A Comparative Study on Compressive Strength & Shear Strength parameter of Clayey Sand Soil Reinforced with randomly dispersed natural fibers

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A Thesis Submitted to the Academic Faculty in Partial Fulfillment of the Requirements for the Degree of

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DECLARATION OF CANDIDATE

We hereby declare that the undergraduate research work reported in this thesis has been performed by us under the supervision of Assistant Professor Farnia Nayar Parshi and this work has not been submitted elsewhere for any purpose.

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DEDICATION

Our thesis project is dedicated to our respective parents, families, and friends. We would also like to honor Assistant Professor Farnia Nayar Parshi, our esteemed supervisor. It's a small token of our gratitude to everybody who has supported us along the journey and motivated us to complete what we've initiated.

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"In the name of Allah, Most Gracious, Most Merciful."

All the praises to Allah (SWT) who has blessed us with the opportunity to conclude this book.

We'd like to convey my gratefulness to Farnia Nayar Parshi, our thesis supervisor, for her guidance and support. She had been a true inspiration who encouraged us to pursue this research during this pandemic. This work was only done because of her concern, support, and inspiration. We are forever indebted.

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ABSTRACT

Composite materials have been widely used in a variety of applications over the last few decades. Many varieties of natural fibers have been studied for use in geotechnical and construction applications. Among them, Arecaceae family fibers are rich in lignin which constituent of fiber increases the water holding capacity and strength of the composite.

The objectives of this research are to compare the effects of different amounts of short Arecaceae family fibers (Coconut, Betel Nut, Toddy Palm) on the geotechnical properties of clayey sand soil in a specific experimental setting. In terms of the dry weight of soil, samples with 0, 0.5, and 1 wt% fiber were analyzed. Unconfined Compressive Strength, Direct Shear test was conducted on the samples. Each fiber improved the ductility and shear parameters of the composite.

1% of betel nut fiber has the best result in compressive strength with increased ultimate strength. For shear strength, 1% of coconut fiber gave the best outcome. Toddy Palm and Coconut fiber both alter the composite to e denser state.

CHAPTER ONE: INTRODUCTION

1.1 General:

It is important to provide access to good soil when constructing new infrastructure. Soil is used to manufacture both direct and indirect construction materials, such as cement and brick. It is also used to produce plants that are used to make building materials, such as wood boards and insulation fibers. Many houses and other buildings have been built from soils or other natural materials or soil that was caked and dried into blocks in the past. Soil and wood are the oldest construction materials known to man, and they will most likely be the last. This is because the soil is the most readily available material, while timber can only be harvested by growing. Some buildings have been constructed with soil for over 4000 years. Man has learned how to use soil for building construction by trial and error, and this experience has been passed down through the years. Dependent on the forming phase, each soil has a different particle size and/or mineral composition. As a consequence, various properties arise that differentiate a soil's constructional abilities. There is a short discussion of soil forms and classification. The main mineral constituents of clays, as well as their properties, are discussed. The various soil properties that make the soil good building material are also discussed. Some soil property checks, such as consistency and compaction, are briefly clarified to classify soil properties. Specific compaction techniques for various soils are discussed. The amount of water in the soil plays an important role in its strength during compaction.

Biodegradable polymers have gotten a lot of attention recently, due to greater pressure on the world's resources and concerns about plastics disposal, which has sparked a lot of interest and commercial activity. (Yu et al., 2009) The use of fibers to develop soil performance on the engineering properties of soil mixtures has gained significance. (Harianto et al., 2009) Fiber or fibers are a kind of material with continuous filaments or isolated elongated fragments that are identical in length to thread. Fibers play a vital role in plant and animal biology by binding tissue together. They're also used in the processing of other products. Fibers may be spun into filaments, thread, or rope that can be used as a part of composite materials or matted into sheets to create items such as paper or felt. Fibers may be natural or synthetic, inorganic or organic. As opposed to natural fibers, synthetic fibers can be manufactured very cheaply and in large quantities. Natural synthetic fabrics such as rayon and nylon are organic. Burlap is a natural fiber made from coarse jute or hemp. Jute cloth is classified as hessian. Natural fabrics are used to make silk and cotton. Mineral fabrics include glass wool, lead wool, and asbestos, with glass wool and lead wool being synthetic. Steel fiber, carbon fiber, and glass fiber are modern and emerging building materials. Natural fibers can also be used as a reinforcement with soil to improve soil behavior.

Soil strengthening is a method for enhancing the engineering properties of soil. Using natural fibers to strengthen soil is an old and ancient concept in this sense. As a result, for the second time, uniformly scattered fiber-reinforced soils have drawn increased interest in geotechnical engineering. Using published research evidence, the key goal of this paper is to analyze the history, advantages, implementations, and potential executive issues of using various forms of natural and/or synthetic fibers in soil reinforcement. Often explored would be statistical models for short fiber soil composites. To put it another way, this paper would look at why, how, and when fibers have been used in soil reinforcement programs, as well as which fibers have been used.

Various fabrics have been used for soil by people all over the world during earth construction. One of the most common techniques for improving the soils of weak properties and providing a workable base for building projects is fiber stabilization of soil with natural fiber.

However, there are very few research studies in this area. Few studies on the use of natural fiber with soil to reinforce earthen structures. This study aims to look into the general properties of fiber stabilized soil using an unconfined compression test, direct shear test and so on.

1.2 Background History:

The principle of soil strengthening is an old technique that can be found in nature in the form of animals, birds, and tree roots. In the fifth and fourth centuries B.C., these tools were used to construct structures (Al Adili et al., 2012). This definition is used to develop a variety of soil properties such as bearing capacity, shear strength (ϕ), permeability, and so on. Vidal (1969) was the first to introduce this idea and theory, demonstrating that adding reinforcing elements to a soil mass raise the medium's shear resistance. At this time, soil stabilization is a well-established technique that is used in a variety of applications, including enhancing bearing capability, filtering, and drainage control. Continuous inclusions of strips, garments, and grids into the soil mass are traditional reinforcing methods. The use of various varieties of fibers at random is often called a variation of the same methodology. These fibers act as a unitary coherent matrix, interlocking particles and aggregates. There is no doubt that curing granular soils with specific short fiber type inclusions would enhance the strength of the soil while still modifying the material's deformation characteristics. (Diambra & Ibraim, 2015)

Bangladesh is a developing country. In Bangladesh, there are 32 million general and administrative households, with 26 million and 6 million households in rural and urban areas, respectively. With a population growth rate of 1.2%, Bangladesh needs new households every year to accommodate these additional residents. To build more houses, especially for low-income families, all locally available materials should be investigated. (Ghavami et al., 1999) Thousands of low-tech brick-making kilns, especially FCKs, have been developed across Bangladesh to supply these households with building materials, polluting the environment, harming crop production, and endangering human health. To fix these concerns and have better environmental and social benefits like sustainable and low-cost structure, this research project aimed to develop a low cost and natural way of soil stabilization process using locally available fibers.

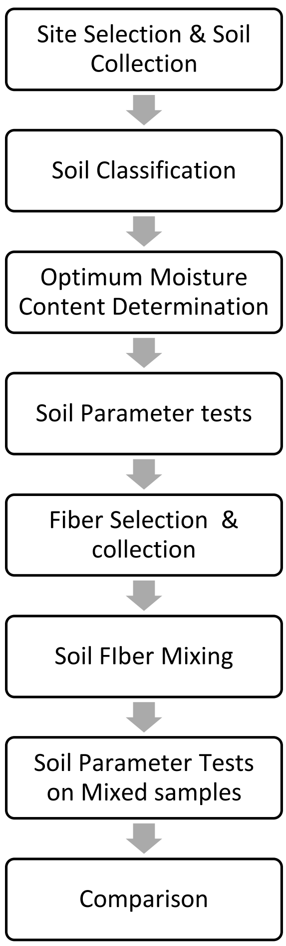
1.3 Objective:

The following are the key objectives of this research project:

- To determine the Compressive Strength of Clayey Sand Soil reinforced with randomly dispersed natural fibers
- To determine the Shear Strength parameter of Clayey Sand Soil reinforced with randomly dispersed natural fibers
- Comparison among coconut, betel nut & toddy palm fiber composite
- To determine the suitability of Arecaceae family fiber composites as compressed earth block (CEB)

1.4 Methodology:

The research was carried out in the following manner:



1.5 Research Plan:

The following is the breakdown of the entire research project:

a) Study of previous research for fibers as reinforcement for soil.

b) Executing soil identification and classification tests in the lab.

c) Studying the parameters of soil.

d) Examining the parameters of soil mixed with fibers.

e) Analyzing the test results and draw a comparison among soil and soil with different fibers.

In this context, Chapter 2 includes the use of soil in infrastructure all over the world and recent relevant researches on soil with fiber reinforcement. Also, the definition, classification, advantages, disadvantages and application of these composite materials are shown.

The experimental procedure is discussed in Chapter 3. The physical properties of each type of soil are described here. The preparation of specimens, the testing methodology, and the specification of test parameters are briefly discussed.

The results of the experiments are mentioned in Chapter 4. Figures, graphs, and tables are used to discuss the outcomes of the test parameters.

Regarding this study, Chapter 5 provides some recommendations. Finally, scopes for further research work are listed in the last portion. This is the concluding phase of this research project.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction:

Composite materials have been widely used in a variety of applications over the last few decades. Many different types of natural fibers have been studied with separate circumstances. Unlike other tropical countries, this practice has been developing in our country also. Access to a lot of natural fibers, different classes of fibers is being used profoundly. Most fibers are being used in the soil as a reinforcement to improve the soil parameters. The improvement of the soil interacts through friction and adhesion properties.

Natural fibers as their availability, low cost, and environmentally friendly quality suggest, more practicing civil engineers are inclined to use them as building a sustainable future.

This chapter describes how fibers work as composites, the application of these matrices in soil improvement, advantages & disadvantages also the practice of using the matrix in Bangladesh.

2.2 Fiber:

Fiber is a hair-like raw material. Amid in natural fibers are fibers that come from bio-based sources such as minerals, crops, and animals. (Singh Dhaliwal, 2020)

2.2.1 Constituents of fiber:

Lignin, cellulose, and hemicellulose are the three primary components of natural fibers. Each type of natural fiber has a different percentage of constituents.

Hemicellulose is bonded to cellulose fibrils by hydrogen bonds, possibly. Hemicellulose polymers are branched and completely amorphous, with such a molecular weight that is slightly lower than cellulose. Hemicellulose is partially soluble in water and hygroscopic due to its open structure containing several hydroxyls and acetyl groups.

Lignin is an amorphous, highly complex, mostly aromatic polymer of phenyl propane units with the lowest water absorption of the natural fiber components. Lignin has several functions in the plant fiber, including water holding capacity, shielding from biological attacks, and supporting the stem against wind and gravitational forces.

Hemicellulose, present in the fibers, is considered to blend lignin and cellulose.

Various factors, however, have quite a significant impact on the quality of natural fibers. Such as age of the plant, species, growing environment, harvesting, humidity, quality of soil, temperature, and processing steps. (Singh Dhaliwal, 2020)

2.2.2 Classification of fibers:

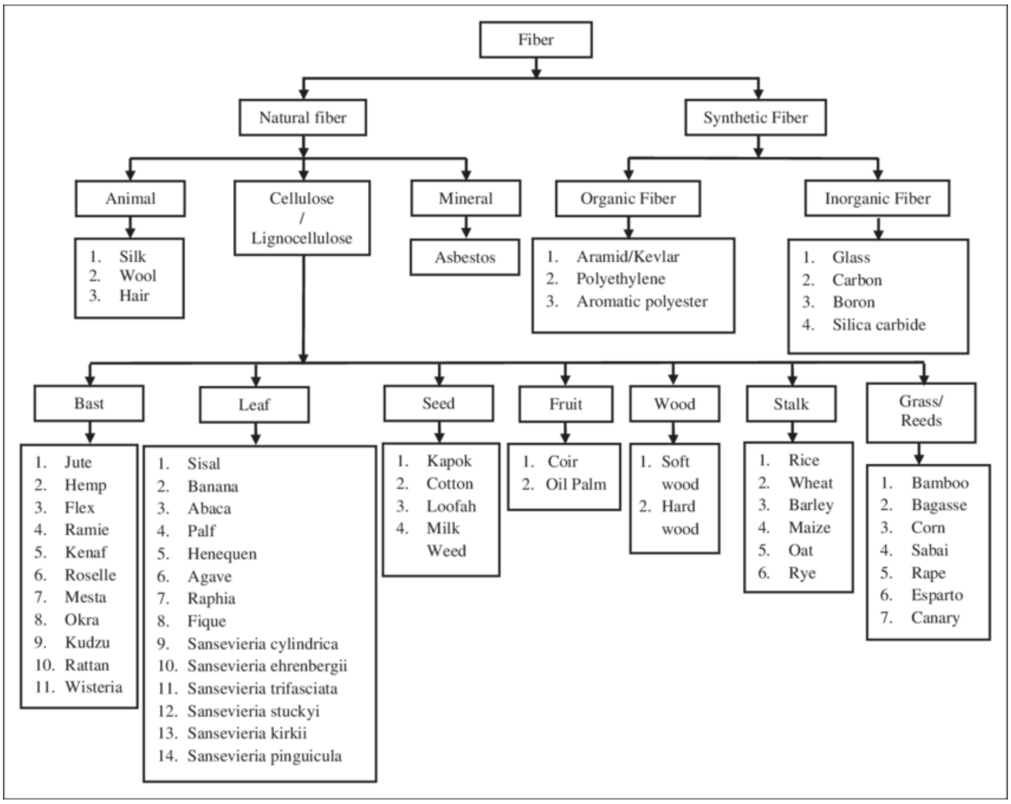


Figure 2.1 Classification of fibers

(Sathishkumar et al., 2014)

2.3 Composite Matrix:

Composites are materials that have reinforcement incorporated in weaker materials (known as a matrix). Reinforcement adds strength and rigidity to a structure, allowing it to withstand more load. The matrix or binder preserves the reinforcement in alignment, holds its orientation, and shifts external loads to the reinforcement. (Pujari, 2013)

The mechanical properties of processed composites are driven by the interfacial bonding between strengthening materials and matrices.

2.3.1 Classification of Composite Matrix:

Mostly on basis of the matrix material, composite materials can be categorized into three parts.

a. Polymer matrix composite (PMC),

b. Metal matrix composite (MMC)

c. Ceramic matrix composite (CMC)

(Kandan & Rajakumar, n.d.)

2.3.2 Applications of Composite Matrix:

Composites are utilized in a wide range of industries, such as the marine, aircraft, automobile, medical, sports, & chemical industries. Also in building construction and soil erosion control.

2.4 Application of Composite Material in Bangladesh:

From the point of socioeconomic view in Bangladesh recently these composites are being used in a wide range. These applications suit Bangladesh due to the availability of the constituents of the composites.

Already reinforcing soil with natural fibers like jute, straw, etc.

Composites are also being used in CEB (Compressed Earth Block) production to achieve a low-cost construction method. (Islam et al., 2008)

Fibers are recently being used to solve the problematic characteristic of clay soil and to improve certain soil parameters.

Properties of the soil-fiber composites vary with the parameters such as the orientation of fiber, strength of fiber, physical properties and interfacial adhesion properties.

2.5 Disadvantages of Soil-Fiber Composite:

Fiber reinforcement may improve the strength of the soil. But the possibility of disfigurement in contact with water is the main casualty. Due to a riverine country with slat terrain, Bangladesh is a flood-prone country.

To counter this measure soil-fiber composite can be used on higher surface with a plastic or bitumen coat.

2.6 Summary:

Due to weak strength in contact with water soil-fiber composites are neglected. These composites can be used not only in clay or cohesive soil but also cohesion less sandy soil.

With a larger percentage of lignin in fiber, the above-mentioned situation can be improved. Arecaceae class fibers have a large percentage of lignin in them and Bangladesh has a wide range of arecaceae family fibers.

CHAPTER THREE: METHODOLOGY

3.1: Introduction

This chapter gives an outline of the research methods that were followed in the study. The systematic process from selecting the location of soil to testing soil parameters with fiber mixed sample is discussed briefly in this chapter. Objective, standard guideline and procedure of the proposed methods are also included in brief. Due to limitations, there were some situations where standard guidelines were not followed thoroughly. So notes were attached there with explanations. The next figure illustrates the whole methodology in a nutshell.

3.2: Outline of Methodology

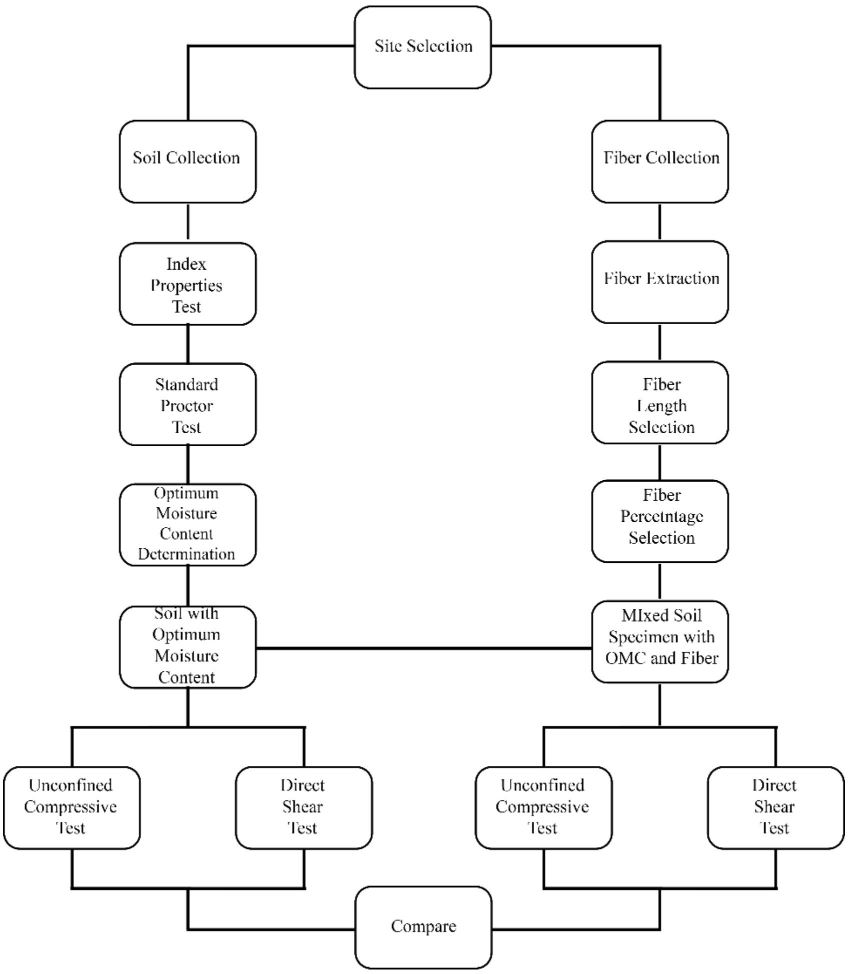


Figure 3.1 Outline of Methodology

Firstly, soil and fiber were collected from the selected site and transported and preserved in the nearby location of test laboratories. Then the index property test was done to classify soil within the Unified Soil Classification System (USCS).

After that, the Optimum Moisture Content (OMC) of the soil was determined with the Standard Proctor Test. Then soil parameters such as compressive strength, shear strength, cohesion and angle of friction were measured ensuring OMC water within the soil sample.

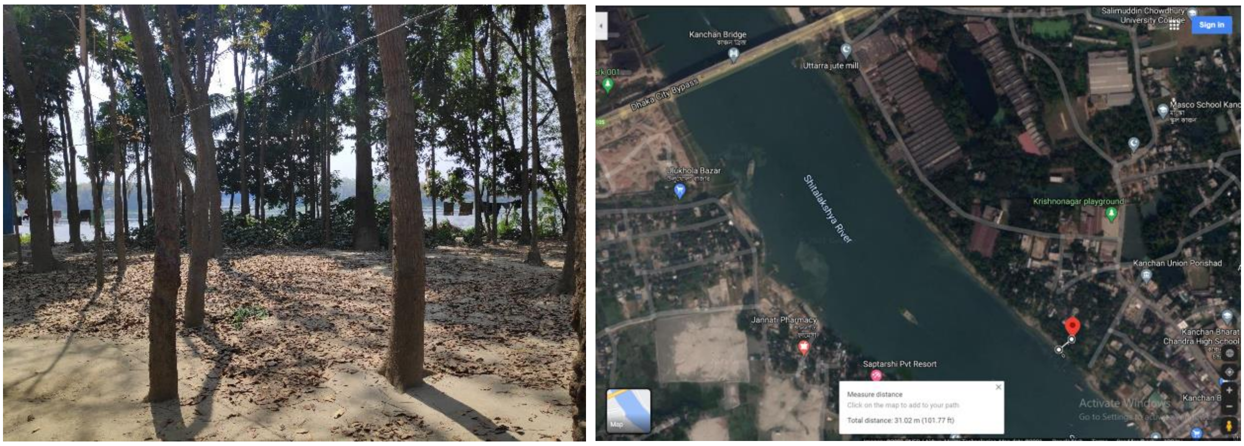
Later fiber mixed sample was prepared and similar soil parameters were determined to compare between plain soil and fiber-reinforced soil.

3.3 Selection of Site:

As there were several practices of building houses with mud Rupganj was the perfect location for the research area.

Coordinates of soil sample location:

Longitude: 23°49'52.9"N, Latitude: 90°33'07.0"E.



(a) (b)

Figure 3.2 (a) Site Location (b) Google Map of Site Location

The soil sample was excavated at Kanchan Porasava road, Rupganj near shitalakshya river at 2 ft depth using a shovel and digging rod.

Figure 3.2 Excavation Point

The soil sample was stored in cement bags. A total of 60 kg of sample was collected.

3.4 Field Identification Test:

Primary soil information is a general requirement that provides site-specific information. Soil or rock materials having similar index properties are likely to exhibit similar engineering behaviour. Simple tests are developed for the approximate identification of major soil components. These tests are known as identification tests.

3.4.1 Dry Strength Test:

It provides a basis for describing the strength as very low, low, medium, high, or very high. A clay fragment can be broken with great effort, whereas a silt fragment crushes easily. The higher the clay content, the higher would be the dry strength. We took some sample and after crushing we describe its strength as high strength.

Figure 3.3 Dry Strength Test

3.4.2 Dilatancy Test:

It describes the permeability as rapid, slow, or none. The higher the silt content, the lower would be the permeability characteristics. Some sample mixed with water was taken into the palm and shaken to observe permeability.

Figure 3.4 Dilatancy test

From the observation, we commented on slow permeability.

3.4.3 Toughness Test:

In this test, highly plastic clay can be rolled into a long thread, with a diameter of approximately 1/8" just before the crumbly state is reached. To understand the plasticity of our sample we undergo this test. For this test, we tried to roll the soil sample into a thread of approximately 1/8" diameter. But our sample failed to do so showing weak plasticity.

Figure 3.5 Toughness test

3.5 Index Properties Test:

3.5.1 Grain Size Distribution:

3.5.1.1: Sieve Analysis:

Grain size analysis is universally used in the engineering classification of soils. The three general procedure of analysis is sieve, hydrometer and combined analysis. A sieve analysis consists of shaking the soil through a stack of wire screens with openings of known sizes. The particle size distribution curve (gradation curve) is used to determine percentage contents of particle sizes necessary for the classification of soils, and to define the grading of the soil. 24 hr oven-dried sample passed through standard sieve size #4, #8, #16, #30, #50, #100 & #200 and tested as per the ASTM D422. Approximately 500 gram of the soil is used and shaken for a minimum of 30 minutes through the sieves to determine the gradation curve of the soil with D10, D30 & D60. For finer portion hydrometer analysis is used.

Figure 3.6 Sieve Analysis

3.5.1.2: Hydrometer Analysis:

Hydrometer analysis is based on Stokes law. According to this law, the velocity at which grains settles out of suspension, all other factors being equal, is dependent upon the shape, weight and size of the grain. In the case of soil, it is assumed that the soil particles are spherical and have the same specific gravity. There are two kinds of hydrometers to work with.

The 151h hydrometer reads the specific gravity of the suspension and has a capacity of about 45g of dry soil in the 1,000 mL liquid solution.

The 152h hydrometer measures the grams per liter of the suspension with a capacity of up to 55g of dry soil in the 1,000 mL liquid solution.

Approximately 50 gram of oven-dried soil is tested in an ASTM 152H hydrometer and readings are taken after 0.25 min, 0.5 min, 1 min, 2 min, 4 min, 8 min, 15 min, 30 min, 1 hr, 2 hrs, 4 hrs, 8 hrs, and 1 day, 2 days, 3 days. Correction to hydrometer reading such as zero correction, meniscus correction and temperature correction were measured accordingly.

Figure 3.7 Hydrometer Analysis

3.5.2 Determination of Specific Gravity of Soil:

The specific gravity of soil is the ratio of the weight in air of a given volume of particles to the weight in air of an equal volume of distilled water at a temperature of 4°C. With the help of a pycnometer, 25 gram of oven-dried soil was tested for specific gravity. Measures have taken seriously to get rid of trapped air inside of the pycnometer.

Figure 3.8 Specific Gravity test

3.5.3 Atterberg Limit Test:

When water is added to soil, the increase or decrease in the amount of water can alternate properties like liquid limit and plastic limit which is directly involved with the plasticity of the soil. According to ASTM D4318 and using Casagrande apparatus we determined liquid limit, plastic limit, plasticity index, flow index and toughness index.

Figure 3.9 Atterberg Limit Test

3.6 Standard Proctor Test:

The Standard Proctor test is a laboratory method to determine the optimal moisture content (OMC) at which a given soil type will achieve its maximum dry density.

4 sets of the test were conducted to find out the optimum moisture content and maximum dry unit weight of soil. Each set required 3 kg of oven-dried soil passed through the no #4 sieve. Each time a different amount of water was used. The exact percentage of water was calculated with the dry soil after the test. 4.5-inch dia mold was filled with soil and compacted in 3 layers and each layer with 25 blows. The weight of the wet sample and the volume of mold was measured for calculation.

Figure 3.10 Soil Sample with water

Figure 3.11 Filling up the soil in Compaction Instrument

Figure 3.12 Compaction Process

Figure 3.13 Compacted Mold

3.7 Soil Sample preparation with Optimum Water Content:

From the previous test after deducing optimum moisture content, extra water was added to attain OMC and mixed thoroughly.

Figure 3.14 Soil Sample preparation with Optimum Water Content

3.8 Unconfined Compressive Strength Test:

The Unconfined Compressive Strength Test (UCS) test is widely used for its economical reason. This test uses soil samples without any lateral confinement. As our soil was clayey sand, we were able to make a sample for the UCS test with our soil.

Soil sample with OMC was prepared and filled up within e 4inch diameter mold. After compaction, the soil sample was reshaped to 38mm dia to undergo the test. The soil sample was placed under the machine with its vertical axis and compressed. Ring dial and vertical deformation dial was measured and collected for stress vs strain curve.

The calibration factor of the UCS machine is: y=0.883x-13.1302

Figure 3.15 UCS Test Procedure

Figure 3.16 Failure Surface after UCS Test

3.8 Direct Shear Test:

Shear strength is to describe the magnitude of the shear stress that a soil can stand. The shear strength of soil is a consequence of friction and the interlocking of grains within the soil.

Ensuring OMC in the soil the soil sample was placed in a circular VJ Tech shear box. With 3 different normal loadings, each sample was consisting of 3 sets with loadings of 3, 6 and 12 kg. (104, 208 & 416 in KPa respectively.)

The diameter of the shear box was 60 mm and the average height of the soil sample was 20 mm.

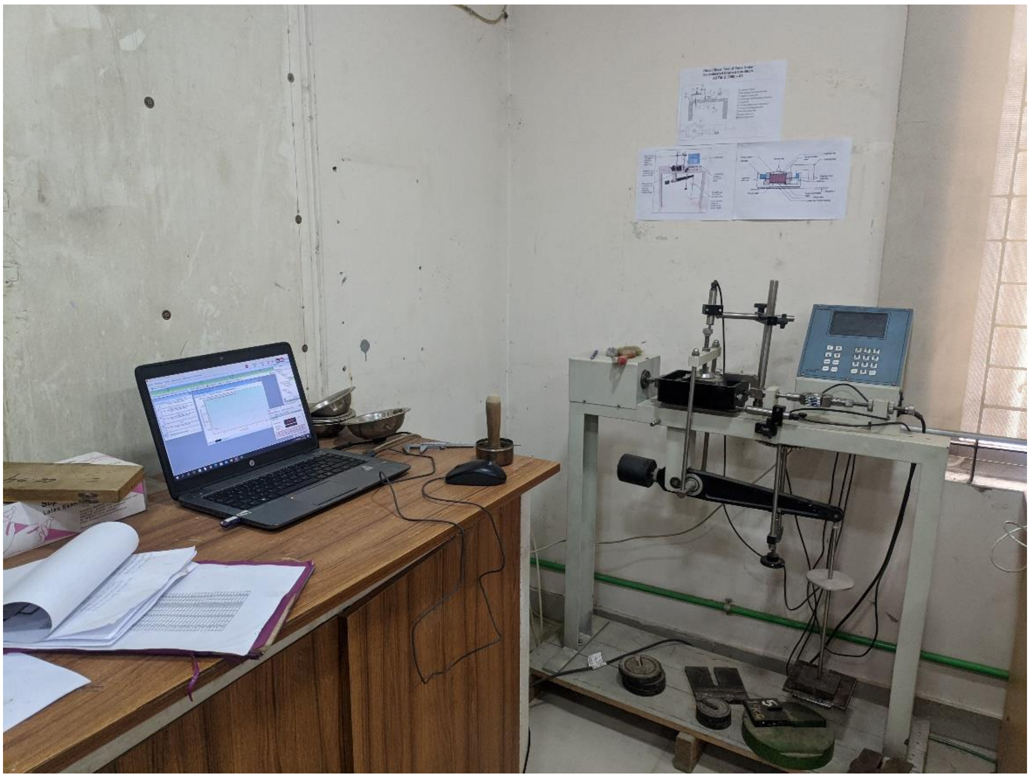


Figure 3.17 Direct Shear Test apparatus

Figure 3.18 Direct Shear Test Procedure

3.9 Fiber Collection and Extraction:

3.9.1 Fiber Class Selection:

From different classes of fiber initially, the fruit class was selected. In Bangladesh, fruits are ubiquitous all over the season and generally are thrown away here and there and eventually they degrade to the soil.

3.9.1 Fiber Family Selection:

Lignin, cellulose and hemicellulose are the three main constituents of a fiber. Amongst lignin aids a fiber to hold more water and also to strengthen the stem against forces like wind and gravity. More the amount of lignin the more its water holding extent and strength. (Singh Dhaliwal, 2020)

Thus locally available fruits (coconut, betel nut, *palm*) of the Arecaceae family were picked. Coconut, betel nut, *palm* have a higher amount of lignin in them.

	Lignin (%)	**Cellulose (%)**	**Hemi-cellulose (%)**
Coconut (Sangian & Widjaja, 2018)	41.18%	26.60%	17.74%
Betel Nut (Yusriah et al., 2012)	7.20%	53.20%	32.98%
Toddy Palm (*Palm*) (Graupner et al., 2019)	17.0-21.5%	45.7-53.4%	29.6-32.8%

Table 3.1 Constituents of Coconut, Betel Nut & Toddy Palm fiber

Later we sun-dried and extorted fibers from the fruits.

Figure 3.19 Coconut Fiber

Figure 3.20 Betel Nut fiber

Figure 3.21 Toddy Palm Fiber

3.9 Fiber Length Selection:

To compare the same length characteristic, we have used same length of all the fibers. Due to being the shortest fiber, we have set every fiber length the same as betel nut fiber.

Figure 3.22 Selected Fiber Length

3.9 Fiber Percentage Selection:

0.5 and 1% of the dry weight of the soil sample were taken as fiber weight. For any test, the weight of the used dry soil sample was measured and then 0.5 and 1% weighted fiber was mixed.

3.10 Mixed Soil Specimen:

0.5 and 1% weight of dry wet of the soil as fiber weight, OMC of water and soil itself was mixed suitably to conduct further tests.

Figure 3.23 Soil, Water & Fiber mixing

3.11 UCS Test of Mixed Soil Specimen:

The mixed specimen was compacted to a 4.5-inch dia mould but failed to reshape to a 38 mm dia specimen. As a result, the mixed specimen was directly compacted in a 38 mm dia mould then subjected to UCS test.

Figure 3.24 Failed Standard Procedure of UCS Test

Figure 3.25 UCS Test Procedure of Fiber-reinforced soil

3.12 Direct Shear Test of Mixed Soil Specimen:

The mixed specimen was tested for shear strength in VJ Tech Shear Box subjected to 3 different normal loadings. Loadings were 3, 6 and 12 kg (104, 208 & 416 KPa respectively)

Figure 3.26 Direct Shear test procedure of fiber-reinforced soil

3.13 Summary:

This chapter mainly describes the experimental program. The location of soil and fiber, index properties of soil have been presented. The fibers used in preparing the specimens are also described briefly. Later UCS and Direct Shear Test were depicted to determine different soil parameter.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Introduction:

The main resolution of this study is not only to investigate the soil parameters after reinforcing with fibers but also to compare between them. The index properties test of soil was done to know the USCS classification of the soil. Standard Proctor test was concducted to determine the maximum dry unit weight and optimum moister content (OMC). Different percentages of fiber were mixed with soil to examine the soil parameters like compressive strength, shear strength, cohesion, angle of friction and to compare between them.

4.2 Identification of Soil Sample:

For identification of soil sample Specific gravity test, Atterberg limit test and Grain size analysis test were performed.

4.2.1 Specific Gravity:

This test was performed with oven-dried soil. By experimenting several times the specific gravity of the soil sample was found at 2.55.

4.2.2 Atterberg Limit Test:

The plastic limit test and Liquid limit test was performed. These tests are performed using an oven-dried powder soil sample.

4.2.2.1 Liquid Limit Test:

From moisture content vs the number of blows measured liquid limit of the soil sample was found 36.64% It is the moisture content regarding 25 blows.

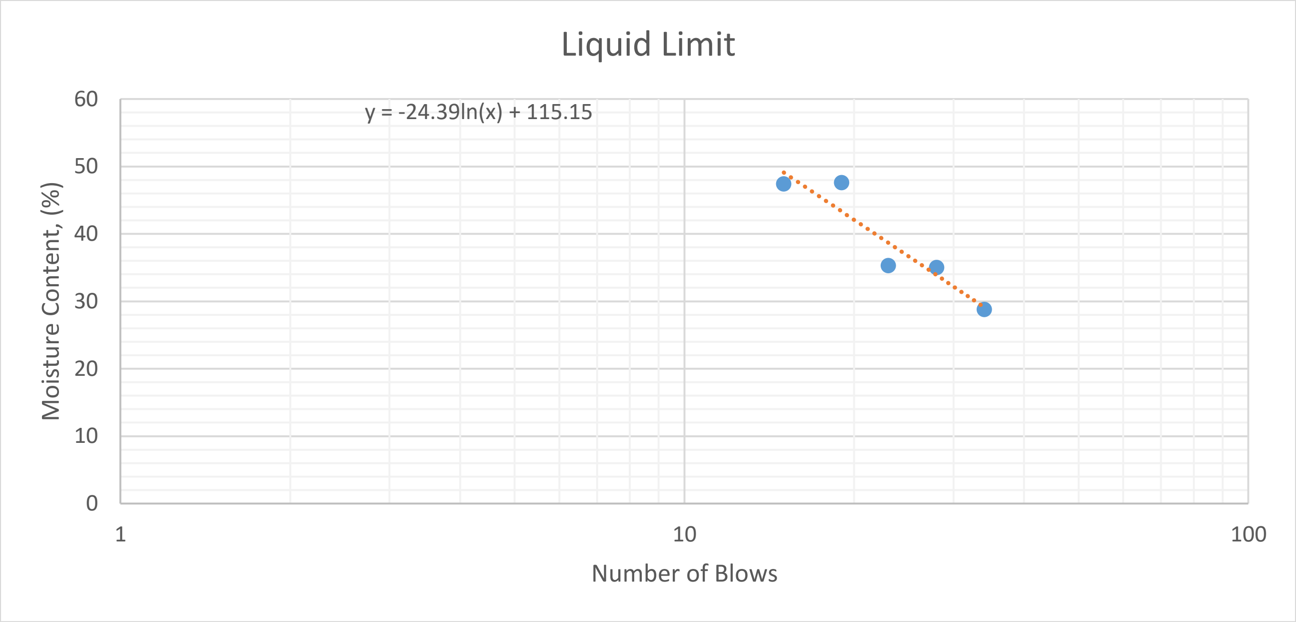


Figure 4.1 Liquid Limit

4.2.2.2 Plastic Limit Test:

Three different containers were used to take three different weight of soil and the calculated average number was determined as the plastic limit of the soil.

The plastic limit of the soil was 24.63%

Sample Location	Parameters	Value	Comment
Rupganj, Narayanganj	Specific Gravity	2.55	Halloysite
	Liquid Limit	36.64%	Kaolinite
	Plastic Limit	24.63%	Kaolinite
	Plasticity Index	12.01	Medium plasticity
	Toughness Index	-0.02	Friable

Table 4.1 Physical Properties of Soil Sample

4.2.3 Grain Size Analysis of the soil sample:

As there were finer particles both combined sieve analysis and hydrometer test was performed for determining the properties of the soil sample.

Result					
%gravel	8.41%	D60	1.058	Cu	165.70
%sand	77.89%	D30	0.149	CC	3.28
%fine	13.70%	D10	0.006		

Figure 4.2 Sieve Analysis results

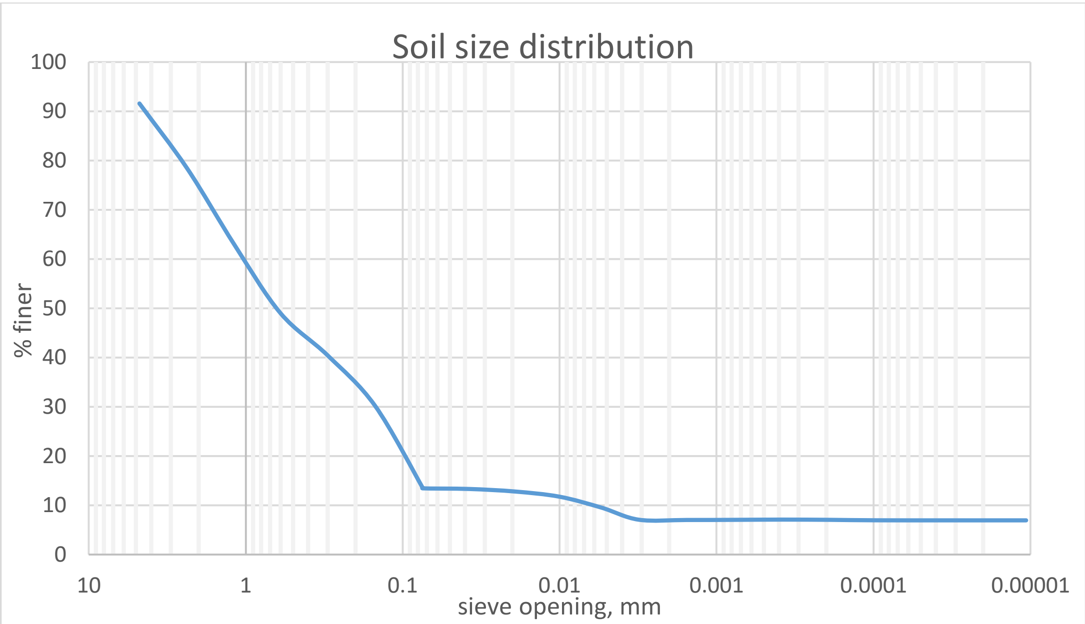


Figure 4.3 Soil Gradation Curve

Unified Soil Classification System (Based on Material Passing 76.2-mm Sieve)

Criteria for assigning group symbols				Group symbol
Coarse-grained soils More than 50% of retained on No.200 sieve	**Gravels** More than 50% of coarse fraction retained on No.4 sieve	Clean gravels Less than 5% fines	$C_u \geq 4$ and $1 \leq C_c \leq 3$	GW
			$C_u < 4$ and/or $1 > C_c > 3$	GP
		Gravels with Fines More than 12% fines	$I_p < 4$ or plots below "A" line	GM
			$I_p > 7$ or plots on or above "A" line	GC
	Sands 50% or more of coarse fraction passes No.4 sieve	Clean sands Less than 5% fines	$C_u \geq 6$ and $1 \leq C_c \leq 3$	SW
			$C_u < 6$ and/or $1 > C_c > 3$	SP
		Sands with Fines More than 12% fines	$I_p < 4$ or plots below "A" line	SM
			$I_p > 7$ or plots on or above "A" line	SC
Fine-grained soils 50% or more passes No.200 sieve	**Silts and clays** Liquid limit less than 50	Inorganic	$I_p > 7$ or plots on or above "A" line	CL
			$I_p < 4$ or plots below "A" line	ML
		Organic	$\frac{\text{Liquid limit (oven dried)}}{\text{Liquid limit (not dried)}} < 0.75$	OL
	Silts and Clays Liquid limit 50 or more	Inorganic	I_p plots on or above "A" line	CH
			I_p plots below "A" line	MH
		Organic	$\frac{\text{Liquid limit (oven dried)}}{\text{Liquid limit (not dried)}} < 0.75$	OH
Highly Organic Soils	Primarily organic matter, dark in color, and organic odor			Pt

Gravels with 5 to 12% fine require dual symbols: GW-GM, GW-GC, GP-GM, GP-GC.
Sands with 5 to 12% fines require dual symbols: SW-SM, SW-SC, SP-SM, SP-SC.

GW → well graded gravel
GP → poorly graded gravel
GM → silty gravel
GC → clayey gravel

SW → well graded sand
SP → poorly graded sand
SM → silty sand
SC → clayey sand

CL → clay with low plasticity or compressibility
ML → silt with low plasticity or compressibility
OH → organic soil with high compressibility
OL → organic soil with low compressibility

Figure 4.4 USCS Classification System

From the USCS Classification System, we can state that our soil sample is Clayey Sand

4.3 Standard Proctor Test:

From the 4 tests and plotting the values in the graph, we found the dry unit weight of 18.89 KN/m^3 and optimum moisture content of 17.5%

Afterwards, all soil samples were made with 17.5% water of the weight of dry soil.

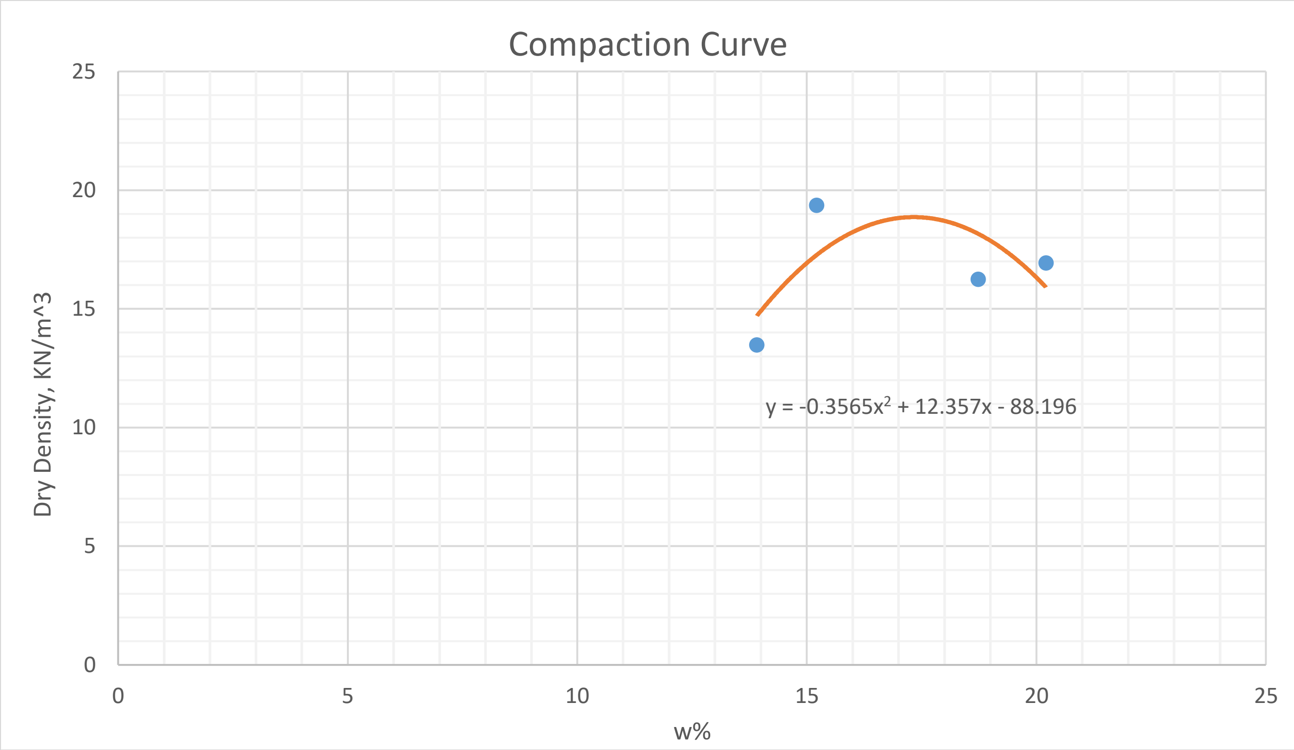


Figure 4.5 Compaction Curve

4.4 Unconfined Compressive Test of the Soil (without fiber):

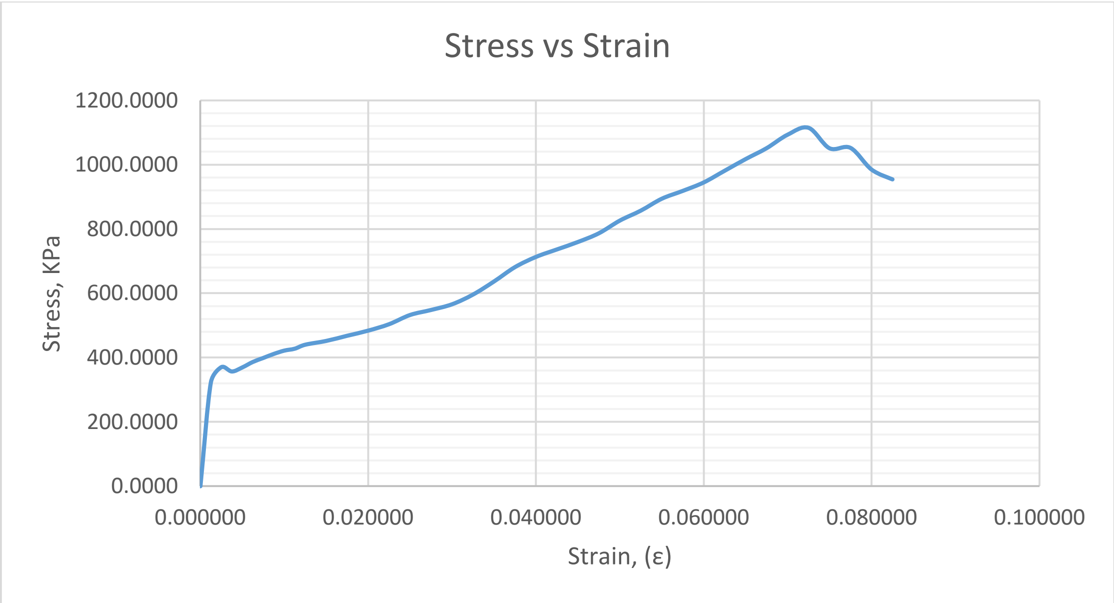


Figure 4.6 Stress vs Strain Curve

Maximum compressive strength: 1120 KPa

Strain: 0.72

4.5 Direct Shear Test of the Soil (without fiber):

104, 208 & 416 KPa of normal loadings are used to conduct the shear test.

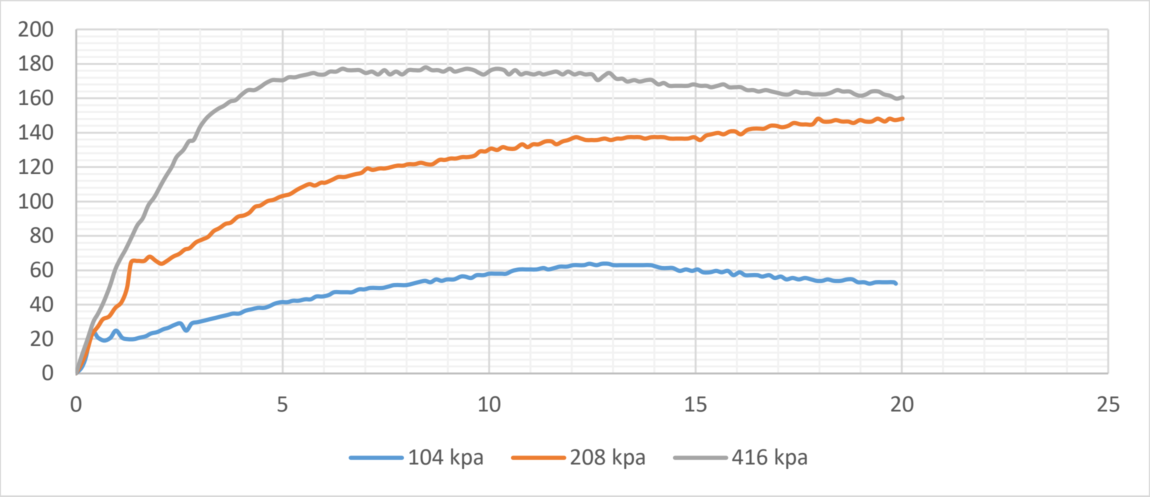


Figure 4.7 Shear Stress vs Shear strain curve

S=C+tanφ was developed from ultimate shear stress and normal shear stress.

Where, S= shear stress, C= cohesion, φ= angle of friction

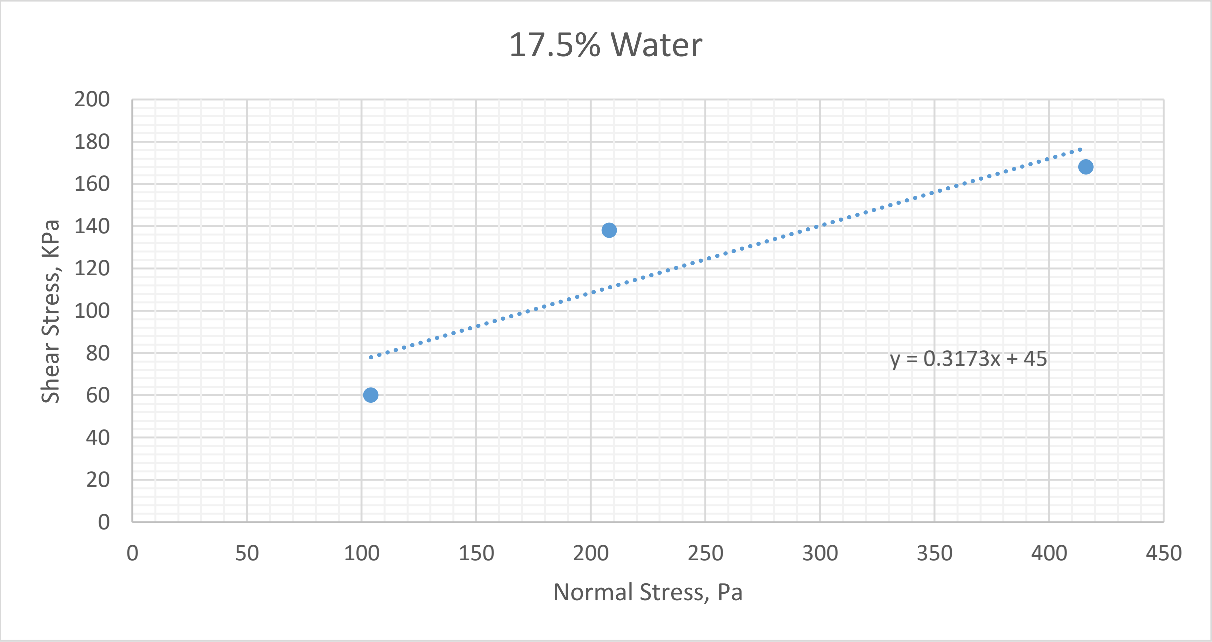


Figure 4.8 Shear Stress vs Normal Stress Curve

C=45 & φ=17.6° were found. From the angle of friction, this soil is in a loose state.

4.6 Unconfined Compressive Test of the Soil (with fibers):

Compressive stress vs strain graph for each fibers with two different percentages are included below.

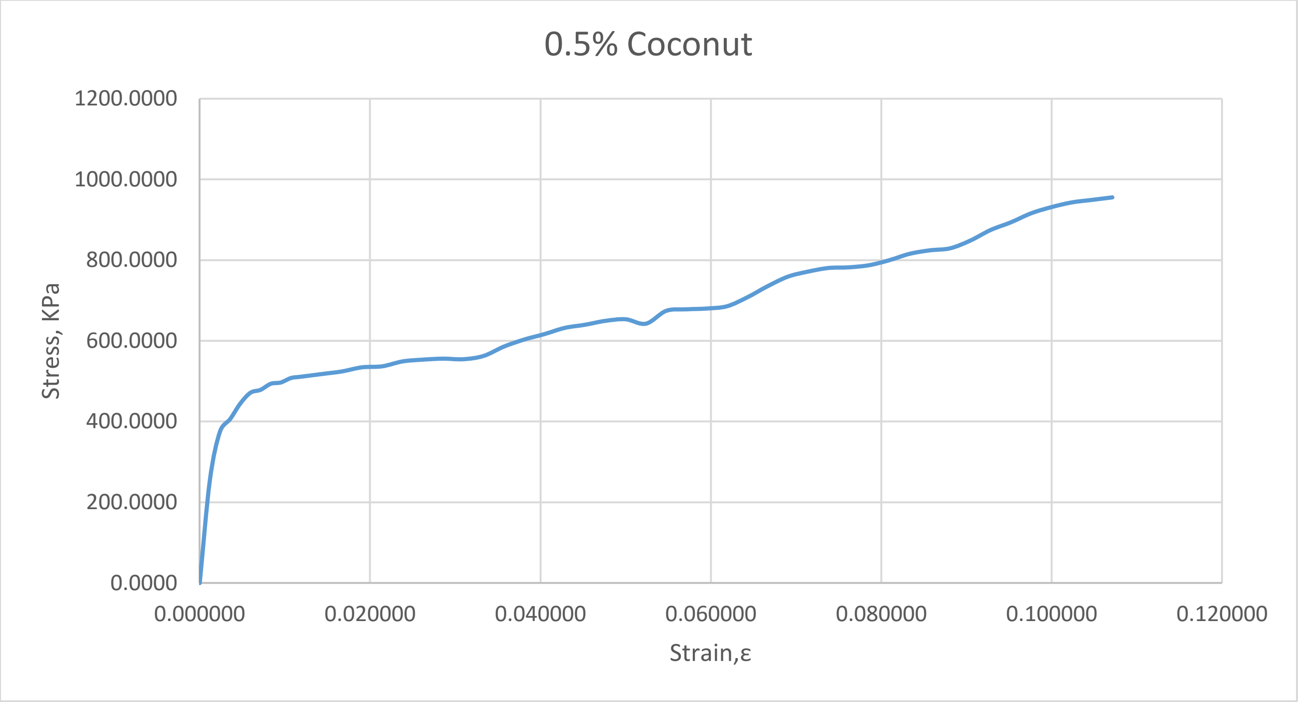


Figure 4.9 Stress vs Strain Curve of 0.5% Coconut fiber

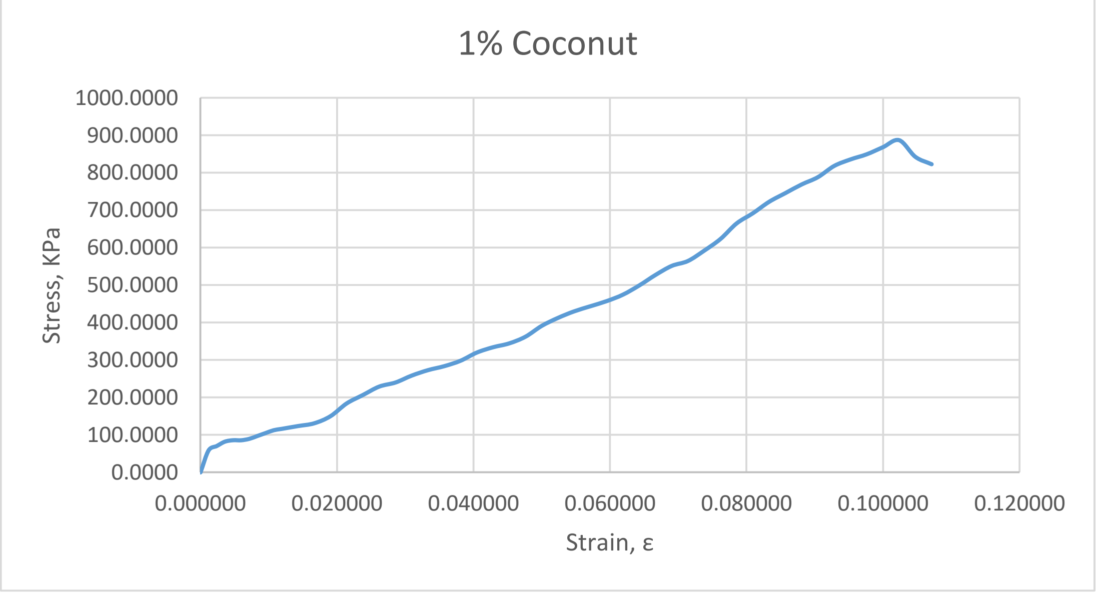


Figure 4.10 Stress vs Strain Curve of 1% of Coconut fiber

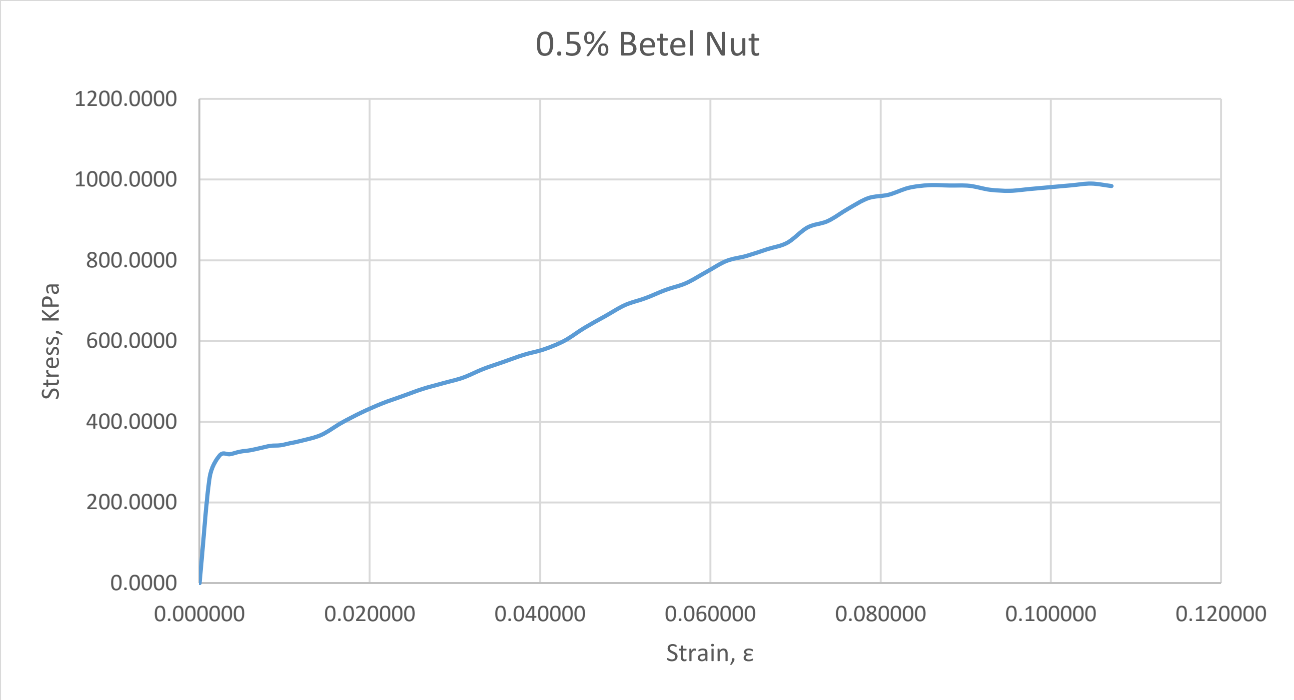


Figure 4.11 Stress vs Strain Curve of 0.5% Betel nut fiber

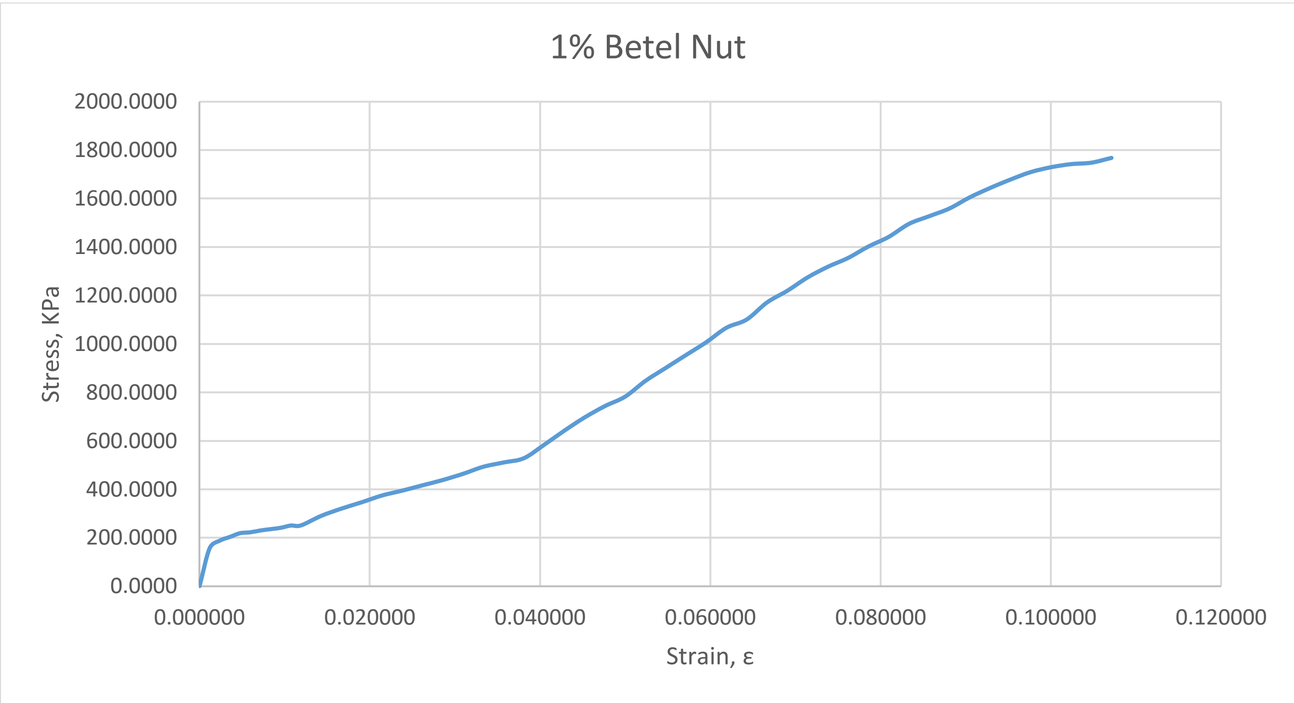


Figure 4.12 Stress vs Strain Curve of 1% betel nut fiber

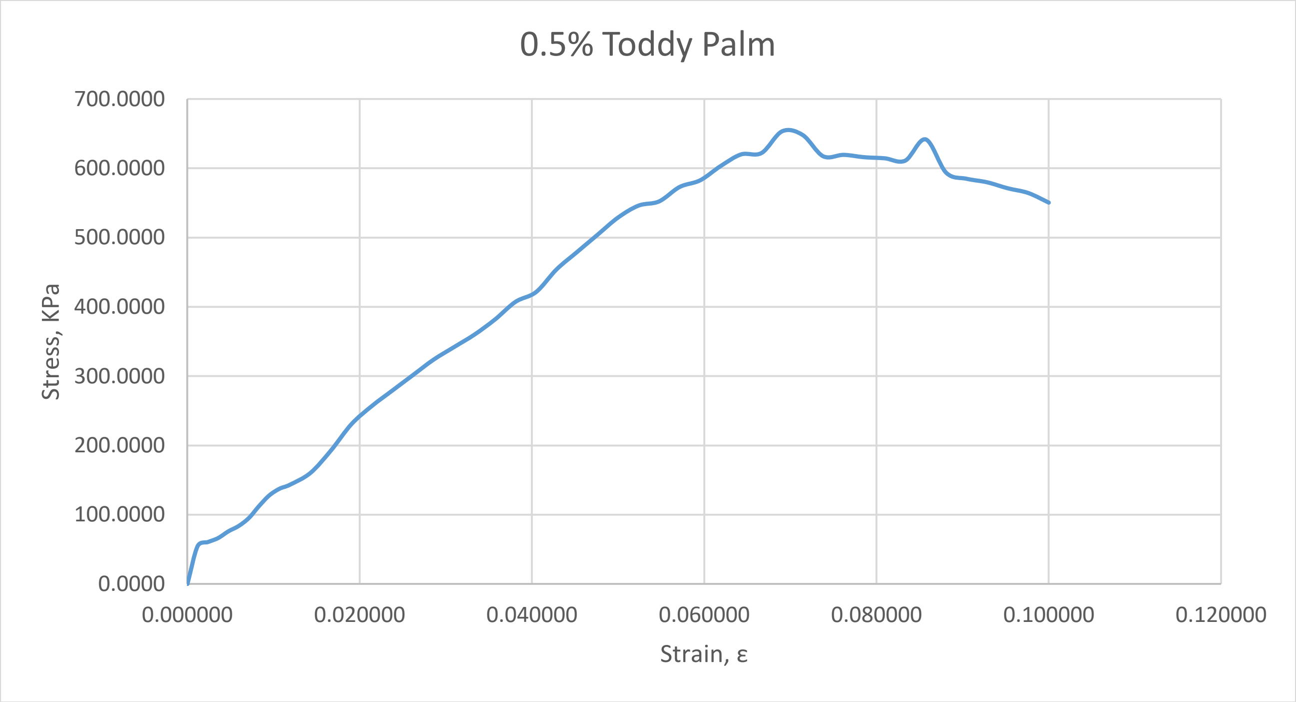


Figure 4.13 Stress vs Strain Curve of 0.5% Toddy Palm fiber

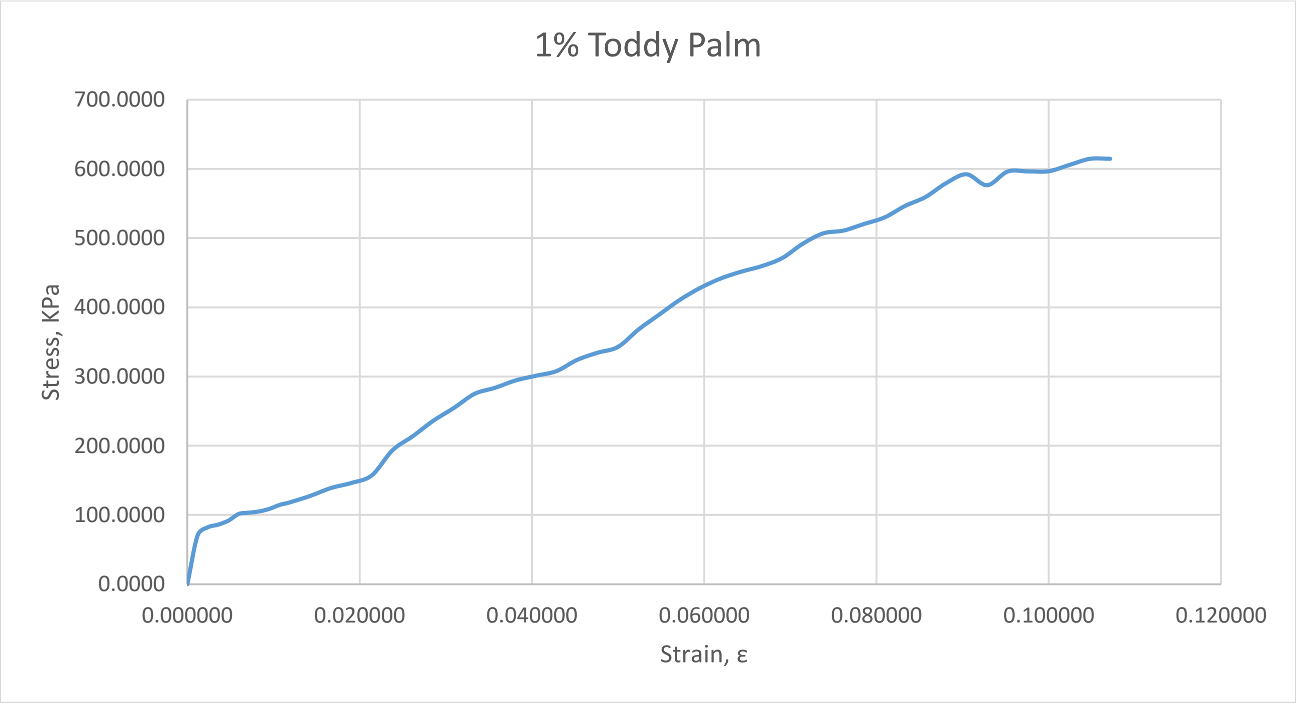


Figure 4.14 Stress vs Strain Curve of 1% Toddy Palm fiber

Here we can see that soil with no fiber failed at higher stress but with less deformation. Whereas fiber reinforced soil samples sustained higher stress in some cases but took larger deformation than soil with no fiber. Some of the soil samples did not collapse entirely.

Reinforcing with fiber changes its behavior from brittle to ductile.

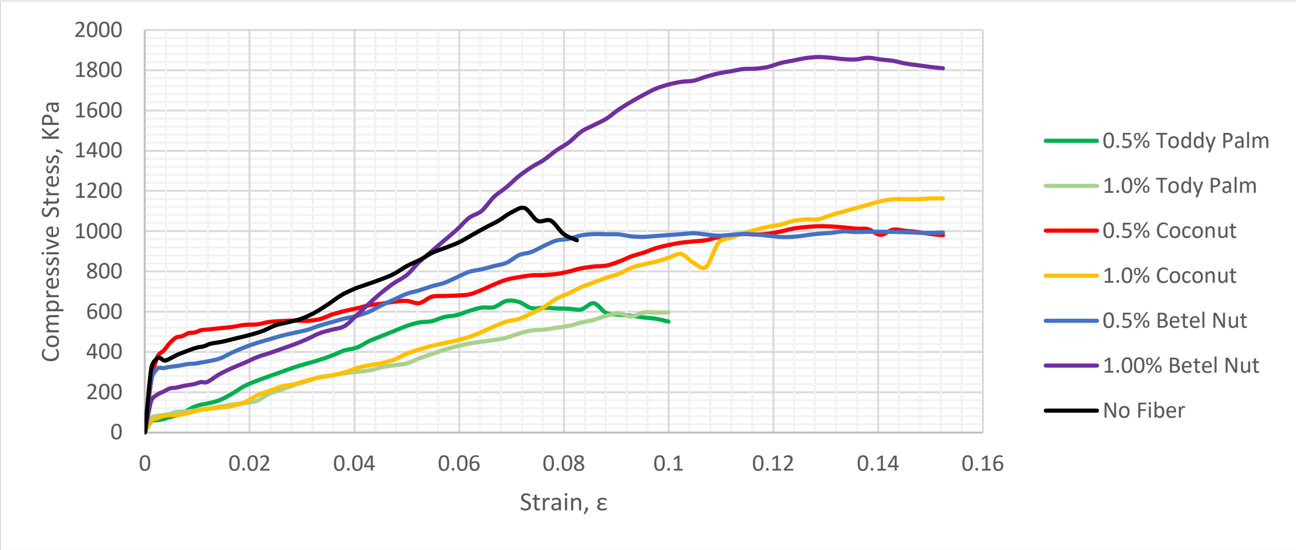


Figure 4.15 Comparison of Stress vs Strain curve among soil with fiber and soil with different fibers

Also, their failure pattern shows that soil with no fiber failed with a steep shear plane and fiber-reinforced soil dominated shear plane failure and deformed to barrel size.

Figure 4.16 Failure Pattern of Soil with no fiber

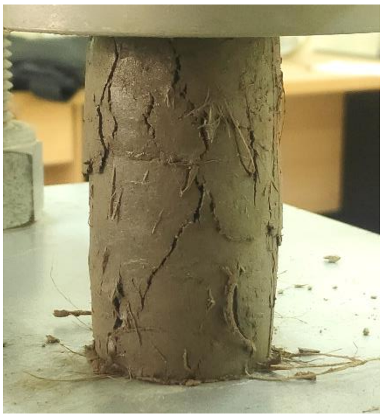


Figure 4.17 Failure Pattern of Soil with 0.5% Coconut

Figure 4.18 Failure Pattern of Soil with 1% Coconut

Figure 4.19 Failure Pattern of Soil with 0.5% Betel nut

Figure 4.20 Failure Pattern of Soil with 1% betel nut

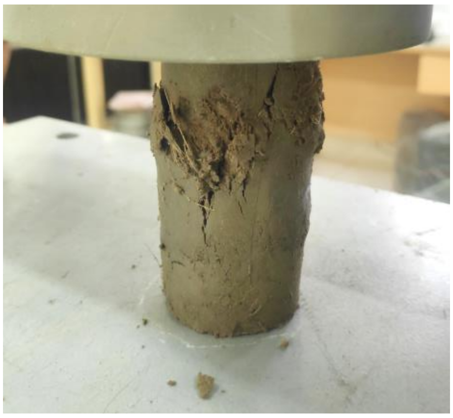


Figure 4.21 Failure Pattern of Soil with 0.5% Toddy palm

Figure 4.22 Failure Pattern of Soil with 1% Toddy Palm

4.7 Direct Shear Test of the Soil (with fibers):

For 3 different normal loadings, these shear stress graphs are given below.

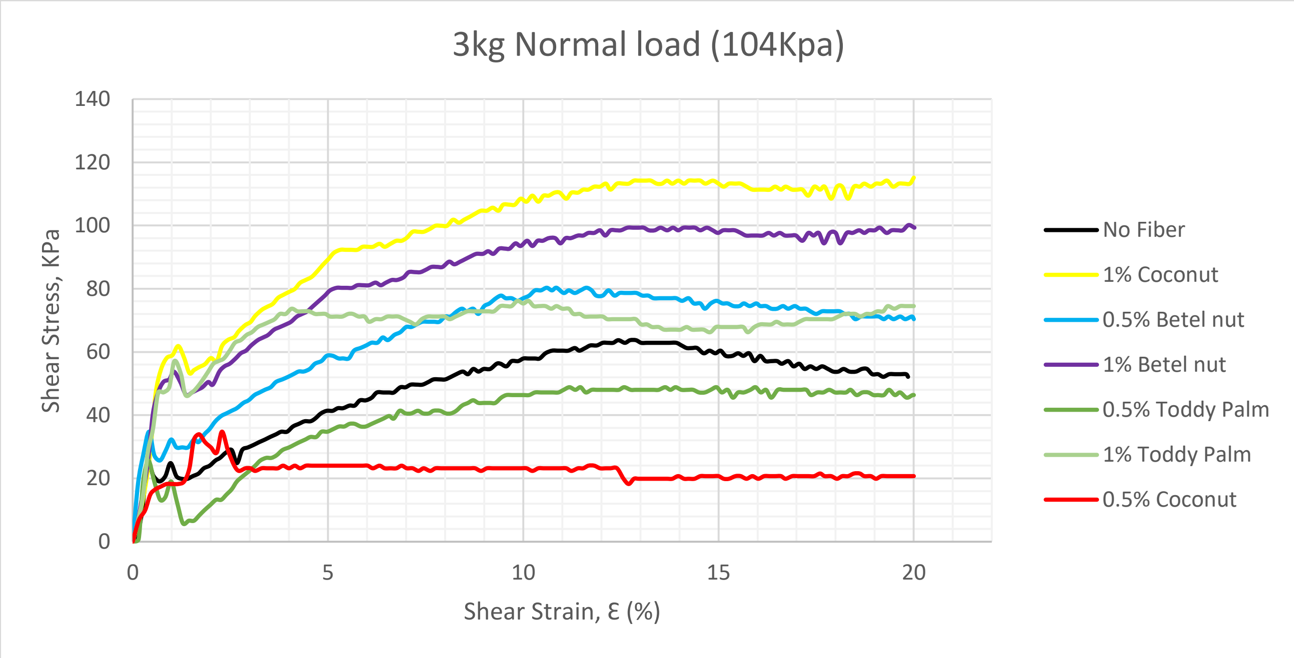


Figure 4.23 Shear Stress vs Shear Strain of 104 Kpa

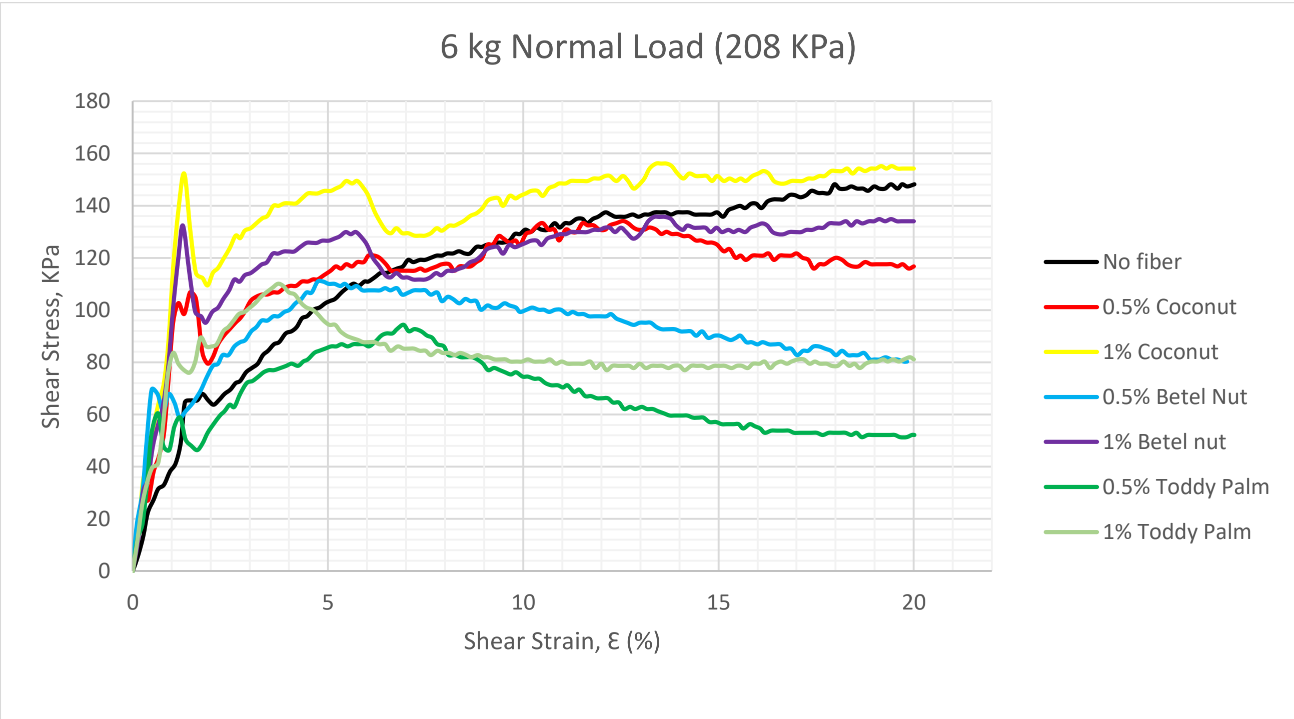


Figure 4.24Shear Stress vs Shear Strain of 208 Kpa

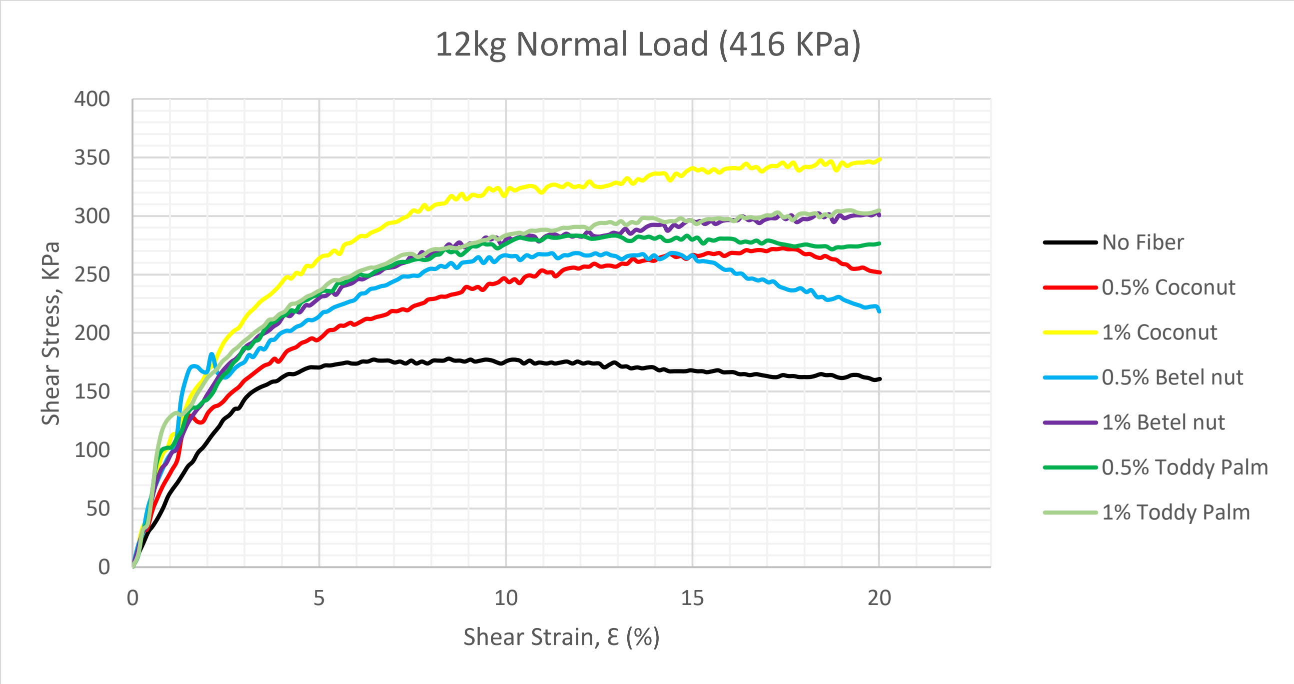


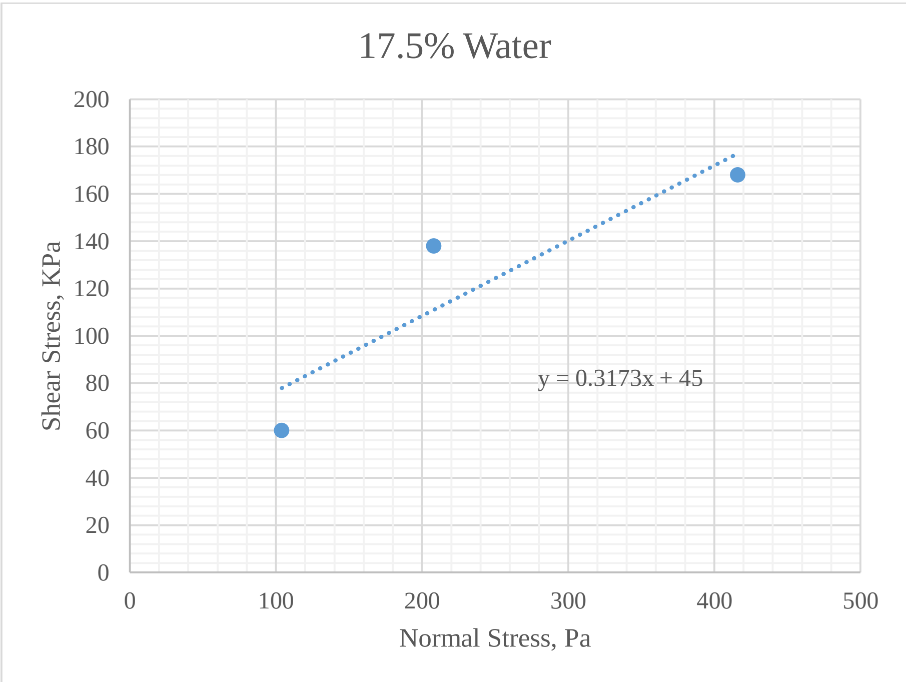
Figure 4.25 Shear Stress vs Shear Strain of 416 KPa

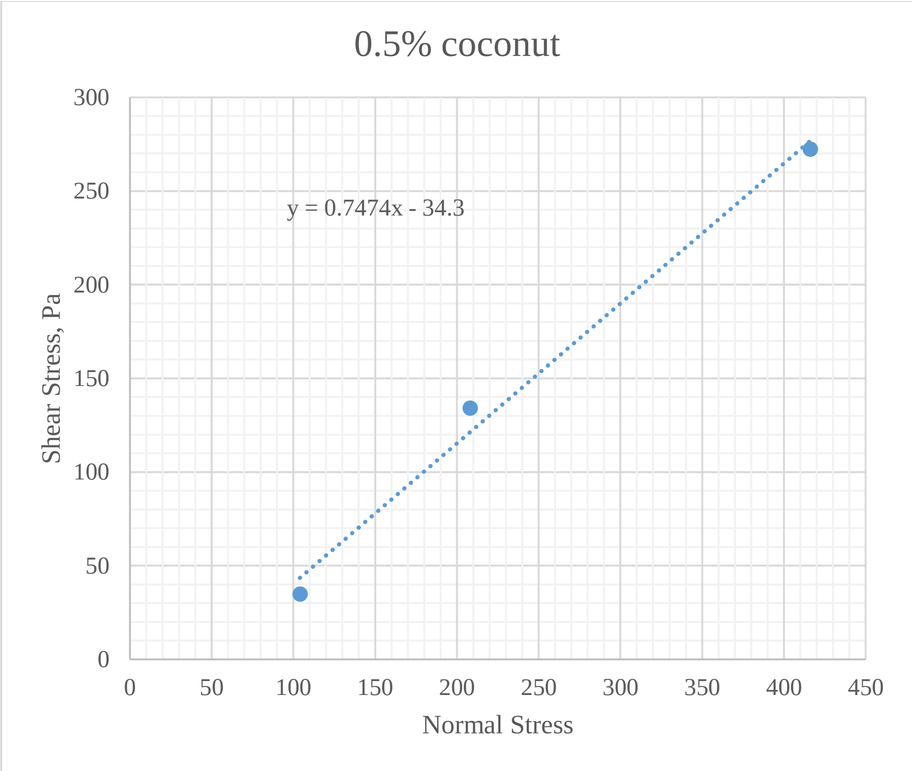
The graphs indicate the quick shear failure of soil without fiber. But fiber reinforced soil obtained increased shear strength. For 3 and 6 kg normal load, soil with no fiber withstands more shear strength than some of the fiber-reinforced soil. As loadings increased soil with no fiber failed due to its brittleness.

We also tabulated their c and phi values from the direct shear test.

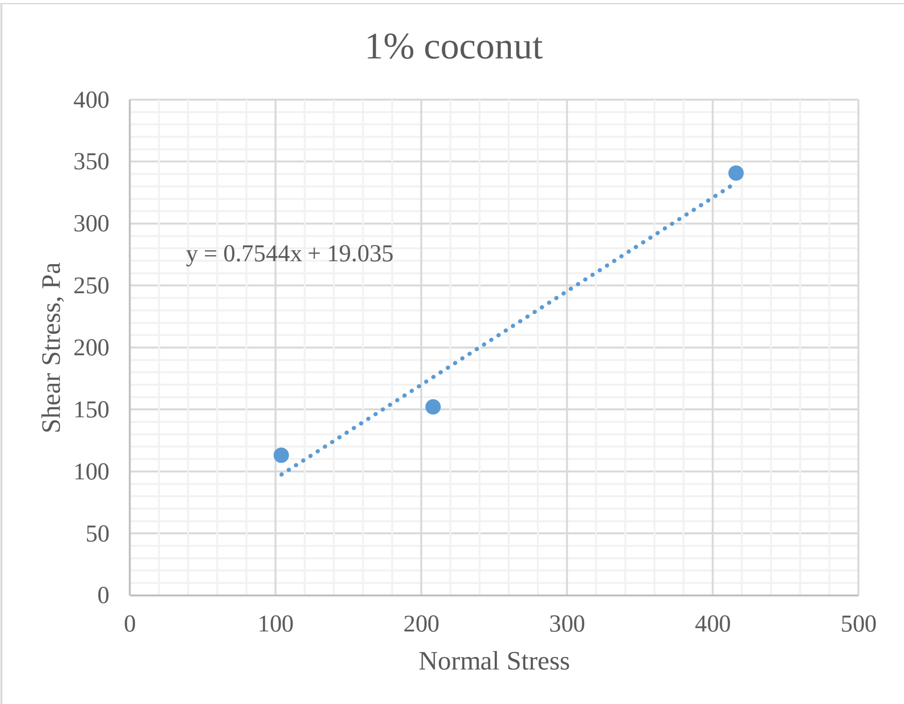
Soil sample (17.5% water)	C	Φ (degree)
No Fiber	45	17.6
0.5% Coconut Fiber	0	36.77
1.0% Coconut Fiber	19.04	37.03
0.5% Betel nut Fiber	1.65	31.97
1.0% Betel nut Fiber	16.6	33.89
0.5% Toddy Palm Fiber	0	37.71
1.0% Toddy Palm Fiber	0	37.21

Table 4.2 Direct Shear Test Result

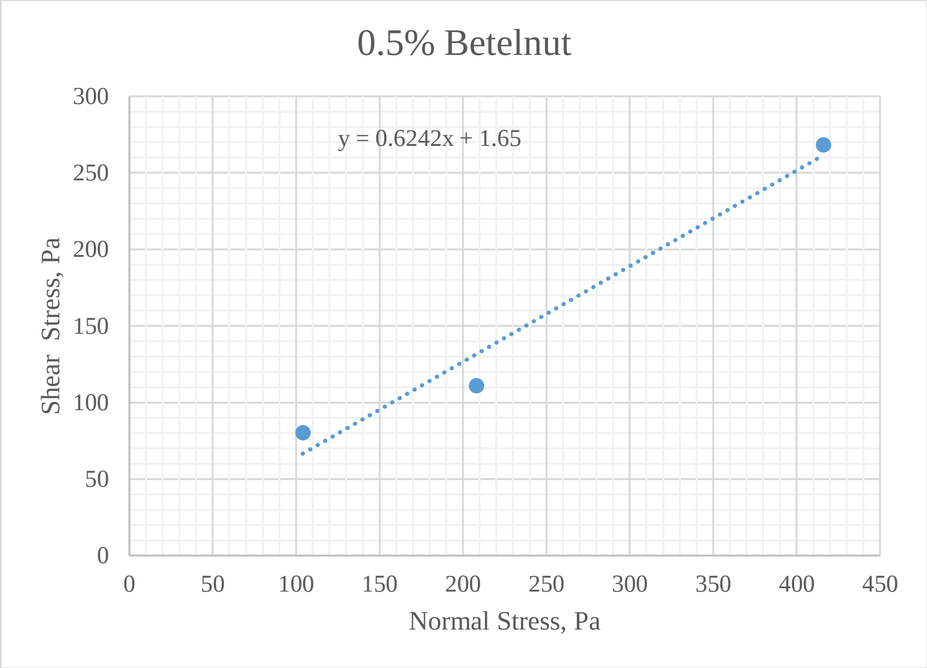


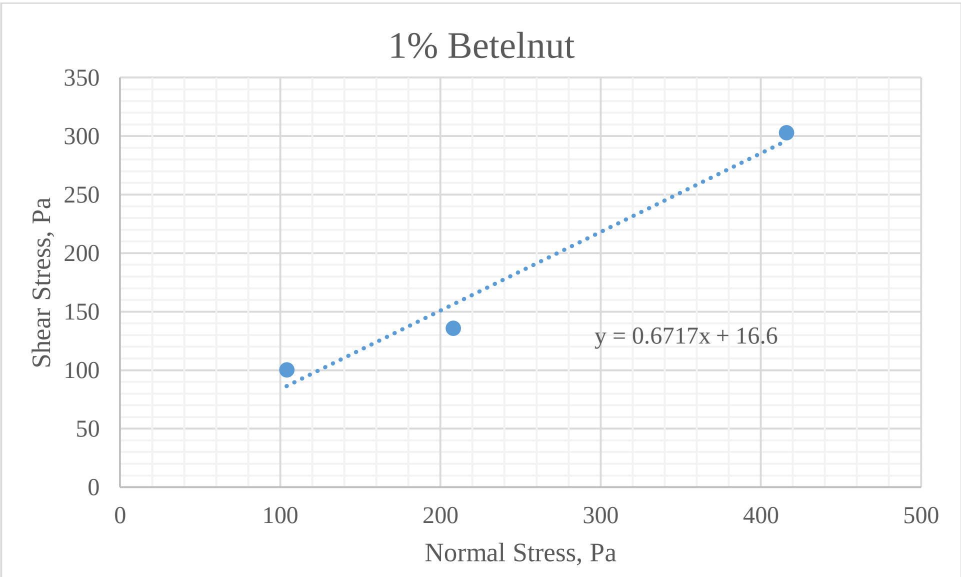


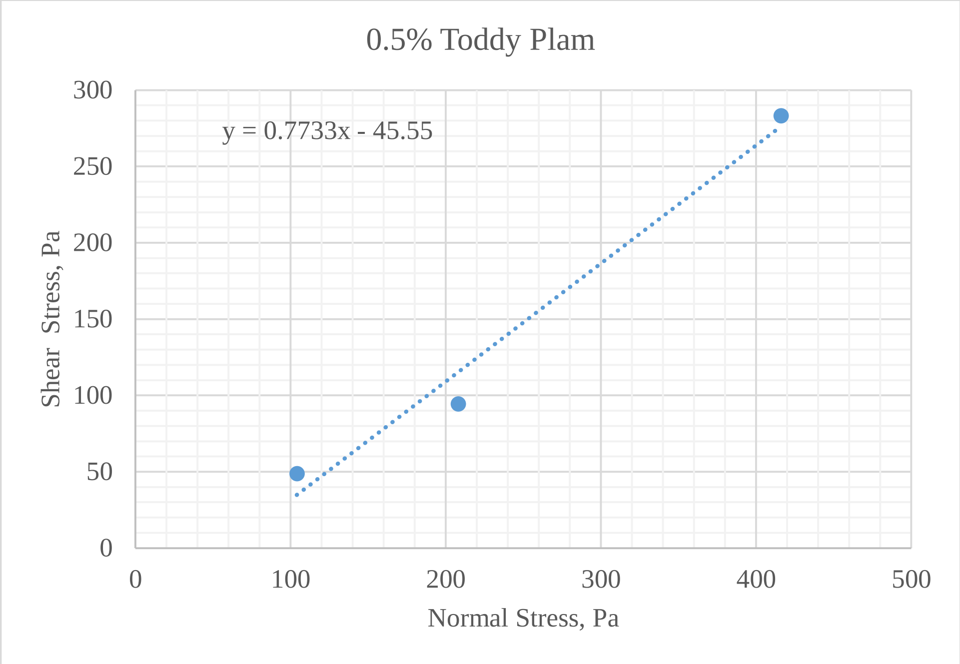
0.5% coconut
y = 0.7474x - 34.3
Shear Stress, Pa
300
250
200
150
100
50
0
0
50
100
150
200
250
300
350
400
450
Normal Stress



1% coconut
y = 0.7544x + 19.035
Shear Stress, Pa
400
350
300
250
200
150
100
50
0
0
100
200
300
400
500
Normal Stress


0.5% Betelnut
y = 0.6242x + 1.65
Shear Stress, Pa
Normal Stress, Pa
0
50
100
150
200
250
300
350
400
450


1% Betelnut
y = 0.6717x + 16.6
Shear Stress, Pa
Normal Stress, Pa
0
50
100
150
200
250
300
350
400
500



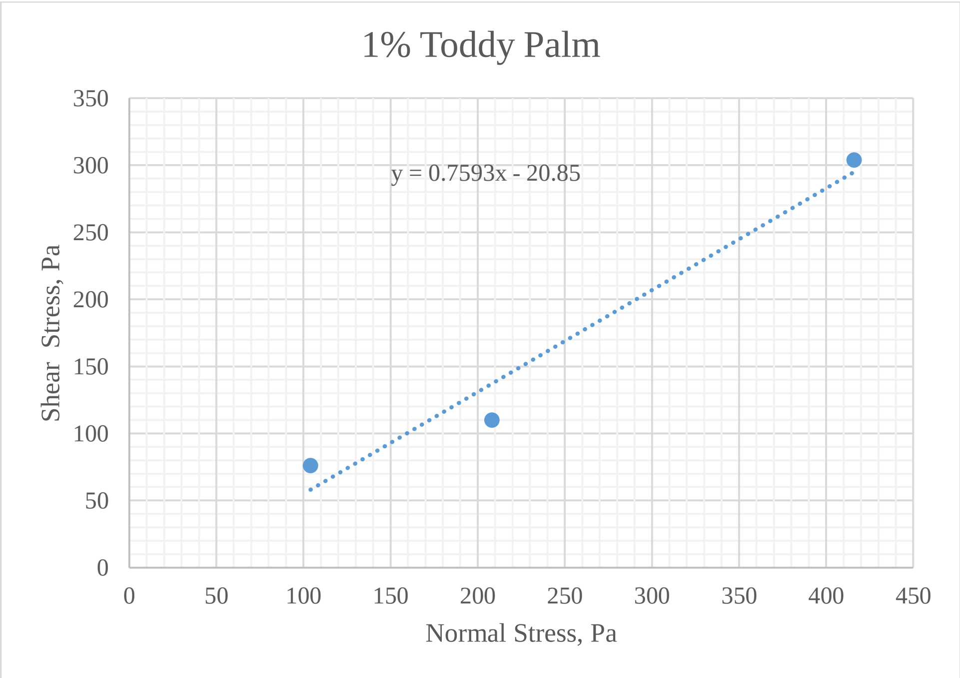


Figure 4.26 Shear Stress vs Normal Stress of 0.5 & 1% of Coconut, Betel Nut & Toddy Palm fiber

Adding fiber decreases its cohesion but nearly doubles its phi value.

And from the correlation of this table, we can state that physical properties changes to more dense soil after adding fibers.

Soil Type	Φ (degree)
Sand: Rounded Grains	
Loose	27-30
Medium	30-35
Dense	35-38

Table 4.3 Correlation between Φ and Soil density (Das, 2010)

4.8 Summary:

The above-mentioned laboratory tests and field investigations of the soils reinforcing with fiber give a clear idea about their failure pattern, compressive strength shear strength and density.

When soil is supported with fiber ductility, the shear strength and density of soil increases. But cohesion decreases.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 General:

The main goal of this study was a comparative discussion among the fibers of the Arecaceae family as reinforcement in clayey sand. Different percentages of fiber by weight was operated also to see the change in the difference of percentages.

5.2 Compressive Strength:

Soil with no fiber was brittle in nature, reinforcing with Arecaceae family fibers improved its ductility. 1% of betel nut not only improved its ductility but also surpassed its ultimate compressive strength. And formed failure pattern changes from steep shear failure to bulged shape. Some of them did not even fail.

5.3 Shear Strength:

Improved shear strength property was the best outcome of this study. Each fiber and each percentage improves shear strength to a greater extent. 1% Coconut has the best result in this case.

5.3 Physical Properties:

Clayey Sand type soil can be densified by reinforcing fibers. Toddy Plam and Coconut got the best result out of it.

5.3 Recommendation:

a) In previous researches, mostly cohesive and finer soil were used as a sample. Our study illustrates that using fiber in sandy soil can have significant benefits.

b) For CEB production, the sand proportion of CEB can be replaced with fiber reinforced sandy soil.

c) Fiber-reinforced sandy soil can be used in soil improvement technics (Such as Vibro replacement) to increase the strength of the soil also as backfill materials. But to use it in drainage further permeability test should be conducted.

5.3 Scope for Further Study:

It is proposed that additional research be undertaken. Those are given below:

a) Permeability test of the samples to observe drainage potential.

b) Biodegradation and water absorption test of the fibers to nominate the best fiber as the reinforcement.

c) Additional adhesives can be used to improved cohesion property.

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