



Faculty of Engineering

**Effect of Waste Tire Reinforcement with and without Cement Additives
on Peat Strength Improvement**

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Effect of Waste Tire Reinforcement with and without Cement Additives on Peat Strength Improvement

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



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ABSTRACT

Peat is generally characterized by its low shear strength, high compressibility, and moisture content. It is subjected to problem of instability and large primary and long-term settlement. This research study aims to investigate the effect on strength enhancement of fiber reinforced peat by using rubber tyre chips with addition of cement to improve the mechanical properties of the untreated peat. Two sizes of rubber tyre chips were chosen in the study, which are 0.05mm and 1-3mm, respectively. The peat samples are taken from Kampung Endap, Kota Samarahan. Both physical and mechanical properties of untreated and treated samples were determined in the study. The peat samples collected have a high moisture content of 400%. As for mechanical properties, Standard Compaction Test were conducted to obtain the optimum moisture content (OMC) and the maximum dry density (MDD) for all the design mix. The optimum dry density value for design mix obtained is used as reference in preparing Unconfined Compressive Strength (UCS) samples. The fiber reinforced peat is treated with a constant 5% of cement, and various percentages ranging from 5%, 10% and 15% of rubber tyre crumbs. The samples were left to air- cured for 7, 28, 56, and 90 days. With the addition of rubber crumbs, the strength of the samples increased as the percentage increases. The highest UCS value recorded is 327.96 kN/m² for peat with 10% rubber size of 0.05mm and 369.87 kN/m² for peat with 15% rubber size of 1-3 mm after 90 days of curing with targeted threshold of 345kPa. In conclusion, the addition of rubber crumbs, significantly improved the strength of the treated peat samples when compared to untreated peat.

Keywords: Cement, improvement, peat, shear strength, stabilization, waste tires

Kesan Pengukuhan Sisa Tayar Dengan dan Tanpa Bahan Tambahan Simen Terhadap Peningkatan Kekuatan Gambut

ABSTRAK

Tanah gambut disifatkan mempunyai kadar pengukuhan ricih yang rendah, kadar kebolehmampatan dan kandungan air yang tinggi justeru mempunyai ciri kekuatan yang rendah. Kajian ini dijalankan untuk mengenalpasti kesan terhadap kekuatan tanah gambut dengan penambahan serat tayar. Dua saiz serat tayar digunakan untuk mengkaji perbezaan terhadap sampel tanah gambut. Sampel tanah gambut tersebut diambil dari Kampung Endap, Samarahan. Ciri fizikal dan mekanikal terhadap sampel tanah gambut yang tidak dirawat dan dirawat dikaji. Sampel tanah gambut mempunyai kandungan air yang tinggi iaitu 400%. Ujian Kemampatan dijalankan untuk mengetahui kadar kelembapan optimum dan kadar ketumpatan kering maksimum, kemudiannya digunakan dalam ujian Kekuatan Mampatan Tidak Terkurung (UCS). Ujian Direct Shear Box dijalankan ke atas tanah gambut, dengan penambahan 10% serat tayar bersaiz 0.05 mm mempunyai kadar kohesion sebanyak 72.10 kN/m² dan sudut rintangan ricih sebanyak 2.58. Tanah gambut dirawat dengan menambah kadar peratusan simen yang sama iaitu 5% dan kadar peratusan serat tayar yang berbeza, 5%, 10% dan 15%. Sampel tersebut dibiarkan selama 7, 28, 56 dan 90 hari untuk pengawetan udara. Dengan penambahan serat tayar, kekuatan tanah gambut dapat diperbaiki, apabila kadar peratusan serat tayar dinaikkan. Kadar Kekuatan Mampatan Tidak Terkurung yang paling tinggi direkodkan adalah 327.96 kN/m² untuk sampel tanah gambut dengan 10% serat tayar bersaiz 0.05mm dan 369.87 kN/m² untuk sampel tanah gambut dengan 15% serat tayar bersaiz 1-3 mm setelah pengawetan selama 90 hari. Secara kesimpulannya, penambahan serat tayar di dalam tanah gambut sedikit

sebanyak menambah baik kekuatan ricih tanah berbanding dengan tanah gambut yang tidak di rawat.

Kata kunci: *Simen, penambahbaikan, gambut, kekuatan ricih, sisa tayar*

TABLE OF CONTENTS

	Page
DECLARATION	i
ACKNOWLEDGEMENT	ii
ABSTRACT	iii
<i>ABSTRAK</i>	iv
TABLE OF CONTENTS	vi
LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF SYMBOLS	xiv
LIST OF ABBREVIATIONS	xv
CHAPTER 1: INTRODUCTION	1
1.1 Background	1
1.2 Problem Statement	2
1.3 Scope of Study	5
1.4 Thesis Outline	6
CHAPTER 2: LITERATURE REVIEW	7
2.1 General	7
2.2 Peat Classification	7
2.3 Peat Behaviour	10
2.4 Peat Stabilisation Technique	12

2.4.1	Chemical Stabilisation of Peat	11
2.4.2	Field Stabilisation of Peat	18
2.5	Current Practice on Road Stabilisation	20
2.6	Case Study on Fibre Reinforced Soil	23
2.7	Summary	37
CHAPTER 3: MATERIALS AND METHODOLOGY		39
3.1	General	39
3.2	Physical Properties	40
3.2.1	Moisture Content	40
3.2.2	Loss On Ignition and Organic Content	41
3.2.3	Fiber Content	42
3.2.4	Atterberg Limit	43
3.2.5	Specific Gravity	45
3.3	Preparation of Samples	43
3.3.1	Peat	46
3.3.2	Rubber Powder	47
3.3.3	Ordinary Portland Cement	48
3.3.4	Design Mix Considerations	48
3.4	Mechanical Properties	49
3.4.1	Vane Shear Test	49
3.4.2	Standard Compaction Test	50
3.4.3	Direct Shear Box	52
3.4.4	Unconfined Compressive Strength Test	54

CHAPTER 4: RESULTS AND DISCUSSION	55
4.0 General	55
4.1 Physical Properties	52
4.1.1 Von Post Degree of Compositon	56
4.1.2 Moisture Content	57
4.1.3 Loss On Ignition and Organic Content	58
4.1.4 Specific Gravity	58
4.1.5 pH Limit	59
4.1.6 Liquid Limit	60
4.1.7 Field Vane Shear	63
4.2 Mechanical Properties	66
4.2.1 Standard Compaction Test	66
4.2.2 Direct Shear Box	70
4.2.3 Unconfined Compressive Strength Test	79
CHAPTER 5: CONCLUSION AND RECOMMENDATIONS	87
5.1 General	87
5.2 Conclusion	87
5.3 Recommendation	90
REFERENCES	91
APPENDICES	97

LIST OF TABLES

	Page
Table 1.1 The total and distribution of the peat in Malaysia (CIDB, 2015)	1
Table 1.2 The estimated total area of peatland throughout Sarawak (CIDB,2015)	3
Table 2.1 Von Post Scale descriptions (Jarret, Geoguide 6: Site Investigation for Organic Soil and Peats,1995)	9
Table 3.1 No. of samples prepared for UCS Test.	47
Table 4.1 Summary of the physical properties of the untreated peat	55
Table 4.2 Moisture Content of Peat Sample	56
Table 4.3 Loss on Ignition and Organic Content of Peat Sample from Kampung Endap, Samarahan	57
Table 4.4 Specific gravity of Peat Sample	57
Table 4.5 pH value of in situ Peat	58
Table 4.6 Summary of the liquid limit of the peat samples	59
Table 4.7 Summary of the Average Corrected Shear Strength (kPa) from three different points	62
Table 4.8 Design mix of the peat samples	65
Table 4.9 Summary results of Standard Compaction Test	67
Table 4.10 Summary of Direct Shear Box Test for Rubber Size 0.05 mm	77
Table 4.11 Summary of Direct Shear Box Test for Rubber Size 1-3 mm	77
Table 5.1 Summary of physical properties of the untreated peat samples	87
Table 5.2 Summary of Liquid Limit test of both untreated and treated peat	87

LIST OF FIGURES

	Page
Figure 1.1 Peat Distribution in Sabah and Sarawak	4
Figure 2.1 Effect of OPC addition and curing period of UCS of the peat soil	13
Figure 2.2 Effect of QL addition and curing period of UCS of the peat soil	13
Figure 2.3 Effect of FA addition and curing period of UCS of the peat soil	14
Figure 2.4 Unconfined Compressive Strength vs Curing days	15
Figure 2.5 Effect of Rice Husk Ash and Hydrated Lime content on Atterberg Limit	16
Figure 2.6 Compressive Strength curve of treated soils at different RHA content	17
Figure 2.7 The variation of unconfined compressive strength for curing period of 4, 7, and 14 days on (a) shedi soil with an addition of 2% of cement and (b) Black cotton soil with an addition of 4% of cement respectively.	24
Figure 2.8 The variation of california bearing test (unsoaked) for curing period of 4, 7, and 14 days on (a) shedi soil with an addition of 2% of cement and (b) Black cotton soil with an addition of 4% of cement respectively	25
Figure 2.9 The variation of california bearing test (soaked) for curing period of 4, 7, and 14 days on (a) shedi soil with an addition of 2% of cement	27

and (b) Black cotton soil with an addition of 4% of cement respectively

Figure 2.10	The CBR value of soil mixture (15 x 30 mm)	28
Figure 2.11	The CBR value of soil mixture (20 x 40 mm)	28
Figure 2.12	The CBR value of soil mixture (25 x 50 mm)	29
Figure 2.13	Compaction curve for soil-tire chips mixture	29
Figure 2.14	Load- penetration curve from unsoaked CBR tests	30
Figure 2.15	Load- penetration curve from soaked CBR tests	30
Figure 2.16	CBR curve for both soaked and unsoaked CBR values	31
Figure 2.17	Maximum CBR values- tire buffing- lime content for the specimens, after 3 day curing period	32
Figure 2.18	UCS values- tire buffing- lime content for the specimens, after 3-day curing period.	33
Figure 2.19	Compressive stress (kPa) vs curing days	34
Figure 2.20	Peat and uncemented reinforcement peat with shredded rubber-crumb	35
Figure 2.21	Peat and cemented reinforcement peat with shredded rubber- crumb	35
Figure 3.1	Flow chart of analysis for this research	38
Figure 3.2	Cone penetration test apparatus for liquid limit test	43
Figure 3.3	0.05mm particle size of air- dried peat sample	45
Figure 3.4	Rubber Fiber of Size 0.05mm	46
Figure 3.5	Rubber Fiber of Size 1-3 mm	46
Figure 3.6	Mould and Proctor Hammer used in the Standard Compaction Test	50
Figure 3.7	Direct Shear Box	52

Figure 3.8	Experimental set up of unconfined compression test	53
Figure 4.1	Peat Sample taken from the site	56
Figure 4.2	pH value taken from the pH meter	58
Figure 4.3	Liquid Limit of Dry Peat from Kampung Endap, Samarahan	60
Figure 4.4	Liquid Limit of Dry Peat and Rubber (Size 0.05mm) from Kampung Endap, Samarahan.	60
Figure 4.5	Liquid Limit of Dry Peat and Rubber (Size 1-3mm) from Kampung Endap, Samarahan.	61
Figure 4.6	Graph of Undrained Shear Strength (kPa) versus Depth (m) at Point 1	63
Figure 4.7	Graph of Undrained Shear Strength (kPa) versus Depth (m) at Point 2	63
Figure 4.8	Graph of Undrained Shear Strength (kPa) versus Depth (m) at Point 3	64
Figure 4.9	Dry Density vs Moisture Content for Dry Peat various percentages of Fiber	68
Figure 4.10	Dry Density vs Moisture Content for Dry Peat with constant 5% Cement and various percentages of Fiber.	68
Figure 4.11	Shear stress vs shear strain with normal stress of 100 kN/m ² .	70
Figure 4.12	Shear stress vs shear strain with normal stress of 200 kN/m ²	70
Figure 4.13	Shear stress vs shear strain with normal stress of 400 kN/m ²	71
Figure 4.14	Shear stress vs shear strain with normal stress of 100 kN/m ²	71
Figure 4.15	Shear stress vs shear strain with normal stress of 200 kN/m ²	72
Figure 4.16	Shear stress vs shear strain with normal stress of 400 kN/m ²	72

Figure 4.17	Vertical Displacement vs Horizontal Displacement at 200 kN/m ²	74
Figure 4.18	Vertical Displacement vs Horizontal Displacement at 200 kN/m ²	74
Figure 4.19	Vertical Displacement vs Horizontal Displacement at 400 kN/m ²	75
Figure 4.20	Shear stress vs Normal stress for Rubber Size 0.05 mm	75
Figure 4.21	Shear stress vs Normal stress for Rubber Size 1-3 mm	76
Figure 4.22	Unconfined Compressive Strength of Size 0.05 mm (7 days)	81
Figure 4.23	Unconfined Compressive Strength of Size 1-3 mm (7 days)	81
Figure 4.24	Unconfined Compressive Strength of Size 0.05 mm (28 days)	82
Figure 4.25	Unconfined Compressive Strength of Size 1-3 mm (28 days)	82
Figure 4.26	Unconfined Compressive Strength of Size 0.05mm (56 days).	83
Figure 4.27	Unconfined Compressive Strength of Size 1-3 mm (56 days)	83
Figure 4.28	Unconfined Compressive Strength of Size 0.05mm (90 days)	84
Figure 4.29	Unconfined Compressive Strength of Size 1-3 mm (90 days)	84
Figure 4.30	Compressive Strength vs Days for 0.05mm Rubber Powder	85
Figure 4.31	Compressive Strength vs Days for 1-3 mm Rubber Powder	85
Figure 4.32	Compressive Strength vs Days for 0.05mm Rubber Powder and 5% Cement	85
Figure 4.33	Compressive Strength vs Days for 0.05mm Rubber Powder and 5% Cement	85

LIST OF SYMBOLS

c	Effective Cohesion
cm	Centimeter
G_s	Specific Gravity
%	Percent
m	Metre
mm	Milimeter
kN	Kilo- Newton
kPa	Kilo- Pascal

LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testings and Materials
BS	British Standard
CBR	California Bearing Ratio
FA	Fly Ash
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
OPC	Ordinary Portland Cement
QL	Quick Lime
SEM	Scanning Electron Microscope
UCS	Unconfined Compressive Strength

CHAPTER 1

INTRODUCTION

1.1 Background

Peat is generally found in poorly- drained lowlands such as river valley and estuaries. In Malaysia, an approximate of 8% of the country total area is cover by peat. Sarawak has the largest peat area while Sabah has the least peat area. The total and distribution of the peat in Malaysia is summarised in Table 1.1 below.

Table 1.1: The total and distribution of the peat in Malaysia (CIDB, 2015).

Region	Total Area of Peat (ha)	%
Sarawak	1,697,847	69.08
Peninsular Malaysia	642,918	26.16
Sabah	116,965	4.76
Total Area	2,457,730	

Peat is a product of accumulation the remnants of the decompose vegetation, with a high organic content. Peat is of high contents of fibrous organic matters and is produced by the partial decomposition and disintegration of mosses, sedges, trees, and the plants that grow in marshes and other wet places in the condition of lack of oxygen (Kazemian et al., 2011). Peat is also characterised by its low shear strength, low compressibility, and high-water content. Peat tends to be deformed when a light load is place on top of it.

Engineers often face geotechnical problems especially in constructing roads on a peat

area. Due to its high settlement, and its tendency to deform with the presence of light load, thus peat is not suitable for road construction. Therefore, some ground improvement techniques are highly recommended especially in road constructions.

1.2 Problem Statement

It is important to take into consideration of the geology of the surface soil layers. Due to low bearing capacity and a high settlement of the peat soil, road construction can be difficult.

Subsidence and drainage potential are the most important factors that will influence the potential of peat soils for sustainable reclamation when constructing roads. Excessive settlement will be worsening because of the drainage due to compaction resulting from the expulsion of free pore water by loading. Hence, this will affect the road constructed above the peat if there is no maintenance being carried out.

In this research, Sarawak peat is chosen for the study due to the abundant sources of peat as Sarawak attributes to the most peatland area with an estimate of nearly 70% of the total peatlands in Malaysia. Peatlands in Sarawak (Figure 1.1) are mostly found near the coastal area. Sibul and Mukah divisions have the highest amount of peatland in Sarawak. Table 1.2 below is the estimation of peatland areas in Sarawak.

Table 1.2: The estimated total area of peatland throughout Sarawak (CIDB,2015).

DIVISION	TOTAL AREA OF PEAT (ha)
Sibu/Mukah	600,387
Sri Aman/ Betong	340,374
Miri	295,995
Samarahan	165,581
Sarikei	74,414
Bintulu	157,422
Limbang	34,730
Kuching	26,827
Kapit	2,097
TOTAL	1,697,847

Under current practice, Public Works Department (JKR), the unsuitable materials are being excavated to such depth and be transported and disposed. It is then being backfilled with a suitable material compacted to a dry density not less than the surrounding material, for example, peat or soft soil. The voids created due to excavation, are backfilled with hard clean crushed rocks, natural gravel, or sand as this lowers the settlement value. This method definitely improves the peat condition whereby the settlement value lowers, while the shear strength, and other engineering properties increases.

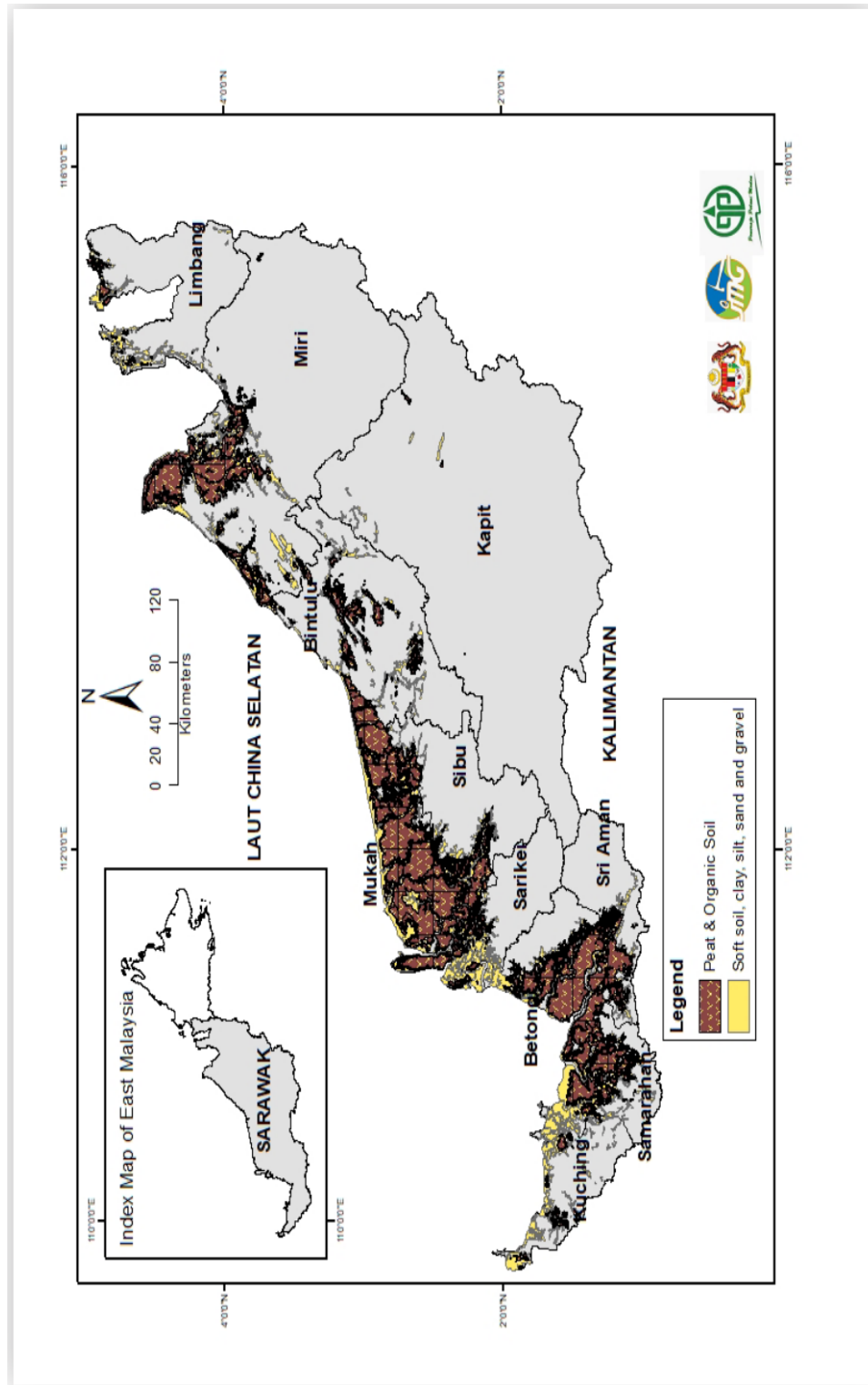


Figure 1.1: Peat Distribution in Sabah and Sarawak. (CIDB, 2019)

1.3 Scope of study

1.3.1 Aim of Study

The current study aims to enhance the strength of stabilised peat in laboratory by investigating the strength of the peat in its untreated and treated peat. The peat is stabilised with waste tire in order to achieve the suitable strength needed for the road constructions purposes.

1.3.2 Objectives of Study

The suitable amount of stabiliser can help in improving the peat. Hence, in this research, laboratory testing and analysis were executed and the samples were collected from Kampung Endap, Samarahan. In this study, the effect of different types of waste tire are investigated which are rubber crumb and rubber powder.

The main research objectives are outline as follows:

- a. To characterise the basic physical properties of peat soil collected from the site based on the Von Post Scale, organic content and fibre content.
- b. To investigate the effect of different size of waste tire on the optimum moisture content (%) and the maximum dry density of treated and untreated peat by performing the Standard Compaction Test in order to perform the Unconfined Compressive Strength Test. A decrease in moisture content increases the dry density value.
- c. To determine and compare the optimum design mix for peat reinforced using tyre-waste product in order to increase the shear strength of the peat. This can be done by performing the Direct Shear Box Test and Unconfined Compression Strength (UCS) Test. A few researches show that fibre reinforced soils, are better than chemical

binders as it helps in reducing the brittleness of the soils, while the chemical binders reduce the ductile behaviour of the soil.

1.4 Thesis Outline

Chapter 1: Introduction This chapter explains the general background on the locality of the peat within Sarawak, as well as the general characteristics of Peat.

Chapter 2: Literature Review. This chapter further review on the related study of peat, the classification, basic properties on peat, past reinforcement studies, and case studies.

Chapter 3: Materials and Methodology. This chapter explains the methods used in investigating the reinforcement of peat, which are further divided into two properties; namely Physical and Mechanical Properties. This chapter includes the pre-planned design mix which will be used for Compression Strength Tests.

Chapter 4: Results and Discussion. This chapter discussed and analyses on the findings or outcomes based on the reinforcements done as discussed in Chapter 2 such as field testing, basic properties of peat, direct shear box tests, compaction and unconfined compressive strength tests.

Chapter 5: Conclusion and Recommendations. This chapter concludes the outcomes obtained from the analysis in this study. Recommendations on the laboratory works are further suggested at the end of the chapter for future reference.

CHAPTER 2

LITERATURE REVIEW

2.1 General

In this chapter, literature review on peat are further discussed. Generally, soil stabilisation on peat by using fibre reinforcement are still in the research stage especially in Malaysia. This chapter focuses on the existing literature and the past research done on peat stabilization in order to further understand the outcome of the research and identify the problems faced by past research on stabilized soil. This desktop study is the main key reference for this research as it helps in achieving the objectives stated.

2.2 Peat Classifications

Peat is a soil comprises primarily of vegetable tissue in various stages of decomposition, usually with an organic odour, a dark brown to black colour, a spongy consistency, and a texture ranging from fibrous to amorphous (Liu et al., 2003). Peat is often described as a naturally occurring highly organic substance derived from plant material. Peat is commonly classified based on its fibre content, organic content, and also ash content. According to Lishtvan (1981), it has different degree of decomposition which depends on the combination of conditions, such as the chemical content of the water supply, the temperature of the region, aeration and the biochemical stability of the peat- forming plant.

Peat is classified according to the Von Post Test which are determined on the field (Adon et al., 2012). This method is based on the scale of humification (refer Figure 2.1) based on water and peat that escaped from fingers when the samples were squeezed by the hand. According to The Public Works Department, (IKRAM and Jarrett, 1995), the organic matter content of peat is more than 75%.

The American Society for Testing and Materials (ASTM), stated that there are three classifications of peat, namely fibric, hemic and sapric, which are classified based on the fibre content, ash content, and the acidity of the soil. Fibric soil contains more than 67% of fibre, with a high organic and fibre content. Hemic soils represent the intermediate between fibric and sapric which its fibre content is around 33-67%. Sapric, on the other hand consists of less than 33% of its fibrous content. Sapric are highly decomposed material. Its water holding capacity is less than fibric and hemic. Sapric soil is also known to have a low permeability, compressibility, and friction angle while its coefficient of earth pressure increases at rest (Huat et al., 2014).

Table 2.1: Von Post Scale descriptions (Jarret, Geoguide 6: Site Investigation for Organic Soil and Peats,1995).

Degree of Humification	Description
H1	Completely undecomposed peat which releases almost clear water. No amorphous material present
H2	Almost completely undecomposed peat which releases clear or yellowish water. Plant remains still easily identifiable. No amorphous material presents.
H3	Very slightly decomposed peat which releases muddy brown water but for which no peat passes between the fingers. Plant remains still identifiable and no amorphous material present.
H4	Slightly decomposed peat which, when squeezed, releases very muddy water dark. No peat is passes between the fingers, but the plant remains are slightly pasty and have lost some of their identifiable features
H5	Moderately decomposed peat which a very indistinct plant structure. When squeezed, releases very ‘muddy’ water with a very small amount of amorphous granular peat escaping between the fingers. The structure of the plant remains is quite indistinct although it is still possible to recognize certain features. The residue is very pasty.
H6	Moderately decomposed peat which a very indistinct plant structure. When squeezed, about one-third of the peat escapes between fingers. The structure more distinctly than before squeezing.
H7	Highly decomposed peat. Contains a lot of amorphous material with very faintly recognizable plant structure. When squeezed, about one – half of the peat escapes between the fingers. The water, if any released is very dark and almost pasty.
H8	Very highly decomposed peat with large quantity of amorphous material with very indistinct plant structure. When squeezed, about two thirds of peat escapes between the fingers. A small quantity of water may be released. The plant material remaining in the hand consists of residues such as roots and fibres that resists decomposition.
H9	Practically fully di composed peat in which there is hardly any recognisable plant structure. When squeezed it is fairly uniform paste.
H10	Completely decomposed peat with no discernible plant structure. When squeezed, all the wet peat escapes between fingers.

2.3 Peat behaviour

Peat is characterised by having high moisture content, low dry density, low pH value, low vane shear strength and a high value of settlement. According to Mutalib et al. (1991), the moisture content of peat based on dry- weight basis is ranging from 100% -1300%. In East Malaysia, the moisture content of peat is ranging from 150%- 2207%. Water is held in organic matter and the cells of the plant. Mutalib et al. (1991) also stated that peat has an ash content of less than 10% and its loss of ignition is more than 90%. Other than that, Mutalib et al. (1991) stated that the pH value of organic soils is between 3.0-4.5 which indicates the acidity of the soils.

Peat with high fibre content are compressible and it is high in water content which would result to a lower value in the shear modulus and a higher damping ratio (Zainorabidin et. al., 2015). Tan and Chan (1993) reported that, the field vane shear strength recorded an average value of 10kPa with sensitivity of 2 to 11 unit, for the Malaysian peat. According to Bell (1983), high water content and a low dry density causes the soils to have a low shear strength. The high amount of water content causes the buoyancy and the high pore volume causes a low bulk density ranging from 0.1 to 0.2 per cubic centimetre (determined for the top 30cm) and low bearing capacity (Mutalib, 1991). The on-going lowering of water in the peat swamp, will cause the drained peat layers to weigh down on the peat below the water table resulting the densities increases with depth, due to compression (Yogeswaran, 1995). Munro (2005), stated that, the greater the moisture and decomposition, the shear strength getting lower, but a higher mineral content gives a higher shear strength. Peat at a shallower depth are more likely to have a greater shear strength due to its fibrous nature compare to humidified peat at depth (Culloch, 2006). The fibrous nature in the shallower depth has a greater strength since the fibres acts as reinforcement and are able to provide effective stress,

where there is none, inducing anisotropy (Huat et al., 2014). Sand, on the other hand, in nature is incompressible, and the stiffness of the soil is dependent on the particle arrangement of the particles which results in a more consistent reading of the damping and shear modulus. Well graded sand has higher values of damping and shear modulus compared to uniformly graded sand due to better interlocking structure (Zainorabidin et al., 2015).

A research was done on the geochemical properties of the different types of soil which includes laterite, kaolin and peat in terms of its properties, compaction, unconfined compressive test, and california bearing test (Mohd Yusof et al., 2015). Peat can be determined to have a higher plasticity index, moisture content, and a higher amount of organic matter. Soil compactibility is determined by soil texture, soil water, organic matter content, soil aggregation, and compaction effort (Barik et al., 2011). It can be concluded that the soil is stiff, and the soil grains are more resistance to compaction due to a lower water content. Well-graded soils tend to give a higher dry density value compared to poor-graded soils. The dry unit weight of peat is lower than the inorganic soils due to the lower specific gravity and higher water holding capacity. Peat has a lower unconfined compression strength value compared to laterite and kaolin due to water content, soil texture and the soil bulk density. Due to compaction, the soil strength is affected by the texture because soils with a wide distribution of particles size are more compactable compared to fine size particles. The California bearing values show that it is dependent on the densification, soil texture and moisture.

Peat drainage plays an important role in determining the geotechnical behaviour of the peat. Peat swamps drainage causes decomposition rate to be higher thus, enhancing consolidation and compaction which leads to subsidence of the ground surface (Musalib et al., 1991).

2.4 Peat Stabilisation Technique

Stabilised peat can be done by mixing cement, sand, bentonite, calcium chloride (CaCl_2) as binder. Mixing peat with binders helps to increase the strength of the peat. This can be proven by the undrained shear strength test, unconfined compression test, direct shear box test and scanning electron microscope test. It can be concluded that the deep soil stabilisation does not only form a soil- column, but it also helps to stabilise the surrounding soil which increase bearing capacity by increasing the friction between the soil column and surrounding stabilised soil.

2.4.1 Chemical Stabilisation of Peat

There are a few chemicals that can be used in stabilizing peat. These stabilizers are used to increase the shear strength of peat by producing a cementitious product. Makusa (2012) has listed a few stabilizing agents which cement are, lime, fly-ash, blast furnace slag, pozzolonas, rice husk ash, gypsum and jet grout. These chemicals react with peat to produce cementitious products in order to bind the peat to increase the strength of peat.

Unconfined compressive strength test has been done on a few peat samples in Matang by using ordinary portland cement (OPC), analytical quick lime (QL) and Fly Ash (FA) (Kolay et al., 2011). Throughout the analysis, the original value of UCS of the peat sample was 14.23kPa. It can be concluded that when the OPC is used to treat the sample, the strength of the peat sample is higher in comparison to when QL and FA were added into the samples.

The strength of soil increases with curing period of all percentage when OPC were added into the sample. It is shown (Figure 2.1) that the value is predominant with higher percentage compare to QL and FA samples.

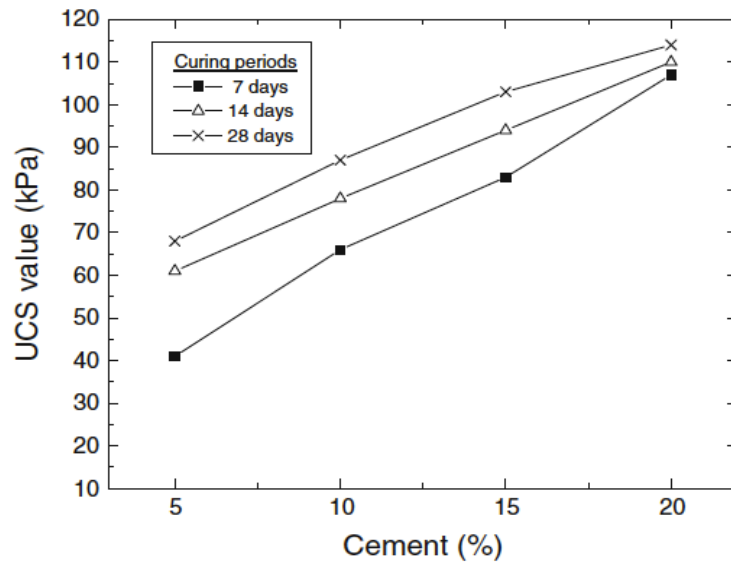


Figure 2.1: Effect of OPC addition and curing period of UCS of the peat soil (Kolay et al., 2011).

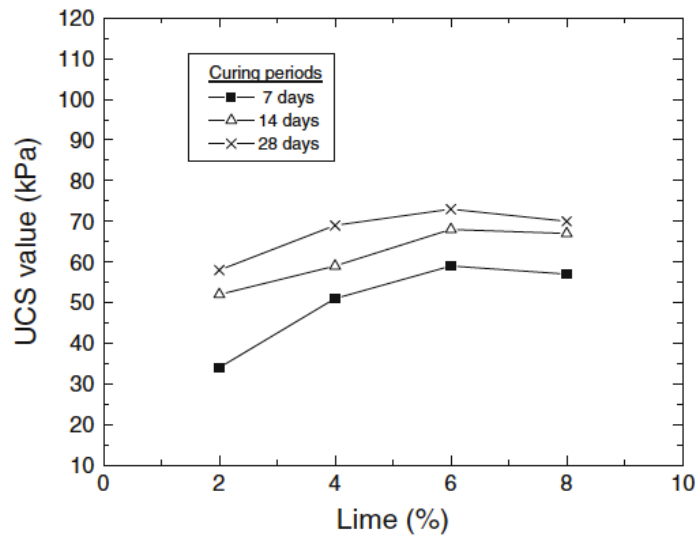


Figure 2.2: Effect of QL addition and curing period of UCS of the peat soil (Kolay et al., 2011).

The UCS value also increase for the QL samples, also, the strength increases with its curing period. It increases with up to 6% but decreases steadily after the percentage (Figure

2.2).

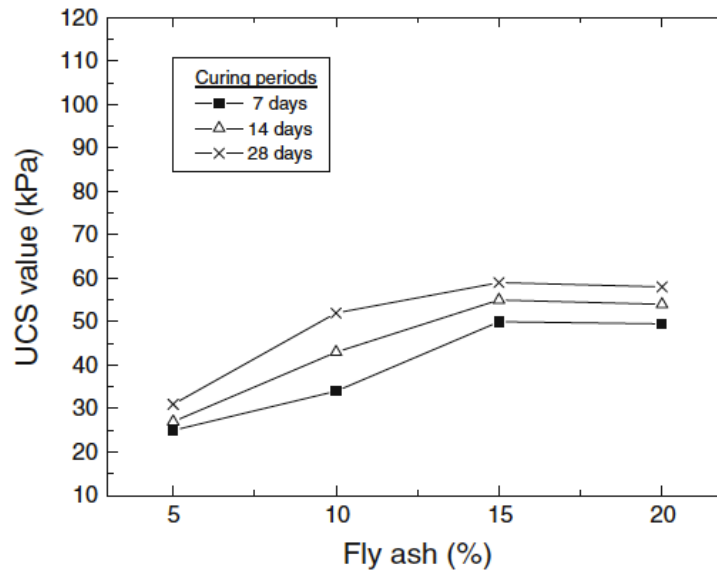


Figure 2.3: Effect of FA addition and curing period of UCS of the peat soil (Kolay et al., 2011).

Based on Figure 2.3, the strength increases with the addition up to 15% of FA. This is due to the fact that FA reacts well with the molecules of the peat. It can be concluded that stabilizers can be used to increase the strength of the peat soil, and OPC is the most suitable stabilizers to use compared to QL and FA, since the strength of the peat is increasing and achieves up to 20% OPC, with the combination of 6% QL and 15% FA.

According to research done by Romali (2019), peat soil reinforced with nylon fiber has the lowest Maximum Dry Density (MDD) of 733 kg/m^3 for its control samples. However, the MDD for its modified samples of peat- nylon- fly ash mixture shows a lower MDD value of 730 kg/m^3 . The highest UCS value is recorded as 94.05 kN/m^2 at 56 days of curing when nylon is added to the peat samples. Romali (2019) proposed 10% of fly ash is the optimum percentage for both control and modified samples. This is due to the high UCS

value of 122.30 kN/m² with an addition of 10% fly ash to the peat sample at 56 curing days, whereas on the other hand, peat with 5% cement, 5% nylon fiber and 10% fly ash produced a UCS value of 123.71 kN/m² at 56 curing days (Figure 2.4).

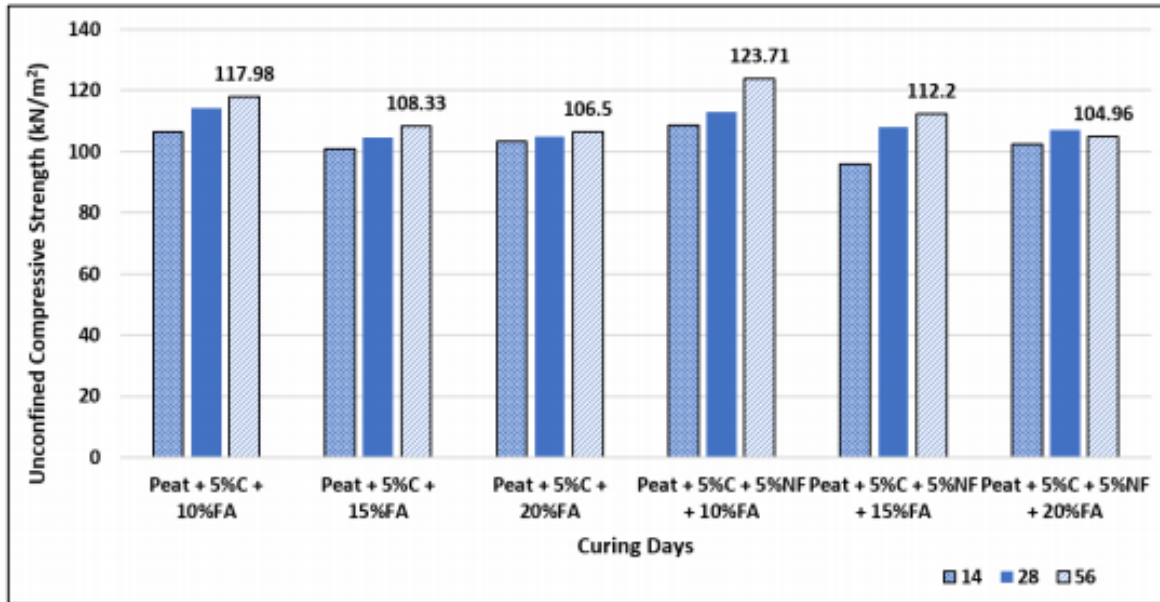


Figure 2.4: Unconfined Compressive Strength vs Curing days (Romali, 2019).

Another research was done by Hamzah et al. (2019) on peat acquired from Jalan Sungai Panjang, Selangor, Malaysia and was treated with sawdust and Rice Husk Ash (RHA). Based on the research done, it can be deduced that, it shows an improving results in both economic and strength capacity. The liquid limit and the plastic limit of the soil is decreasing as the percentage of the RHA increasing. This is due to the presence of silica content and mineralogy which controls the Atterberg limit of the soil.

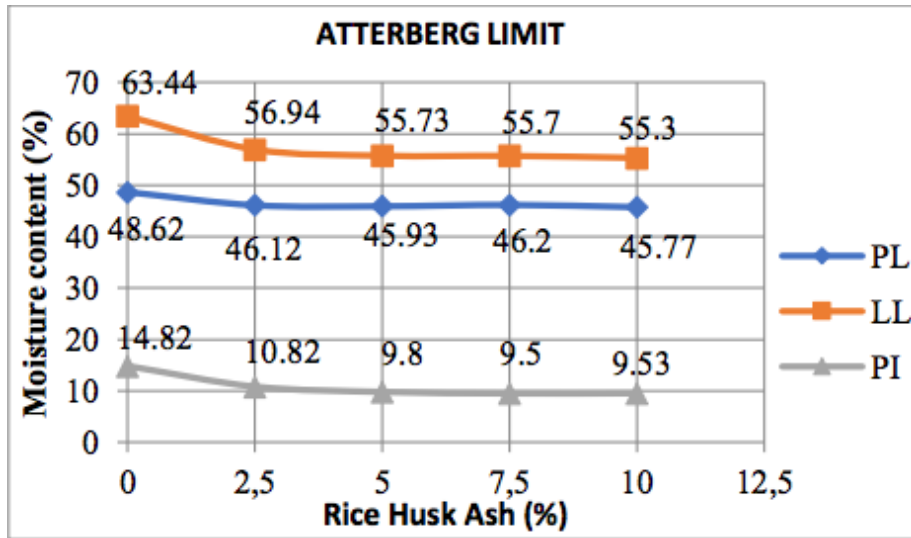


Figure 2.5: Effect of Rice Husk Ash and Hydrated Lime content on Atterberg Limit (Hamzah et al., 2019).

For the UCS test, the value increases to high limit at an optimum value of 7.5% of RHA content and 2% Lime. Due to clay content reduction in soil, the value decreases at 10% of RHA. This results in the reduction of cohesive force in the soil sample. Initially, RHA with high silica content forms the cementations compound giving the good cohesion, but as the RHA content increases, it slows down the pozzolanic reaction by occupying the void spaces in the soil thus reducing the bond between the soil and RHA. Hence, the optimum percentage of RHA addition is at 7.5%.

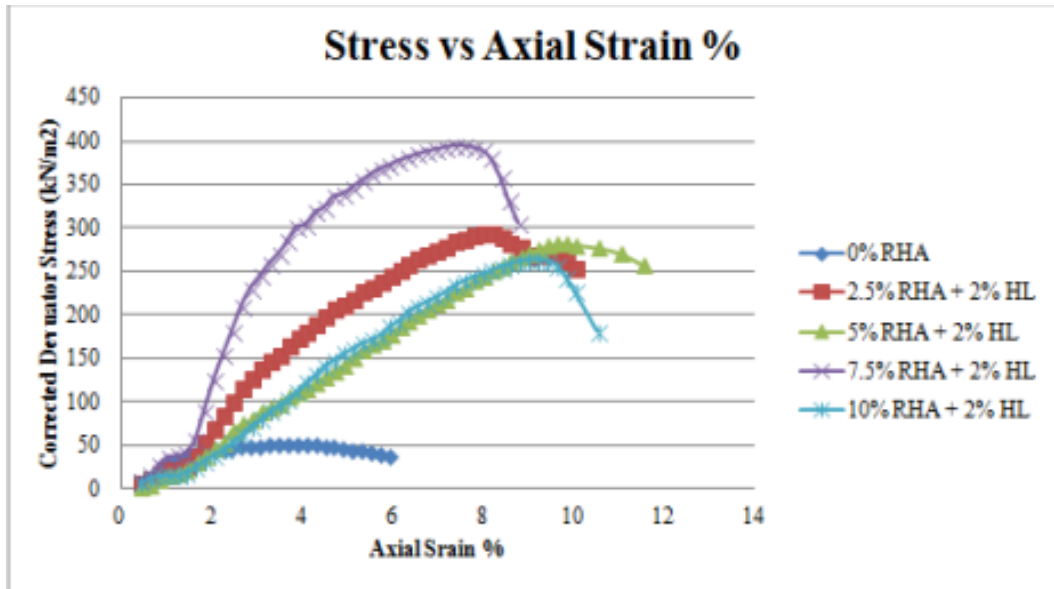


Figure 2.6: Compressive Strength curve of treated soils at different RHA content (Hamzah et al., 2019).

2.4.2 Field Stabilization of Peat

Huat (2004) has listed a few types of field stabilization practices. These methods are used to increase the shear strength of peat. There are two categories for the type of field stabilization, namely, mass stabilization and mechanical stabilization.

a. Mass stabilization

- **Deep mixing (dry & wet conditions)**

Broms and Boman (1979) stated that this method, forming soil- cement columns is a popular method to increase the bearing capacity of soft soils and decrease the total settlement of soft ground. This method helps in improving the mechanical and physical properties of the existing soil, in which the soil is mixed with cement, known as soil-cement. The soil that have been stabilised have a higher strength, lower permeability and lower compressibility. The soils need to be improved by using the slurry including binder (wet DSM) or dry binder (dry DSM). Soil with high moisture content uses the dry method while the slurry including binders is suitable for soft clays, silts and fine-grained sands with lower moisture content. This method is economical, environmentally friendly, flexible in application, reduces construction time and vibration free (Keller,2017).

- **Sand drains and sand/ stone columns**

Stone columns are basically a vertical cylindrical “hole” executed in a soft soil filled with compacted stone fragments and gravel having high potential drainage. This method is used to improve the soft layers under dams and embankments to increase the bearing capacity, which helps in decreasing the settlements and to

accelerate the consolidation process like a vertical drain (Bouassida et al., 2008).

- **Prefabricated Vertical Drain (PVD)**

PVD is composed of a plastic core encased by a geotextile for the purpose of expediting consolidation of the slow draining wall. The plastic core act as the filter fabric and provides longitudinal flow paths along the drain length. PVD also provides resistance to longitudinal stretching as well as buckling of the drain (Fox et. al., 2014). There two types of PVD:

- Hydraulic Prefabricated Vertical Drain (PVD)
- Vacuum Prefabricated Vertical Drain (PVD)

b. Mechanical

- **Vibrated concrete column**

Vibrated Concrete column is also known as vibro stone column, are used to improve the soil quality from loose sedimentary sands to soft soils which have the the undrained shear strength of 15kPa or more. However it has been proven to be ineffective for low cohesive soils which possess a lover undrained shear strength of below 10kPa. According to Shirazi et al, it has said to be this method is efficient and cost effective to treat problematic soils (2015).

- **Vacuum preloading**

This method was first introduced in Sweden by Kjellman (1942), to accelerate the consolidation of the soft ground worldwide. This method is appropriate to use for a very soft clay where a high surcharge embankment cannot be constructed

without affecting stability or having to work within a tight construction schedule (Indraratna, 2010).

2.5 Current Practice on Road Stabilisation

Road constructions being carried out from the year 2000 in Poland, often involved in crossing areas with the poor soil conditions, which includes a large deposit of organic soils such as peat and gytja, soft soils. These cause a major geotechnical problem and thus requires preparations of soil improvement projects. A study done by a few researchers in Poland concluded that there are two possible solutions in overcoming the geotechnical problems, which are, deep soil replacement and pile deck system where organic soil replacement was not possible.

Deep soil replacement or exchange is carried out whereby it is the major soil improvement techniques in all peat areas except on deep peat areas. In the area of shallow and smaller peat area (2- 4m), the simple dredging methods was applied. All the organic soils are removed are then replace with new mineral, which was constructed in layers with compaction, which are executed in the dry conditions, and the groundwater are below the bottom of organic deposits. Deeper peat areas exceeding the depth of 4m, not only the dredging method were use, an addition of ‘push out’ method was use. Sandy fill with a low density are used to replace all the organic soils, once the dredging and ‘push out’ method is complete.

The pile-deck system was introduced on a large part of the longest and deepest peat area whereby the prefabricated piles are designed to be installed on a 250m long and 36m wide stretch (Wojtasik et al., 2006).

A number of constructions with different method have been carried out on peat some of which are road construction while others are building constructions (Munro et al., 2007, Fox & Edil, 2001). There are two ways in doing construction over peat, which are the complete removal of peat, and the other is leaving the peat in place but with a certain modification. According to Munro (2007), there are a few sub- headings involve in peat removal, which are avoidance, excavation, replacement and displacement.

Another method which is currently becoming more attractive among the engineers are by leaving the peat in place as construction works done are more economical and more budgets reduce through waste minimisation and environmental considerations (Munro, 2004). This method includes methods of accelerating consolidation (preloading, stage construction and vertical drain), ground improvement techniques which aids in reducing deformation, stabilisation of peat, load modification and piling methods. Ground improvement techniques are used in influencing the engineering properties of the peat, which helps increasing the shear strength, compressibility, stiffness and permeability. Thus, this involves various techniques such as stone columns, cement columns, geopiers, soil column and surface reinforcement such as geotextiles, geogrid, timber or bamboo mattress.

A study has been done by a few researchers from UNIMAS, to study the relationship between road construction methods and post- construction rate of settlement. The study aims in conducting an analysis on the problems of constructing road on peat and to determine the suitable method to construct the road with respect to different depths of peat relative to the density of the traffic flow (Buking et al., 2009). This study found that the partial replacement method was found to be more suitable for road construction with a higher traffic volume. Replacement method and by using bamboo mattress and geotextile, on the other hand, are more suitable for roads with a lower traffic volume. The findings concluded that the

settlement of the road varies with the depth of peat, operation time, level of service, peat properties and pavement thickness.

It is recommended that more site investigation reports are used together with the method of the road construction for future research on peat. Other than that, the level of the road is being checked every year. There are also important things which need to be taken into consideration when constructing road are the construction period, the site condition, material condition, number of passes by compactor, work constraint and equipment mobility.

According to a few researchers from Erode Segunthar Engineering College (2014), Ordinary Portland Cement appears to perform better compared to the performance of cement and lime. The study proves that the maximum dry density of the soil increases while optimum water content decrease, with the increase of cement and lime. The value of the Unconfined Compressive Strength Test (UCS) on the peat, increases with the addition of cement (96 kPa to 124 kPa) compared to the untreated peat (54 kPa). As for the peat which is treated with lime, the UCS value increases to 89 kPa to 113 kPa when compared to the untreated peat.

Soil reinforcement is a procedure where natural or synthesised additives are used to improve the conditions of the soil. In a simple review done by researcher from Isfahan University of Technology (Hejazi et al., 2011), both natural (coir, sisal, palm, jute, flax, straw, bamboo and cain) and synthetic (PP, PE, PET, Nylon, Glass PVA and Steel) fibres that have been yet used to reinforce soil were investigated. It is proven that the strength of fiber reinforced soil increases with increase in aspect ratio, fibre content, fibre modulus and soil finer surface friction. It is no doubt that chemical binders help to improve the soil conditions. However, they decrease the ductile behaviour of the soil. Fibres, on the other

hand, help to reduce the brittleness factor of the composite soil. Using fiber reinforcement method are economical, easy to work with, and feasible in all weather conditions. In addition, it helps in preventing the formation of tensile cracks, increasing hydraulic conductivity and liquefaction strength, reducing the thermal conductivity and weight of building materials, restraining the swelling tendency of expansive soils and decreasing the soil brittleness. In this study, the method use was by mixing the fibres into the soil. There are two methods involve in investigating, which are mixing the fibres in soil matrix manually or by mechanical means.

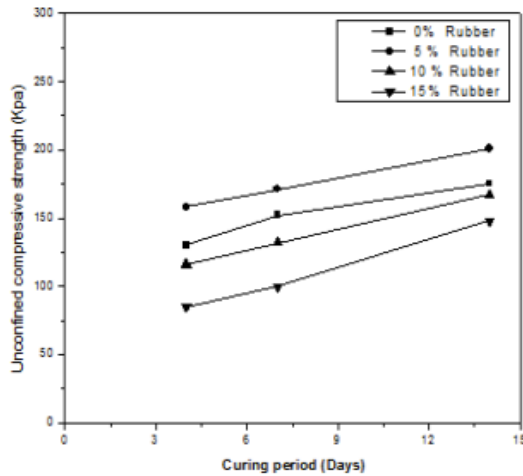
According to Ghani et al. (2002), there are a lot of studies being done by using scrap tyres. The applications of the tyre scrap depend on the processing of the tyres which includes shredding, removing of metal reinforcement and further shredding until the desired material is achieved (Carreon, 2006). The use of shredded tyres and rubber sand, which includes the weight of fill, adequate stability, low settlements, good drainage and the large quantities of local waste tyres, which contributes to positive impact on the environment, produce a technical, economic and environmental benefits (Andres et al.,1996).

2.6 Case Study on Fibre Reinforced Soil

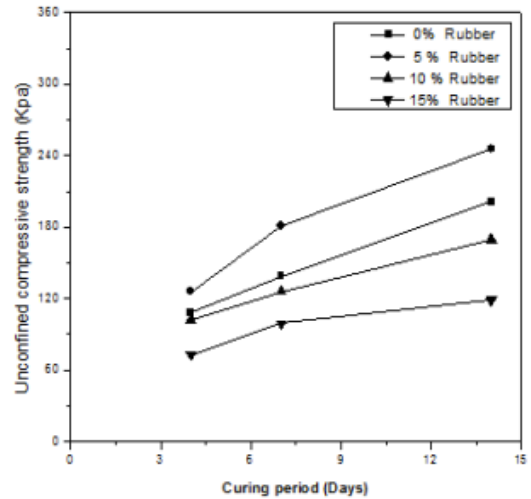
Stabilization in a broad sense incorporates the various method employed for modifying the properties of a soil to improve its engineering performances. It is a process of fundamentally changing the chemical properties of soft soils by adding binders or stabilizers, either in wet or dry conditions to increase the strength and stiffness of the originally weak soil (Jan et al., 2015). Studies on soils, especially weak soils such as peat, reinforced with fibre, are not broadly explore in Malaysia. In this subtopic, past research on soil stabilize with waste tyres are emphasis more due to the abundant of waste tyres which contribute to

disposal problem.

A study was done on black cotton soil and shedi soil in India with randomly distributed shredded rubber tyre chips with 5%, 10% and 15% and cement with 2% and 4% percentage. Soil improved with cement, generally reduce the liquid limit, plastic limit and the potential for volume change of soils (Bell, 1988), however, there will be an increase in the shrinkage limit and shear strength of the soil. Shredded tyre material of length 10mm to 25mm and thickness of 2mm to 3mm were used in stabilizing the soil samples. The specific gravity of the shredded tyre obtained ranges from 0.90 to 1.12. The soil passing through 425 μ is mixed with cement (2% and 4%) and cured for 4, 7 and 14 days are prepared with different percentage of shredded rubber chips (0%, 5%, 10% and 15%) at optimum moisture content totaling 48 samples were prepared.



(a) Shedi soil with an addition of 2% of cement



(b) Black cotton with an addition of 4% of cement

Figure 2.7: The variation of unconfined compressive strength for curing period of 4, 7, and 14 days on (a) shedi soil with an addition of 2% of cement and (b) Black cotton soil with an addition of 4% of cement respectively (Bell, 1988).

From Figure 2.7, the maximum unconfined compressive strength at 5% of rubber content and curing period of 14 days for black cotton is at 74kPa and shedi soil is 201 kPa. The compressive strength value of 14 days cured soil for 5% rubber content and 4% of cement is at 246 kPa for black cotton soil and 328kPa for shedi soil. It can be concluded that, the increase in curing period affects to the increase of the unconfined compressive value at an optimum 5% mix of rubber chips.

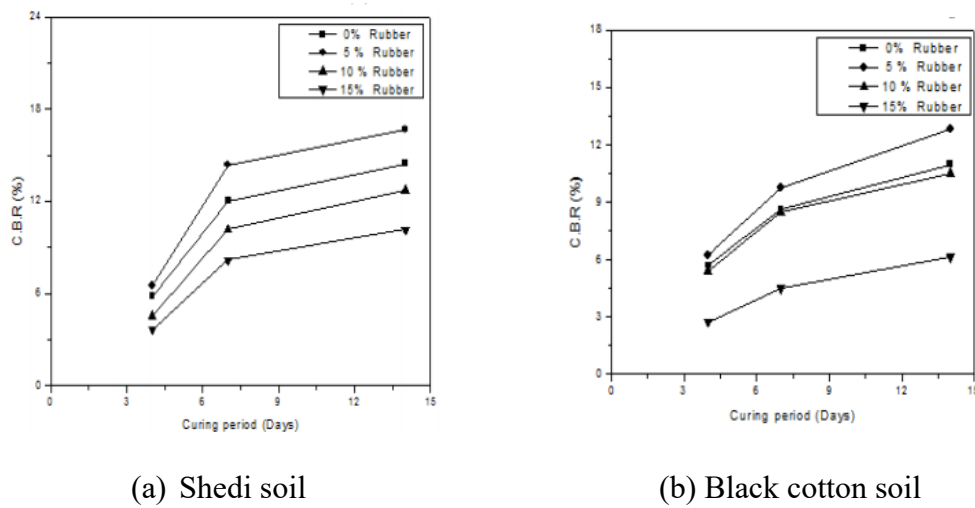
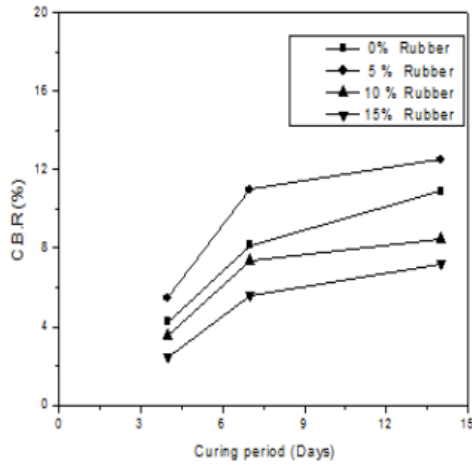
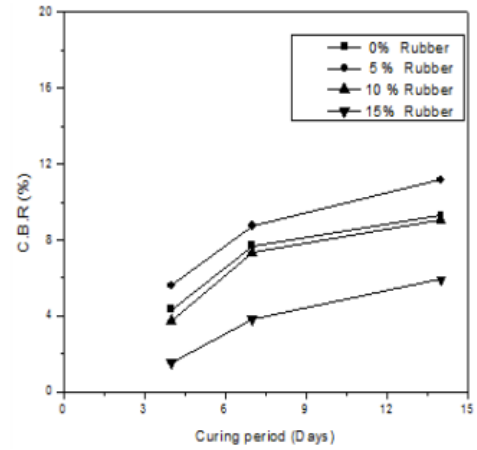


Figure 2.8: The variation of california bearing test (unsoaked) for curing period of 4, 7, and 14 days on (a) shedi soil with an addition of 2% of cement and (b) Black cotton soil with an addition of 4% of cement respectively (Bell, 1988).

The results indicate that the longer curing period affects the increase in California bearing ratio at an optimum mix of 5% shredded rubber tyre. The increase in value is not only affected by the hydration of cement but also due to the optimum rubber content. Based on Figure 2.8, for 2% cement and curing of 14 days, the black cotton soil produced a value of 4.33% whereas shedi soil shows a higher value of 16.68%. At an addition of 4% cement with 5% shredded rubber, the black cotton soil shows a value of 12.83% while shedi soil shows 21.06%.



(a) Shedi Soil



(b) Black cotton soil

Figure 2.9: The variation of california bearing test (soaked) for curing period of 4, 7, and 14 days on (a) shedi soil with an addition of 2% of cement and (b) Black cotton soil with an addition of 4% of cement respectively (Bell, 1988).

Based on soaked CBR test, it also indicates that the period of curing affects the increase in value of bearing capacity of the soil. Figure 2.9 shows that the soil mixed with 2% cement, with an optimum rubber content of 5%, the black cotton soil shows a value of 2.93% while the shedi soil shows a value of 12.52%.

All three analyses, which includes unconfined compressive strength tests and California bearing test (soaked and unsoaked) values increase with the increase in cement at an optimum fiber content of 5%. The black cotton soil increases from 15kPa to 74kPa (2% cement) and 246kPa (4% cement) for its unconfined compressive value and it increases from 1.24% to 11.16% for 4% cement respectively. Shedi Soil increases from 59.40kPa to 201kPa (2% cement) and 328kPa (4% cement) for its unconfined compressive strength value and increases from 2.63% to 13.79% for 4% cement. The increase of CBR value significantly reduce the total thickness of the pavement and inevitably reduces the total cost involved in the project (Hambirao et al., 2014).

Another research studied on stabilizing soil collected from CCET, Sec.26 (Chandigarh), India, using shredded tyre (Jan et al., 2015), concluded that the optimum moisture content and the maximum dry densities decrease with the increase of the rubber tyre content. The samples collected are mixed with a few sizes of rubber chips (15 x30 mm, 20 x 40 mm and 25 x 50 mm) at a percentage of 4%, 6%, 8% and 10% by weight of soil. The bearing ratio increases with the addition of rubber tyre up to 8% and decrease with the increment of rubber content to the soil. It is determined that the optimum value of rubber tyre is 8% of size 25mm x 50mm in unsoaked condition. In an unsoaked condition, the CBR value is 66.28% where with the increase in the value can reduce the total thickness of the pavement and the total cost involved in the project. Below (Figures 2.10, 2.11, 2.12) shows the comparison on the CBR value for all the sizes used in the analysis:

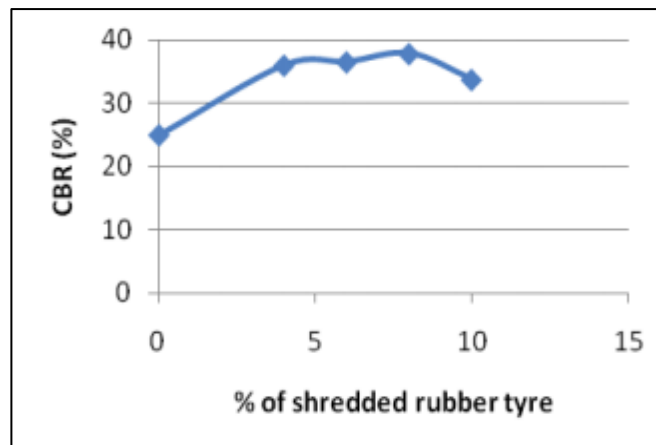


Figure 2.10: The CBR value of soil mixture (15 x 30 mm) (Jan et al., 2015).

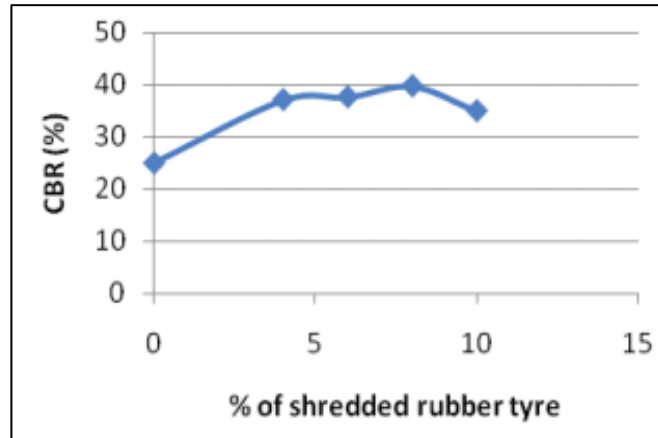


Figure 2.11: The CBR value of soil mixture (20 x 40 mm) (Jan et al., 2015).

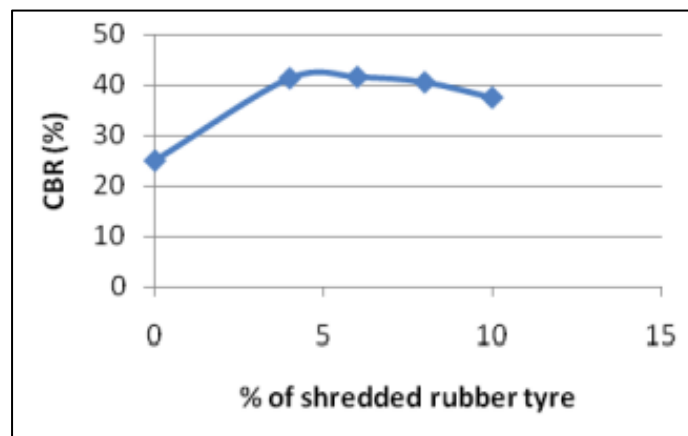


Figure 2.12: The CBR value of soil mixture (25 x 50 mm) (Jan et al., 2015),

An investigation was carried out on a poorly graded silty sand soil in which 75% of the particles are in the range of 0.2 and 0.1mm collected from IIT Delhi campus (Ayothiraman, 2011). Shredded tires with a specific gravity ranges from 0.90 to 1.12, thickness of 2 to 3mm, and a size of 10 x 20mm is used in this study. The soil is mixed with

1%, 2%, 3%, 4%, 5%, 6%, and 9% of shredded tire by weight of soil. It is determined that the optimum moisture content increases and the maximum dry densities decrease due to the increment of the percentage of the shredded tire. Below (Figure 2.10) shows the compaction curve:

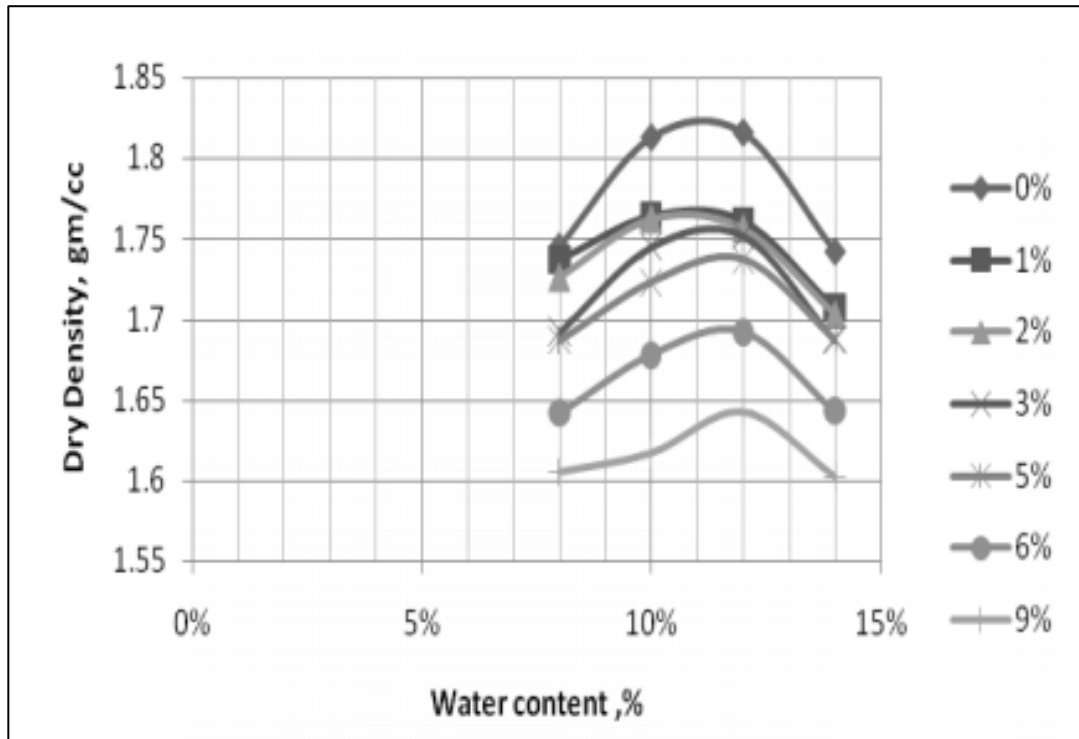


Figure 2.13: Compaction curve for soil-tire chips mixture (Ayothiraman, 2011).

The bearing ratio of the soil with the shredded tire were determined by performing the California bearing ratio test. The thickness of the pavement can also be determined from the CBR value. Below shows the load- penetration curve obtained from the CBR tests for different percentages of tire chips mixed in the soil:

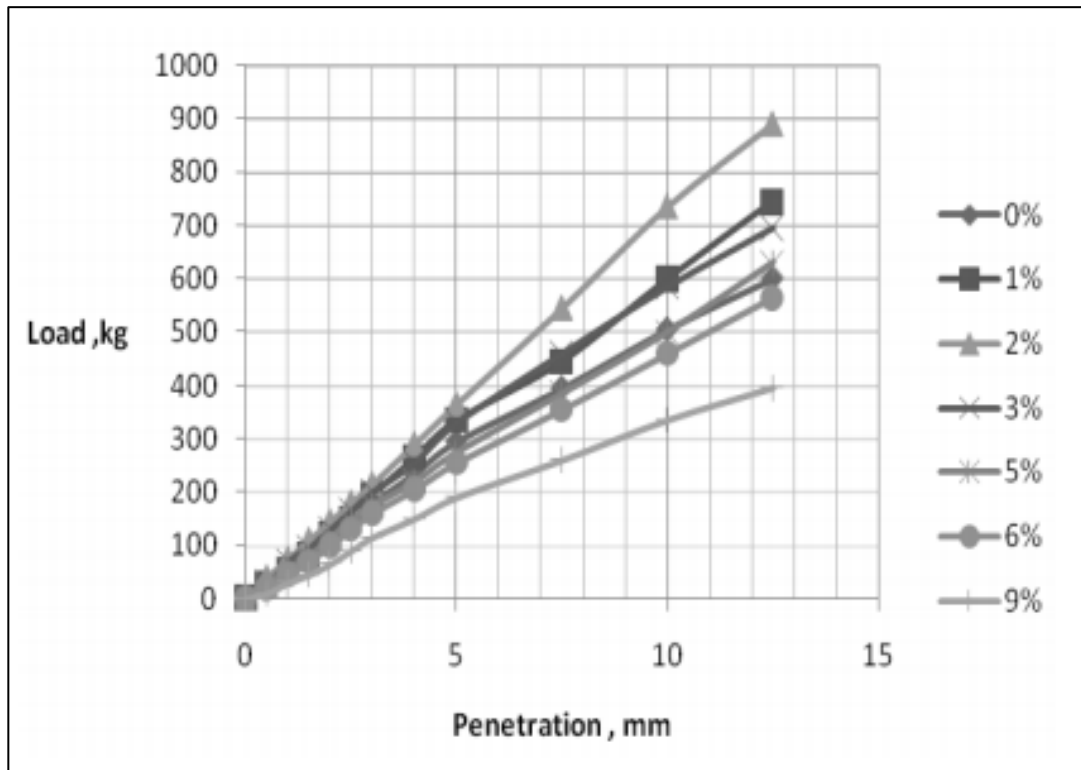


Figure 2.14: Load- penetration curve from unsoaked CBR tests (Ayothiraman, 2011).

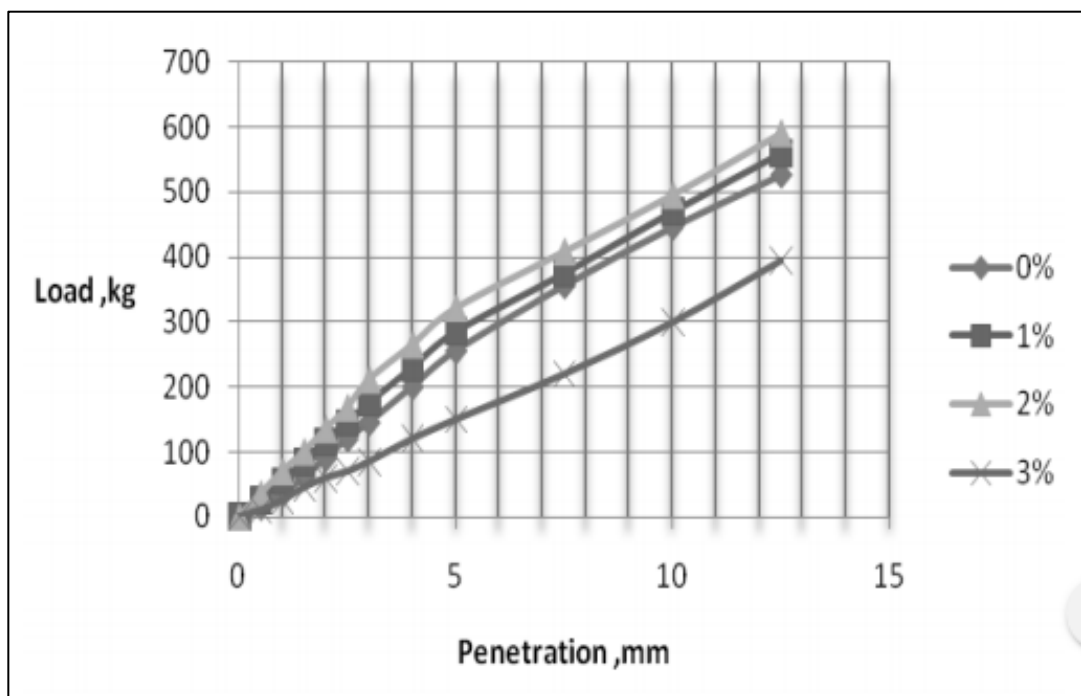


Figure 2.15: Load- penetration curve from soaked CBR tests (Ayothiraman, 2011).

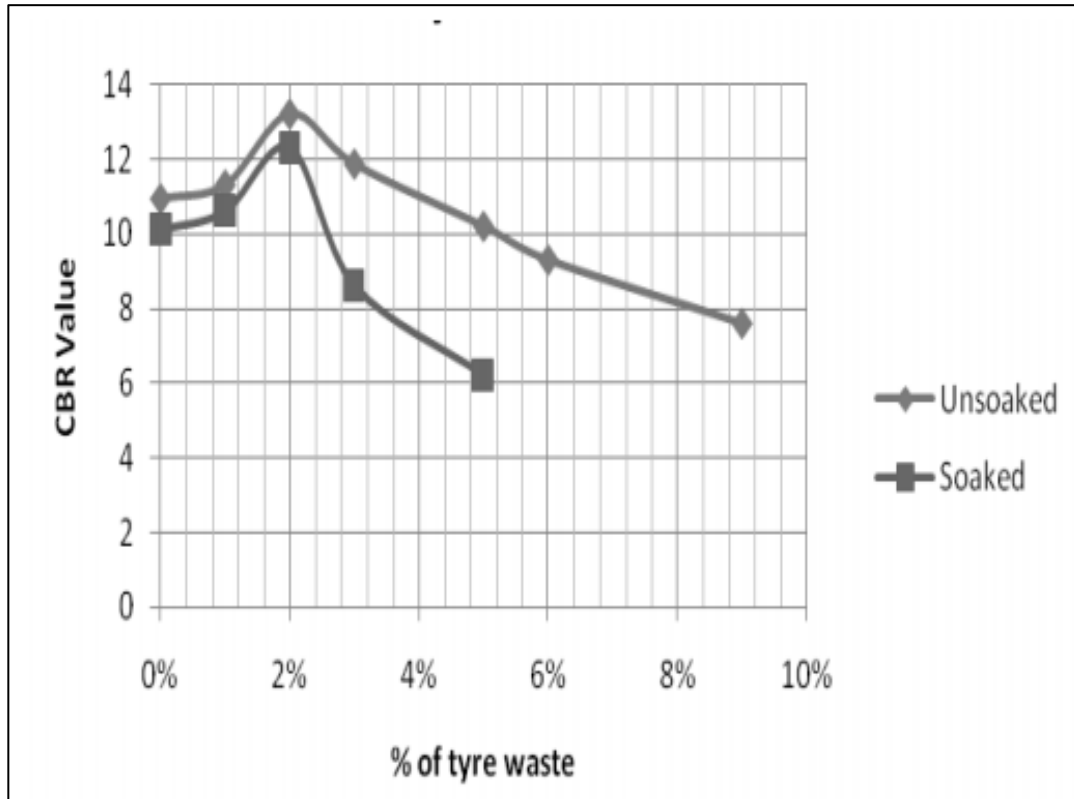


Figure 2.16: CBR curve for both soaked and unsoaked CBR values (Ayothiraman, 2011).

The percentage improvement in CBR value in stabilized soil is 21% in unsoaked and 22% in soaked condition, thus reduces the total thickness of the pavement and significantly lessen the total costs involved in the project. The optimum moisture content value of tire waste content is determined at 2% in both soaked and unsoaked condition and its maximum CBR values are 12.21% and 12.31% respectively. These values lie in the range of 10% to 25% as per AASHTO standards of CBR values for sub grade soils. The researchers suggested in investigating the long- term durability and sustainability of subgrade with different ground water conditions before implementing the method in the field.

Clay samples quarried from Gaziantep University Campus in which its plastic limit and liquid limit value are 23.3 and 49.5 respectively based on ASTM D4318 have been stabilize by using tire buffing and lime. Based on tests done on the low plasticity clay, the optimum moisture content and the maximum dry densities decrease as the content of tire buffings increase in clay. The CBR and UCS values shows that the increase in tire buffing reduces the value of CBR and UCS. However, the increase in lime content increases the optimum water content which might be attribute to the high-water absorption capacity of lime particles, and also water utilized during the pozzolonic reactions between the lime and clay particles. The addition of 4% lime with or without tire buffings displays the highest CBR and UCS value compared to other percentages of lime addition. The increase in lime in the samples with tire buffings decreases the maximum dry unit weight (Calabar et al., 2014).

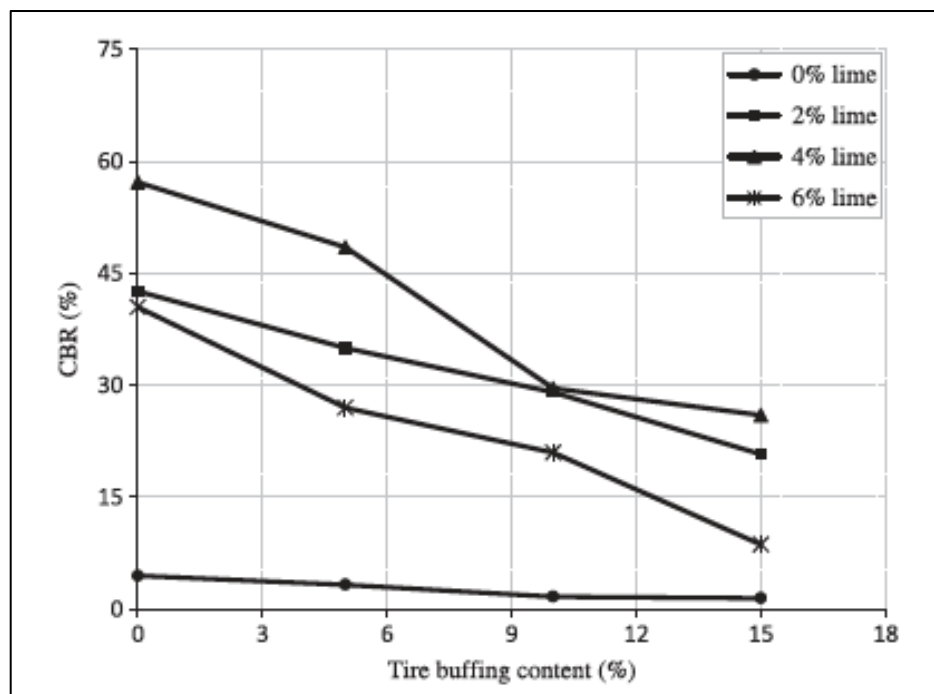


Figure 2.17: Maximum CBR values- tire buffing- lime content for the specimens, after 3- day curing period (Calabar et al., 2014).

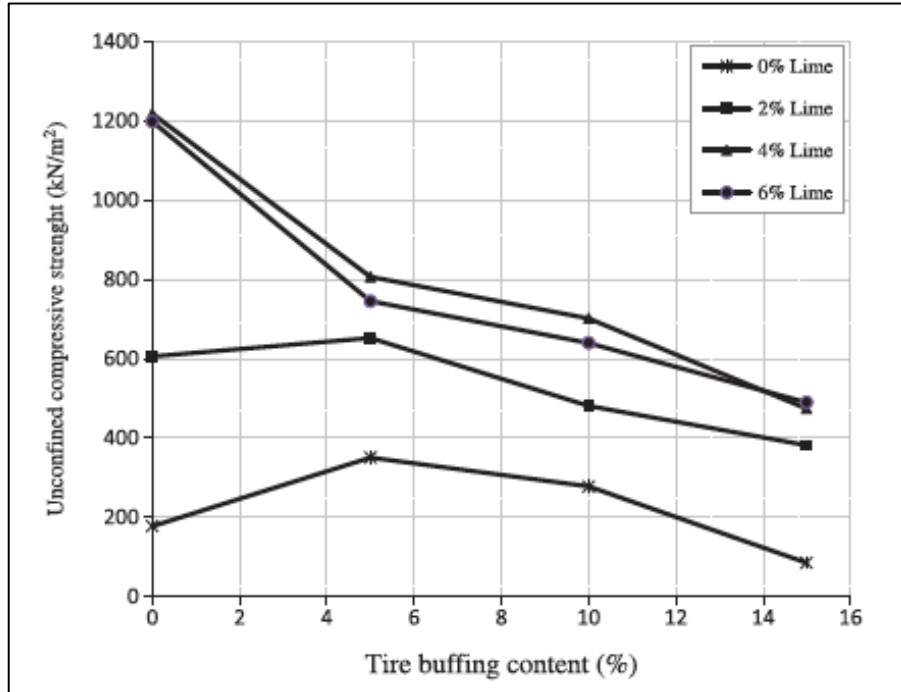


Figure 2.18: UCS values- tire buffing- lime content for the specimens, after 3- day curing period (Calabar et. al., 2014).

Another study done by Chai (2019), the strength of peat increase with an addition of rubber crumb as the main reinforcement material, cement as binder and silica fume as the additive. The strength of peat developed with the curing period from 0 days to 28 days. The highest UCS value recorded is 221.31 kPa for the control sample at 7 curing days for peat- cement- silica fume and 10% rubber crumbs. However the increase in the percentage of rubber does not guarantee the strength development of peat, due to the UCS value obtained for the same sample design mix at 28 days is recorded lower than 7 days of curing, at 175.8 kPa (Figure 2.5).

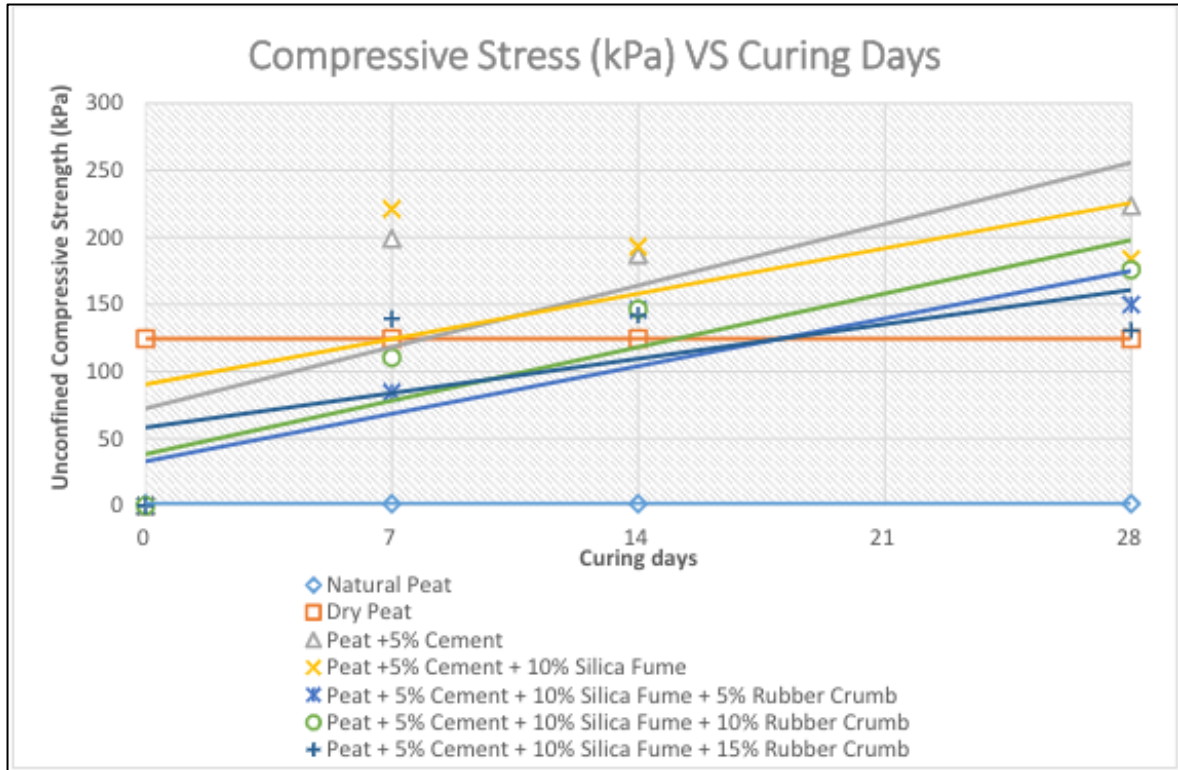


Figure 2.19: Compressive stress (kPa) vs curing days (Chai, 2019).

A research was done on the peat obtained from Kampung Endap, Kota Samarahan by Sa'don et al. (2018) investigates the strength enhancement of peat reinforced with fibre-polyester. The study shows an increment on the strength for both cemented and uncemented on the UCS test with the inclusion up to 5% Rubber Crumbs for both cemented and uncemented peat. The highest compressive strength recorded is at 48 kPa for uncemented peat with 5% shredded rubber crumb at 28 days of curing (Figure 2.19) while for the cemented peat, the highest compressive strength recorded is at 55 kPa, for peat with 5% rubber crumbs at 28 days of curing (Figure 2.20).

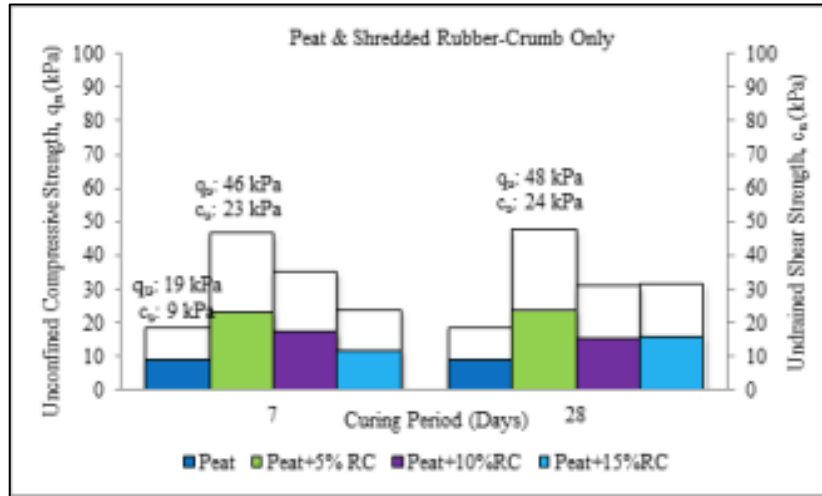


Figure 2.20: Peat and uncemented reinforcement peat with shredded rubber- crumb (Sa'don et al., 2018).

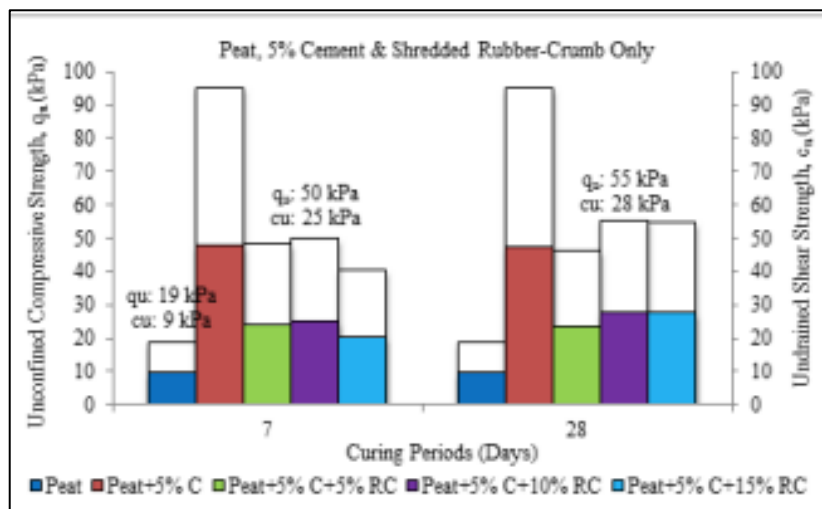


Figure 2.21: Peat and cemented reinforcement peat with shredded rubber- crumb (Sa'don et al., 2018).

2.7 Summary

It is known that Sarawak contributes to the most peat at approximately 80% of the total value of peat soil in Malaysia. It is often described as having a high-water content, low shear strength and low compressibility.

According to the current practice, whereby, excavation and backfill done to the peat field, even though the method definitely increases the strength of the peat and lowers the settlement, this method is costly and uneconomical.

Based on the previous studies done, the researchers often focus more on chemical stabilizers, such as ordinary Portland cement, and fly ash, and field stabilizers such as geotextiles, and bamboo mattress, on peat soil in order to increase the strength of the peat. However, there are inadequate amount of research done by adding tyre scrap, rubber, or crumbs to peat soil in order to increase the strength of the soil and favourable for road construction especially in Sarawak peat itself. Soil stabilised by tire scraps is believed to decrease the optimum moisture content and the maximum dry densities, but it helps in increasing the unconfined compressive strength test value and the California bearing ratio tests value. Stabilizing by using the tire wastes not only increasing the strength of the soil, but it also ultimately helps in reducing the disposal problems.

Soil stabilisation on peat in Malaysia especially when treated using tyre waste are still considered in the research stage and has yet to be fully implemented in the road construction industry. Waste tyres is known to be one of the disposal problems due to an increasing number of vehicles being manufactured in the world today. According to Calabar et al. (2014), waste tyre stockpiles constitute environmental and health risks by producing air pollution from tyre stockpiles fires and breeding grounds for potential diseases. Flexibility,

resiliency, strength and high frictional resistance contributes advantages for engineering purposes which is suitable to increase the strength of the weak soil, especially, peat, which fits the proposed research study.

Hence, the present research was performed in order to investigate the strength of the peat soil whereby the chemical, physical and geotechnical properties of the soil will be focus more. In addition to that, this study hopefully will be more beneficial environmentally and economically to the construction industry. The result of this study, eventually, engineers and future researchers will help them to refer as one of the technique to stabilized peat for the strength enhancement on road construction.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 General

This chapter summarise the materials and the methodology will be used in this research. Methodology is important in every study as it explain the flow on handling the specimen in order to obtain an accurate data. All of the methods used in this study are in accordance to British Standard, Malaysian Standard, and ASTM, which will be specified in every method in this chapter. Figure 3.1 shows the flow chart of procedures that are planned in the study:

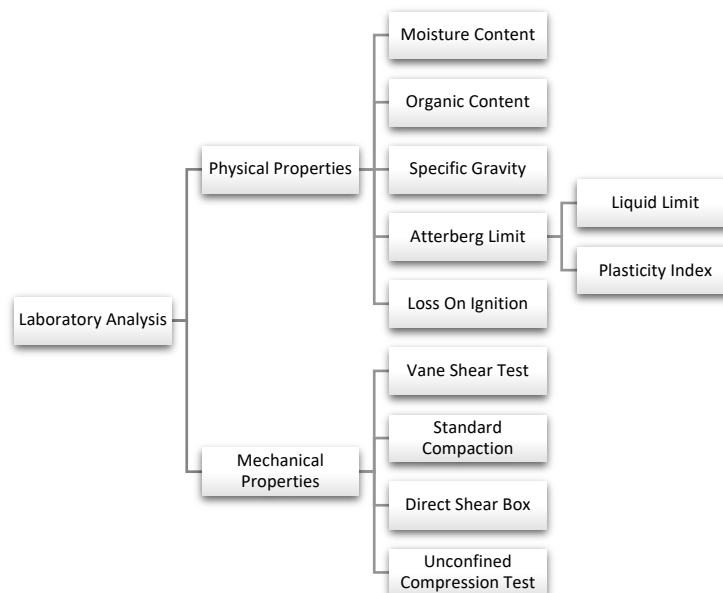


Figure 3.1: Flow chart of analysis for this research.

3.2 Physical Properties

3.2.1 Moisture Content

This analysis is done based on BS 1377: Part 2 1990. This test is to determine the natural moisture content of the soil. An empty crucible is weighed and labelled W_3 . Soil specimen were weighed and placed into an empty crucible at an approximate weight of 20g and labelled W_1 . The crucible filled with specimen is placed in a 105°C oven and is labelled W_2 . The specimen is dried in the oven overnight. The procedure is repeated three times in order to get the average percentage of the moisture content. The percentage of the moisture content is calculated using the following equation:

Moisture Content,

$$w\% = [(W_1 - W_2) / (W_2 - W_3)] \times 100\% \quad \text{Equation 3.1}$$

where,

W_1 = Weight of empty crucible + saturated soil (g)

W_2 = Weight of empty crucible + oven dried soil (g)

W_3 = Weight of empty crucible

3.2.2 Loss on Ignition and Organic Content

Loss on Ignition of peat is determined by the percentage of oven dried mass. This analysis is done to determine the organic content of the soil based on BS 1377: 1990 Test 3.

The calculation of Loss on Ignition is by using the formula below:

$$N\% = [(m_2 - m_3) / (m_2 - m_1)] \times 100\% \quad \text{Equation 3.2}$$

where,

m_1 = Mass of crucible (g)

m_2 = Mass of crucible and dry soil (g)

m_3 = Mass of crucible and dry soil after ignition (g)

The percentage of organic content is calculated using the formula:

Organic content;

$$OC \% = 1 - 1.04 (C - N) \quad \text{Equation 3.3}$$

where;

$C = 1$ for 440°C or 1.04 for 550°C temperature

N = Ignition loss

3.2.3 Fibre Content

The fibre content is determined from the dry weight of the fibres retained on 150µm sieve. An approximately 100g of soil specimen were placed into a sieve and soaked into the water for 24hours and washed until all the soil particles passes through the sieve. The specimen is then kept in the oven overnight and is weighed. The fibre content is calculated using the same formula:

Fibre Content;

$$\text{Fibre Content} = [(M_2 - M_1) / 100] \times 100\% \quad \text{Equation 3.4}$$

where;

M_1 = Mass of 150µm sieve

M_2 = Mass of 150µm sieve + retained soil

3.2.4 Atterberg Limit

Albert Mauritz Atterberg (1846- 1916), a chemist from Sweden is the founder of this analyses. Atterberg limit is also considered as consistency limit. In order to determine the plasticity index of the soil, liquid limit and also plastic limit must be determined.

3.2.4.1 Liquid Limit

This analysis is done based on BS 1377: 1990. There are two methods available for Liquid limit tests which is known as the Casagrande method and cone penetrometer. Cone penetrometer method is chosen for this research as it gives a more accurate and consistent result compare to casagrande method.

According to Beavis (1985), liquid limit is defined as the boundary between the liquid and the plastic conditions of the soil. This test is done to determine the moisture content of the soil from plastic to liquid condition.

At approximately 200g of the soil is mix with distilled water. The mixture is placed in an aluminium mould. In order to minimise the air content in the mould, the soil is filled at the side and then the centre of the mould. The mould is then placed on the penetrometer. The measurement reading is ensured to be at zero and the end of the cone is lowered until it reaches the surface of the soil in the aluminium mould. The button is pressed in order to drop the cone into the specimen. The reading is recorded and a graph of the depth of penetration against moisture content is plotted.

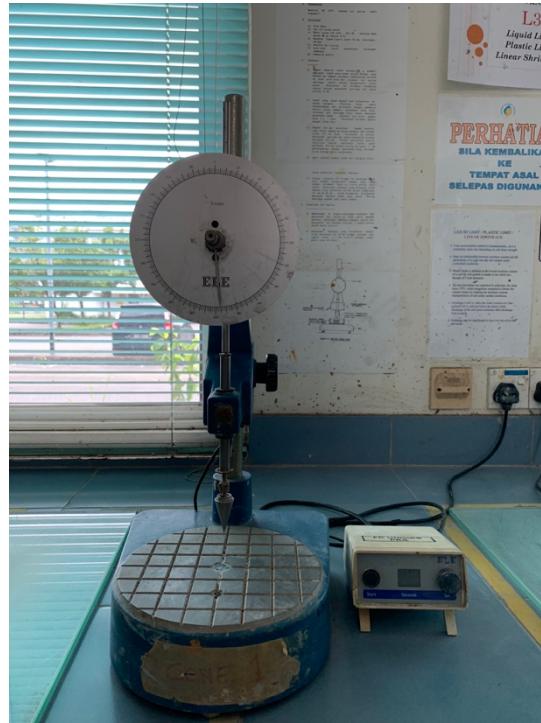


Figure 3.2: Cone penetration test apparatus for liquid limit test.

3.2.5 Specific Gravity

Specific gravity is determined as per BS1377: 1990 Test 2. Specific gravity is the ratio of unit of dry soil sample to water unit. A small pyknometer is used in this analysis.

The following is the formula used in calculating the specific gravity of the soil.

$$G_s = [(M_2 - M_1) / [(M_4 - M_1) - (M_3 - M_2)]] \quad \text{Equation 3.5}$$

where;

M_1 = mass of pyknometer + stopper (g)

M_2 = mass of pynometer + stopper + dry soil (g)

M_3 = mass of pyknometer + stopper + soil with water (g)

M_4 = mass of pyknometer + stopper when full of water (g)

3.3 Preparation of Samples

3.3.1 Peat

The peat samples were taken from Kampung Endap, Kota Samarahan. The samples were taken at a depth of 1m from the ground surface to minimise the disturbance on the surface. The fresh samples are taken to the lab and the basic properties of the sample are determined before being reinforced with the rubber powders. The peat samples are then air-dried and before sieving to 0.05mm particle size.



Figure 3.3: 0.05 mm particle size of air- dried peat sample.

3.3.2 Rubber Powder

Rubber powder are used in the research to reinforce the peat soil samples. Two sizes of rubber have been considered which are, size 0.05 mm and size 1-3mm. Different percentages of rubber powder are used in the study varying from 5%, 10% and 15% of the total weight. This is to obtain the optimum design mix from the Unconfined Compressive Strength Test.



Figure 3.4: Rubber Fiber of Size 0.05 mm



Figure 3.5: Rubber Fiber of Size 1-3 mm

3.3.3 Ordinary Portland Cement

Ordinary Portland Cement are used as a binding agent between the soil and the rubber powders in order to stabilise the peat. A constant value of 5% of cement are used in the study.

3.3.4 Design Mix Considerations

The curing period is used to decrease the moisture content of the mixture (Kalantari et al., 2008). Hypothetically, the soil is hardened as the water content decreases, and the strength will be improved with the curing period. The samples are cured are as follows:

Table 3.1: No. of samples prepared for UCS Test.

Samples	Curing Period (day(s))									
	0	7	28	56	90	0	7	28	56	90
	Size of Rubber									
	0.05mm					1-3mm				
	No. of samples									
Peat + 0% Rubber Chips	2	2	2	2	2	2	2	2	2	2
Peat + 5% Rubber Chips	2	2	2	2	2	2	2	2	2	2
Peat + 10% Rubber Chips	2	2	2	2	2	2	2	2	2	2
Peat + 15% Rubber Chips	2	2	2	2	2	2	2	2	2	2
Peat + 5% Cement	2	2	2	2	2	2	2	2	2	2
Peat + 5% Cement + 5% Rubber Chips	2	2	2	2	2	2	2	2	2	2
Peat + 5% Cement + 10% Rubber Chips	2	2	2	2	2	2	2	2	2	2
Peat + 5% Cement + 15% Rubber Chips	2	2	2	2	2	2	2	2	2	2

3.4 Mechanical Properties

3.4.1 Vane Shear Test

Shear strength plays a vital role in constructions. Low shear strength and high compressibility of the peat soils confined in the problematic category (Huat, 2006). This analysis is conducted to determine the undrained shear strength of fine- grained soil specimen.

Two to three specimens of dimensions of 37.5 mm diameter and 75 mm length in specimen are prepared. The specimen container is mounted with the specimen on the base of the vane shear apparatus. A hole of about 1 mm is provided at the other end, if the specimen container is closed at one end. The shear vane is gently lowered into the specimen. The top of the vanes should be at least 10mm below the top of the specimen. The angle of twist is recorded.

The vanes are rotated at a uniform rate at approximately 0.1° per second by suitable operating the torque application handle until the specimen fails. The final reading of the angle is recorded. The value of blade height and width is recorded in centimetre (cm).

Shear strength, S:

$$\text{Shear strength } S = \frac{T}{\pi \left(\frac{D^2 H}{2} + D^3 \right)} \quad \text{Equation 3.6}$$

where,

S = Shear strength of soil in kg/cm²

T = Torque in cm-kg

= Spring constant/ 180° x difference in degrees

D = Overall diameter of the vane in cm

3.4.4 Standard Compaction Test

This analysis involves compaction which the solid particles are packed closely between the particles by mechanical means, which increase the dry density of the soil. The degree of compaction affects the amount of dry density achieved. An optimum moisture content is achieved when the dry density obtained reaches its maximum value at a given degree of compaction. Hence, this analysis is to determine the relationship between the moisture content and the dry density of soil.

The soil is mix with water. The compaction mould is weighed together with its callipers in order to determine its volume. The soil mixture is then compacted using the standard compaction method in 3 layers with 25 blows per layer. Both top and base of the compacted cylinder are strike carefully with the steel straight edge.

After the compaction, the mould and cylinder of the soil is weighed, and the mass is recorded. The soil is extruded from the mould, split it and take three samples from each layer, to perform the moisture content tests. More water is added on the original sample mass of 3 or 4 kg. the soil mixture is remix and the compaction procedure are repeated.

From this analysis, bulk density, average moisture content, dry densities, is calculated. Each bulk density and dry densities are plotted against moisture content. A smooth curve is drawn through each point, and the curves for 0, 5, 10 % air voids may be plotted.



Figure 3.6: Mould and Proctor Hammer used in the Standard Compaction Test.

3.4.3 Direct Shear Box

The analysis is to determine the shearing strength of the soil using the direct shear box apparatus.

The inner dimension of the soil container is checked by calculating the volume and the weight of the container (W_1). The parts are assembled together. The soil is placed inside the container at approximately 10mm thick. The soil container is weighed (W_2) and the difference of the weight is the weight of the soil (W_3).

The density of the soil is then calculated.

$$W_3 = W_2 - W_1$$

Equation 3.7

Where;

W_1 = The weight of the container

W_2 = The weight of the soil container

W_3 = The weight of the soil

The upper grating on stone and loading block is placed on top of the soil. The thickness of the soil specimen is measured. The desired normal load is applied. The shear pin is removed, and the shear box is unlocked and slightly separated the two halves of the box by turning the separation screws. Prior to shearing, all screws are removed.

The dial gauge which is attached to the changes in volume is attached and the initial reading of the dial gauges and calibration values are recorded. All adjustments are required to check to ensure that there is no connection between two parts except sand/soil before

proceeding with the test. The motor is then started, and the reading of the shear force are recorded. The readings of the volume changes are recorded till failure. 5kg of normal stress 0.5kg/cm³ are added and the experiment is continued till failure. The readings are recorded. The experiment is repeated three more times using a higher normal stress increment. The amount of soil is ensured to be the same throughout the experiment to ensure that the initial density is the same for every test.



Figure 3.7: Direct Shear Box

3.4.5 Unconfined Compressive Strength Test

This analysis is conducted to test the strength on the samples, as to determine the shear parameters of the cohesive soil.

The soil specimen is placed in between two frictionless bearing plates of 75mm diameter, with 2kN load proving ring. The testing is completed until the soil samples failed, as the values observed is decreased or the strains reaches 15%.



Figure 3.8: Experimental set up of unconfined compression test

CHAPTER 4

RESULTS AND DISCUSSION

4.0 General

This chapter discussed and the results obtained are presented in the corresponding graphs and tables. The tests results obtained are compared with the past research which are related to the current study. The data obtained were divided into the categories, which are physical and mechanical properties.

Physical properties testing was conducted on the untreated peat samples obtained from Kampung Endap. The peat samples obtained are then stabilized with various percentage of rubber powder and cement as outlined in chapter 3.

All of the tests carried out are in accordance to the British Standard (BS) 1377, and the American Soil Testing Materials (ASTM) or otherwise stated.

4.1 Physical Properties

The peat samples taken from Kampung Endap were tested and the physical properties were determined. The physical properties consist of Von Post classification, moisture content, specific gravity, liquid limit, linear shrinkage, organic content, and pH value. Table 4.1 below shows the summary of the physical properties of the untreated peat.

Table 4.1: Summary of the physical properties of the untreated peat.

Properties	Values
Degree of Decomposition	H7
Moisture Content (%)	399.49 %
Specific Gravity	1.31
pH Value	4.33
Liquid Limit (%)	442%
Loss on Ignition (%)	78.87 %
Organic Content (%)	81.99 %

4.1.1 Von Post Degree of Composition

The sample was taken from 0.5 to 1 m depth in order to determine the degree of humidification. The test was conducted by taking a handful of the sample before squeezing it. The result is examined and compared to the Von Post Scale.

When squeezes, almost all peat escaped from the fingers and the colour of the peat is dark brown. Hence, it is determined that the sample is classified at H7- H8, or sapric peat (ASTM D4427).



Figure 4.1: Peat Sample taken at the site.

4.1.2 Moisture Content

The testing is done to determine the percentage of the moisture content available in soil. This shows the amount of water that can be contained by the soil. The result shows that peat have more than 200% of water content (Huat et al., 2011). The samples from Kampung Endap shows a value of 399.49% .

Table 4.2: Moisture Content of Peat Sample.

Peat Samples	M1	M2	M3	Average, W%
Kampung Endap	416.80 %	366.20%	415.46%	399.49%

4.1.3 Loss on Ignition and Organic Content

Organic Content analysis and its Loss on Ignition (LOI) were also performed on the peat samples. The test results are presented in the Table 4.2. The LOI value for sample from Kampung Endap shows that it can ignites easily when exposed to high temperature. The organic content also shows high value of more than 75% which indicates that the peat is highly organic (Huat, 2004). The table below (Table 4.2) presents the summary of the Loss on Ignition (LOI) and Organic Content of peat samples from Kampung Endap.

Table 4.3: Loss on Ignition and Organic Content of Peat Sample from Kampung Endap, Samarahan

Analysis	M1	M2	M3	Average
Loss on Ignition, %	78.28	75.00	83.33	78.87
Organic Content, %	81.37	77.96	86.63	81.99

4.1.4 Specific Gravity

The specific gravity of a sample can be obtained by using the specific gravity test. The specific gravity is the ratio of a unit air given volume of soil particles to the unit in air of an equal volume of water. The average specific gravity is at 1.31 and the results are presented in the table below.

Table 4.4: Specific gravity of Peat Sample

Peat Sample	M1	M2	M3	Average
Kampung Endap	1.25	1.25	1.43	1.31

4.1.5 pH Limit

The pH values are examined on in-situ peat using portable pH metre. Table 4.5 below shows the results taken from the site. An average of three values are calculated.

Table 4.5: pH value of in situ Peat

Locality	1	2	3	Average
pH value	4.30	4.35	4.33	4.33



Figure 4.2: pH value taken from the pH meter.

4.1.6 Liquid Limit

Liquid limit tests are carried out by using the cone penetrometer, in accordance to the BS 1377: 1990. It is the minimum moisture content when the soil is penetrated at 20mm. It is performed to determine the liquid limit from plastic conditions to liquid conditions.

The liquid limit of the dry peat was determined, which acts as a control. Meanwhile, in another stage, the same tests were carried out, with an addition of 10% rubber crumbs of two sizes, which are 0.05 mm and 1-3 mm respectively. This serves the purpose to give the general idea on how the rubber affects the peat when added. According to the previous study done by Chai (2019), peat with 10% of rubber crumbs gives the significant decrease in moisture content compared to the moisture content of the dry peat, at 94.50 and 128.25% respectively. Hence, an addition of 10% of rubber is chosen in this study.

According to the Figure 4.1, it is obvious that the liquid limit for dry peat has the highest moisture content of 442%. When 10% of rubber crumbs are mixed with the dry peat, the liquid limit of the mixture is at 172% for the rubber of size 0.05mm, and 24.4% for rubber crumbs of size 1-3mm. This concludes that by adding rubber into the dry peat decreases the moisture content in the peat (refer to Figure 4.2.and 4.3). The table below (Table 4.6) shows the summary of the liquid limit of the peat samples.

Table 4.6: Summary of the liquid limit of the peat samples.

Samples	Liquid Limit
Untreated Peat	442%
Peat + 10% Rubber Powder (0.05mm)	171%
Peat + 10% Rubber Powder (1-3mm)	24%

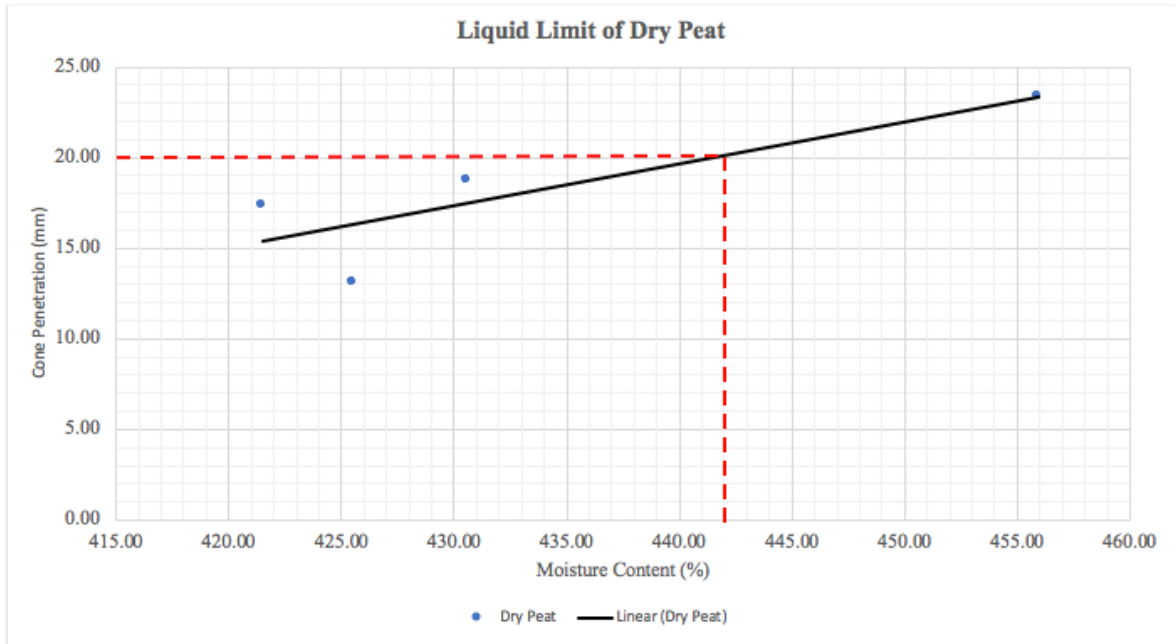


Figure 4.3: Liquid Limit of Dry Peat from Kampung Endap, Samarahan.

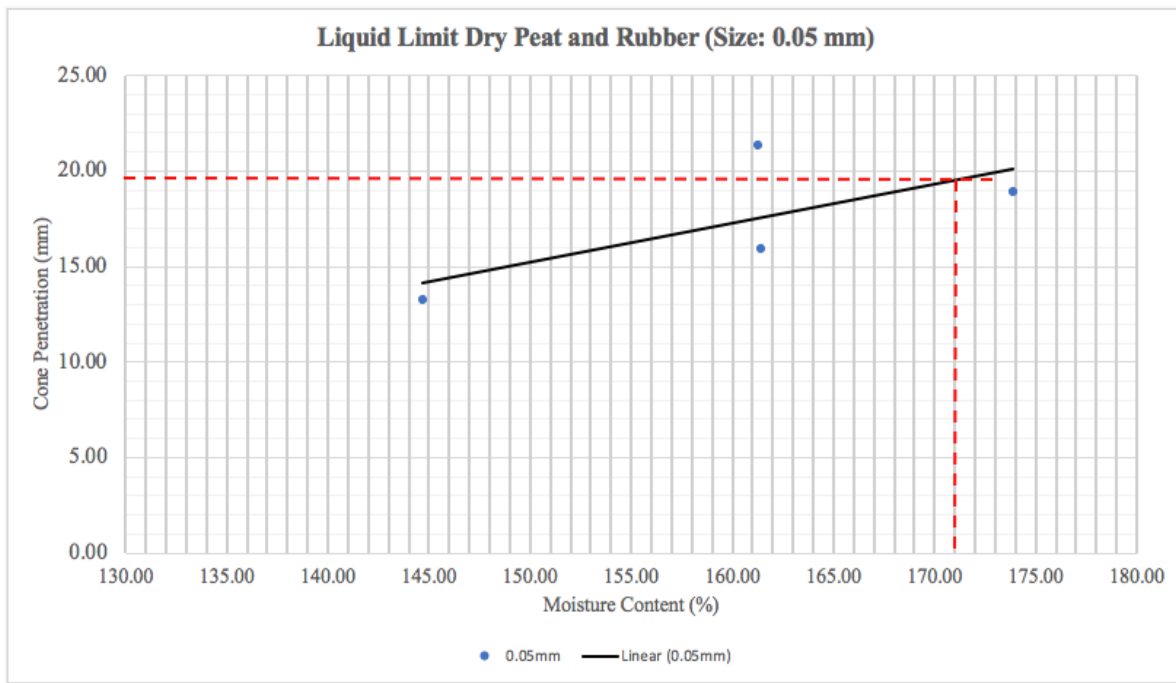


Figure 4.4: Liquid Limit of Dry Peat and Rubber (Size 0.05mm) from Kampung Endap, Samarahan.

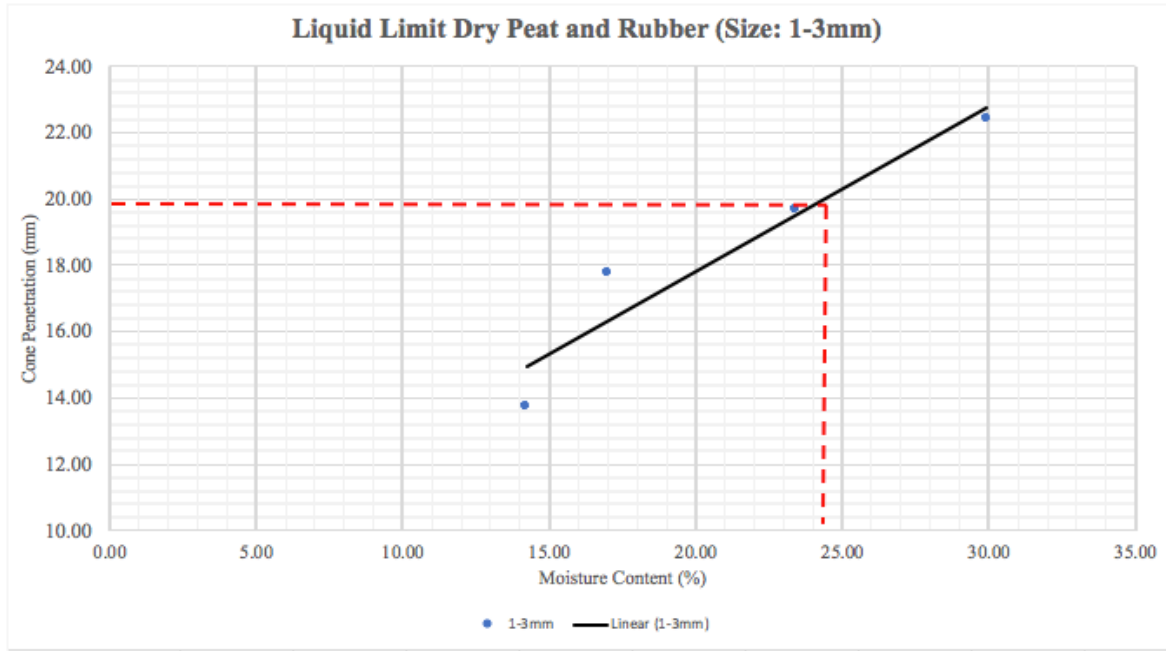


Figure 4.5: Liquid Limit of Dry Peat and Rubber (Size 1-3mm) from Kampung Endap, Samarahan.

4.1.7 Field Vane Shear Test

The average field vane shear strength for tropical peat found in Sarawak to be only 10 kPa while the sensitivity ranges the degree of humification of the soils, with more fibrous soils having higher undrained strength (Yogeswaran, 1995). Huat (2006) reported that the plot of moisture content against vane shear strength portrays a decreasing behaviour of shear strength with increasing moisture content.

The vane shear test was done until 2 metres deep with a reading taken at an interval of 20 cm. As suggested by Noto (1991), the value of 0.5 was used as a correction factor to the original reading due to the inaccuracy of the result from the in-situ test.

The test was conducted on the site at three different points in order to obtain the vane shear values. Based on Table 4.7, it is proven that the tropical peat in Sarawak have a low average field vane shear which ranges from 8.70 kPa to 11.60 kPa. The high moisture content of 399.49% (Table 4.2) seconded Huat (2006) whereby the increasing moisture content resulted in a lower shear strength of and average of 10.66 kPa (Table 4.7).

Table 4.7: Summary of the Average Corrected Shear Strength from three different points.

Point	Coordinate	Average Corrected Shear Strength Value (kPa)	
		Undisturbed Soil (kg) with slow twist within two minutes	Remolded Soil (after 10 times twist)
1	1.4273 110.4595	8.50	5.20
2		11.90	5.10
3		11.60	5.70
Average (kPa)		10.66	5.33

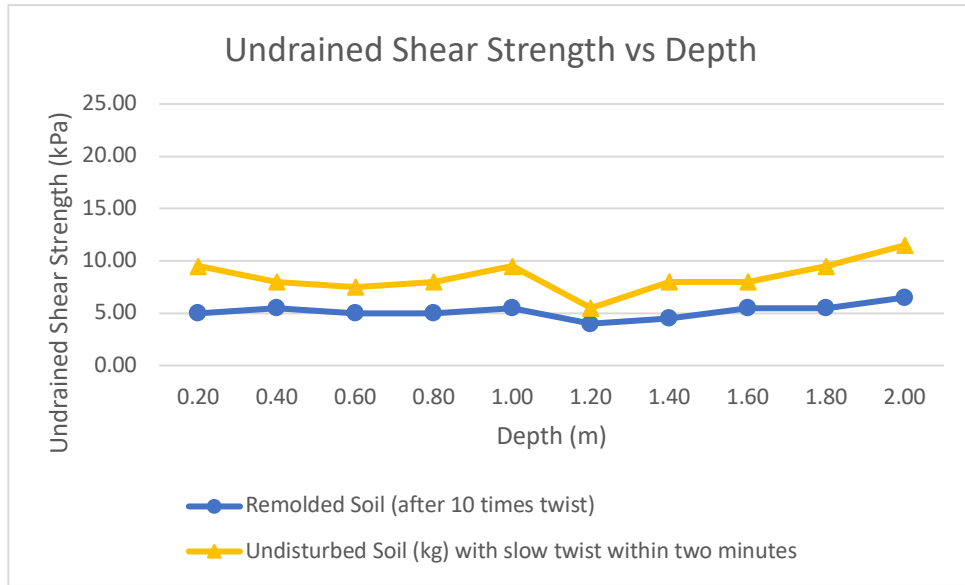


Figure 4.6: Graph of Undrained Shear Strength (kPa) versus Depth (m) at Point 1.

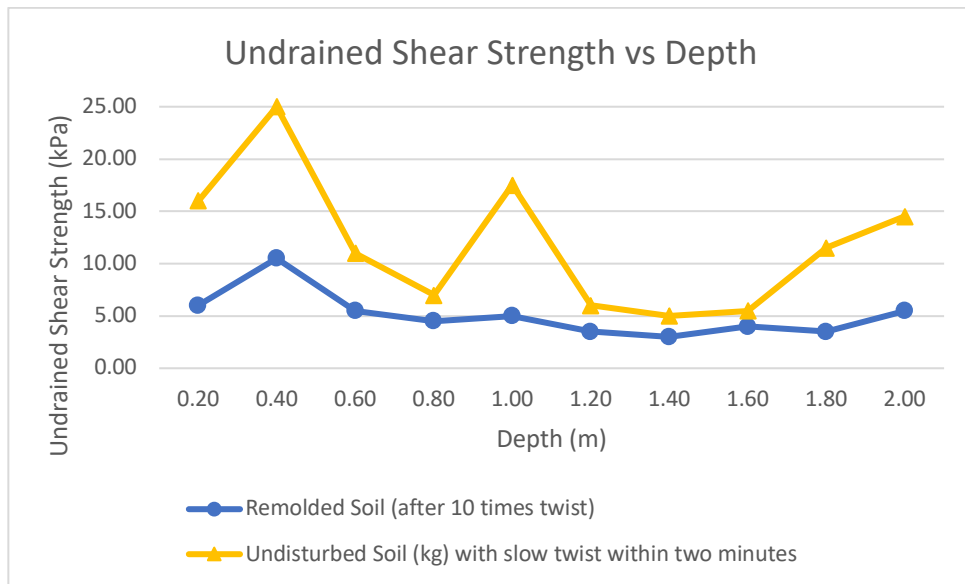


Figure 4.7: Graph of Undrained Shear Strength (kPa) versus Depth (m) at Point 2.

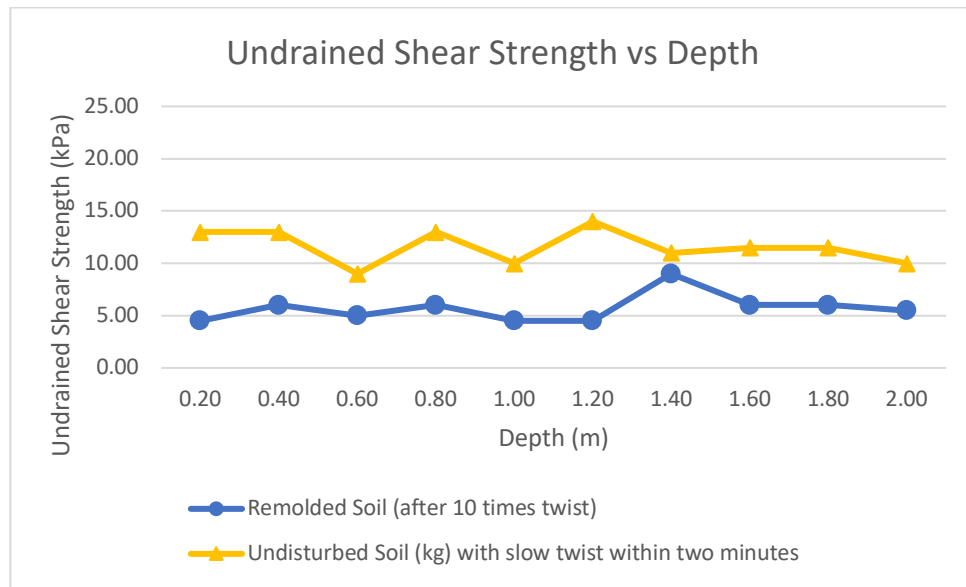


Figure 4.8: Graph of Undrained Shear Strength (kPa) versus Depth (m) at Point 3.

4.2 Mechanical Properties

The mechanical properties determination consists of Field Vane Shear Test, Standard Compaction Test, Direct Shear Box and Unconfined Compression Test.

4.2.1 Standard Compaction Test

The standard compaction test was carried out on both untreated and stabilised peat. The samples were mix with a constant percentage of cement (5%) which acts as binder and various percentage of rubber powder. Table 4.8 below shows the control samples of the peat mixtures.

Table 4.8: Design mix of the peat samples.

Samples	Design mix
1	Dry Peat
2	Peat + 5% Cement
Size: 0.05mm	
3	Peat + 5% Rubber
4	Peat + 10% Rubber
5	Peat + 15% Rubber
6	Peat + 5% Cement + 5% Rubber
7	Peat + 5% Cement + 10% Rubber
8	Peat + 5% Cement + 15% Rubber
Size: 1-3mm	
9	Peat + 5% Rubber
10	Peat + 10% Rubber
11	Peat + 15% Rubber

12	Peat + 5% Cement + 5% Rubber
13	Peat + 5% Cement + 10% Rubber
14	Peat + 5% Cement + 15% Rubber

The data obtained are summarised and tabulated in a Table 4.9. The data is then summarised in Figure 4.9 to Figure 4.10. According to the Figure 4.7, the maximum dry density increases as the moisture content decreases when peat is stabilised with both cement and rubber powder. With an addition of rubber powder, the optimum moisture content decreases as the dry density decreases. The increase in the percentage of rubber by 15% decreases the optimum moisture content to 84% and increases the dry density to 0.67 mg/m³.

It can be concluded that the strength increases as the moisture decreases with the addition of rubber and cement to the peat. However, for peat with only rubber, it does not give any significant difference to the optimum moisture content and the dry density of the peat. This is because the rubber fibre itself does not possessed the strength to improve the peat characteristics. Hence, cement acts as a binder, is added into the mix, to give a better, stabilised peat.

Table 4.9: Summary results of Standard Compaction Test.

Design mix	Optimum Moisture Content (%)	Maximum dry Density (Mg/m³)
Peat	159.00	0.468
Peat + 5% Cement	142.00	0.440
Size: 0.05 mm		
Peat + 5% Rubber	156.00	0.468
Peat + 10% Rubber	130.00	0.472
Peat + 15% Rubber	138.00	0.472
Peat + 5% Cement + 5% Rubber	120.00	0.480
Peat + 5% Cement + 10% Rubber	130.00	0.468
Peat + 5% Cement + 15% Rubber	113.00	0.515
Size: 1-3 mm		
Peat + 5% Rubber	162.00	0.460
Peat + 10% Rubber	138.00	0.570
Peat + 15% Rubber	104.00	0.590
Peat + 5% Cement + 5% Rubber	106.00	0.600
Peat + 5% Cement + 10% Rubber	88.00	0.650
Peat + 5% Cement + 15% Rubber	84.00	0.670

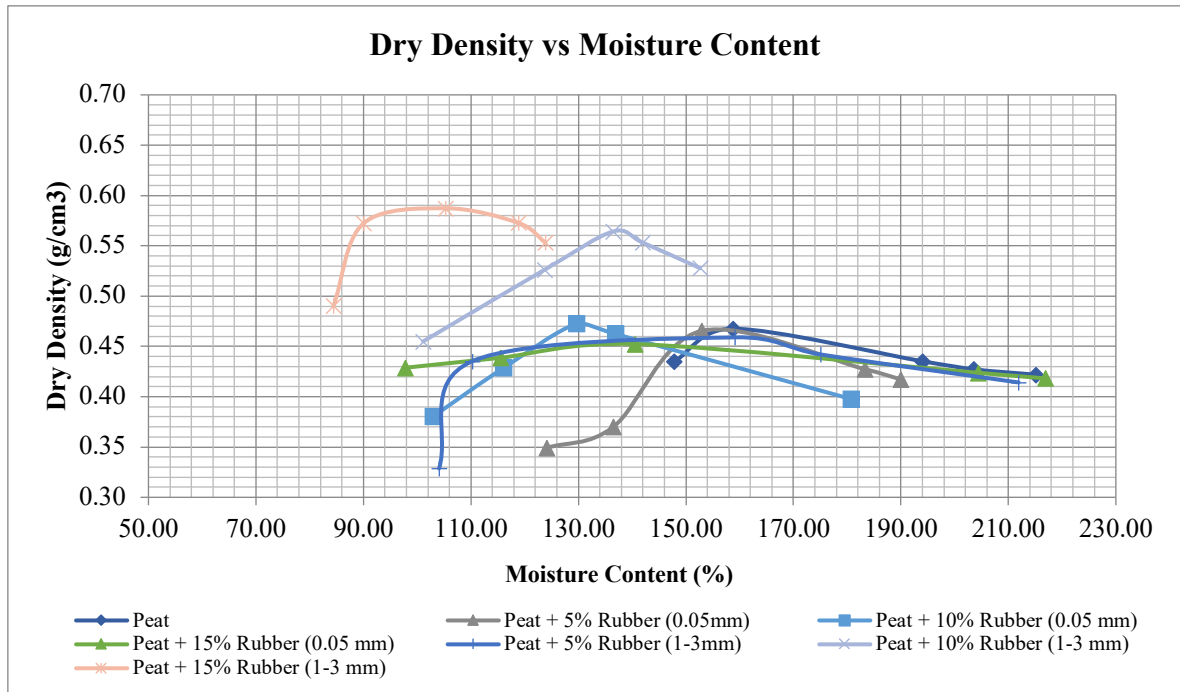


Figure 4.9: Dry Density vs Moisture Content for Dry Peat various percentages of Fiber.

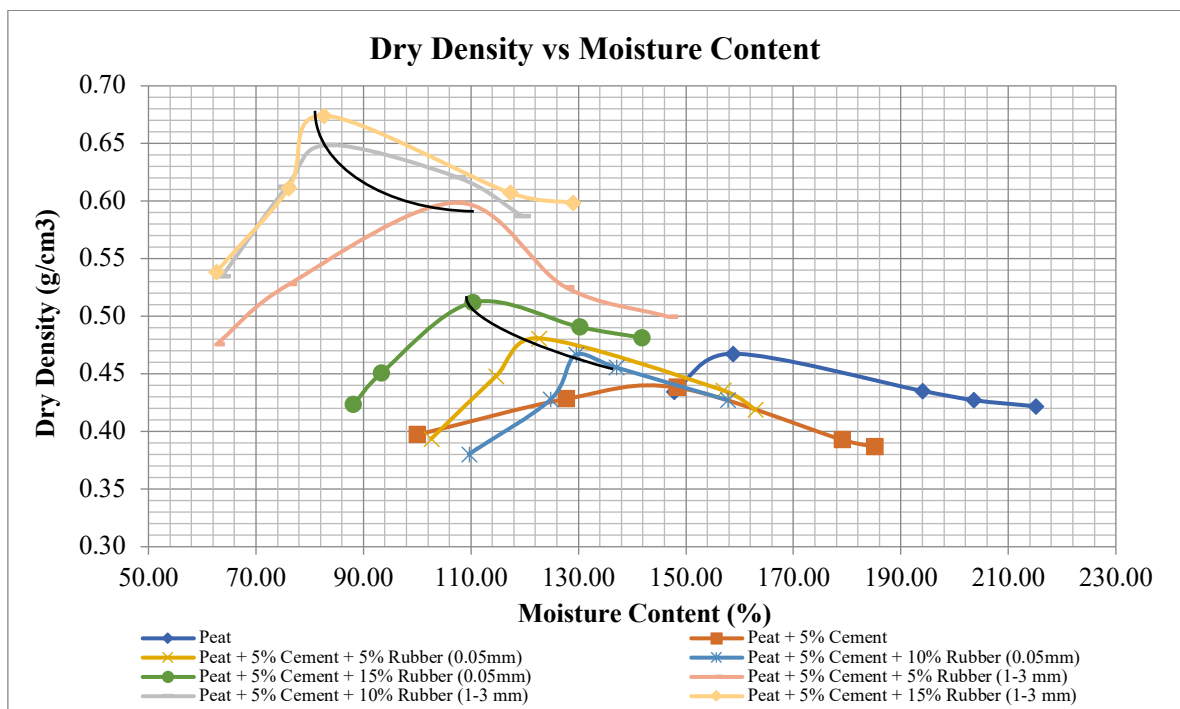


Figure 4.10: Dry Density vs Moisture Content for Dry Peat with constant 5% Cement and various percentages of Fiber.

4.2.2 Direct Shear Box

Shear strength is the strength of a material or component against the type of yield or structural failure where the material or component fails in shear (Powell, 2018).

The high moisture content of the peat sample taken from Kampung Endap, contributes to the sample having a low bearing capacity and bulk density. From the Standard Compaction Test (Table 4.9), it is proven that, the untreated peat has a low bulk density resulting in a higher optimum moisture content and a lower maximum dry density, compared to stabilised peat samples.

Based on the experiment results, the addition of rubber indeed improves the characteristics of the peat soil. As the percentage of the rubber increases, the shear stress increases. Peat- rubber samples achieve higher shear stress with an addition of cement. This is because according to Jawad et al. (2014), the cement reactions are time dependent and require long periods of time because such reaction are functions of temperature, calcium quantity, pH value and percentage of silica in soil mineral.

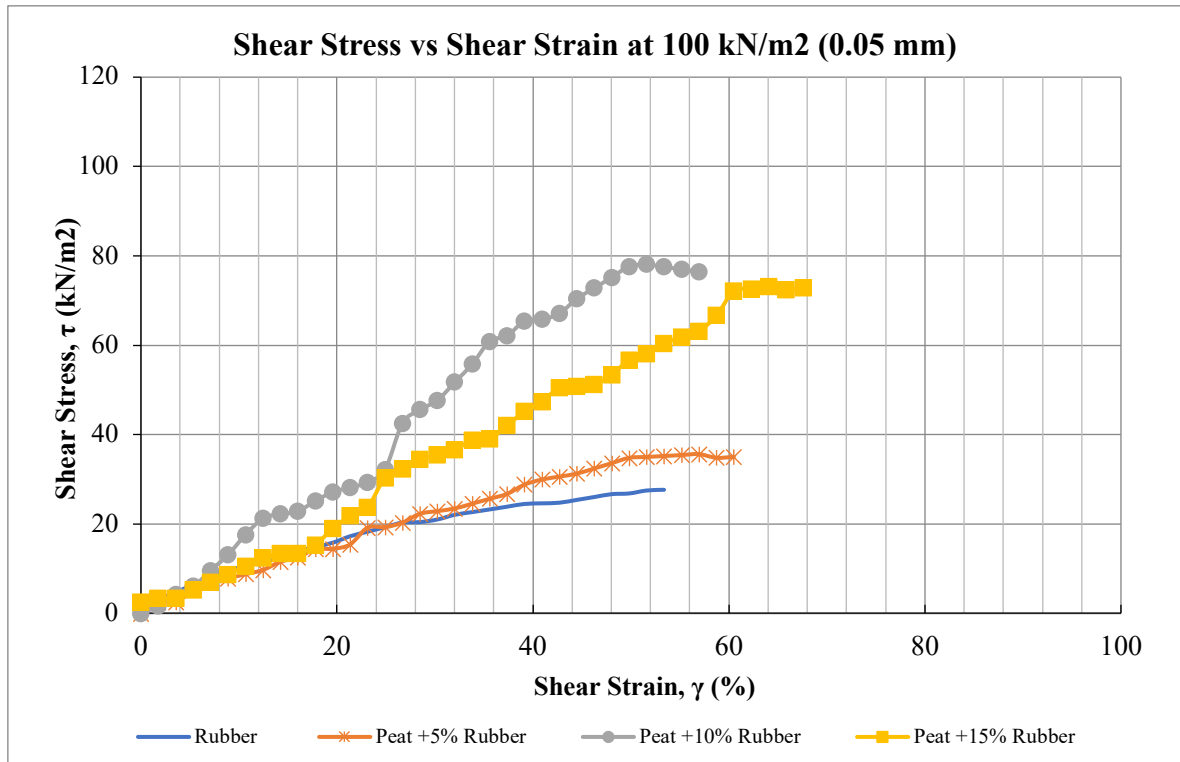


Figure 4.11: Shear stress vs shear strain with normal stress of 100 kN/m².

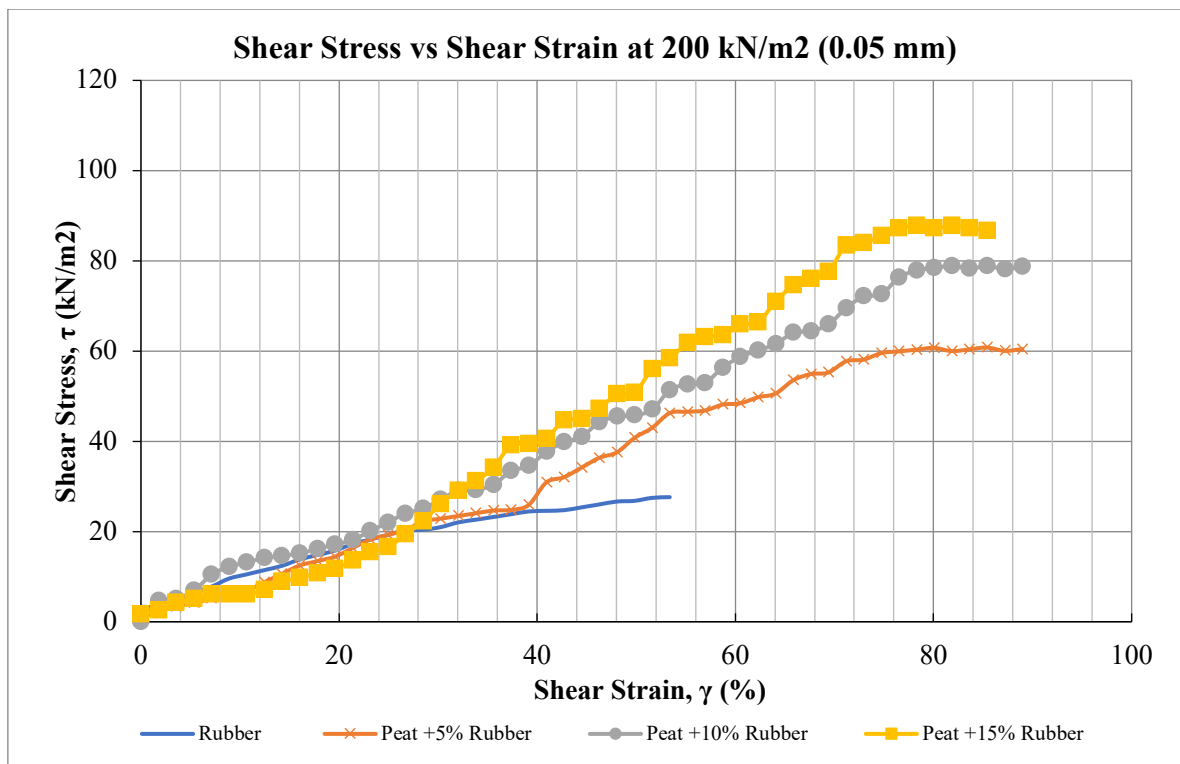


Figure 4.12: Shear stress vs shear strain with normal stress of 200 kN/m².

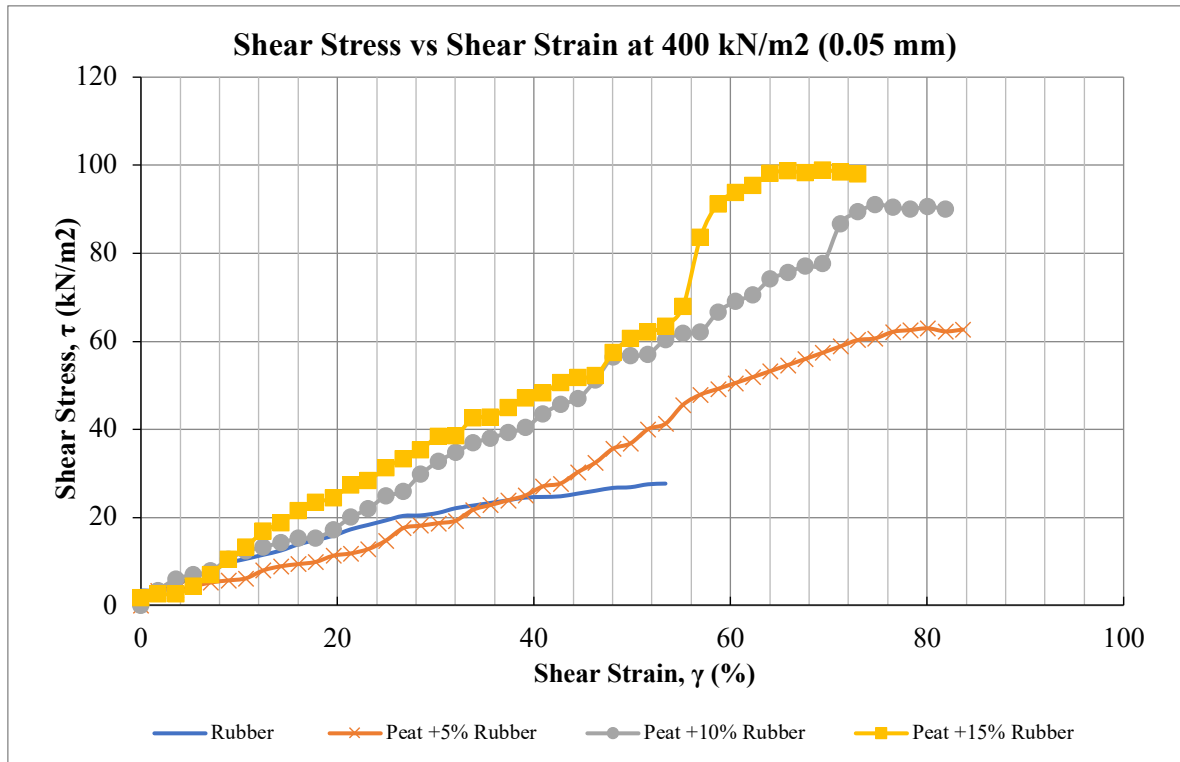


Figure 4.13: Shear stress vs shear strain with normal stress of 400 kN/m².

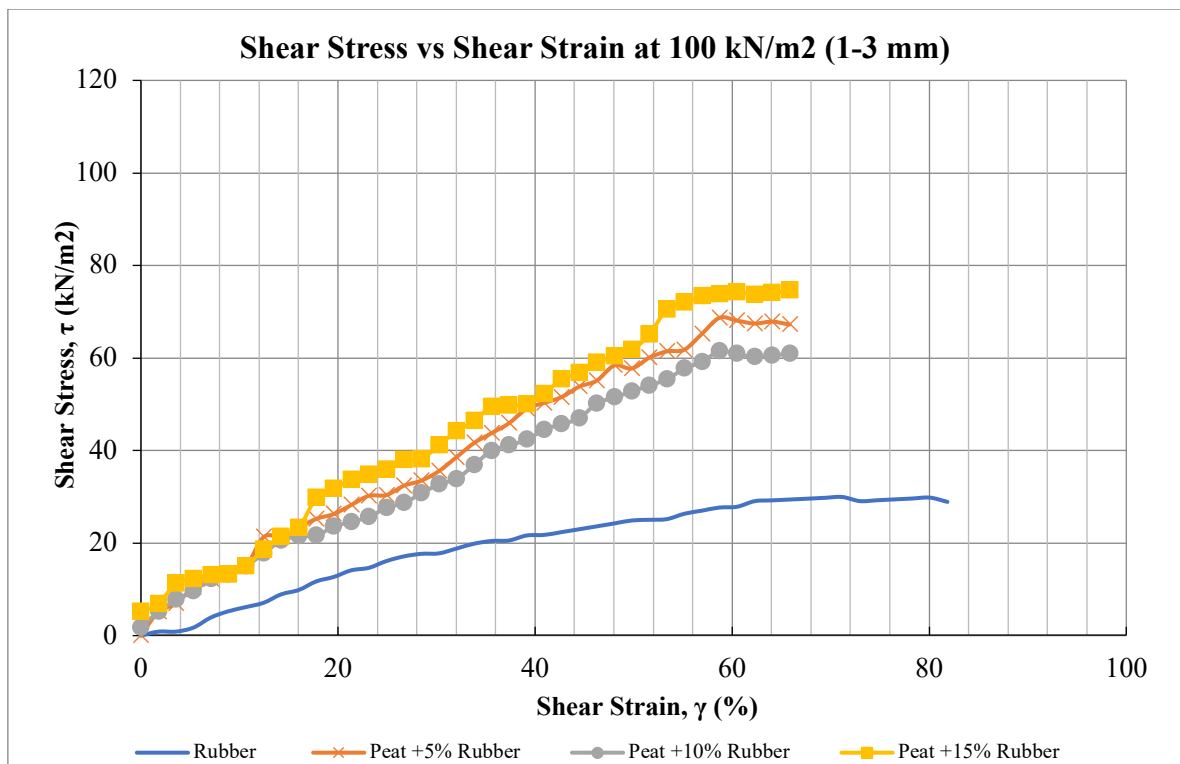


Figure 4.14: Shear stress vs shear strain with normal stress of 100 kN/m².

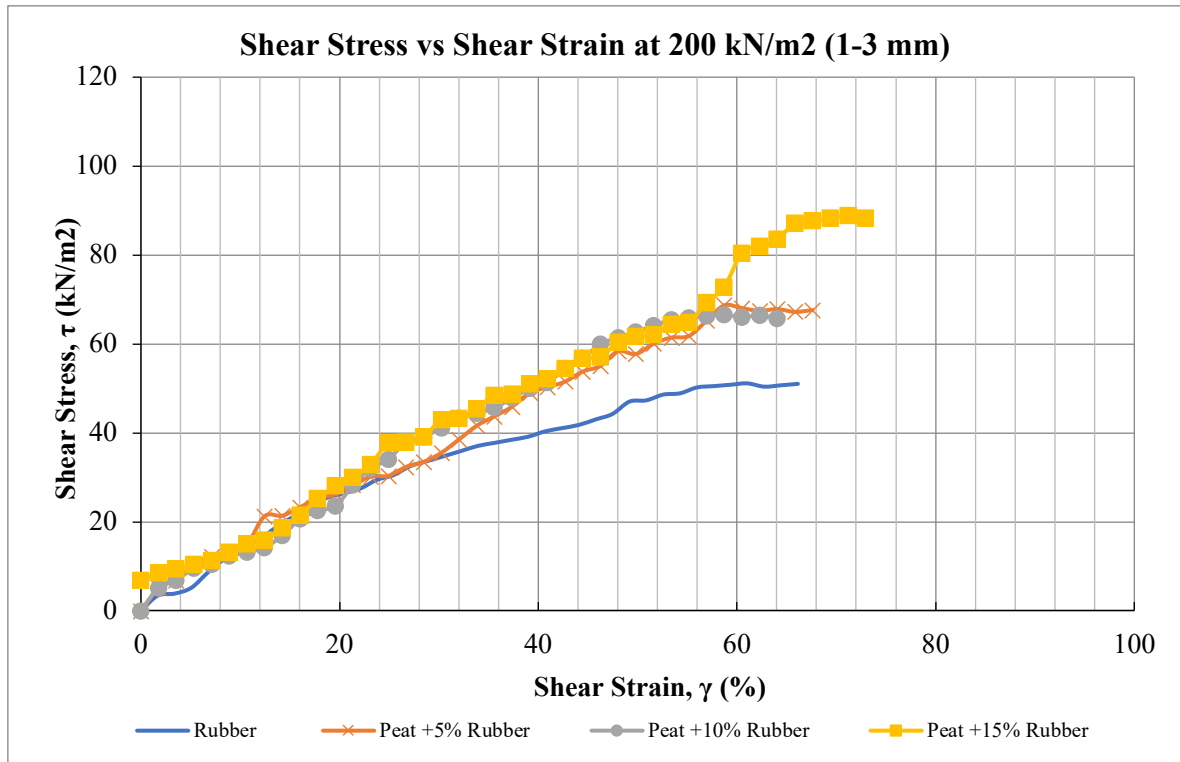


Figure 4.15: Shear stress vs shear strain with normal stress of 200 kN/m².

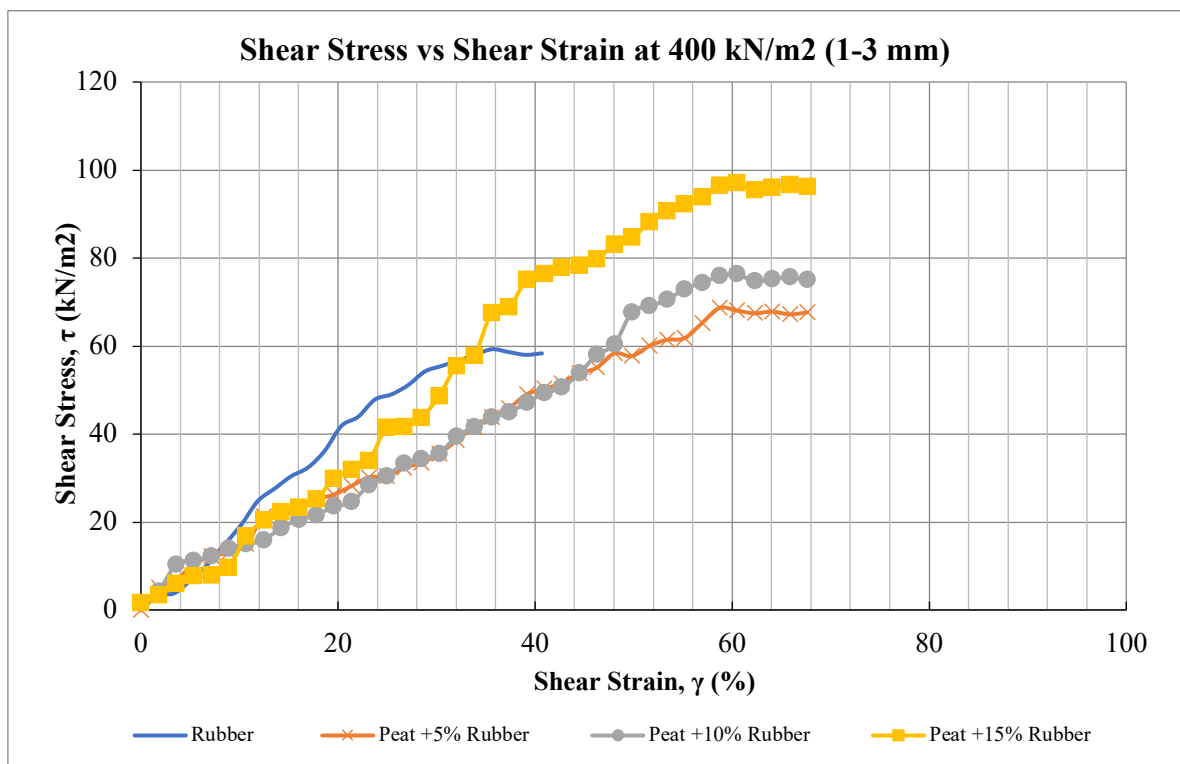


Figure 4.16: Shear stress vs shear strain with normal stress of 400 kN/m².

Based on Figure 4.13, peat treated with rubber shows an increment in the shear stress as the normal stress increases. Peat with 15% rubber shows the highest value of shear stress of 98.90 kN/m^2 at 400 kN/m^2 . As for 5% rubber, there is no significant different in value compared to the shear stress value of only rubber sample.

From Figure 4.16, the samples with rubber size varies from 1-3 mm, shows an increase in the shear stress as the normal stress increases. The shear stress for both 5% and 10% fiber shows a little increase from 50.96 kN/m^2 to 61.52 kN/m^2 at 200 kN/m^2 of normal stress. However, with 15% of rubber addition to the peat, it shows an increase of shear stress at 96.92 kN/m^2 .

Figure 4.20 to 4.21 shows the effect of different percentage of rubber tyre against different normal stress applied. From the graph shown, cohesion is determine from the y-intercept and the angle of shear resistance is given from the line gradient. Based on Table 4.10, peat with 10% rubber of size 0.05mm shows the highest cohesion value, of 72.10 kN/m^2 , with an angle of shear resistance of 2.58° . It can be observed from Table 4.9 and Table 4.10, the cohesion and the angle of shear resistance, supposedly show an increment, however at an addition of 10% of rubber, it shows a decrement in value.

In conclusion, both peat samples treated with an 15% rubber for both sizes shows a high shear stress value. Between the two rubber sizes, the rubber size of 0.05 mm shows a higher shear stress at 98.90 kN/m^2 compared to 15% of rubber of size 1-3 mm at 96.92 kN/m^2 . This concludes that the void between the soils particles are filled with finer sizes of the rubber which results in a higher shear strength.

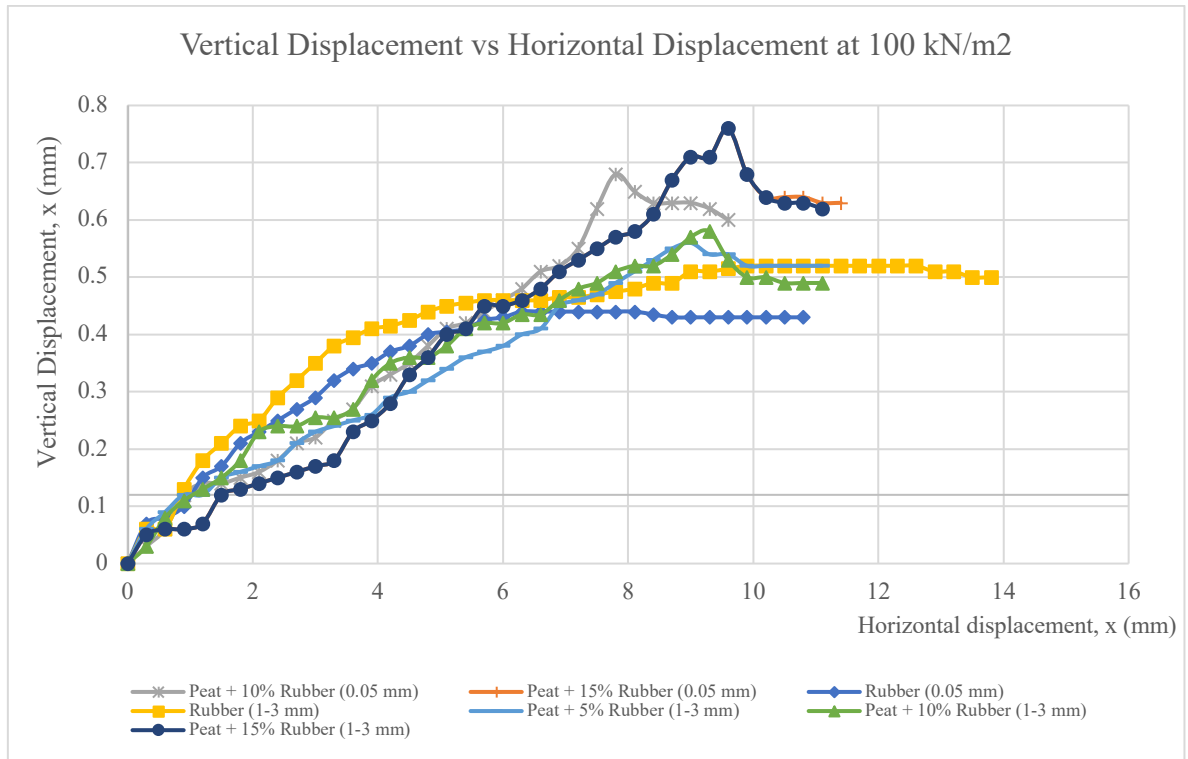


Figure 4.17: Vertical Displacement vs Horizontal Displacement at 100 kN/m².

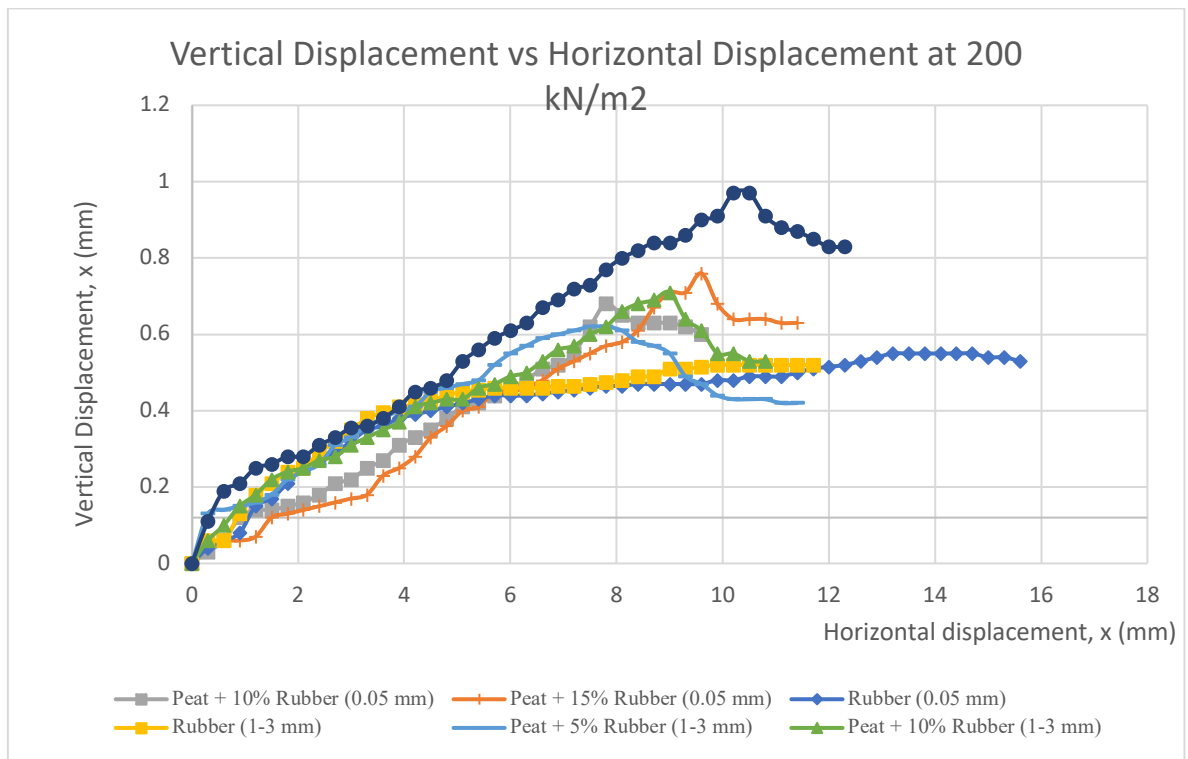


Figure 4.18: Vertical Displacement vs Horizontal Displacement at 200 kN/m².

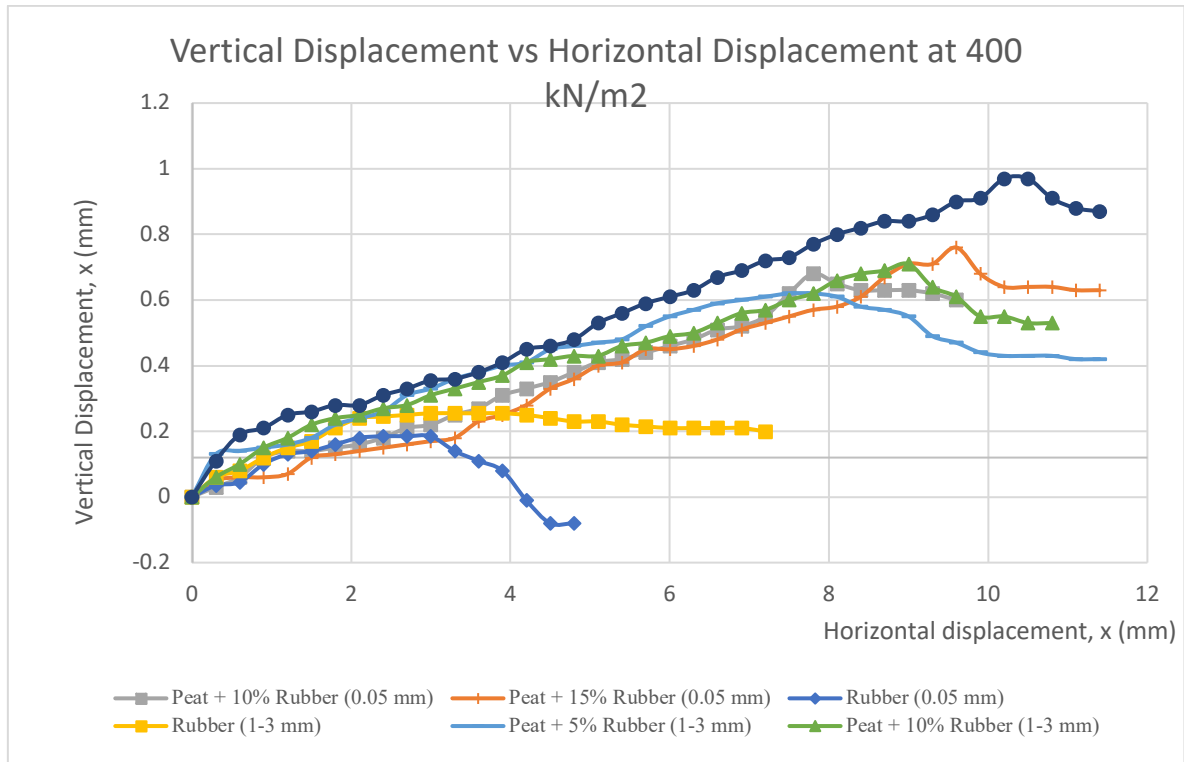


Figure 4.19: Vertical Displacement vs Horizontal Displacement at 400 kN/m².

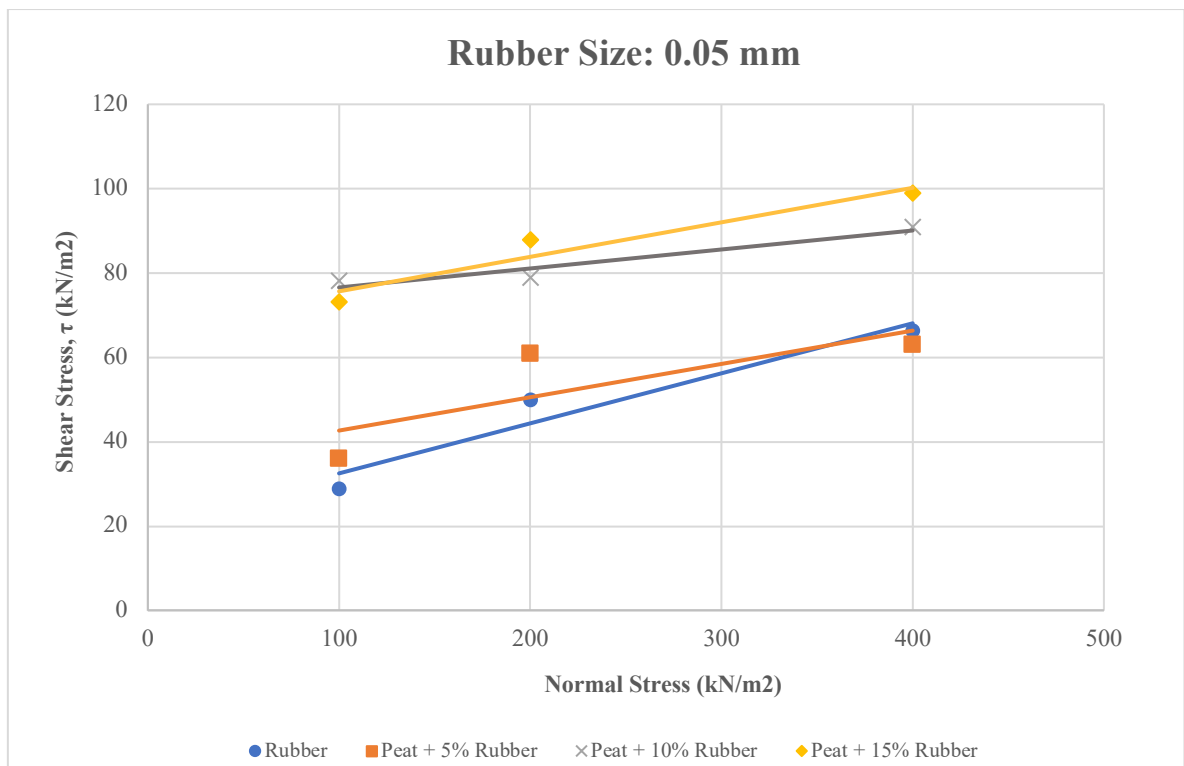


Figure 4.20: Shear stress vs Normal stress for Rubber Size 0.05 mm.

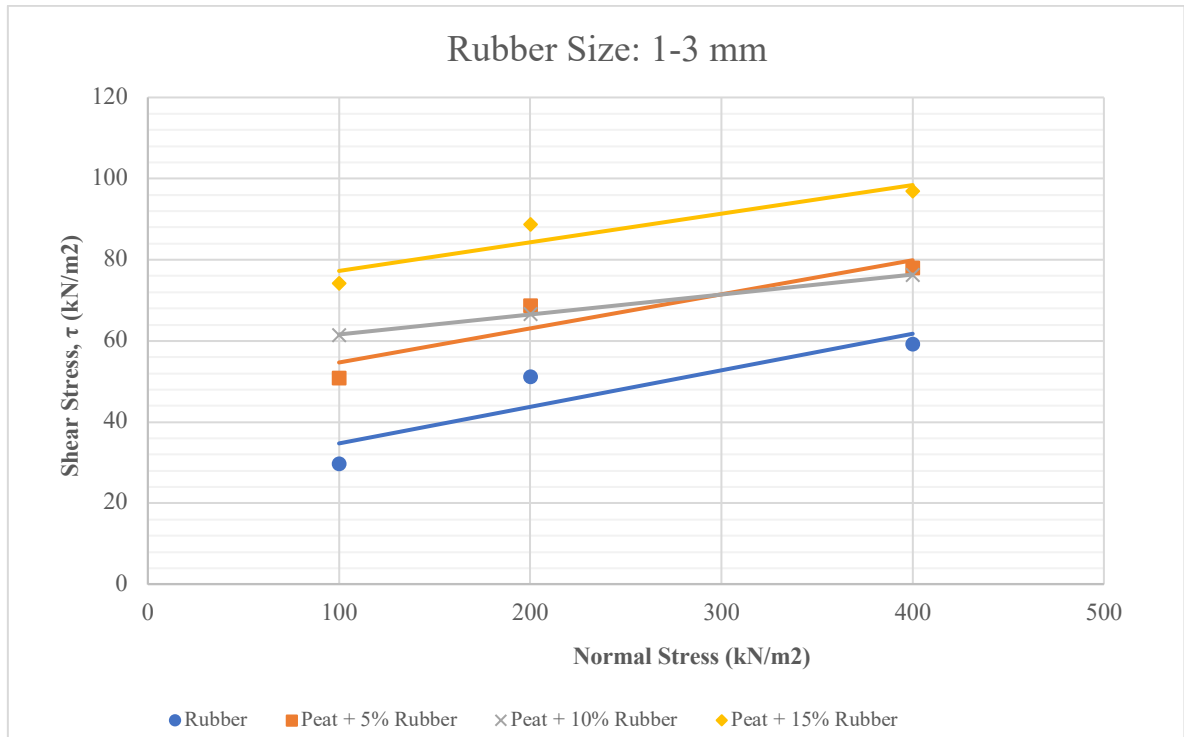


Figure 4.21: Shear stress vs Normal stress for Rubber Size 1-3 mm.

Table 4.10: Summary of Direct Shear Box Test for Rubber Size 0.05 mm

Size	0.05 mm											
Sample	Rubber			Peat + 5% Rubber			Peat + 10% Rubber			Peat + 15% Rubber		
Normal Stress (kN/m ²)	100	200	400	100	200	400	100	200	400	100	200	400
Peak Shear Stress (kN/m ²)	28.88	49.89	66.28	35.86	60.82	62.96	78.10	78.85	90.85	73.05	87.80	98.90
Angle of Shear Resistance	6.80°			4.60°			2.58°			4.70°		
Cohesion (kN/m ²)	20.685			34.79			72.10			67.50		

Table 4.11: Summary of Direct Shear Box Test for Rubber Size 1-3 mm

Size	1-3 mm											
Sample	Rubber			Peat + 5% Rubber			Peat + 10% Rubber			Peat + 15% Rubber		
Normal Stress (kN/m ²)	100	200	400	100	200	400	100	200	400	100	200	400
Peak Shear Stress (kN/m ²)	29.82	51.16	59.31	50.96	68.69	78.02	61.52	66.64	76.32	74.26	88.80	96.92
Angle of Shear Resistance	5.14°			4.60°			2.82°			4.03°		
Cohesion (kN/m ²)	25.745			46.30			56.68			70.20		

4.2.3 Unconfined Compressive Strength Test

The unconfined compressive strength tests are conducted in order to determine the shear strength of the soil. The tests are prepared in two stages. Firstly, the tests are done with different percentages of 5%, 10% and 15% of 0.05 mm rubber powder. In the second stage, a constant 5% cement tests are conducted with the same percentage of peat- rubber mixture. Both tests are repeated using a different size of 1-3mm rubber crumbs. All the tests carried out are at the optimum moisture content which is determined from the standard compaction tests. The samples are then were left to air- cured at 7, 28, 56 and 90 days by wrapping the samples using a plastic wrapper.

The shear strength results of the respective mixture are illustrated in graphs (Figures 4.16 to 4.23). From the graphs mentioned, it is clear that an increase of curing period, increases the shear strength of the stabilizes peat.

According to the published work done by Annadurai et al. (2014), the UCS value for soil reinforced with rubber, increases with an increases in the percentage of rubber tyres. Based on Figures 4.24 to 4.27, there is an increase in the compressive strength of the samples as the percentage of the rubber crumbs increases. Peat on its own have a low compressive strength which is correlated to its high moisture content of 159% and a low maximum dry density value of 0.468 which is obtained from the Standard Compaction Test (Table 4.9).

From the 7 days of curing, peat with 5% fiber shows the highest compressive strength of 205.02 kN/m² for the rubber size of 0.05mm while for the rubber size of 1-3 mm, peat with 10% fiber too shows a highest value of 151.04 kN/m² (Figure 4.26 and Figure 4.27). Peat samples that have been treated with cement, on the other hand (Figure 4.28 and Figure 4.29), the control samples of peat with cement shows the highest value of compressive strength for both rubber crumbs size of 227.23 kN/m².

The results obtained from the 28 days of curing, peat with 10% fiber shows a high compressive strength of 214.12 kN/m² for rubber size 0.05 mm and peat with 5% rubber of size 1-3 mm shows a value of 231.05 kN/m². As for peat- cement mixture, peat and cement shows the high value of compressive strength of 117 kN/m². Although, peat with cement gives out a high compressive stress value, it has a low strain stress compared to the other samples with has been treated with the rubber crumbs (Figures 4.20 to 4.21).

Based on results for 56 days of curing, the highest compressive strength is shown from sample peat with 5% fiber for rubber crumbs size 0.05mm at 244.07 kN/m² and peat with 10% of rubber crumbs size 1-3mm is at 291.70 kN/m². However between the two sizes, peat with 10% rubber crumbs of size 1-3mm shows a higher percentage of strain stress (Figure 4.23). This shows the peat reinforced fiber behaves from brittle to ductile. Both of these values shows an increase from 28 days of curing, which hypothetically stated that with an increase of curing days increases the compressive strength. As the curing days progressed, the compressive strength for peat with only 5% cement, decreases.

From the 90 days of curing results (Figure 4.29), there is a significant increase in compressive strength as the percentage of the rubber crumbs increase for peat- rubber- cement samples. Both peat- cement samples, for rubber 0.05mm and 1-3mm shows the highest value of compressive strength of 327.96 kN/m² and 369.87 kN/m² respectively. This corresponds to the optimum moisture content at 113% and 84% and the dry density of 0.515 and 0.67 respectively obtained from the Standard Compaction Test (Table 4.9). Although the two samples shows a great significant value of compressive strength, rubber size of 0.05mm sustain a higher strain stress of more than 8% compared to the rubber size of 1-3 mm.

It can be concluded that, the compressive strength shows an increment as the curing period increases. Stabilised peat with 5% cement and 15% rubber of both sizes shows a high compressive strength value. Peat that has been treated with 15% rubber of size 1-3 mm with 5% cement, shows a higher compressive strength with a low optimum moisture content and a high dry density compared to peat with 15% rubber of size 0.05mm.

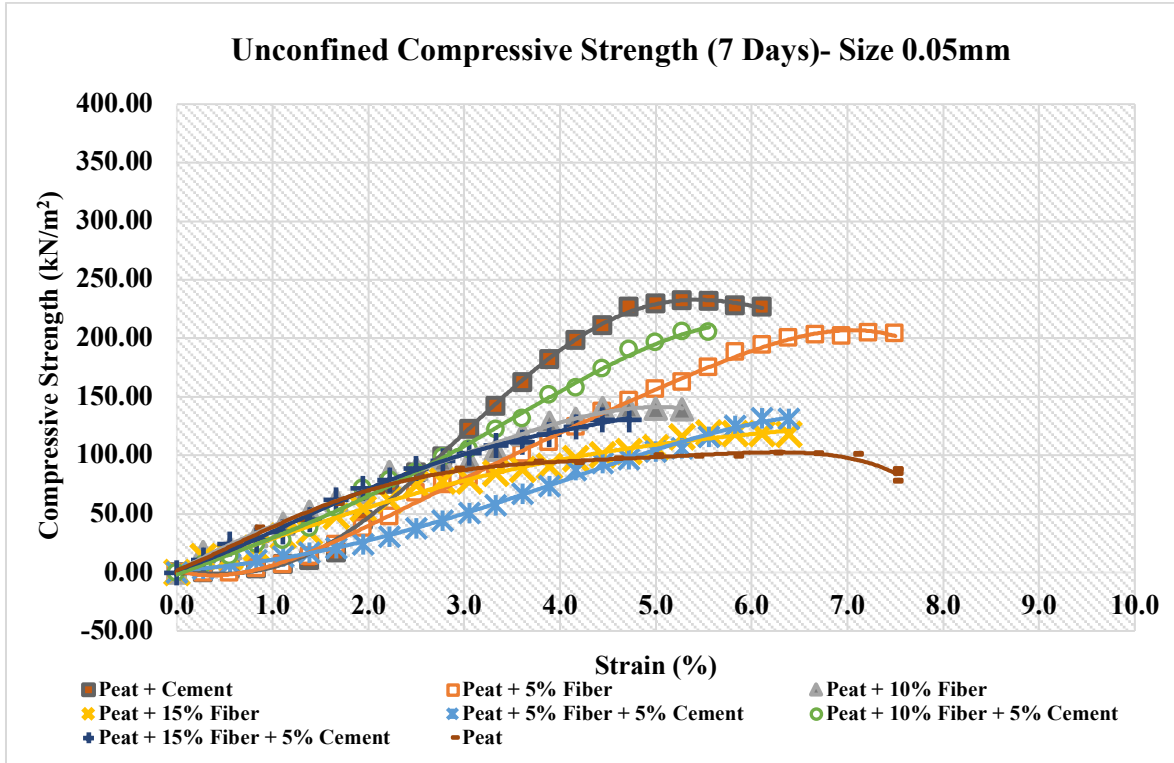


Figure 4.22: Unconfined Compressive Strength of Size 0.05 mm (7 days).

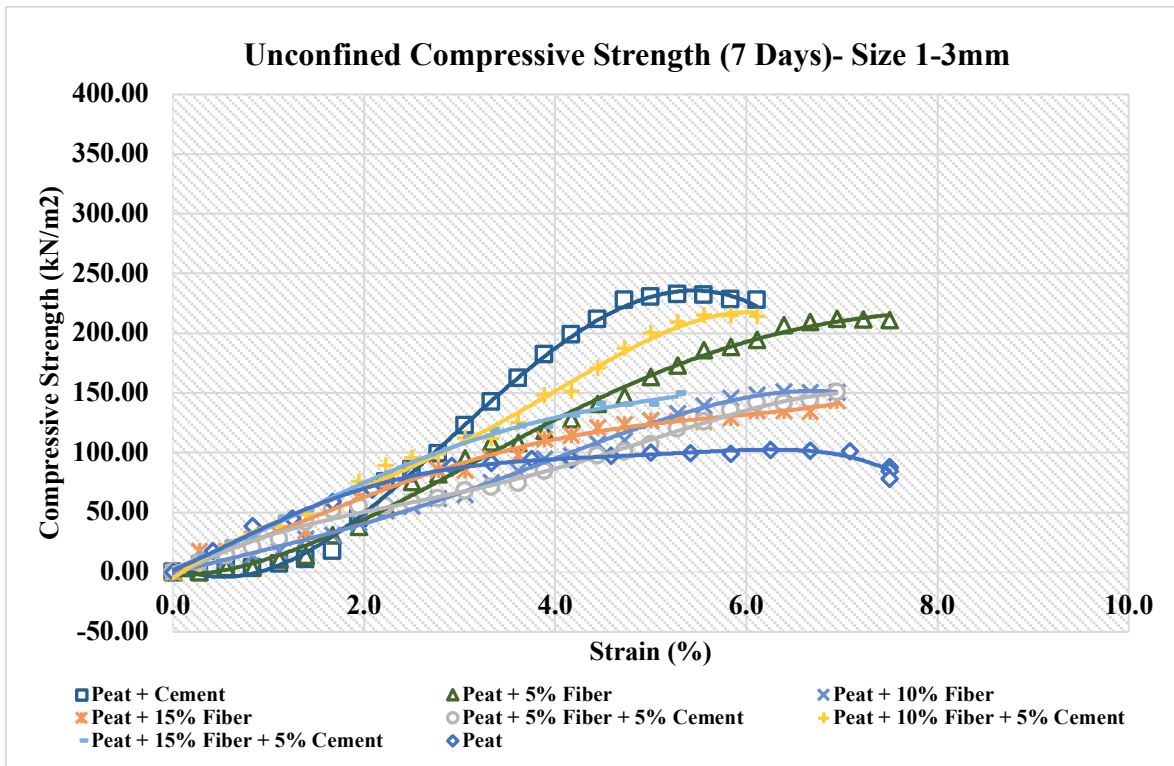


Figure 4.23: Unconfined Compressive Strength of Size 1-3 mm (7 days).

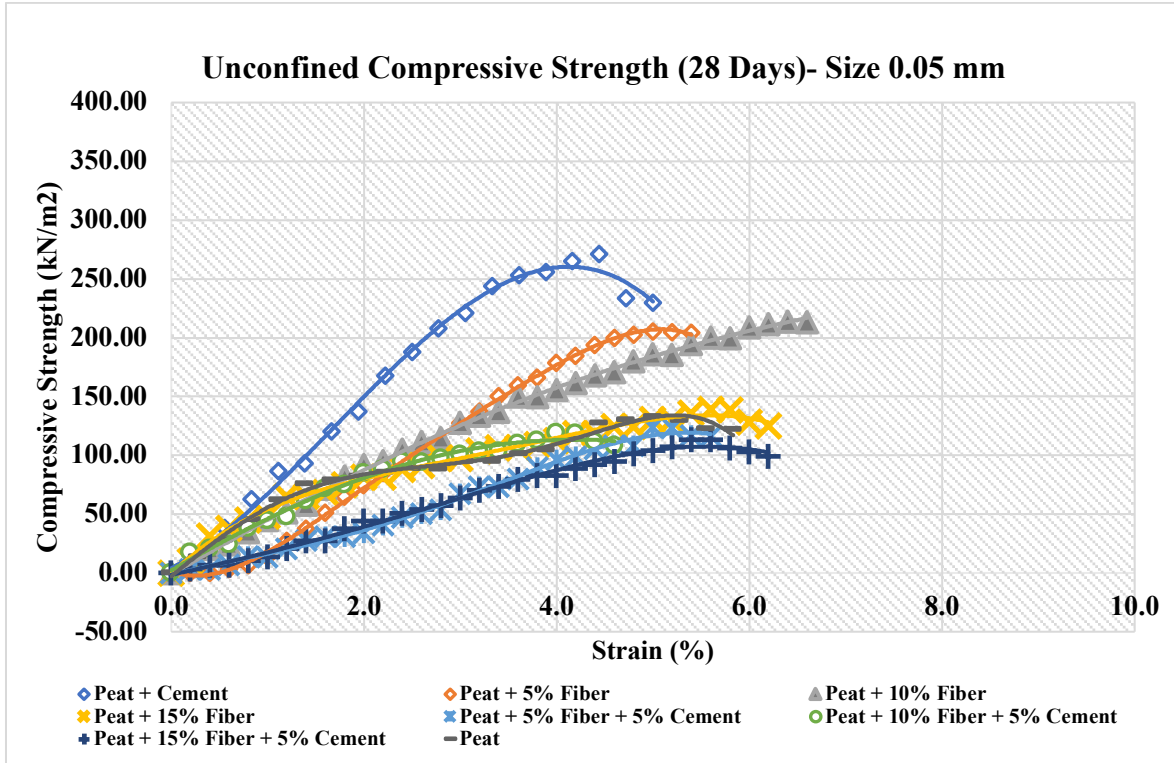


Figure 4.24: Unconfined Compressive Strength of Size 0.05 mm (28 days).

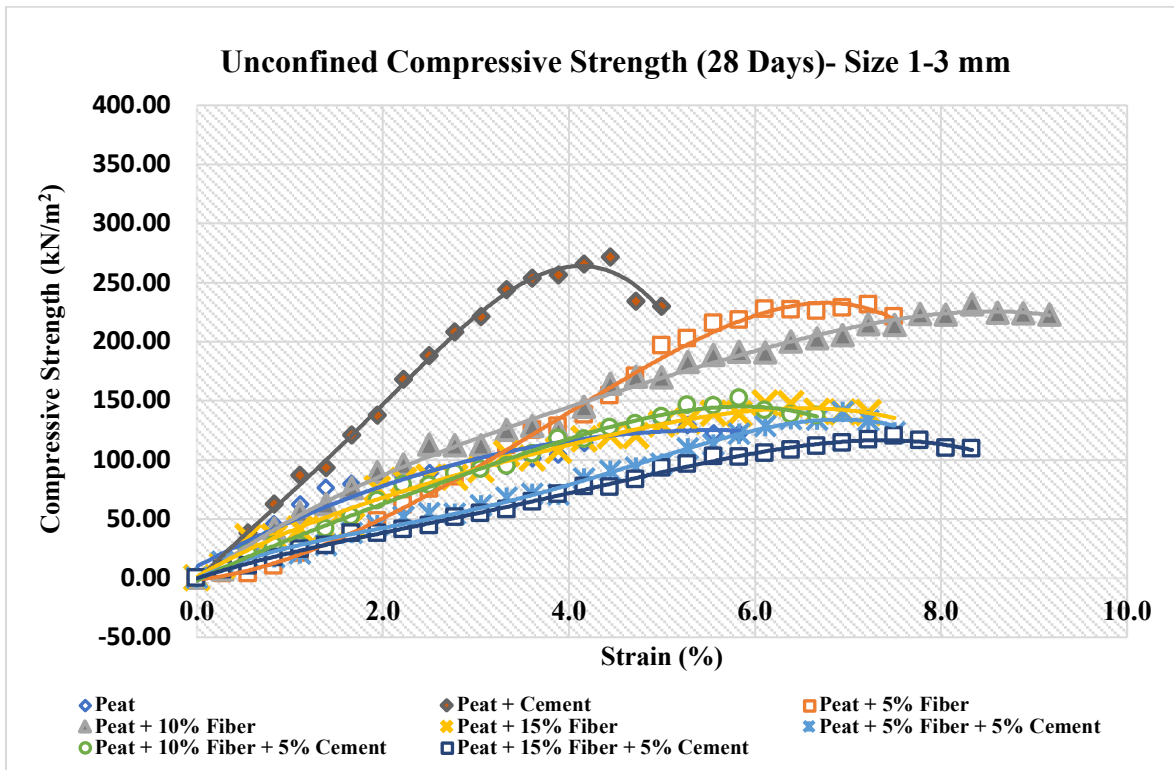


Figure 4.25: Unconfined Compressive Strength of Size 1-3 mm (28 days).

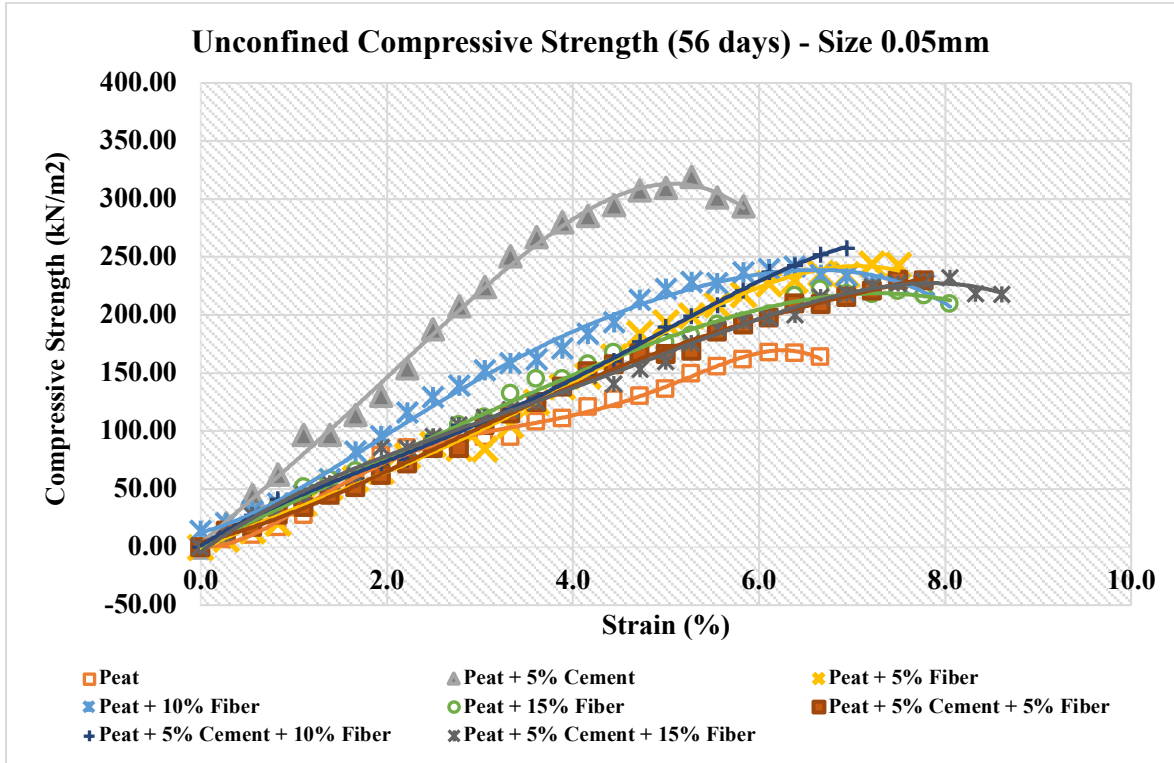


Figure 4.26: Unconfined Compressive Strength of Size 0.05mm (56 days).

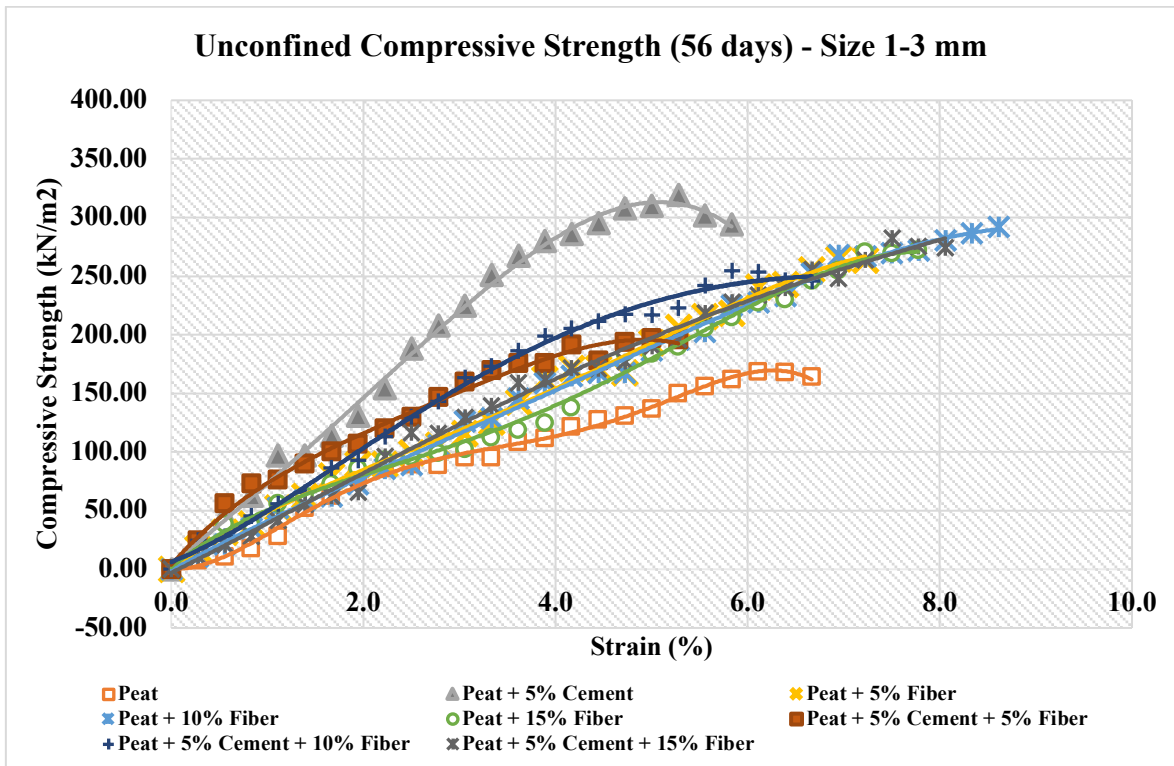


Figure 4.27: Unconfined Compressive Strength of Size 1-3 mm (56 days).

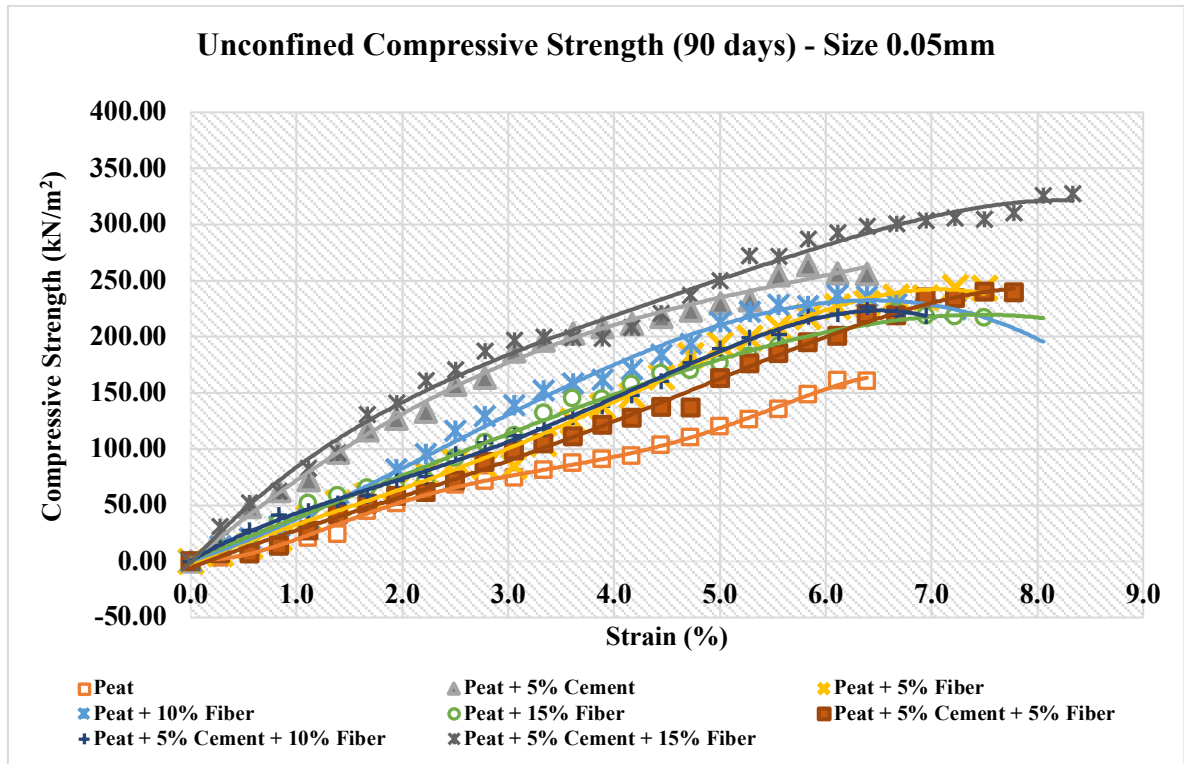


Figure 4.28: Unconfined Compressive Strength of Size 0.05mm (90 days).

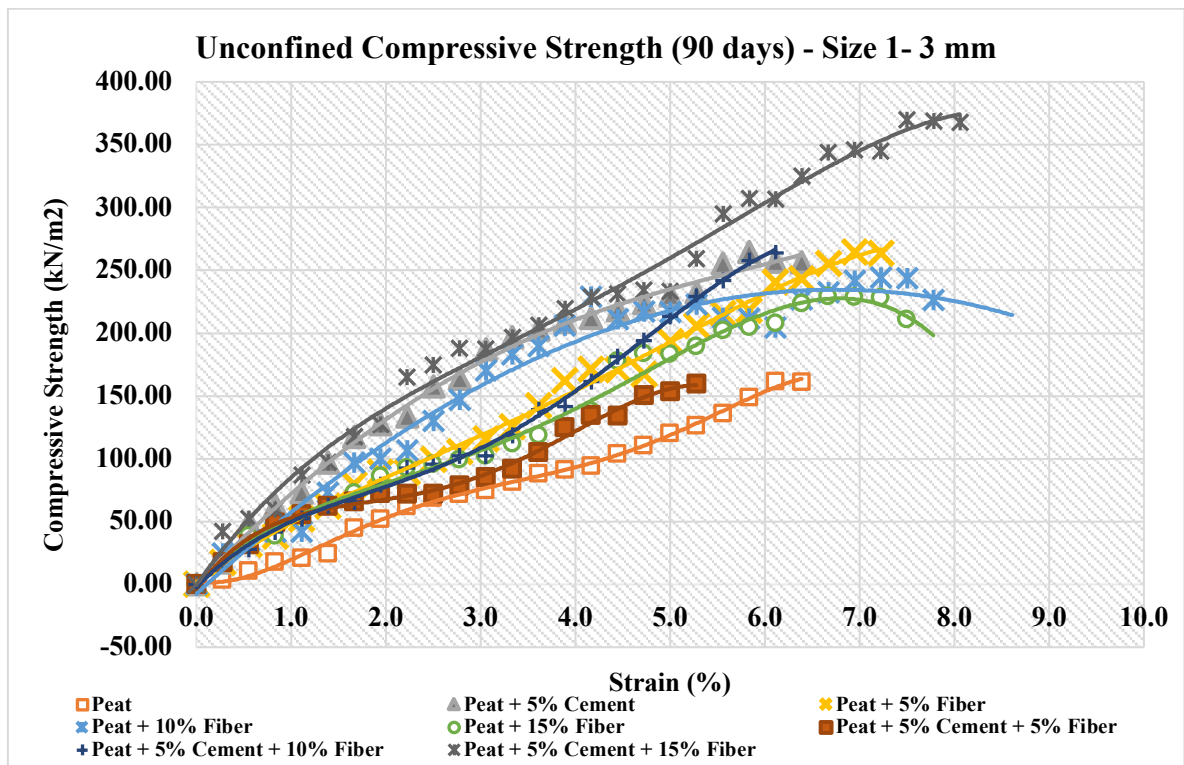


Figure 4.29: Unconfined Compressive Strength of Size 1-3 mm (90 days).

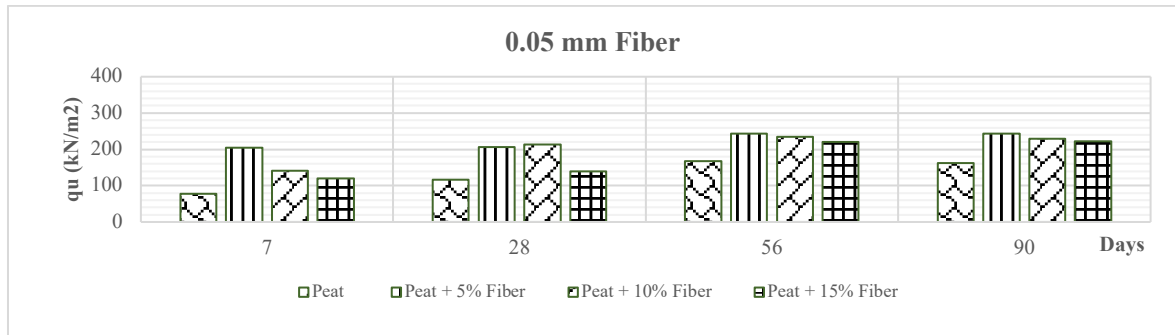


Figure 4.30: Compressive Strength vs Days for 0.05 mm Rubber Powder.

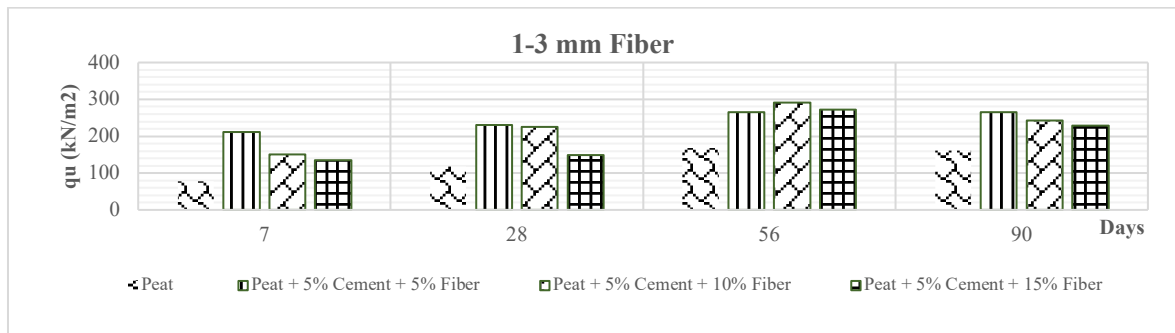


Figure 4.31: Compressive Strength vs Days for 1-3 mm Rubber Powder.

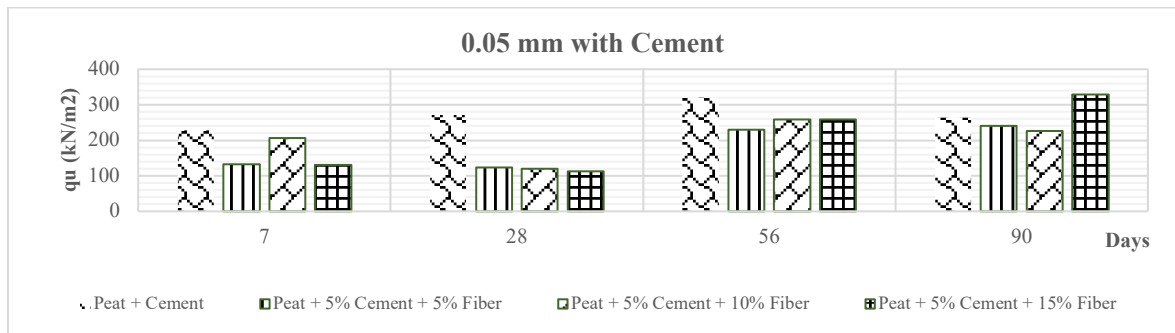


Figure 4.32: Compressive Strength vs Days for 0.05 mm Rubber Powder and 5% Cement.

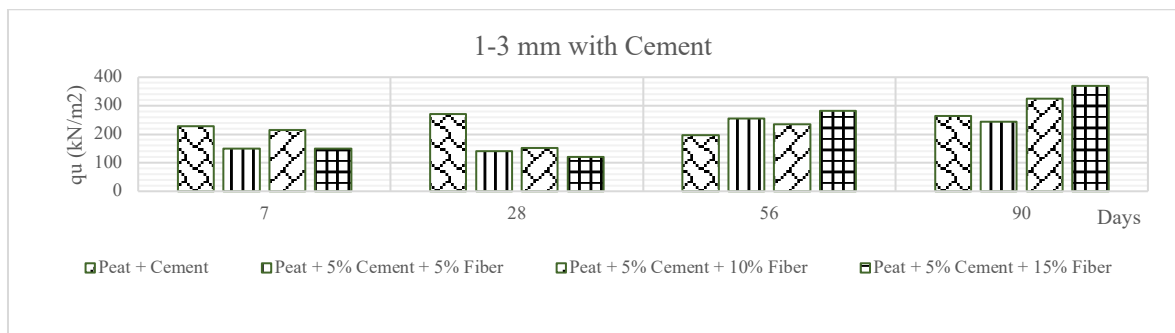


Figure 4.33: Compressive Strength vs Days for 1-3 mm Rubber Powder and 5% Cement.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 General

This chapter summarises the physical and the mechanical properties of the stabilised peat with different percentages of rubbers with a constant 5% cement as binders.

5.2 Conclusions

This section summarises the physical and mechanical properties of the stabilised peat with different percentages of rubbers.

- a) The Von Post degree of decomposition of the peat samples obtained from Kampung Endap is H7- H8, which is also categorised as sapric peat, as almost all of the peat escapes when squeezes out (ASTM D4427). It has an organic content of 81.99% with 78.87% of Loss on Ignition value. Kampung Endap peat has a high moisture content of 399.49%. The peat samples have the specific gravity value of 1.31. An in- situ pH test shows an acidic value of 3.54. The following (Table 5.1) shows the summary of the physical properties of the untreated peat.

Table 5.1: Summary of physical properties of the untreated peat samples.

Properties	Values
Degree of Decompostion	H7
Moisture Content (%)	399.49 %
Specific Gravity	1.31
Liquid Limit (%)	442%
Loss on Ignition (%)	78.87 %
Organic Content (%)	81.99 %
pH value	3.54

- b) For the liquid limit test, it is done with both the untreated and the treated peat. The liquid limit shows a higher value with the untreated peat, which is at 442% compared to the treated peat. After an addition of 10% of rubber tyres (0.05mm and 1-3mm), a significant drop can be observed from the liquid limit values with 172% and 24.4% respectively. This gives an overview that the moisture decreases with an addition of the rubber tyres.

Table 5.2: Summary of Liquid Limit test of both untreated and treated peat.

Samples	Liquid Limit
Untreated Peat	442%
Peat + 10% Rubber Powder (0.05mm)	172%
Peat + 10% Rubber Powder (1-3mm)	24.4%

- c) Field Vane Shear test were carried out on the site. According to Yogeswaran (1995), the average field vane shear strength for tropical peat found in Sarawak to be only 10 kPa while the sensitivity ranges the degree of humification of the soils, with more fibrous soils having higher undrained strength. The average field vane shear at Kampung Endap is at 10.66kPa.
- d) Based on the data obtained from the standard compaction test, the maximum dry density increases to 0.67 mg/m³ with an addition of 15% rubber powder of size 1-3mm from its total weight. This is proportional to the optimum moisture content, where the value decreases to 84%.
- e) Peat sample that has been treated with 15% rubber results in a higher shear strength value for both sizes. 0.05mm shows a value of 98.90 kN/m² which is higher than peat with 15% rubber of size 1-3 mm which is at 96.92 kN/m². Based on the direct shear box test, peat with 10% rubber of size 0.05mm shows the highest cohesion value, of 72.10 kN/m², with an angle of shear resistance of 2.58°.
- f) Peat samples that have been stabilised with 15% rubber of both sizes, after 90 days of curing gives out the highest compressive strength. However, between the two rubber sizes, 1-3mm rubber, shows a higher value of 369.89 kN/m² compared to 327.96 kN/m² for the rubber of size 0.05mm.

5.3 Recommendations

A few recommendations are made for further research work are present in this section. These recommendations are based on the experimental study that had been carried out.

- a) A further continuation needed to be done for this study to be completed. An increase in percentage of rubber tyres need to be added in the soil, to widen the strength development range.
- b) It is recommended to carry out experiments of peat soil with another binder instead of cement, to compare the results, parallel with the current study (rubber and cement).
- c) More samples from different locations with different compositions; namely fibric, sapric and hemic, should be tested out to identify the strength development towards the rubber tyres and cement.
- d) Different sizes of rubber are recommended in the future research study in comparison to the current study. Since size 1-3 mm gives out a significant increase to the peat strength in the current study, it is proposed to use a bigger size than 1-3 mm of rubber tyre be used in the future study.

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APPENDICES

Moisture Content

Peat			
Location : Kampung Endap, Samarahan			
Container No.	A1	A2	A3
Mass of container (m ₁) g	27.34	27.82	28.14
Mass of wet soil + container (m ₂) g	47.34	47.82	48.14
Mass of dry soil + container (m ₃) g	31.21	32.11	32.02
Mass of dry soil (m ₃ - m ₁) g	3.87	4.29	3.88
Mass of moisture (m ₂ - m ₃) g	16.13	15.71	16.12
Moisture content $w = \frac{(m_2 - m_3)}{(m_3 - m_1)} \times 100\%$	416.80	366.20	415.46
Average moisture content, w = %	399.49		

Loss on Ignition and Organic Content

Peat			
Location : Kampung Endap, Samarahan			
Crucible No.	1	2	3
Mass of oven crucible (m ₁) g	19.89	20.00	22.00
Mass of crucible + oven - dried soil (m ₂) g	25.00	28.00	28.00
Mass of crucible + soil after ignition (m ₃) g	21.00	22.00	23.00
Loss of ignition	78.28	75.00	83.33
Average loss of ignition, N %	78.87		
Organic Content %	81.37	77.96	86.63
Average organic content, H %	81.99		

Liquid Limit

Location : Kota Samarahan

Test No	1			2			3			4		
Cone Penetration (mm)	13.2 0	13.1 0	13.0 0	17.7 0	17.0 0	17.4 0	19.0 0	18.7 0	18.7 0	23.2 0	23.4 0	23.5 0
Average penetration (mm)	13.10			17.37			18.80			23.37		
Container no.	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3
Mass of container (m1) g	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
Mass of container + wet soil (m2) g	16.0 0	19.0 0	19.0 0	19.0 0	16.7 0	17.9 0	19.0 0	17.5 0	18.0 0	19.0 0	19.0 0	19.0 0
Mass of container + dry soil (m3) g	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Mass of dry soil (m3 - m1) g	3.29	3.29	3.29	3.29	3.29	3.29	3.29	3.29	3.29	3.29	3.29	3.29
Moisture loss (m2 - m3) g	12.0 0	15.0 0	15.0 0	15.0 0	12.7 0	13.9 0	15.0 0	13.5 0	14.0 0	15.0 0	15.0 0	15.0 0
Moisture content $\frac{\text{Moisture loss}}{\text{Mass of dry soil}} \times 100\%$	364.74	455.93	455.93	455.93	386.02	422.49	455.93	410.33	425.53	455.93	455.93	455.93
Average moisture content %	410.33			439.21			440.73			455.93		

Specific Gravity

Location : Kota Samarahan Kampung Endap, Samarahan

No.	1			2		
Pycnometer no.	1	2	3	4	5	6
Mass of bottle (m1) g	22	21	23	21	21	21
Mass of bottle + soil (m2) G	32	31	33	31	31	31
Mass of bottle + soil + water (m3) g	74	74	76	74	75	74
Mass of bottle full of water (m4) g	72	72	73	72	73	72
Mass of soil (m2 - m1) g	10	10	10	10	10	10
Mass of water in full bottle (m4 - m1) g	50	51	50	51	52	51
Mass of water used (m3 - m2) g	42	43	43	43	44	43
Volume of soil particles (m4 - m1) - (m3 - m2) mL	8	8	7	8	8	8
Specific Gravity $G_s = \frac{(m_2 - m_1)}{(m_4 - m_1) - (m_3 - m_2)}$	1.25	1.25	1.43	1.25	1.25	1.25
Average Specific Gravity, Gs	1.31			1.25		

Field Vane Shear

Point 1

Coordinate 1.427 110.4595

Depth	Shear Strength (kPa)		Corrected Shear Strength	
	Undisturbed Soil (kg) with slow twist within two minutes	Remolded Soil (after 10 times twist)	Undisturbed Soil (kg) with slow twist within two minutes	Remolded Soil (after 10 times twist)
0.20	19.00	10.00	9.50	5.00
0.40	16.00	11.00	8.00	5.50
0.60	15.00	10.00	7.50	5.00
0.80	16.00	10.00	8.00	5.00
1.00	19.00	11.00	9.50	5.50
1.20	11.00	8.00	5.50	4.00
1.40	16.00	9.00	8.00	4.50
1.60	16.00	11.00	8.00	5.50
1.80	19.00	11.00	9.50	5.50
2.00	23.00	13.00	11.50	6.50
AVERAGE			8.50	5.20

Point 2

Coordinate 1.4273 110.4595

Depth	Shear Strength (kPa)		Corrected Shear Strength	
	Undisturbed Soil (kg) with slow twist within two minutes	Remolded Soil (after 10 times twist)	Undisturbed Soil (kg) with slow twist within two minutes	Remolded Soil (after 10 times twist)
0.20	32.00	12.00	16.00	6.00
0.40	50.00	21.00	25.00	10.50
0.60	22.00	11.00	11.00	5.50
0.80	14.00	9.00	7.00	4.50
1.00	35.00	10.00	17.50	5.00
1.20	12.00	7.00	6.00	3.50
1.40	10.00	6.00	5.00	3.00
1.60	11.00	8.00	5.50	4.00
1.80	23.00	7.00	11.50	3.50
2.00	29.00	11.00	14.50	5.50
AVERAGE			11.90	5.10

Point 3

Coordinate

1.4273

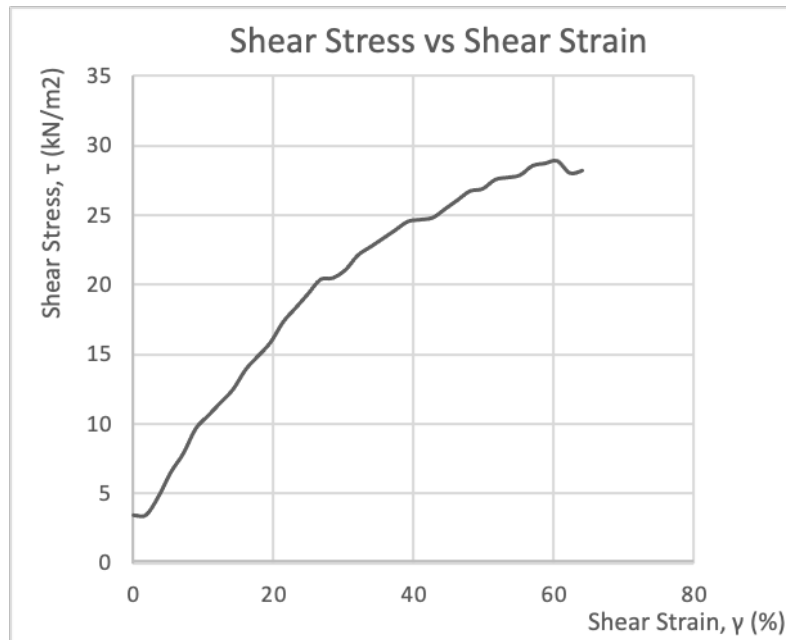
110.4595

Depth	Shear Strength (kPa)		Corrected Shear Strength	
	Undisturbed Soil (kg) with slow twist within two minutes	Remolded Soil (after 10 times twist)	Undisturbed Soil (kg) with slow twist within two minutes	Remolded Soil (after 10 times twist)
0.20	26.00	9.00	13.00	4.50
0.40	26.00	12.00	13.00	6.00
0.60	18.00	10.00	9.00	5.00
0.80	26.00	12.00	13.00	6.00
1.00	20.00	9.00	10.00	4.50
1.20	28.00	9.00	14.00	4.50
1.40	22.00	18.00	11.00	9.00
1.60	23.00	12.00	11.50	6.00
1.80	23.00	12.00	11.50	6.00
2.00	20.00	11.00	10.00	5.50
AVERAGE			11.60	5.70

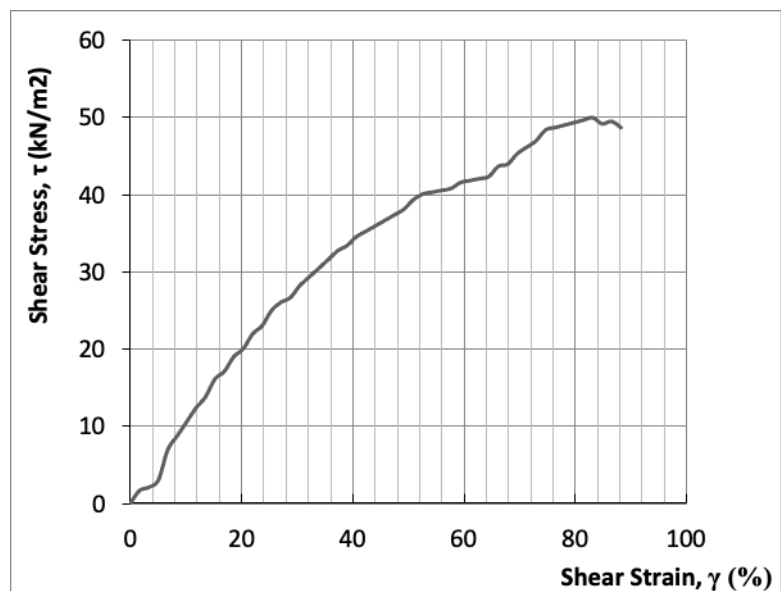
Direct Shear Box

0.05 mm Rubber

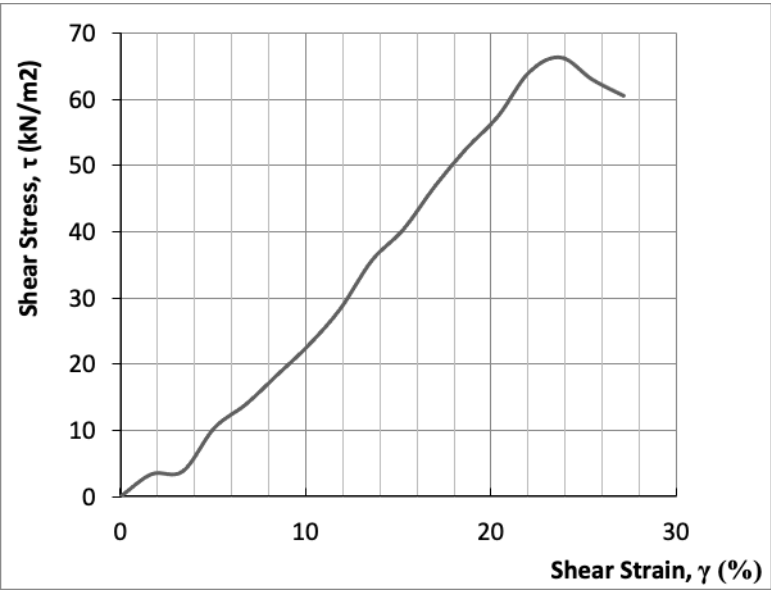
100 kN/m²



200 kN/m²

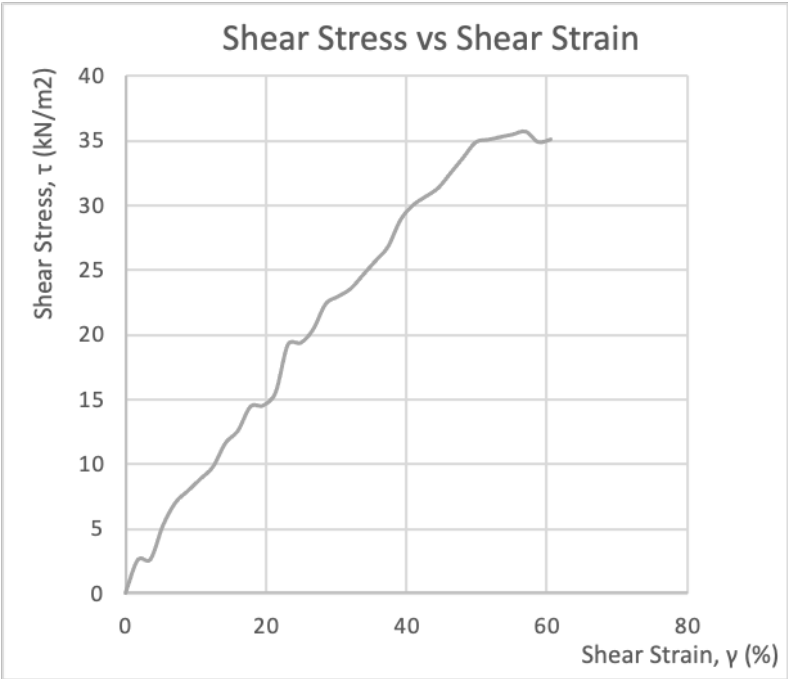


400 kN/m²

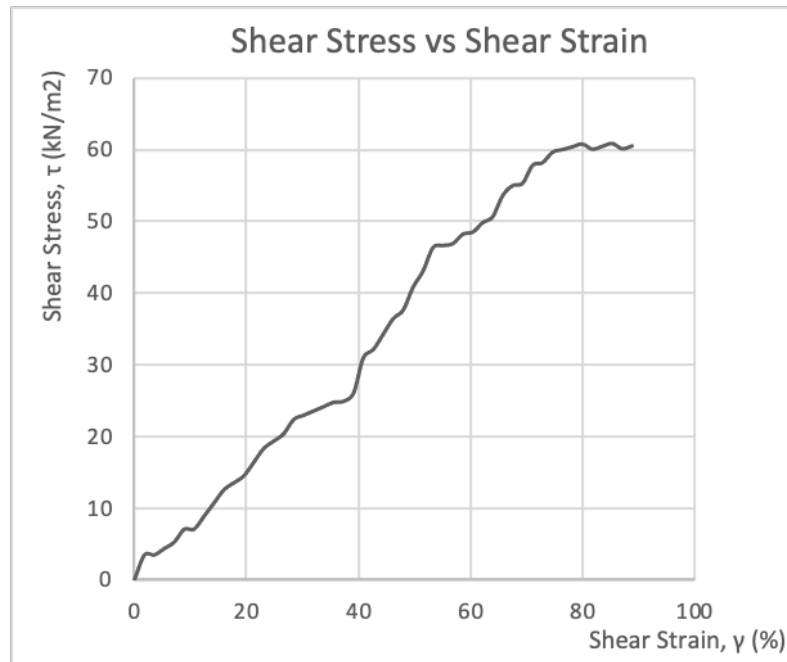


Peat + 5% Rubber (0.05 mm)

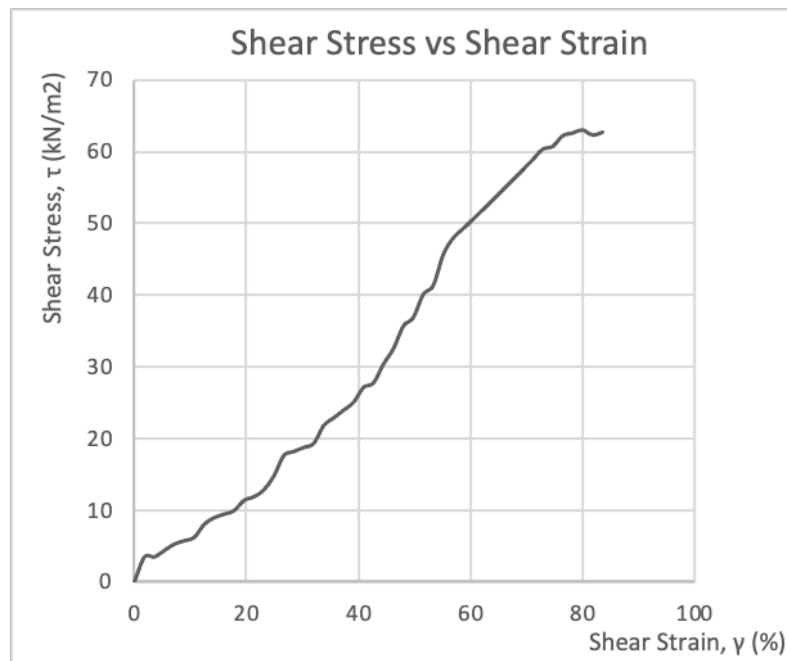
100 kN/m²



200 kN/m²

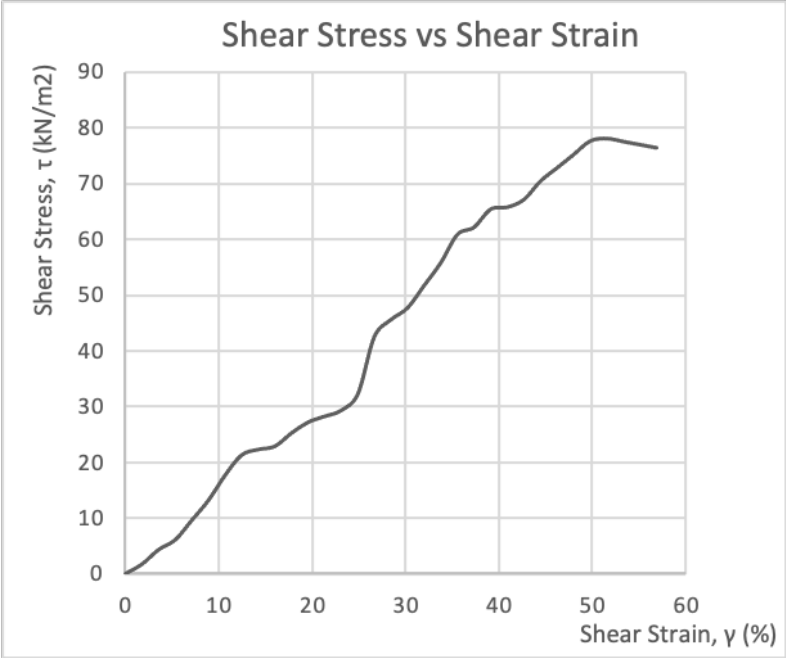


400 kN/m²

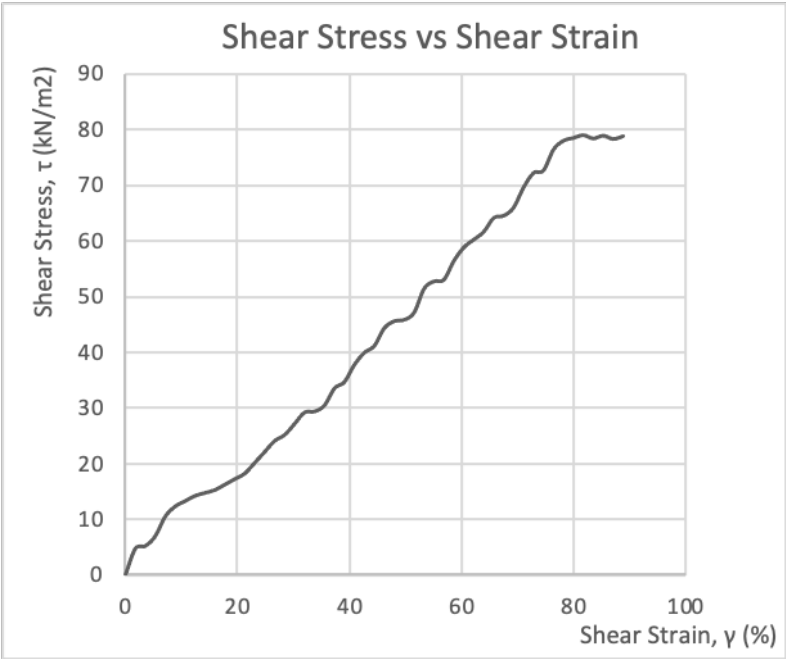


Peat + 10% Rubber (0.05 mm)

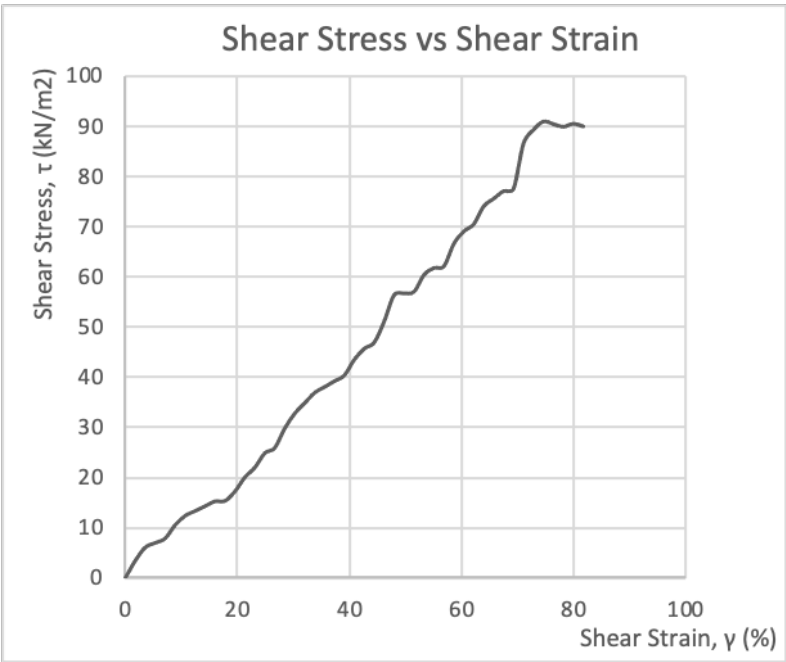
100 kN/m²



200 kN/m²

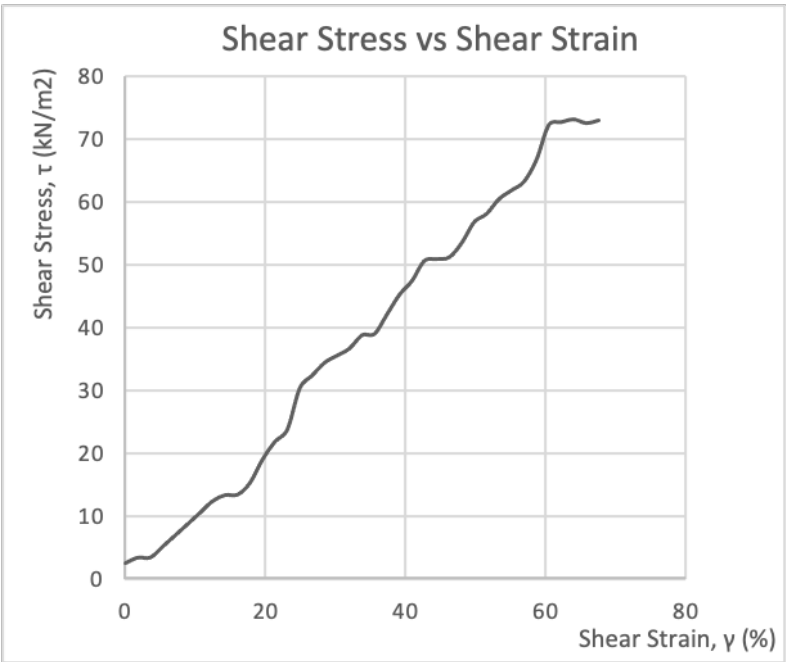


400 kN/m²

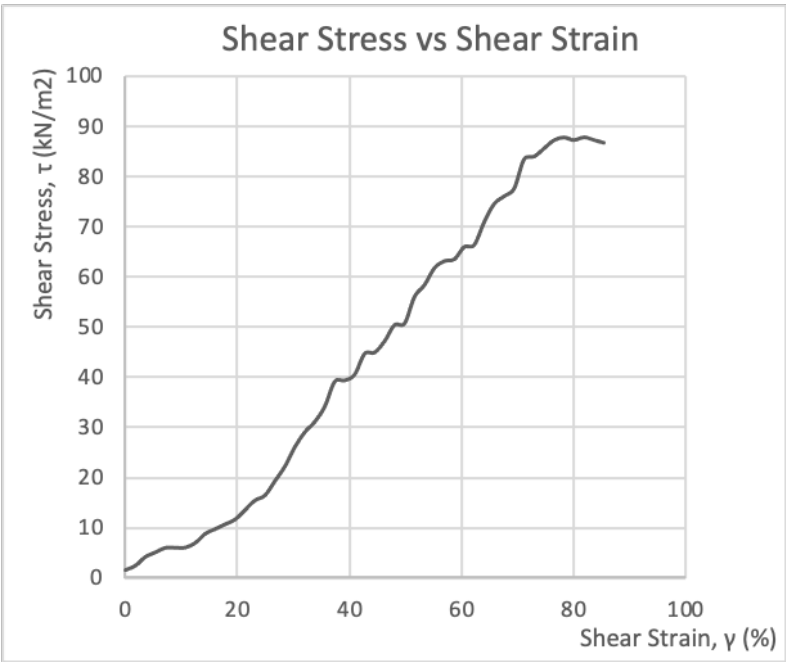


Peat + 15% Rubber (0.05 mm)

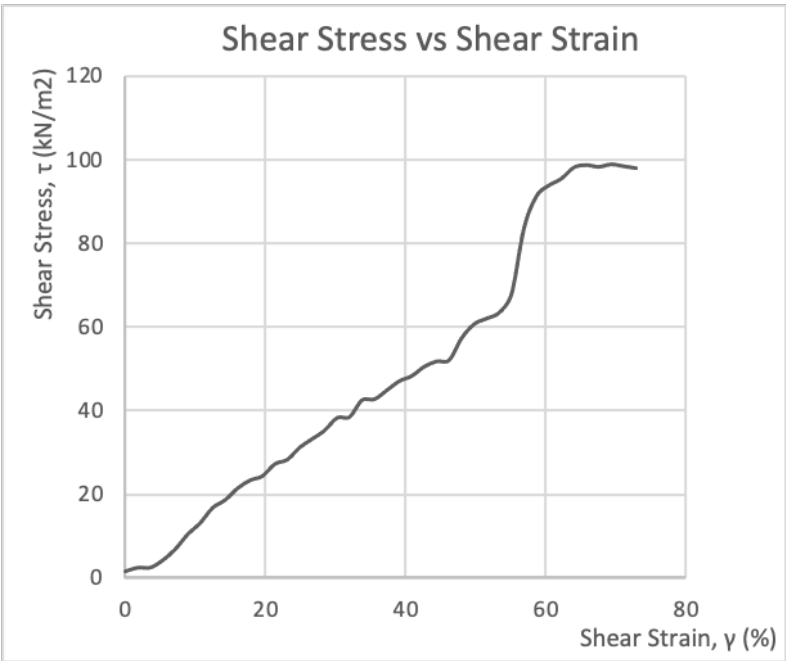
100 kN/m²



200 kN/m²

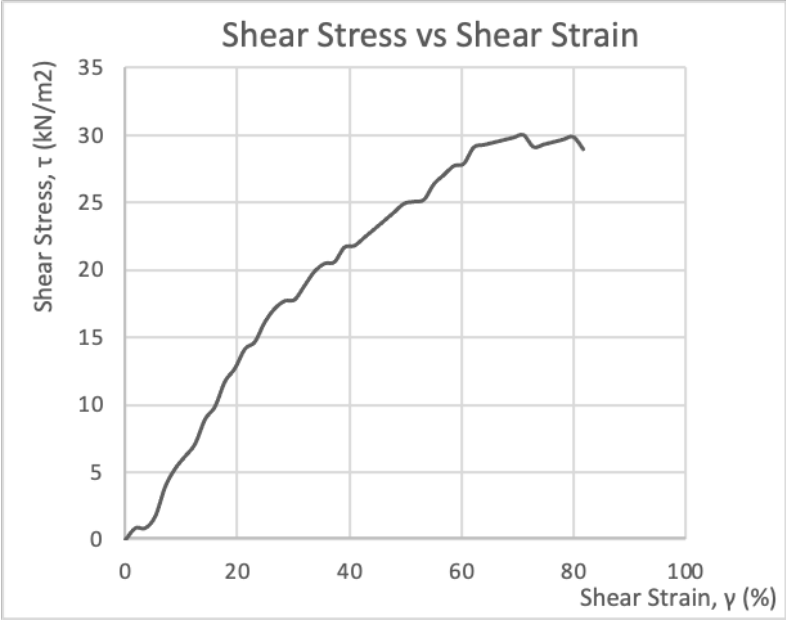


400 kN/m²

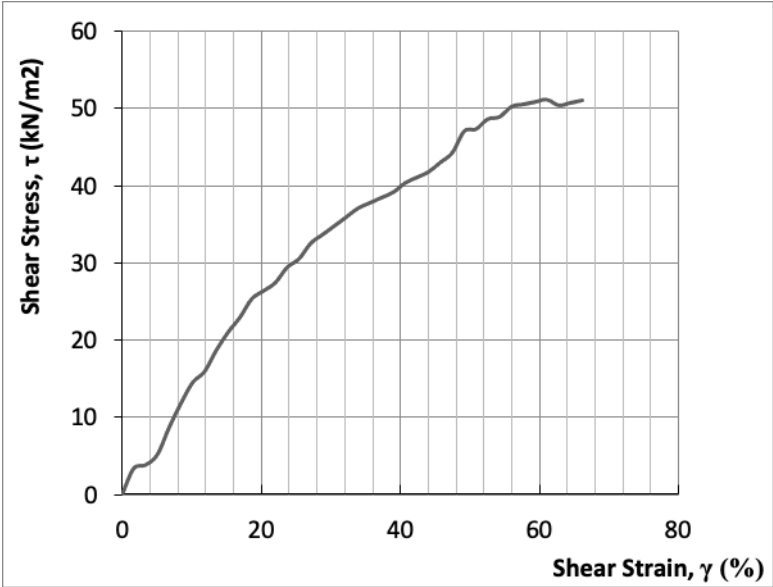


Rubber 1-3 mm

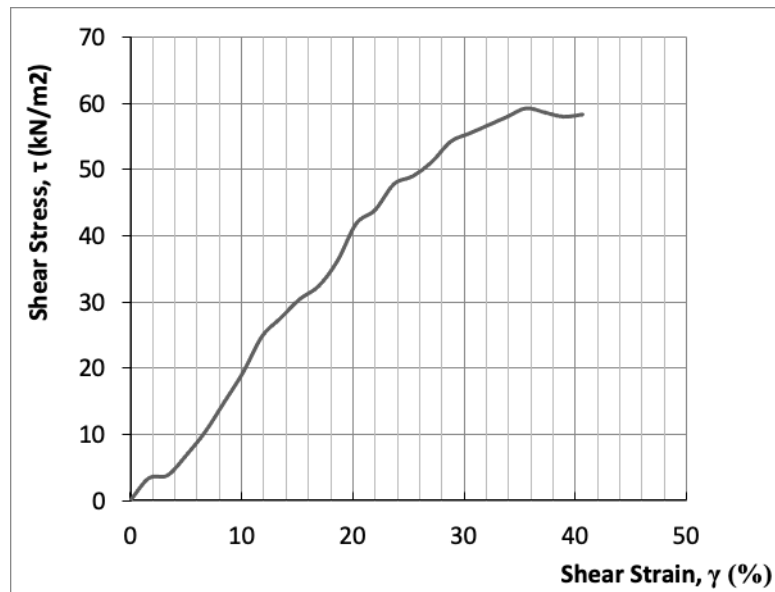
100 kN/m²



200 kN/m²

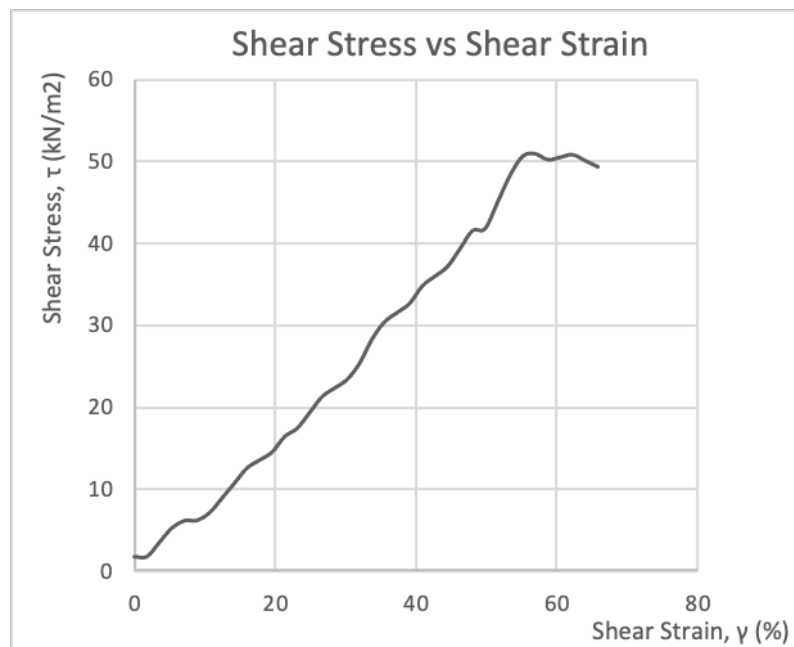


400 kN/m²

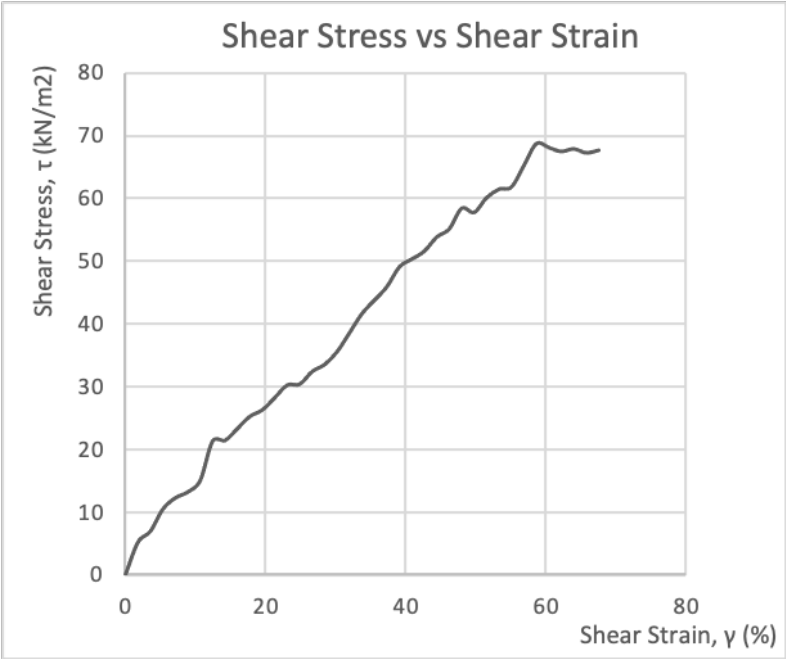


Peat + 5% Rubber (1-3 mm)

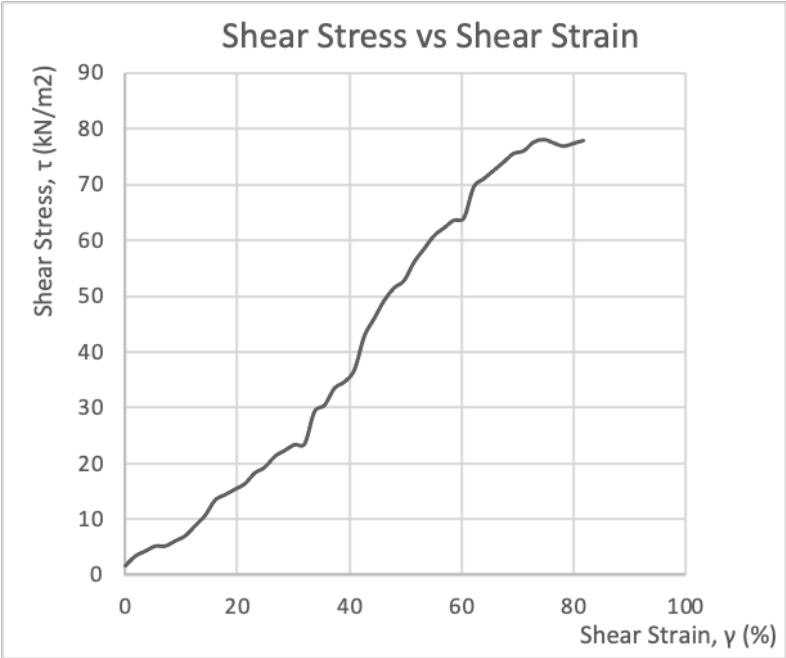
100 kN/m²



200 kN/m²

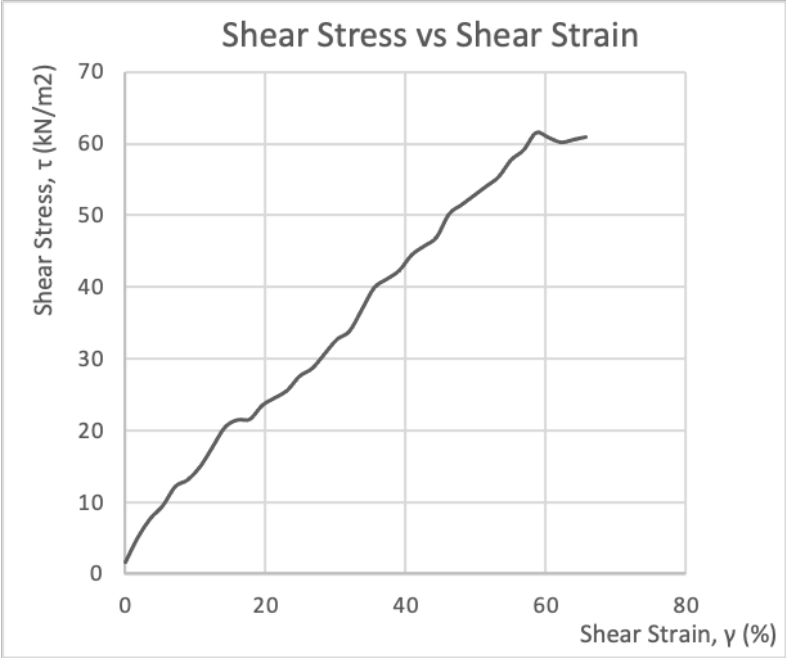


400 kN/m²

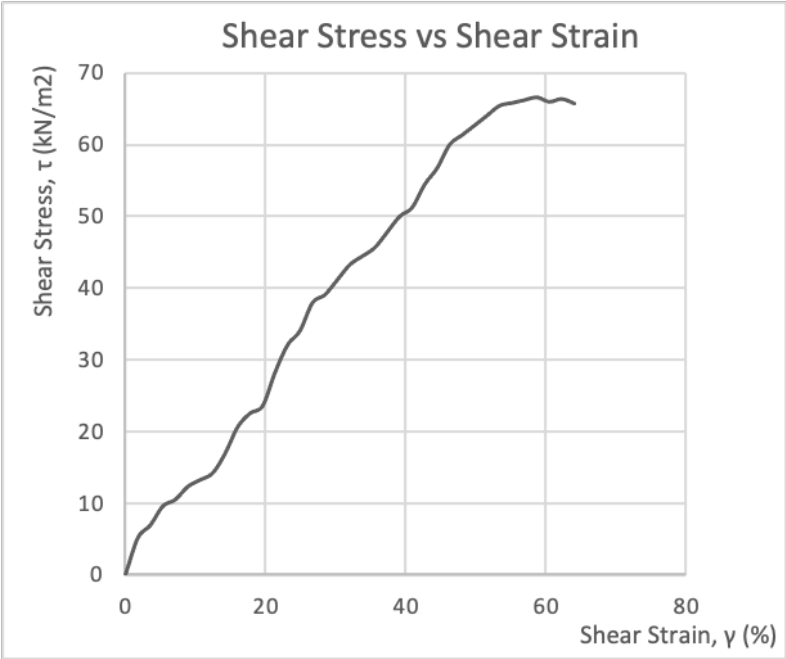


Peat + 10% Rubber (1-3 mm)

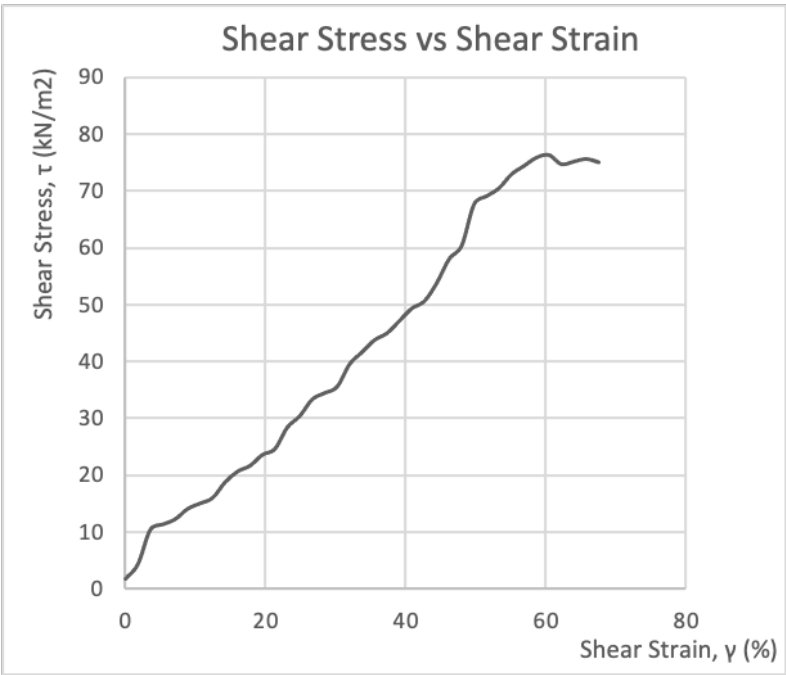
100 kN/m²



200 kN/m²

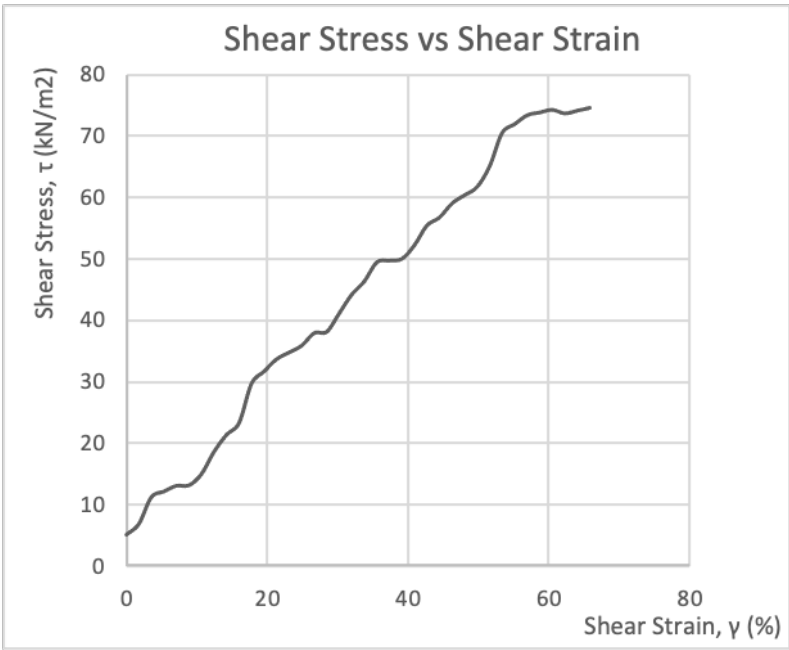


400 kN/m²

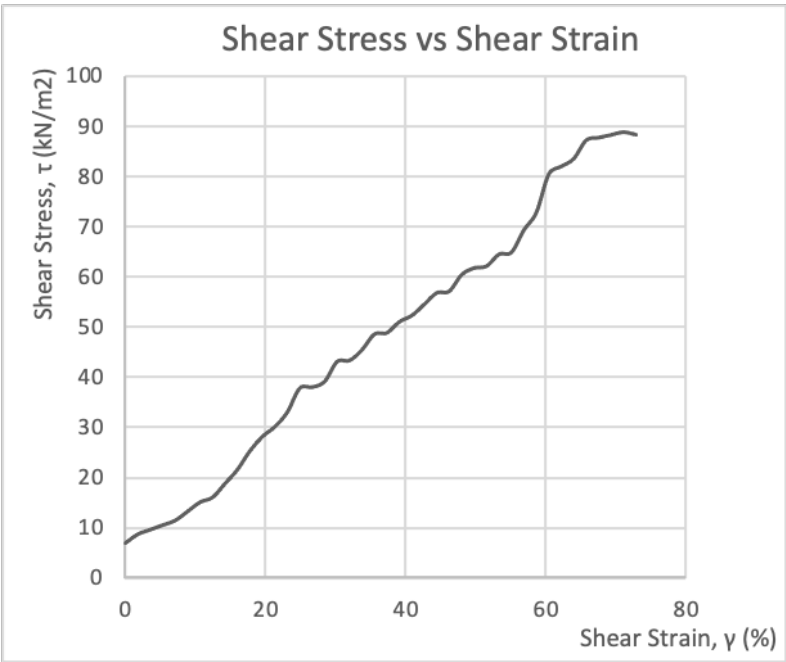


Peat + 15% Rubber (1-3 mm)

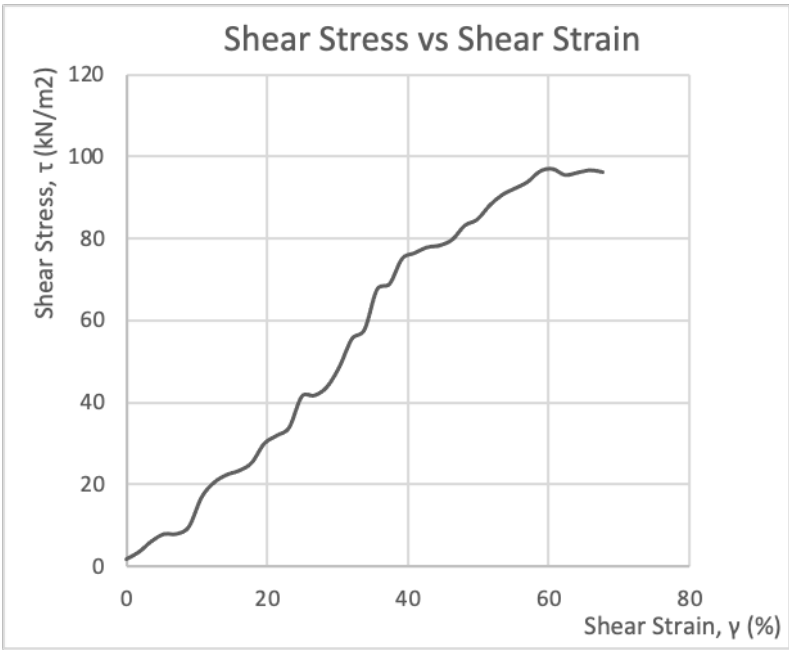
100 kN/m²



200 kN/m²

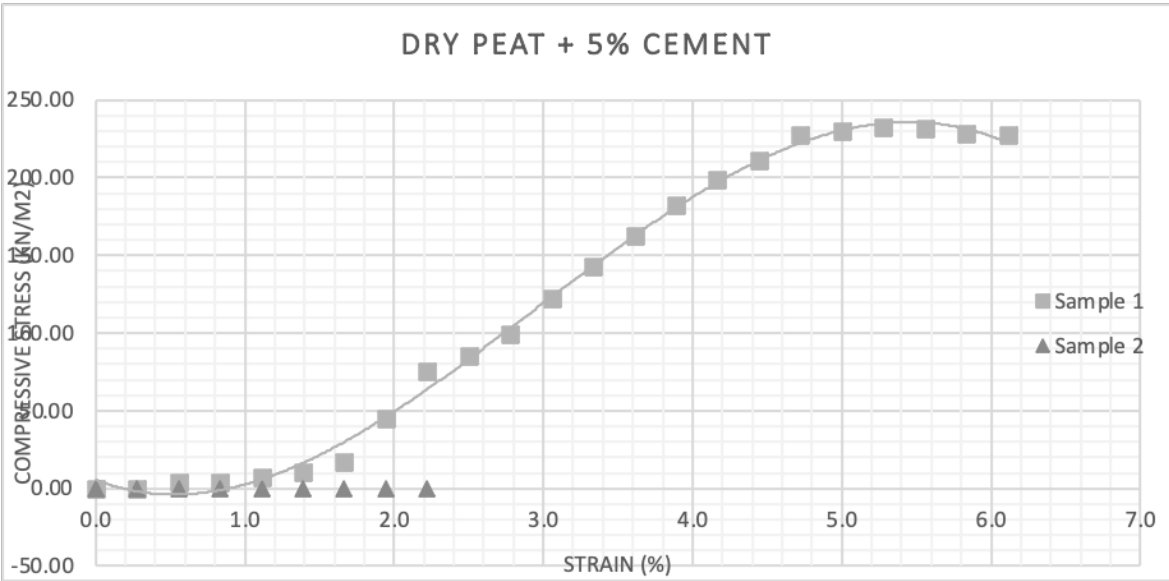
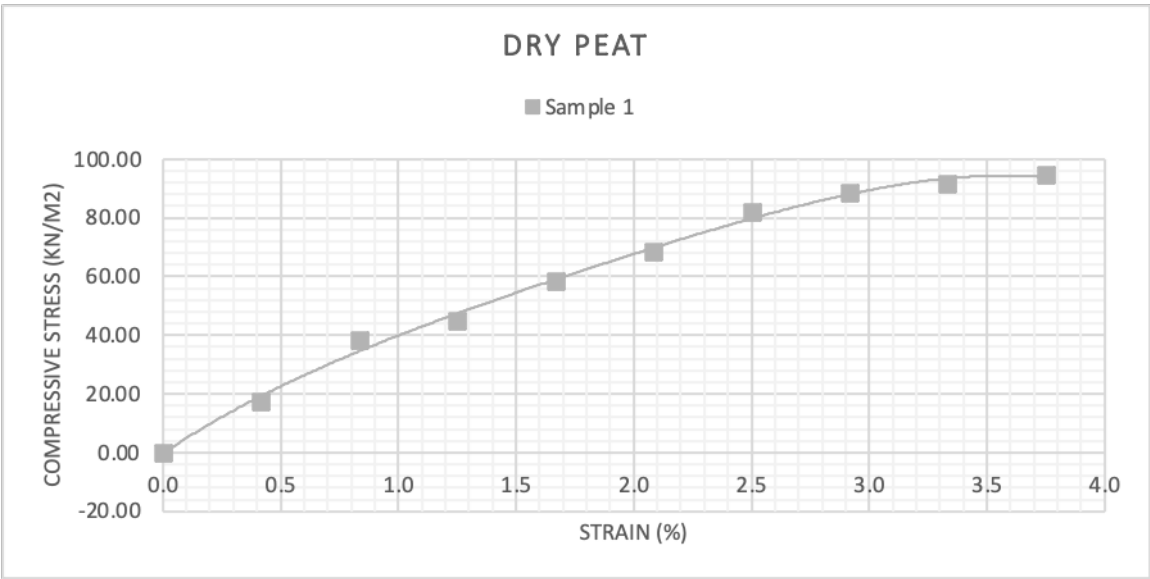


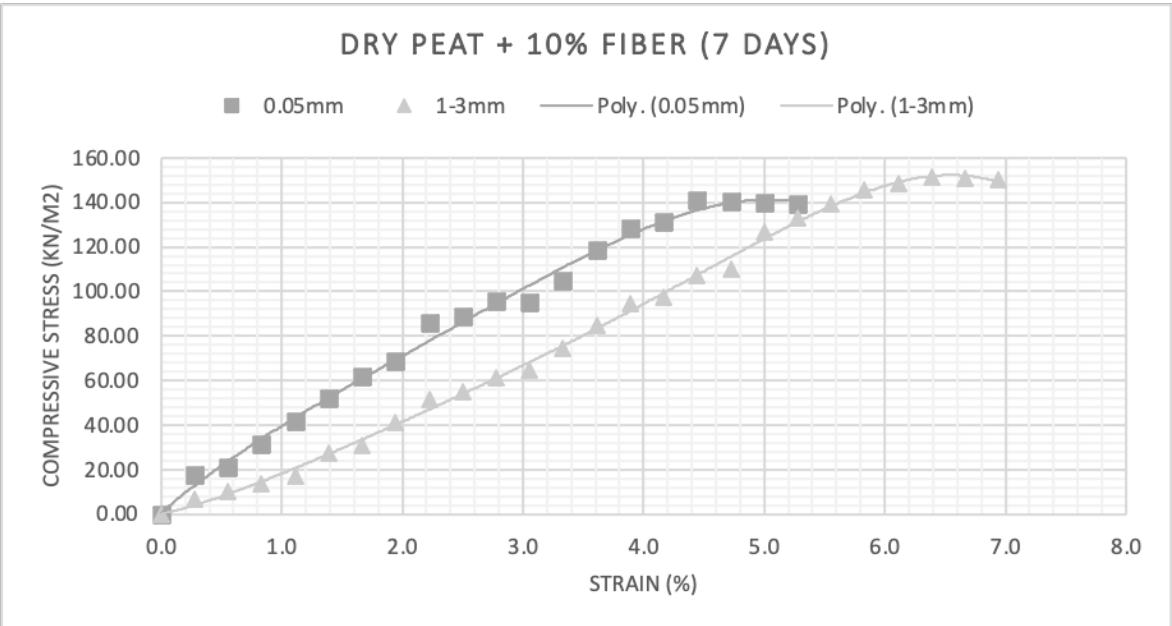
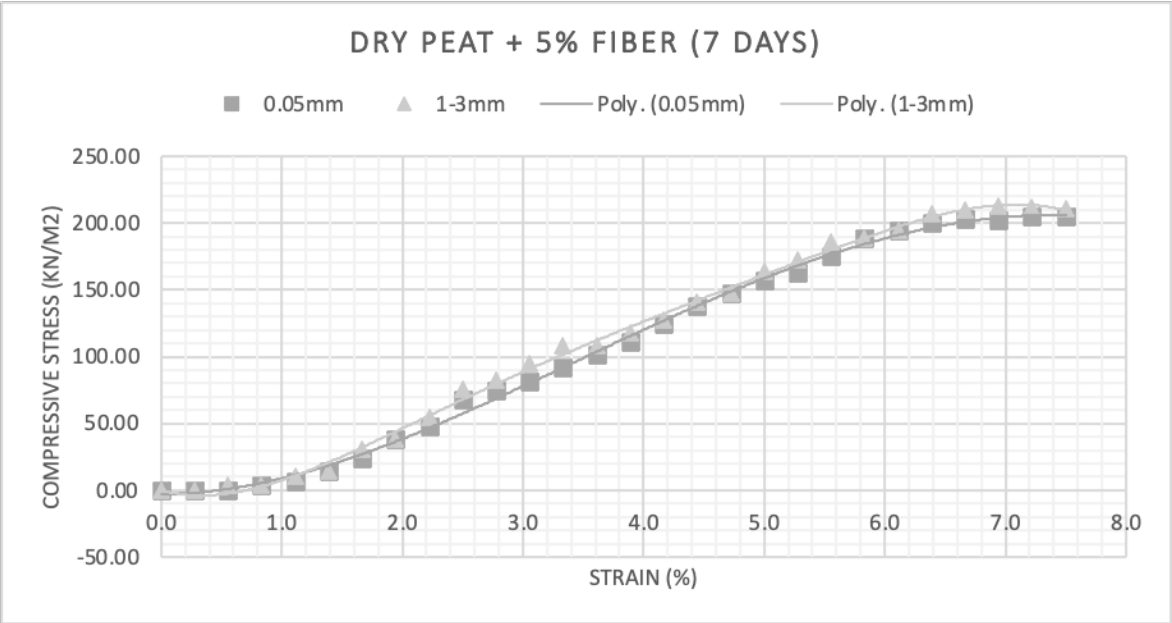
400 kN/m²

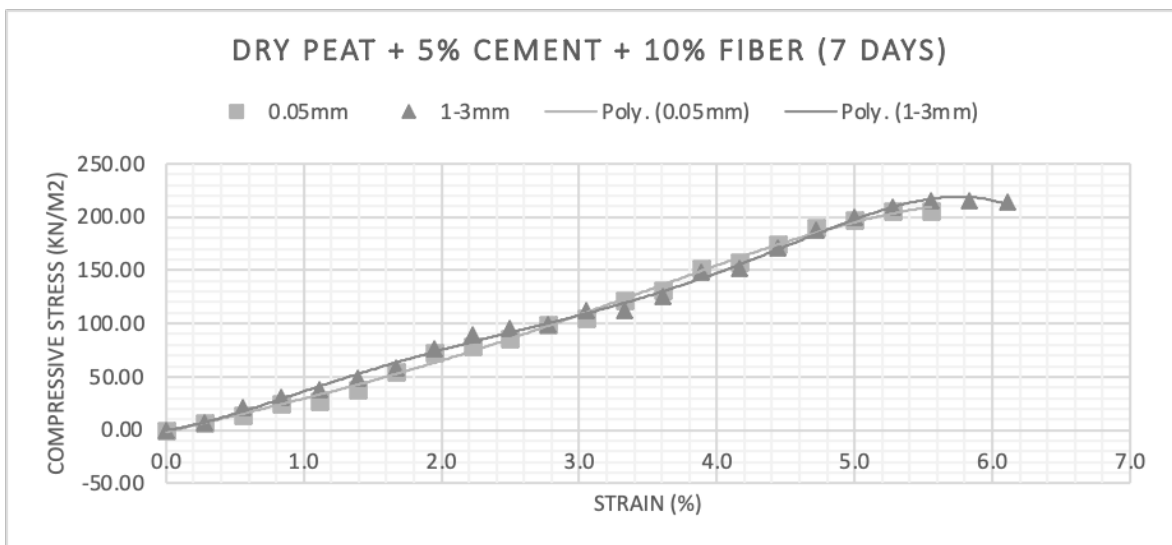
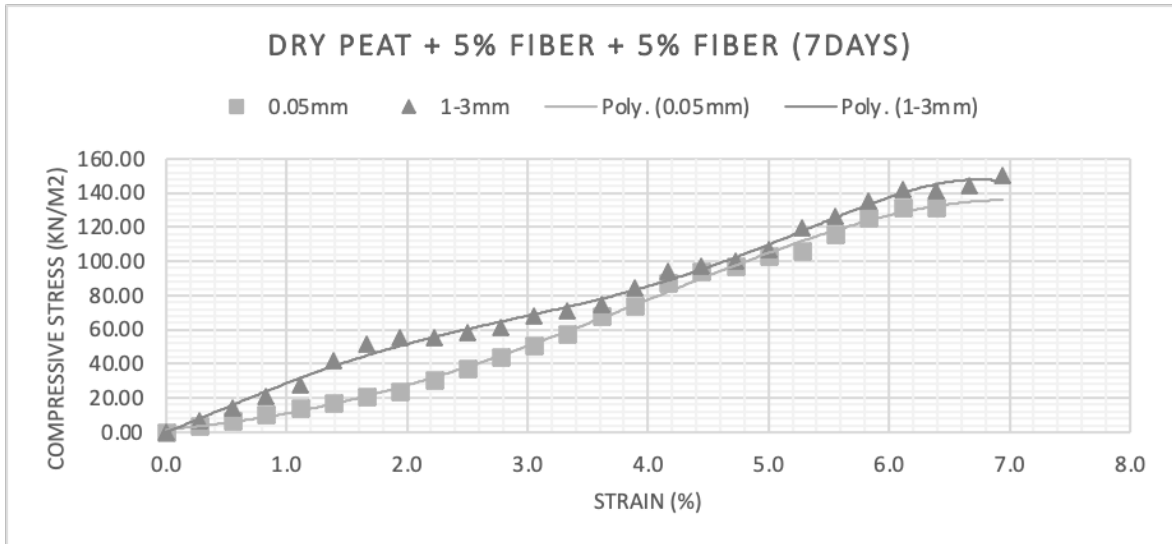
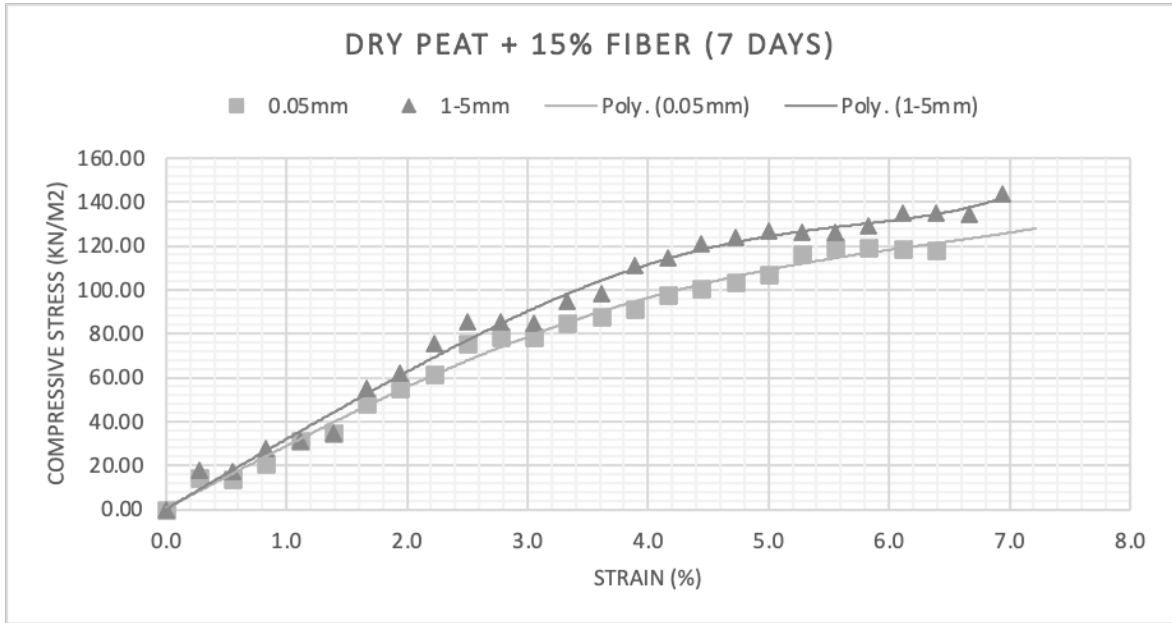


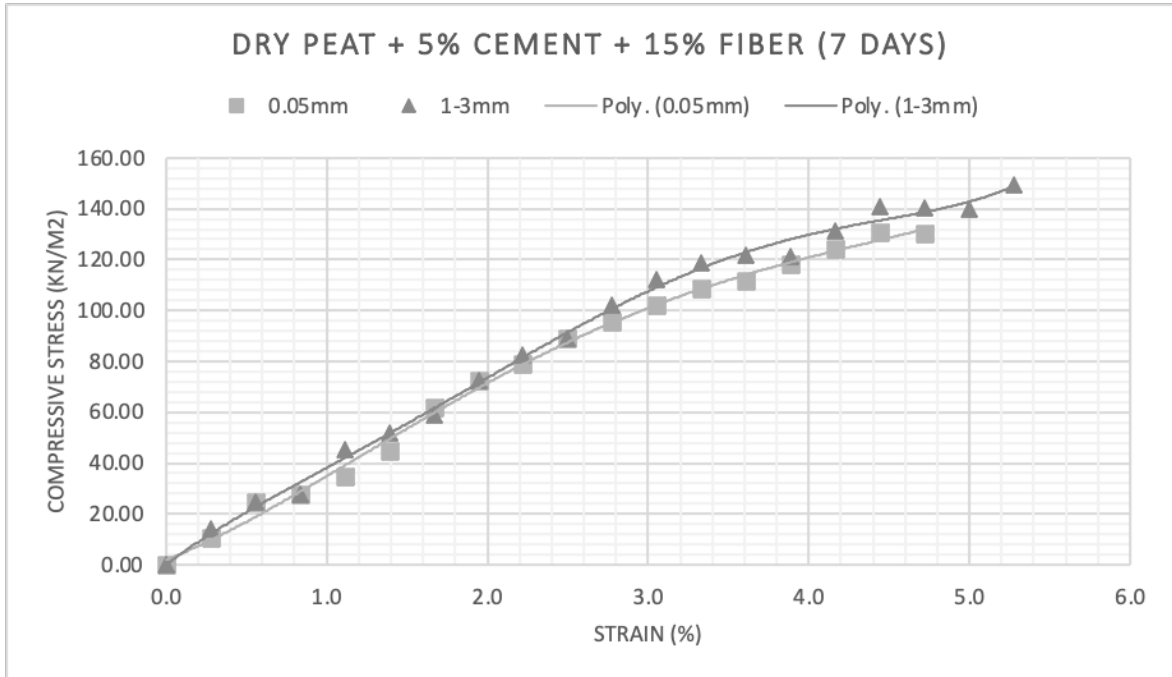
Unconfined Compressive Strength (UCS)

7 Days









28 Days

