleviating environmental problems. Fly ash has become an attractive construction material because of its self hardening character which depends on the availability of free lime in it. The variation of its properties depends on nature of coal, fineness of pulverization, type of furnace, and firing temperature (Ghosh and Subbarao, 2007). The increase of the byproduct from coal burning may become a problem thus utilization of the PFA will reduce the amount of byproduct dumped on waste site

1.3. Objectives And Scope Of Study

The objectives of this project are:

- To improve shear strength of mining sand by using PFA and lime as additive.
- To analyze the effect of PFA and Lime on mining sand through the shear strength analysis.
- To provide data of mining sand improved with PFA as reference for construction purpose.

CHAPTER 2

LITERATURE REVIEW

2.1. Soil Classification

Any system of soil classification involves grouping the different soil types into categories which possess similar properties to provide the engineer with a systematic method of soil description. Although soils include materials of various origins, for purpose of engineering classification it is sufficient to consider their simple index properties which can be assessed easily such as the particle size distribution, consistency limits or density. (Bell 2000)

In general, soils are formed by weathering of rocks. The physical properties of a soil are dictated by the minerals that constitute the soil particles and the rock from which it is derived. The sizes of the particles that make up soil vary over a wide range. Soils classification depends on the predominant size of particles within the soils. To describe soils by their particle size, several organizations have developed particle-size classifications. Table 2.1 shows the classification of the soils based on the organizations. (Das 2002)

Table 2.1: Particle-Size Classification (Das 2002)

Name of organization	Grain Size (mm)			
	Gravel	Sand	Silt	Clay
Massachusetts Institute of Technology (MIT)	>2	2 to 0.06	0.06 to 0.002	<0.002
U.S. Department of Agriculture (USDA)	>2	2 to 0.05	0.05 to 0.002	<0.002
American Association of State Highway and Transportation Officials (AASHTO)	76.2 to 2	2 to 0.075	0.075 to 0.002	<0.002
Unified Soil Classification System (ASTM)	76.2 to 4.75	4.75 to 0.075	Fines (i.e., Silts and Clays) <0.075	

Two methods are normally used to find the particle-size distribution of the soil which is sieve analysis for particle sizes larger than 0.075 mm in diameter and hydrometer for particle sizes smaller than 0.075 mm in diameter. (Das 2002)

The classifications system considers the factors of grain-size distribution, particle sizes, and the effect of moisture. Due to wide variation among the soils encountered on site project, soil testing is usually conducted. (Bell 2000)

2.2. Particle Size Analysis

Sieve analysis consists of shaking the soil sample through a set of sieves size that has standard openings. Soil must be dried and break into small particles and the total soil is weighted. Then the soil is placed on the top of sieve and the entire set of sieve where the size was decrease from top to bottom and shaken mechanically or by hand. The weight of particle remain on each of the sieve size is determined and calculated as a percentage from the total weight. The gradation of fill materials can be determined from sieve analysis test.

Three types of gradation can be determined that is as below:

- Well-Graded Soil

  A well-graded soil has a uniformity coefficient greater than about 4 for gravels and 6 for sands, and coefficient of gradation between 1 and 3 for gravels and sands. (Das 2002)

- Uniformly Graded Soil

  A Uniformly Graded Soil is a type of soil which most of the soil grains is at the same size. (Das 2002)

- Gap Graded Soil

  Types soil that having no or small amount of soil retained on certain sieve size and usually near zero retain was located on the middle of the gradation.

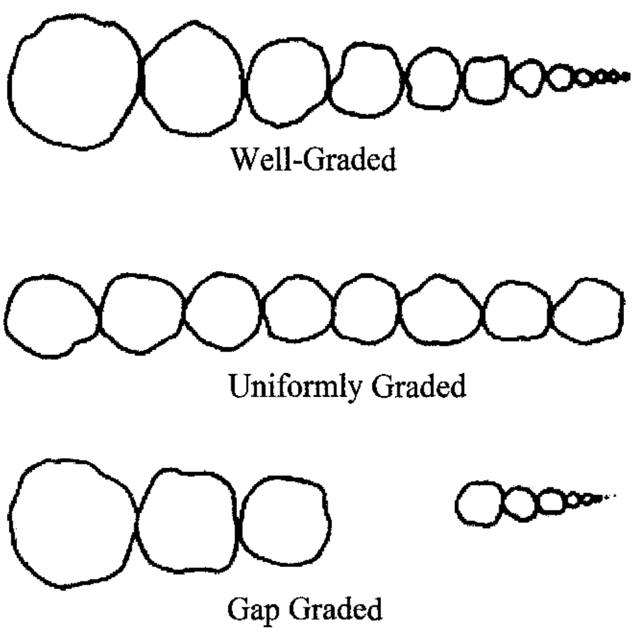


Figure 2.1: Three types of gradation from sieve analysis. They are well-graded, uniformly graded and gap graded soil.

2.3. Particle-Size Distribution Curve

The advantage of plotting particle-size distribution curve is it enables us to recognize instantly the grading characteristic of a soil far more easily than from tabulated figures. Moreover the position of a curve on the chart indicates the fineness or coarseness of the grain. The steepness, flatness and general shape indicate the distribution of grain sizes within the soil. (Head 1992)

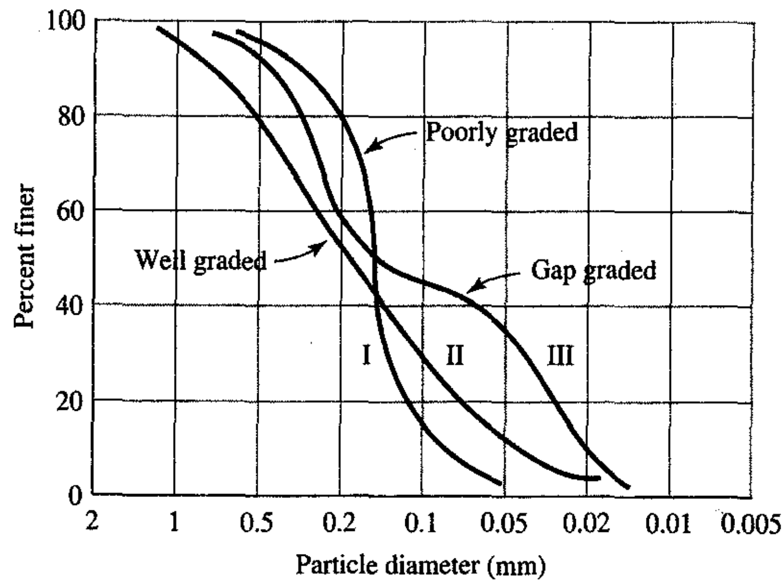


Figure 2.2: Different type of particle-size distribution curves. (Das 2002)

2.4. Compaction Tests

Compaction of soil is the process by which the soil particles are packed more closely together by mechanical means, thus increasing the dry density (Markwick, 1944). It is achieved through the reduction of air voids with little reduction in the water content in the soil. With proper control, minimum air voids could be obtained by compaction. The relationship between dry density and moisture content for soil subjected to a compaction provides reference data for the specification and control of soil place as fill. The laboratory compaction tests are supplemented by field compaction trials by using the actual placing and compacting equip which is to be employed for construction (Williams, 1949). Figure 2.3 shows various compaction curves of different types of soil:

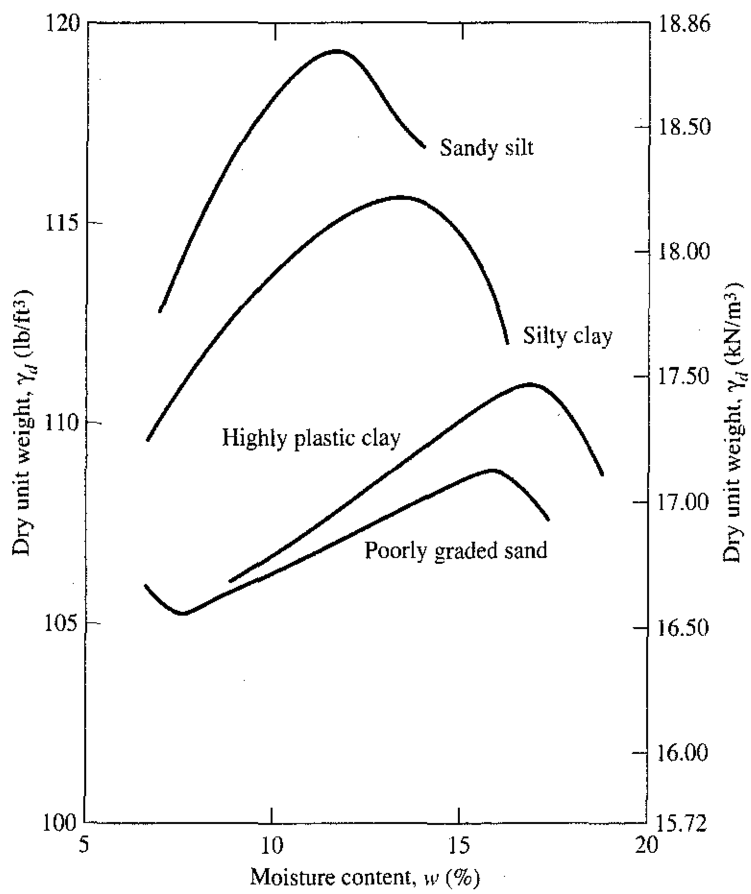


Figure 2.3: Typical compaction curves for four soils. (ASTM D-698)

Moisture content has shown a strong influence on degree of compaction achieved by a given soil. Besides moisture content, other important factors that affect compaction are soil type and compaction effort (energy per unit volume). On certain period, it is necessary to adjust the moisture content of the soil to produce the effective compaction (Head 1992).

2.5. Pulverized Fuel Ash (PFA) Standard Classification ASTM C618 (ASTM2005).

The specification covers coal fly ash and raw or calcined natural pozzolan for use as a mineral admixture in concrete where cementitious or pozzolanic action or both is desired.

Table 2.2: Classification for Coal Fly Ash and Raw or Calcined Natural Pozzolan (ASTM 2005)

Classification	Description
Class N	Raw or calcined natural pozzolans that comply with applicable requirement for the class.
Class F	Fly ash normally produced from burning anthracite or bituminous coal that meets the applicable requirements for this class.
Class C	Fly ash normally produced from lignite or sub-bituminous coal that meets the applicable requirements for this class.

The chemical requirement for each of the classification is as in Table 2.4:

Table 2.3: Chemical requirement for each of the class based on ASTM C618 (ASTM 2005)

	Mineral Admixture Class		
Class	N	F	C
Silicon dioxide (SiO_2) plus aluminium oxide (Al_2O_3) plus Iron Oxide (Fe_2O_3), min %	70.0	70.0	50.0
Sulfur trioxide (SO_3), max %	4.0	5.0	5.0

2.6. Standards and Requirements for Construction Fill based on Jabatan Kerja Raya (JKR) Standards.

The earthwork for roadwork projects under JKR was based on JKR Standard Specification for Road Works and Bridges. Most of the JKR Standards were referred to BS1377: Part 1: 1990 until Part 9:1990 (British Standard Methods of test for Soil for civil engineering purposes). In JKR standard and specification, the contractors are required to conduct tests on fill materials before starting compaction. The test result should be complying with JKR standard and specification before the fill material is used and compacted. The JKR standard for degree of compaction of the embankment shall achieve 90% for cohesive material or 95% for non-cohesion material of the maximum dry density determined in the BS1377 Compaction Test.

Table 2.4: Criteria required for fill material (JKR/SPJ, 1988)

Unsuitable material for fill material	Running silt, peat, logs, stumps, perishable or toxic material, slurry or mud, or any material consisting of highly organic clay and silt, contains large amount of roots, grass and other vegetable matter.
Liquid Limit	<80%
Plasticity Index	<55%, not susceptible to spontaneous combustion
Loss of weight on ignition	<2.5%

Table 2.5: Grading Limits of Materials for Replacement of Unsuitable Material (JKR/SPJ, 1988)

B. S. Sieve Size	% Passing By Weight
Crushed Rock or Gravel	
63.0 mm	100
37.5 mm	85 - 100
20.0 mm	0 - 20
10 mm	0 - 5
Sand	
10.0 mm	100
5.0 mm	90 - 100
1.18 mm	45 - 80
300 μm	10 - 30
150 μm	2 - 10

Suitable material shall mean those materials that fulfill the requirement in Table 2.4 and Table 2.5.

2.7. Value of Unconfined Compression Strength from Journals.

The characteristics of soil, PFA and carbide lime used in the Consoli et al. (2001) is shown as in Table 2.6

Table 2.6: Characteristics of soil, PFA and carbide lime used for Consoli, N. C. et al, (2001)

Sand		
Origin	Region of Porto Alegre, in southern Brazil	
Specific gravity	2.70	
Grain-size distribution	27.8% medium sand (0.2mm<Φ<0.6 mm)	
	33.4% fine sand (0.06mm<Φ<0.2mm)	
	31.3% silt (0.002mm <Φ<0.06mm)	
	7.5% clay (Φ<0.002mm)	
The Atterberg limits	liquid limit of 22%, plastic limit of 15%	
X-ray diffraction	The fine portion is predominantly kaolinite	
Soil pH	4.7 (acidic)	
Cation exchange capacity	2.4 meq/100 g	
PFA		
Types	F	
Specific gravity	2.03	
Grain-Size Distribution	5.3% medium sand	
	18.6% fine sand	
	74.3% silt	
	1.8% clay	
The Atterberg limits	Non Plastic	
Soil pH	6.0 (slightly acidic)	
Chemical Analysis	SiO_2	67.1%
	Al_2O_3	21.3%
	Fe_2O_3	7.2%
	K_2O	1.4%
	CaO	0.8%
	SO_3	0.1%
Cation exchange capacity	3.0 meq/100g	
carbon content	<0.05%	
loss on ignition at 1,000°C	0.5%	
Lime		
Chemical analysis	CaO	96.6%
	$CaCO_3$	0.7%
	MgO	0.2%

The soil used in journal is classified nonplastic silty sand (SM) according to the Unified Soil Classification System and the soil is derived from weathered sandstone, obtained from the region of Porto Alegre, in southern Brazil.

All the specimens tested were prepared by mixing the relevant quantities of dry soil, fly ash, carbide lime, and water, according to the mixture proportions and molding parameters. The maximum 25% of PFA was used throughout experiment by Consoli, N.C. et al. (2001) is fall into the interval recommended by National Cooperative Highway Research Program (NCHRP) (1976) and was selected and taking into account compaction difficulties found using higher amounts of fly ash. Table 2.7 shows the unconfined compression strength of mixtures from Consoli, N.C. et al. (2001).

Table 2.7: Mixture Proportions, Curing Conditions and Test Summary. (Consoli, N. C. et al, 2001)

Soil (%)	Lime (%)	Fly Ash (%)	Moisture Content (%)	Curing Period (days)	Unconfined compression strength (kN/m²)
100	0	0	15.8	-	-
75	0	25	15.3	-	-
96	4	0	16.3	-	-
71	4	25	17.0	0	-
				7	410
				28	1000
			14.8	90	1793
			18.5	180	6975
68	7	25	17.7	7	536
				28	1247
				90	1817
				180	8567
65	10	25	18.1	7	634
				28	1243
				90	1924
				180	9373

From Table 2.7, the curing period for percentage had given significant increase on the unconfined compressive strength of the samples. This shows that curing period for soil is different that curing period of concrete by the continuous reaction tremendously after 28 days.

The typical values for 28 days curing were gathered from various journals on mixing soil with PFA and other agent such as lime and concrete.

Table 2.9: Unconfined compression strength for various mixtures at 28 days. (Consoli, N. C. et al, 2001) (Ghataora G. S. et al, 2000).

Sand (%)	Lime (%)	Fly Ash (%)	Moisture Content (%)	Curing Period (days)	Unconfined compression strength (kN/m^2)
71	4	25	17.0	28	1000
68	7	25	17.7	28	1247
65	10	25	18.1	28	1243
Sand (%)	Cement (%)	Fly Ash (%)	Moisture Content (%)	Curing Period (days)	Unconfined compression strength (kN/m^2)
60	8	32	-	28	8500
46	8	46	-	28	6200
32	8	60	-	28	6000

The typical value for 28 days shows that the different mixtures caused different effect on unconfined compression strength. When the value of lime is increase, the unconfined compressive strength is also increase. For PFA, if there is excessive amount of PFA used in mixtures, the effect shows that the unconfined compression strength is reduced. This shows that excessive amount of PFA in mixtures does not improve the mixtures itself anymore but also caused reduction in term on strength. This value will be the benchmark for the unconfined compression strength acquired from this project.

CHAPTER 3
PROJECT METHODOLOGY

3.1 Introduction

Project methodology shows the methods and the process of the project conducted. The Preliminary Research Works involved the research on the topic selection including the literature review on the related information regarding the mining sand and also interviews of organizations involve directly and indirectly to the construction that using mining sand as construction material. This stage was conducted during the early period of the project.

The Field Work is conducted to allocate the site of abandoned tin mine for sampling purposes. The location for mining sand for sampling in this project is at Tronoh that is approximately 3km from Universiti Teknologi Petronas.

The Laboratory Work is the laboratory procedures and tests conducted for the sample collected to find the parameters needed for analysis. The experiment conducted should meet the objectives listed. These laboratory works will be conducted in geotechnical lab in university and depends on the availability of equipment in the lab.

The result from experiment conducted will be analyzed. Any problems related to collected data, experiment conducted and the result of experiment will be discussed.

The project methodology for this project is as shown in the flow chart in Figure 3.1.

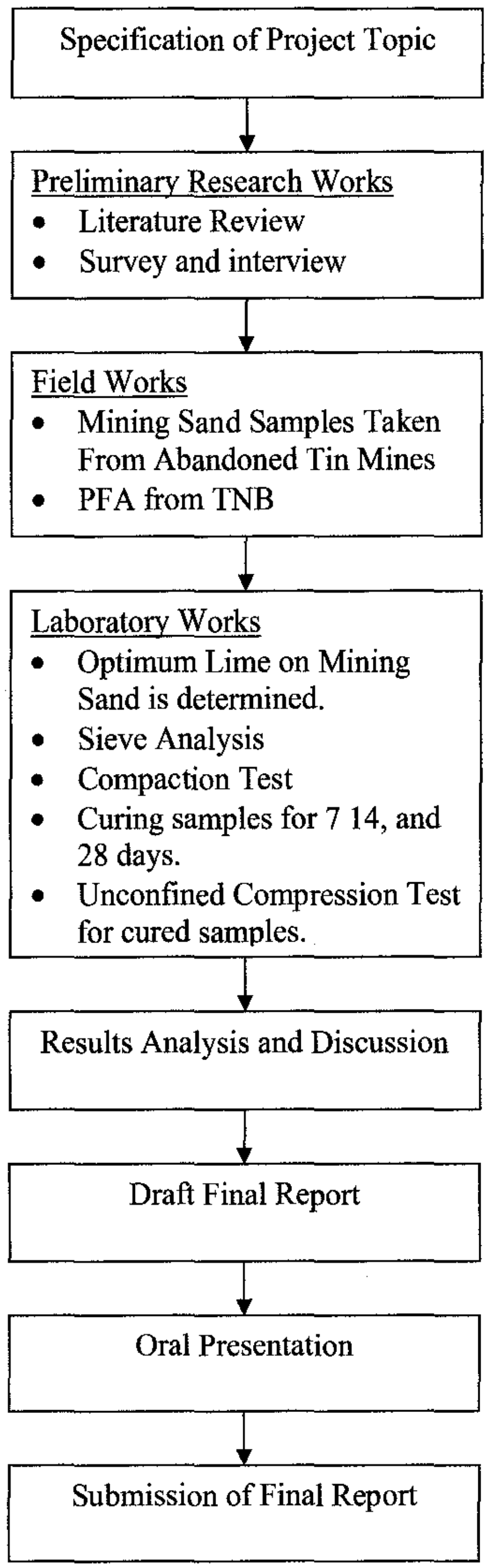


Figure 3.1: Project Methodology flow chart for this project

3.2. Sample Preparation.

Mining sand was taken from abandoned tin mines location called Tasik Putra just besides Universiti Teknologi Petronas. Mining sand taken was oven dried for 24 hours before conducting experiment. Pulverized Fuel Ash (PFA) was obtained from TNB Coal Generator at Manjung and PFA is keep sealed inside container and taken when necessary. Lime was obtained from laboratory storage and kept from moisture to avoid the lime from hardening.

3.3. Determine Optimum Lime for Mining Sand.

If the maximum density of the soil is higher, the better compaction of the soil could be achieved. The optimum lime for mining sand will be determined based on the proctor test conducted for each of samples of lime ranged from 0% until when the maximum density of the mixtures had reduced. The graph of maximum density versus percentage of lime is plotted to observe the optimum lime that is when the maximum density is the highest.

3.4. Mixtures Percentage for mixing between mining sand with PFA and lime.

For this project, the mixtures were mixed based on the PFA percentage and lime percentage. The mining sand amount is based on the remaining percentage after PFA and lime. The optimum lime should be fixed throughout the experiment because in the mixtures, lime will act as an additive to promote cementitious reaction in the mixtures. The increment 5% of PFA for each of mixtures is conducted until 25% of PFA. Table 3.1 shows the percentage of mixtures distribution for each of mixtures based on 10% optimum lime obtained from proctor test.

Table 3.1: Percentage mixtures distribution for PFA range from 5% until 25%

Mixtures	Mining Sand (%)	PFA (%)	Lime (%)
Mix 1	85	5	10
Mix 2	80	10	10
Mix 3	75	15	10
Mix 4	70	20	10
Mix 5	65	25	10

3.5. Curing Process for Mixtures.

The mixtures were extracted from mould into cylindrical shape for unconfined compression test. For the curing of mixtures, the mixtures were wrapped in moisture proof bags and stored in a humid room to cure before testing (Consoli, N. C. et al, 2001). The samples are cured for 7, 14 and 28 days before unconfined compression tests conducted.

Table 3.2: Amount of samples taken for curing period on each of the mix

Mixtures	Amount of Samples per Curing Period		
	7 days	14 days	28 days
Mix 1	2	2	2
Mix 2	2	2	2
Mix 3	2	2	2
Mix 4	2	2	2
Mix 5	2	2	2
Total	10	10	10

3.6. X-Ray Fluorescent.

The XRF method is widely used to measure the elemental composition of materials. Since this method is fast and non-destructive to the sample, it is the method of choice for field applications and industrial production for control of materials. Depending on the application, XRF can be produced by using not only x-rays but also other primary excitation sources like alpha particles, protons or high energy electron beams. When a primary x-ray excitation source from an x-ray tube or a radioactive source strikes a sample, the x-ray can either be absorbed by the atom or scattered through the material. During this process, if the primary x-ray had sufficient energy, electrons are ejected from the inner shells, creating vacancies. These vacancies present an unstable condition for the atom. As the atom returns to its stable condition, electrons from the outer shells are transferred to the inner shells and in the process giving off a characteristic x-ray whose energy is the difference between the two binding energies of the corresponding shells. This testing was performed only by qualified person and small amount of PFA were given to the lab for XRF.

3.7. Laboratory Experiment for Mining Sand with PFA and Lime.

The laboratory experiment for this project was identified by considering certain condition that is the suitability of the experiment to mining sand sample and the availability of the experiment apparatus in the geotechnical laboratory in university. The identified experiments were stated in this section. (Head 1992)

3.7.1. Oven Drying (BS1377: Part 2: 1990: 3.2, and ASTM D2216)

A standard temperature of 105°C – 110°C is used for drying temperature. This temperature is suitable for mining sand due to absence of organic material and gypsum. This temperature will dry up all of the moisture content in the sample. The sample obtained from site should be packed properly to avoid moisture released to atmosphere. Sample was placed in clean and dry container and weighted. After that, the sample in the container was placed in the oven at the specific temperature. The drying in the oven should be continued until the specimen has reached the constant mass. (Head 1992)

3.7.2. Simple Dry Sieving (BS1377: Part 2:1990:9.3)

According to British Standard (BS1377), dry sieving may be carried out only for materials which give the same results as the wet-sieving procedure. The sample was place on the tray and allowed to dry in an oven at 105°C – 110°C. After drying to constant weight, the sample is cooled and weighed to accuracy within 0.1% or less of its total mass. The dried soil then placed on top of the sieve and shaken for enough of all particles to pass through the sieve. Each of sieve sizes then weighed with the sieved sample and empty pan sizes to find the weight retained on the pan. The required percentage passing is then calculated from the total mass and mass retained. For this experiment, Mix 1 until Mix 5 was sieved based on dry sieving method. Table 3.3 shows the sieve size opening used to sieve the mixtures.

Table 3.3: Sieve size opening used for sieving the mixtures

Sieve Size Opening	Percentage Passing
2 mm	xx
1.18 mm	xx
600 μm	xx
425 μm	xx
300 μm	xx
212 μm	xx
150 μm	xx
63 μm	xx
pan	xx

3.7.3. Proctor Test (BS1377: Part 4:1990:3.3)

The proctor test is performed to establish maximum dry density and the optimum moisture content of mixture. There are 6 samples were prepared for proctor test. For each of the sample, initial amount used is 4% and then compacted in three equal layers with a 2.5 kg hammer by delivers 27 blows with a 30.5 mm drop to each layer. For each of compaction, the water increased by 2% for sandy soil for 3 kg of mixtures based on BS1377: Part 4:1990:3.3. The proctor test conducted for this experiment is twice for each of the mixtures. The first compaction is to find the dry density relationship based on the moisture increment and the second compaction is to prepare samples for unconfined compression test.

3.7.4. Unconfined Compression Test (BS1377: Part 7:1990:7.2)

Unconfined compression test is a common practice to determine the strength of stabilized materials. Unconfined compression tests were conducted in accordance with ASTM D2166-85 (1985). Specimens were cured to study the effect of pozzolanic reaction on shear strength of the soil (Ghosh and Subbarao, 2007).

Unconfined compression test a cylindrical specimen of cohesive soil is subjected to a steadily increasing axial compression until failure occurs. The test provides an immediate approximate value of the compression strength of the soil. The compression is applied to the specimen at selected rate and the simultaneous reading of the force-measuring device and the axial deformation gauges at regular intervals of compression are recorded (BS1377, 1990).

The samples prepared for unconfined compression test is at 76mm long and 38mm diameter. The amount of samples used to conduct unconfined compression test for this project is in table 3.4.

Table 3.4: Samples Prepared for Unconfined Compression Test

Mixtures	Sample Quantity	Curing Period	Total Samples
Mix 1	2	7	6
	2	14	
	2	28	
Mix 2	2	7	6
	2	14	
	2	28	
Mix 3	2	7	6
	2	14	
	2	28	
Mix 4	2	7	6
	2	14	
	2	28	
Mix 5	2	7	6
	2	14	
	2	28	
Total Samples Prepared			30

For this experiment, each of the mix consists of 6 samples and cured for 7, 14 and 28 days. The total quantity of overall mix samples is 30 samples.

3.8. Project Hazards Assessment

Hazard is defined as danger or risk or anything that can cause harm such as chemical, electricity, and many more (Oxford Dictionary, 1994). Risk is the chance or possibility of danger, loss, and injury, and also defined as person or thing causing a risk or regarded in relation to risk (Oxford Dictionary, 1994). Danger is liability or exposure to harm and thing that causes or may cause harm (Oxford Dictionary, 1994). A hazard may be present but there may be little danger because of the control precautions taken.

3.8.1. Noise Hazard From Sieve Machine

Noise hazard from the machine was identified when the hearing is nearly ear to mouth speak so that the person could hear. This condition had met the noise hazard requirement that needs a person to shout or talk loudly to be understood by someone with 1 meter. There are few cases that having ringing or buzzing noises in ears at the end of the sieve machine work. When conducting sieve machine, ear plug and ear cuff should be used to avoid the noise hazard affecting a person.

3.8.2. Heat Hazards from Drying Oven

The oven could burn skin if touches the grill at the oven. Few people had scars on their hand due to burning from the oven. Precaution should be made by wearing glove and protection to avoid burn cases that lead to serious injuries.

3.8.3. Dust Hazard from Soil and Lime

The lime dust could cause skin irritation and rash. This occurs due to hydration activities from the lime when exposed to the moisture. This hydration activity could absorb skin moistures and caused rash and irritation. Also inhalation of lime dust could cause respiratory problem if exposed in long period. Wear mask to avoid the inhalation of lime and always wash skin exposed to the lime dust.

CHAPTER 4

RESULT AND DISCUSSION

4.1. X-Ray Fluorescent for PFA.

The x-ray fluorescent is used to determine the class of PFA. The result for PFA samples is in Table 4.1:

Table 4.1: Classification of PFA used on the mixtures based on XRF results

Class	C	
XRF for Chemical Composition (%)	MgO	2.14 %
	SiO_2	26.5 %
	Al_2O_3	10.5 %
	Fe_2O_3	29.7 %
	K_2O	1.25 %
	CaO	7.49 %
	SO_3	1.38 %
	CuO	1.21 %
	SrO	2.28 %
	ZrO_2	0.807 %
	Re	8.92 %
Silicon dioxide (SiO_2) plus aluminium oxide (Al_2O_3) plus Iron Oxide (Fe_2O_3), %	66.7 % > 50 %	
Sulfur trioxide (SO_3), %	1.38 % < 5 %	

The PFA used for this project is classified as Class C and also contain CaO for 7.49% which could react with moisture for cementitious reaction.

4.2. The percentage of optimum lime for mining sand.

Figure 4.1 shows the result from the standard proctor test conducted on mining sand mixed with various percentage of lime addtive.

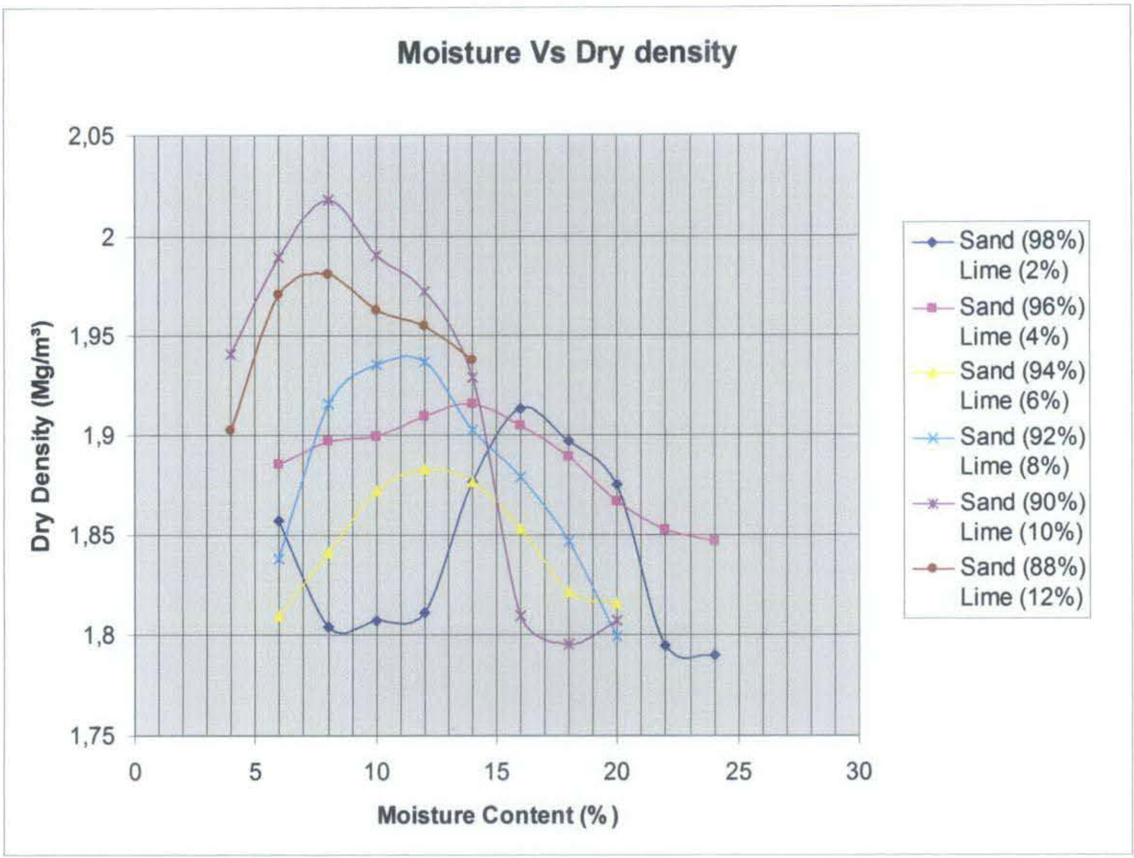


Figure 4.1: Moisture content versus maximum dry density from standard proctor compaction for mining sand mix with various percentage of lime.

From the result in Figure 4.1, the maximum dry density for each of percentage was analyzed. From this graph, we can observe that the optimum moisture content is reducing as the percentage of lime is increased. This shows that the lime had filled the voids in the mixtures and less softening agent is required for the compaction. Figure 4.2 shows the various percentage of lime mixed with mining sand versus the maximum dry density obtained from the standard proctor test.

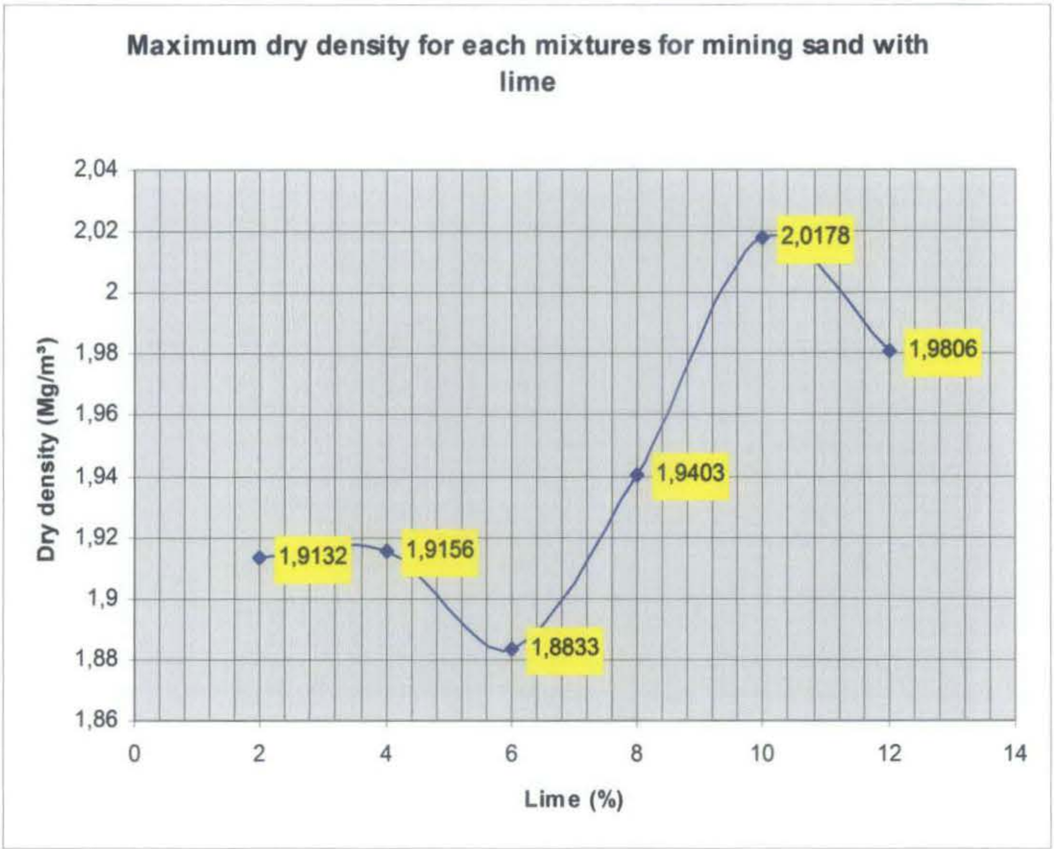


Figure 4.2: Percentage lime versus maximum dry density for the various percentage of lime used in each of the sample mixtures.

From the Figure 4.2, the 10% of lime was selected as optimum lime because of the highest value for this percentage that is 2.0178 Mg/m^3. The 10% of lime mixture is selected and mixed with each of the mixtures for mining sand with PFA and lime.

4.3. Sieve analysis for the samples.

The data for the percentage passing is in the Figure 4.3:

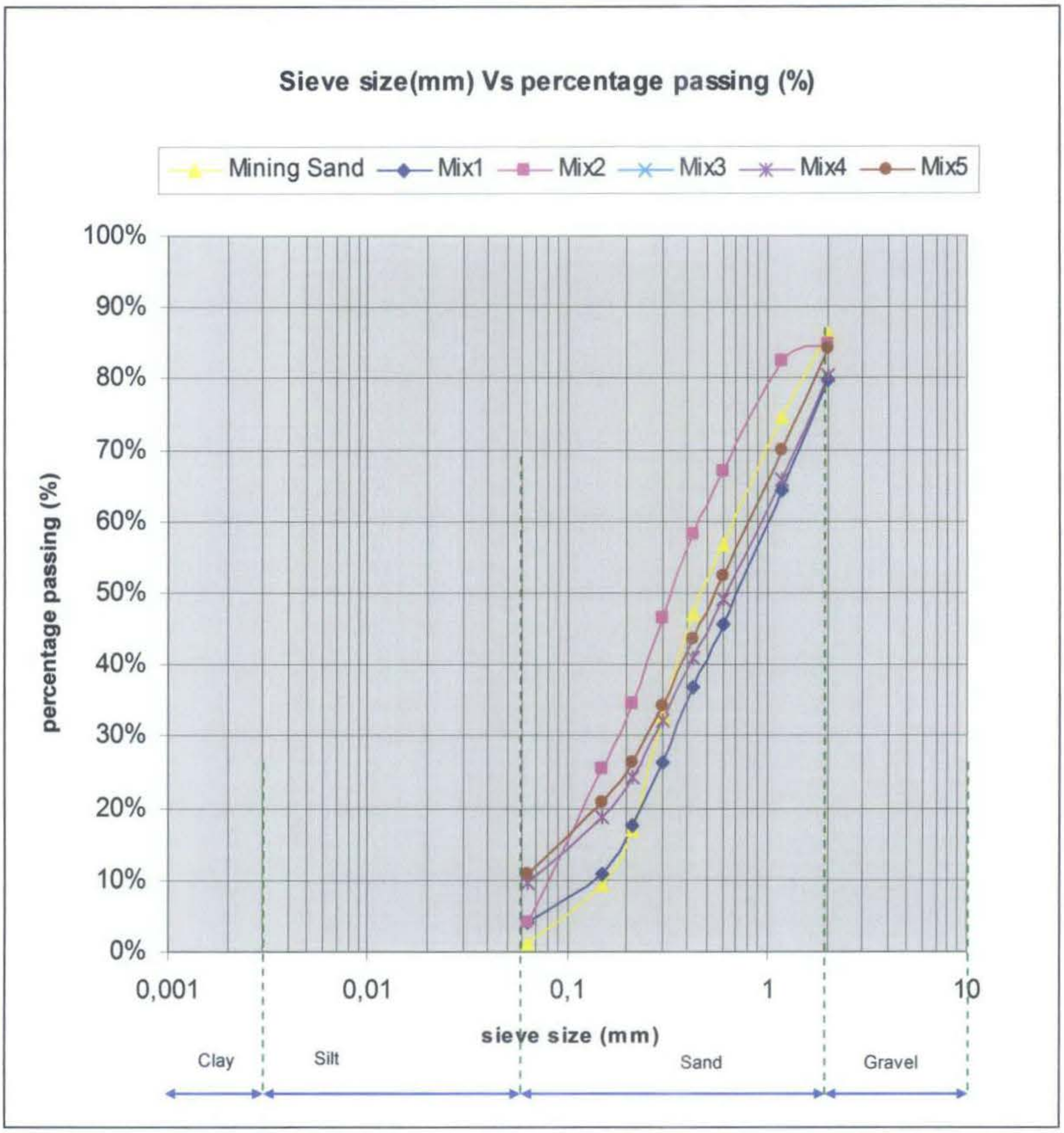


Figure 4.3: Particle size distribution graph for each of the mix.

Figure 4.3 shows that as the percentage of PFA increased, the curve of the graph is also improved from poorly graded curve into well graded curve. This show significant improves in the fine particles of mixtures. The fine particles improvement had shown that the PFA is acting as filler for voids in mining sand.

The percentage for each of the component on each mixture is as in Figure 4.4:

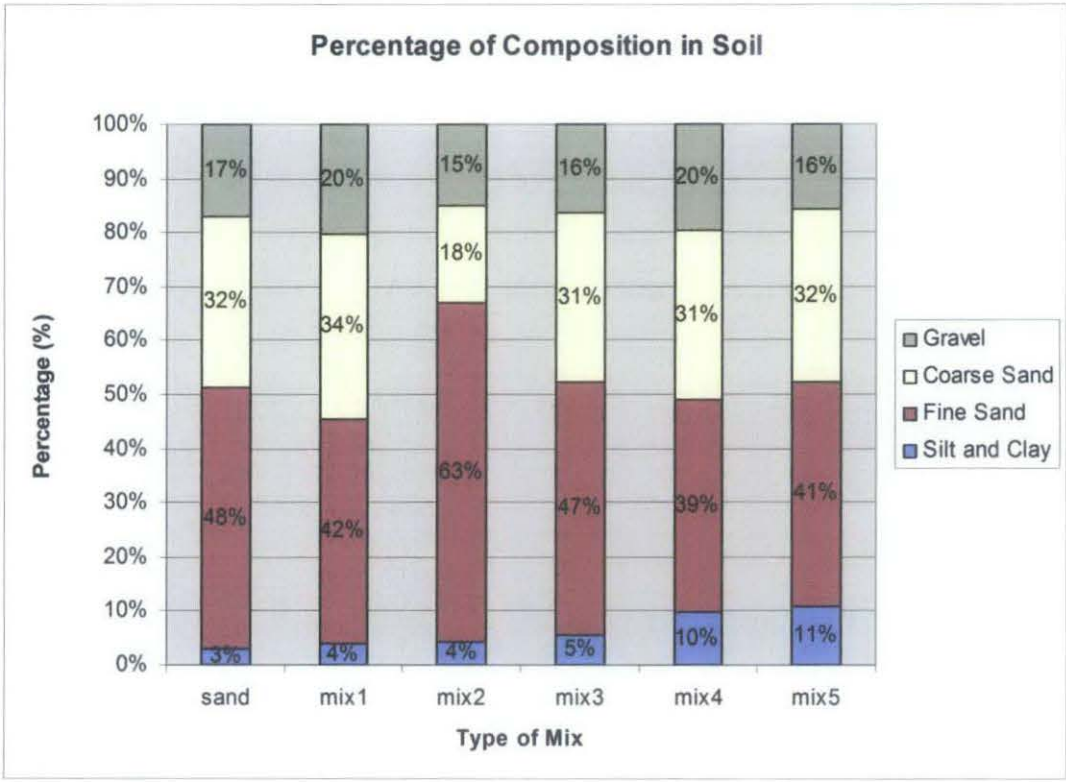


Figure 4.4: Percentage of particle based on particle size ranges of soil.

From the composition results, the value of silt and clay was increased when amount of PFA is increased. This shows that PFA in the samples had successfully filled the voids in the mixtures as in particle size distribution curve.

From the Figure 4.4, we could say that the sand had changed from poorly graded sand to become silty sand due to PFA increment of amount of silt and clay in the samples. The amount of increment is from 3% in the original mining sand to 11% for Mix 5. This increment had changed the sand from the poorly graded soil into silty soil.

4.4. Results of Specific Gravity of mixtures.

The result for specific gravity (SG) for each of mixtures is as in Figure 4.5.

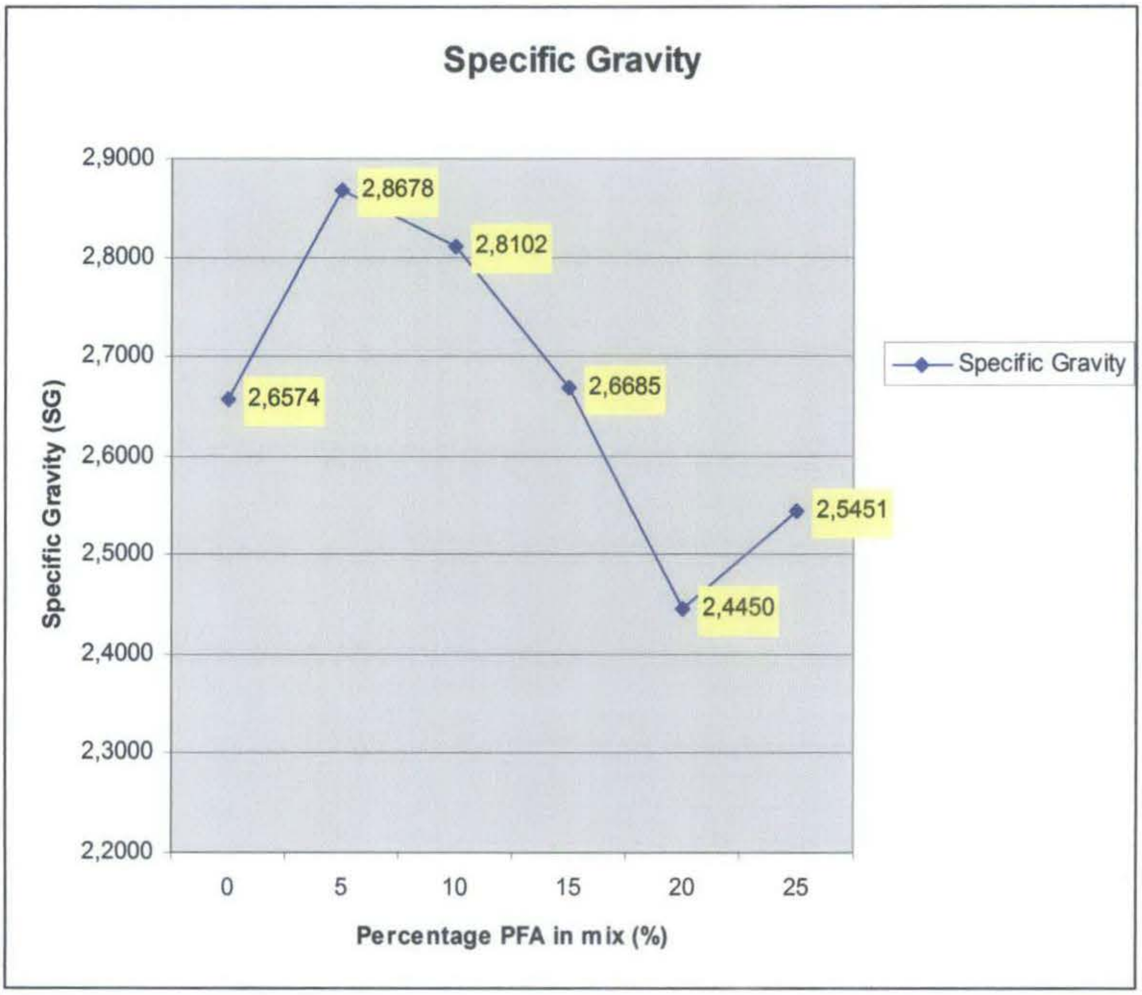


Figure 4.5: Specific gravity for mixtures of mining sand with PFA and lime based on percentage of PFA in each mix.

From the Figure 4.5, there is reduction on specific gravity when PFA is increased from 5% percentage until 20% percentage of PFA from 2.8678 to 2.4450. This is because PFA is a lightweight material and the reduction of the amount of mining sand. These two factors had contributed to loss of specific gravity in the mixtures.

4.5. Results of Standard Proctor Test.

The data between optimum moisture versus maximum dry density was obtained from the standard proctor test. The result for the moisture content versus compaction is in the Figure 4.6.

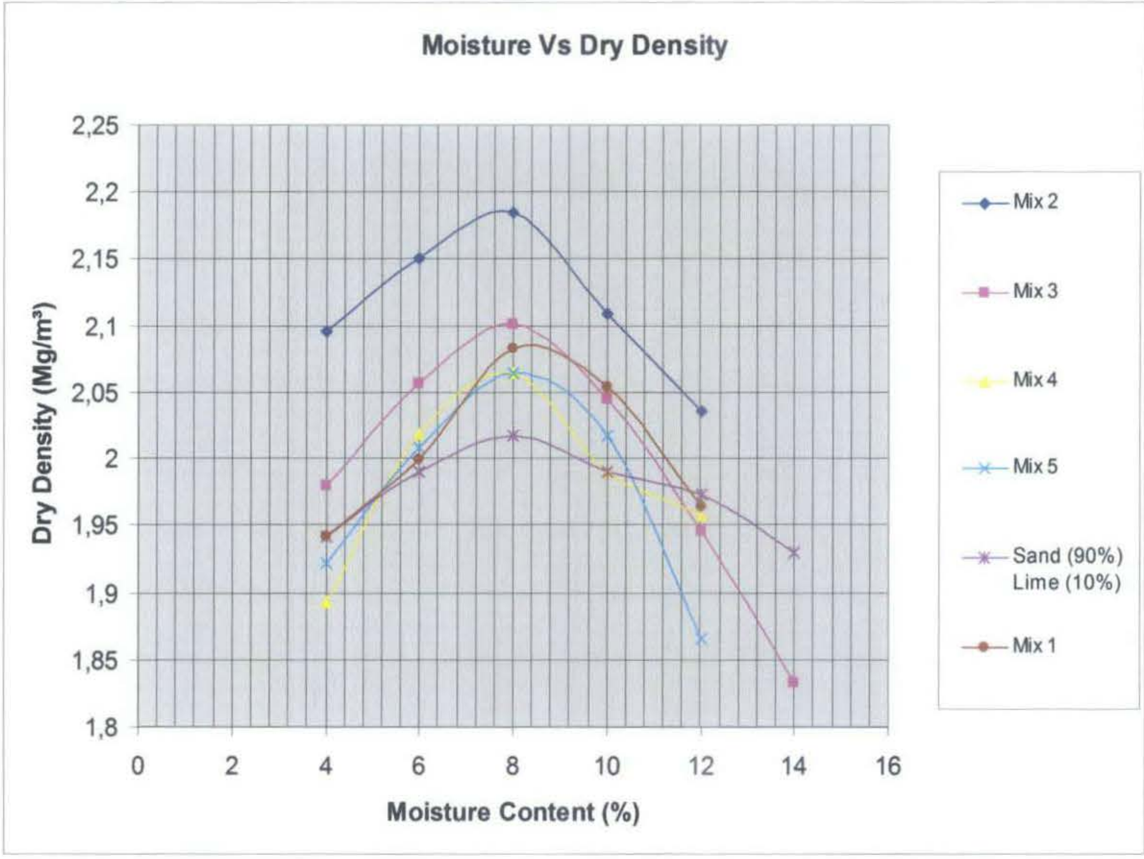


Figure 4.6: The moisture content versus dry density obtained from the standard proctor compaction test.

From the Figure 4.6, it shows that the moisture content of 8% is at optimum for each of the mixture. The optimum PFA also is on the Mix 2 where Mix 2 is the highest maximum dry density obtained. The analyzed data for each of the mixtures based on the maximum dry density is shown as in Figure 4.7.

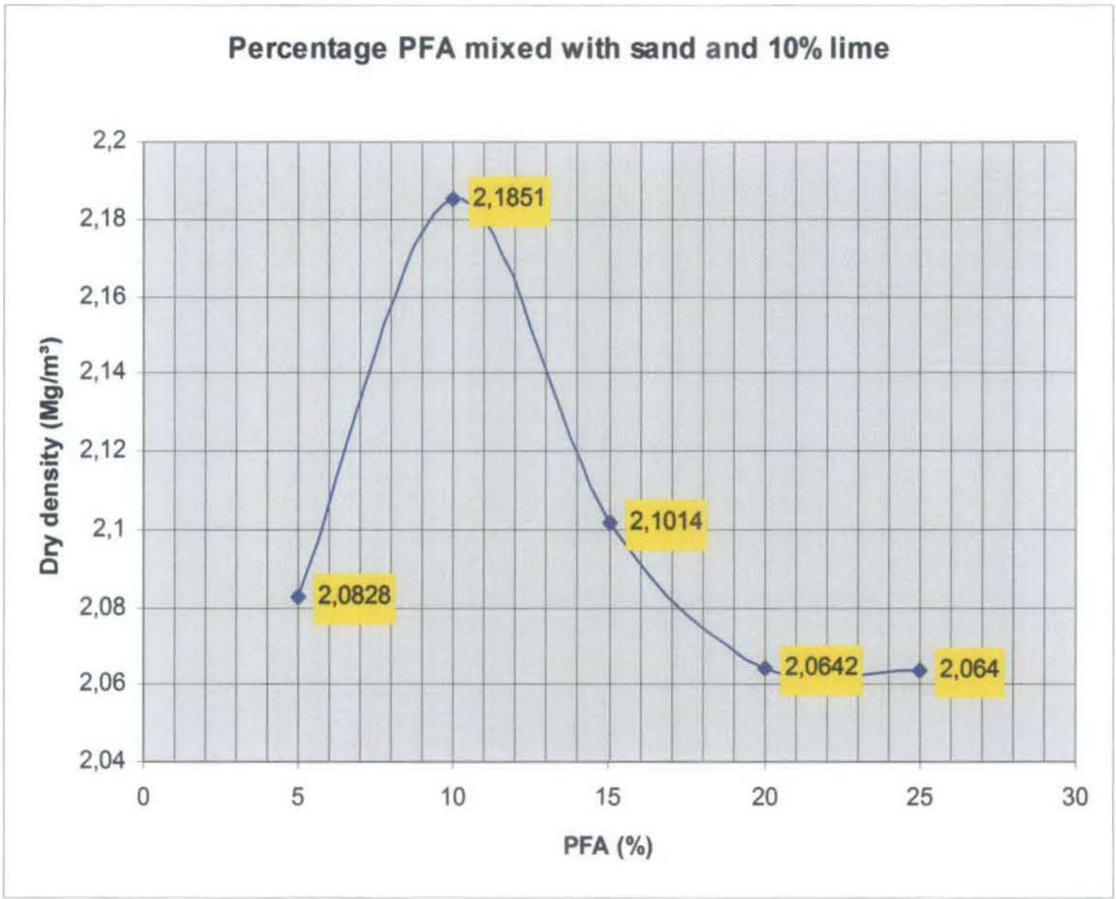


Figure 4.7: The maximum dry density for each mixture.

From the graph in Figure 4.7, the dry density of the sample mixtures had significantly reduced from 2.1851 Mg/m^3 to 2.064 Mg/^{3} when the percentage amount pulverized fuel ash (PFA) was increased from 10% to 25%. The decrease of dry density had occurred due to the reduction of the sand in the mixtures when the PFA was increased. This shows that when the percentage amount of PFA is increase, the mixture become harder to be compacted. From the proctor test based on the highest dry density, the maximum compaction for mixtures could be achieved when the mixtures was at Mix 2. This is because in the Mix 2, the increasing fine particles were already at 20% including percentage lime added to the mixture.

4.6. Unconfined Compression Test for 7, 14 and 28 days curing soil mixed with PFA and lime additive.

The unconfined compression test result for each of the mix is shown in the Figure 4.8.

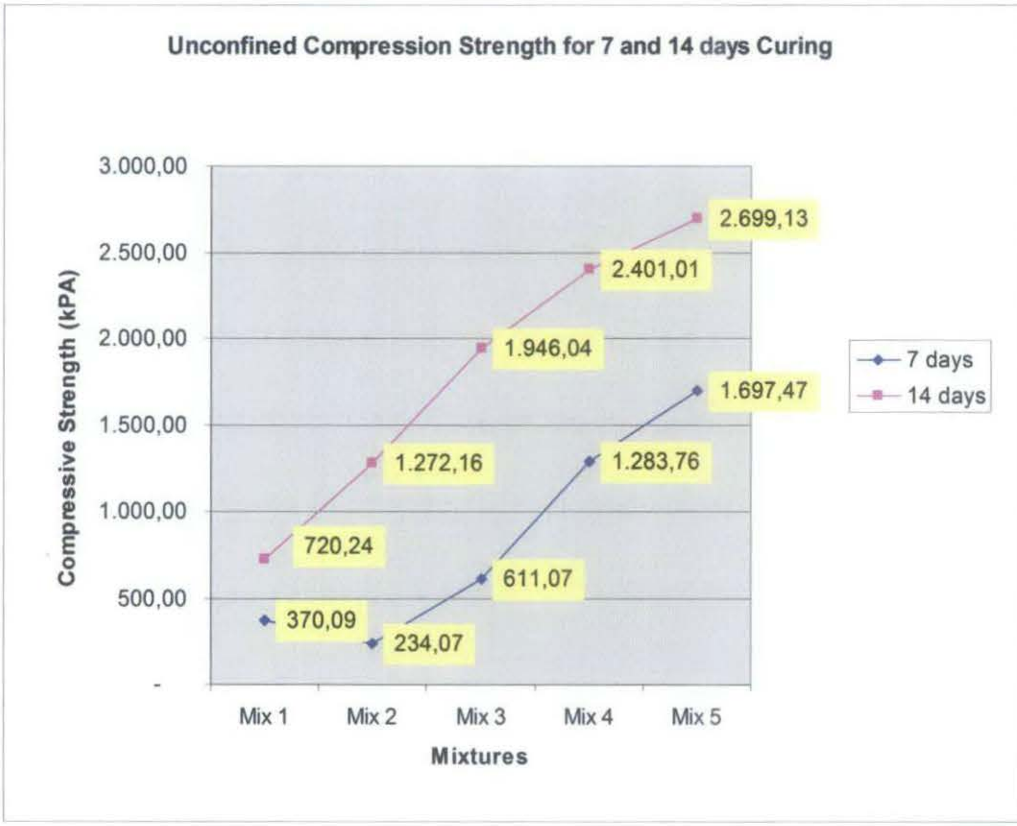


Figure 4.8: Unconfined compression strength for mixtures based on percentage of PFA and curing for 7 and 14 days.

The graph shows significant increase on the strength of the mixtures based on the PFA increment and the curing period. Figure 4.9 shows the unconfined compression test for 28 days curing period.

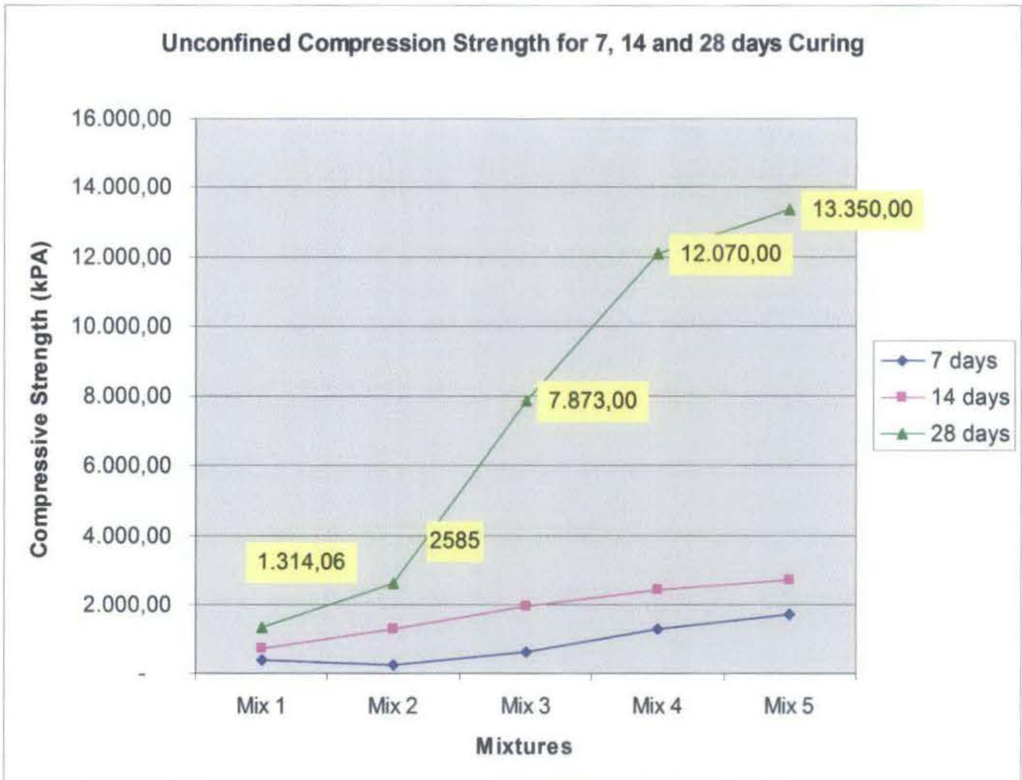


Figure 4.9: Unconfined compression strength for each of mixtures based on percentage of PFA and curing for 7, 14 and 28 days.

From the unconfined compression test result, the undrained shear strength was acquired. Figure 4.10 and Figure 4.11 shows the undrained shear strength for each of the mixtures based on the curing period and the percentage of PFA in each of mixtures.

Figure 4.10: Undrained Shear Strength for each of mixtures based on percentage of PFA and 7 and 14 days curing period

Based on the result of the undrained shear strength in Figure 4.10 and Figure 4.11, the amount of undrained shear strength at 7 days for Mix 1 is 185.05 kPA and for Mix 5 is at 848.74 kPa. This shows the significant increase of undrained shear strength as the PFA percentage was increased. From this increment, it shows that the percentage amount of PFA had affected the amount of undrained shear strength.

Mix 3 for 7 days undrained shear strength was at 305.53 kPa while for 28 days of curing was at 3.935 MPa. This value of undrained shear strength had shown that the curing period also affect the mixtures. The undrained shear strength is increased for longer curing period.

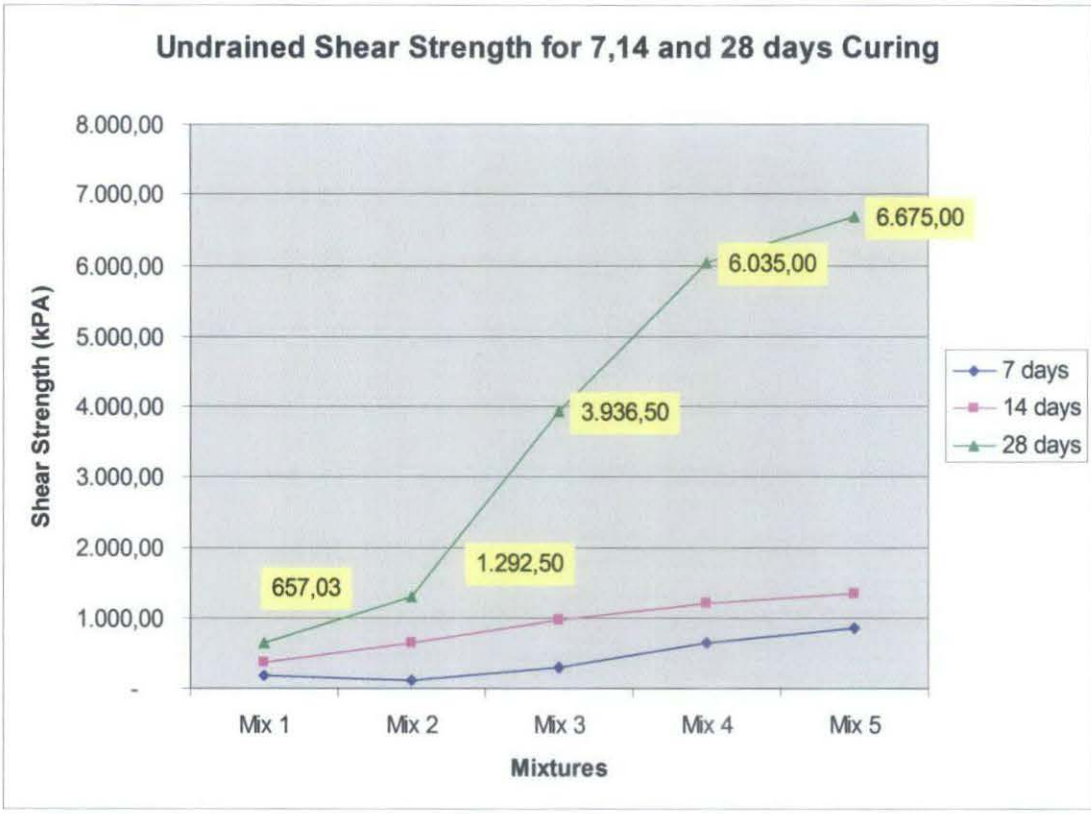


Figure 4.11: Undrained Shear Strength for each of mixtures based on percentage of PFA and 7, 14 and 28 days curing period.

Based on the result obtained, as for more percentage of PFA, the reaction is increased. This is because of the increasing occurrence of lime itself in the PFA that increase the cementitious reaction in the mixtures. The curing period also had affected the undrained shear strength of the mixtures. The difference can be observed for Mix 3 that is at 305.53 kPa for 7 days while at 3.935 MPa for 28 days of curing. This value had shown that for more curing period, the higher strength of mixtures could be achieved.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The 10% of lime was determined as the optimum lime from the experiment conducted and this was fixed through the mixtures with PFA. The sieve analysis for each of the mixtures shows significant increase on percentage of the silt and clay that was for 3% of raw mining sand to 11% for Mix 5. This had occur because the PFA size is mostly silt and clay size, and the percentage shows that PFA is acting as filler in void for each of the mixtures. The standard proctor test conducted on the samples shows that the highest maximum dry density could be achieved for 2.1851 Mg/m^3 when the amount of PFA 10% in Mix 2. Thus, the optimum percentage for maximum compaction for mixture could be considered was at Mix 2. The maximum dry density then reduced as PFA was increase throughout the result analysis from 2.1851 Mg/m^3 at Mix 2 to 2.064 Mg/m^3 at Mix 4. This shows that when the percentage amount of PFA is increase, the mixture become harder to be compacted.

The Undrained Shear Strength shows significant increase based on curing period and the increasing percentage of PFA. The highest undrained shear strength occurs at Mix 5 for 28 days curing period that is at 6.675 MPa. This shows that as the percentage of PFA is increased, the undrained shear strength also increased. For more percentage of PFA, the cementitious reaction is increased because of the increasing occurrence of lime itself in the PFA. The curing period of the mixtures also affect the undrained shear strength. For longer curing period, the undrained shear strength is higher as shown for Mix 3 that is at 305.53 kPa for 7 days while at 3.935 MPa for 28 days of curing.

5.2. Recommendation

The percentage of the Lime 10% for each of the mix based on the optimum lime can be reduced to 4%. This is because the graph shows double peak curve and thus 4% lime can also be considered as optimum lime. If lime can be reduced, the cost for implementation on site also can be reduced significantly because the cost of lime is quite expensive. This project should continue of 4% lime for each of the mixtures to observe the effect of lime reduction on undrained shear strength for each of the mixture.

The curing period for mixtures should be increased to more than 28 days to observe the effect of the cementitiouss reaction of mixtures. Unlike concrete, the reaction in soil could go through more than 28 days. This was shown in the journals that observe the curing effect for samples to 180 days (Consoli, N. C et al, 2001).

The curing condition for mixtures should be in soaked and unsoaked condition. For each of mixtures, the samples should be place in water to observe the cementitious reaction at high moisture condition. This is because if there are more amount of moisture occurs, the higher cementitious reaction could be achieve and significantly increase the strength of the mixtures.

The unconfined compression equipment should be adjusted or replaced to cater the compressive strength of the samples. This is because the gauge of the force reading is already at limit while the samples did not failed. The actual reading for maximum compression strength was not acquired because the sample was not failed.

REFERENCES

Books

ASTM (2005). "*Annual Book of ASTM Standards.*"

Bell, F. G. (2000), "*Engineering Properties of Soils and Rocks, Fourth Edition.*" Blackwell Science, UK.

BS1377 (1990), "*British Standard Methods of test for Soil for civil engineering purposes.*" British Standards Institution.

Das, B. M. (2002), "*Principles of Geotechnical Engineering, Fifth Edition.*" Brooks / Cole, CA, US.

JKR/SPJ. (1988). "*Standard Specification for Road Works and Bridges (Volume 2).*" Jabatan Kerja Raya Malaysia.

K. H. Head (1992), "*Manual of Soil Laboratory Testing. Volume 1: Soil Classification and Compaction Test*" Prentech Press, London.

Lancellotta, R. (1992), "*Geotechnical Engineering.*" Zanichelli Editore S.p.A., Bologna.

RMK-9 (2006), "*Chapter 19: Sustainable Energy Development.*" Government of Malaysia.

Rollings, M. P., and Rollings, R. S. (1996), "*Geotechnical Materials in Construction*", McGraw–Hill, New York.

Oxford Dictionary (1994), "Pocket Oxford Dictionary" Oxford University Press, Walton Street, Oxford.

Journals

Consoli, N. C., Prietto P. D. M Carraro, J. A. H and Heineck K. S. (2001), "*Behavior Of Compacted Soil-Fly Ash-Carbide Lime Mixtures.*" Journal of Geotechnical and Geoenvironmental Engineering, ASCE.

Ghosh, A., and Subbarao, C. (2007), "*Strength Characteristics of Class F Fly Ash Modified with Lime and Gypsum.*" Journal of Geotechnical and Geoenvironmental Engineering, ASCE.

Ghataora, G. S., Alobaidi I. M., and Billam J. (2000)*"Use Of Pulverized Fuel Ash In Trench Backfill."* Journal of Geotechnical and Geoenvironmental Engineering, ASCE.

Lhantzis, (2006), "X-Ray Fluorescence (XRF)", Amptek Inc. 14 DeAngelo Drive, Bedford, MA 01730-2204 USA.

Phani Kumar, B. R. and Sharma R. S. (2004), "*Effect of Fly Ash on Engineering Properties of Expansive Soils.*" Journal of Geotechnical and Geoenvironmental Engineering, ASCE.

Interviews

Encik Othman, Technical Assistant, Bahagian Jurutera Daerah, Jabatan Kerja Raya (JKR) Perak Darul Ridzuan, Perak. Personal Interview. 3rd October 2007

Thesis

Siti Fairouz Yaakub 2007, "*The Maximum Dry Density & Optimum Moisture Content of Tronoh's Mining Sand*", Degree Bachelor Thesis, Universiti Teknologi Petronas, Tronoh.

APPENDICES

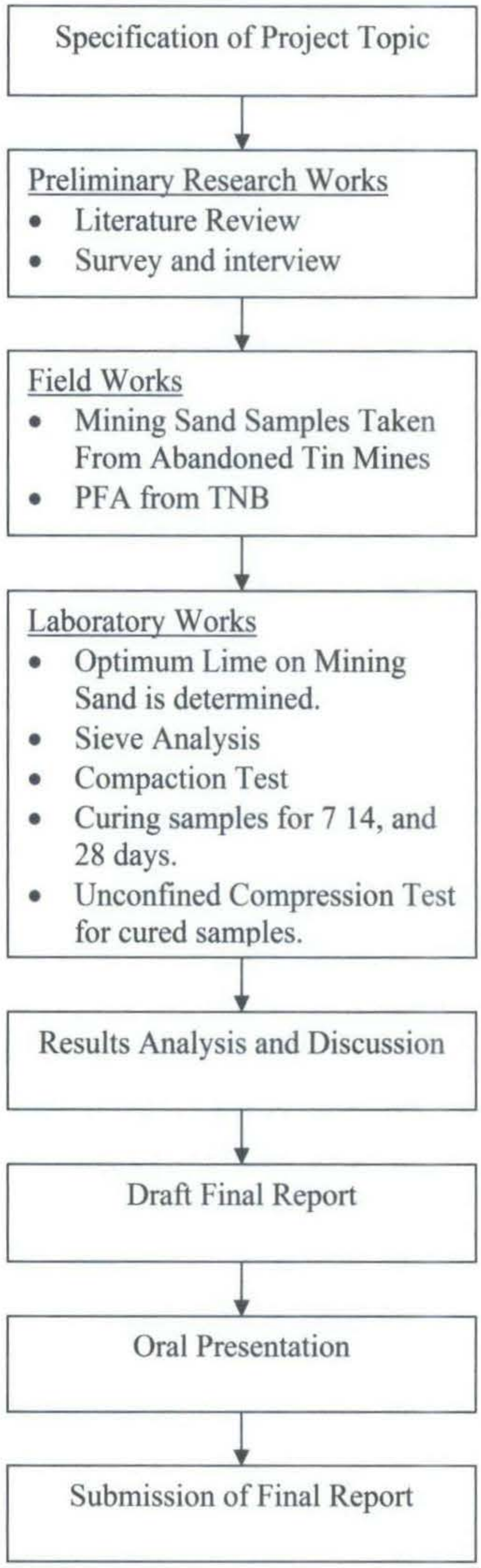
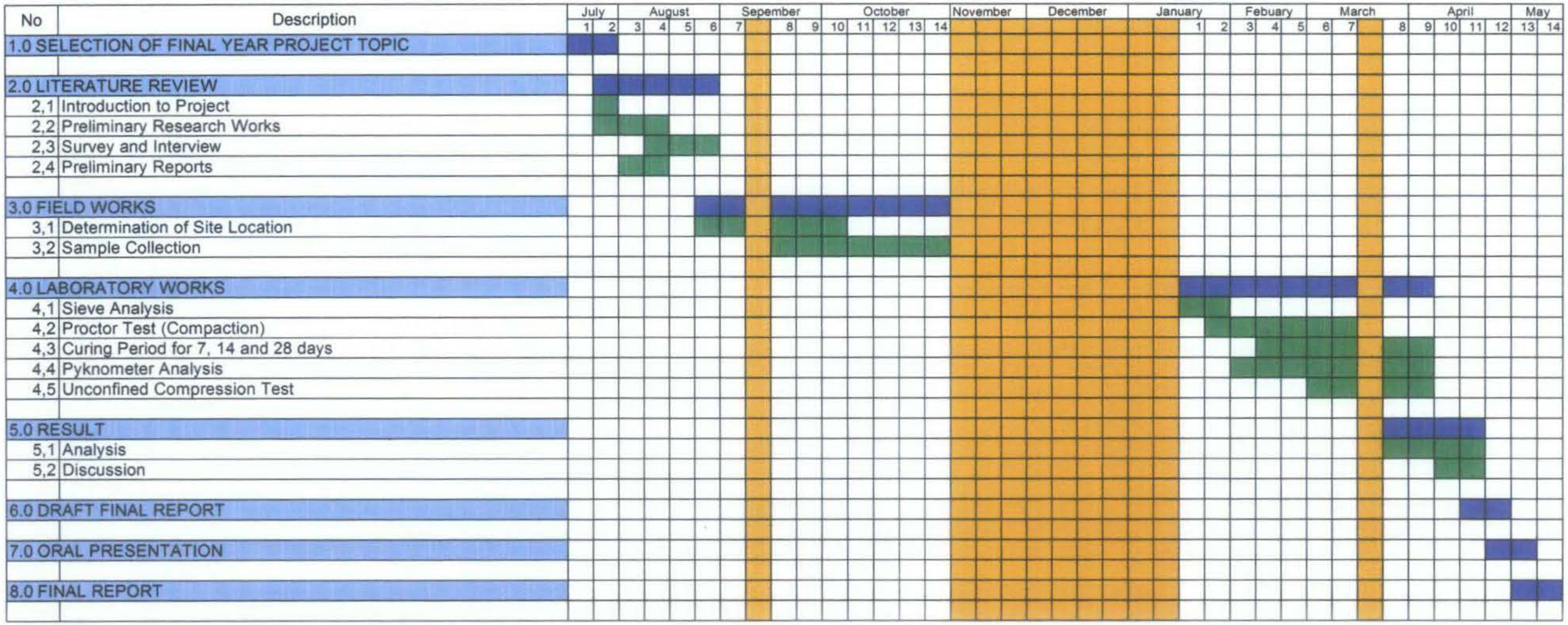


Figure : Project Methodology flow chart for this project

3.2. Project Planning Schedule



- Semester Break

- Main Progress

- Sub Progress

** FYP I is from July to October and FYP II is from January to May*

Project Planning Scheduled for Final Year Project I and

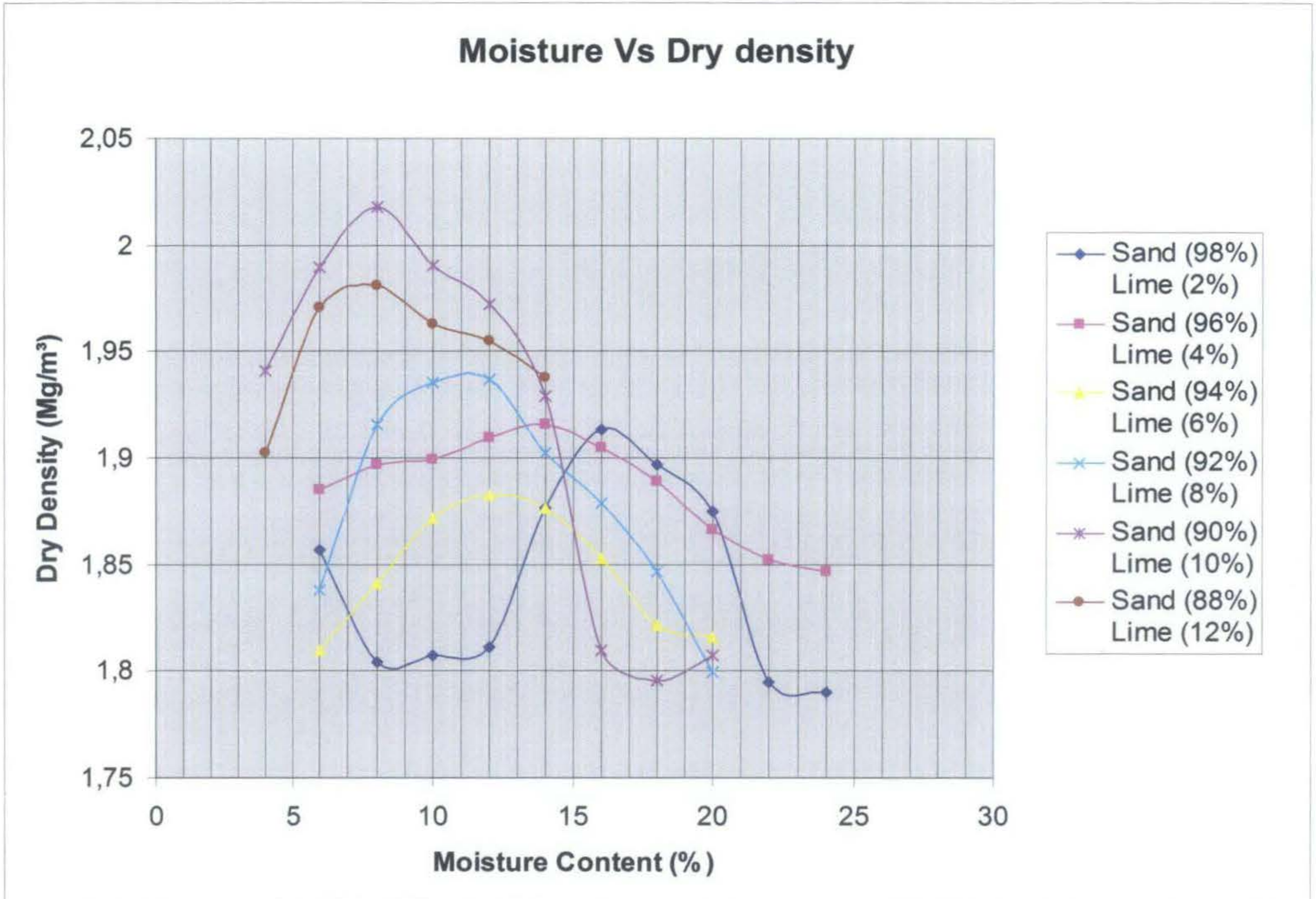


Figure : The moisture content versus dry density obtained from the standard proctor compaction test.

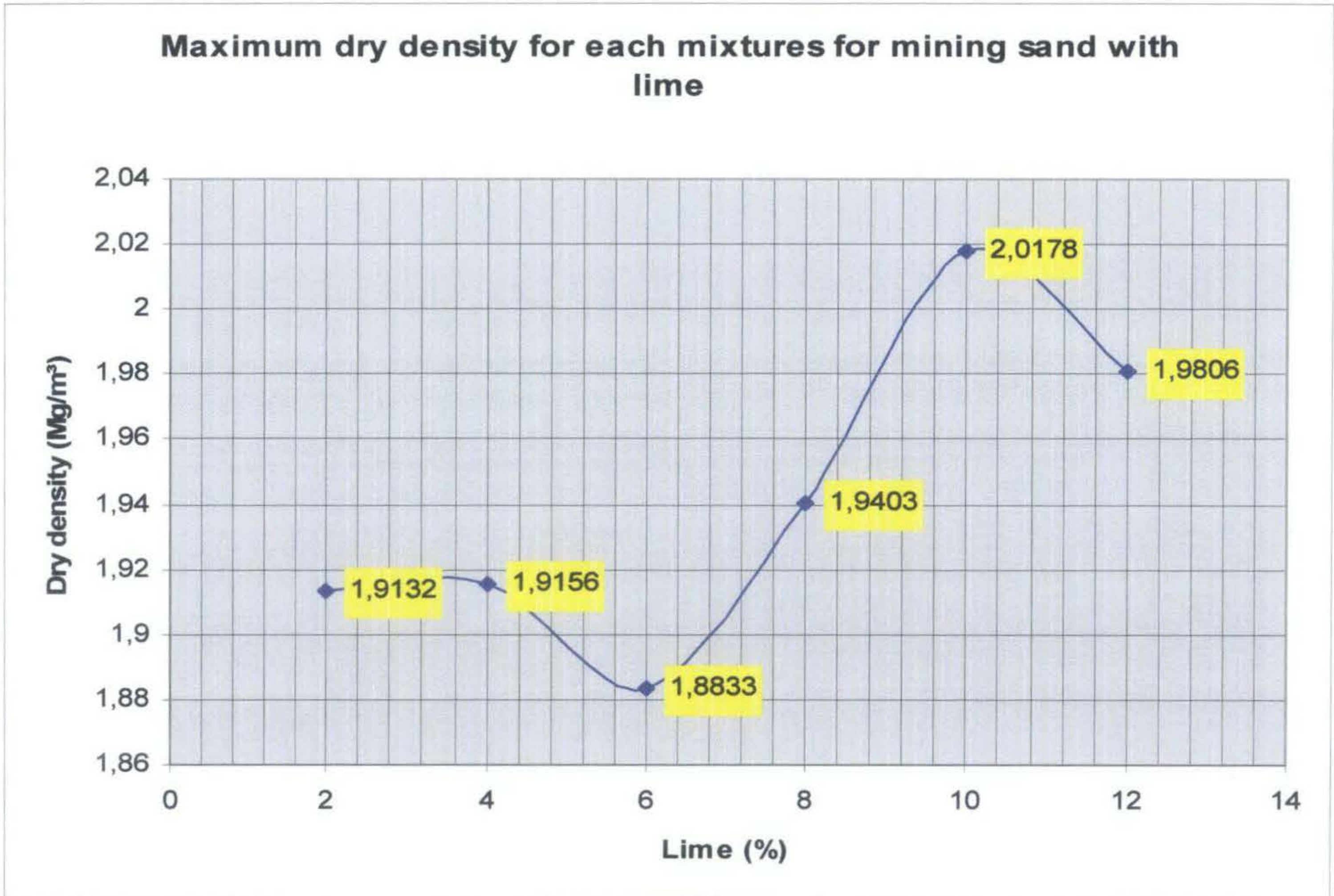


Figure: Percentage lime versus maximum dry density for the various percentage of lime used in each of the sample mixtures.

Table: Percentage passing for each of the samples for the sieve size opening

Sieve Size	Sand	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
2 mm	84%	80%	85%	84%	80%	84%
1.18 mm	68%	64%	82%	70%	66%	70%
600 µm	54%	46%	67%	52%	49%	52%
425 µm	44%	37%	58%	43%	41%	44%
300 µm	32%	26%	47%	33%	32%	34%
212 µm	20%	18%	35%	23%	24%	26%
150 µm	12%	11%	25%	17%	19%	21%
63 µm	2%	4%	4%	5%	10%	11%
pan	0%	0%	0%	0%	0%	0%

**Note: Mix 1 - Mining Sand (85) PFA (5%) Lime (10%)*
Mix 2 - Mining Sand (80%) PFA (10%) Lime (10%)
Mix 3 - Mining Sand (75%) PFA (15%) Lime (10%)
Mix 4 - Mining Sand (70%) PFA (20%) Lime (10%)
Mix 5 - Mining Sand (65%) PFA (25%) Lime (10%)

Table: Soil Classification for each of mixtures based on USCS

Sample	C_u	C_z	USCS Classification
Sand	3.78	0.65	SP, poorly graded sand, gravelly sand, little or no fines
Mix 1	5.92	0.72	SP, poorly graded sand, gravelly sand, little or no fines
Mix 2	5	0.8	SM, silty sand, sand-silt mixtures
Mix 3	10	0.98	SM, silty sand, sand-silt mixtures
Mix 4	15.2	1.32	SM, silty sand, sand-silt mixtures
Mix 5			Hydrometer Analysis Required

**Note: Mix 1 - Mining Sand (85%) PFA (5%) Lime (10%)*
Mix 2 - Mining Sand (80%) PFA (10%) Lime (10%)
Mix 3 - Mining Sand (75%) PFA (15%) Lime (10%)
Mix 4 - Mining Sand (70%) PFA (20%) Lime (10%)
Mix 5 - Mining Sand (65%) PFA (25%) Lime (10%)

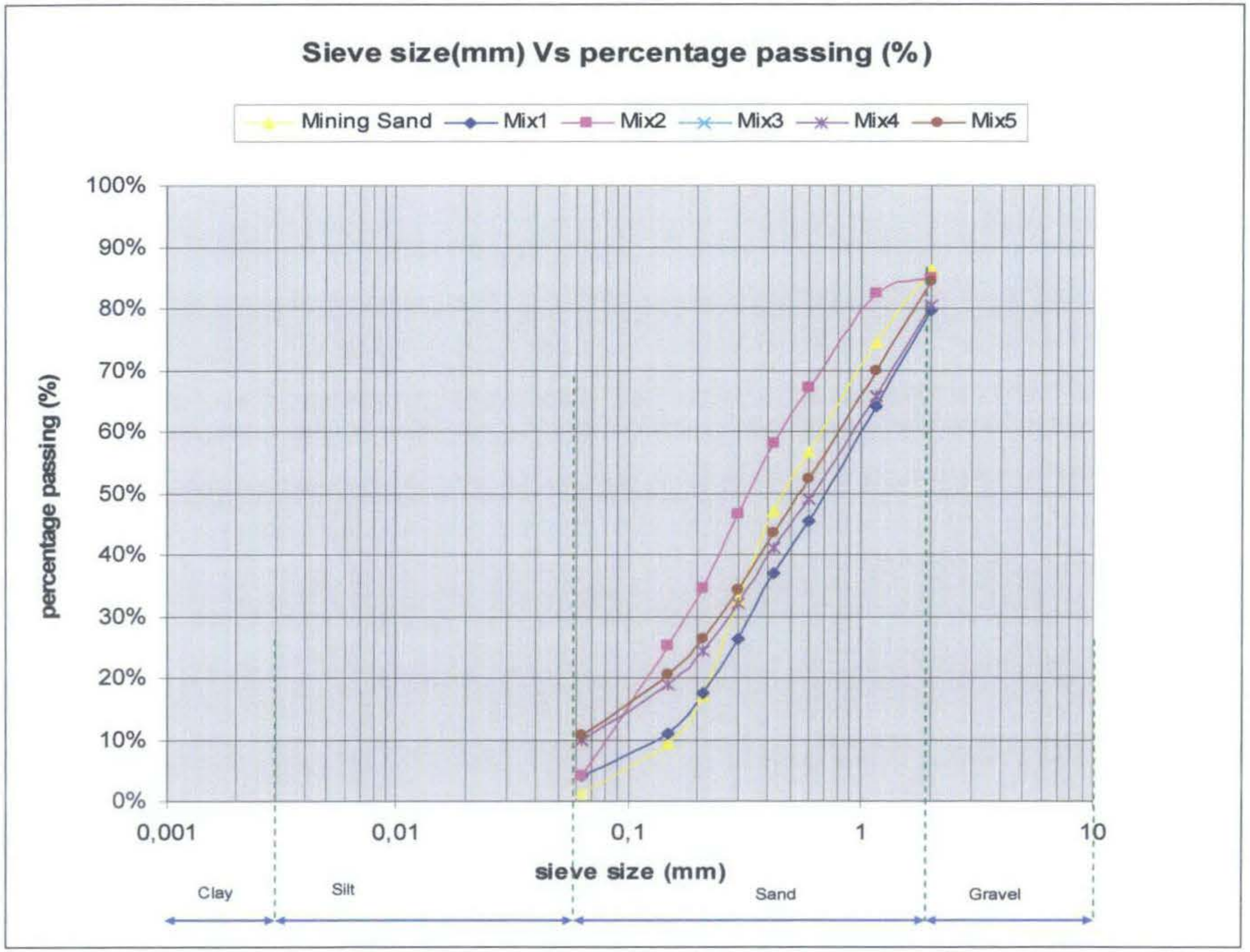
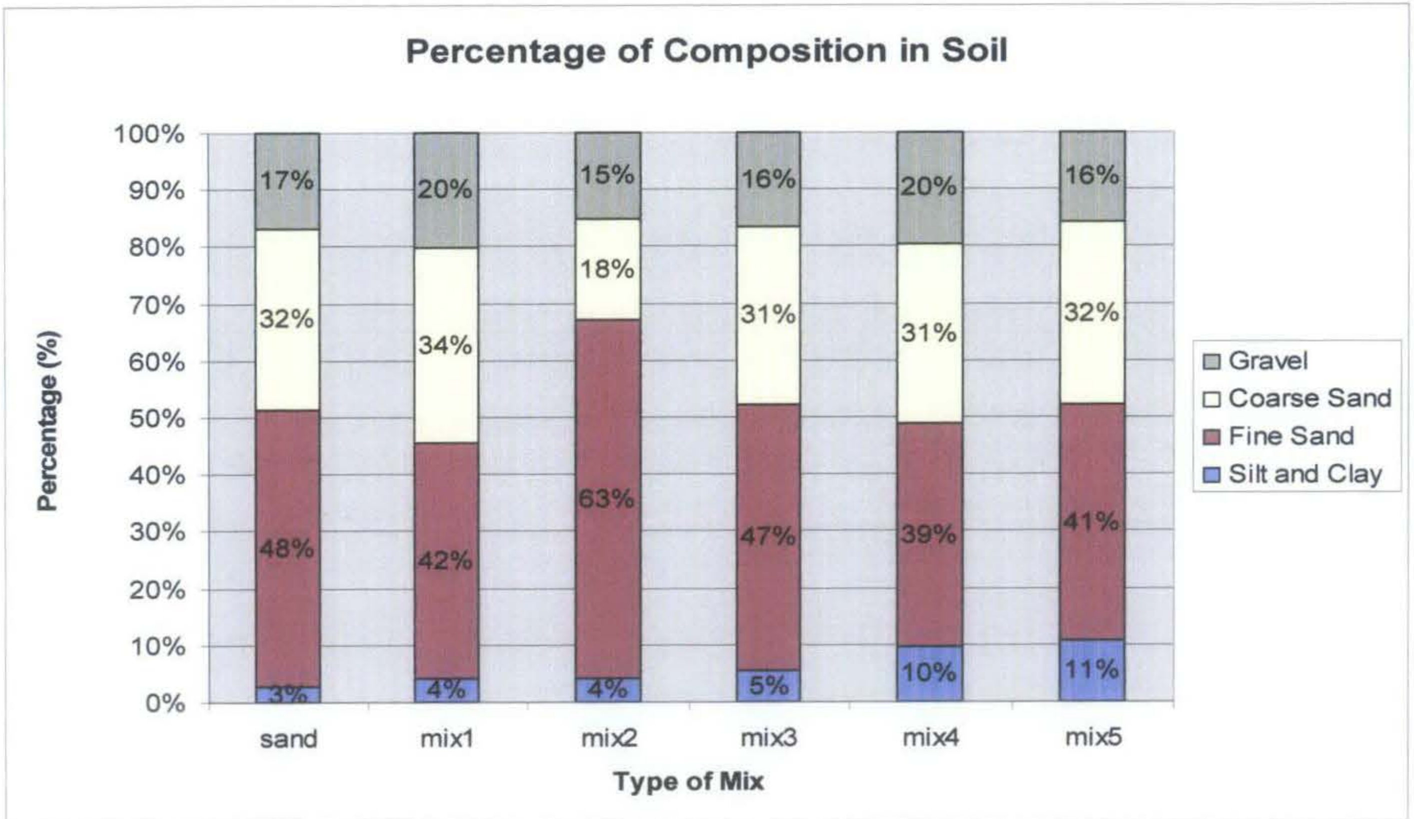


Figure: Moisture content versus maximum dry density from standard proctor compaction for mining sand mix with various percentage of lime.



Note: Mix 1 - Mining Sand (85) PFA (5%) Lime (10%)
Mix 2 - Mining Sand (80%) PFA (10%) Lime (10%)
Mix 3 - Mining Sand (75%) PFA (15%) Lime (10%)
Mix 4 - Mining Sand (70%) PFA (20%) Lime (10%)
Mix 5 - Mining Sand (65%) PFA (25%) Lime (10%)

Figure : Percentage of particle based on particle size ranges of soil.

Table: Data for Specific Gravity (SG) for Mining Sand and Mix 1 to Mix 5.

Mining Sand

	Mass (g)
Pyknometer + cap	537,36
Pyknometer + cap + sand	941,04
Pyknometer + cap + sand + water	1820,69
Pyknometer + cap + water	1568,92
Mass of Soil	403,68
Mass of water in full jar	1031,56
Mass of water used	879,65
Volume of soil particles	151,91
Particle density (SG)	2,657

Mix 1
Mining Sand (85%) PFA (5%) Lime (10%)

	Mass (g)
Pyknometer + cap	535,98
Pyknometer + cap + sand	939,8
Pyknometer + cap + sand + water	1812,49
Pyknometer + cap + water	1549,48
Mass of Soil	403,82
Mass of water in full jar	1013,5
Mass of water used	872,69
Volume of soil particles	140,81
Particle density (SG)	2,868

Mix 2
Mining Sand (80%) PFA (10%) Lime (10%)

	Mass (g)
Pyknometer + cap	535,78
Pyknometer + cap + sand	935,73
Pyknometer + cap + sand + water	1818,94
Pyknometer + cap + water	1561,31
Mass of Soil	399,95
Mass of water in full jar	1025,53
Mass of water used	883,21
Volume of soil particles	142,32
Particle density (SG)	2,810

Mix 3
Mining Sand (75%) PFA (15%) Lime (10%)

	Mass (g)
Pyknometer + cap	536,01
Pyknometer + cap + sand	938,69
Pyknometer + cap + sand + water	1820,69
Pyknometer + cap + water	1568,91
Mass of Soil	402,68
Mass of water in full jar	1032,9
Mass of water used	882
Volume of soil particles	150,90
Particle density (SG)	2,669

Mix 4

Mining Sand (70%) PFA (20%) Lime (10%)

	Mass (g)
Pyknometer + cap	536,64
Pyknometer + cap + sand	952,88
Pyknometer + cap + sand + water	1820,24
Pyknometer + cap + water	1574,24
Mass of Soil	416,24
Mass of water in full jar	1037,6
Mass of water used	867,36
Volume of soil particles	170,24
Particle density (SG)	2,445

Mix 5

Mining Sand (65%) PFA (25%) Lime (10%)

	Mass (g)
Pyknometer + cap	539,25
Pyknometer + cap + sand	946,11
Pyknometer + cap + sand + water	1811,37
Pyknometer + cap + water	1564,37
Mass of Soil	406,86
Mass of water in full jar	1025,12
Mass of water used	865,26
Volume of soil particles	159,86
Particle density (SG)	2,545

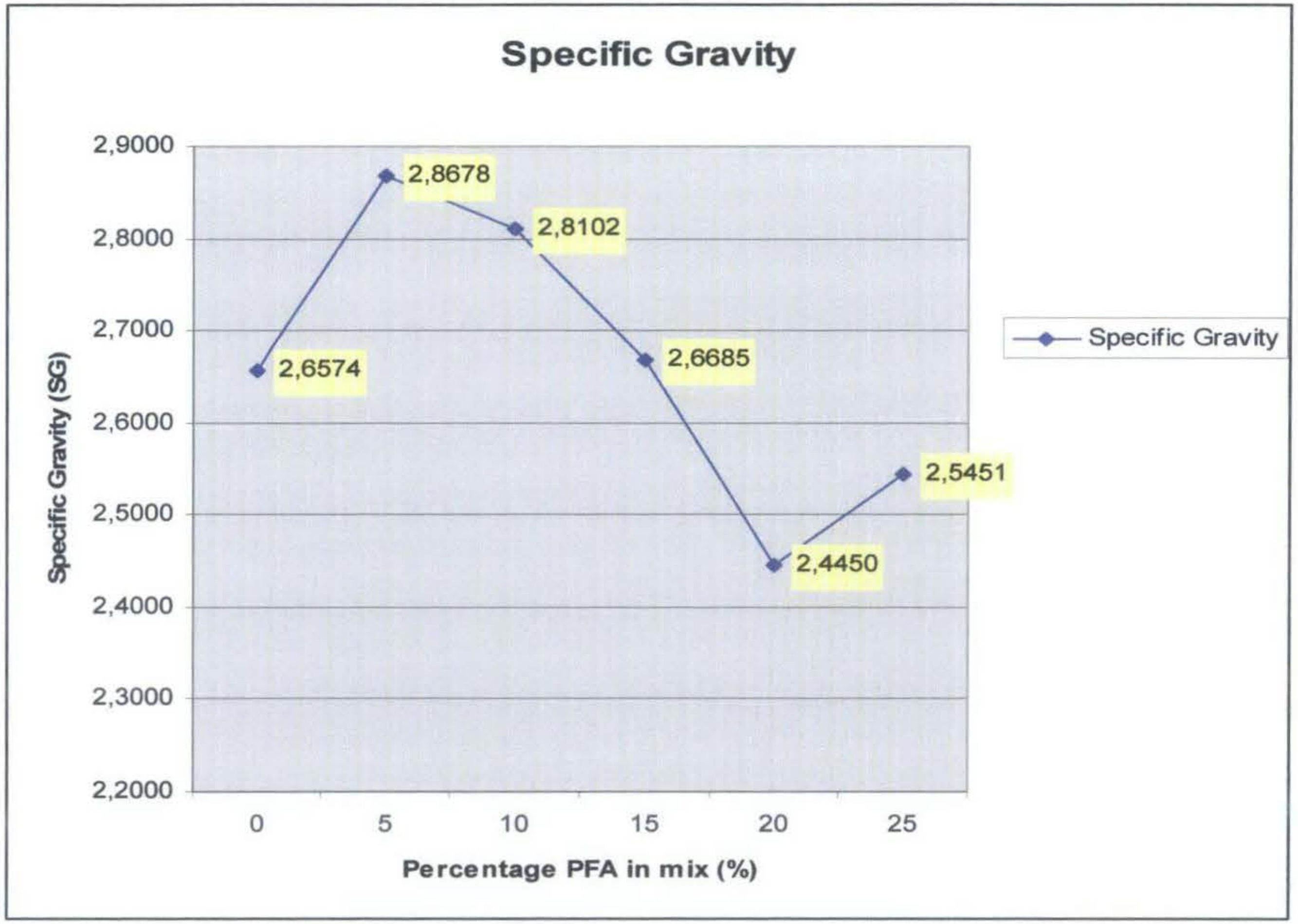


Figure : Specific gravity for mixtures of mining sand with PFA and lime based on percentage of PFA in each mix.

Table: Data for Compaction Test of Mix 1 until Mix 5.

Mix 1 Sand (85%) PFA (5%) Lime (10%)
3000g

Sand (80%)	PFA (5%)	Lime (10%)	w/c (%)	m (compacted soil)	ρd (Mg/m³)
2550g	150g	300g	4	2010	1,9409
2550g	150g	300g	6	2110	1,999
2550g	150g	300g	8	2240	2,0828
2550g	150g	300g	10	2250	2,0541
2550g	150g	300g	12	2190	1,9636

Mix 2 Sand (80%) PFA (10%) Lime (10%)
3000g

Sand (80%)	PFA (10%)	Lime (10%)	w/c (%)	m (compacted soil)	ρd (Mg/m³)
2400g	300g	300g	4	2170	2,095
2400g	300g	300g	6	2270	2,1506
2400g	300g	300g	8	2350	2,1851
2400g	300g	300g	10	2310	2,1089
2400g	300g	300g	12	2270	2,0354

Mix 3 Sand (75%) PFA (15%) Lime (10%)
3000g

Sand (75%)	PFA (15%)	Lime (10%)	w/c (%)	m (compacted soil)	ρd (Mg/m³)
2250g	450g	300g	4	2050	1,9795
2250g	450g	300g	6	2170	2,0558
2250g	450g	300g	8	2260	2,1014
2250g	450g	300g	10	2240	2,045
2250g	450g	300g	12	2170	1,9457
2250g	450g	300g	14	2080	1,8323

Mix 4 Sand (70%) PFA (20%) Lime (10%)
3000g

Sand (75%)	PFA (15%)	Lime (10%)	w/c (%)	m (compacted soil)	ρd (Mg/m³)
2100g	600g	300g	4	1960	1,8926
2100g	600g	300g	6	2130	2,0179
2100g	600g	300g	8	2220	2,0642
2100g	600g	300g	10	2180	1,9902
2100g	600g	300g	12	2160	1,9567

Mix 5 Sand (65%) PFA (25%) Lime (10%)
3000g

Sand (75%)	PFA (15%)	Lime (10%)	w/c (%)	m (compacted soil)	ρd (Mg/m³)
1950g	750g	300g	4	1990	1,9216
1950g	750g	300g	6	2120	2,0085
1950g	750g	300g	8	2220	2,064
1950g	750g	300g	10	2210	2,0176
1950g	750g	300g	12	2080	1,865

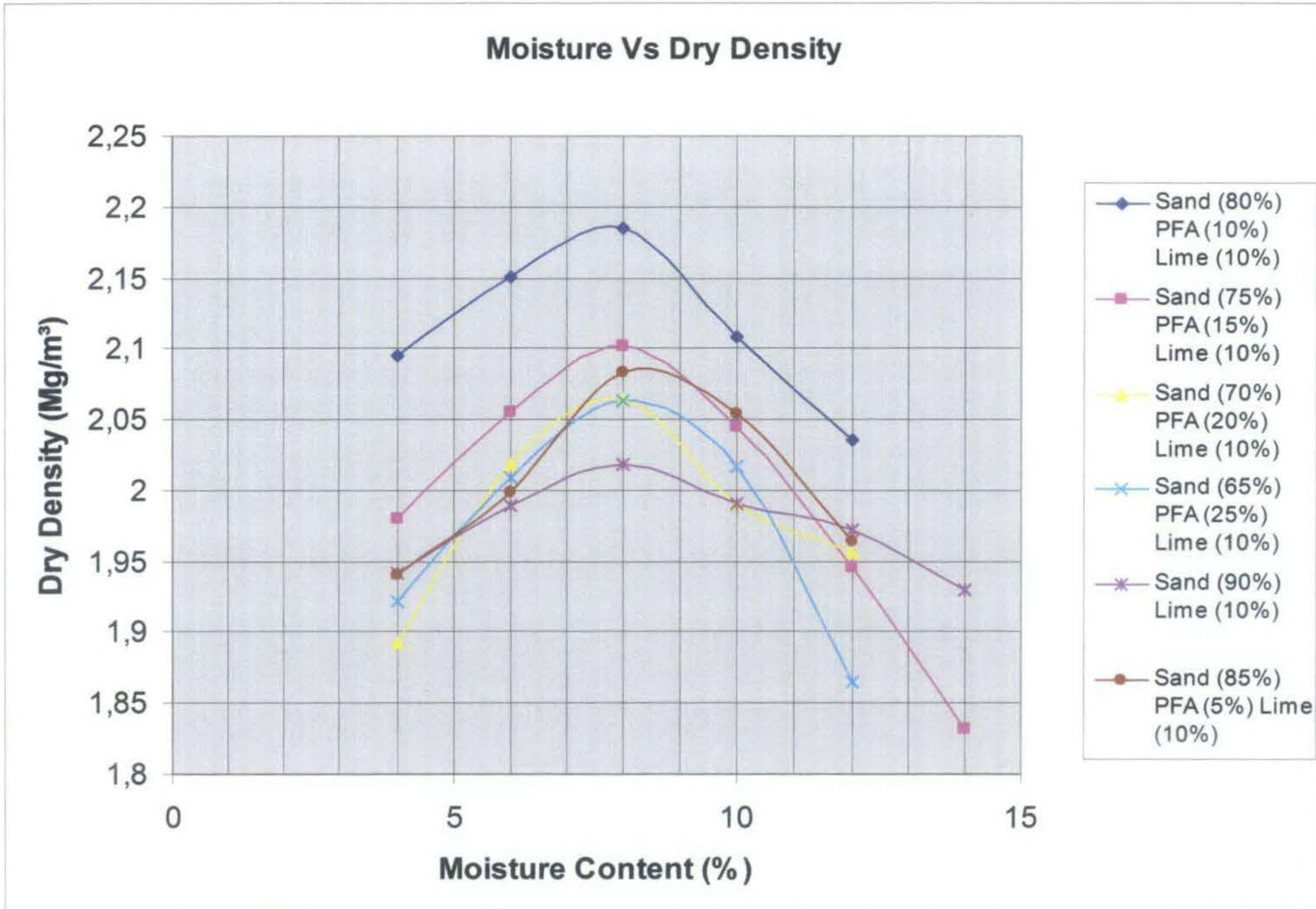


Figure: The moisture content versus dry density obtained from the standard proctor compaction test.

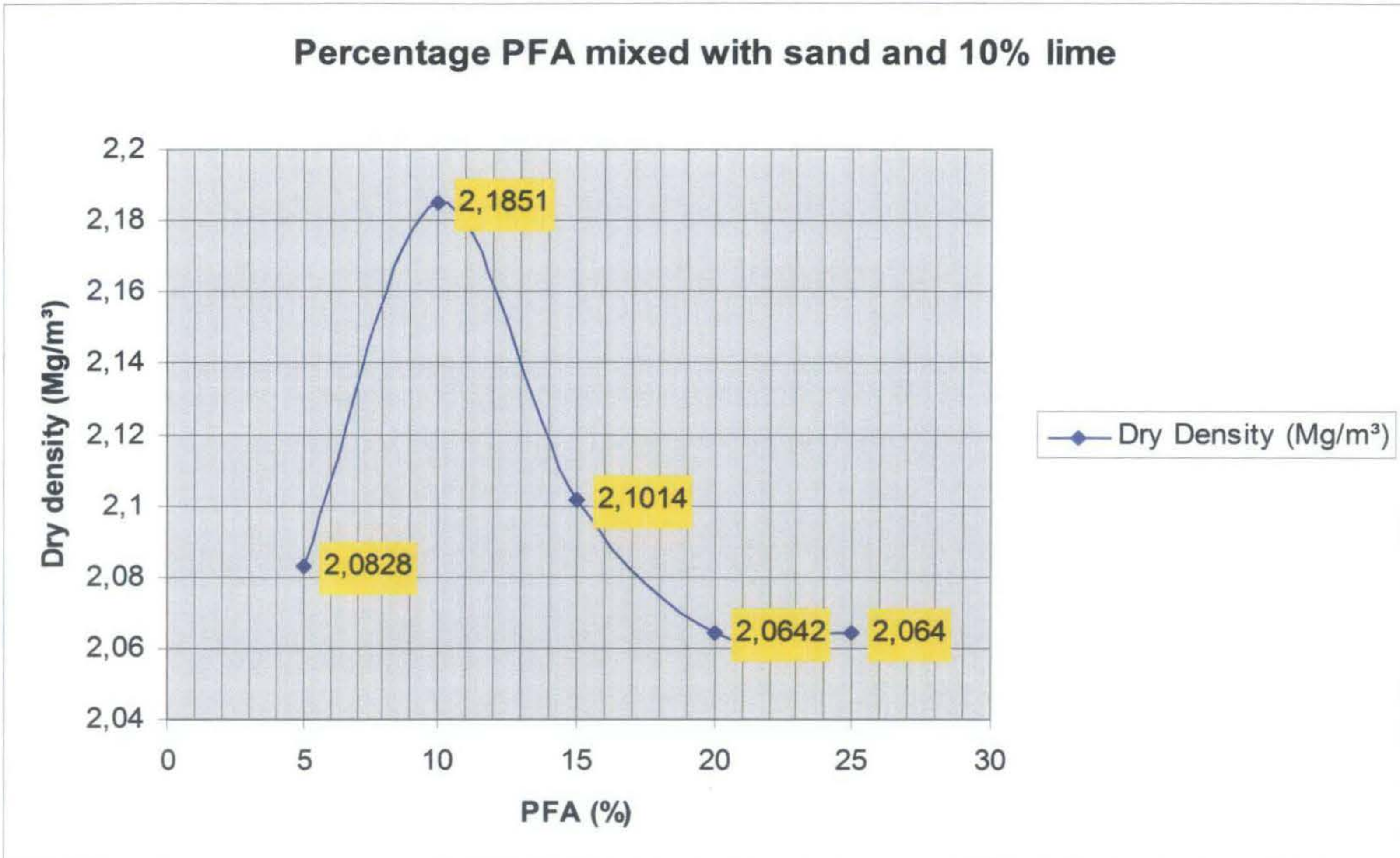


Figure: Particle size distribution graph for each of the mix.

Table: Data for Unconfined Compression Test for Mix 1 at 7, 14 and 28 days curing.

7 Days

Length	77,42	Area	1168,55
Diameter	38,57		

Deformation Gauge (mm)	Compression of Speciment (mm)	Strain, ϵ	Force Gauge Reading	Axial Force P	Corrected Area	Axial Stress (kPa/div)	Shear Strength
20	0,20	0,003	18	27,90	1.168,542	23,88	11,94
40	0,40	0,005	33	51,15	1.168,540	43,77	21,89
60	0,60	0,008	50	77,50	1.168,537	66,32	33,16
80	0,80	0,010	72	111,60	1.168,535	95,50	47,75
100	1,00	0,013	91	141,05	1.168,532	120,71	60,35
120	1,20	0,015	115	178,25	1.168,530	152,54	76,27
140	1,40	0,018	130	201,50	1.168,527	172,44	86,22
160	1,60	0,021	140	217,00	1.168,524	185,70	92,85
180	1,80	0,023	160	248,00	1.168,522	212,23	106,12
200	2,00	0,026	182	282,10	1.168,519	241,42	120,71
220	2,20	0,028	200	310,00	1.168,517	265,29	132,65
240	2,40	0,031	215	333,25	1.168,514	285,19	142,60
260	2,60	0,034	228	353,40	1.168,511	302,44	151,22
280	2,80	0,036	240	372,00	1.168,509	318,35	159,18
300	3,00	0,039	255	395,25	1.168,506	338,25	169,13
320	3,20	0,041	268	415,40	1.168,504	355,50	177,75
340	3,40	0,044	275	426,25	1.168,501	364,78	182,39
360	3,60	0,046	279	432,45	1.168,499	370,09	185,05

14 Days

Length	78,08	Area	1205,18
Diameter	39,17		

Deformation Gauge (mm)	Compression of Speciment (mm)	Strain, ϵ	Force Gauge Reading	Axial Force P	Corrected Area	Axial Stress (kPa/div)	Shear Strength
20	0,20	0,003	45	69,75	1.205,181	57,88	28,94
40	0,40	0,005	76	117,80	1.205,179	97,74	48,87
60	0,60	0,008	125	193,75	1.205,176	160,76	80,38
80	0,80	0,010	160	248,00	1.205,174	205,78	102,89
100	1,00	0,013	185	286,75	1.205,171	237,93	118,97
120	1,20	0,015	205	317,75	1.205,169	263,66	131,83
140	1,40	0,018	230	356,50	1.205,166	295,81	147,90
160	1,60	0,020	246	381,30	1.205,163	316,39	158,19
180	1,80	0,023	254	393,70	1.205,161	326,68	163,34
200	2,00	0,026	270	418,50	1.205,158	347,26	173,63
220	2,20	0,028	285	441,75	1.205,156	366,65	183,28
240	2,40	0,031	320	496,00	1.205,153	411,57	205,78
260	2,60	0,033	470	728,50	1.205,151	604,49	302,24
280	2,80	0,036	560	868,00	1.205,148	720,24	360,12

28 Days

Length 77,54 Area 1248,02

Diameter 39,86

Deformation Gauge (mm)	Compression of Speciment (mm)	Strain, Є	Force Gauge Reading	Axial Force P	Corrected Area	Axial Stress (kPa/div)	Shear Strength
20	0,20	0,003	55	85,25	1.248,015	68,31	34,15
40	0,40	0,005	80	124,00	1.248,013	99,36	49,68
60	0,60	0,008	98	151,90	1.248,010	121,71	60,86
80	0,80	0,010	136	210,80	1.248,007	168,91	84,45
100	1,00	0,013	180	279,00	1.248,005	223,56	111,78
120	1,20	0,015	230	356,50	1.248,002	285,66	142,83
140	1,40	0,018	290	449,50	1.248,000	360,18	180,09
160	1,60	0,021	350	542,50	1.247,997	434,70	217,35
180	1,80	0,023	410	635,50	1.247,995	509,22	254,61
200	2,00	0,026	475	736,25	1.247,992	589,95	294,97
220	2,20	0,028	540	837,00	1.247,989	670,68	335,34
240	2,40	0,031	610	945,50	1.247,987	757,62	378,81
260	2,60	0,034	680	1054,00	1.247,984	844,56	422,28
280	2,80	0,036	740	1147,00	1.247,982	919,08	459,54
300	3,00	0,039	800	1240,00	1.247,979	993,61	496,80
320	3,20	0,041	860	1333,00	1.247,976	1.068,13	534,06
340	3,40	0,044	915	1418,25	1.247,974	1.136,44	568,22
360	3,60	0,046	970	1503,50	1.247,971	1.204,76	602,38
380	3,80	0,049	1012	1568,60	1.247,969	1.256,92	628,46
400	4,00	0,052	1058	1639,90	1.247,966	1.314,06	657,03

Table: Data for Unconfined Compression Test for Mix 2 at 7, 14 and 28 days curing.

7 days

Length	79,09	Area	1165,52
Diameter	38,52		

Deformation Gauge (mm)	Compression of Speciment (mm)	Strain, є	Force Gauge Reading	Axial Force P	Corrected Area	Axial Stress (kPa/div)	Shear Strength
20	0,20	0,003	60	93,00	1.165,515	79,79	39,90
40	0,40	0,005	80	124,00	1.165,512	106,39	53,20
60	0,60	0,008	100	155,00	1.165,510	132,99	66,49
80	0,80	0,010	120	186,00	1.165,507	159,59	79,79
100	1,00	0,013	133	206,15	1.165,505	176,88	88,44
120	1,20	0,015	134	207,70	1.165,502	178,21	89,10
140	1,40	0,018	136	210,80	1.165,500	180,87	90,43
160	1,60	0,020	150	232,50	1.165,497	199,49	99,74
180	1,80	0,023	160	248,00	1.165,495	212,79	106,39
200	2,00	0,025	165	255,75	1.165,492	219,44	109,72
220	2,20	0,028	168	260,40	1.165,490	223,43	111,71
240	2,40	0,030	170	263,50	1.165,487	226,09	113,04
260	2,60	0,033	176	272,80	1.165,484	234,07	117,03

14 Days

Length	76,99	Area	1184,35
Diameter	38,83		

Deformation Gauge (mm)	Compression of Speciment (mm)	Strain, є	Force Gauge Reading	Axial Force P	Corrected Area	Axial Stress (kPa/div)	Shear Strength
20	0,20	0,003	30	46,50	1.184,350	39,26	19,63
40	0,40	0,005	45	69,75	1.184,347	58,89	29,45
60	0,60	0,008	72	111,60	1.184,345	94,23	47,11
80	0,80	0,010	115	178,25	1.184,342	150,51	75,25
100	1,00	0,013	138	213,90	1.184,339	180,61	90,30
120	1,20	0,016	170	263,50	1.184,337	222,49	111,24
140	1,40	0,018	200	310,00	1.184,334	261,75	130,88
160	1,60	0,021	230	356,50	1.184,331	301,01	150,51
180	1,80	0,024	270	418,50	1.184,329	353,36	176,68
200	2,00	0,026	320	496,00	1.184,326	418,80	209,40
220	2,20	0,029	365	565,75	1.184,324	477,70	238,85
240	2,40	0,031	420	651,00	1.184,321	549,68	274,84
260	2,60	0,034	468	725,40	1.184,318	612,50	306,25
280	2,80	0,037	520	806,00	1.184,316	680,56	340,28
300	3,00	0,039	585	906,75	1.184,313	765,63	382,82
320	3,20	0,042	650	1007,50	1.184,310	850,71	425,35
340	3,40	0,045	705	1092,75	1.184,308	922,69	461,35
360	3,60	0,047	750	1162,50	1.184,305	981,59	490,79
380	3,80	0,050	800	1240,00	1.184,303	1.047,03	523,51
400	4,00	0,052	835	1294,25	1.184,300	1.092,84	546,42
420	4,20	0,055	870	1348,50	1.184,297	1.138,65	569,32
440	4,40	0,058	910	1410,50	1.184,295	1.191,00	595,50
460	4,60	0,060	945	1464,75	1.184,292	1.236,81	618,41
480	4,80	0,063	972	1506,60	1.184,290	1.272,16	636,08

28 days

Concrete Compressive Strength

Max Load	4,4	kN
Stress	2.585	kPa
Pace Rate	5,3	kN/s

Table: Data for Unconfined Compression Test for Mix 3 at 7, 14 and 28 days curing.

7 Days

Length	78,38	Area	1164,31
Diameter	38,5		

Deformation Gauge (mm)	Compression of Speciment (mm)	Strain, Є	Force Gauge Reading	Axial Force P	Corrected Area	Axial Stress	Shear Strength
20	0,20	0,003	70	108,50	1.164,305	93,19	46,59
40	0,40	0,005	95	147,25	1.164,302	126,47	63,24
60	0,60	0,008	141	218,55	1.164,300	187,71	93,85
80	0,80	0,010	195	302,25	1.164,297	259,60	129,80
100	1,00	0,013	250	387,50	1.164,295	332,82	166,41
120	1,20	0,015	300	465,00	1.164,292	399,38	199,69
140	1,40	0,018	360	558,00	1.164,290	479,26	239,63
160	1,60	0,020	415	643,25	1.164,287	552,48	276,24
180	1,80	0,023	434	672,70	1.164,284	577,78	288,89
200	2,00	0,026	442	685,10	1.164,282	588,43	294,22
220	2,20	0,028	450	697,50	1.164,279	599,08	299,54
240	2,40	0,031	454	703,70	1.164,277	604,41	302,20
260	2,60	0,033	458	709,90	1.164,274	609,74	304,87
280	2,80	0,036	459	711,45	1.164,272	611,07	305,53

14 days

Length 77,83 Area 1174,61

Diameter 38,67

Deformation Gauge (mm)	Compression of Speciment (mm)	Strain, Є	Force Gauge Reading	Axial Force P	Corrected Area	Axial Stress	Shear Strength
20	0,20	0,003	60	93,00	1.178,866	78,89	39,44
40	0,40	0,005	140	217,00	1.178,864	184,08	92,04
60	0,60	0,008	210	325,50	1.178,861	276,11	138,06
80	0,80	0,010	290	449,50	1.178,859	381,30	190,65
100	1,00	0,013	350	542,50	1.178,856	460,19	230,10
120	1,20	0,015	420	651,00	1.178,854	552,23	276,12
140	1,40	0,018	490	759,50	1.178,851	644,27	322,14
160	1,60	0,020	560	868,00	1.178,849	736,31	368,16
180	1,80	0,023	630	976,50	1.178,846	828,35	414,18
200	2,00	0,025	710	1100,50	1.178,844	933,54	466,77
220	2,20	0,028	780	1209,00	1.178,841	1.025,58	512,79
240	2,40	0,030	860	1333,00	1.178,839	1.130,77	565,39
260	2,60	0,033	930	1441,50	1.178,836	1.222,82	611,41
280	2,80	0,035	1000	1550,00	1.178,833	1.314,86	657,43
300	3,00	0,038	1065	1650,75	1.178,831	1.400,33	700,16
320	3,20	0,040	1140	1767,00	1.178,828	1.498,95	749,47
340	3,40	0,043	1210	1875,50	1.178,826	1.590,99	795,49
360	3,60	0,045	1280	1984,00	1.178,823	1.683,03	841,52
380	3,80	0,048	1360	2108,00	1.178,821	1.788,23	894,11
400	4,00	0,050	1415	2193,25	1.178,818	1.860,55	930,27
420	4,20	0,053	1435	2224,25	1.178,816	1.886,85	943,43
440	4,40	0,055	1448	2244,40	1.178,813	1.903,95	951,97
460	4,60	0,058	1452	2250,60	1.178,811	1.909,21	954,61
480	4,80	0,060	1460	2263,00	1.178,808	1.919,74	959,87
500	5,00	0,063	1480	2294,00	1.178,806	1.946,04	973,02

28 days

Concrete Compressive Strength

Max Load	9.7	kN
Stress	7.873	Mpa
Pace Rate	5.3	kN/s

Table: Data for Unconfined Compression Test for Mix 4 at 7, 14 and 28 days curing

7 days

Length	79,66	Area	1195,36
Diameter	39,01		

Deformation Gauge (mm)	Compression of Speciment (mm)	Strain, Є	Force Gauge Reading	Axial Force P	Corrected Area	Axial Stress (kPa/div)	Shear Strength
20	0,20	0,003	30	46,50	1.195,356	38,90	19,45
40	0,40	0,005	70	108,50	1.195,353	90,77	45,38
60	0,60	0,008	130	201,50	1.195,351	168,57	84,28
80	0,80	0,010	190	294,50	1.195,348	246,37	123,19
100	1,00	0,013	250	387,50	1.195,346	324,17	162,09
120	1,20	0,015	320	496,00	1.195,343	414,94	207,47
140	1,40	0,018	380	589,00	1.195,341	492,75	246,37
160	1,60	0,020	450	697,50	1.195,338	583,52	291,76
180	1,80	0,023	510	790,50	1.195,336	661,32	330,66
200	2,00	0,025	575	891,25	1.195,333	745,61	372,80
220	2,20	0,028	640	992,00	1.195,331	829,90	414,95
240	2,40	0,030	700	1085,00	1.195,328	907,70	453,85
260	2,60	0,033	760	1178,00	1.195,326	985,51	492,75
280	2,80	0,035	770	1193,50	1.195,323	998,47	499,24
300	3,00	0,038	820	1271,00	1.195,321	1.063,31	531,66
320	3,20	0,040	890	1379,50	1.195,318	1.154,09	577,04
340	3,40	0,043	990	1534,50	1.195,316	1.283,76	641,88

14 Days

Length	78,99		Area	1142,64
Diameter	38,14			

Deformation Gauge (mm)	Compression of Speciment (mm)	Strain, Є	Force Gauge Reading	Axial Force P	Corrected Area	Axial Stress (kPa/div)	Shear Strength
20	0,20	0,003	55	85,25	1.142,633	74,61	37,30
40	0,40	0,005	110	170,50	1.142,630	149,22	74,61
60	0,60	0,008	180	279,00	1.142,628	244,17	122,09
80	0,80	0,010	250	387,50	1.142,625	339,13	169,57
100	1,00	0,013	328	508,40	1.142,623	444,94	222,47
120	1,20	0,015	400	620,00	1.142,620	542,61	271,31
140	1,40	0,018	480	744,00	1.142,618	651,14	325,57
160	1,60	0,020	560	868,00	1.142,615	759,66	379,83
180	1,80	0,023	638	988,90	1.142,613	865,47	432,74
200	2,00	0,025	715	1108,25	1.142,610	969,93	484,96
220	2,20	0,028	790	1224,50	1.142,607	1.071,67	535,84
240	2,40	0,030	875	1356,25	1.142,605	1.186,98	593,49
260	2,60	0,033	960	1488,00	1.142,602	1.302,29	651,15
280	2,80	0,035	1060	1643,00	1.142,600	1.437,95	718,97
300	3,00	0,038	1150	1782,50	1.142,597	1.560,04	780,02
320	3,20	0,040	1245	1929,75	1.142,595	1.688,92	844,46
340	3,40	0,043	1340	2077,00	1.142,592	1.817,80	908,90
360	3,60	0,045	1435	2224,25	1.142,590	1.946,67	973,34
380	3,80	0,048	1525	2363,75	1.142,587	2.068,77	1.034,38
400	4,00	0,050	1620	2511,00	1.142,585	2.197,65	1.098,82
420	4,20	0,053	1720	2666,00	1.142,582	2.333,31	1.166,66
440	4,40	0,055	1795	2782,25	1.142,580	2.435,06	1.217,53

28 days

Concrete Compressive Strength

Max Load	13.7	kN
Stress	12.070	Mpa
Pace Rate	7.8	kN/s

Table: Data for Unconfined Compression Test for Mix 5 at 7, 14 and 28 days curing

7 Days

Length	78,63	Area	1152,84
Diameter	38,31		

Deformation Gauge (mm)	Compression of Speciment (mm)	Strain, Є	Force Gauge Reading	Axial Force P	Corrected Area	Axial Stress (kPa/div)	Shear Strength
20	0,20	0,003	73	113,15	1.152,841	98,149	49,07
40	0,40	0,005	125	193,75	1.152,839	168,063	84,03
60	0,60	0,008	190	294,50	1.152,836	255,457	127,73
80	0,80	0,010	260	403,00	1.152,834	349,573	174,79
100	1,00	0,013	390	604,50	1.152,831	524,361	262,18
120	1,20	0,015	460	713,00	1.152,829	618,479	309,24
140	1,40	0,018	530	821,50	1.152,826	712,597	356,30
160	1,60	0,020	610	945,50	1.152,824	820,160	410,08
180	1,80	0,023	675	1046,25	1.152,821	907,556	453,78
200	2,00	0,025	750	1162,50	1.152,818	1.008,398	504,20
220	2,20	0,028	830	1286,50	1.152,816	1.115,963	557,98
240	2,40	0,031	900	1395,00	1.152,813	1.210,083	605,04
260	2,60	0,033	980	1519,00	1.152,811	1.317,649	658,82
280	2,80	0,036	1040	1612,00	1.152,808	1.398,324	699,16
300	3,00	0,038	1090	1689,50	1.152,806	1.465,555	732,78
320	3,20	0,041	1130	1751,50	1.152,803	1.519,340	759,67
340	3,40	0,043	1200	1860,00	1.152,801	1.613,462	806,73
360	3,60	0,046	1260	1953,00	1.152,798	1.694,139	847,07

14 days

Length	77,42	Area	1168,55
Diameter	38,57		

Deformation Gauge (mm)	Compression of Speciment (mm)	Strain, ϵ	Force Gauge Reading	Axial Force P	Corrected Area	Axial Stress (kPa/div)	Shear Strength
20	0,20	0,003	30	46,50	1.168,542	39,793	19,90
40	0,40	0,005	115	178,25	1.168,540	152,541	76,27
60	0,60	0,008	190	294,50	1.168,537	252,024	126,01
80	0,80	0,010	270	418,50	1.168,535	358,141	179,07
100	1,00	0,013	350	542,50	1.168,532	464,258	232,13
120	1,20	0,015	430	666,50	1.168,530	570,375	285,19
140	1,40	0,018	520	806,00	1.168,527	689,757	344,88
160	1,60	0,021	610	945,50	1.168,524	809,140	404,57
180	1,80	0,023	690	1069,50	1.168,522	915,259	457,63
200	2,00	0,026	770	1193,50	1.168,519	1.021,378	510,69
220	2,20	0,028	855	1325,25	1.168,517	1.134,130	567,07
240	2,40	0,031	940	1457,00	1.168,514	1.246,883	623,44
260	2,60	0,034	1030	1596,50	1.168,511	1.366,268	683,13
280	2,80	0,036	1100	1705,00	1.168,509	1.459,125	729,56
300	3,00	0,039	1200	1860,00	1.168,506	1.591,776	795,89
320	3,20	0,041	1290	1999,50	1.168,504	1.711,163	855,58
340	3,40	0,044	1380	2139,00	1.168,501	1.830,550	915,28
360	3,60	0,046	1475	2286,25	1.168,499	1.956,571	978,29
380	3,80	0,049	1570	2433,50	1.168,496	2.082,592	1.041,30
400	4,00	0,052	1660	2573,00	1.168,493	2.201,981	1.100,99
420	4,20	0,054	1755	2720,25	1.168,491	2.328,003	1.164,00
440	4,40	0,057	1840	2852,00	1.168,488	2.440,761	1.220,38
460	4,60	0,059	1930	2991,50	1.168,486	2.560,151	1.280,08
480	4,80	0,062	2020	3131,00	1.168,483	2.679,542	1.339,77
500	5,00	0,065	2021	3132,55	1.168,480	2.680,875	1.340,44

28 days

Concrete Compressive Strength

Max Load	15.7	kN
Stress	13.350	Mpa
Pace Rate	7.8	kN/s

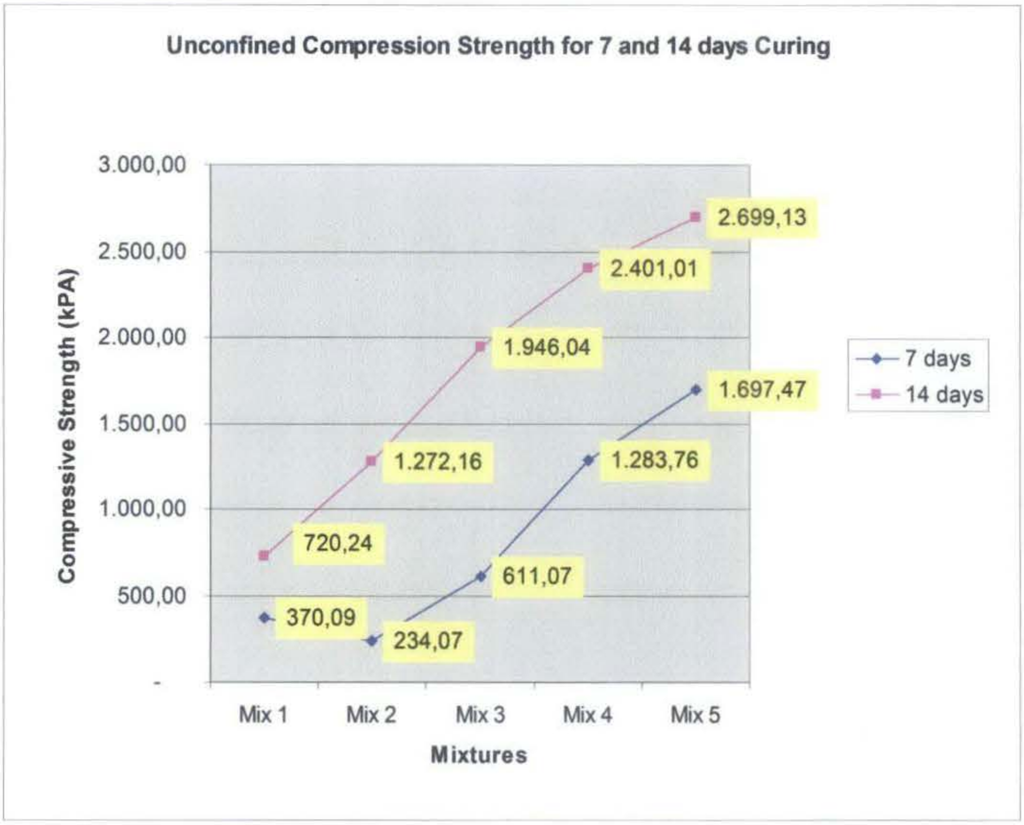


Figure: Unconfined compression strength for mixtures based on percentage of PFA and curing for 7 and 14 days.

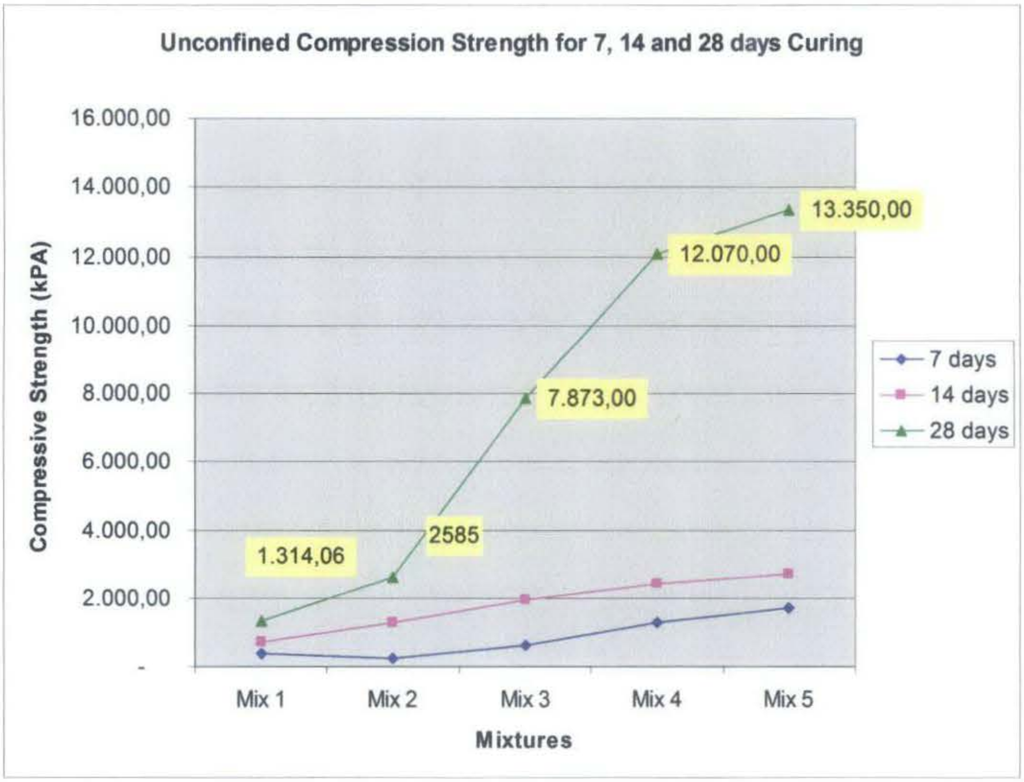


Figure: Unconfined compression strength for each of mixtures based on percentage of PFA and curing for 7, 14 and 28 days.

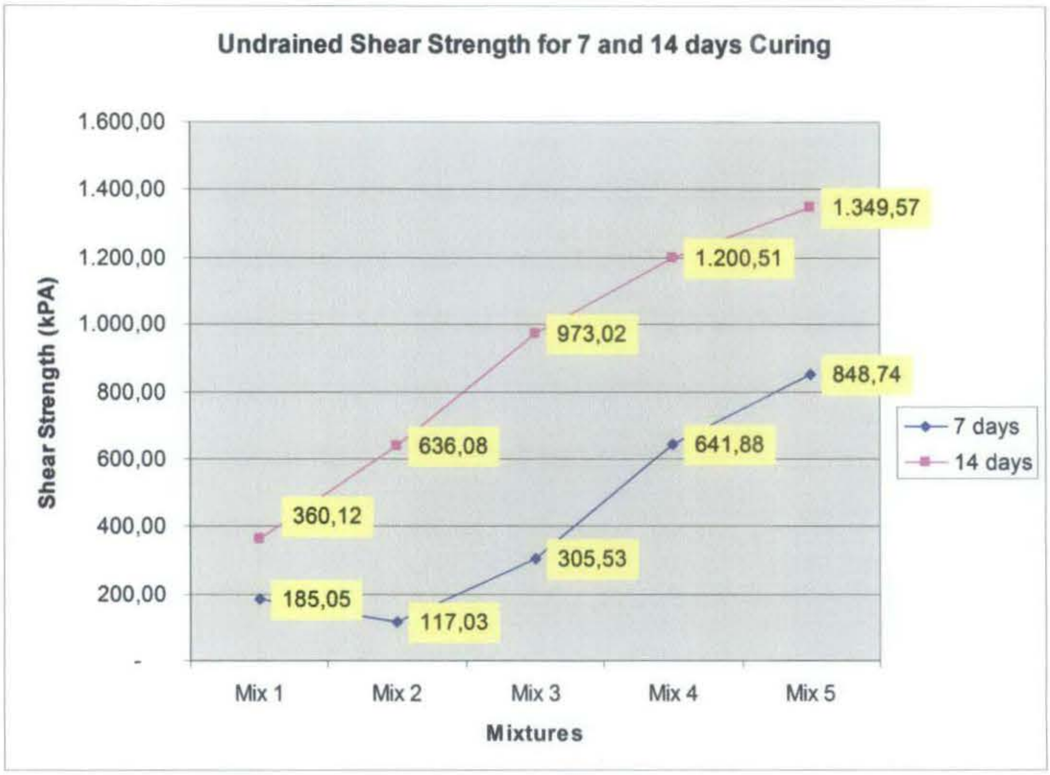


Figure: Undrained Shear Strength for each of mixtures based on percentage of PFA and 7 and 14 days curing period.

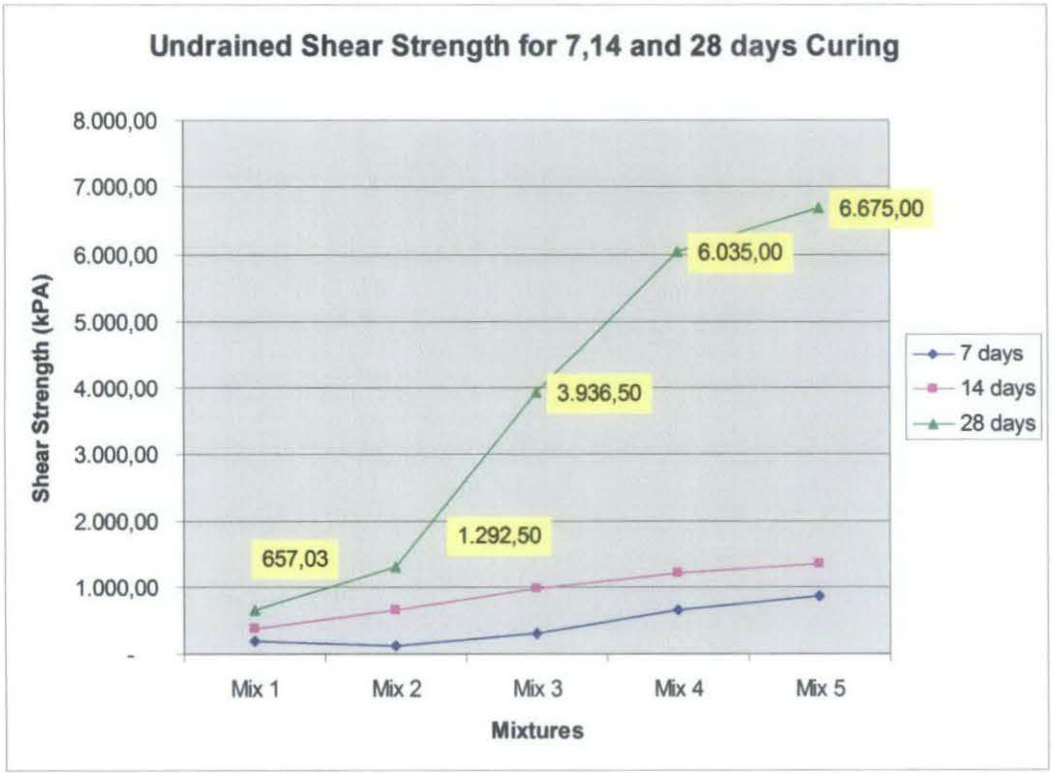


Figure: Undrained Shear Strength for each of mixtures based on percentage of PFA and 7, 14 and 28 days curing period.

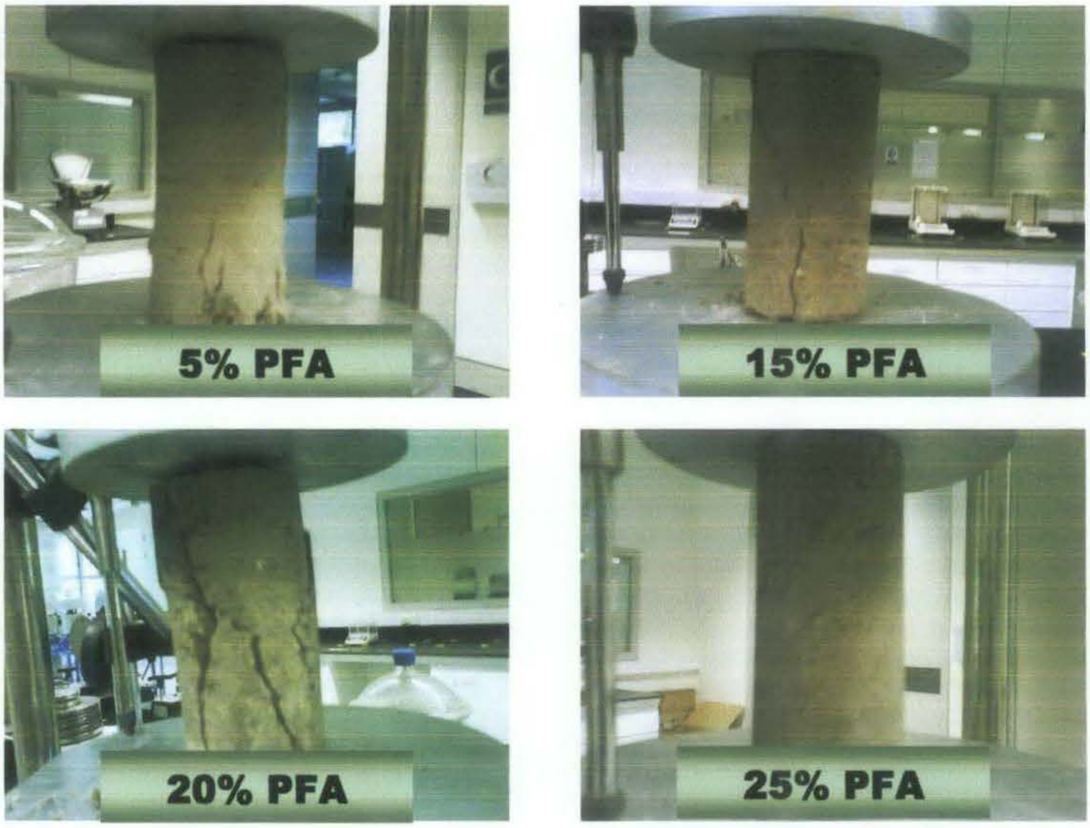


Figure: Unconfined Compression Test for 7 days Curing Period.

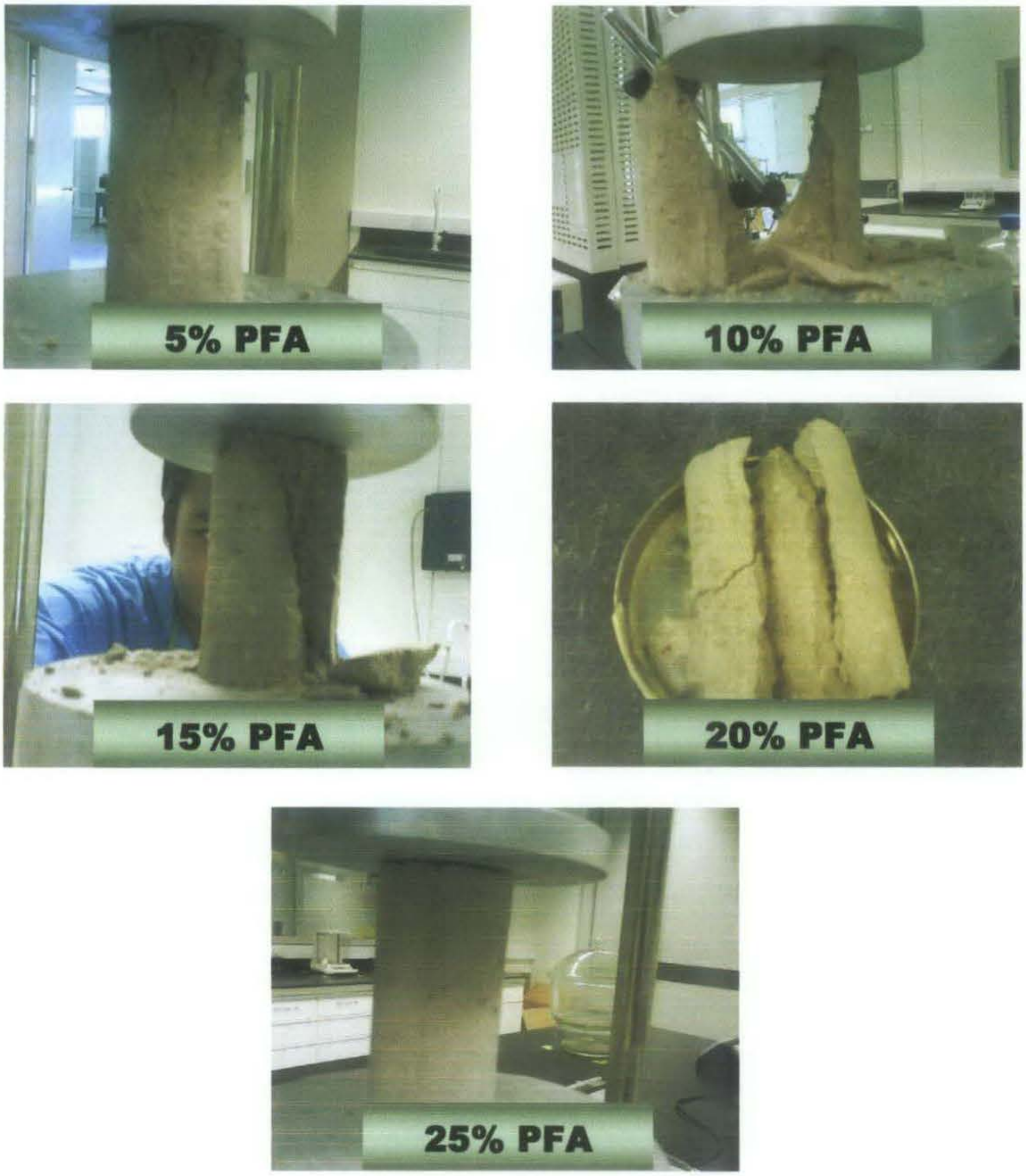


Figure: Unconfined Compression Test for 14 days Curing Period.

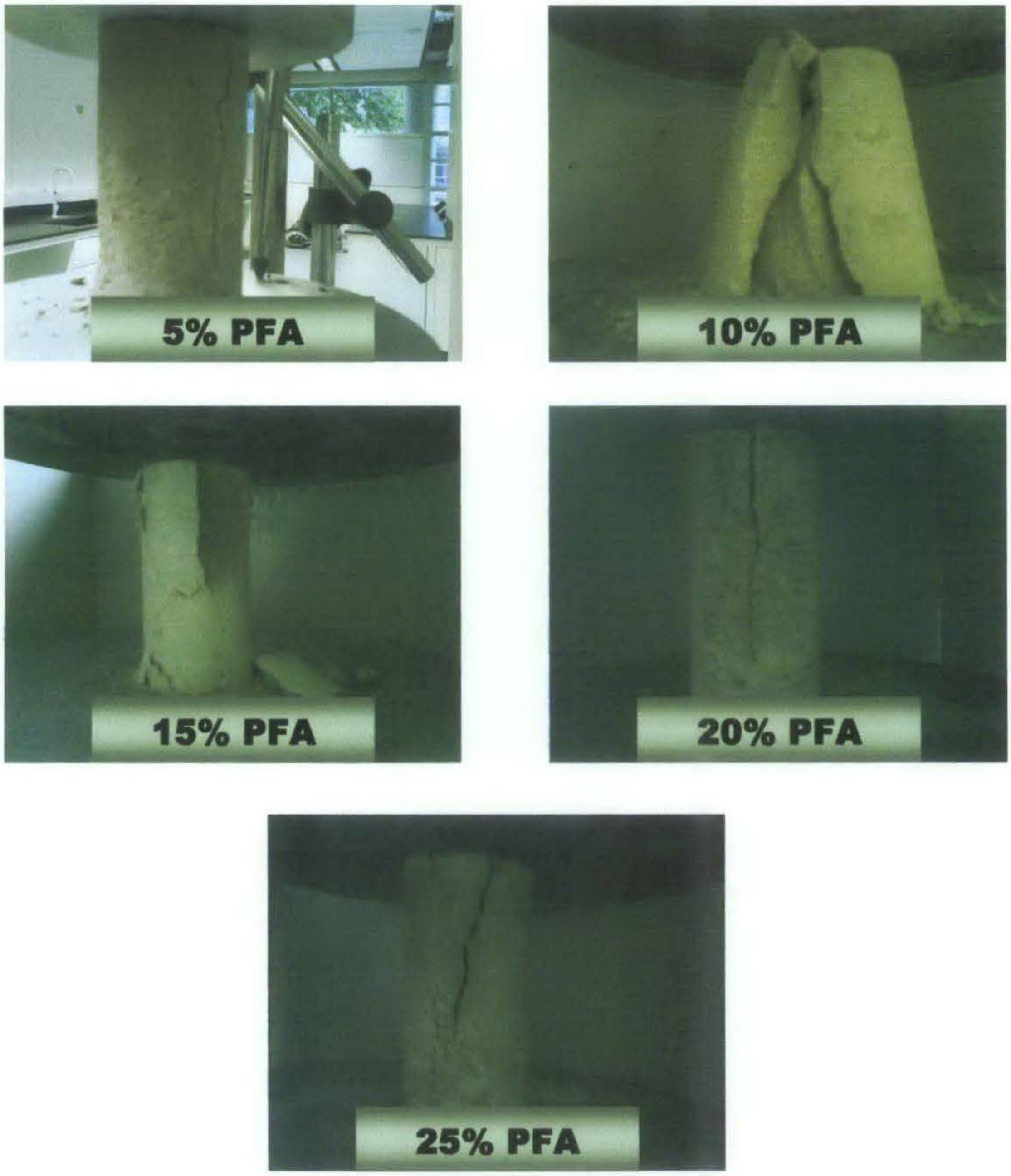


Figure: Unconfined Compression Test for 28 days Curing Period.