"IMPROVEMENT OF SHEAR STRENGTH OF BLACK COTTON SOIL USING POLYESTER FIBERS"
A PROJECT

Submitted in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision of

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June, 2016

CERTIFICATE

This is to certify that the work which is being presented in the project title **"IMPROVEMENT OF SHEAR STRENGTH OF CLAYEY SOIL USING POLYESTER FIBERS"** in partial fulfillment of the requirements for the award of the degree of Bachelor of technology and submitted in Civil Engineering Department, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by Akash Jaiswal (121649) and Ashish Pathania (121651) during a period from July 2016 to December 2016 under the supervision of **Niraj Singh Parihar,** Assistant Professor, Civil Engineering Department, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of my knowledge.

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ACKNOWLEDGEMENT

It is our proud privilege and duty to acknowledge the kind of help and guidance received from several people in preparation of this report. It would not have been possible to prepare this report in this form without their valuable help, cooperation and guidance.

The topic **“Improvement of strength properties of clayey soil with the help of polyester fiber”** was very helpful to us in giving the necessary background information and inspiration in choosing this topic for the project. Our sincere thanks to Asst. Prof.**Niraj Singh Parihar,** Project Guide and Asst. Prof.**Abhilash Shukla,** Project Coordinator for having supported the work related to this project. Their contributions and technical support in preparing this report are greatly acknowledged.

ABSTRACT

Construction of building and other civil engineering structures on available clayey soil is highly risky on geotechnical grounds due to poor strength properties of the clayey soil. There may be the need for soil treatment to improve the engineering properties of soil. In practice admixtures with fly ash, lime and geogrids are used frequently to stabilize soils and improve their strength properties. Polyester fibers have been extensively used in civil engineering applications for many years. These fibers are used in concrete as a three dimensional secondary reinforcement. The influence of randomly oriented polyester fiber on the engineering behaviour of soil has not been reported to the same extent. Ease of application and reduction in cost are making this treatment more popular. The purpose of this investigation is to identify and quantify the influence of fiber variables (content and length) on performance of fiber reinforced soil specimens. In this study polyester fibers were mixed with clayey soil in various proportions (0%,0.25% 0.50%, 0.75%, and 1.0% by weight of dry clayey soil) to investigate the relative strength gained in terms of unconfined compression . It was found that strength properties of clayey soil increases with the inclusion of fibers up to 0.75%.

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1. INTRODUCTION

In today’s era, due to rapid growth in urbanization and modernization, less amount of land is available for construction. Besides, the increasing value of land and the limited availability of sites for construction, construction of various structures these days, is being carried on land having weak or soft clayey soil. The stability of any structure depends on the properties of soil on which it is to be built. If the soil is good at shallow depth below the ground surface, shallow foundation such as footings and rafts, are generally most economical. However, if the soil just below the ground surface is not good but a strong stratum exists at a great depth, deep foundations, such as piles, wells and caissons are required. Deep foundations are quite expensive and are cost effective only where the structure to be supported is quite heavy and huge. Some-times the soil conditions are very poor even at greater depth and even it is not practical to construct deep foundation.

Geotechnical engineers face various problems while designing the foundations on highly compressible clayey soil due to poor bearing capacity and excessive settlement. Most of the soil available are such that they have good compressive strength, adequate shear strength. To overcome the same, many researchers have concentrated their studies on soil improvement techniques by developing new such materials, through the elaboration of composites.

Improvement of certain desired properties of soil like compaction, unconfined compression, shear strength, swelling characteristics can be undertaken by a variety of soil improvement techniques. There are many soil improvement techniques either chemical or mechanical. They may be classified as ground reinforcement, ground improvement, and ground treatment but all these techniques require skilled man-power and equipment to ensure adequate performance.

Recently, soil reinforcement has emerged as effective and reliable technique for improving strength and stability of soils. The concept of earth reinforcement is an ancient technique and demonstrated abundantly in nature by animals, birds and the action of tree roots. The nature is the best example of earth reinforcement. In nature, the roots of plant and trees hold the earth during heavy rain and cyclone.These reinforcement resists tensile stress developed within the soil mass thereby restricting shear failure. Reinforcement interacts with the soil through friction and adhesion .The inclusion of randomly distributed discrete fiber increases strength parameters of the soil same as that in case of reinforced concrete construction.

The majority of currently published literature about randomly oriented fiber reinforcement deals with the reinforcement of cohesionless or granular soils. Most of these studies were conducted on soil samples in C.B.R., unconfined compression, triaxial and direct shear tests (Andersland and Khattak, 1979: Hoare 1979: Gray and Ohashi, 1983; Maher and Gray, 1990; Charan, 1985; Michalowski and Zhao, 1960; Michalowski and Cermak, 2003; Kaniraj and Havangi, 2001; Kaniraj and Gayatri, 2003; Gosavi et al., 2004, Yetimoglu et al., 2005). Only limited information has been reported on the use of randomly distributed discrete fibers for highly compressible clayey soil. Thus an experimental programme to study the effect of randomly distributed fibers on highly compressible clayey soil using unconfined compression has been undertaken.

2. SIGNIFICANCE

In geotechnical practice, there are many cases when it is necessary to improve soils. There are also many methods to improve soils, including using natural and synthetic fibres. A simple review of soil reinforcement by using natural and synthetic fibres is introduced because availability, economical benefits, easy to work, rapid to perform and feasibility of using in all weather conditions are the general advantages of short fibre composite soils. It also states that strength and stiffness of the composite soil is improved by fibre reinforcement. It is concluded that the increase in strength and stiffness was reported to be a function of: fibre characteristics such as aspect ratio, skin friction, weight fraction and modulus of elasticity. On the basis of predictive models presented in the paper, it is clear that the strength of fibre reinforced soil increases with increase in aspect ratio, fibre content, fibre modulus and soil fibre surface friction., unconfined compression test have demonstrated that shear strength is increased and post-peak strength loss is reduced when discrete fibres are mixed with the soil. Because there are various kinds of soils to be improved and we can use various kinds of fibres with different properties, it is always necessary to carry out the tests to find improvement rate. In this paper we have introduced results of unconfined compression test, carried out on soil specimens with polyester fibres.

It is a well-known fact that water is the worst enemy of all structures, particularly in expansive soil areas. Water penetrates into the foundation from three sides viz. top surface, and from bottom layers due to capillary action.

Fig.1.Typical Cracks in Black Cotton Soil in Dried State
Picture Reference—(www.ijera.com)

Fig.2.Black Cotton Soil On Site
Picture Reference—(www.ijest.info)

The surfacing must be impervious, sides paved to check capillary rise of water. It has been found during handling of various investigation project assignments for assessing causes of structural failures that water has got easy access into the foundations. It saturates the soil and thus lowers its bearing capacity, ultimately resulting in heavy depressions and settlement. Water lubricates the soil particles and makes the mechanical interlock unstable. In the top surface, raveling, stripping and cracking develop due to water stagnation and its seepage into the bottom layers. Generally, construction agencies do not pay sufficient attention to the aspects of construction and maintenance of sides. In expansive soil areas, unpaved offsets pose the maximum problem as they become slushy during rains, as they are most neglected.Fig.1. shows development of alligator cracks and extensive depression as well as upheavals respectively in bituminous surfacing in black cotton soil areas.

3. LITERATURE REVIEW

3.1 Soil Improvement Using Polyester Fibers by <u>Giang Nguyen, Eva Hrubesova , Adam Voltr (2015)</u>

The paper deals with soil improvement using polyester fibres of length 70mm mixed in soil SC as random reinforcement in amount of 0.5%, 1.0% and 1.5%. Improvement of soil was measured by direct shear tests, using shear box of size 0.3m x 0.3m x0.15m. It will be shown that for tested soil, optimal amount of fibres is 1.0%, when increase of angle of internal friction was up to6.0 degree (from 45.3 to 51.3) and increase of cohesion was up to 17.5kPa (from 0 kPa to 17.5 kPa) in comparison with soil without fibers.

3.2.Effect Of Polyester Fibers On Clayey Soil Of High Plasticity by <u>KalpanaMaheshwari, Dr. Chandresh H Solanki, Dr. Atul K Desai(2013)</u>

The purpose of this investigation is to identify and quantify the influence of fiber variables (content and length) on performance of fiber reinforced soil specimens. In this study polyester fibers were mixed with clayey soil in various proportions (0%,0.25% 0.50%, 0.75%, 1.00% and 1.50% by weight of dry clayey soil) to investigate the relative strength gained in terms of compaction, CBR, unconfined compression, shear parameters, and consolidation parameters etc. It was found that strength properties of clayey soil increases with the inclusion of fibers up to 0.50%.

3.3.Influence of Fly Ash, Lime, and Polyester Fibers on Compaction and Strength Properties of Expansive Soil by<u>Arvind Kumar, Baljit Singh Walia, Asheet Bajaj (2007)</u>

Samples were tested with 0, 0.5, 1.0, 1.5, and 2% plain and crimped polyester fibers by dry weight. Based on the favorable results obtained, it can be concluded that the expansive soil can be successfully stabilized by the combined action of fibers, lime, and fly ash.

4. MATERIALS

4.1 Soil

The engineering properties of black cotton soil used is given in Table 1.

Properties	Value
Specific Gravity	2.43
Liquid Limit	49.6%
Plastic Limit	34.2%
Plasticity Index	15.4 %
Maximum Dry Density	1.67g/cm^3
Optimum Moisture Content	22.5%
IS Classification	OI

Table 1-Engineering properties of black cotton soil

4.2 Polyester fiber

The physical and engineering properties of polyester fiber used is given in Table 2.

Type	Polyester
Cut Length	20mm
Cross Section	Triangular
Diameter	0.5mm
Colour	White

Table 2- Physical and engineering properties of polyester fiber

5. OBJECTIVE

The objective of the present work is :

- To improve the shear strength of black soil samples mixed with polyester fiber in different proportions (by weight) and analyzing the results obtained.

- To determine the optimum aspect ratio of polyester fiber.

- To determine the optimum fiber content.

6. TESTS PERFORMED

6.1 Determination of Specific Gravity

Fig.3.Pycnometer

Picture Reference—(www.dir.indiamart.com)

Objective

To determine the specific gravity of soil by pycnometer method.

Reference Standard

IS : 2720 (Part 4) – 1985 – Method of test for soil (Part 4-Grain size analysis)

Equipment & Apparatus

- Pycnometer
- Sieve(4.75 mm)
- Vacuum pump
- Oven
- Weighing balance
- Glass rod

Preparation Sample

After receiving the soil sample it is dried in oven at a temperature of 105 to 115^{0}C for a period of 16 to 24 hours.

Procedure

- Pycnometer is dried and weighed with its cap(W_1)
- About 200 g to 300 g of oven dried soil passing through 4.75mm sieve is poured into the pycnometer and weighed again(W_2).
- Water is added to cover the soil and screwed on the cap.
- Pycnometer is shaken well and connected it to the vacuum pump to remove entrapped air for about 10 to 20 minutes.
- After the air has been removed, the pycnometer is filled with water and weighed it (W_3).
- Pycnometer is cleaned by washing thoroughly.
- Cleaned pycnometer is filled completely with water upto its top with cap screw on.
- Pycnometer is weighed after drying it on the outside thoroughly(W_4).

Precautions taken

- Soil grains whose specific gravity is to be determined were taken completely dry.
- If on drying soil lumps are formed, they were broken to its original size.
- Inaccuracies in weighing and failure to completely eliminate the entrapped air were the main sources of error.

6.2Liquid limit test of soil (using Casagrande apparatus IS-2720-part-5-1985)

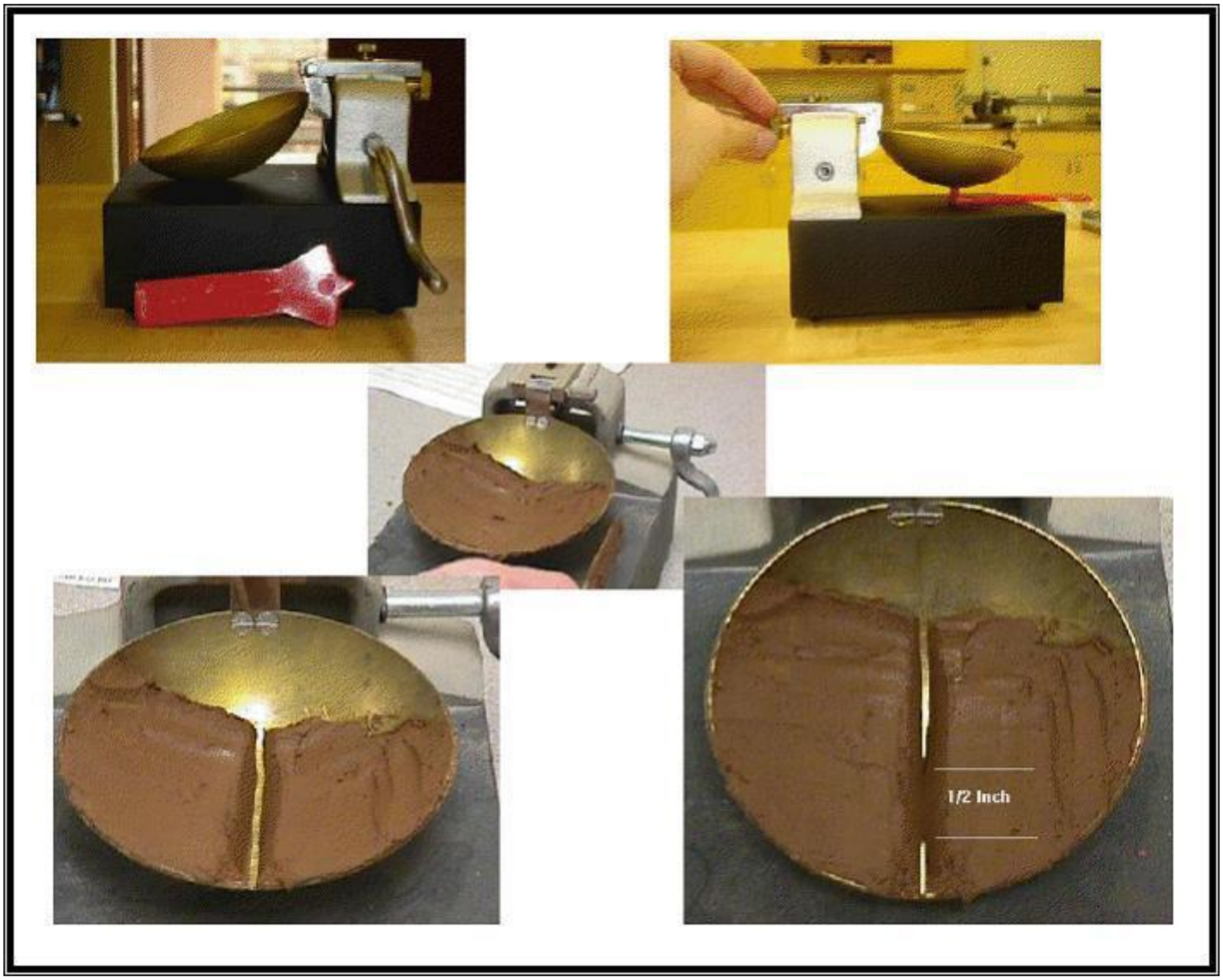


Fig.4. Casagrande Apparatus

Picture Reference—(www.civilblog.org)

Objective

To determine the liquid limit of soil using casagrande apparatus.

Reference Standard

IS : 2720(Part 5)-1985- Methods of test for soils : Determination of liquid and plastic limit.

Equipment & Apparatus

Oven

Balance (0.01g accuracy)

Sieve [425 micron]

Casagrande apparatus

Preparation of sample

After receiving the soil sample it is dried in air or in oven (maintained at a temperature of 60^0C). If clods are there in soil sample then it is broken with the help of wooden mallet. The soil passing 425 micron sieve is used in this test.

Procedure

- About 120 gm. of air dried soil from thoroughly mixed portion of material passing 425 micron IS sieve is obtained.
- Distilled water is mixed to the soil thus obtained in a mixing disc to form uniform paste. The paste shall have a consistency that would require 30 to 35 drops of cup to cause closer of standard groove for sufficient length.
- A portion of the paste is placed in the cup of casagrande device and spread into portion with few strokes of spatula.
- It is trimmed to a depth of 1 cm at the point of maximum thickness and excess of soil is returned to the dish.
- The soil in the cup is divided by the firm strokes of the grooving tool along the diameter through the centre line of the follower so that clean sharp groove of proper dimension is formed.
- Then the cup is dropped by turning crank at the rate of two revolutions per second until two halves of the soil cake come in contact with each other for a length of about 12 mm. by flow only.
- The number of blows required to cause the groove close for about 12 mm. is recorded.
- A representative portion of soil is taken from the cup for water content determination.
- The test is repeated with different moisture contents at least 3 times for blows between 10 and 40.

Precautions taken

- Soil used for liquid limit determination should not be oven dried prior to testing.
- In LL test the groove should be closed by the flow of soil and not by slippage between the soil and the cup
- After mixing the water to the soil sample , sufficient time should be given to permeate the water throughout out the soil mass
- Wet soil taken in the container for moisture content determination should not be left open in the air, the container with soil sample should either be placed in desiccators or immediately be weighed.

6.3 Plastic limit test of soil(IS-2720-part-5-1985)

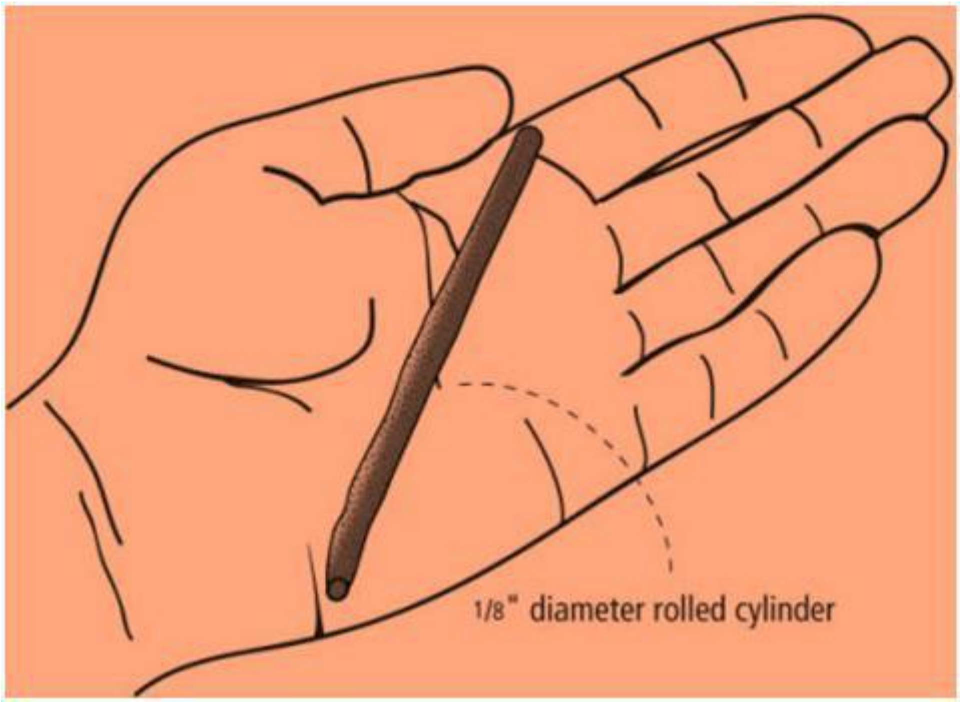


Fig.5. Sample of plastic limit test

Picture Reference—(www.septic.umn.edu)

Objective

To determine the plastic limit of soil.

Reference Standard

IS : 2720(Part 5)-1985- Methods of test for soils : Determination of liquid and plastic limit.

Equipment & Apparatus

- Oven
- Balance (0.01 g accuracy)
- Sieve [425 micron]
- Flat glass surface for rolling

Preparation of sample

After receiving the soil sample it is dried in air or in oven (maintained at a temperature of 60^0C). If clods are there in soil sample then it is broken with the help of wooden mallet. The soil passing 425 micron sieve is used in this test.

Procedure

- A soil sample of 20 gm. passing 425 micron IS sieve is to be taken.
- It is to be mixed with distilled water thoroughly in the evaporating dish till the soil mass becomes plastic enough to be easily moulded with fingers.
- It is to be allowed to season for sufficient time, to allow water to permeate throughout the soil mass.
- 10 gms. of the above plastic mass is to be taken and is to be rolled between fingers and glass plate with just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length. The rate of rolling shall be between 60 and 90 stokes per minute.
- The rolling is to be continued till the thread becomes 3 mm. in diameter.
- The soil is then kneaded together to a uniform mass and rolled again.
- The process is to be continued until the thread crumbled with the diameter of 3 mm.
- The pieces of the crumbled thread are to be collected in a air tight container for moisture content determination.

Precautions taken

- Soil used for plastic limit determination should not be oven dried prior to testing.
- After mixing the water to the soil sample , sufficient time should be given to permeate the water throughout out the soil mass
- Wet soil taken in the container for moisture content determination should not be left open in the air, the container with soil sample should either be placed in desiccators or immediately be weighed.

6.4 Light/standard proctor compaction test of soil(IS-2720-part-7-1980)

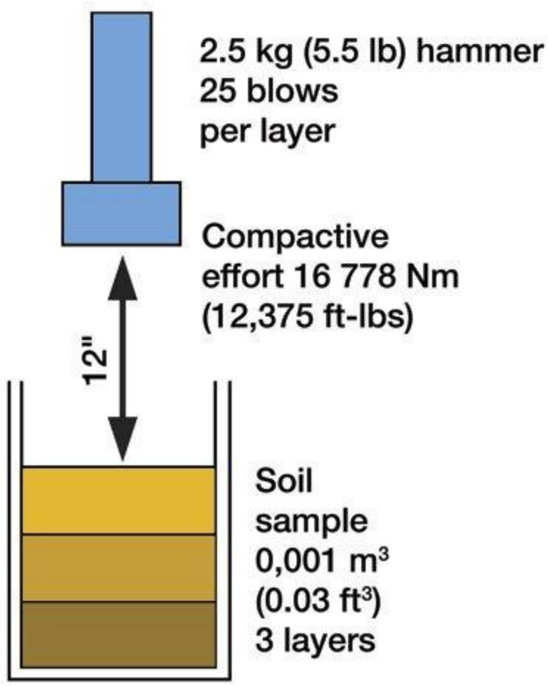


Fig.6.Standard proctor test apparatus

Picture Reference—(www.engineering.purdue.edu)

Objective

To determine the relation between the water content and the dry density of soils using light compaction.

Reference Standard

IS: 2720(Part 7)-1980- Methods of test for soils: Determination of water content-dry density relation using light compaction.

Equipments & Apparatus

- Cylindrical mould& accessories [volume = 1000cm^3]
- Rammer [2.6 kg]
- Balance [1g accuracy]
- Sieves [19mm]
- Mixing tray
- Trowel
- Graduated cylinder [500 ml capacity]
- Metal container

Preparation Sample

Obtain a sufficient quantity (10 kg) of air-dried soil and pulverize it. Take about 5 kg of soil passing through 19mm sieve in a mixing tray.

Procedure

- 5 Kg. of soil is taken and the water is added to it to bring its moisture content to about 4 % in coarse grained soils and 8% in case of fine grained soils with the help of graduated cylinder
- The mould with base plate attached is weighed to the nearest 1 gm (M_1). The extension collar is to be attached with the mould.
- Then the moist soil in the mould is compacted in three equal layers, each layer being given 25 blows from the 2.6 Kg rammer dropped from a height of 310 mm. above the soil.
- The extension is removed and the compacted soil is leveled off carefully to the top of the mould by means of a straight edge.
- Then the mould and soil is weighed to the nearest 1 gm. (M_2).
- The soil is removed from the mould and a representative soil sample is obtained water content determination.

Precautions taken

- Use hand gloves & safety shoes while compacting.
- Adequate period (about 15 minutes for clayey soils and 56 minutes for coarse grained soils) is allowed after mixing the water and before compacting into the mould.
- The blows should be uniformly distributed over the surface of each layer.

6.5Unconfined compressive strength test of soil

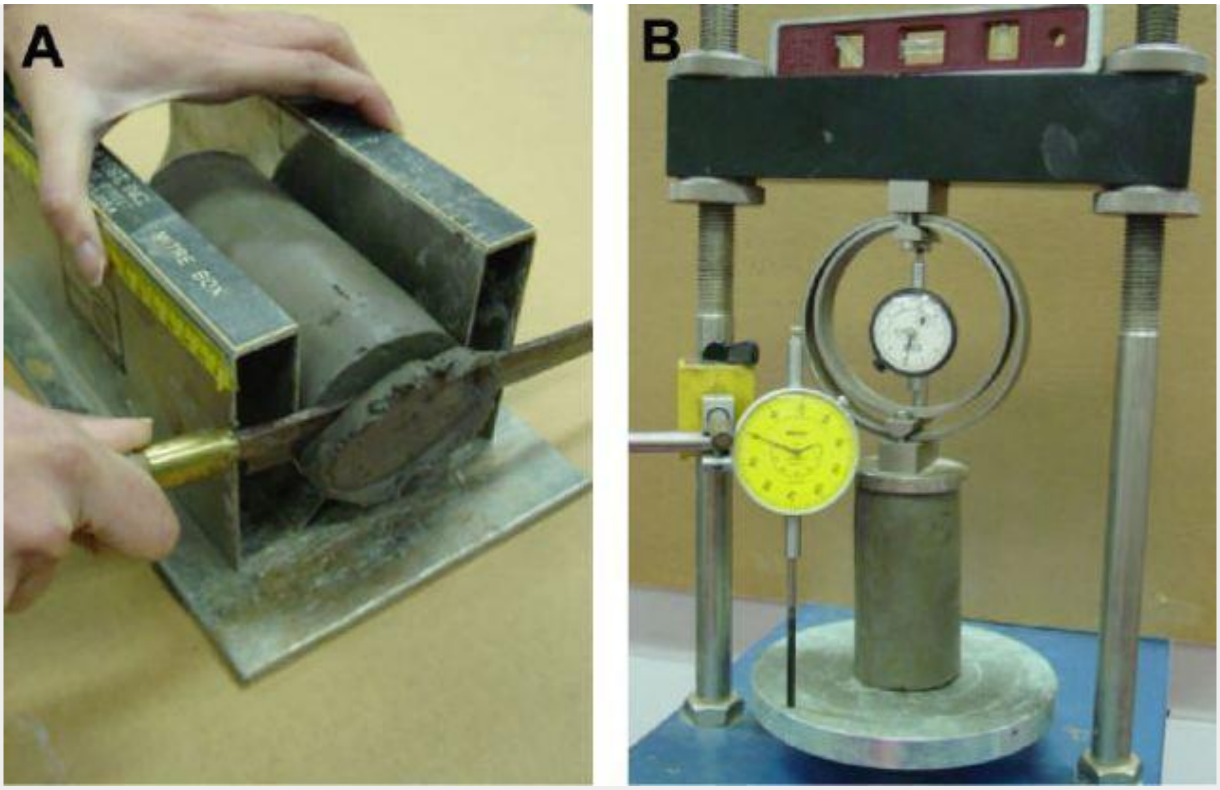


Fig.7.Unconfined compression test apparatus

Picture Reference—(www.protest.com.tr)

Objective

To determine the unconfined compressive strength of soil

Standard Reference

ASTM D 2166 – Standard Test Method for Unconfined Compressive Strength of Cohesive Soil

Equipments & Apparatus

(1)Compression device suitable for unconfined compression test (motorised or manual).

(2)Sample extractor.

(3)Proving ring of capacity 500 N and 1000 N.

(4)Dial gauges with 0.01 mm least count.

(5)Knife.

(6)Split mould of 3.8 cm diameter and 7.6 cm long.

Procedure

(1) The sample is carefully ejected from the linear of spine spoon sampler of standard penetration test, then it is cut into pieces with a length approximately twice its diameter. The initial length and diameter of the sample is measured.

(2) The two ends of the sample is trimmed ,shaped and placed on the conical bottom plate loading device.

(3) The load dial gauge and strain dial gauge is set to zero.

(4) The load is applied by raising the bottom plate of the load device.

(5) The load dial gauge and strain dial gauge reading is noted after every 30 secs.

(6) The sample is compressed until it fails or a vertical deformation of 20%.

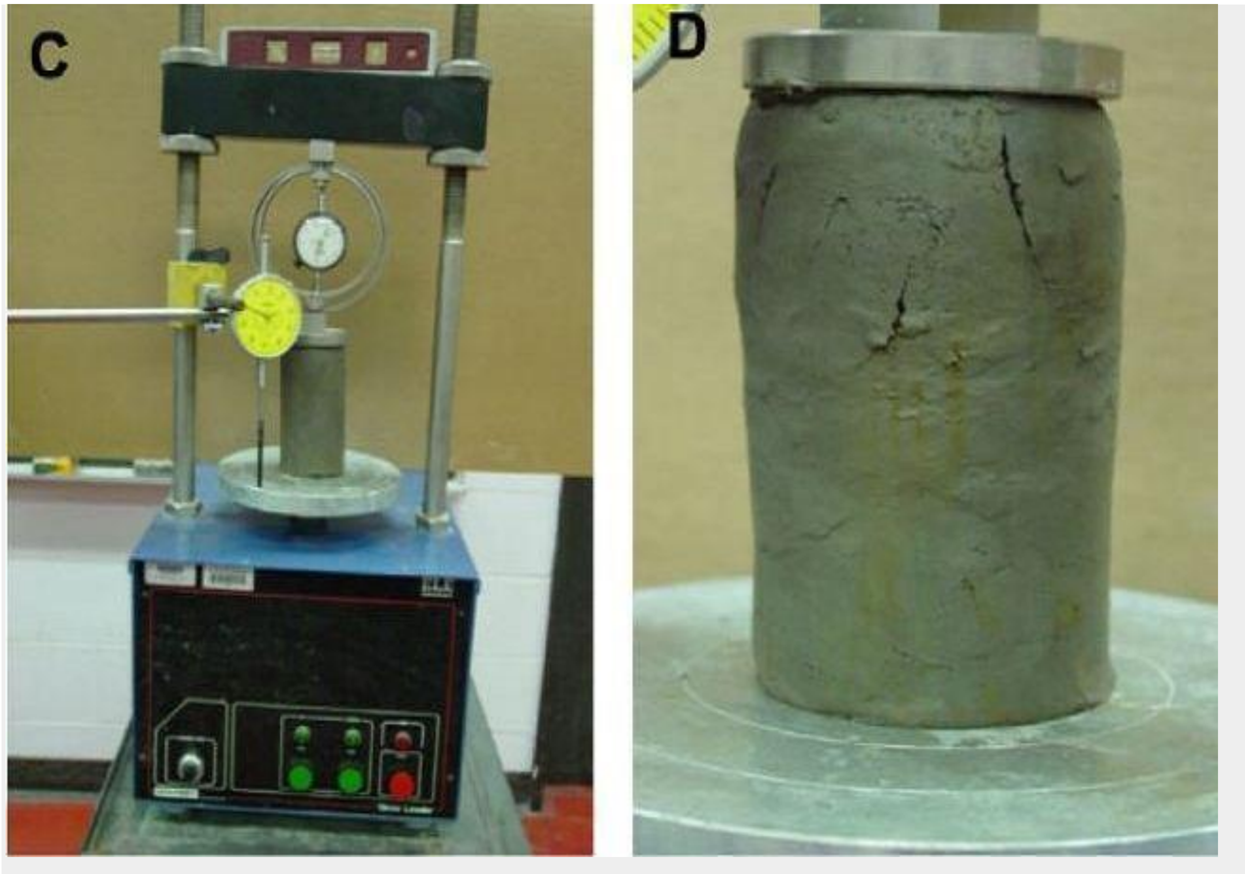


Fig.8.Shear failure of sample

Picture Reference—(www.engineering.najah.edu)

Precautions taken

(1) Both the ends of the sample are shaped so that it should sit properly on the bottom plate of the loading frame.

(2) Rate of loading of the sample should be constant.

7. RESULTS & CONCLUSIONS

7.1 Specific Gravity Test

Calculation

The specific gravity of soil solids (Gs) is calculated using the following equation.

W_1=Empty weight of pycnometer = 461.8 g

W_2=Weight of pycnometer + oven dry soil = 661.8 g

W_3=Weight of pycnometer + oven dry soil + water = 1304.3 g

W_4=Weight of pycnometer + water full = 1186.7 g

Specific gravity of soil = Density of water at 27 C / Weight of water of equal volume

$$= (W_2 - W_1) / [(W_2 - W_1) - (W_3 - W_4)]$$

Result

The range of specific gravity for different soils is given in Table 3 :

Soil	Specific gravity
Sand	2.63-2.67
Silt	2.5-2.7
Clay & Silty Clay	2.67-2.9
Organic Soils	< 2.45

Table 3- Range of specific gravity for different soils

Specific gravity of black cotton soil is found to be **2.43.**

7.2 Liquid Limit Test

Calculation

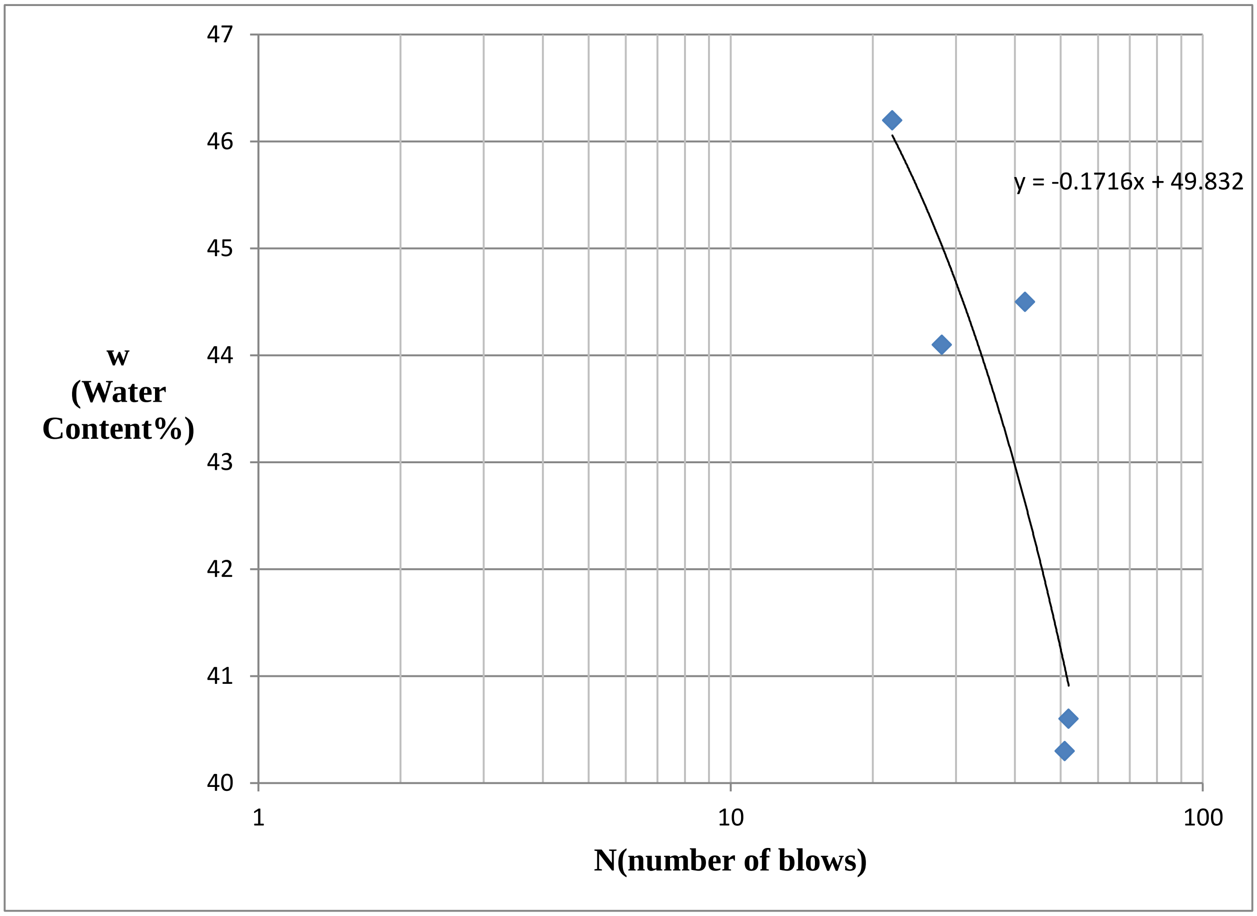
- A ‘**flow curve**’ is to be plotted on a semi-logarithmic graph representing water content in arithmetic scale and the number of drops on logarithmic scale.
- The flow curve is a straight line drawn as nearly as possible through four points.
- The moisture content corresponding to 25 blows as read from curve is the liquid limit of that soil.

Observations

Serial Number	1	2	3	4	5
Container number	37	12	5	6	41
Weight of container(g)	28.6	27.6	25.8	27	28.1
Weight of container + wet soil (g)	56.8	45.9	47.6	40.6	51.8
Weight of container + dry soil (g)	48.7	40.3	41.3	36.3	44.5
Weight of water (g)	8.1	5.6	6.3	4.3	7.3
Weight of dry soil (g)	20.1	12.7	15.5	9.3	16.4
Moisture content (%)	40.3	44.1	40.6	46.2	44.5
No. of blows	51	28	52	22	42

Computation

A graph is drawn showing the relationship between water content (on y-axis) and number of blows (on x-axis) on semi-log graph. The curve obtained is called flow curve. The moisture content corresponding to 25 drops (blows) as read from the represents liquid limit. It is usually expressed to the nearest whole number (Refer to Graph 1.)



Graph 1-Liquid Limit

Result

The liquid limit of black soil is found to be 49.6 %

Inference

Since the liquid limit comes out to be < 50 %.Therefore the soil is medium plastic.

7.3Plastic Limit Test

Observation & Reporting

At intervals the diameter of thread was compared with the rod. When the diameter reduces to 3 mm, the cracks on the surface of thread were noted.

Observation Table

Container No.	42	11	1
Wt. of container + lid,W_1 (g)	27.5	29.3	28.6
Wt. of container + lid + wet sample,W_2(g)	30.6	31	31.5
Wt. of container + lid + dry sample,W_3(g)	29.9	30.5	30.8
Wt. of dry sample(g) = W_3 - W_1	2.4	1.2	2.2
Wt. of water in the soil (g)= W_3-W_2	0 .7	0.5	0.7
Water content (%) = (W_3- W_2) / (W_3 - W_1) * 100	29.2	41.6	31.8

Result

The average plastic limit of black soil is found to be 34.2 %

Inference

Since plasticity index of black cotton soil is equal to 15.4% .Therefore the soil is medium plastic.

7.4 Light Weight Standard Proctor Test

Observations

Cylinder specifications

Diameter - 10cm, Height - 11.7cm ,Volume - 942cc , Weight of cylinder - 4319.1 gm

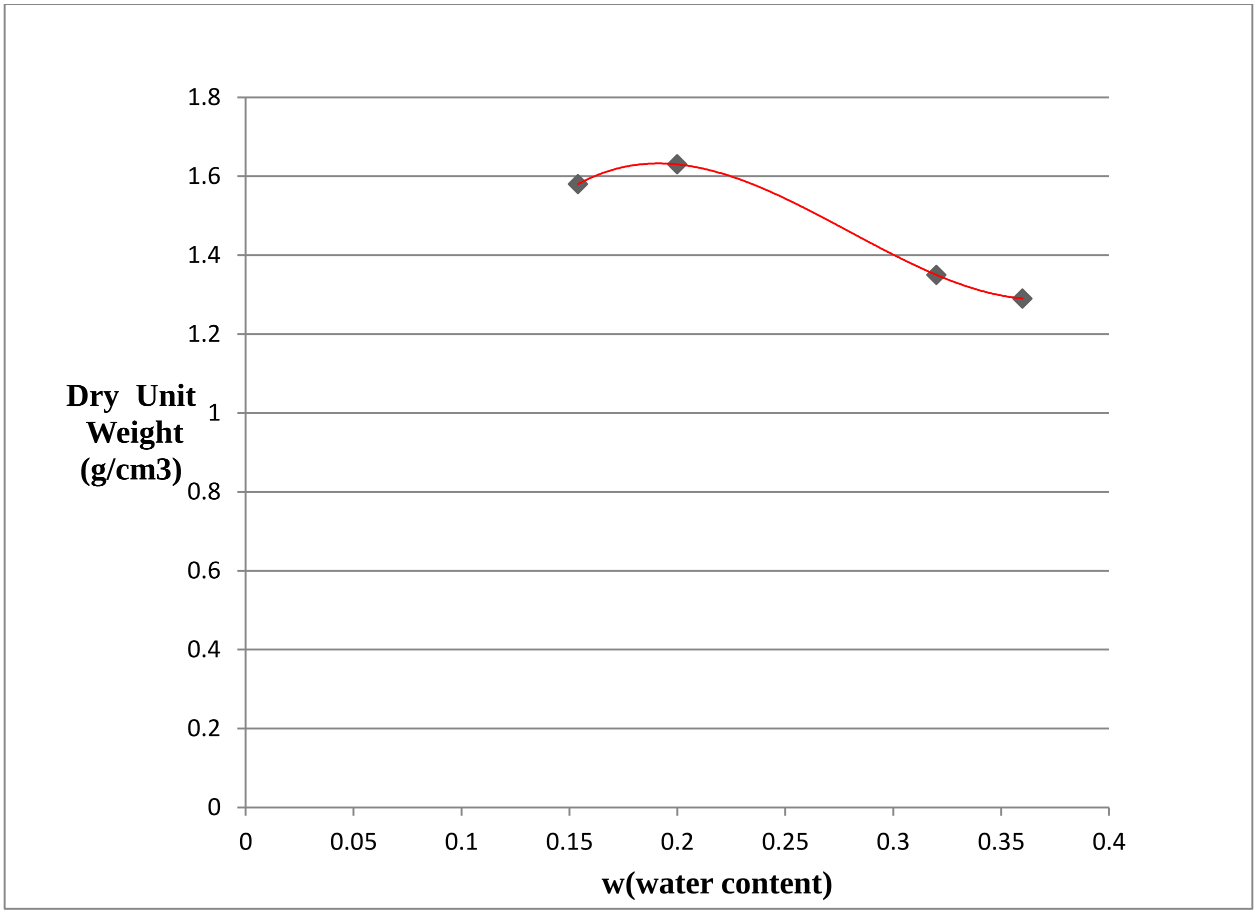
Density(g/cc)	1.825	1.949	1.780	1.756
Serial No.	1	2	3	4
Water to be added (%)	8	15	22	29
Weight of water to be added (g)	200	375	550	725
Weight of cylinder + compacted soil (g)	6144.2	6268.6	6100	6076
Weight of compacted soil (g)	1825.1	1949.5	1780.9	1756.9
Average moisture content (%)	26	26	26	26
Density of water(g /cc)	1000	1000	1000	1000
Dry density (g/cc)	1.581	1.633	1.35	1.291
Water content(%)	15.4	20	32	36
Container No.	11	46	8	34
Wt. of container + wet soil (g)	40.5	52.2	54.7	76.8
Wt. of container + dry soil (g)	38.6	48.1	48.4	63.8
Wt of container alone (g)	26.3	27.6	28.7	27.8
Wt. of water (g)	1.9	4.1	6.3	13
Wt. of dry soil (g)	12.3	20.5	19.7	36
Percentage of water Content	8	15	22	29

Calculation

Dry density = Bulk density/(1+w)

where w is the moisture content of the soil.

The dry density was plotted against the moisture content and the maximum dry density and optimum moisture for the soil was found out (refer to Graph 2.)



Graph 2-Optimum Moisture Content

Result

The maximum dry density of black cotton soil as calculated from graph no.2 is 1.67 g/cm^3 and optimum moisture content is 22.5 %

7.5 Unconfined Compression Test

The observation table of unconfined compression test is given in -

Annexure I –

1.1 Unconfined Compression Test Samples 1,2,3 (black soil)

1.2 Unconfined Compression Test Samples 1,2,3 (black soil reinforced with 0.25% of polyester fiber, L/D =40)

1.3 Unconfined Compression Test Samples 1,2,3 (black soil reinforced with 0.5% of polyester fiber, L/D =40)

1.4 Unconfined Compression Test Samples 1,2,3 (black soil reinforced with 0.75% of polyester fiber, L/D =40)

1.5 Unconfined Compression Test Samples 1,2,3 (black soil reinforced with 1% of polyester fiber, L/D =40)

Annexure II –

2.1 Unconfined Compression Test Samples 1,2,3 (black soil reinforced with 0.75% of polyester fiber, L/D =20)

2.2 Unconfined Compression Test Samples 1,2,3 (black soil reinforced with 0.75% of polyester fiber, L/D =60)

Calculations

Specific gravity (G_S) of black soil used is 2.43

Water content of the soil sample used is 22.5 %

Diameter (D_o) of the sample is 3.8 cm , Area of cross-section of the sample is 11.26 cm^2

Initial length (L_o) of the sample is 76 mm .

Analysis

(1) The dial readings to the appropriate load and length units were converted and these values were entered on the data sheet in the deformation and total load columns.

(2) The sample cross-sectional area is computed as $\mathbf{A_0 = \pi*(d^2)/4}$.

(3) The deformation (ΔL) corresponding to 15% strain (e) was computed.

Strain (e) = $\mathbf{\Delta L / L_0}$

Where $\mathbf{L_0}$ = Original specimen length (as measured in step 3).

(4) The corrected area is computed as $\mathbf{A' = A_0 / (1-e)}$

(5) Using A', the specimen stress is computed as $\mathbf{s_c = P/A'}$.

(6) The water content, **w%** was computed.

(7) The stress versus strain curve was plotted showing $\mathbf{q_u}$ as the peak stress (or at 15% strain) of the test.

Graphs

The stress-strain graphs of black soil samples and black soil samples reinforced with different proportions of polyester fiber are given in Annexure 3.1 and 3.2 respectively.

While the comparison of shear strength of black cotton soil before and after reinforcement is shown in graph 3.

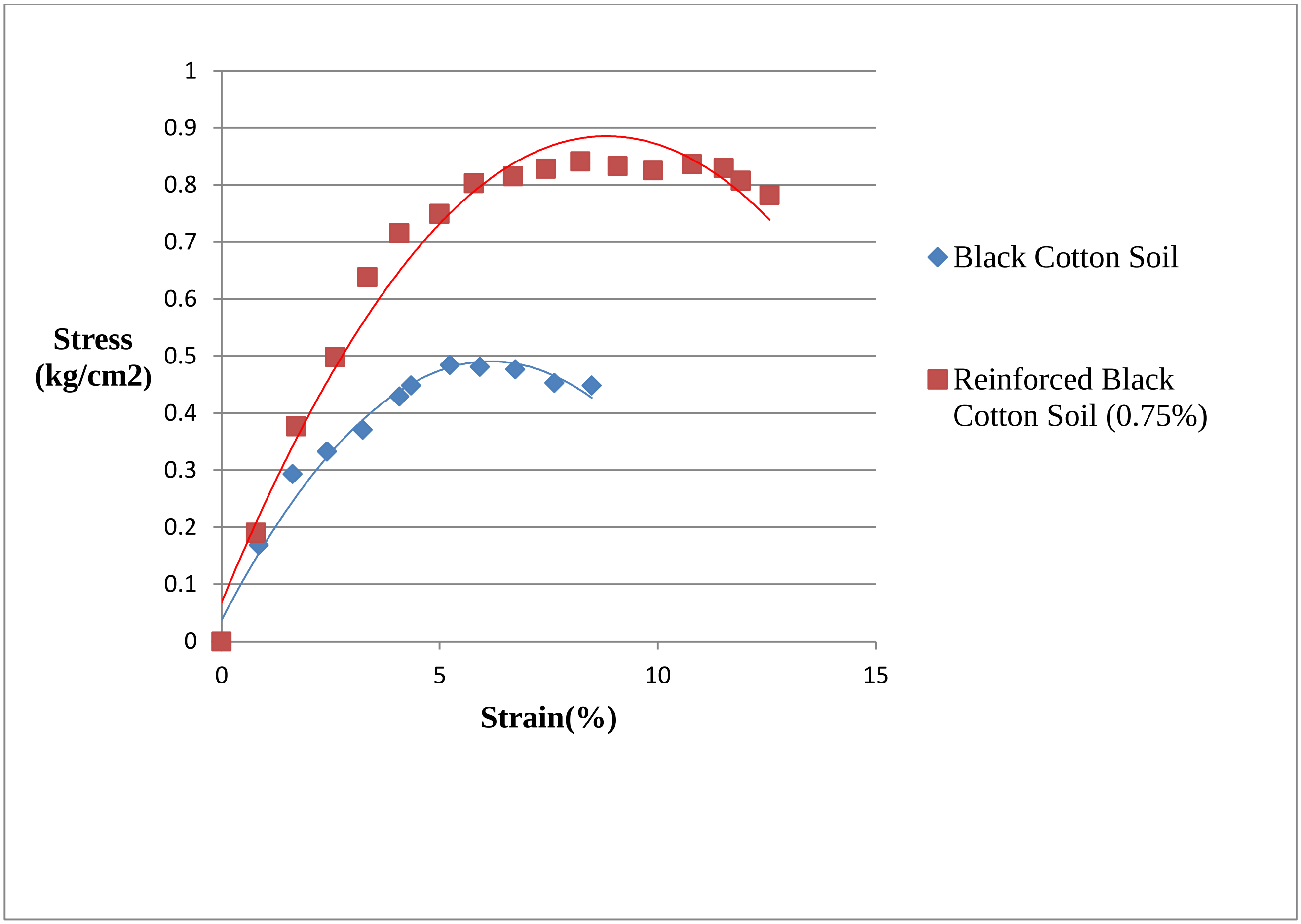
Result

Unconfined compressive strength of the soil = q_u =0.432 kg/cm^2

Unconfined compressive strength of reinforced soil(0.75% polyester fiber)=q_u=0.825 kg/cm^2

Shear strength of the soil = $q_u/2$ =0.216 kg/cm^2

Shear strength of the reinforced soil(0.75% polyester fiber) = $q_u/2$ =0.412 kg/cm^2



Graph 3- Increase in shear strength of black cotton soil after reinforcement

The % increase in shear strength of black cotton soil as seen in graph 3 is found to be **91%.**

8. DETERMINATION OF OPTIMUM ASPECT RATIO

The **aspect ratio** is defined as the proportional relationship between its width and its height. It is commonly expressed as two numbers separated by a colon, as in *16:9*. The values x and y do not represent actual widths and heights but, rather, the relationship between width and height.
As we know that change in aspect ratio of polyester fiber affects the shear strength of black cotton soil .So, to find the optimum aspect ratio, we varied the cut length of the thread by 10mm.

Observation

The observation tables of the unconfined compression test samples with variations in aspect ratio of the polyester fiber are given :

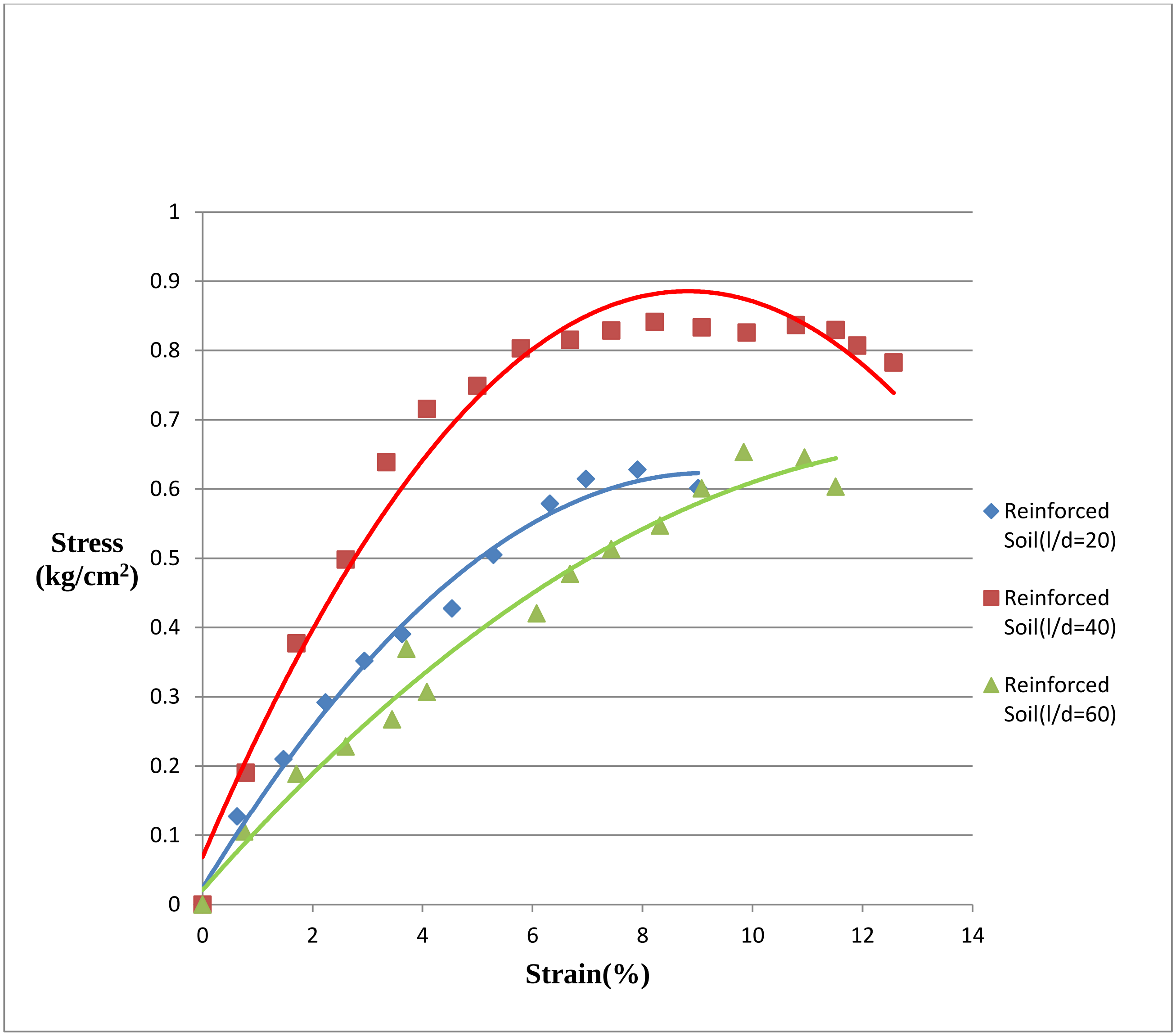
Annexure II –

2.1 Unconfined compression test samples 1,2,3 (black soil reinforced with 0.75% of polyester fiber, L/D =20).

2.2 Unconfined compression test samples 1,2,3 (black soil reinforced with 0.75% of polyester fiber, L/D =60).

Comparison of results

The stress-strain graphs of black soil reinforced with polyester fibers of different aspect ratios are given in Annexure 3.3
The comparison graph of reinforced black soil samples with different aspect ratios is given below :



Graph 4- Comparison of stress-strain behaviour of black cotton soil at different aspect ratios

The comparison graph of unconfined compressive strength shows that the UCS value of soil increases with the increase in aspect ratio up to 40. It becomes maximum at aspect ratio 40 for all fiber lengths. Then it decreases with further increase in aspect ratio beyond 40.

Result

The comparison of shear strength at different aspect ratio is given in Table 4 :-

Properties	Aspect ratio 20	Aspect ratio 40	Aspect ratio 60
Unconfined Compressive Strength (Kg/cm^2)	0.581	**0.825**	0.620
Shear Strength (Kg/cm^2)	0.290	**0.412**	0.310

Table 4- Comparison of shear strength at different aspect ratio

The optimum aspect ratio at which the shear strength of black cotton soil is maximum is found to be **40.**

9. DETERMINATION OF OPTIMUM FIBER CONTENT

Shear strength of black cotton soil changes with the amount of polyester fiber added in it. So, to find the optimum fiber content , the fiber content was varied by 0.25% (by weight of the black cotton soil).

Observation

The observation tables of the unconfined compression tests on black cotton soil with variations in fiber content are given :

Annexure I –

1.1 Unconfined Compression Test Samples 1,2,3 (black soil)

1.2 Unconfined Compression Test Samples 1,2,3 (black soil reinforced with 0.25% of polyester fiber, L/D =40)

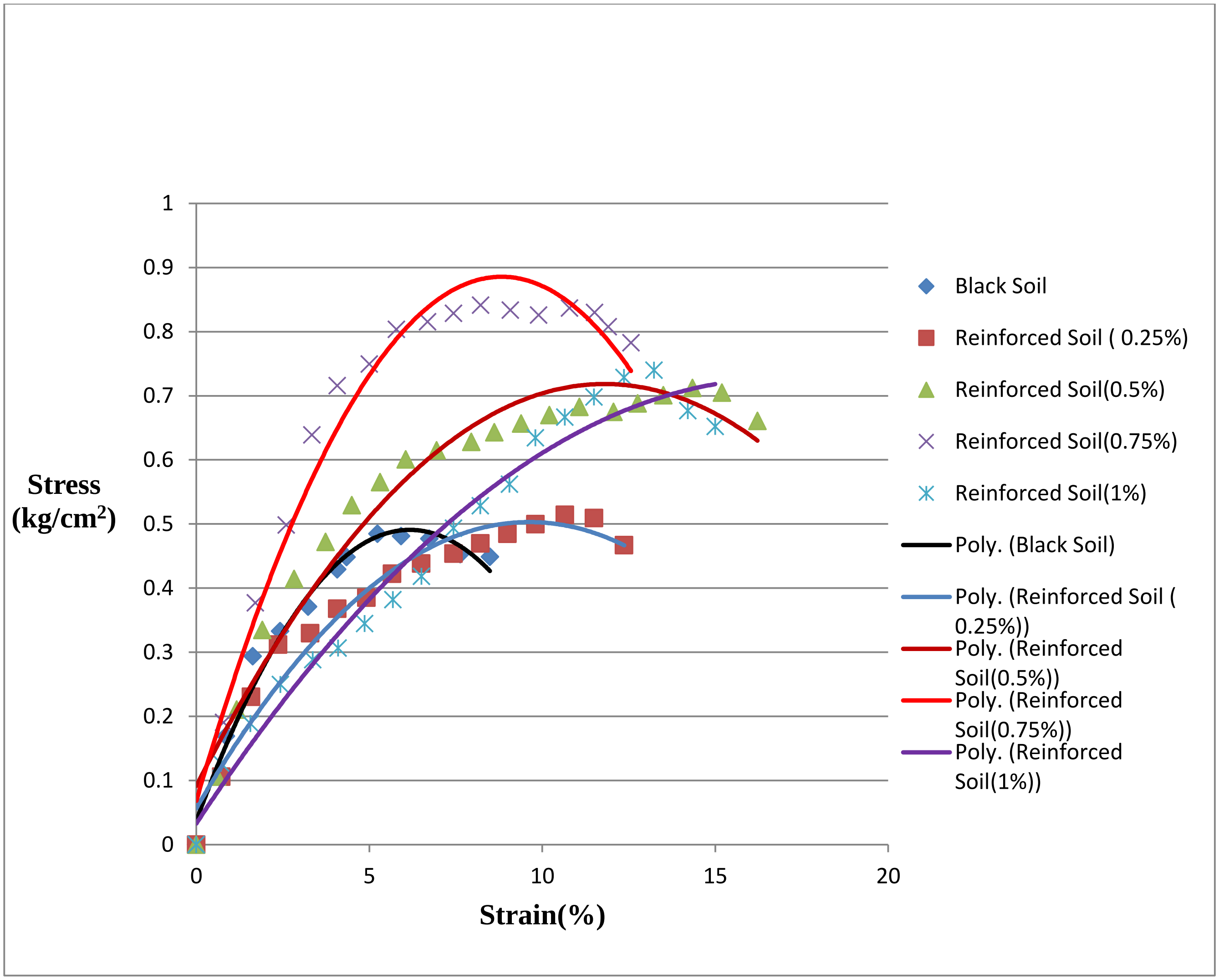
1.3 Unconfined Compression Test Samples 1,2,3 (black soil reinforced with 0.5% of polyester fiber, L/D =40)

1.4 Unconfined Compression Test Samples 1,2,3 (black soil reinforced with 0.75% of polyester fiber, L/D =40)

1.5 Unconfined Compression Test Samples 1,2,3 (black soil reinforced with 1% of polyester fiber, L/D =40)

Comparison of results

The stress-strain graphs of black soil reinforced with different proportions of polyester fiber are given in graph 5.



Graph 5- Comparison of stress-strain behavior of black cotton soil reinforced with different proportions of polyester fiber

The comparison graph of unconfined compressive strength shows that the UCS value of soil increases with the inclusion of polyester fiber up to 0.75%. It becomes maximum at 0.75% fiber content for all fiber lengths. Then it decreases with further inclusion of fibers beyond 0.75%.

Result

The percentage increase in shear strength of black cotton soil with the variation in amount of polyester fiber(by weight) is given in Table 5 :-

Amount of polyester fiber (in % by weight)	% increase in shear strength
0.25	13.2
0.50	64.8
0.75	**90.9**
1.00	69.4

Table 5-Percentage increase in shear strength of black cotton soil

The optimum fiber content at which the shear strength of black cotton soil is found to be maximum is **0.75%.**

10. COMPARISON OF RESULTS

The comparison of strength between black cotton soil and reinforced black cotton soil is given in Table 6.

Properties	Black Soil	0.25% Fiber	0.5% Fiber	0.75% Fiber	1% Fiber
Unconfined Compressive Strength (Kg/cm^2)	0.432	0.489	0.712	0.825	0.724
Shear Strength (Kg/cm^2)	0.216	0.244	0.356	0.412	0.362

Table 6- Comparison of shear strength between black cotton soil and reinforced black cotton soil

The percentage increase in shear strength of black cotton soil with the variation in amount of polyester fiber(by weight) is given in Table 7.

Amount of polyester fiber (in % by weight)	% increase in shear strength
0.25	13.2
0.50	64.8
0.75	90.9
1.00	69.4

Table 7 Percentage increase in shear strength of black cotton soil and reinforced black cotton soil

The comparison of strength at different aspect ratio is given in Table 8.

Properties	**Aspect ratio 20**	**Aspect ratio 40**	**Aspect ratio 60**
Unconfined Compressive Strength **(**Kg/cm^2)	0.581	0.825	0.620
Shear Strength **(**Kg/cm^2)	0.290	0.412	0.310

Table 8- Comparison of shear strength at different aspect ratio

11. CONCLUSION

- Improvement in strength properties of clayey soil like unconfined compression and shear strength were obtained by the inclusion of polyester fibers. The increase in strength was observed with the inclusion of fibers up to 0.75% and beyond that it decreases. The maximum strength gain was observed at 0.75% fiber content.

- The increase in strength was observed with the increase in aspect ratio of polyester fiber up to 40 and beyond that it decreases. The maximum strength gain was observed at aspect ratio(L/D) 40.

- With increase in fiber content, there is an increase in homogeneous and isotropic properties of soil medium and soil becomes more uniform. Beyond 0.75% fiber content, with further inclusion of fibers the strength properties of fiber reinforced clayey soil decreases.

12. FUTURE SCOPE

Based on the above study and literature review the study of fiber for soil reinforcement has a good scope in terms of future perspectives. There is very less research done on combining two ground improvement techniques. And even less research work on inclusion of fiber with geocell reinforcement overlaying poorly graded sand although separately there are plenty. So the usage of fiber alone and in combination reduces the increasing number of fiber that has posed a serious threat to environmental protection and public health efforts in recent years. Review of literature highlights the beneficial effect of using reinforcements to increase the load carrying capacity of the weak subgrade. Various applications as given above have suitably reduced the negative effects of fibers that are being deposited every year. Its scope in properties, suitability, applications in various construction works and future prospective have risen considerably in recent years. Various researchers have already started studies related to its application and usage as given above. Not only its environmental damage gets reduced but also its usage in construction works creates a huge beneficial effect for future. It can be concluded from the geocell and fibers both have potential to improve the strength and stiffness of soil. Individual application of this reinforcement is reported by different researchers. But combined effect of the both of the reinforcement is yet to be explored. It is therefore envisaged to investigate, under this research work, if the fiber reinforcement can be used as a secondary reinforcement, in the soils, with geocell as the main reinforcement. Geosynthetics have great potential to be used as cost-effective solutions for several engineering problems. This paper presented recent advances in geosynthetic products, on the utilization of these materials in reinforced soil structures and in environmental applications. Manufacturing of geosynthetics products allows incorporating recent advances in material sciences. Therefore, the expectation is that innovations in products, types and properties will continue to take place, adding to the already vast range of applications of these materials.

13. REFERENCES

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ANNEXURE I

1.1 Black soil samples

1.1
Sample 1

Elapsed time	Compression dial reading	Compression dial reading(ΔL)	Strain (ϵ)	Area Ac=Ao/(1-ϵ)	Proving ring	No. of	Axial load (P)	Compressive stress(P/Ac)
3(min.)	(ΔL)	(least count = .01mm)	(%)	(cm2)	reading	division	(.24 kg/div)	(kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	55	0.55	0.723684211	11.34208085	1.8	9	2.16	0.190441245
1	115	1.15	1.513157895	11.43299933	2.2	11	2.64	0.230910536
1.5	178	1.78	2.342105263	11.53004581	2.6	13	3.12	0.270597364
2	245	2.45	3.223684211	11.63507818	3	15	3.6	0.30940918
2.5	315	3.15	4.144736842	11.74687714	3.2	16	3.84	0.326895391
3	365	3.65	4.802631579	11.82805805	3.4	17	4.08	0.344942507
3.5	428	4.28	5.631578947	11.93195761	3.6	18	4.32	0.362052912
4	490	4.9	6.447368421	12.03600563	3.8	19	4.56	0.378863233
4.5	556	5.56	7.315789474	12.1487791	3.8	19	4.56	0.375346359
5	625	6.25	8.223684211	12.26896057	3.8	19	4.56	0.371669627
5.5	685	6.85	9.013157895	12.37541576	4	20	4.8	0.387865757
6	740	7.4	9.736842105	12.47463557	4	20	4.8	0.38478078
6.5	805	8.05	10.59210526	12.59396615	3.8	19	4.56	0.362078153
7	875	8.75	11.51315789	12.72505576	3.6	18	4.32	0.339487707

1.1
Sample 2

Elapsed time	Compression dial reading	Compression dial reading(ΔL)	Strain (ϵ)	Area Ac=Ao/(1-ϵ)	Proving ring	No. of	Axial load (P)	Compressive stress(P/Ac)
(min.)	(ΔL)	(least count = .01mm)	(%)	(cm2)	reading	division	(.24 kg/div)	(kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	65	0.65	0.855263158	11.35713338	1.6	8	1.92	0.169056745
1	124	1.24	1.631578947	11.44676297	2.8	14	3.36	0.293532766
1.5	184	1.84	2.421052632	11.53937433	3.2	16	3.84	0.332773675
2	246	2.46	3.236842105	11.63666032	3.6	18	4.32	0.371240535
2.5	310	3.1	4.078947368	11.7388203	4.2	21	5.04	0.429344676
3	330	3.3	4.342105263	11.77111417	4.4	22	5.28	0.44855567
3.5	398	3.98	5.236842105	11.88225493	4.8	24	5.76	0.484756474
4	450	4.5	5.921052632	11.96867133	4.8	24	5.76	0.481256427
4.5	512	5.12	6.736842105	12.07336343	4.8	24	5.76	0.477083294
5	580	5.8	7.631578947	12.19031339	4.6	23	5.52	0.452818547
5.5	645	6.45	8.486842105	12.30424155	4.6	23	5.52	0.448625783

1.1
Sample 3

Elapsed time	Compression dial reading	Compression dial reading(ΔL)	Strain (ϵ)	Area Ac=Ao/(1-ϵ)	Proving ring	No. of	Axial load (P)	Compressive stress(P/Ac)
(min.)	(ΔL)	(least count = .01mm)	(%)	(cm2)	reading	division	(.24 kg/div)	(kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	55	0.55	0.723684211	11.34208085	1.8	9	2.16	0.190441245
1	115	1.15	1.513157895	11.43299933	2	10	2.4	0.209918669
1.5	178	1.78	2.342105263	11.53004581	2.4	12	2.88	0.249782182
2	245	2.45	3.223684211	11.63507818	2.8	14	3.36	0.288781901
2.5	315	3.15	4.144736842	11.74687714	3	15	3.6	0.306464429
3	365	3.65	4.802631579	11.82805805	3	15	3.6	0.304361036
3.5	428	4.28	5.631578947	11.93195761	3.6	18	4.32	0.362052912
4	490	4.9	6.447368421	12.03600563	3.8	19	4.56	0.378863233
4.5	556	5.56	7.315789474	12.1487791	4	20	4.8	0.39510143
5	625	6.25	8.223684211	12.26896057	4.2	21	5.04	0.410792746
5.5	685	6.85	9.013157895	12.37541576	4.4	22	5.28	0.426652332
6	740	7.4	9.736842105	12.47463557	4.4	22	5.28	0.423258858
6.5	805	8.05	10.59210526	12.59396615	4.2	21	5.04	0.400191643
7	875	8.75	11.51315789	12.72505576	4.2	21	5.04	0.396068991

1.2 Reinforced soil samples (0.25% fiber content)

1.2
Sample 1

Elapsed time (min.)	Compression dial reading (ΔL)	Compression dial reading(ΔL) (least count = .01mm)	Strain (ϵ) (%)	Area Ac=Ao/(1-ϵ) (cm2)	Proving ring reading	No. of division	Axial load (P) (.24 kg/div)	Compressive stress(P/Ac) (kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	55	0.55	0.723684211	11.34208085	1	5	1.2	0.105800692
1	120	1.2	1.578947368	11.44064171	2.2	11	2.64	0.230756287
1.5	180	1.8	2.368421053	11.53315364	3	15	3.6	0.312143592
2	250	2.5	3.289473684	11.6429932	3.2	16	3.84	0.329812097
2.5	310	3.1	4.078947368	11.7388203	3.6	18	4.32	0.368009722
3	374	3.74	4.921052632	11.84278993	3.8	19	4.56	0.385044405
3.5	430	4.3	5.657894737	11.93528591	4.2	21	5.04	0.422277274
4	494	4.94	6.5	12.04278075	4.4	22	5.28	0.438436945
4.5	565	5.65	7.434210526	12.16432125	4.6	23	5.52	0.453786108
5	624	6.24	8.210526316	12.26720183	4.8	24	5.76	0.469544732
5.5	684	6.84	9	12.37362637	5	25	6	0.484902309
6	745	7.45	9.802631579	12.4837345	5.2	26	6.24	0.499850425
6.5	810	8.1	10.65789474	12.60324006	5.4	27	6.48	0.514153501
7	874	8.74	11.5	12.72316384	5.4	27	6.48	0.509307282
7.5	940	9.4	12.36842105	12.84924925	5	25	6	0.466953351

1.2
Sample 2

Elapsed time	Compression dial reading	Compression dial reading(ΔL)	Strain (ϵ)	Area Ac=Ao/(1-ϵ)	Proving ring	No. of	Axial load (P)	Compressive stress(P/Ac)
(min.)	(ΔL)	(least count = .01mm)	(%)	(cm2)	reading	division	(.24 kg/div)	(kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	62	0.62	0.815789474	11.35261343	0.8	4	0.96	0.084562027
1	120	1.2	1.578947368	11.44064171	2	10	2.4	0.209778443
1.5	192	1.92	2.526315789	11.55183585	2.2	11	2.64	0.228535103
2	250	2.5	3.289473684	11.6429932	2.8	14	3.36	0.288585585
2.5	310	3.1	4.078947368	11.7388203	3.2	16	3.84	0.327119753
3	380	3.8	5	11.85263158	3.6	18	4.32	0.364476021
3.5	440	4.4	5.789473684	11.95195531	3.8	19	4.56	0.381527531
4	490	4.9	6.447368421	12.03600563	4.2	21	5.04	0.418743573
4.5	560	5.6	7.368421053	12.15568182	4.8	24	5.76	0.473852482
5	670	6.7	8.815789474	12.34862915	4.8	24	5.76	0.466448537
5.5	690	6.9	9.078947368	12.38437048	4.6	23	5.52	0.4457231

1.2
Sample 3

Elapsed time	Compression dial reading	Compression dial reading(ΔL)	Strain (ϵ)	Area Ac=Ao/(1-ϵ)	Proving ring	No. of	Axial load (P)	Compressive stress(P/Ac)
(min.)	(ΔL)	(least count = .01mm)	(%)	(cm2)	reading	division	(.24 kg/div)	(kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	70	0.7	0.921052632	11.36467463	1.2	6	1.44	0.126708423
1	135	1.35	1.776315789	11.46363027	1.6	8	1.92	0.167486211
1.5	195	1.95	2.565789474	11.55651587	1.8	9	2.16	0.186907544
2	272	2.72	3.578947368	11.6779476	2.2	11	2.64	0.226067122
2.5	325	3.25	4.276315789	11.76302405	2.6	13	3.12	0.265237917
3	390	3.9	5.131578947	11.86907074	2.8	14	3.36	0.283088716
3.5	450	4.5	5.921052632	11.96867133	3.2	16	3.84	0.320837618
4	510	5.1	6.710526316	12.06995769	3.8	19	4.56	0.377797513
4.5	560	5.6	7.368421053	12.15568182	4	20	4.8	0.394877068
5	635	6.35	8.355263158	12.28657574	4.6	23	5.52	0.449270824
5.5	690	6.9	9.078947368	12.38437048	4.8	24	5.76	0.465102365
6	735	7.35	9.671052632	12.46554989	5	25	6	0.48132654
6.5	830	8.3	10.92105263	12.64047267	4.6	23	5.52	0.436692531

1.3 Reinforced soil samples (0.5% fiber content)

1.3
Sample 1

Elapsed time	Compression dial reading	Compression dial reading(ΔL)	Strain (ϵ)	Area Ac=Ao/(1-ϵ)	Proving ring	No. of	Axial load (P)	Compressive stress(P/Ac)
(min.)	(ΔL)	(least count = .01mm)	(%)	(cm2)	reading	division	(.24 kg/div)	(kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	46	0.46	0.605263158	11.32856765	1	5	1.2	0.105926895
1	89	0.89	1.171052632	11.39342298	2	10	2.4	0.210647845
1.5	145	1.45	1.907894737	11.47900738	3.2	16	3.84	0.334523698
2	215	2.15	2.828947368	11.58781313	4	20	4.8	0.414228288
2.5	284	2.84	3.736842105	11.69710224	4.6	23	5.52	0.471911751
3	342	3.42	4.5	11.79057592	5.2	26	6.24	0.529236234
3.5	404	4.04	5.315789474	11.89216231	5.6	28	6.72	0.565078059
4	460	4.6	6.052631579	11.98543417	6	30	7.2	0.600729176
4.5	528	5.28	6.947368421	12.10067873	6.2	31	7.44	0.614841544
5	604	6.04	7.947368421	12.23213265	6.4	32	7.68	0.627854539
5.5	655	6.55	8.618421053	12.32195824	6.6	33	7.92	0.642754978
6	714	7.14	9.394736842	12.42753413	6.8	34	8.16	0.656606525
6.5	776	7.76	10.21052632	12.54044549	7	35	8.4	0.669832663
7	842	8.42	11.07894737	12.66291802	7.2	36	8.64	0.682307189
7.5	917	9.17	12.06578947	12.80502768	7.2	36	8.64	0.674734972
8	970	9.7	12.76315789	12.90739065	7.4	37	8.88	0.687977938
8.5	1026	10.26	13.5	13.01734104	7.6	38	9.12	0.700603908
9	1090	10.9	14.34210526	13.1453149	7.8	39	9.36	0.712040759
9.5	1155	11.55	15.19736842	13.27788984	7.8	39	9.36	0.704931289
10	1233	12.33	16.22368421	13.44055285	7.4	37	8.88	0.660687109

1.3
Sample 2

Elapsed time	Compression dial reading	Compression dial reading(ΔL)	Strain (ϵ)	Area Ac=Ao/(1-ϵ)	Proving ring	No. of	Axial load (P)	Compressive stress(P/Ac)
(min.)	(ΔL)	(least count = .01mm)	(%)	(cm2)	reading	division	(.24 kg/div)	(kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	75	0.75	0.986842105	11.37222591	1.2	6	1.44	0.126624287
1	110	1.1	1.447368421	11.42536716	2.4	12	2.88	0.252070674
1.5	175	1.75	2.302631579	11.52538721	3.2	16	3.84	0.333177526
2	220	2.2	2.894736842	11.59566396	4	20	4.8	0.413947836
2.5	292	2.92	3.842105263	11.70990695	4.6	23	5.52	0.471395718
3	355	3.55	4.671052632	11.81173223	5.2	26	6.24	0.528288305
3.5	44	0.44	0.578947368	11.32556908	5.6	28	6.72	0.593347668
4	475	4.75	6.25	12.01066667	6	30	7.2	0.59946714
4.5	570	5.7	7.5	12.17297297	6.4	32	7.68	0.630905861
5	624	6.24	8.210526316	12.26720183	7	35	8.4	0.684752734
5.5	684	6.84	9	12.37362637	7.2	36	8.64	0.698259325
6	726	7.26	9.552631579	12.44922898	7.2	36	8.64	0.694018884
6.5	792	7.92	10.42105263	12.56991774	7	35	8.4	0.66826213
7	856	8.56	11.26315789	12.68920522	6.8	34	8.16	0.64306628

1.3 Sample 3

Elapsed time (min.)	Compression dial reading (ΔL)	Compression dial reading(ΔL) (least count = .01mm)	Strain (ϵ) (%)	Area Ac=Ao/(1-ϵ) (cm2)	Proving ring reading	No. of division	Axial load (P) (.24 kg/div)	Compressive stress(P/Ac) (kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	55	0.55	0.723684211	11.34208085	1	5	1.2	0.105800692
1	105	1.05	1.381578947	11.41774516	2.2	11	2.64	0.231219033
1.5	160	1.6	2.105263158	11.50215054	3	15	3.6	0.312984949
2	225	2.25	2.960526316	11.60352542	4.4	22	5.28	0.455034122
2.5	290	2.9	3.815789474	11.70670315	4.8	24	5.76	0.492025802
3	350	3.5	4.605263158	11.80358621	5.2	26	6.24	0.528652893
3.5	425	4.25	5.592105263	11.92696864	5.6	28	6.72	0.563428999
4	478	4.78	6.289473684	12.01572592	6	30	7.2	0.599214733
4.5	545	5.45	7.171052632	12.129837	6.2	31	7.44	0.61336356
5	609	6.09	8.013157895	12.24088113	6.6	33	7.92	0.647012246
5.5	664	6.64	8.736842105	12.33794694	7	35	8.4	0.6808264
6	714	7.14	9.394736842	12.42753413	7.2	36	8.64	0.695230438
6.5	776	7.76	10.21052632	12.54044549	7.6	38	9.12	0.727246892
7	842	8.42	11.07894737	12.66291802	7.6	38	9.12	0.720213144
7.5	920	9.2	12.10526316	12.81077844	7.6	38	9.12	0.711900533
8	972	9.72	12.78947368	12.91128546	7.4	37	8.88	0.687770403
8.5	1028	10.28	13.52631579	13.0213025	7.4	37	8.88	0.681959428
9	1096	10.96	14.42105263	13.15744157	7.2	36	8.64	0.656662616

1.4 Reinforced soil samples (0.75% fiber content)

1.4
Sample 1

Elapsed time	Compression dial reading	Compression dial reading(ΔL)	Strain (є)	Area Ac=Ao/(1-є)	Proving ring	No. of	Axial load (P)	Compressive stress(P/Ac)
(min.)	(ΔL)	(least count = .01mm)	(%)	(cm2)	reading	division	(.24 kg/div)	(kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	60	0.6	0.789473684	11.34960212	1.8	9	2.16	0.190315042
1	130	1.3	1.710526316	11.45595716	3.6	18	4.32	0.377096382
1.5	198	1.98	2.605263158	11.56119968	4.8	24	5.76	0.498218192
2	254	2.54	3.342105263	11.64933297	6.2	31	7.44	0.638663177
2.5	310	3.1	4.078947368	11.7388203	7	35	8.4	0.71557446
3	380	3.8	5	11.85263158	7.4	37	8.88	0.74920071
3.5	440	4.4	5.789473684	11.95195531	8	40	9.6	0.803215855
4	508	5.08	6.684210526	12.06655386	8.2	41	9.84	0.815477237
4.5	565	5.65	7.434210526	12.16432125	8.4	42	10.08	0.828652893
5	625	6.25	8.223684211	12.26896057	8.6	43	10.32	0.841147051
5.5	690	6.9	9.078947368	12.38437048	8.6	43	10.32	0.833308404
6	752	7.52	9.894736842	12.49649533	8.6	43	10.32	0.825831542
6.5	820	8.2	10.78947368	12.62182891	8.8	44	10.56	0.836645789
7	875	8.75	11.51315789	12.72505576	8.8	44	10.56	0.829858839
7.5	905	9.05	11.90789474	12.78207618	8.6	43	10.32	0.807380574
8	955	9.55	12.56578947	12.87825433	8.4	42	10.08	0.78271478

1.4
Sample 2

Elapsed time	Compression dial reading	Compression dial reading(ΔL)	Strain (ϵ)	Area Ac=Ao/(1-ϵ)	Proving ring	No. of	Axial load (P)	Compressive stress(P/Ac)
(min.)	(ΔL)	(least count = .01mm)	(%)	(cm2)	reading	division	(.24 kg/div)	(kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	58	0.58	0.763157895	11.34659242	1.4	7	1.68	0.148062073
1	130	1.3	1.710526316	11.45595716	2.8	14	3.36	0.293297186
1.5	203	2.03	2.671052632	11.56901447	3.6	18	4.32	0.373411237
2	262	2.62	3.447368421	11.66203325	4.4	22	5.28	0.452751239
2.5	310	3.1	4.078947368	11.7388203	5.8	29	6.96	0.592904553
3	380	3.8	5	11.85263158	6.6	33	7.92	0.668206039
3.5	440	4.4	5.789473684	11.95195531	7	35	8.4	0.702813873
4	508	5.08	6.684210526	12.06655386	7.4	37	8.88	0.735918482
4.5	565	5.65	7.434210526	12.16432125	7.8	39	9.36	0.769463401
5	632	6.32	8.315789474	12.28128588	8	40	9.6	0.781677106
5.5	692	6.92	9.105263158	12.38795599	8.2	41	9.84	0.794319903
6	752	7.52	9.894736842	12.49649533	8.4	42	10.08	0.806626157
6.5	820	8.2	10.78947368	12.62182891	8.4	42	10.08	0.798616435
7	880	8.8	11.57894737	12.73452381	8.4	42	10.08	0.791549032
7.5	912	9.12	12	12.79545455	8.2	41	9.84	0.769023091
8	955	9.55	12.56578947	12.87825433	8	40	9.6	0.745442647

1.4
Sample 3

Elapsed time	Compression dial reading	Compression dial reading(ΔL)	Strain (ϵ)	Area Ac=Ao/(1-ϵ)	Proving ring	No. of	Axial load (P)	Compressive stress(P/Ac)
(min.)	(ΔL)	(least count = .01mm)	(%)	(cm2)	reading	division	(.24 kg/div)	(kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	62	0.62	0.815789474	11.35261343	1.6	8	1.92	0.169124053
1	144	1.44	1.894736842	11.47746781	2.4	12	2.88	0.250926428
1.5	206	2.06	2.710526316	11.57370841	3.8	19	4.56	0.393996448
2	262	2.62	3.447368421	11.66203325	5	25	6	0.514490044
2.5	324	3.24	4.263157895	11.76140737	5.8	29	6.96	0.591765916
3	378	3.78	4.973684211	11.84934921	6.6	33	7.92	0.668391138
3.5	424	4.24	5.578947368	11.92530658	7.2	36	8.64	0.724509676
4	512	5.12	6.736842105	12.07336343	7.8	39	9.36	0.775260353
4.5	578	5.78	7.605263158	12.18684136	8	40	9.6	0.787734879
5	620	6.2	8.157894737	12.26017192	8.4	42	10.08	0.822174441
5.5	692	6.92	9.105263158	12.38795599	8.6	43	10.32	0.833067215
6	735	7.35	9.671052632	12.46554989	8.6	43	10.32	0.827881649
6.5	810	8.1	10.65789474	12.60324006	8.6	43	10.32	0.818837057
7	875	8.75	11.51315789	12.72505576	8.4	42	10.08	0.792137983
7.5	920	9.2	12.10526316	12.81077844	8	40	9.6	0.749368982

1.5 Reinforced soil samples (1% fiber content)

1.5 Sample 1

Elapsed time	Compression dial reading	Compression dial reading(∆L)	Strain (є)	Area Ac=Ao/(1-є)	Proving ring	No. of	Axial load (P)	Compressive stress(P/Ac)
(min.)	(∆L)	(least count = .01mm)	(%)	(cm2)	reading	division	(.24 kg/div)	(kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	54	0.54	0.710526316	11.34057779	1.2	6	1.44	0.126977657
1	119	1.19	1.565789474	11.43911242	1.8	9	2.16	0.188825839
1.5	185	1.85	2.434210526	11.54093055	2.4	12	2.88	0.249546602
2	256	2.56	3.368421053	11.65250545	2.8	14	3.36	0.288350005
2.5	312	3.12	4.105263158	11.74204171	3	15	3.6	0.306590633
3	370	3.7	4.868421053	11.8362379	3.4	17	4.08	0.344704123
3.5	432	4.32	5.684210526	11.93861607	3.8	19	4.56	0.381953819
4	495	4.95	6.513157895	12.04447572	4.2	21	5.04	0.418449098
4.5	565	5.65	7.434210526	12.16432125	5	25	6	0.49324577
5	624	6.24	8.210526316	12.26720183	5.4	27	6.48	0.528237824
5.5	688	6.88	9.052631579	12.38078704	5.8	29	6.96	0.562161354
6	745	7.45	9.802631579	12.4837345	6.6	33	7.92	0.63442554
6.5	810	8.1	10.65789474	12.60324006	7	35	8.4	0.666495279
7	874	8.74	11.5	12.72316384	7.4	37	8.88	0.697939609
7.5	940	9.4	12.36842105	12.84924925	7.6	38	9.12	0.709769094
8	1006	10.06	13.23684211	12.97785866	7.8	39	9.36	0.721228382
8.5	1080	10.8	14.21052632	13.12515337	8	40	9.6	0.731420024
9	1140	11.4	15	13.24705882	7.6	38	9.12	0.688454707

1.5
Sample 2

Elapsed time (min.)	Compression dial reading (ΔL)	Compression dial reading(ΔL) (least count = .01mm)	Strain (є) (%)	Area Ac=Ao/(1-є) (cm2)	Proving ring reading	No. of division	Axial load (P) (.24 kg/div)	Compressive stress(P/Ac) (kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	60	0.6	0.789473684	11.34960212	1.2	6	1.44	0.126876694
1	119	1.19	1.565789474	11.43911242	2	10	2.4	0.209806488
1.5	185	1.85	2.434210526	11.54093055	2.8	14	3.36	0.291137702
2	262	2.62	3.447368421	11.66203325	3	15	3.6	0.308694026
2.5	312	3.12	4.105263158	11.74204171	3.6	18	4.32	0.367908759
3	372	3.72	4.894736842	11.839513	4	20	4.8	0.405422081
3.5	432	4.32	5.684210526	11.93861607	4.2	21	5.04	0.422159484
4	503	5.03	6.618421053	12.0580527	4.8	24	5.76	0.477689072
4.5	576	5.76	7.578947368	12.1833713	5.4	27	6.48	0.531872488
5	624	6.24	8.210526316	12.26720183	5.8	29	6.96	0.567366551
5.5	688	6.88	9.052631579	12.38078704	6.2	31	7.44	0.600931102
6	750	7.5	9.868421053	12.49284672	6.8	34	8.16	0.653173787
6.5	810	8.1	10.65789474	12.60324006	7	35	8.4	0.666495279
7	874	8.74	11.5	12.72316384	7.4	37	8.88	0.697939609
7.5	950	9.5	12.5	12.86857143	7.6	38	9.12	0.708703375
8	1012	10.12	13.31578947	12.9896782	7.8	39	9.36	0.720572123
8.5	1092	10.92	14.36842105	13.14935464	7.4	37	8.88	0.675318314

1.5
Sample 3

Elapsed time	Compression dial reading	Compression dial reading(ΔL)	Strain (ϵ)	Area Ac=Ao/(1-ϵ)	Proving ring	No. of	Axial load (P)	Compressive stress(P/Ac)
(min.)	(ΔL)	(least count = .01mm)	(%)	(cm2)	reading	division	(.24 kg/div)	(kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	54	0.54	0.710526316	11.34057779	1	5	1.2	0.105814714
1	119	1.19	1.565789474	11.43911242	1.8	9	2.16	0.188825839
1.5	185	1.85	2.434210526	11.54093055	2	10	2.4	0.207955502
2	256	2.56	3.368421053	11.65250545	2.8	14	3.36	0.288350005
2.5	312	3.12	4.105263158	11.74204171	3.4	17	4.08	0.347469384
3	370	3.7	4.868421053	11.8362379	3.8	19	4.56	0.385257549
3.5	432	4.32	5.684210526	11.93861607	4.6	23	5.52	0.462365149
4	495	4.95	6.513157895	12.04447572	5	25	6	0.498153688
4.5	565	5.65	7.434210526	12.16432125	5.8	29	6.96	0.572165093
5	624	6.24	8.210526316	12.26720183	6.4	32	7.68	0.626059643
5.5	688	6.88	9.052631579	12.38078704	6.8	34	8.16	0.659085725
6	745	7.45	9.802631579	12.4837345	7.4	37	8.88	0.711325605
6.5	810	8.1	10.65789474	12.60324006	7.6	38	9.12	0.723623446
7	874	8.74	11.5	12.72316384	7.4	37	8.88	0.697939609

ANNEXURE II

2.1 Reinforced Soil Sample (l/d=20)

2.1
Sample 1

Elapsed time	Compression dial reading	Compression dial reading(ΔL)	Strain (ϵ)	Area Ac=Ao/(1-ϵ)	Proving ring	No. of	Axial load (P)	Compressive stress(P/Ac)
(min.)	(ΔL)	(least count = .01mm)	(%)	(cm2)	reading	division	(.24 kg/div)	(kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	58	0.58	0.763157895	11.34659242	0.8	4	0.96	0.084606899
1	132	1.32	1.736842105	11.45902517	1.4	7	1.68	0.14660933
1.5	2.6	0.026	0.034210526	11.26385342	1.8	9	2.16	0.191763859
2	262	2.62	3.447368421	11.66203325	2.2	11	2.64	0.226375619
2.5	315	3.15	4.144736842	11.74687714	2.6	13	3.12	0.265602505
3	390	3.9	5.131578947	11.86907074	3	15	3.6	0.303309339
3.5	442	4.42	5.815789474	11.95529478	3.8	19	4.56	0.381420959
4	502	5.02	6.605263158	12.0563539	4.2	21	5.04	0.418036833
4.5	570	5.7	7.5	12.17297297	4.8	24	5.76	0.473179396
5	630	6.3	8.289473684	12.27776184	5.4	27	6.48	0.527783491
5.5	690	6.9	9.078947368	12.38437048	5.8	29	6.96	0.561998691
6	760	7.6	10	12.51111111	5.8	29	6.96	0.556305506
6.5	830	8.3	10.92105263	12.64047267	5.6	28	6.72	0.531625689
7	880	8.8	11.57894737	12.73452381	5.6	28	6.72	0.527699355

2.1
Sample 2

Elapsed time	Compression dial reading	Compression dial reading(ΔL)	Strain (ϵ)	Area Ac=Ao/(1-ϵ)	Proving ring	No. of	Axial load (P)	Compressive stress(P/Ac)
(min.)	(ΔL)	(least count = .01mm)	(%)	(cm2)	reading	division	(.24 kg/div)	(kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	58	0.58	0.763157895	11.34659242	1	5	1.2	0.105758624
1	142	1.42	1.868421053	11.47438992	1.4	7	1.68	0.146413013
1.5	198	1.98	2.605263158	11.56119968	1.8	9	2.16	0.186831822
2	254	2.54	3.342105263	11.64933297	2.4	12	2.88	0.247224455
2.5	310	3.1	4.078947368	11.7388203	2.8	14	3.36	0.286229784
3	380	3.8	5	11.85263158	3.4	17	4.08	0.344227353
3.5	440	4.4	5.789473684	11.95195531	3.8	19	4.56	0.381527531
4	520	5.2	6.842105263	12.08700565	4	20	4.8	0.397120688
4.5	565	5.65	7.434210526	12.16432125	4.6	23	5.52	0.453786108
5	632	6.32	8.315789474	12.28128588	4.8	24	5.76	0.469006263
5.5	710	7.1	9.342105263	12.4203193	5.4	27	6.48	0.521725717
6	760	7.6	10	12.51111111	5.8	29	6.96	0.556305506
6.5	830	8.3	10.92105263	12.64047267	5.8	29	6.96	0.550612321
7	875	8.75	11.51315789	12.72505576	5.8	29	6.96	0.546952417
7.5	920	9.2	12.10526316	12.81077844	5.6	28	6.72	0.524558287

2.1
Sample 3

Elapsed time	Compression dial reading	Compression dial reading(ΔL)	Strain (ϵ)	Area Ac=Ao/(1-ϵ)	Proving ring	No. of	Axial load (P)	Compressive stress(P/Ac)
(min.)	(ΔL)	(least count = .01mm)	(%)	(cm2)	reading	division	(.24 kg/div)	(kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	48	0.48	0.631578947	11.3315678	1.2	6	1.44	0.12707862
1	112	1.12	1.473684211	11.4284188	2	10	2.4	0.210002805
1.5	170	1.7	2.236842105	11.51763122	2.8	14	3.36	0.291726652
2	224	2.24	2.947368421	11.60195228	3.4	17	4.08	0.351664953
2.5	276	2.76	3.631578947	11.68432551	3.8	19	4.56	0.39026643
3	345	3.45	4.539473684	11.79545141	4.2	21	5.04	0.42728335
3.5	402	4.02	5.289473684	11.88885802	5	25	6	0.504674208
4	480	4.8	6.315789474	12.01910112	5.8	29	6.96	0.579078246
4.5	530	5.3	6.973684211	12.10410184	6.2	31	7.44	0.614667664
5	601	6.01	7.907894737	12.22688956	6.4	32	7.68	0.628123773
5.5	685	6.85	9.013157895	12.37541576	6.2	31	7.44	0.601191923

2.2 Reinforced soil samples (l/d=60)

2.2
Sample1

Elapsed time	Compression dial reading	Compression dial reading(ΔL)	Strain (ϵ)	Area Ac=Ao/(1-ϵ)	Proving ring	No. of	Axial load (P)	Compressive stress(P/Ac)
(min.)	(ΔL)	(least count = .01mm)	(%)	(cm2)	reading	division	(.24 kg/div)	(kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	60	0.6	0.789473684	11.34960212	1.2	6	1.44	0.126876694
1	130	1.3	1.710526316	11.45595716	1.8	9	2.16	0.188548191
1.5	198	1.98	2.605263158	11.56119968	2.4	12	2.88	0.249109096
2	254	2.54	3.342105263	11.64933297	2.8	14	3.36	0.288428531
2.5	310	3.1	4.078947368	11.7388203	3.4	17	4.08	0.347564738
3	380	3.8	5	11.85263158	4	20	4.8	0.404973357
3.5	440	4.4	5.789473684	11.95195531	4.8	24	5.76	0.481929513
4	508	5.08	6.684210526	12.06655386	5.2	26	6.24	0.517131906
4.5	565	5.65	7.434210526	12.16432125	5.6	28	6.72	0.552435262
5	625	6.25	8.223684211	12.26896057	5.8	29	6.96	0.56728522
5.5	690	6.9	9.078947368	12.38437048	6	30	7.2	0.581377956
6	752	7.52	9.894736842	12.49649533	6.2	31	7.44	0.595366925
6.5	820	8.2	10.78947368	12.62182891	6.4	32	7.68	0.608469664
7	875	8.75	11.51315789	12.72505576	6.4	32	7.68	0.603533701
7.5	905	9.05	11.90789474	12.78207618	6	30	7.2	0.563288773

2.2
Sample 2

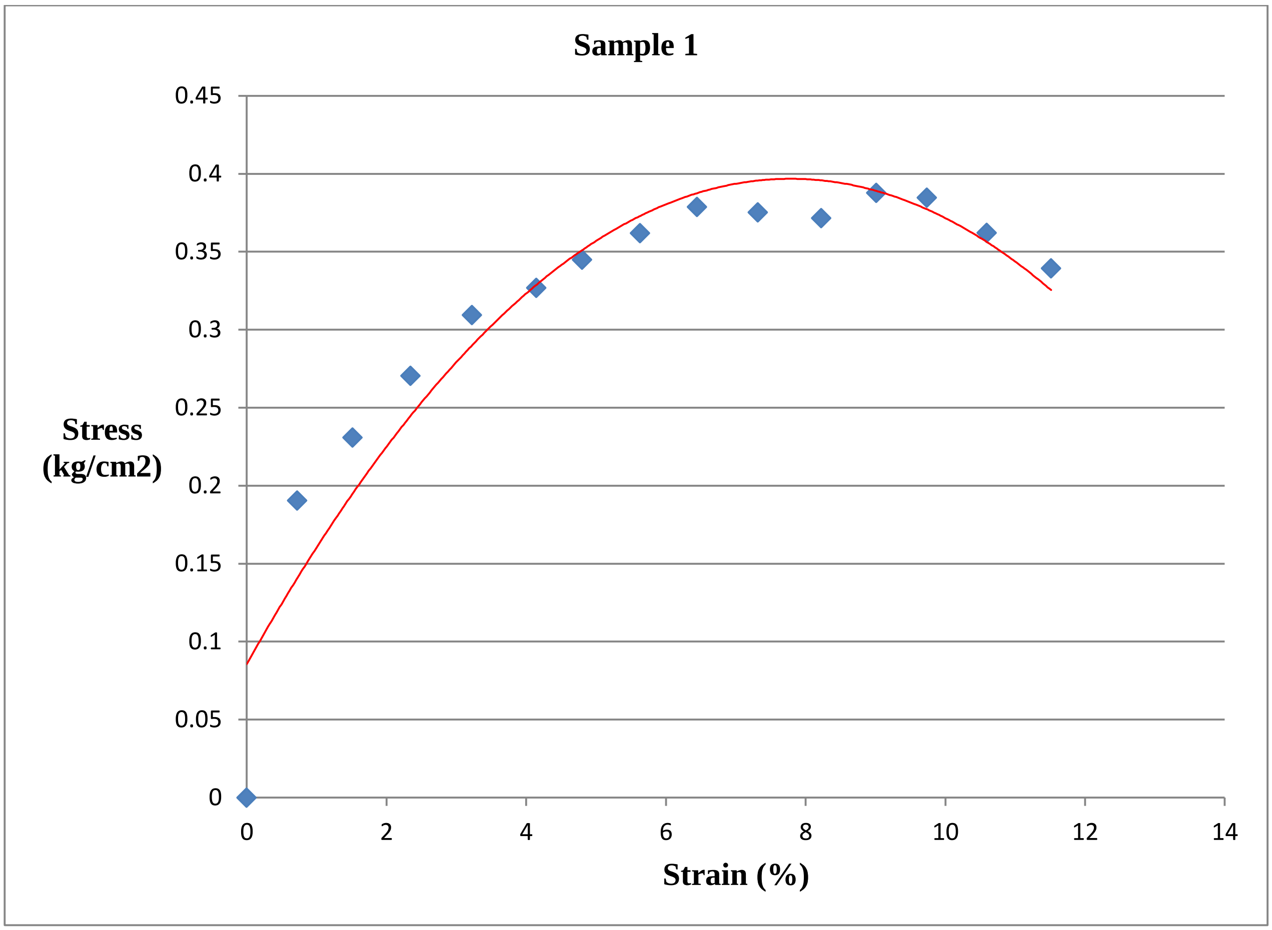
Elapsed time	Compression dial reading	Compression dial reading(ΔL)	Strain (ϵ)	Area Ac=Ao/(1-ϵ)	Proving ring	No. of	Axial load (P)	Compressive stress(P/Ac)
(min.)	(ΔL)	(least count = .01mm)	(%)	(cm2)	reading	division	(.24 kg/div)	(kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	58	0.58	0.763157895	11.34659242	1	5	1.2	0.105758624
1	130	1.3	1.710526316	11.45595716	1.8	9	2.16	0.188548191
1.5	198	1.98	2.605263158	11.56119968	2.2	11	2.64	0.228350005
2	262	2.62	3.447368421	11.66203325	2.6	13	3.12	0.267534823
2.5	310	3.1	4.078947368	11.7388203	3	15	3.6	0.306674769
3	282	2.82	3.710526316	11.69390544	3.6	18	4.32	0.369423203
3.5	462	4.62	6.078947368	11.98879238	4.2	21	5.04	0.420392633
4	508	5.08	6.684210526	12.06655386	4.8	24	5.76	0.477352529
4.5	565	5.65	7.434210526	12.16432125	5.2	26	6.24	0.512975601
5	632	6.32	8.315789474	12.28128588	5.6	28	6.72	0.547173974
5.5	690	6.9	9.078947368	12.38437048	6.2	31	7.44	0.600757222
6	748	7.48	9.842105263	12.48920023	6.8	34	8.16	0.653364495
6.5	832	8.32	10.94736842	12.64420804	6.8	34	8.16	0.645354772
7	875	8.75	11.51315789	12.72505576	6.4	32	7.68	0.603533701

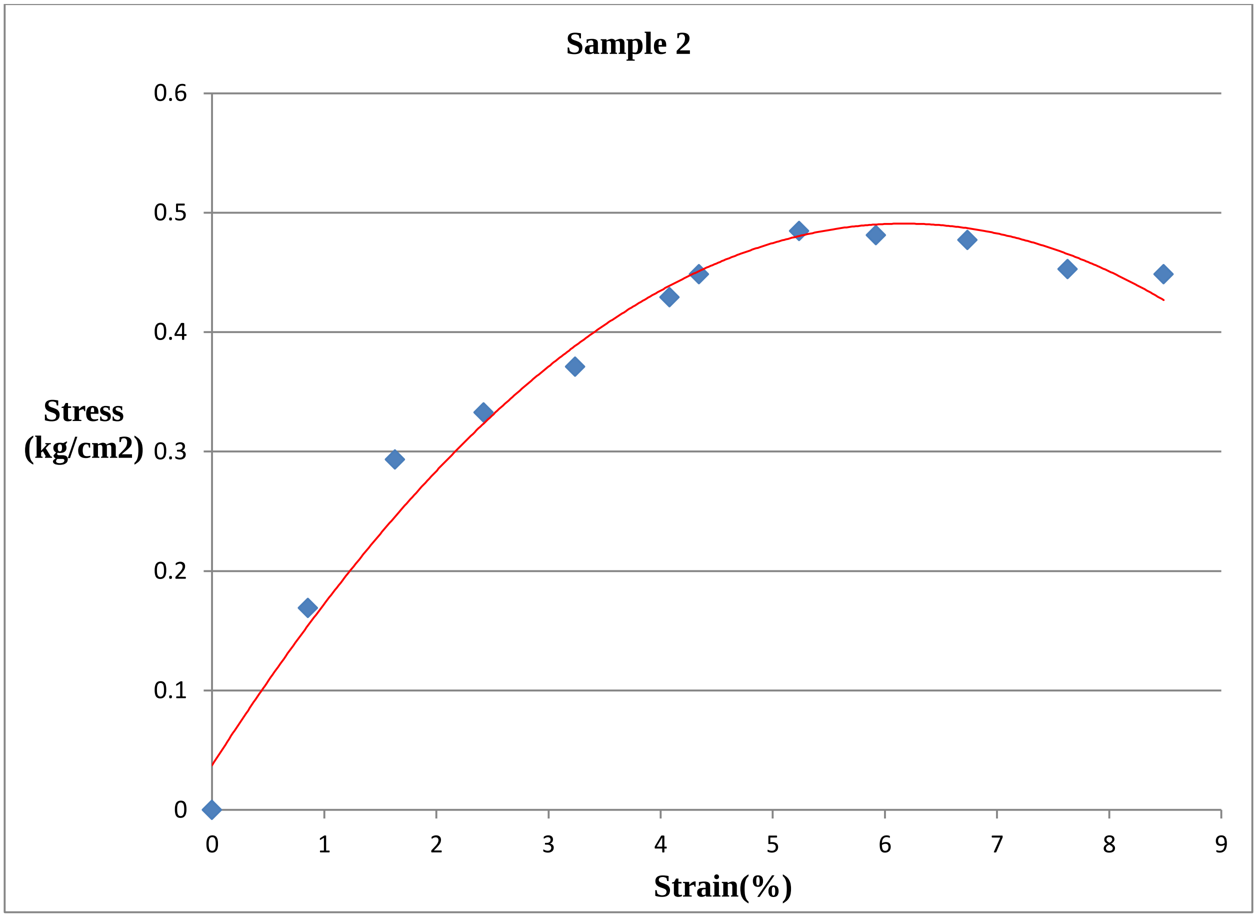
2.2
Sample 3

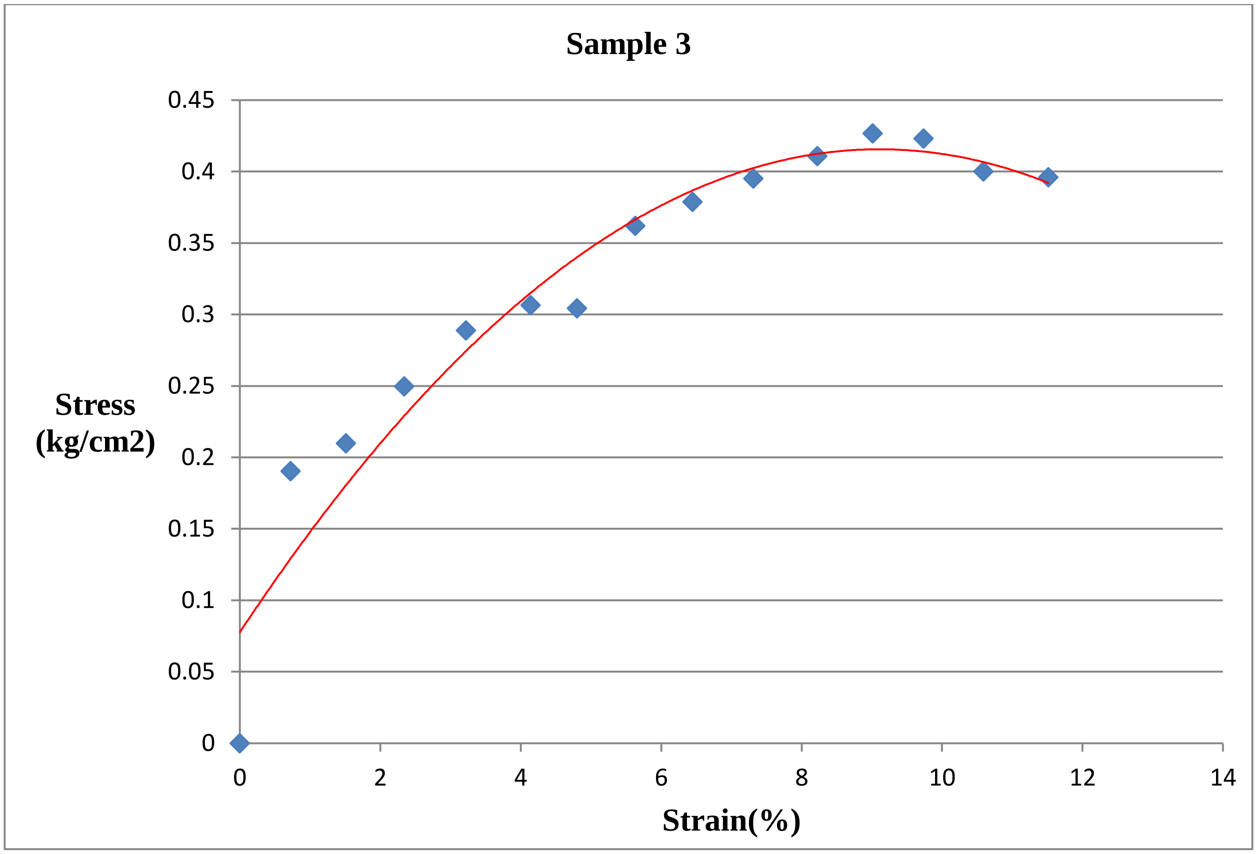
Elapsed time	Compression dial reading	Compression dial reading(ΔL)	Strain (є)	Area Ac=Ao/(1-є)	Proving ring	No. of	Axial load (P)	Compressive stress(P/Ac)
(min.)	(ΔL)	(least count = .01mm)	(%)	(cm2)	reading	division	(.24 kg/div)	(kg/cm2)
0	0	0	0	11.26	0	0	0	0
0.5	60	0.6	0.789473684	11.34960212	1.2	6	1.44	0.126876694
1	130	1.3	1.710526316	11.45595716	1.8	9	2.16	0.188548191
1.5	198	1.98	2.605263158	11.56119968	2.4	12	2.88	0.249109096
2	254	2.54	3.342105263	11.64933297	2.8	14	3.36	0.288428531
2.5	310	3.1	4.078947368	11.7388203	3.6	18	4.32	0.368009722
3	380	3.8	5	11.85263158	4	20	4.8	0.404973357
3.5	440	4.4	5.789473684	11.95195531	4.8	24	5.76	0.481929513
4	508	5.08	6.684210526	12.06655386	5.2	26	6.24	0.517131906
4.5	565	5.65	7.434210526	12.16432125	5.8	29	6.96	0.572165093
5	625	6.25	8.223684211	12.26896057	6	30	7.2	0.586846779
5.5	690	6.9	9.078947368	12.38437048	6.2	31	7.44	0.600757222
6	752	7.52	9.894736842	12.49649533	6	30	7.2	0.576161541

ANNEXURE III

3.1 Black soil samples

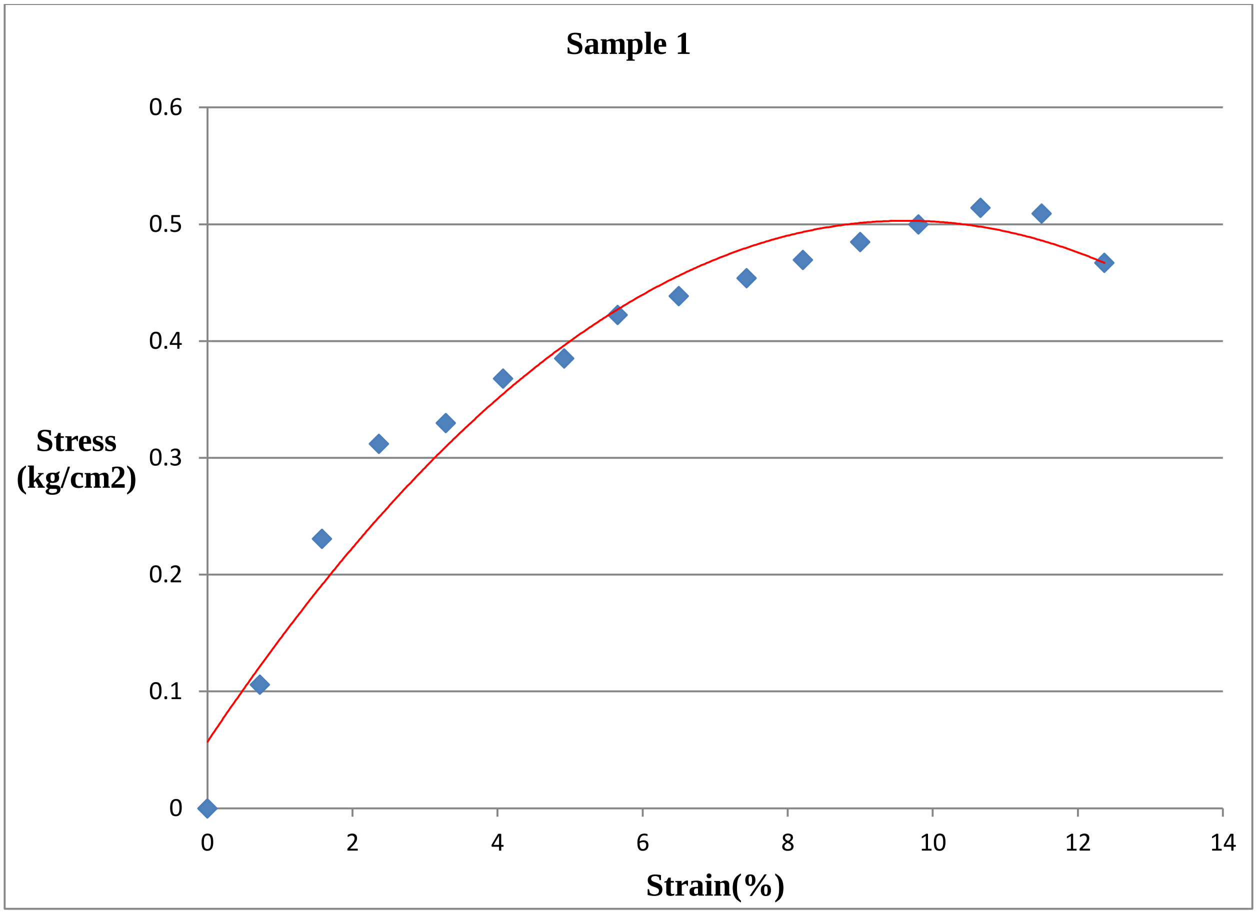


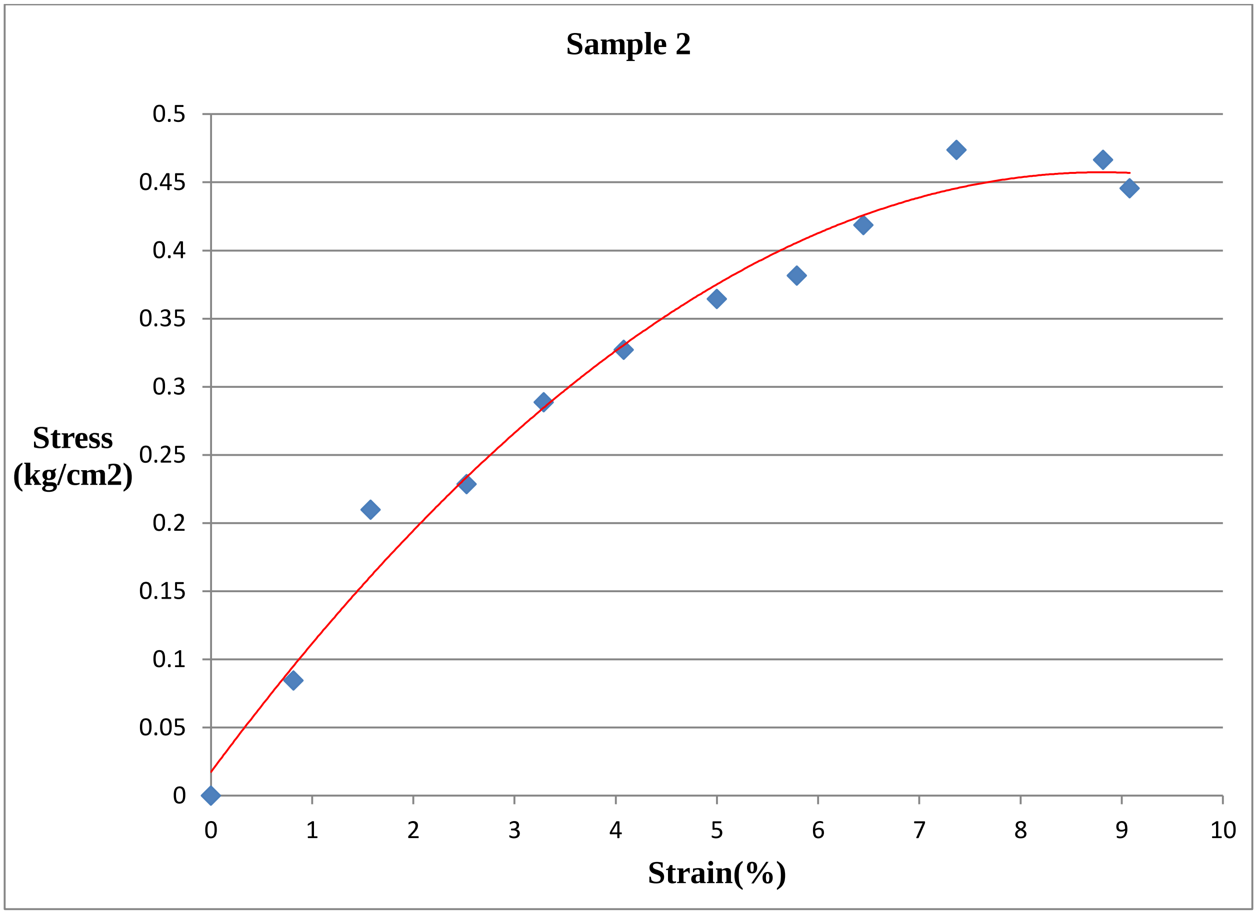

Sample 2
Stress (kg/cm2)
0
0.1
0.2
0.3
0.4
0.5
0.6
0
1
2
3
4
5
6
7
8
9
Strain(%)

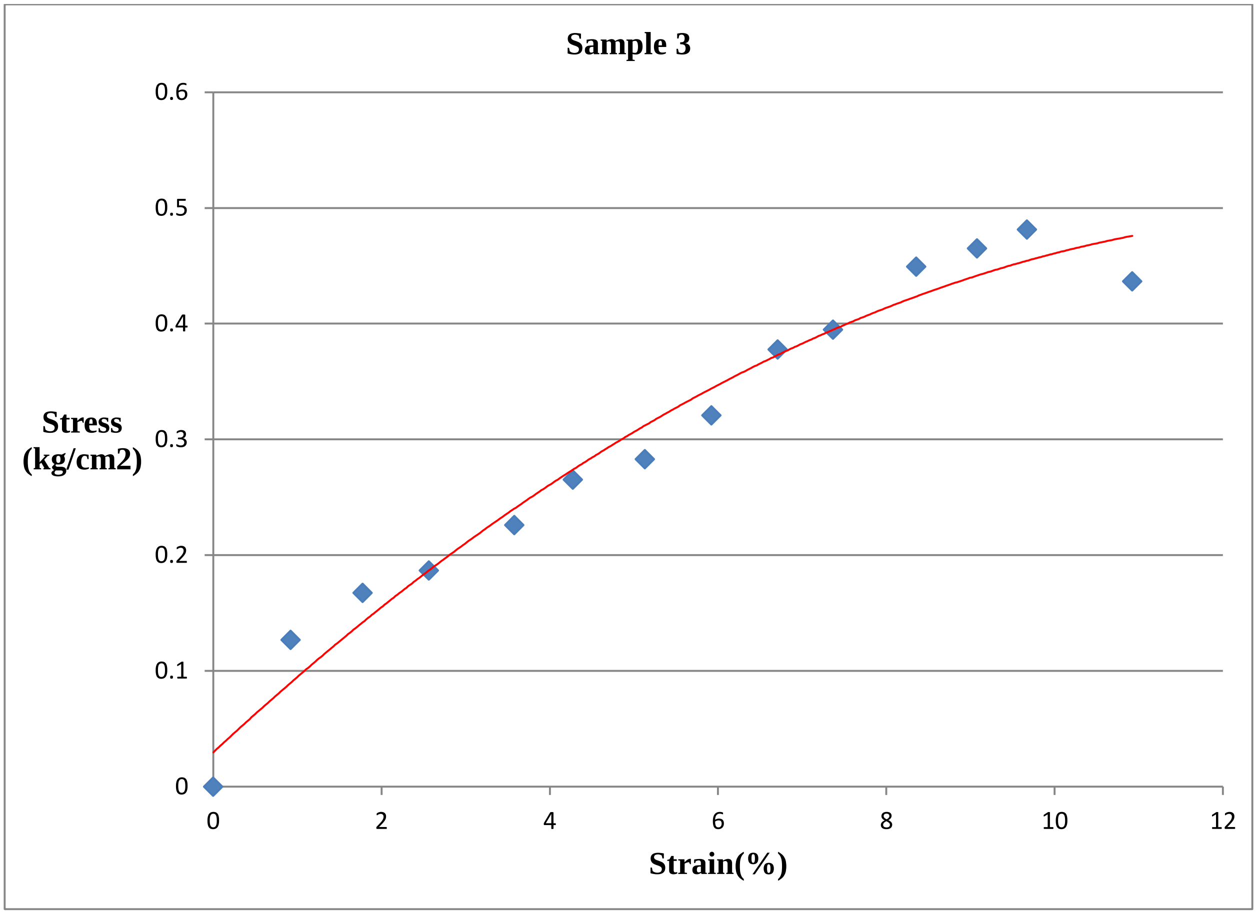

Sample 3
Stress (kg/cm2)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10
12
14
Strain(%)

3.2 Reinforced black soil samples

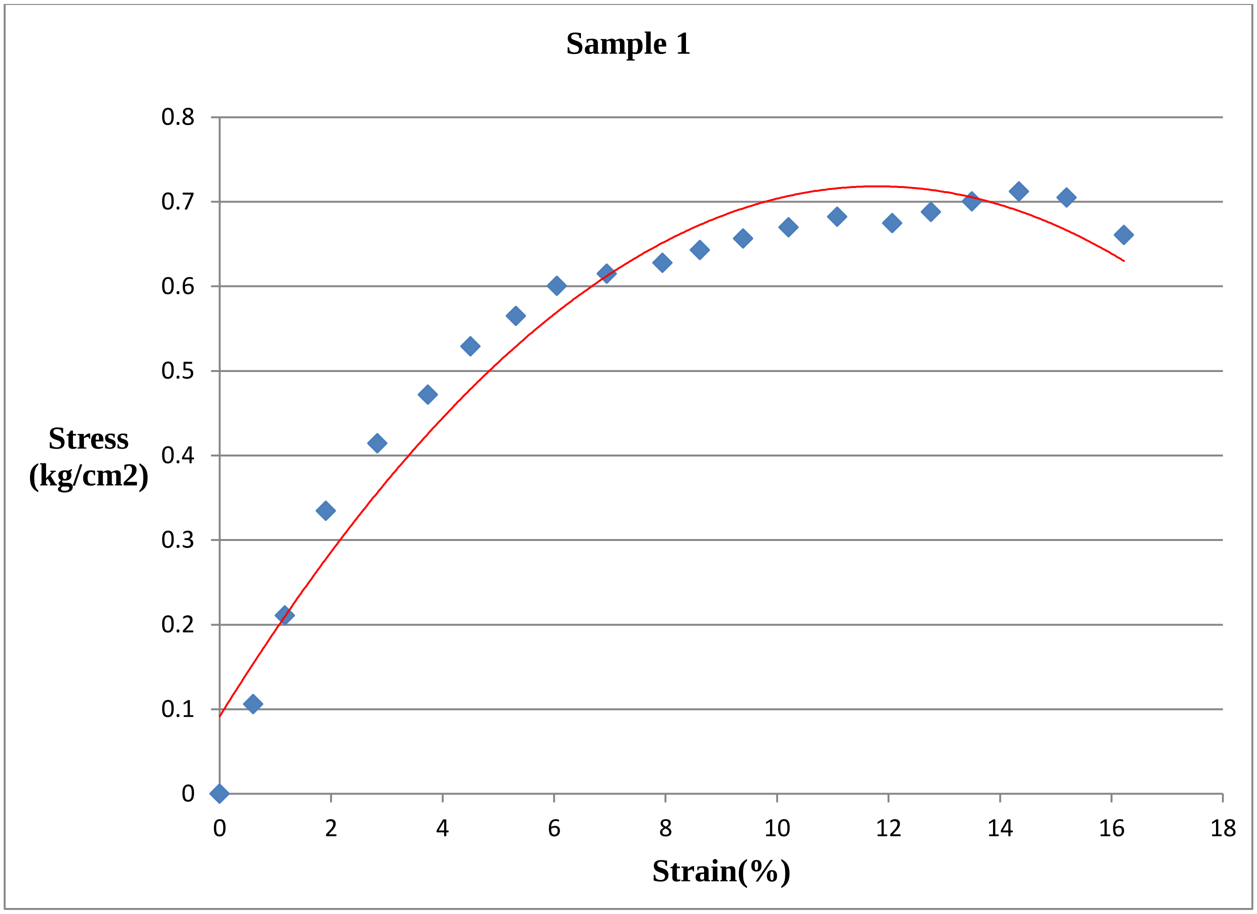
3.2.1 Reinforced with 0.25% polyester fiber

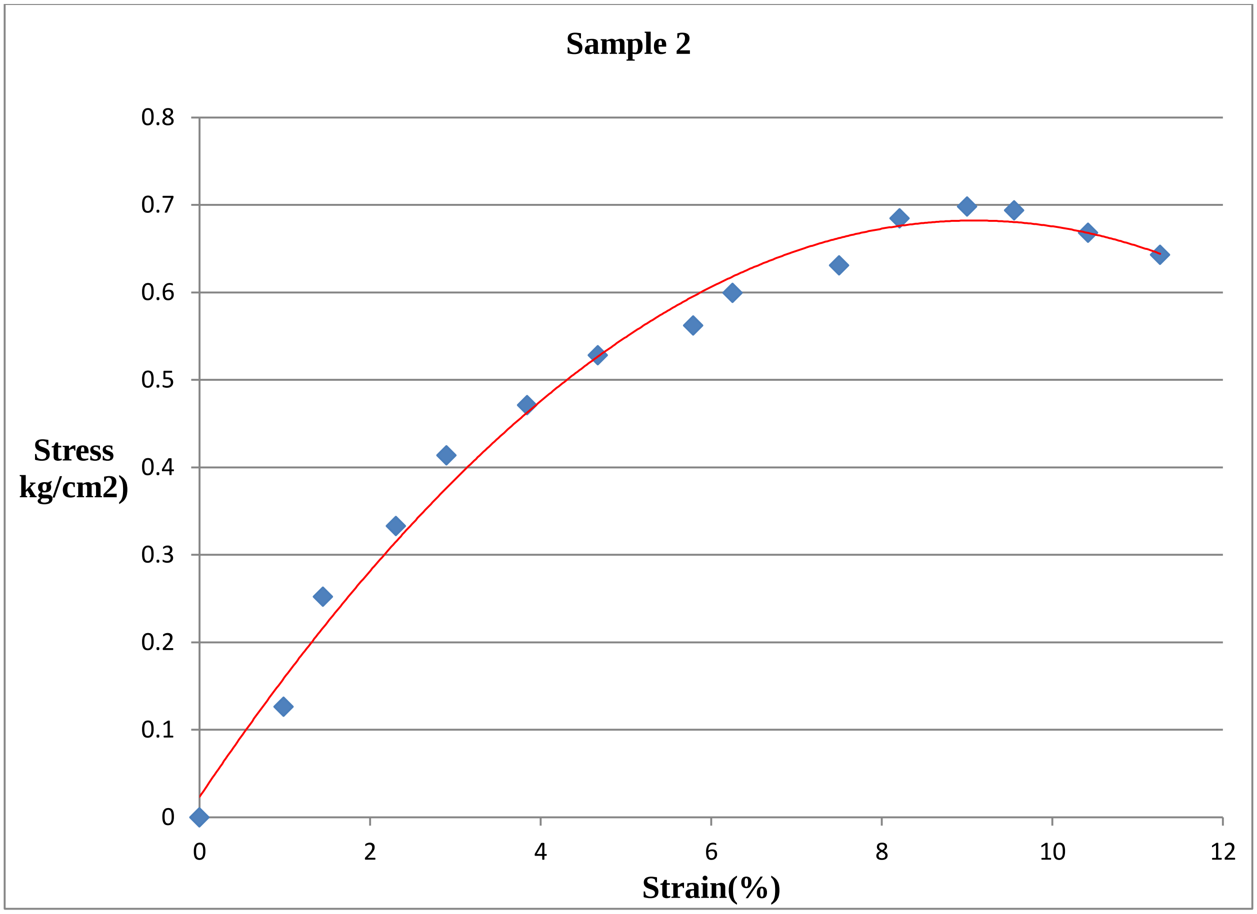


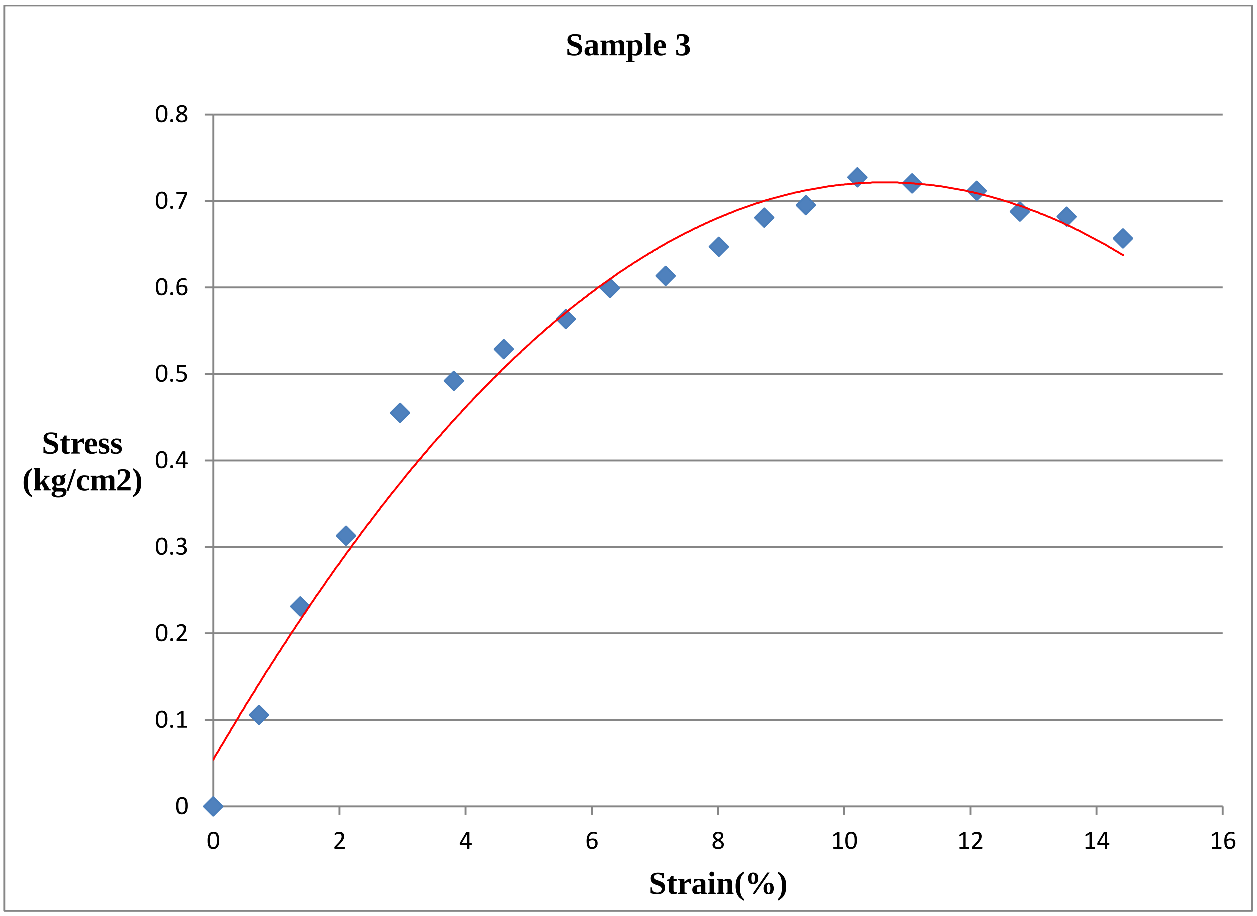

Sample 2
Stress (kg/cm2)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
1
2
3
4
5
6
7
8
9
10
Strain(%)


Sample 3
Stress (kg/cm2)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
Strain(%)

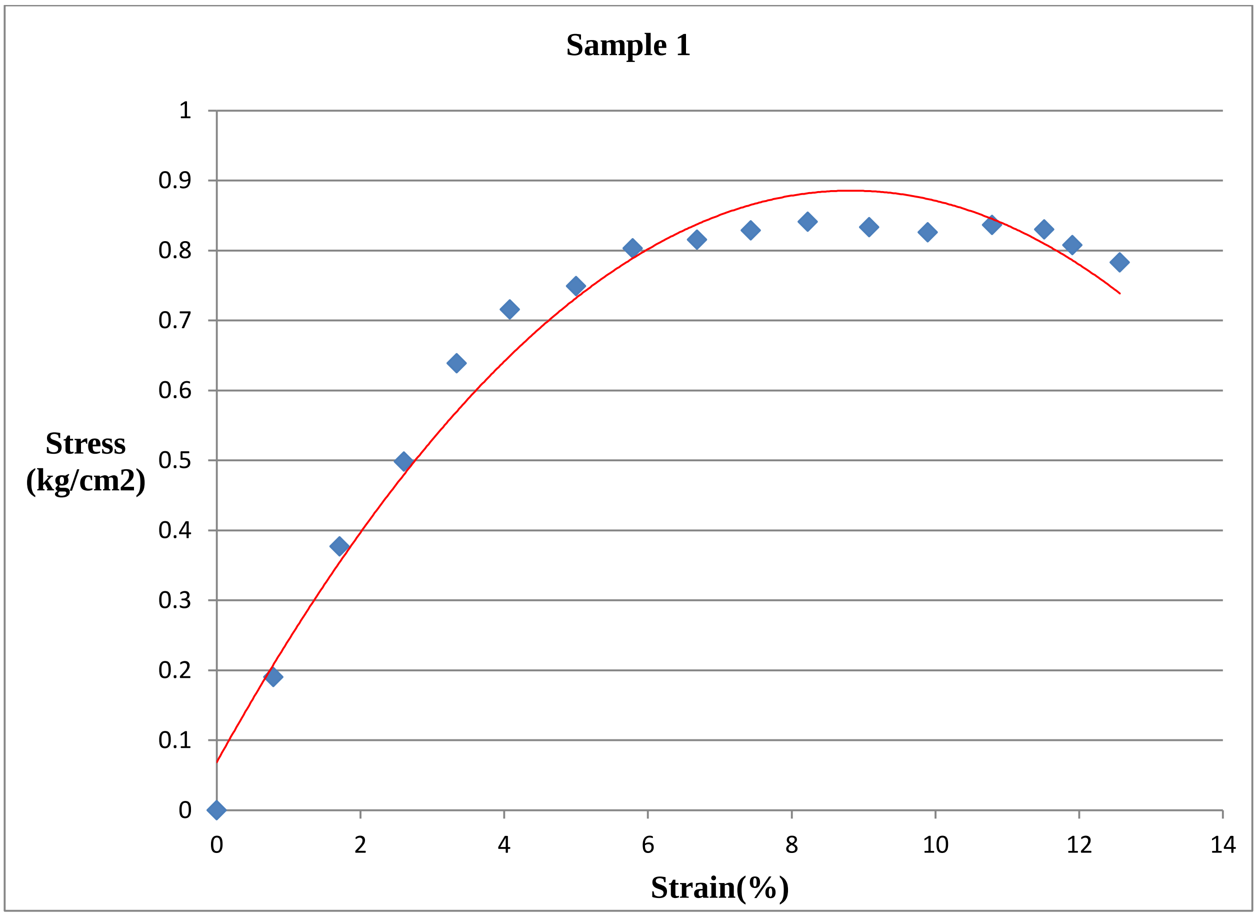
3.2.2 Reinforced with 0.50% polyester fiber

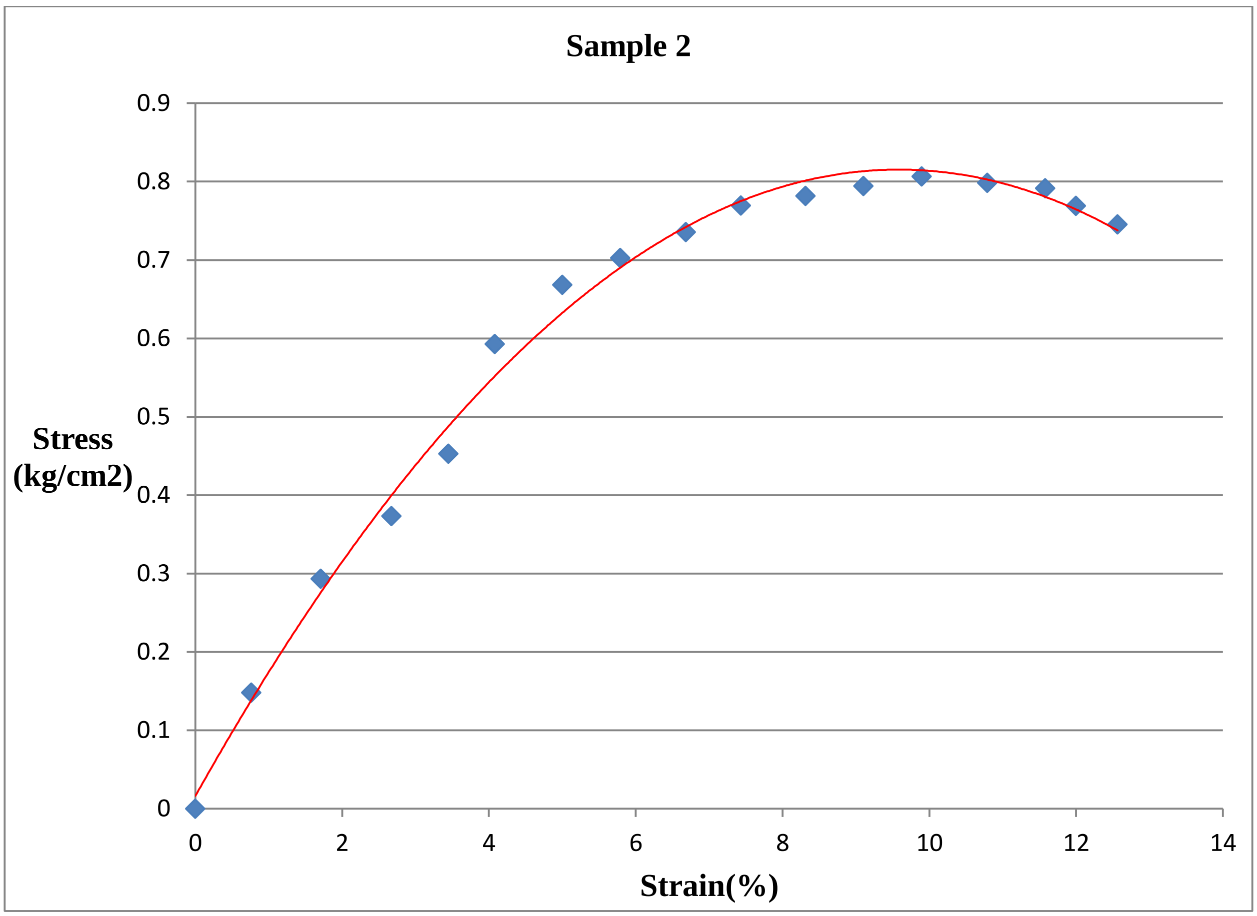


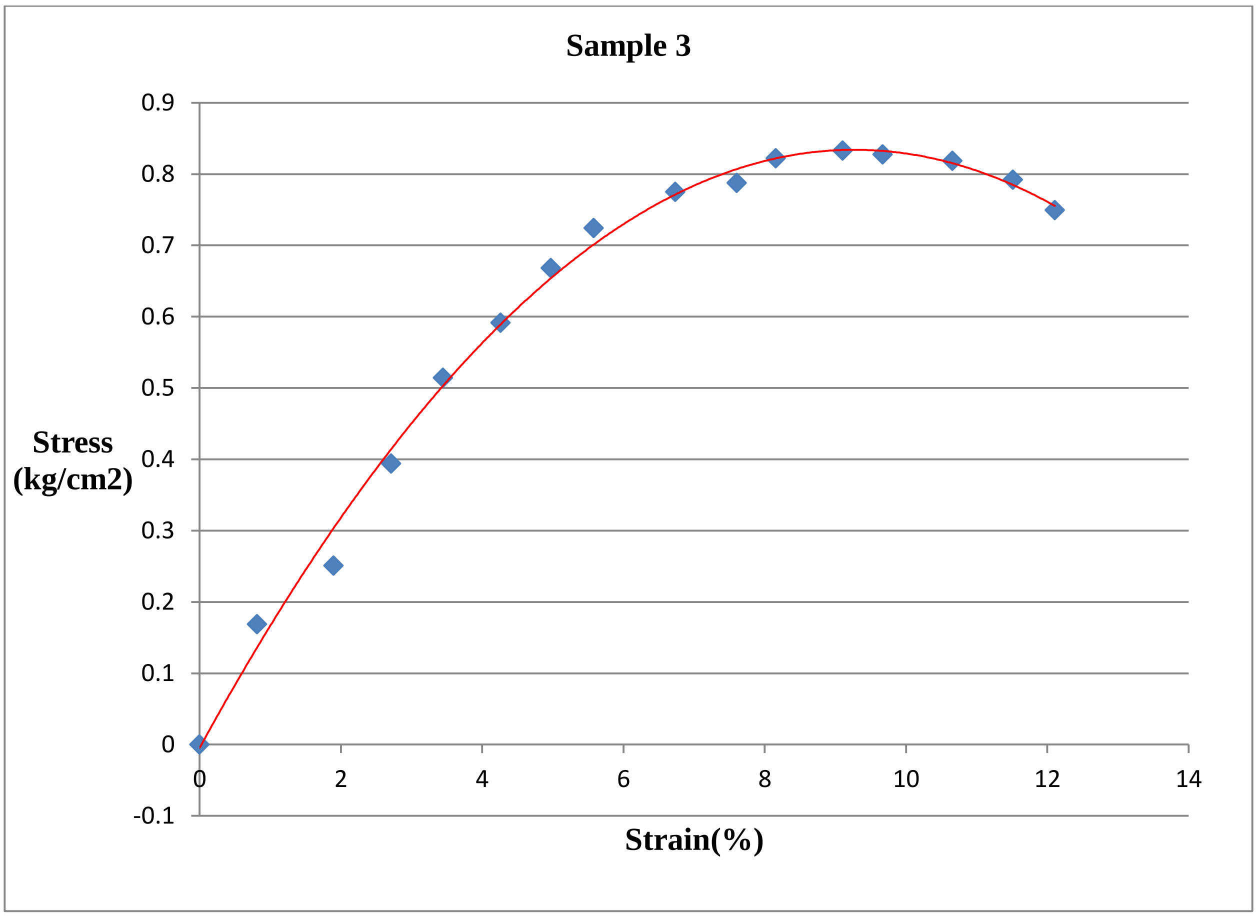

Sample 2
Stress kg/cm2)
Strain(%)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12


Sample 3
Stress (kg/cm2)
Strain(%)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
2
4
6
8
10
12
14
16

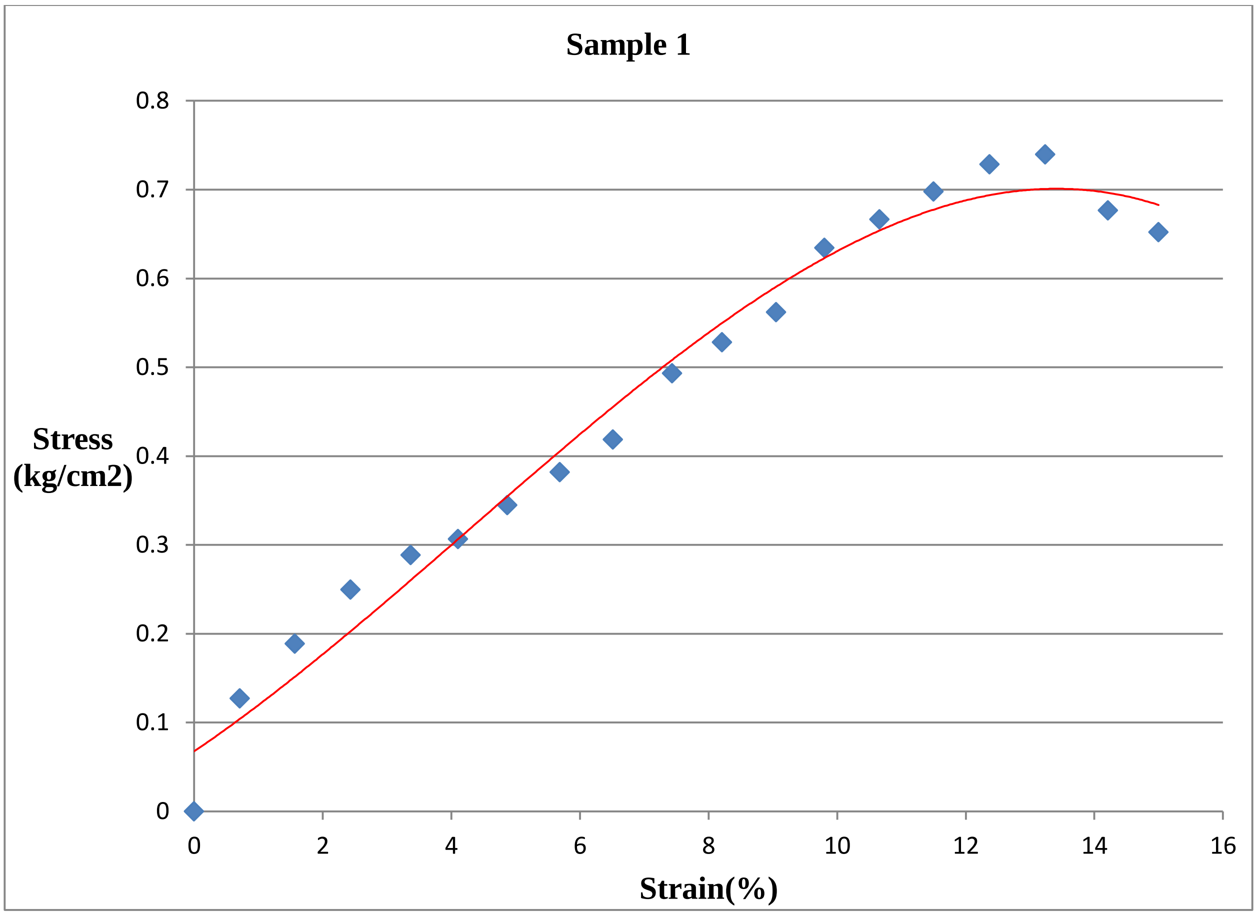
3.2.3 Reinforced with 0.75% polyester fiber

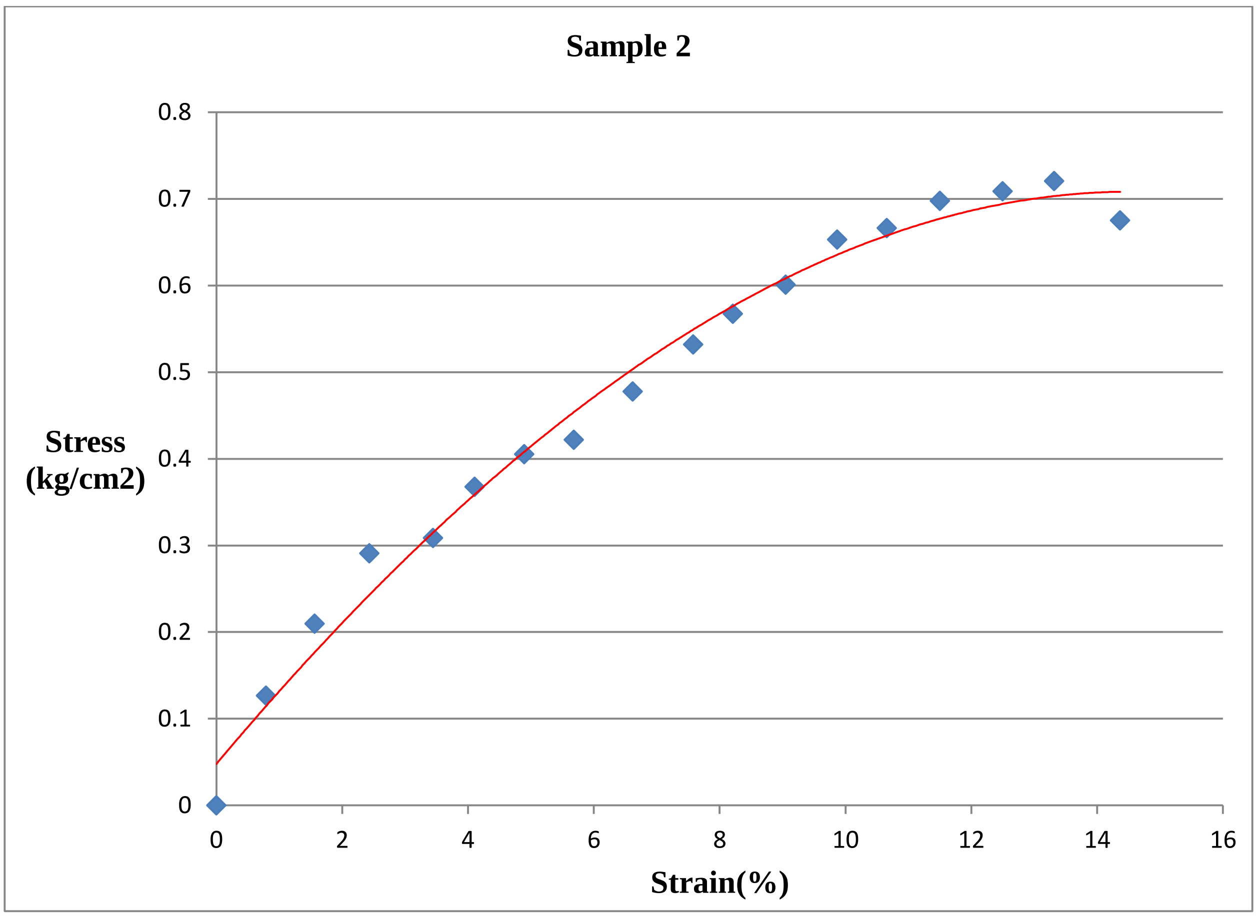


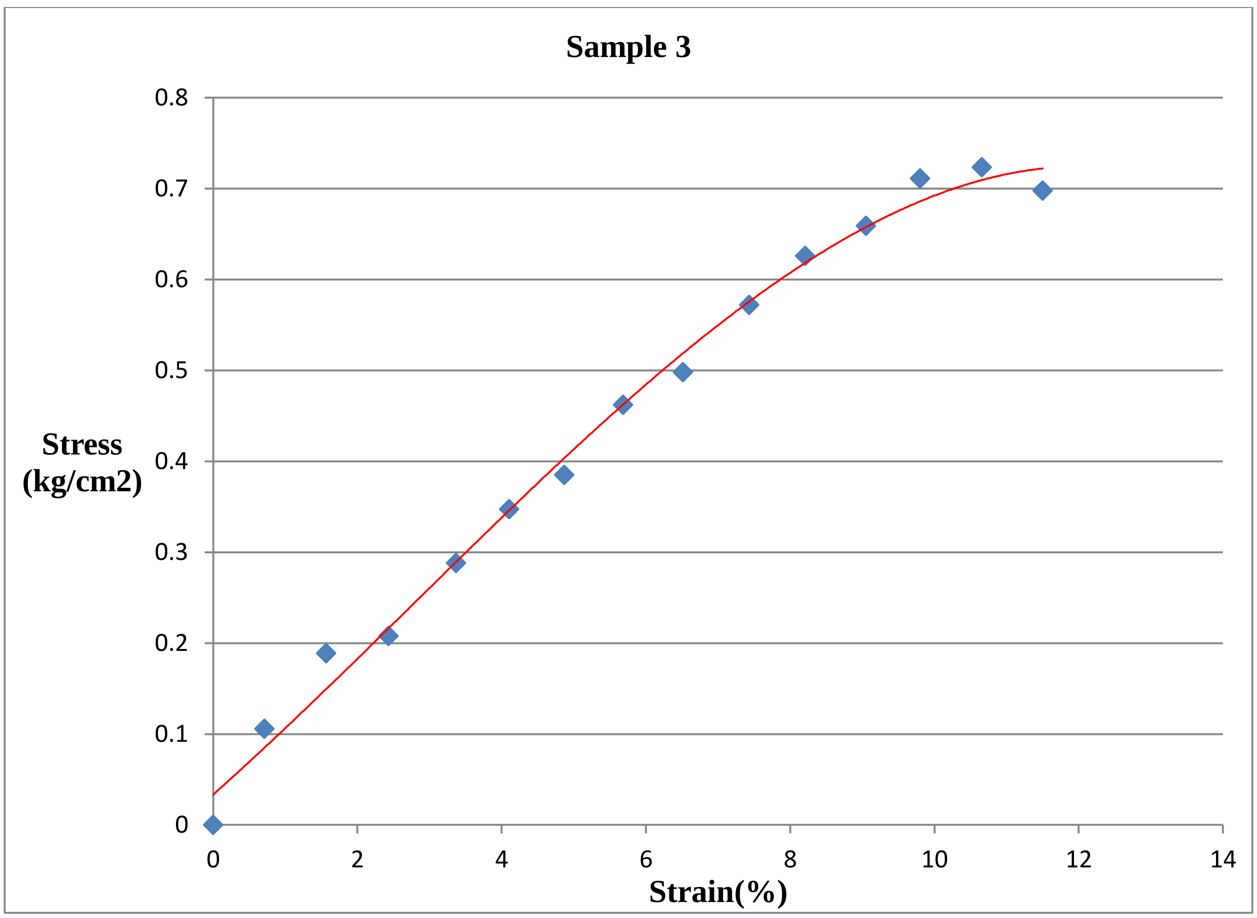

Sample 2
Stress (kg/cm2)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
14
Strain(%)


Sample 3
Stress (kg/cm2)
Strain(%)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
0
2
4
6
8
10
12
14

3.2.4 Reinforced with 1% polyester fiber

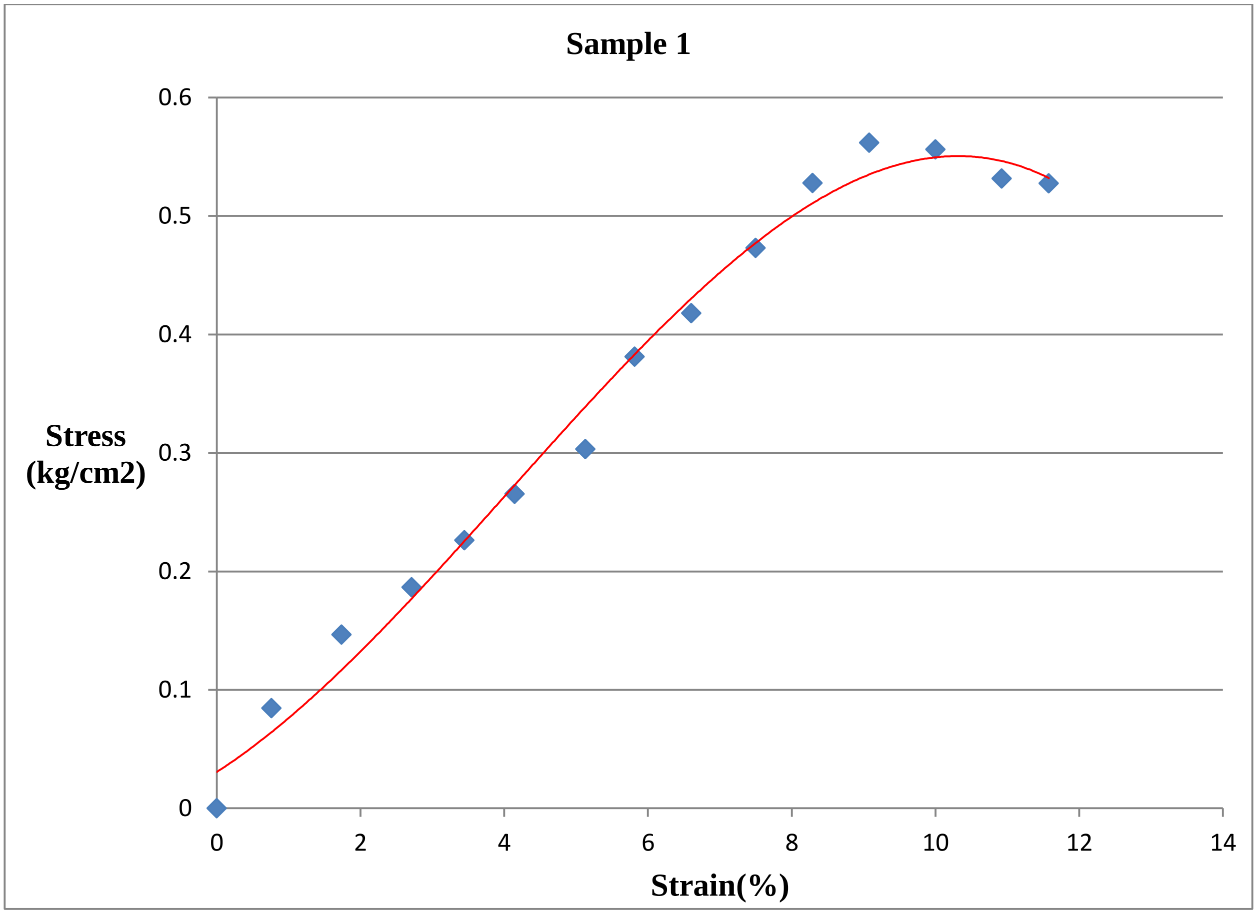


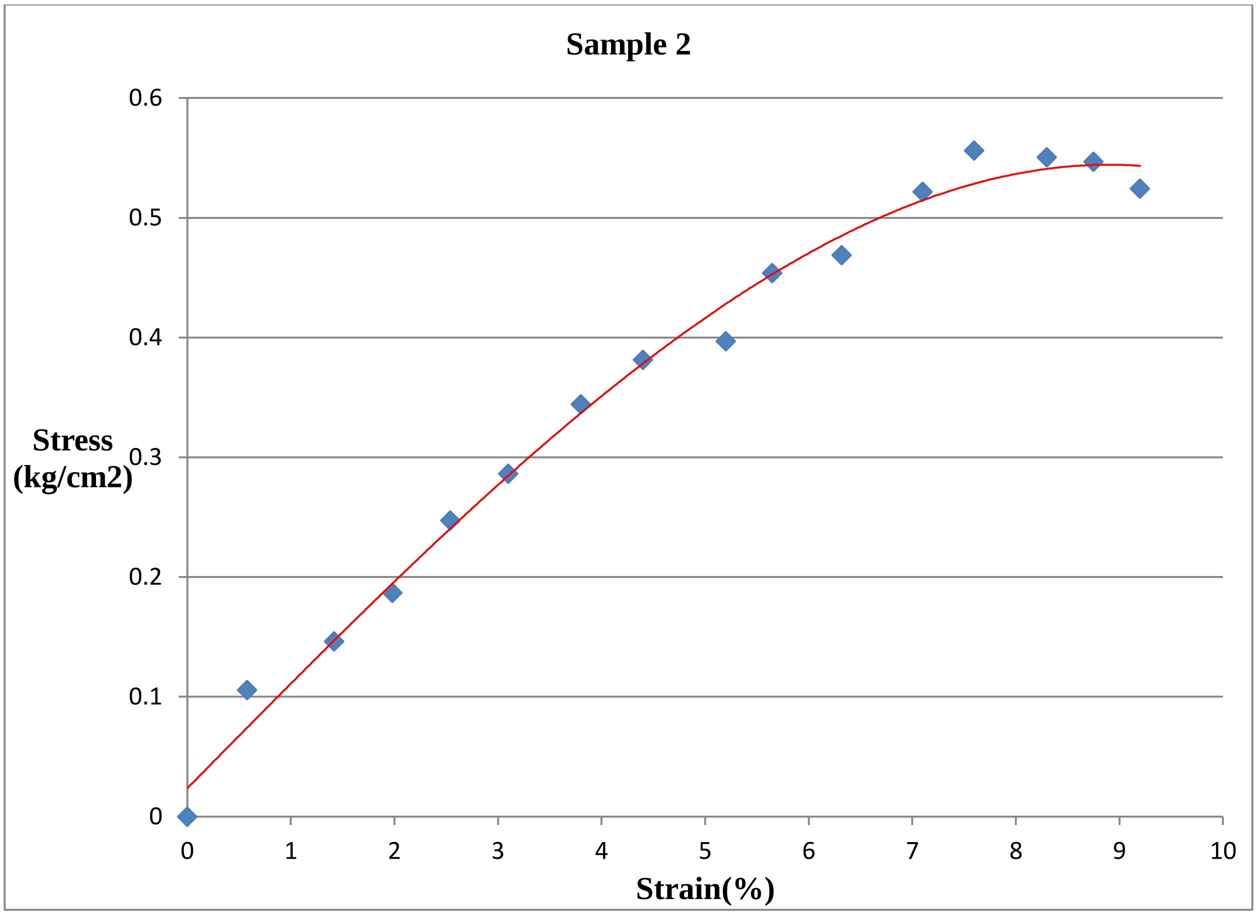

Sample 2
Stress (kg/cm2)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
14
16
Strain(%)

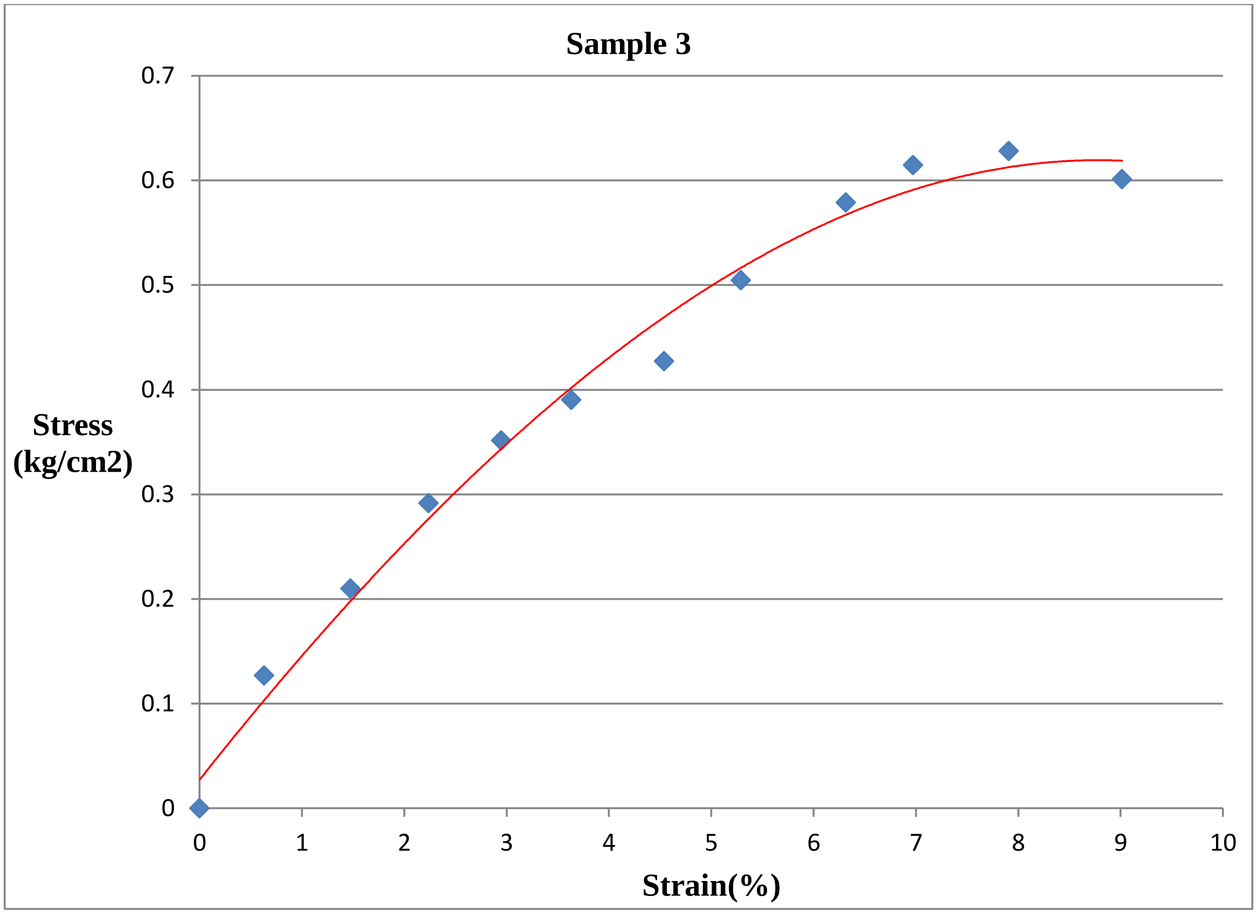

Sample 3
Stress (kg/cm2)
Strain(%)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
2
4
6
8
10
12
14

3.3 Reinforced black soil samples

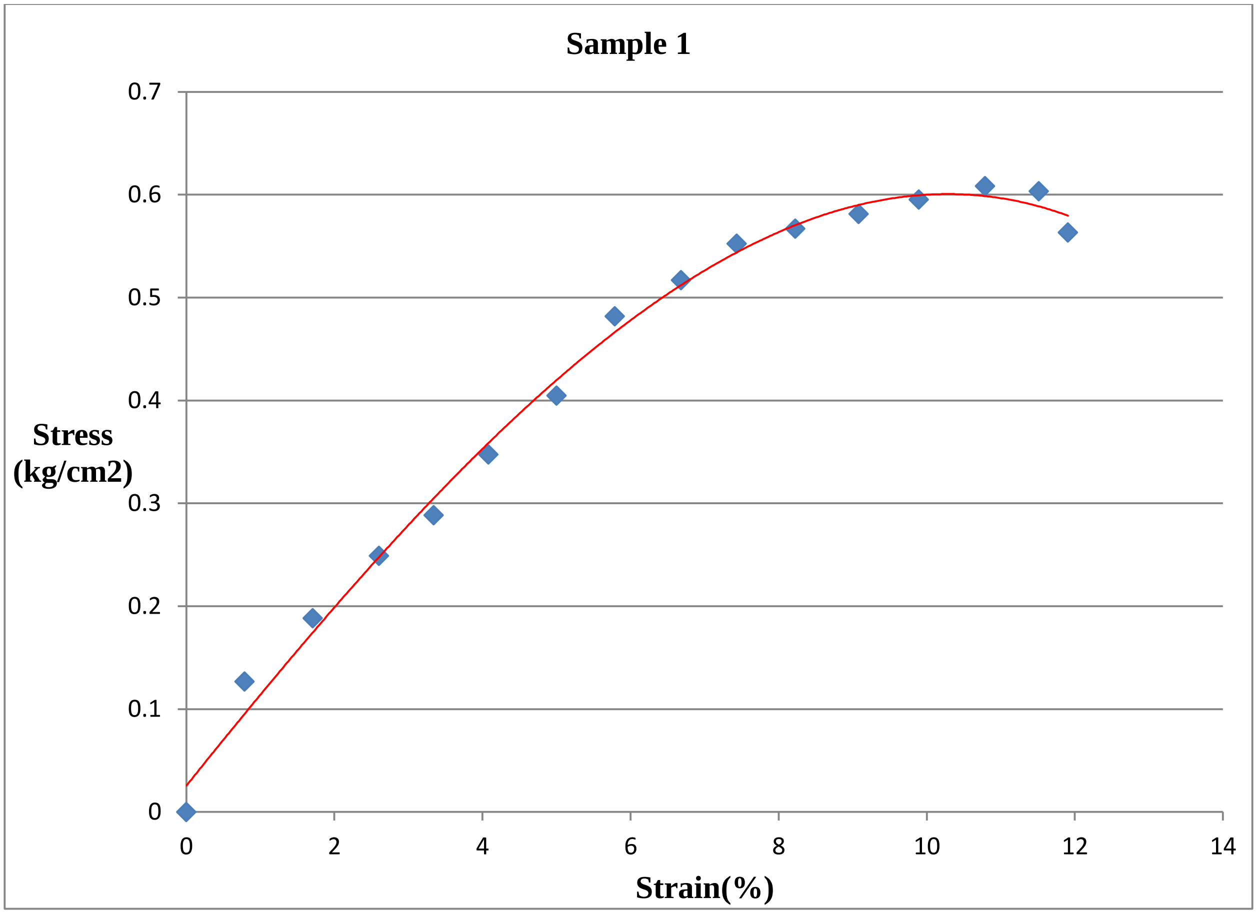
3.3.1 Aspect ratio 20

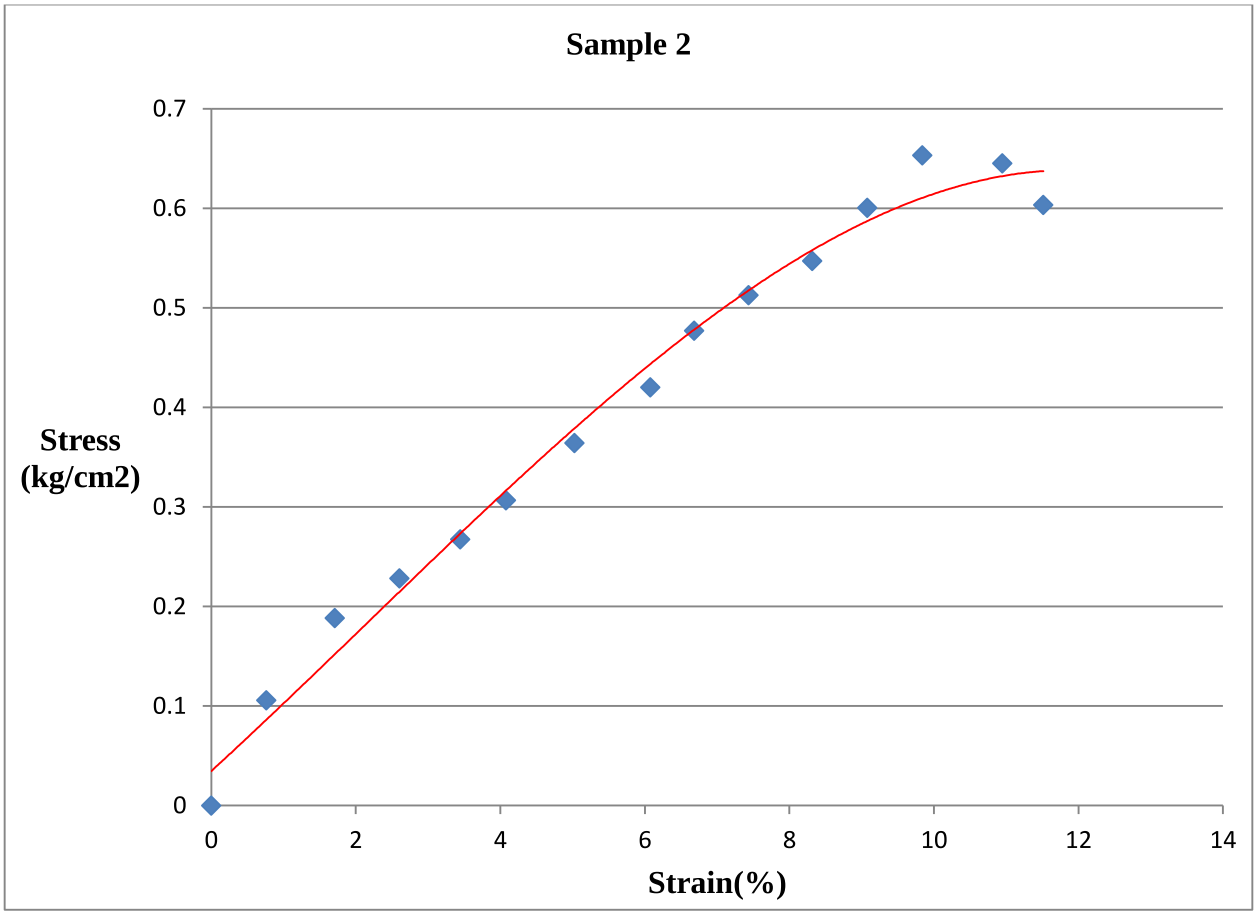


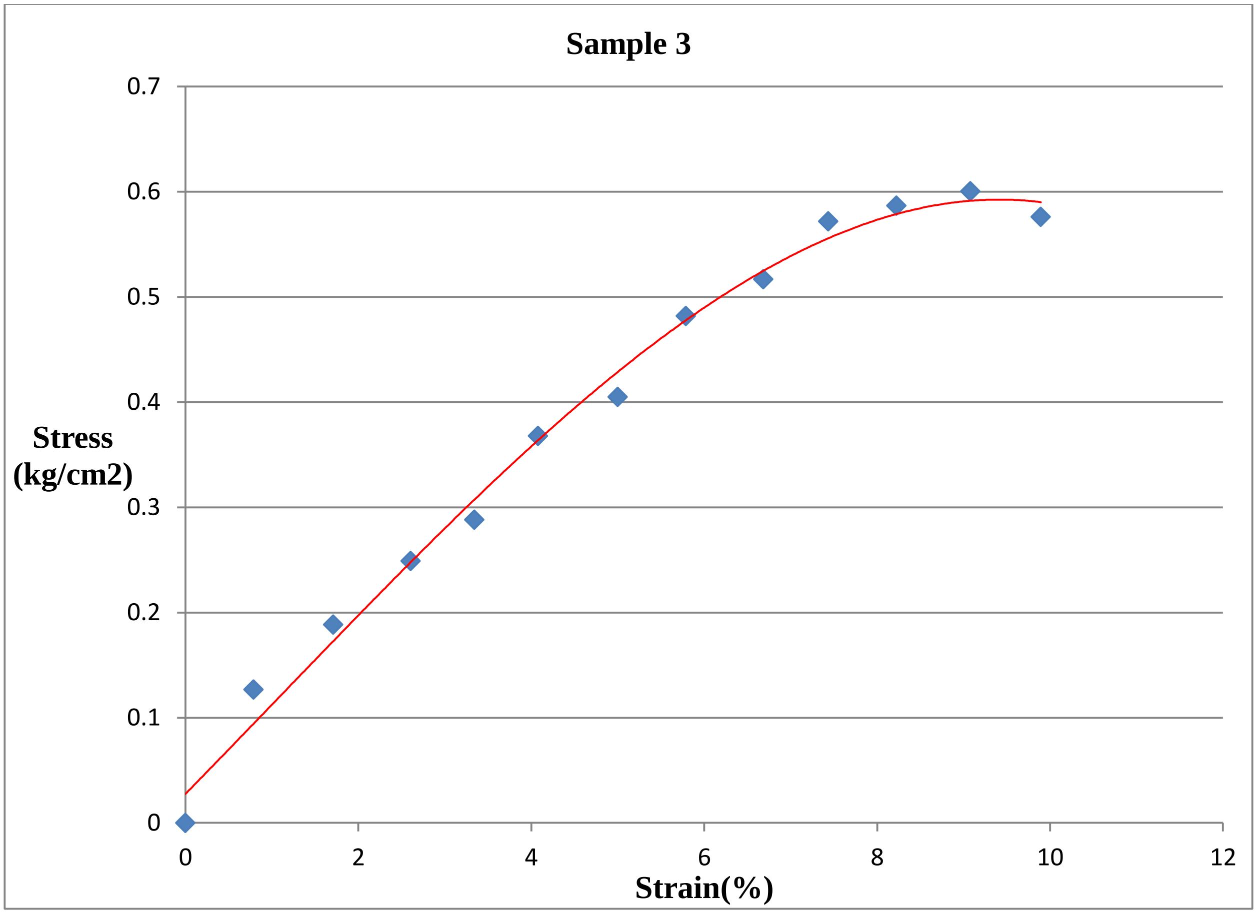

Sample 2
Stress (kg/cm2)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9
10
Strain(%)


Sample 3
Stress (kg/cm2)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 1 2 3 4 5 6 7 8 9 10
Strain(%)

3.3.2 Aspect ratio 60




Sample 2
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Stress
(kg/cm2)
0
2
4
6
8
10
12
14
Strain(%)


Sample 3
Stress (kg/cm2)
Strain(%)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12