# STRENGTH BEHAVIOUR OF FIBRE REINFORCED RIVER SAND

# A PROJECT

***Submitted in fulfilment of the requirements for the award of the degree of***

**BACHELOR OF TECHNOLOGY**

**IN**

**CIVIL ENGINEERING**

Under the supervision of

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By

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To

**JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY**

**WAKNAGHAT SOLAN – 173 234, HIMACHAL PRADESH INDIA**

**June, 2016**

# CERTIFICATE

This is to certify that the work which is being presented in the project title **"Strength behaviour of Fibre Reinforced River Sand"** in fulfilment 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 Suparn Rana (121669) and Kartik Sharma(121670) during a period from July 2015 to June 2016 under the supervision of **Mr.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.

Date: - ………………………

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# CONTENTS

# ABSTRACT

The need for improvement of ground is ever increasing due to rapid growth in infrastructure development. The fibre reinforced sand is one of the popular ground improvement techniques. Efforts were made in this study to check the improvement of strength of sand by incorporating of fibre reinforcement. To achieve the objective, a series of direct shear tests were conducted on Beas river sand in its natural grain size form reinforced with three different fibre materials viz., Nylon, Jute and Coir. These fibres were mixed in 2% proportion, duly varying the Aspect Ratios at 10, 15 and 20. Most appropriate aspect ratio was selected for each fibre and the direct shear test was conducted at different mix proportions.

The investigations showed an improvement in angle of internal friction upto 15.88%, 11.28% and 6.04% when 3% of nylon (Aspect ratio = 15), 3% of jute (Aspect ratio = 10) and 2% of coir fibres (Aspect ratio = 15) respectively, are used.

The results indicated an improvement in strength behaviour of reinforced sand upto 29%, 36% and 19% when 3% of nylon (Aspect ratio = 15), 3% of jute (Aspect ratio = 10) and 2% of coir fibres (Aspect ratio = 15) respectively, are used.

# 1. INTRODUCTION

Soil has been used as a construction material from the time immortal. Being poor in mechanical properties, it has offered challenges to civil engineers to improve its properties depending upon the requirement which varies from site to site.
Thus improvement of ground is a mighty challenge before Geotechnical Engineers worldwide. Geo-reinforcement is a very promising field of improvement of bearing capacity of soil. Concept involving the reinforcement of soil using fibres has been used since ancient times. For example, early civilizations added straws and plants roots to soil bricks to improve their properties, even while building the Great Wall of China the clay soil was mixed with tamarisk branches, although the reinforcing mechanism may have not been fully understood.
While fibre reinforced soil has been used in many countries in the recent past, there is still need for thorough understanding of behaviour of fibre reinforced soil.
Fibre reinforcement is found to be effective in all types of soils (i.e. sand, silt and clay). Use of natural material such as Jute, coir, sisal and bamboo, as reinforcing materials in soil is prevalent from a long time and they are abundantly used in many countries like India, Philippines, Bangladesh etc. The main advantages of these materials are that they are locally available and are very cheap. If these materials are used effectively, the rural economy can get uplift and also the cost of construction can be reduced.

Many studies have been conducted relating to the behaviour of soil reinforced with randomly distributed fibre and various efforts were made to formulate a constitutive model to predict the behaviour of Randomly Distributed Fibre Reinforced Soil.
In this project, a series of direct shear tests have been conducted on Beas river sand in its natural grain size form reinforced with three different fibre materials viz., Nylon, Jute and Coir. These fibres have been mixed in 2% proportion, duly varying the Aspect Ratios at 10, 15 and 20. This has been done in order to find out the optimum aspect ratios for the fibres used and to observe the changes in strength characteristics of natural sand by the addition of these fibres.

## 1.1 SIGNIFICANCE

There are various benefits of using fibre reinforcement in natural sand. The major benefits are as follows:

- The inclusion of reinforcement in sand improves the shear resistance of the sand.
- Land acquisition can be kept to a minimum.
- The inclusion of reinforcement enables construction on poorer quality sands.
- Use of natural fibre in civil engineering for improving soil properties is advantageous because they are cheap, locally available, biodegradable and eco-friendly.

# 2. LITERATURE REVIEW

- **T.Sambaiah, May 2013, "Strength behaviour of randomly Distributed fibre reinforced Natural sand."**

A series of tri-axial tests were conducted on Aleru River Sand in its Natural grain size form reinforced with four different fibre materials viz., Nylon, Steel, Plastic coated copper wire and coir. Efforts were made in this study to conduct a series of triaxial compression tests and based on the test results, efforts were made to constitute a statistical model. The fibres were mixed in 1%, 3%, 4% and 5% proportion duly varying the Aspect Ratios at 25 and 85. The results indicated an improvement in strength behaviour of Sand Reinforced with fibre in randomly distributed form. The investigations showed an improvement in Strength Ratio upto 4.06 and Bearing Capacity Ratio upto 5.58 when 5% of steel fibre with Aspect ratio 25 is used.

- **H. P. Singh & M. Bagra, August 2013, "Improvement in CBR value of soil reinforced with jute fibre."**

An experimental study was conducted on locally available (Doimukh, Itanagar, Arunachal Pradesh, India) soil reinforced with Jute fibre. In this study the soil samples were prepared at its maximum dry density corresponding to its optimum moisture content in the CBR mould with and without reinforcement. The percentage of Jute fibre by dry weight of soil was taken as 0.25%, 0.5%, 0.75% and 1%. The lengths of fibre were taken as 30 mm, 60 mm and 90 mm considering two different diameters 1 mm and 2 mm were considered for each fibre length. The laboratory CBR values of soil and soil reinforced with Jute fibre were determined. The effects of lengths and diameters of fibre on CBR value of soil were also investigated. Tests result indicates that CBR value of soil increases with the increase in fibre content. It was also observed that increasing the length and diameter of fibre further increases the CBR value of reinforced soil and this increase is substantial at fibre content of 1 % for 90 mm fibre length having diameter 2 mm..

Thus there is significant increase in CBR value of soil reinforced with Jute fibre and this increase in CBR value will substantially reduce the thickness of pavement subgrade.

- **Gopal Ranjan, R.M. Vasan& H.D. Charan, May 2012, "Behaviour of plastic-fibre-reinforced sand."**

Stress-deformation behaviour of sand reinforced with discrete randomly distributed fibres depends on the properties of the fibres and sand-fibre surface friction. This paper presents the results of triaxial compression tests, performed to determine stress-strain behaviour of fine sand reinforced with discrete, randomly distributed plastic fibres, the influence of fibre properties (i.e. weight fraction and aspect ratio) and confining stress on shear strength of reinforced sand were also observed. The results indicated that the sand-fibre composites have a curved or a bilinear failure envelope, with the break occurring at a certain confining stress, called the ‘critical confining stress’. The magnitude of the critical confining stress decreases with increase in aspect ratio of the fibres. The shear strength of plastic-fibre-reinforced sand increases with increase in fibre content and aspect ratio.

- **G. Venkatappa Rao, R.K. Dutta & Ujwala D., August 2007, “Strength characteristics of sand reinforced with coir fibres and coir geotextiles.”**

This paper presents the results of triaxial compression tests, performed to determine stress-strain behaviour of fine sand reinforced with discrete, randomly distributed coir fibres, and to observe the influence of fibre properties on shear strength of reinforced sand.Laboratory triaxial compression tests were carried out in order to determine the strength characteristics of sand reinforced with coir fibres and coir geotxtiles. The mechanical behaviour of the composite material was investigated through varying four confining pressures (24.5 kPa to 196 kPa), two types of coir fibres in a random arrangement as well as in a layered arrangement with percentage varying from 0.5% to 1%. For oriented reinforcement, two types of woven coir geotextiles of different mass per unit area and aperture size and one non-woven coir geotextile were used. Tests were performed on 100 mm diameter and 200 mm high specimens. The results indicated that inclusion of coir fibres and coir geotextiles improves the performance of sand specimens. The admixtures can be used in rural roads and for ground improvement

- **Harsh Vardhan, April 1952, “A note on physical characteristics of river sand”**

A few experiments were conducted on the sand available on the banks of river Yamuna. These deal with sieve analysis, variation in dry density with compactive efforts and moisture content and variations in shear strength. It has been found that Yamuna sand resembles to a fair degree to Daytona beach and Port Said beach sands in grain size distribution. The bulk density of dry sand increases with compaction to a maximum and then remains constant. Further increase in the compactive effort leads to breaking of soil grains. Addition of moisture to sand, on the other hand, lowers the dry density rapidly at first and slowly afterwards.

# 3. OBJECTIVES

The main objectives of the work are as follows:

- To find the most appropriate aspect ratio with respect to different reinforcing fibres (coir, jute and nylon).
- To find out the change in the strength of the soil reinforced with fibre material against the strength of natural river sand at the most appropriate aspect ratio of each fibre.

In order to achieve the above objective, the river sand has been randomly reinforced with three types of fibres i.e. **coir, jute** and **nylon**. These fibres enhance the strength of the river sand. Series of tests including direct shear test are conducted on the sample soil with different % by weight and aspect ratio of fibres.

# 4. METHODOLOGY

The methodology includes classification of the natural river sand and the three types of fibres used as reinforcement materials. Later, the preparation of the specimen and the test procedure are described.

## 4.1 Experimental Investigations

The experimental work consists of the following steps:

4.1.1 Specific gravity of sand

4.1.2 Sieve Analysis

4.1.3 Determination of sand properties

- $D_{10}$, $D_{60}$
- $C_U$, $C_C$
- Classification of sand

4.1.4 Determination of optimum moisture content (OMC).
4.1.5 Direct shear test on pure sand

4.1.6 Direct Shear Test on reinforced sand taking different aspect ratio.

## 4.2 Brief steps involved in the experiments

### 4.2.1 Specific gravity of the sand

The test was performed according to IS 2720(III/SEC-I): 1980 which consists method of test for determination of specific gravity for sands.

The specific gravity of soil is the ratio between the weight of the soil solids and weight of equal volume of water. It is calculated by the help of a volumetric flask in a very simple experimental setup where the volume of the soil is found out and its weight is divided by the weight of equal volume of water. The steps involved are as follows:

1. Mass of clean and dry pycnometer was measured.

2. The cap was unscrewed and about 200g of oven dried soil was placed in the pycnometer. Mass ($M_2$) was measured.

3. Water was added to the pycnometer containing soil and mass ($M_3$) was measured.

4. The pycnometer was filled with water completely upto the mark and was dried from outside. Mass ($M_4$) was measured.

5. The experiment was repeated three times and average reading has been calculated.

### 4.2.2 Sieve Analysis

The test was performed according to IS 2720 PART-4: 1985 which included steps to perform grain size analysis. The following procedure was followed in order to determine particle size distribution curve.

1. 1000g of oven dried soil was taken.
2. The soil particles were crushed using the pestle and mortar.
3. The mass of sample $W_t$ (g) was determined.
4. A sieve stack was prepared (4.75mm to 0.075mm)
5. Soil particles stuck in the openings were removed using brush.
6. The soil was poured and the stack of sieves was placed on sieve shaker for 10-15 minutes.
7. The sieve shaker was stopped and the weight of the soil retained in each sieve was measured.

### 4.2.3 Determination of optimum moisture content (OMC)

The test was performed according to IS 2720(VII):1980 which consisted methods of test for sands and determination of water content dry density relation using light compaction.

The following procedure was followed in order to determine OMC of sand.

1. A 5 kg oven dried soil sample was taken and water was added to it.
2. The weight of proctor mould with base plate and collar was measured and soil was placed in it and compacted in 3 layers giving 25 blows per layer with the 2.5 kg rammer falling through.
3. The collar was removed the compacted soil was trimmed.
4. The weight of the compacted specimen was divided by 1000cc and the results were recorded as the wet weight $g_{wet}$ in grams per cubic centimeter of the compacted soil.
5. The remainder of the material was broken until it passed a no.4.

6. Water was added in sufficient amounts to increase the moisture content of the soil sample by one or two percentage points and the above procedure was repeated for each increment of water added.

### 4.2.4 Direct shear test

The test was performed in accordance with IS 2720(XIII):1986 which included methods of test for Sands and direct shear test.

This test is used to find out the cohesion (c) and the angle of internal friction (φ) of the sand, these are the soil shear strength parameters. The shear strength is one of the most important soil properties and it is required whenever any structure depends on the soil shearing resistance. The following procedure was followed to conduct the test.

1. The sand was put inside the shear box which is made up of two independent parts.
2. A constant normal load (ς) was applied to obtain one value of c and φ.
3. Horizontal load (shearing load) was increased at a constant rate and was applied till the failure point was reached. This load when divided with the area gives the shear strength 'τ' for that particular normal load. The equation goes as follows:

$$\tau = c + \sigma * \tan(\varphi)$$

4. The experiment was conducted for different normal loads.

# 5. TEST MATERIAL

## 5.1 SAND

The investigation was carried out on Beas river sand available in Mandi district of Himachal Pradesh. The natural colour of the sand was light brown and was having a water content of 7%. The sand was smooth to touch. After the tests were performed the results indicated that the sand was poorly graded or uniformly graded thus represented by SP according to IS: 1498-1970.

The sand had a specific gravity of 2.67 and optimum moisture content of 11 %.

## 5.2 COIR FIBRES

Coir is a natural fibre extracted from the husk of coconut and used in products such as floor mats, doormats, brushes, mattresses, etc. Coir is the fibrous material found between the hard, internal shell and the outer coat of a coconut. It is having a specific gravity of 0.80 and is produced in abundance in India thus was chosen as a reinforcing fibre for this project The coir fibre used in this project is the one which is used as a filler material in a sofa. It was in the form of long fibers having rough surface and was obtained from a furniture producing company in Chandigarh.

## 5.3 JUTE

Jute is a long, soft, shiny fibre that can be spun into coarse, strong threads. It is easily available and is produced in abundance in India and because of this reason it was chosen as one of the reinforcing fibres used in this project. The jute fibre used in this project is the one which is used to make ropes. Long and thin threads were spun together to form a thin rope of jute. This rope was used as a reinforcing fibre in this project and was obtained from a furniture company in Chandigarh.

## 5.4 NYLON

Nylon is also used in this project as one of the reinforcing fibres because it was easily available and was cheap. The specific gravity of nylon is 0.86. The nylon fibre used was in the form of thin rope with a smooth surface. It was blue in colour and was obtained from the same furniture company in Chandigarh.

# 6. RESULTS & DISCUSSIONS

## 6.1. SPECIFIC GRAVITY OF THE SAND

The following observations were made when specific gravity test was conducted on pure sand sample.

| Description | Test 1 | Test 2 | Test 3 | Average Weight |
|---|---|---|---|---|
| $w_1$ (empty pycnometer) (g) | 460.7 | 460.7 | 460.7 | 460.7 |
| $w_2$ (pycnometer + soil) (g) | 660.7 | 660.7 | 661.7 | 660.7 |
| $w_3$ (pycnometer + soil + water) (g) | 1377.1 | 1374.1 | 1373.1 | 1374.7 |
| $w_4$ (pycnometer+ water) (g) | 1250.5 | 1250.5 | 1250.5 | 1250.5 |

**Table1: Calculation table for determining the specific gravity of sand**

The following formula was used to calculate the specific gravity of the given sand sample.

$$\textbf{Sp. Gravity} = (w_2-w_1)/\ ((w_2-w_1)-(w_3-w_4))$$

Using this formula the specific gravity was found out to be 2.67.

The calculated value of the specific gravity of the soil is between 2.6 and 2.7 thus proving it is a coarse grained soil.

## 6.2. SIEVE ANALYSIS

A 1000 gram sample of natural river sand was taken and the test was performed according to IS 2720 PART-4: 1985. The following data was obtained from the test conducted.

| Sieve size(mm) | Mass retained(g) | % retained | Cumulative % retained | Cumulative % finer |
|---|---|---|---|---|
| 4.75 | 122.4 | 12.24 | 12.24 | 87.76 |
| 2 | 136.8 | 13.68 | 25.92 | 74.08 |
| 1 | 198 | 19.8 | 45.72 | 54.28 |
| 0.6 | 115.2 | 11.52 | 57.24 | 42.76 |
| 0.425 | 99.6 | 9.96 | 67.2 | 32.8 |
| 0.3 | 19.8 | 1.98 | 69.18 | 30.82 |
| 0.212 | 149 | 14.9 | 84.08 | 15.92 |
| 0.15 | 60.4 | 6.04 | 90.12 | 9.88 |
| 0.075 | 63 | 6.3 | 96.42 | 3.58 |

**Table2: Calculation table obtained after sieve analysis of sand**

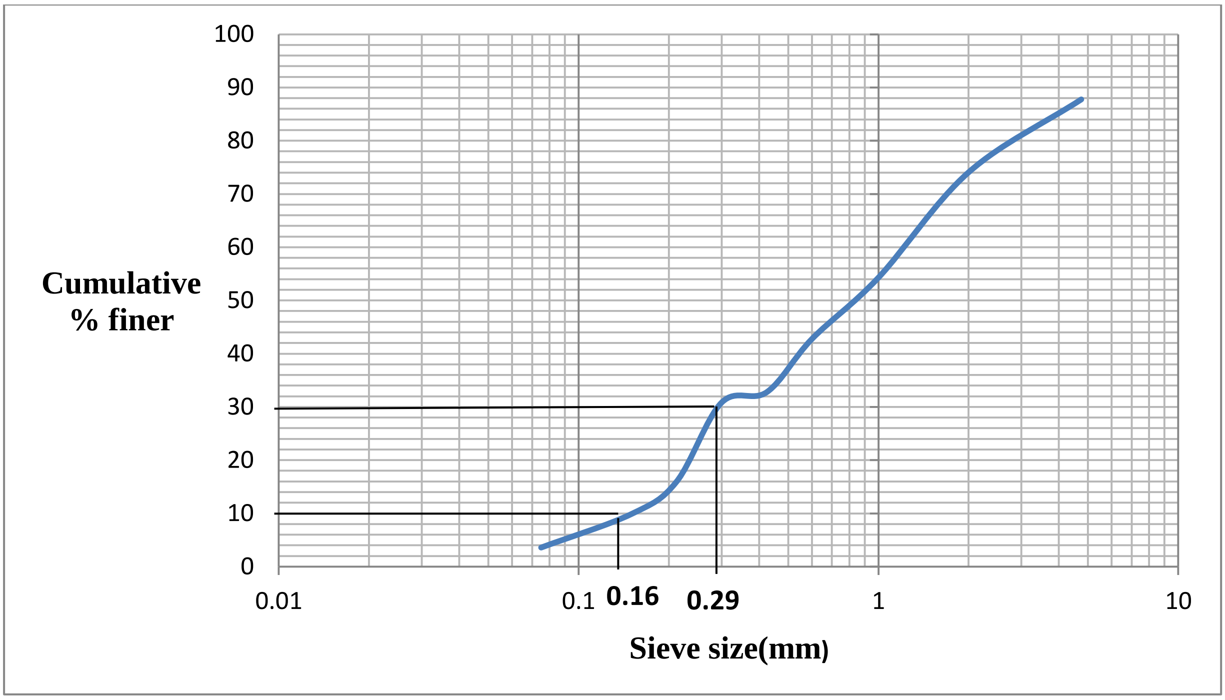


**Fig. 1: Particle size distribution curve**

| $D_{10}$ | $D_{30}$ | $D_{60}$ | Cu | Cc | Classification |
|---|---|---|---|---|---|
| 0.16 | 0.29 | 1.25 | 7.81 | 0.41 | Poorly graded (SP) |

**Table 3: Particle size and classification**

The value of Cu and Cc were calculated by using the following formulas:

$$Cu = D_{60}/ D_{10} \qquad Cc = D_{30}^2 / D_{60} * D_{10}$$

For sand to be well graded Cu should be greater than 6 and Cc should be between 1 and 3. But for the given data the value of Cc does not lie in the range provided.

Thus Beas river sand is classified as poorly graded as per IS: 1498-1970.

## 6.3. DETERMINATION OF OPTIMUM MOISTURE CONTENT (OMC)

The following table was obtained when OMC test was conducted on a pure sand sample. The values of $\gamma$ (g/cm$^3$) and $\gamma_d$ (g/cm$^3$) were calculated by using the following formulas:

**$\gamma$ (g/cm$^3$) = wt. of soil/volume** **$\gamma_d$ (g/cm$^3$) = $\gamma_d$ / 1+W**

| Wt. of soil (g) | W% | Volume(cm$^3$) | $\gamma$ (g/cm$^3$) | $\gamma_d$ (g/cm$^3$) |
|---|---|---|---|---|
| 1907.8 | 4 | 1000 | 1.907 | 1.834 |
| 1993.9 | 8 | 1000 | 1.993 | 1.845 |
| 2073.6 | 12 | 1000 | 2.074 | 1.852 |
| 2105.1 | 16 | 1000 | 2.105 | 1.814 |
| 2143.7 | 20 | 1000 | 2.144 | 1.786 |

**Table 4: Calculation table for determining the OMC of sand**

The graph was plotted between $\gamma_d$ and water content (w) to obtain the value of OMC.

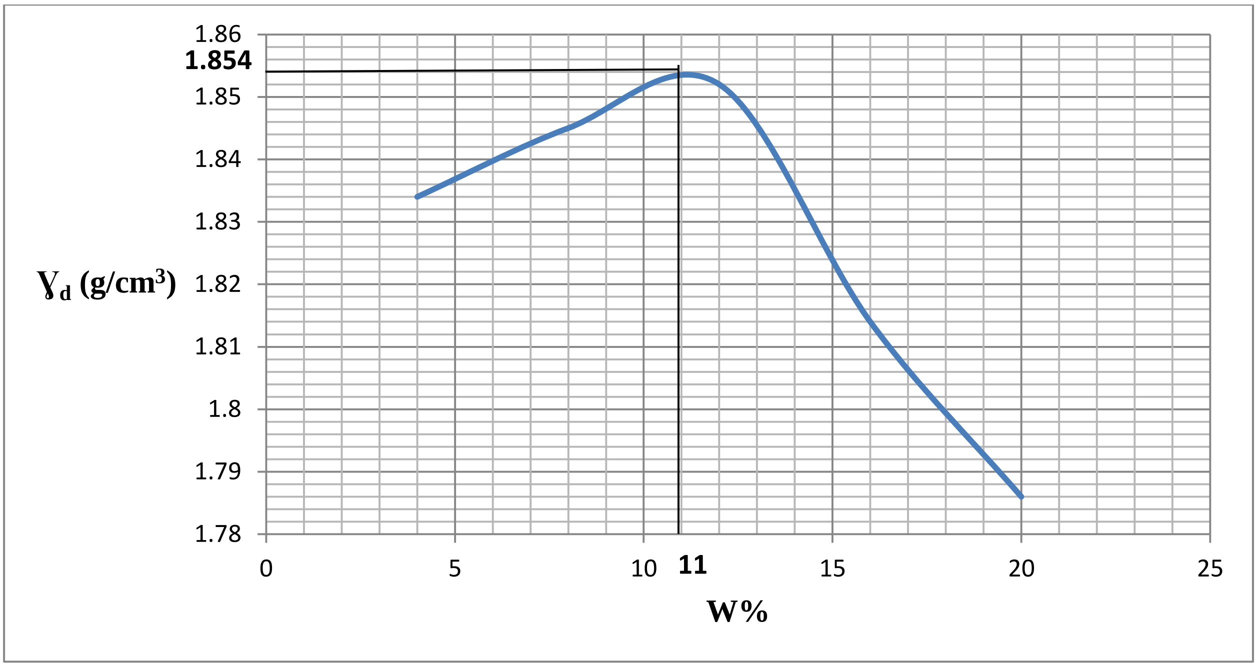


**Fig.2: Optimum moisture content**

The optimum moisture content as calculated from the graph plotted was found out to be 11% with respect to the maximum value of dry density (**$\gamma_d$**) which was 1.854 g/cm$^3$.

## 6.4. DIRECT SHEAR TEST

The test was carried on pure and reinforced sand samples at normal loads of 0.55kg, 0.95kg and 1.15kg. Nylon, jute and coir fibres were added as reinforcement in pure sand at the aspect ratios of 10, 15 and 20 and at 2% concentration. Direct shear test was conducted on these samples in order to find the most appropriate aspect ratio and the increase in the shear strength of the sand reinforced with fibres having most appropriate aspect ratio to the natural sand.

### 6.4.1. PURE SAND SAMPLE

The graph between shear stress and shear strain for the direct shear test done on pure sand sample for normal loading of 0.55 kg, 0.95kg and 1.15kg is shown in the figure 3.

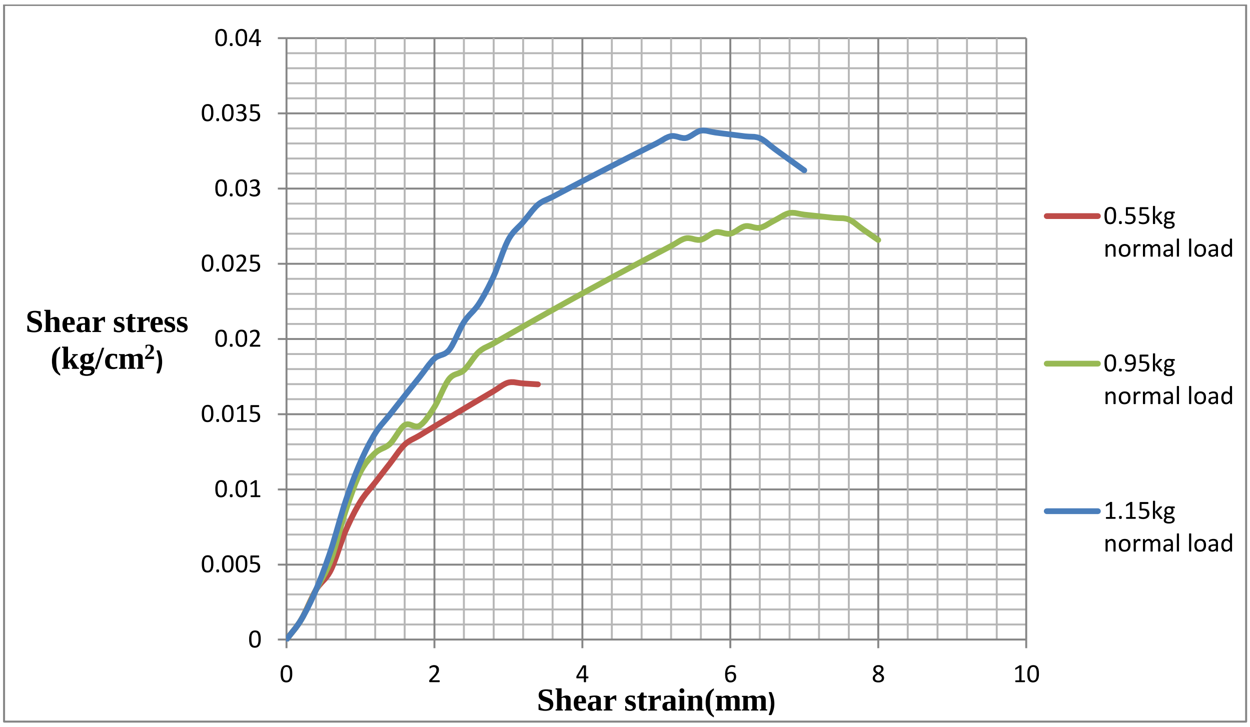


**Fig. 3: Shear stress vs shear strain for pure sand**

The sand sample failed at the shear stress of 0.0173 kg/cm$^2$, 0.0284 kg/cm$^2$ and 0.0339 kg/cm$^2$ under 0.55 kg, 0.95 kg and 1.55 kg normal loads.

The table for shear stress and normal stress for the direct shear test done on pure sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the table 5.

| Normal Stress (kg/cm$^2$) | Peak Shear Stress (kg/cm$^2$) |
|---|---|
| 0.0153 | 0.0173 |
| 0.0264 | 0.0284 |
| 0.0319 | 0.0339 |

**Table 5: Normal stress & Shear stress for pure sand**

The graph between normal stress (kg/cm$^2$) & shear stress (kg/cm$^2$) was plotted using the data provided in table 5.

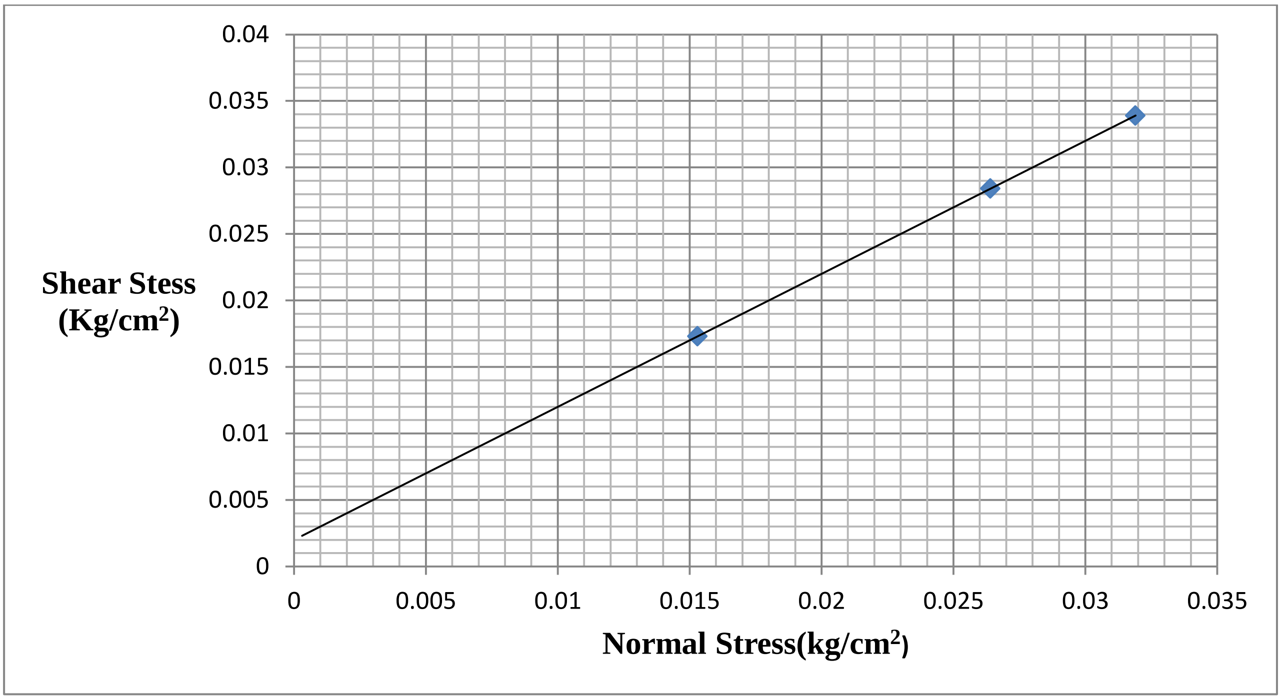


**Fig. 4: Shear stress vs normal stress for pure sand**

From the above graph the following results were obtained:

C (cohesion) = **0.0019** & ϕ (angle of internal friction) = **45.15°**

### 6.4.2. SAND SAMPLES REINFORCED WITH NYLON

After conducting the tests on pure sand and calculating c, ɸ values, nylon fibres were added to it and direct shear test was performed.

The fibre percentage was taken as 2% by weight and aspect ratio as 10, 15 and 20.

- The graph between shear stress and shear strain for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the figure 5 when aspect ratio was 10.

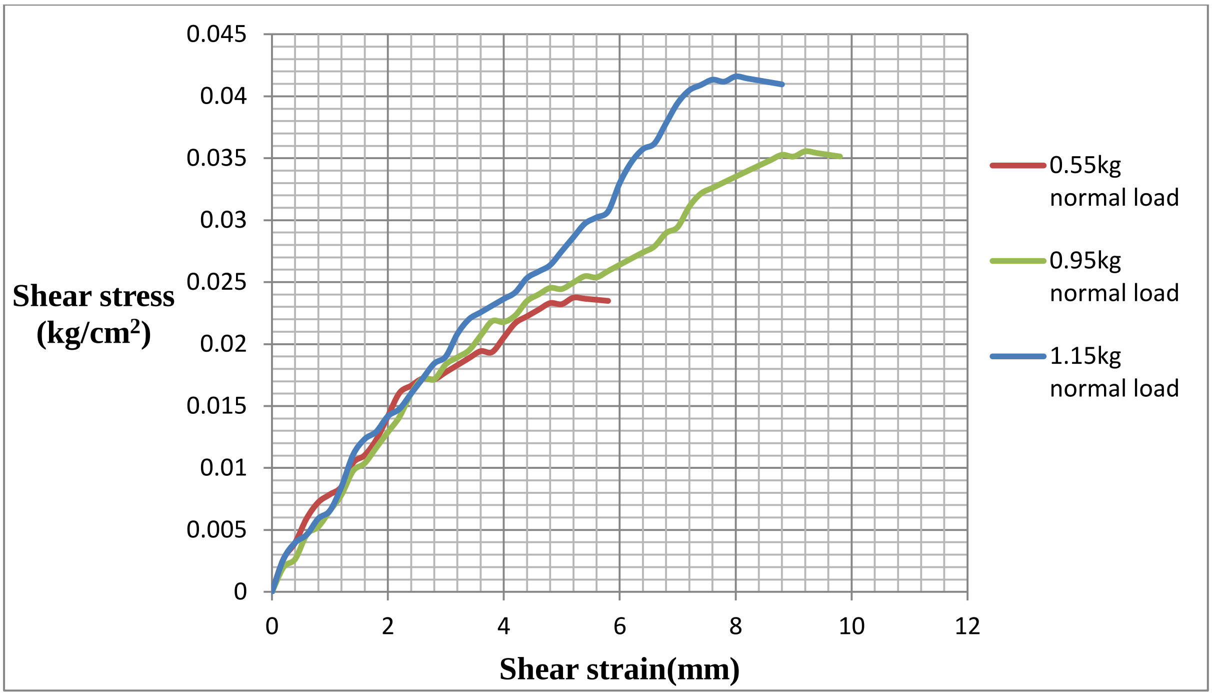


**Fig. 5: Shear stress vs shear strain for sand reinforced with nylon fibre (As = 10)**

The sand sample failed at the shear stress of 0.0201 kg/cm$^2$, 0.03556 kg/cm$^2$ and 0.0416 kg/cm$^2$ under 0.55 kg, 0.95 kg and 1.55 kg normal loads.

The table for shear stress and normal stress for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the table 6.

| **Normal Stress (Kg/cm$^2$)** | **Peak Shear Stress (Kg/cm$^2$)** |
|---|---|
| 0.0153 | 0.0201 |
| 0.0264 | 0.03556 |
| 0.0319 | 0.0416 |

**Table 6: Normal stress & Shear stress for nylon reinforced sand (As = 10)**

The graph between normal stress (kg/cm$^2$) & shear stress (kg/cm$^2$) was plotted using the data provided in table 6.

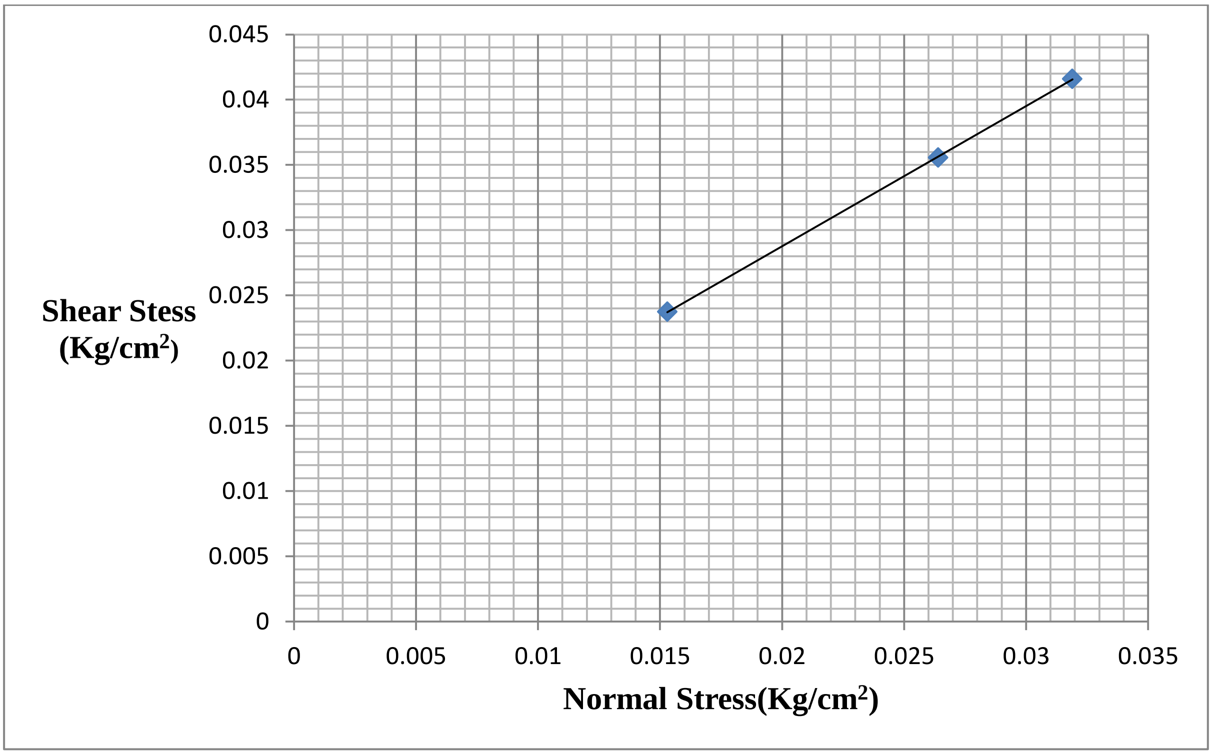


**Fig. 6: Shear stress vs normal stress for sand reinforced with 2% fibre (As =10)**

From the above graph the following results were obtained:

C (cohesion) = **0.0075** & ϕ (angle of internal friction) = **46.71°**

- The graph between shear stress and shear strain for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the figure 7 when aspect ratio was 15.

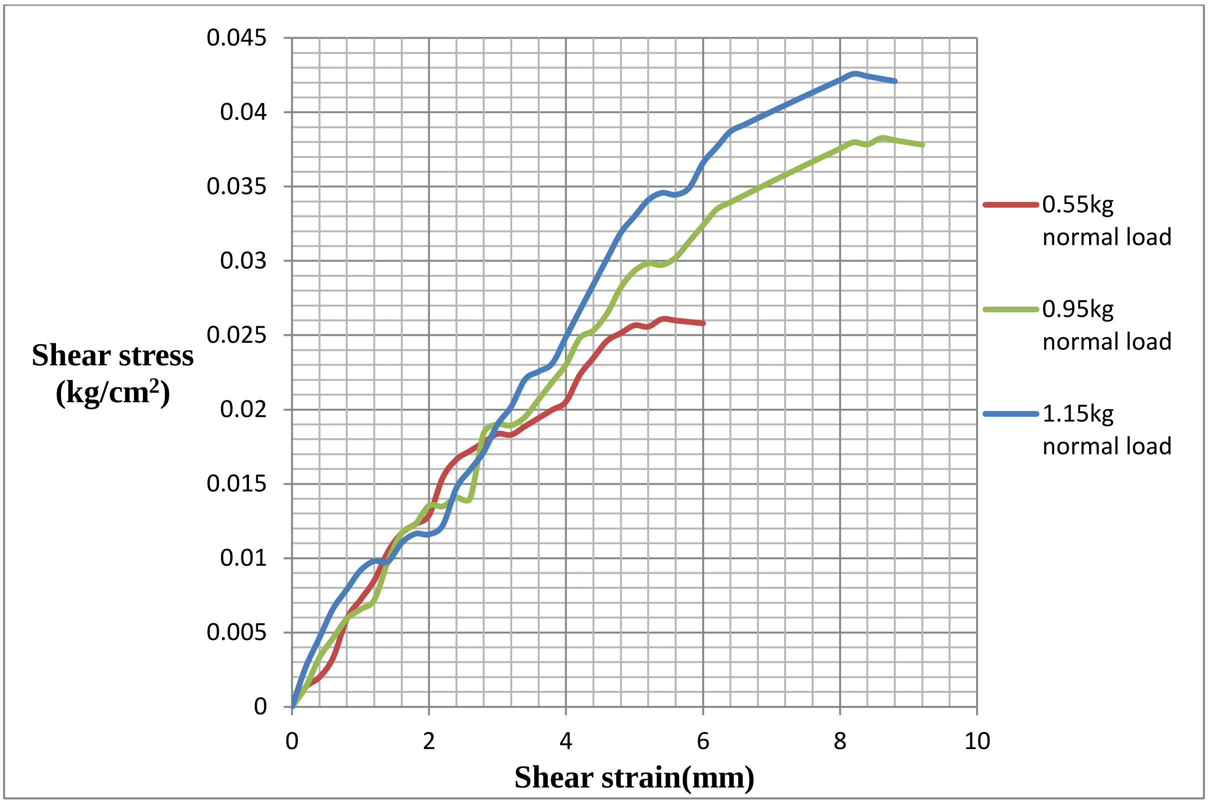


**Fig. 7: Shear stress vs shear strain for sand reinforced with nylon fibre (As = 15)**

The sand sample failed at the shear stress of 0.0219 kg/cm$^2$, 0.03648 kg/cm$^2$ and 0.04259 kg/cm$^2$ under 0.55 kg, 0.95 kg and 1.55 kg normal loads.

The table for shear stress and normal stress for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the table 7.

| Normal Stress ($Kg/cm^2$) | Peak Shear Stress ($Kg/cm^2$) |
|---|---|
| 0.0153 | 0.0219 |
| 0.0264 | 0.03648 |
| 0.0319 | 0.04259 |

**Table 7: Normal stress & Shear stress for nylon reinforced sand (As = 15)**

The graph between normal stress ($kg/cm^2$) & shear stress ($kg/cm^2$) was plotted using the data provided in table 7.

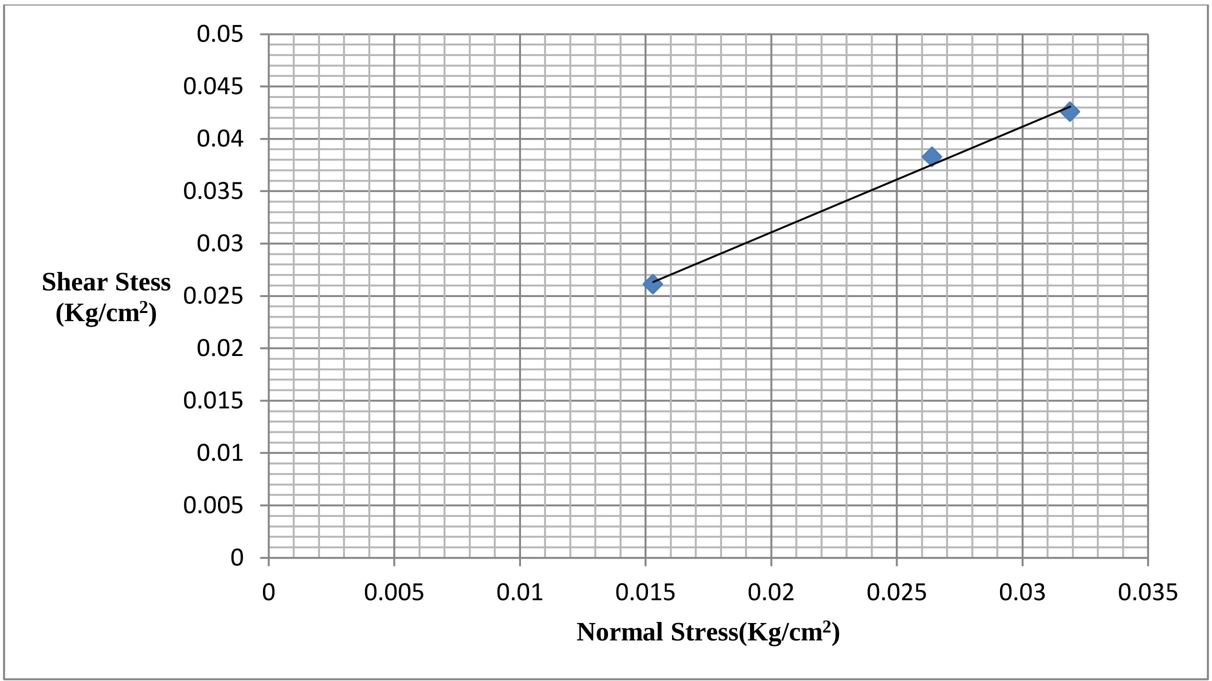


**Fig. 8: Shear stress vs normal stress for sand reinforced with 2% fibre (As =15)**

From the above graph the following results were obtained:

C (cohesion) = **0.009** & ϕ (angle of internal friction) = **48.16°**

- The graph between shear stress and shear strain for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the figure 9 when aspect ratio was 20.

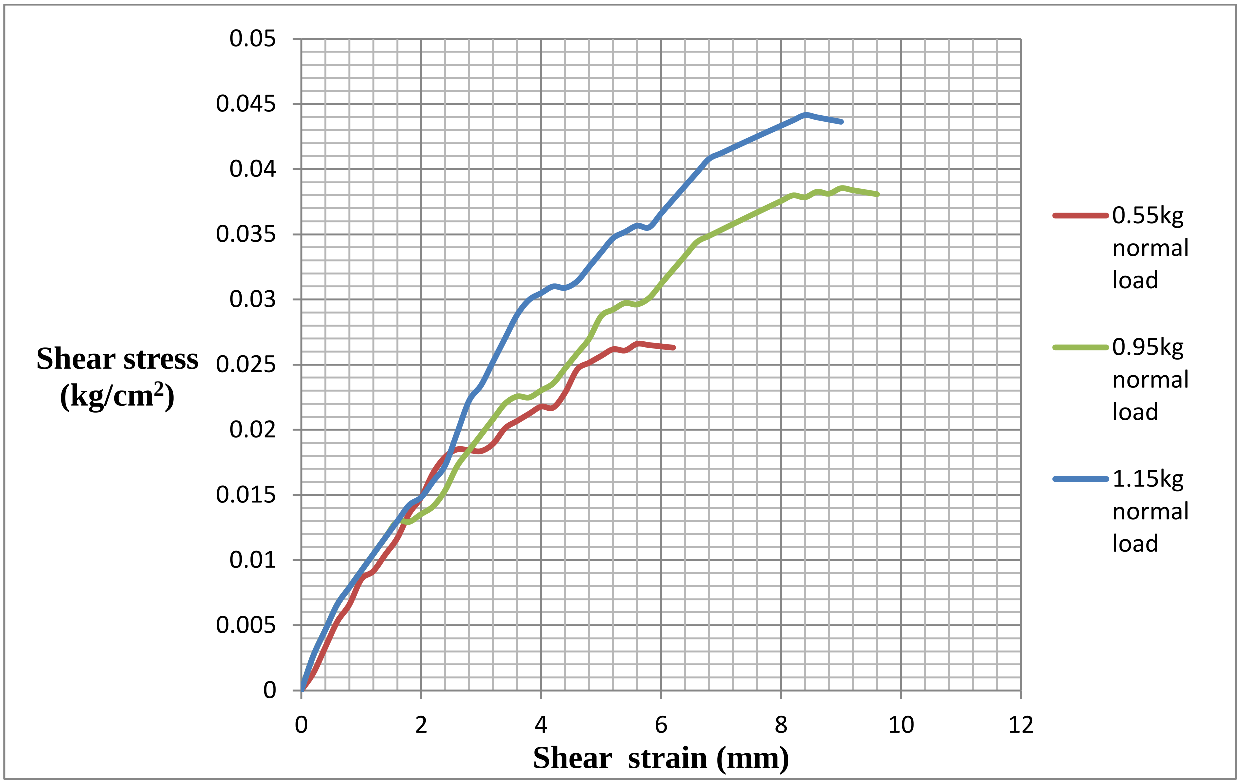


**Fig.9: Shear stress vs shear strain for sand reinforced with nylon fibre (As = 20)**

The sand sample failed at the shear stress of 0.02659 kg/cm$^2$, 0.03853 kg/cm$^2$ and 0.04415 kg/cm$^2$ under 0.55 kg, 0.95 kg and 1.55 kg normal loads.

The table for shear stress and normal stress for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the table 8.

| Normal Stress (Kg/cm$^2$) | Peak Shear Stress (Kg/cm$^2$) |
|---|---|
| 0.0153 | 0.02659 |
| 0.0264 | 0.03853 |
| 0.0319 | 0.04415 |

**Table 8: Normal stress & Shear stress for nylon reinforced sand (As = 20)**

The graph between normal stress (kg/cm$^2$) & shear stress (kg/cm$^2$) was plotted using the data provided in table 8.

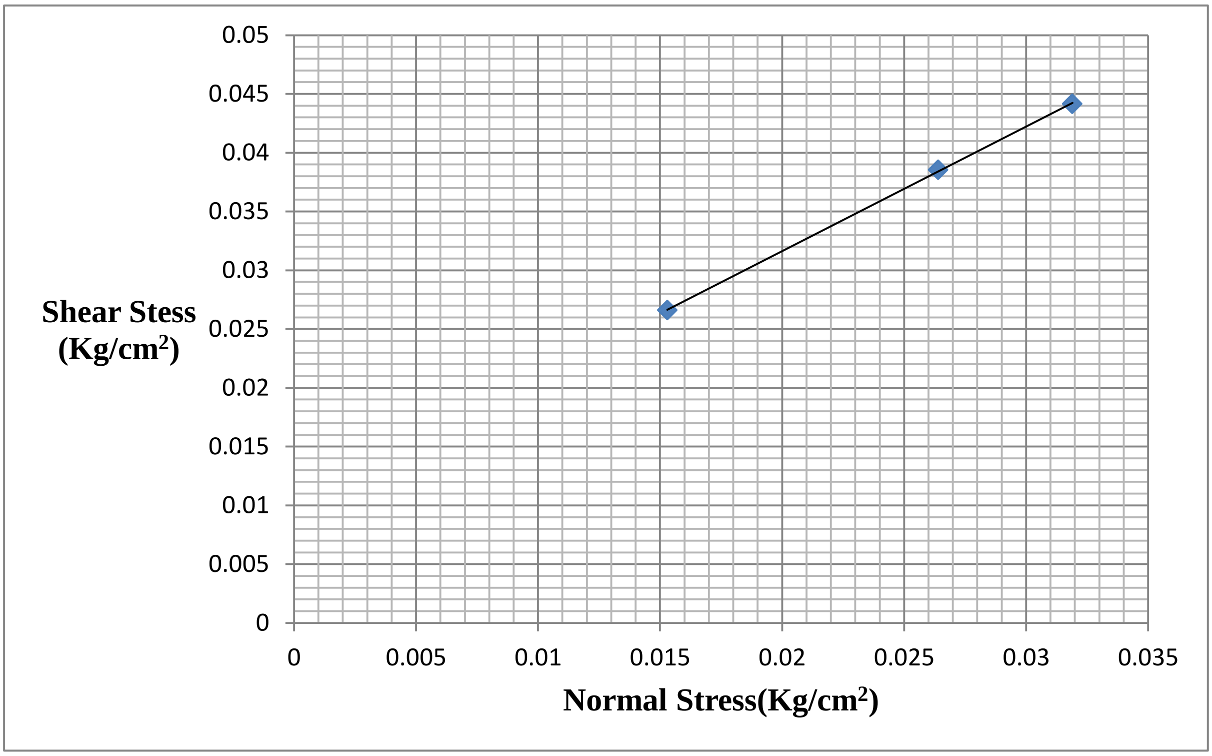


**Fig. 10: Shear stress vs normal stress for sand reinforced with 2% fibre (As =20)**

From the above graph the following results were obtained:

C (cohesion) = **0.01** & ɸ (angle of internal friction) = **46.95°**

### 6.4.2.1 COMPARISON OF RESULTS

Through the direct shear test conducted on nylon reinforced sand samples following results were obtained.

- Most appropriate aspect ratio for nylon

| Aspect Ratio | Cohesion ($kg/cm^2$) | Φ (degree) | % Increase in φ w.r.t pure sand |
|---|---|---|---|
| 10 | 0.0075 | 46.71 | 3.8 |
| 15 | 0.009 | 48.16 | 7.02 |
| 20 | 0.01 | 46.95 | 4.33 |

**Table 9: Comparison table of φ for nylon fibre**

Graph between the % increase in the value of φ and the aspect ratio is show in the figure below:

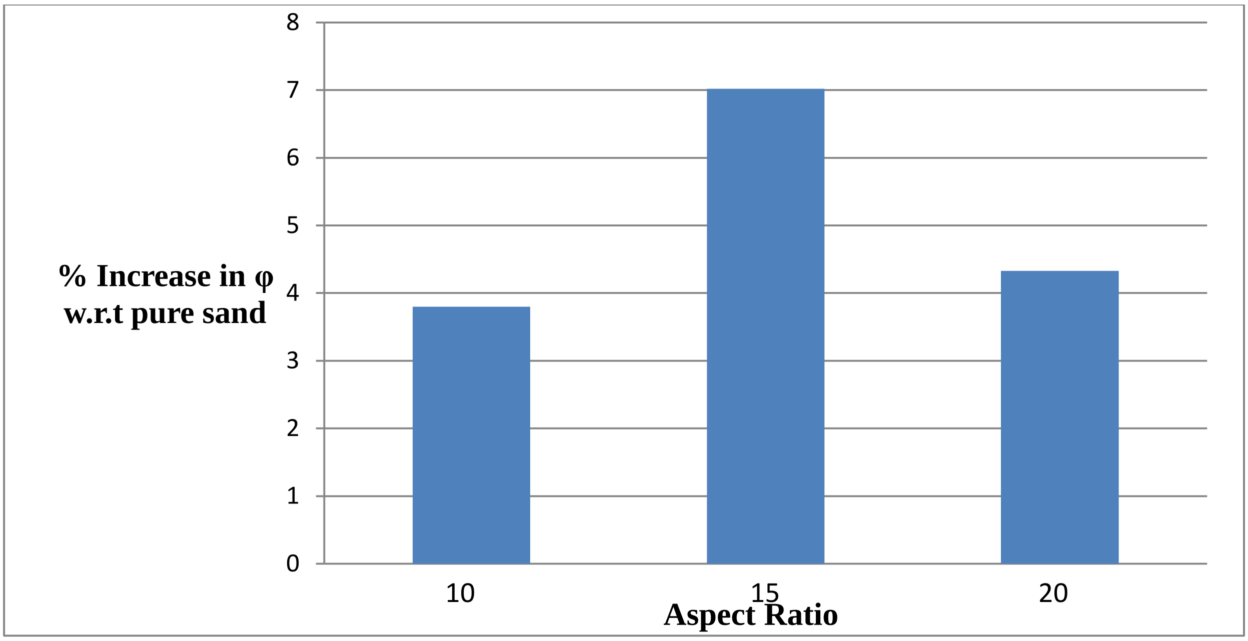


**Fig. 11: % increase in the value of φ with respect to the aspect ratio**

Thus for the aspect ratio of 15 maximum percentage increase in the φ value was observed to be 7.02%.

Therefore, the most appropriate aspect ratio for nylon is 15.

### 6.4.3. SAND SAMPLES REINFORCED WITH JUTE

After conducting the tests on pure sand and calculating c, ϕ values, jute fibres were added to it and direct shear test was performed.

The fibre percentage was taken as 2% by weight and aspect ratio as 5, 10 and 15.

- The graph between shear stress and shear strain for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the figure 10 when aspect ratio was 5.

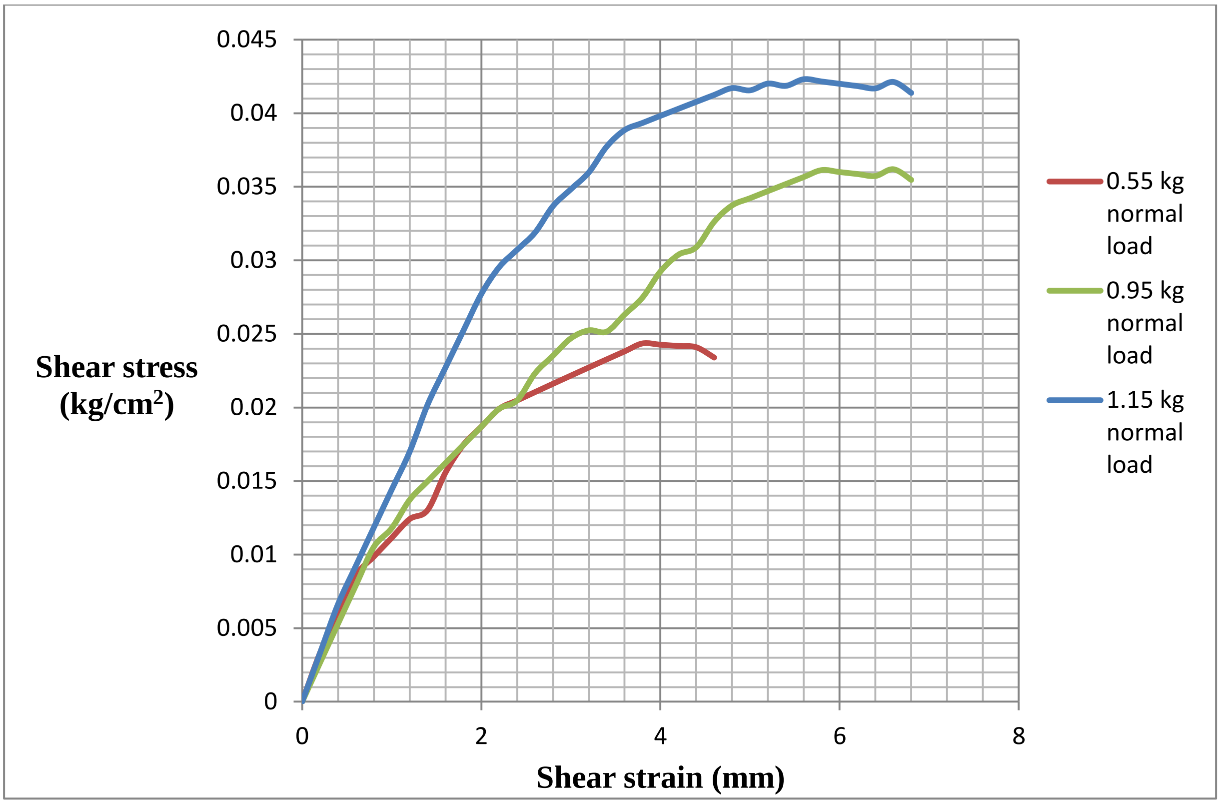


**Fig. 12: Shear stress vs shear strain for sand reinforced with jute fibre (As = 5)**

The sand sample failed at the shear stress of 0.02435 kg/cm$^2$, 0.0361 kg/cm$^2$ and 0.0422 kg/cm$^2$ under 0.55 kg, 0.95 kg and 1.55 kg normal loads.

The table for shear stress and normal stress for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the table 11.

| **Normal Stress (Kg/cm$^2$)** | **Peak Shear Stress (Kg/cm$^2$)** |
|---|---|
| 0.0153 | 0.02435 |
| 0.0264 | 0.0361 |
| 0.0319 | 0.0422 |

**Table 10: Normal stress & Shear stress for jute reinforced sand (As = 5)**

The graph between normal stress (kg/cm$^2$) & shear stress (kg/cm$^2$) was plotted using the data provided in table 11.

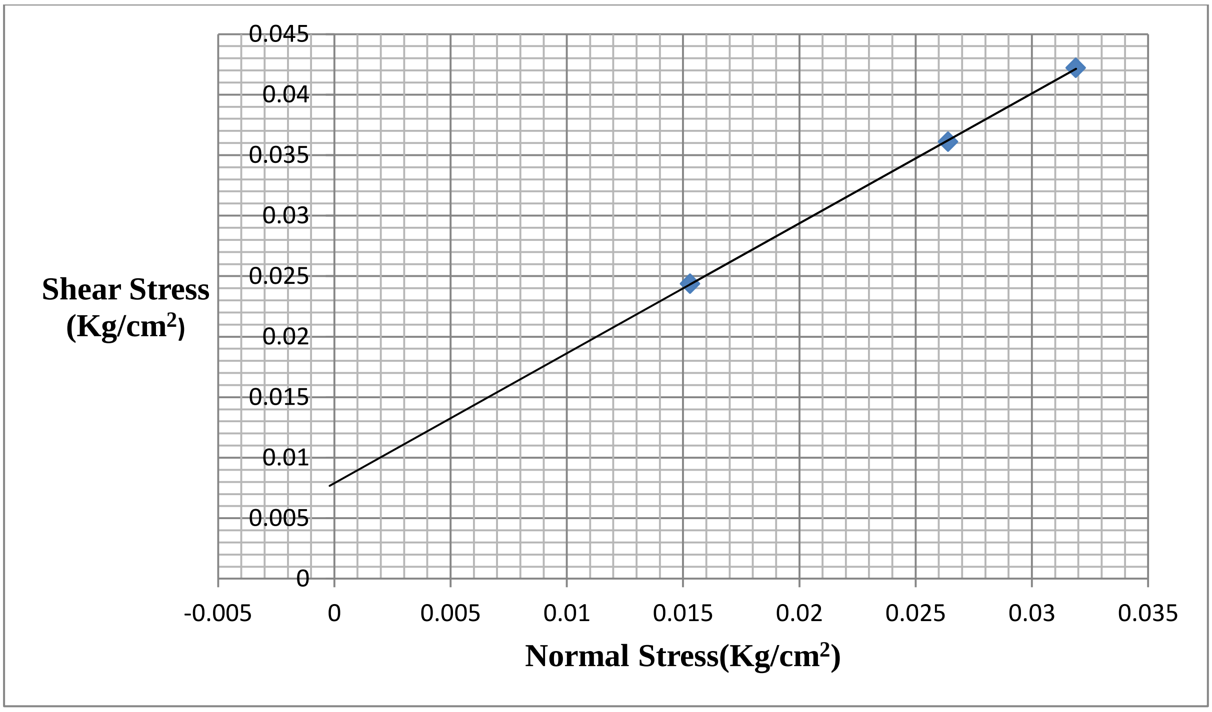


**Fig. 13: Shear stress vs normal stress for sand reinforced with 2% fibre (As = 5)**

From the above graph the following results were obtained:

C (cohesion) = **0.008** & ϕ (angle of internal friction) = **46.9°**

- The graph between shear stress and shear strain for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the figure 12 when aspect ratio was 10.

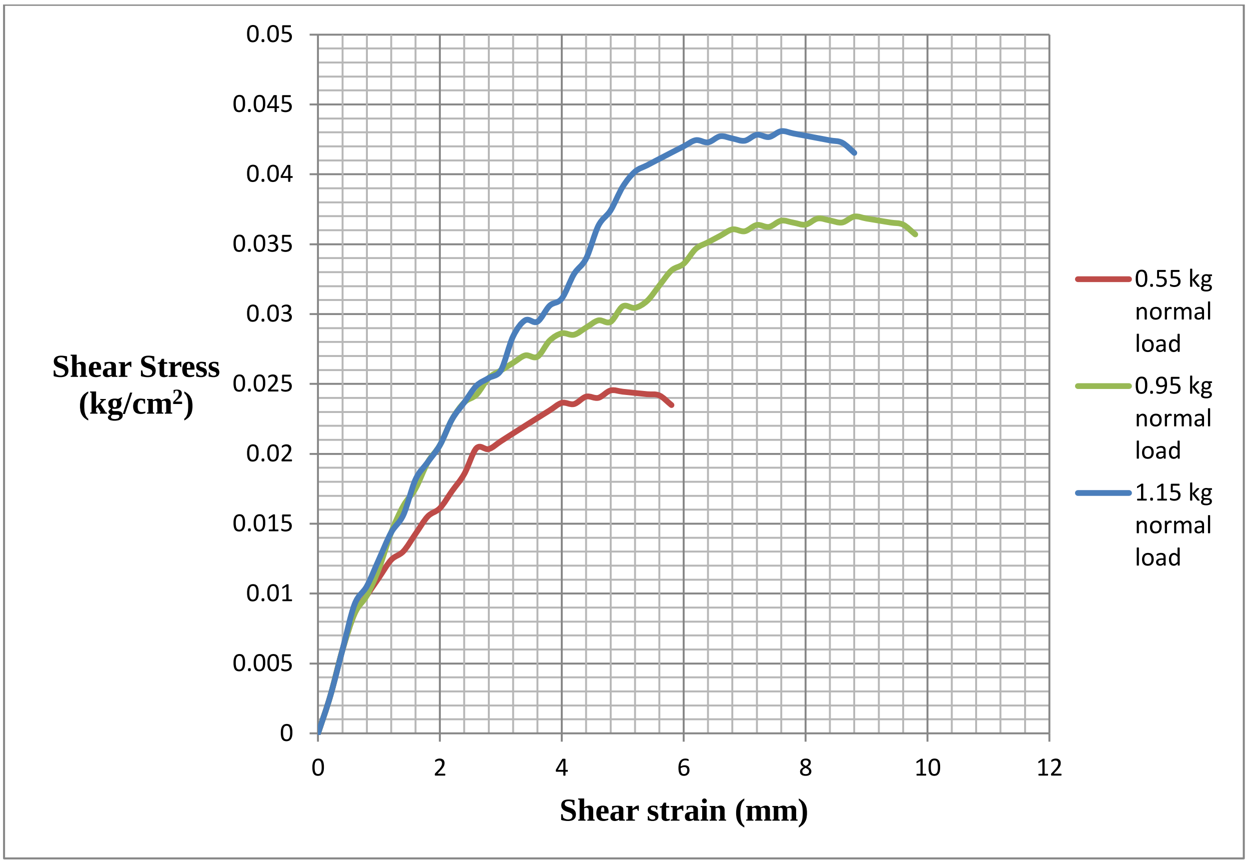


**Fig. 14: Shear stress vs shear strain for sand reinforced with jute fibre (As = 10)**

The sand sample failed at the shear stress of 0.02253 kg/cm$^2$, 0.03697 kg/cm$^2$ and 0.04409 kg/cm$^2$ under 0.55 kg, 0.95 kg and 1.55 kg normal loads.

The table for shear stress and normal stress for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the table 12.

| Normal Stress (Kg/cm$^2$) | Peak Shear Stress (Kg/cm$^2$) |
|---|---|
| 0.0153 | 0.02253 |
| 0.0264 | 0.03697 |
| 0.0319 | 0.04409 |

**Table 11: Normal stress & Shear stress for jute reinforced sand (As = 10)**

The graph between normal stress (kg/cm$^2$) & shear stress (kg/cm$^2$) was plotted using the data provided in table 12.

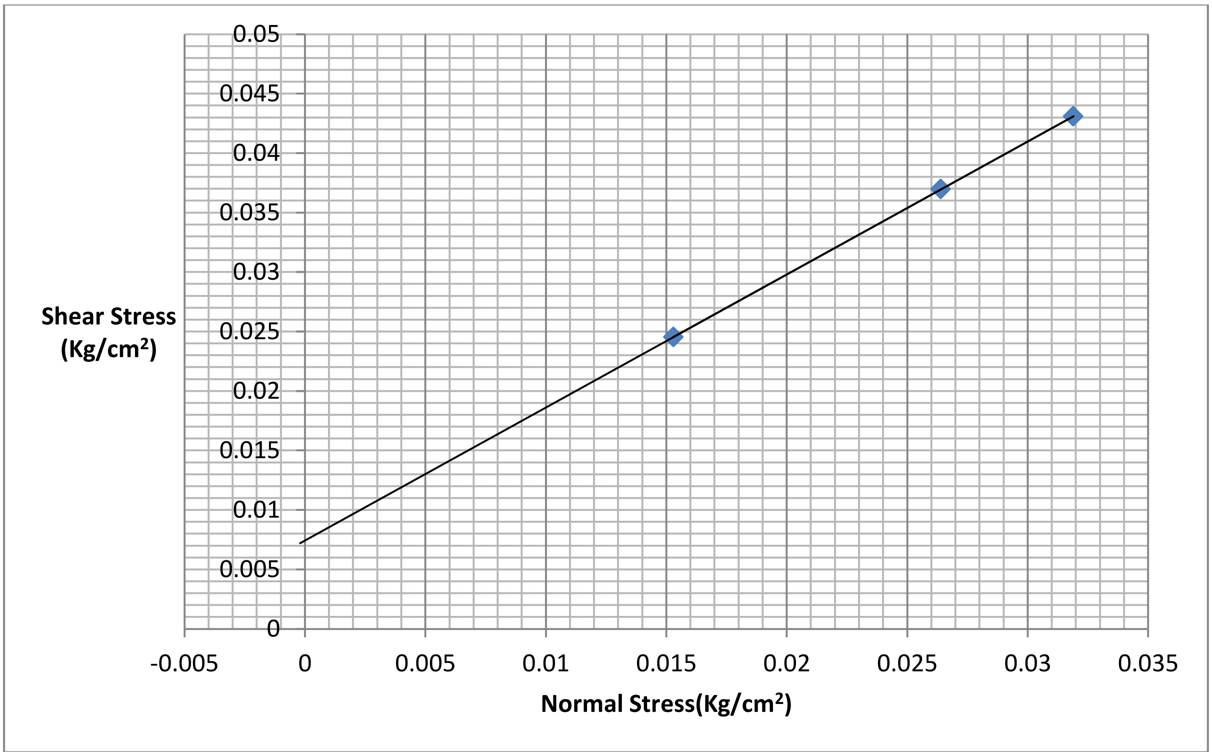


**Fig.15: Shear stress vs normal stress for sand reinforced with 2% fibre (As =10)**

From the above graph the following results were obtained:

C (cohesion) = **0.0075** & ϕ (angle of internal friction) = **48.86°**

- The graph between shear stress and shear strain for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the figure 14 when aspect ratio was 15.

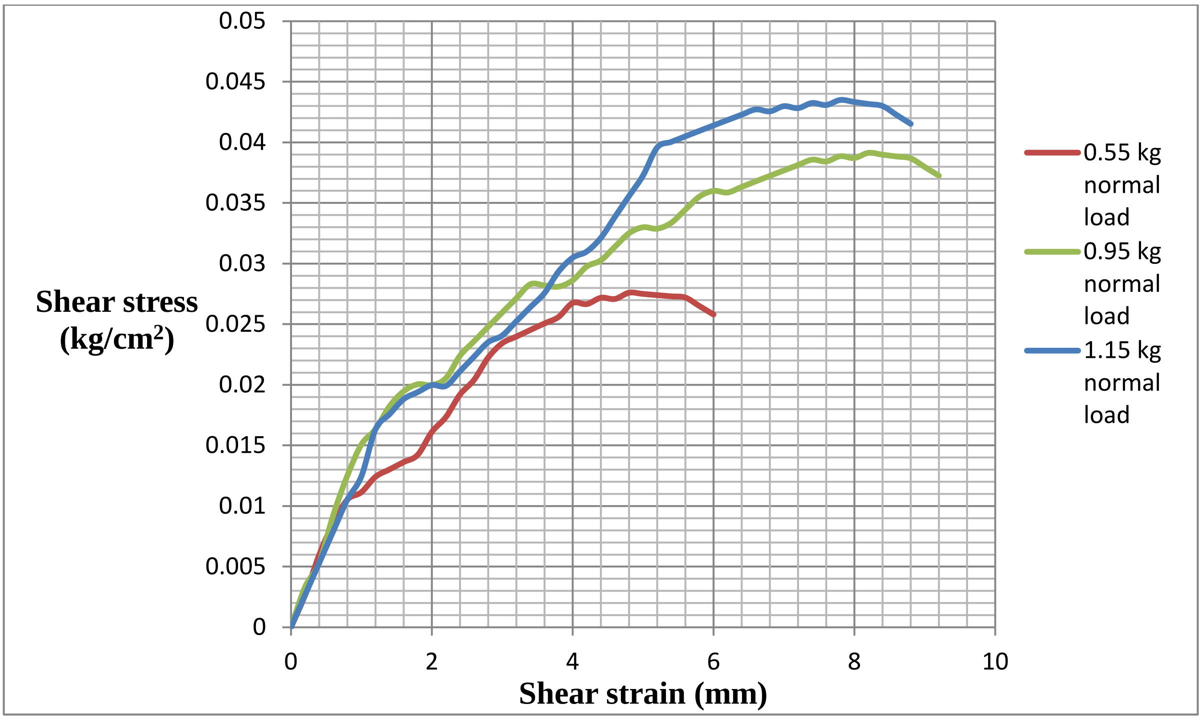


**Fig.16: Shear stress vs shear strain for sand reinforced with jute fibre (As = 15)**

The sand sample failed at the shear stress of 0.0276 kg/cm$^2$, 0.0391 kg/cm$^2$ and 0.0435 kg/cm$^2$ under 0.55 kg, 0.95 kg and 1.55 kg normal loads.

The table for shear stress and normal stress for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the table 13.

| **Normal Stress (Kg/cm$^2$)** | **Peak Shear Stress (Kg/cm$^2$)** |
|---|---|
| 0.0153 | 0.0276 |
| 0.0264 | 0.0391 |
| 0.0319 | 0.0435 |

**Table 12: Normal stress & Shear stress for jute reinforced sand (As = 15)**

The graph between normal stress (kg/cm$^2$) & shear stress (kg/cm$^2$) was plotted using the data provided in table 13.

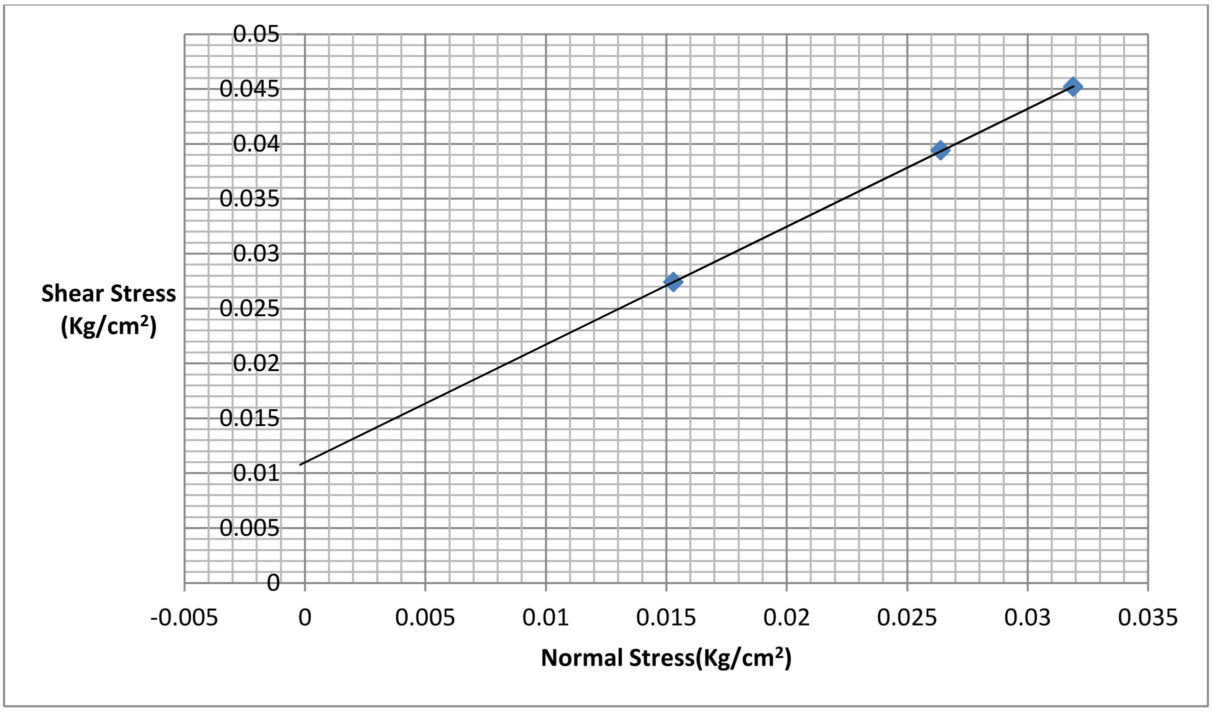


**Fig. 17: Shear stress vs normal stress for sand reinforced with 2% fibre (As =15)**

From the above graph the following results were obtained:

C (cohesion) = **0.011** & ф (angle of internal friction) = **47.036°**

### 6.4.3.1 COMPARISON OF RESULTS

Through the direct shear test conducted on jute reinforced sand samples following results were obtained.

- Most appropriate aspect ratio for jute

| Aspect Ratio | Cohesion | φ | % Increase in φ w.r.t pure sand |
|---|---|---|---|
| 5 | 0.008 | 46.9 | 4.23 |
| 10 | 0.0075 | 48.86 | 8.57 |
| 15 | 0.011 | 47.063 | 4.58 |

**Table 13: Comparison table of φ for jute fibre**

Graph between the % increase in the value of φ and the aspect ratio is show in the figure below:

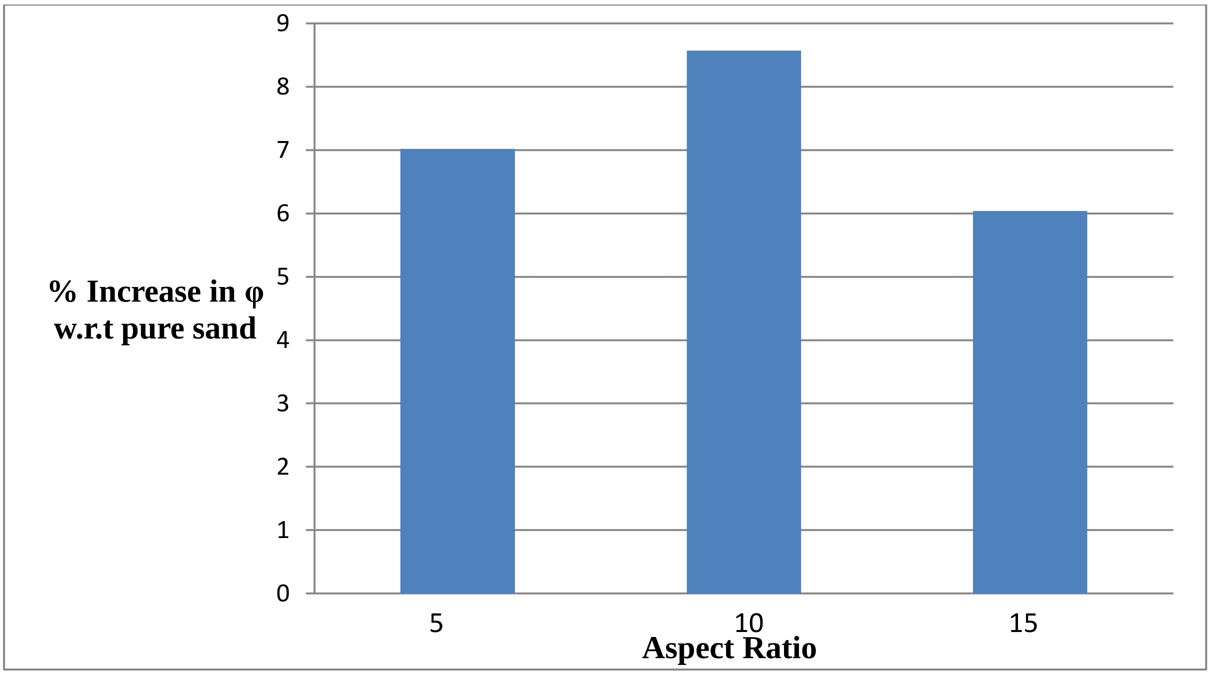


**Fig. 18: % increase in the value of φ with respect to the aspect ratio**

Thus for the aspect ratio of 10 maximum percentage increase in the φ value was observed to be 8.57%.

Therefore, the most appropriate aspect ratio for jute is 10.

### 6.4.4. SAND SAMPLES REINFORCED WITH COIR

After conducting the tests on pure sand and calculating c, ϕ values, coir fibres were added to it and direct shear test was performed.

The fibre percentage was taken as 2% by weight and aspect ratio as 10, 15 and 20.

- The graph between shear stress and shear strain for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the figure 16 when aspect ratio was 10.

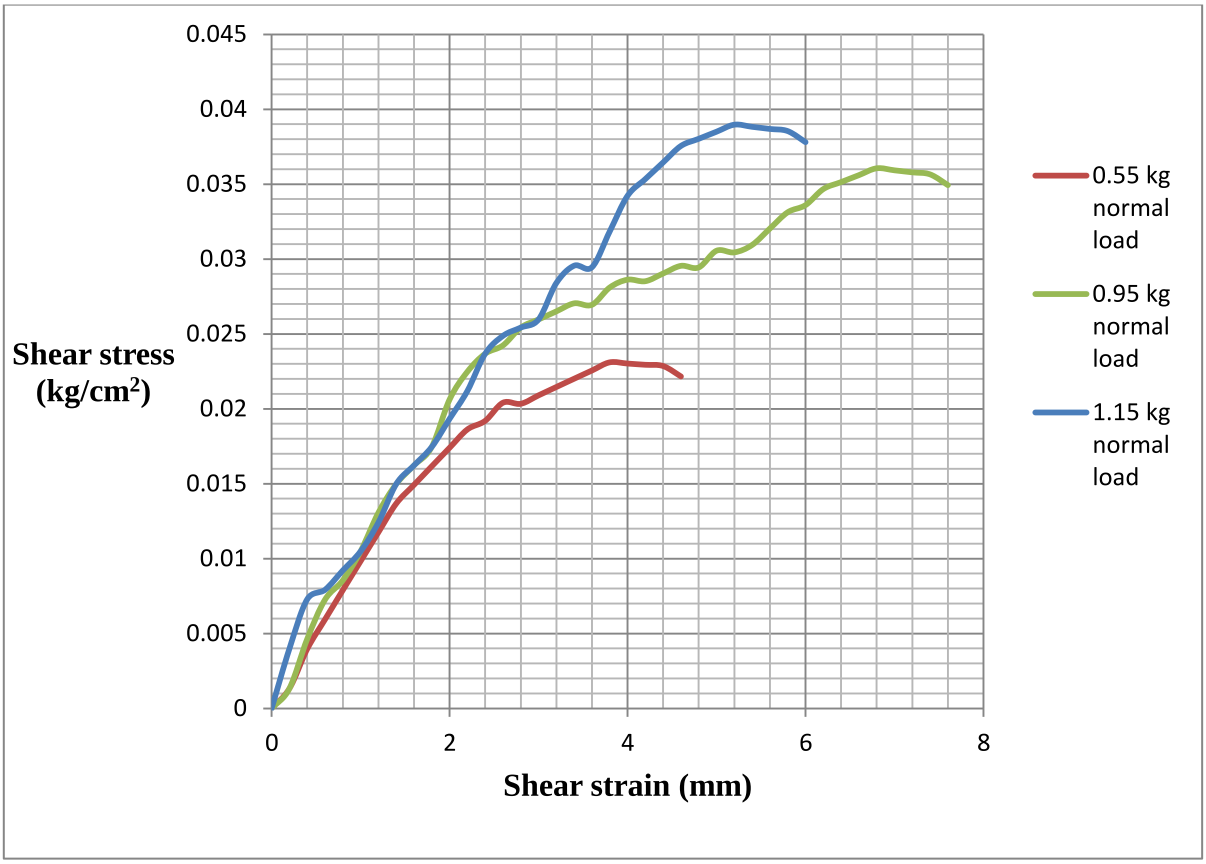


**Fig. 19: Shear stress vs shear strain for sand reinforced with coir fibre (As = 10)**

The sand sample failed at the shear stress of 0.020104 kg/cm$^2$, 0.036057 kg/cm$^2$ and 0.03896 kg/cm$^2$ under 0.55 kg, 0.95 kg and 1.55 kg normal loads.

The table for shear stress and normal stress for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the table 16.

| Normal Stress (Kg/cm$^2$) | Peak Shear Stress (Kg/cm$^2$) |
|---|---|
| 0.0153 | 0.020104 |
| 0.0264 | 0.036057 |
| 0.0319 | 0.03896 |

**Table 14: Normal stress & Shear stress for coir reinforced sand (As = 10)**

The graph between normal stress (kg/cm$^2$) & shear stress (kg/cm$^2$) was plotted using the data provided in table 16.

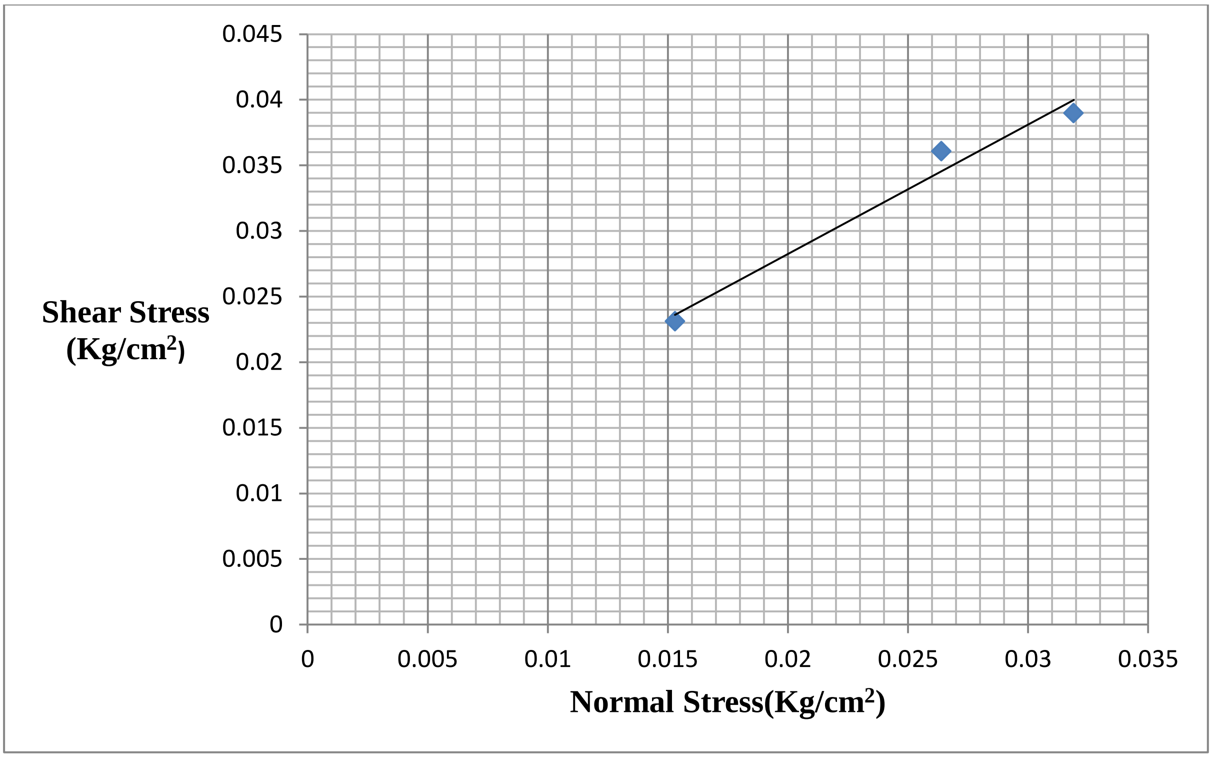


**Fig. 20: Shear stress vs normal stress for sand reinforced with 2% fibre (As = 10)**

From the above graph the following results were obtained:

C (cohesion) = **0.0085** & ϕ (angle of internal friction) = **45.65** °

- The graph between shear stress and shear strain for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the figure 18 when aspect ratio was 15.

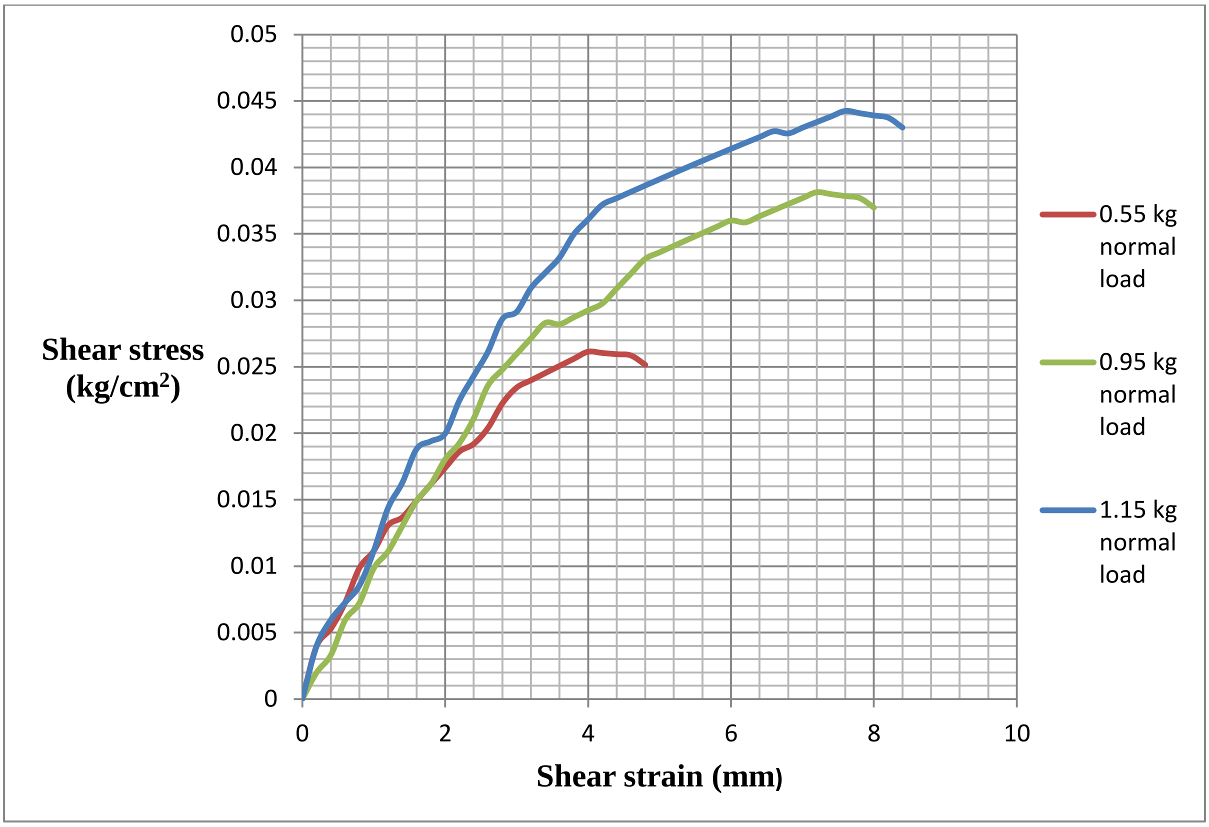


**Fig. 21: Shear stress vs shear strain for sand reinforced with coir fibre (As = 15)**

The sand sample failed at the shear stress of 0.0210 kg/cm$^2$, 0.0341 kg/cm$^2$ and 0.040 kg/cm$^2$ under 0.55 kg, 0.95 kg and 1.55 kg normal loads.

The table for shear stress and normal stress for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the table 17.

| Normal Stress (Kg/cm$^2$) | Peak Shear Stress (Kg/cm$^2$) |
|---|---|
| 0.0153 | 0.0210 |
| 0.0264 | 0.0341 |
| 0.0319 | 0.040 |

**Table 15: Normal stress & Shear stress for coir reinforced sand (As = 15)**

The graph between normal stress (kg/cm$^2$) & shear stress (kg/cm$^2$) was plotted using the data provided in table 17.

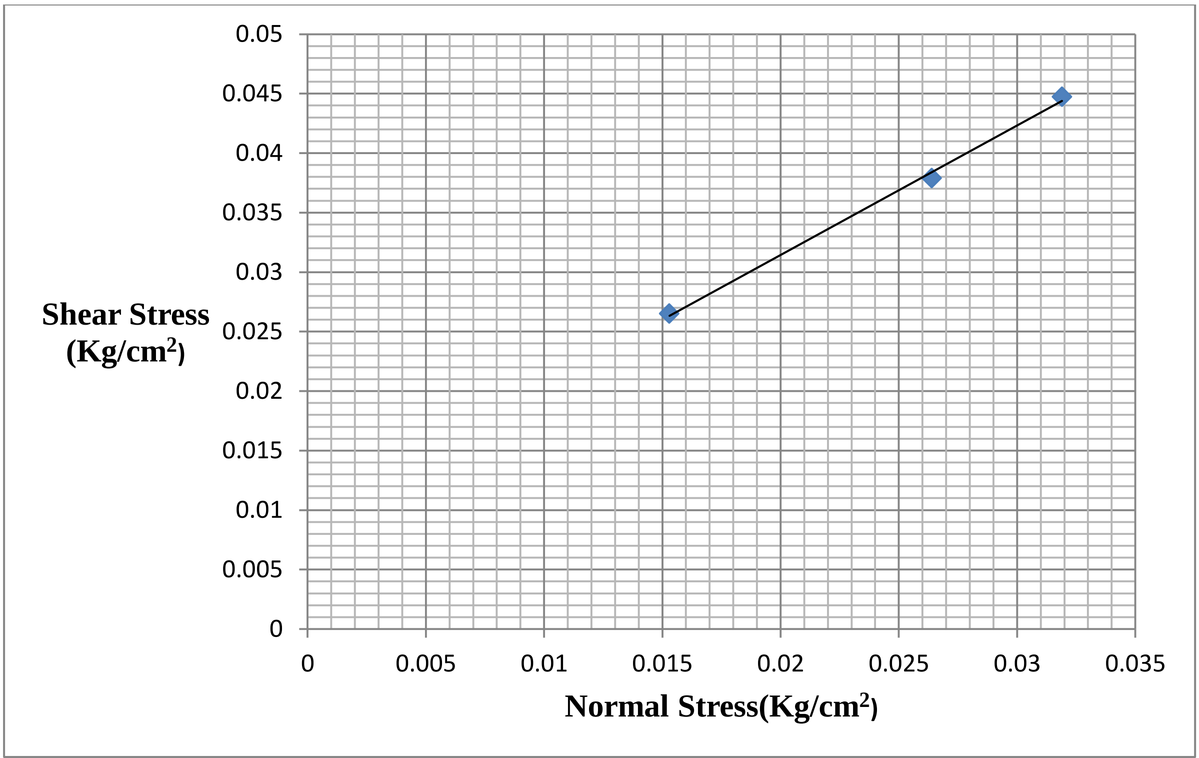


**Fig.22: Shear stress vs normal stress for sand reinforced with 2% fibre (As =15)**

From the above graph the following results were obtained:

C (cohesion) = **0.0065** & ϕ (angle of internal friction) = **47.72°**

- The graph between shear stress and shear strain for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the figure 20 when aspect ratio was 15.

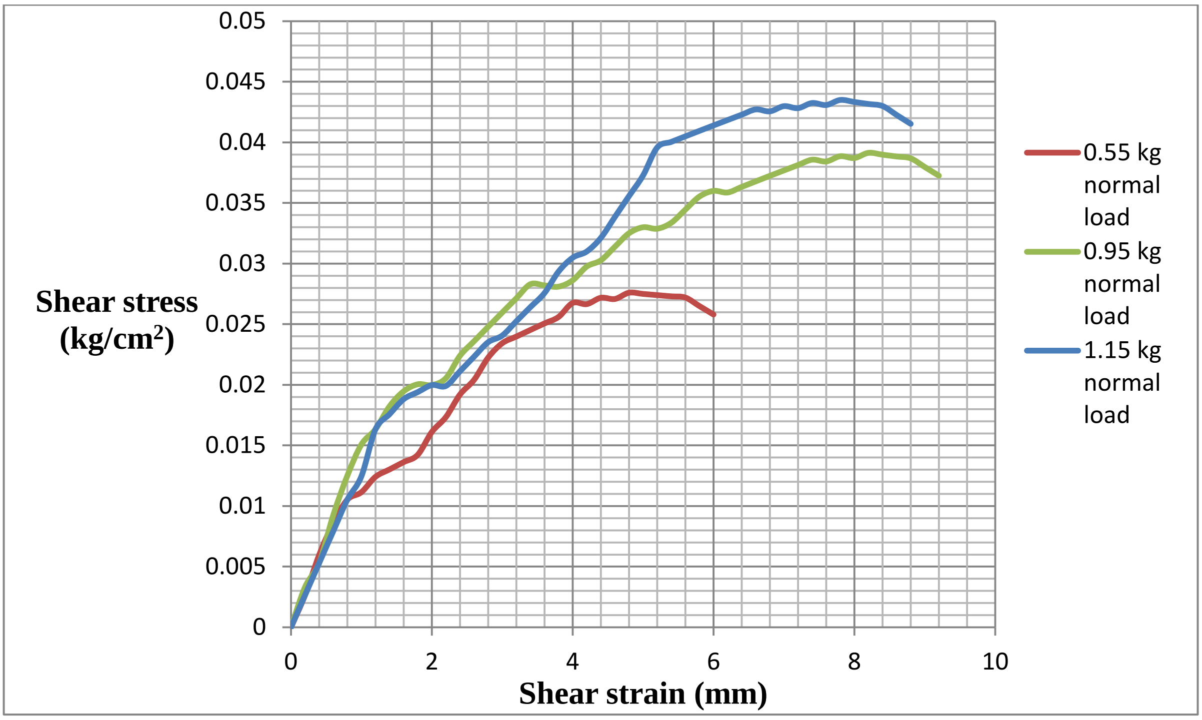


**Fig.23: Shear stress vs shear strain for sand reinforced with coir fibre (As = 20)**

The sand sample failed at the shear stress of 0.02613 kg/cm$^2$, 0.03738 kg/cm$^2$ and 0.0439 kg/cm$^2$ under 0.55 kg, 0.95 kg and 1.55 kg normal loads.

The table for shear stress and normal stress for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the table 18.

| Normal Stress (Kg/cm$^2$) | Peak Shear Stress (Kg/cm$^2$) |
|---|---|
| 0.0153 | 0.02613 |
| 0.0264 | 0.03738 |
| 0.0319 | 0.0439 |

**Table 16: Normal stress & Shear stress for coir reinforced sand (As = 20)**

The graph between normal stress (kg/cm$^2$) & shear stress (kg/cm$^2$) was plotted using the data provided in table 18.

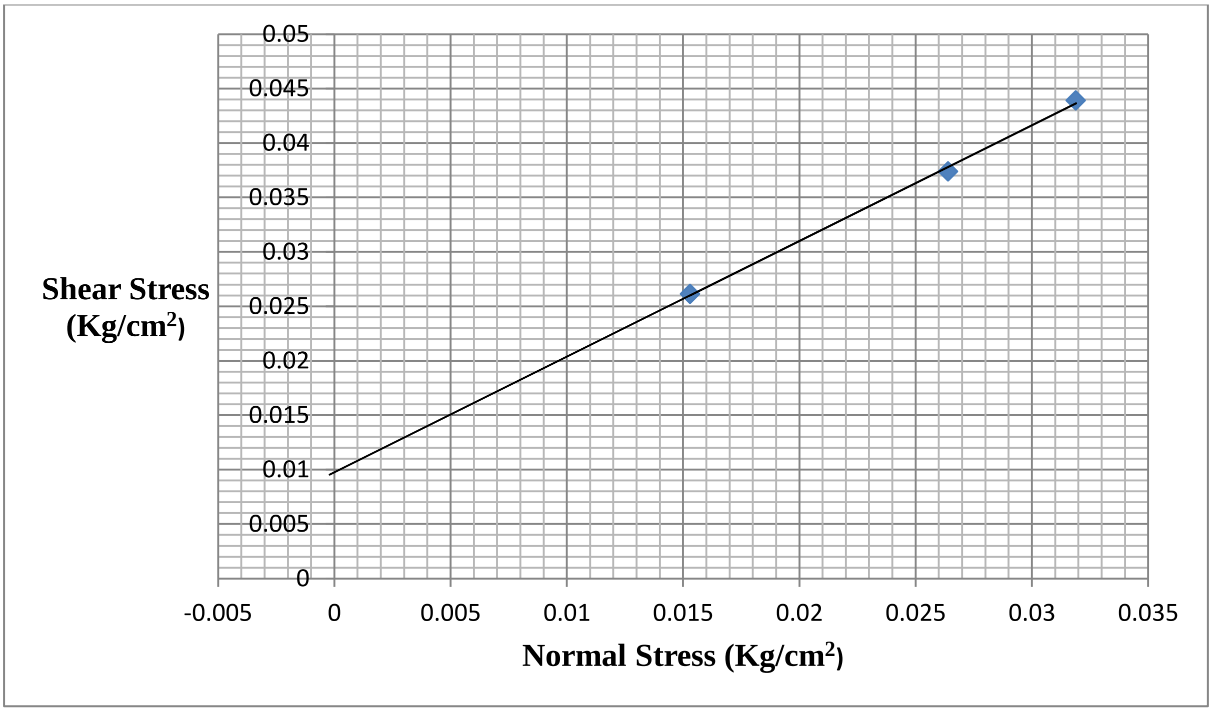


**Fig. 24: Shear stress vs normal stress for sand reinforced with 2% fibre (As =20)**

From the above graph the following results were obtained:

C (cohesion) = **0.095** & ϕ (angle of internal friction) = **46.74°**

#### 6.4.4.1 COMPARISON OF RESULTS

Through the direct shear test conducted on coir reinforced sand samples following results were obtained.

- Most appropriate aspect ratio for coir

| Aspect Ratio | Cohesion ($kg/cm^2$) | Φ (degree) | % Increase in φ w.r.t pure sand |
|---|---|---|---|
| 10 | 0.0085 | 45.65 | 1.14 |
| 15 | 0.0065 | 47.72 | 6.04 |
| 20 | 0.095 | 46.74 | 3.89 |

**Table 17: Comparison table of φ for coir fibre**

Graph between the % increase in the value of φ and the aspect ratio is show in the figure below:

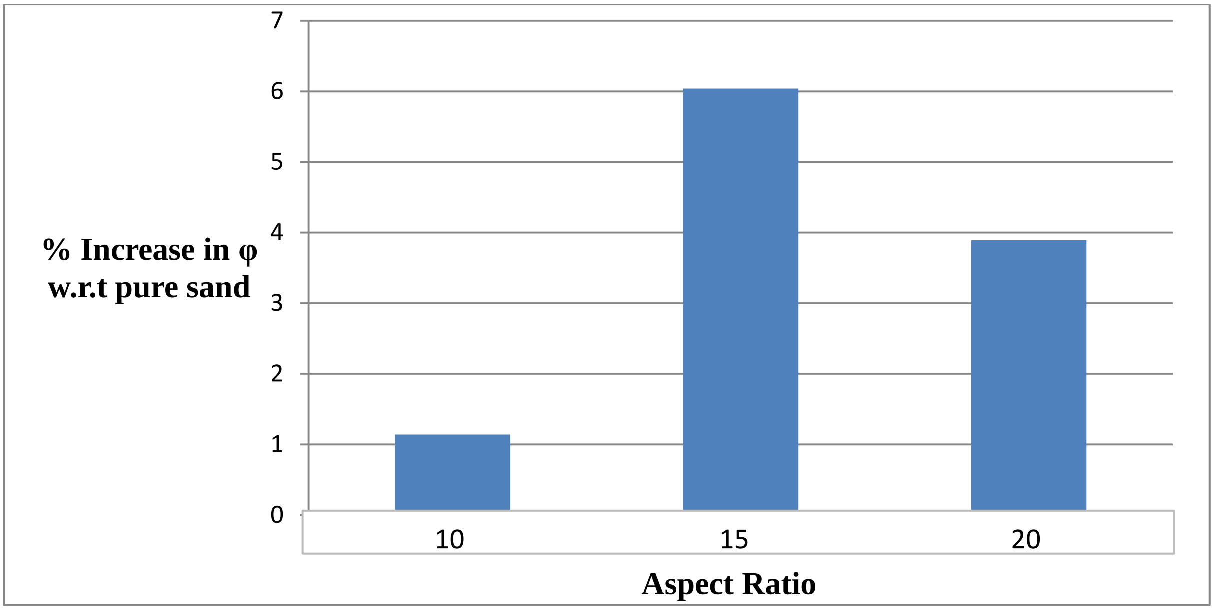


**Fig. 25: % increase in the value of φ with respect to the aspect ratio**

Thus for the aspect ratio of 15 maximum percentage increase in the φ value was observed to be 6.04 %.

Therefore, the most appropriate aspect ratio for coir is 15.

### 6.4.5. SAND SAMPLES REINFORCED WITH NYLON FIBRES AT 3% AND 4% MIX PROPORTIONS

The direct shear test was performed on sand reinforced with nylon fibre (As = 15) at the normal loads of 0.55 kg, 0.95 kg and 1.15 kg.

The fibre percentage was taken as 3% and 4%.

- The graph between shear stress and shear strain for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the figure below when 3% by weight of fibre was added to the sample.

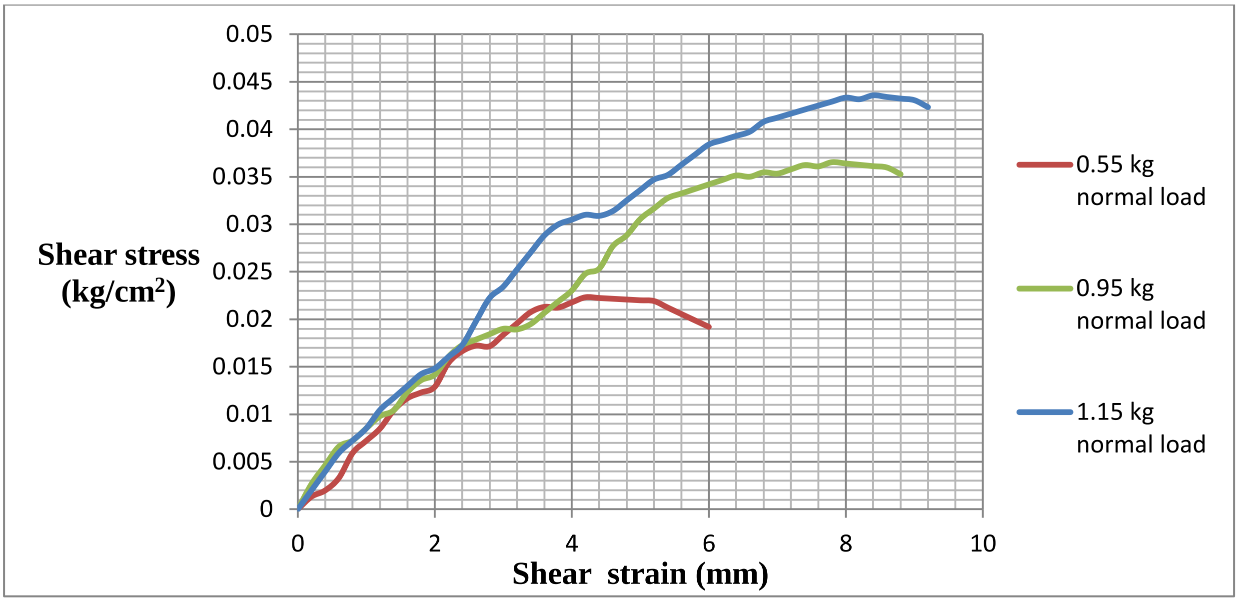


**Fig. 26: Shear stress vs shear strain for sand reinforced with 3% fibre**

The sand sample failed at the shear stress of 0.02232 kg/cm$^2$, 0.03654 kg/cm$^2$ and 0.04357 kg/cm$^2$ under 0.55 kg, 0.95 kg and 1.55 kg normal loads.

The table for shear stress and normal stress for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown below.

| Normal Stress (Kg/cm$^2$) | Peak Shear Stress (Kg/cm$^2$) |
|---|---|
| 0.0153 | 0.02232 |
| 0.0264 | 0.03654 |
| 0.0319 | 0.04357 |

**Table 18: Normal stress & Shear stress for nylon reinforced sand (fibre content = 3%)**

The graph between normal stress (kg/cm$^2$) & shear stress (kg/cm$^2$) was plotted using the data provided in the above table.

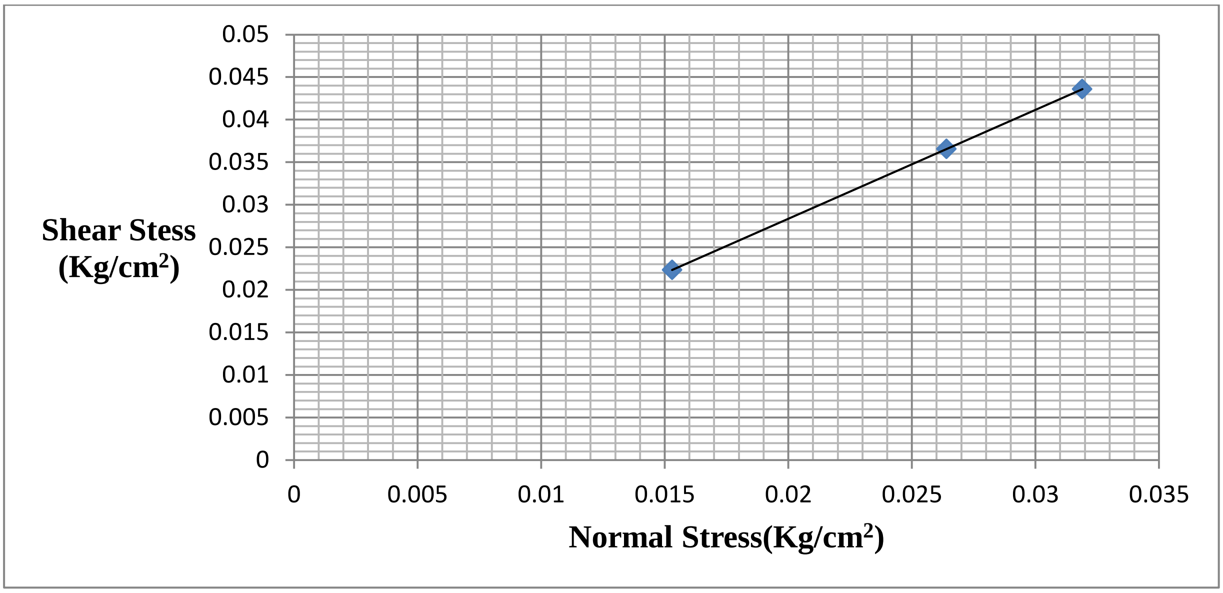


**Fig. 27: Shear stress vs normal stress for sand reinforced with 3% fibre**

From the above graph the following results were obtained:

C (cohesion) = **0.005** & ϕ (angle of internal friction) = **50.08°**

- The graph between shear stress and shear strain for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the figure below when 4% by weight of fibre was added to the sample.

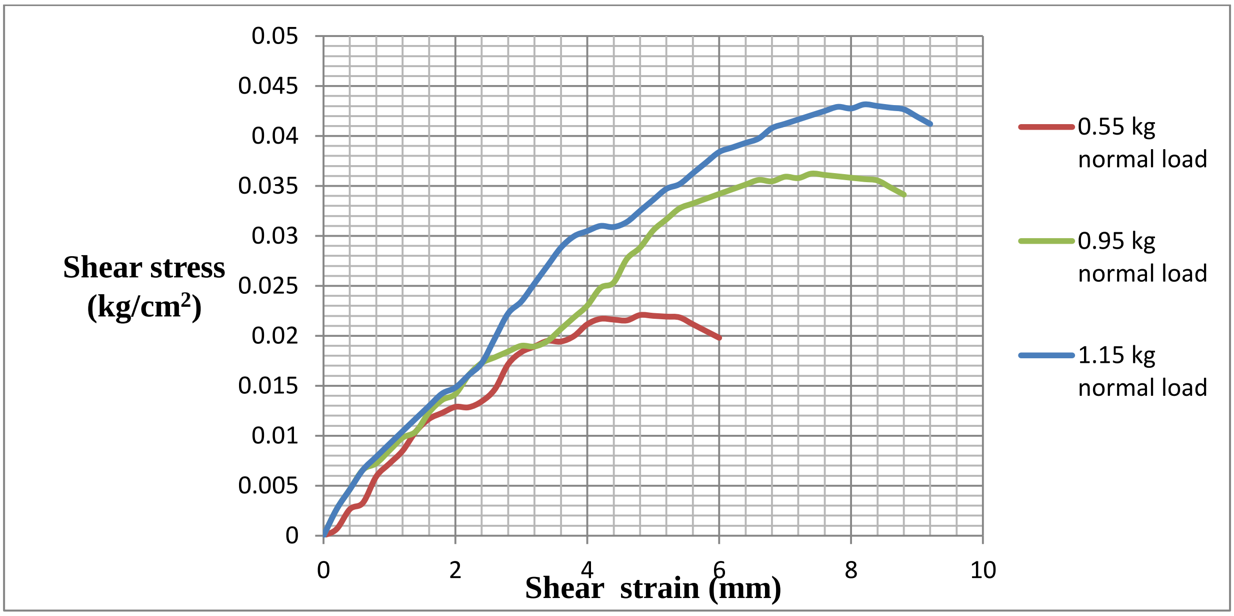


**Fig. 28: Shear stress vs shear strain for sand reinforced with 4% fibre**

The sand sample failed at the shear stress of 0.02208 kg/cm$^2$, 0.03623 kg/cm$^2$ and 0.04316 kg/cm$^2$ under 0.55 kg, 0.95 kg and 1.55 kg normal loads.

The table for shear stress and normal stress for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown below.

| Normal Stress (Kg/cm$^2$) | Peak Shear Stress (Kg/cm$^2$) |
|---|---|
| 0.0153 | 0.02208 |
| 0.0264 | 0.03623 |
| 0.0319 | 0.04316 |

**Table 19: Normal stress & Shear stress for nylon reinforced sand (fibre content = 4%)**

The graph between normal stress ($kg/cm^2$) & shear stress ($kg/cm^2$) was plotted using the data provided in the above table.

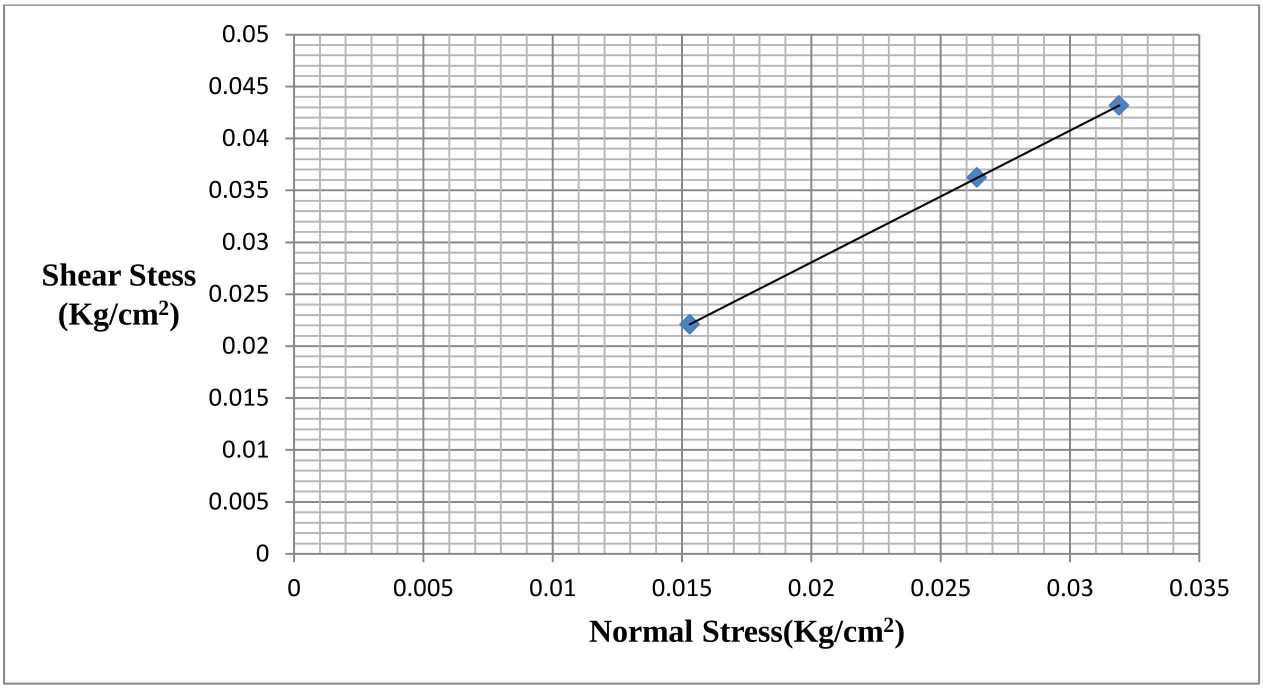


**Fig. 29: Shear stress vs normal stress for sand reinforced with 4% fibre**

From the above graph the following results were obtained:

C (cohesion) = **0.008** & ϕ (angle of internal friction) = **47.01°**

### 6.4.5.1 COMPARISON OF RESULTS

Through the direct shear test conducted on nylon reinforced sand samples following results were obtained.

- % Increase in φ

| Mix proportion (%) | Cohesion ($kg/cm^2$) | Φ (degree) | % Increase in φ w.r.t pure sand |
|---|---|---|---|
| 2 | 0.009 | 48.16 | 7.02 |
| 3 | 0.005 | 50.08 | 11.28 |
| 4 | 0.008 | 47.01 | 4.46 |

**Table 20: Comparison table of φ for nylon fibre**

For the most appropriate aspect ratio of 15 maximum percentage increase in the φ value was observed to be 11.28% at 3% mix proportion.

- Change in shear strength of reinforced sand with respect to natural sand at 2% mix proportion

| Normal load (kg) | Natural sand maximum shear strength ($kg/cm^2$) | Nylon (As = 15) maximum shear strength ($kg/cm^2$) | % Change in Shear strength |
|---|---|---|---|
| 0.55 | 0.0173 | 0.0219 | 26.58 |
| 0.95 | 0.0284 | 0.0364 | 28.45 |
| 1.15 | 0.0339 | 0.0426 | 25.75 |

**Table 21: Comparison table of shear strength for nylon fibre at 2% mix proportion**

An average 26% increase in the shear strength of the sand was observed when 2% nylon fibre (As = 15) was added to the natural sand.

- Change in shear strength of reinforced sand with respect to natural sand at 3% mix proportion

| Normal load (kg) | Natural sand maximum shear strength ($kg/cm^2$) | Nylon (As = 15) maximum shear strength ($kg/cm^2$) | % Change in Shear strength |
|---|---|---|---|
| 0.55 | 0.0173 | 0.02232 | 29.01 |
| 0.95 | 0.0284 | 0.03654 | 29.66 |
| 1.15 | 0.0339 | 0.04357 | 28.58 |

**Table 22: Comparison table of shear strength for nylon fibre at 3% mix proportion**

An average 29% increase in the shear strength of the sand was observed when 3% nylon fibre (As = 15) was added to the natural sand.

- Change in shear strength of reinforced sand with respect to natural sand at 4% mix proportion

| Normal load (kg) | Natural sand maximum shear strength ($kg/cm^2$) | Nylon (As = 15) maximum shear strength ($kg/cm^2$) | % Change in Shear strength |
|---|---|---|---|
| 0.55 | 0.0173 | 0.02208 | 27.6 |
| 0.95 | 0.0284 | 0.03623 | 27.57 |
| 1.15 | 0.0339 | 0.04316 | 27.31 |

**Table 23: Comparison table of shear strength for nylon fibre at 4% mix proportion**

An average 27% increase in the shear strength of the sand was observed when 4% nylon fibre (As = 15) was added to the natural sand.

### 6.4.6. SAND SAMPLES REINFORCED WITH JUTE FIBRES AT 3% AND 4% MIX PROPORTIONS

The direct shear test was performed on sand reinforced with jute fibre (As = 10) at the normal loads of 0.55 kg, 0.95 kg and 1.15 kg.

The fibre percentage was taken as 3% and 4%.

- The graph between shear stress and shear strain for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the figure below when 3% by weight of fibre was added to the sample.

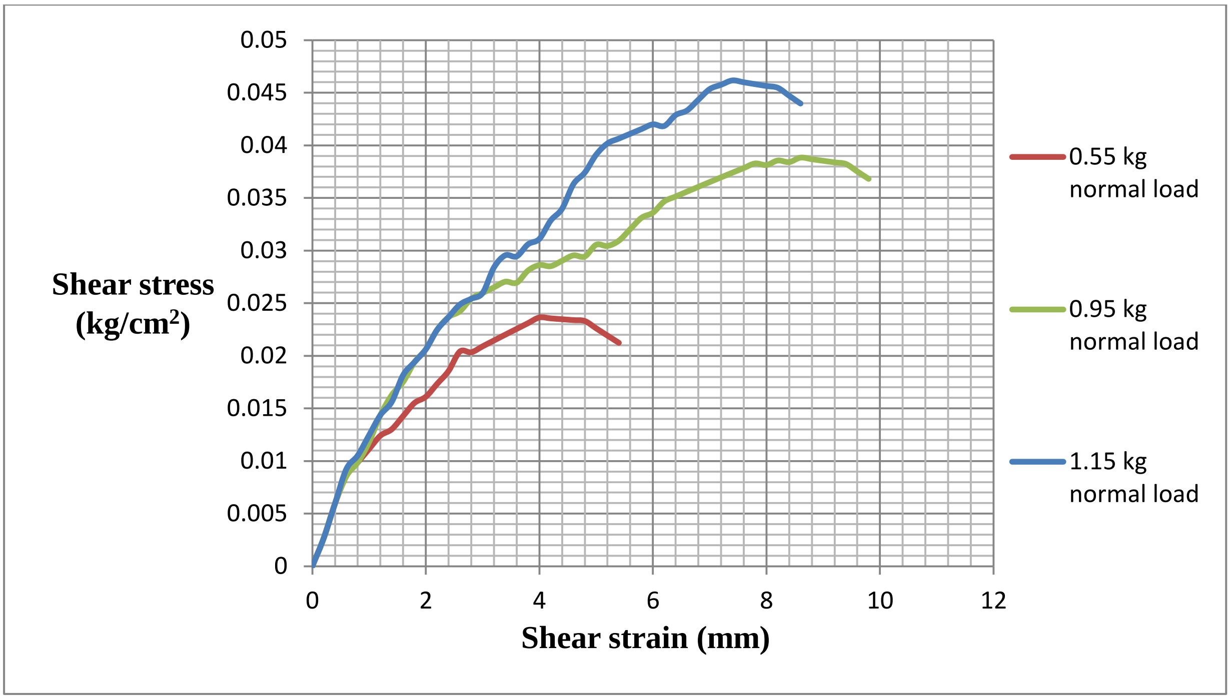


**Fig. 30: Shear stress vs shear strain for sand reinforced with 3% fibre**

The sand sample failed at the shear stress of 0.02364 kg/cm$^2$, 0.03883 kg/cm$^2$ and 0.04617 kg/cm$^2$ under 0.55 kg, 0.95 kg and 1.55 kg normal loads.

The table for shear stress and normal stress for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown below.

| Normal Stress (Kg/cm$^2$) | Peak Shear Stress (Kg/cm$^2$) |
|---|---|
| 0.0153 | 0.02364 |
| 0.0264 | 0.03883 |
| 0.0319 | 0.04617 |

**Table 24: Normal stress & Shear stress for jute reinforced sand (fibre content = 3%)**

The graph between normal stress (kg/cm$^2$) & shear stress (kg/cm$^2$) was plotted using the data provided in the above table.

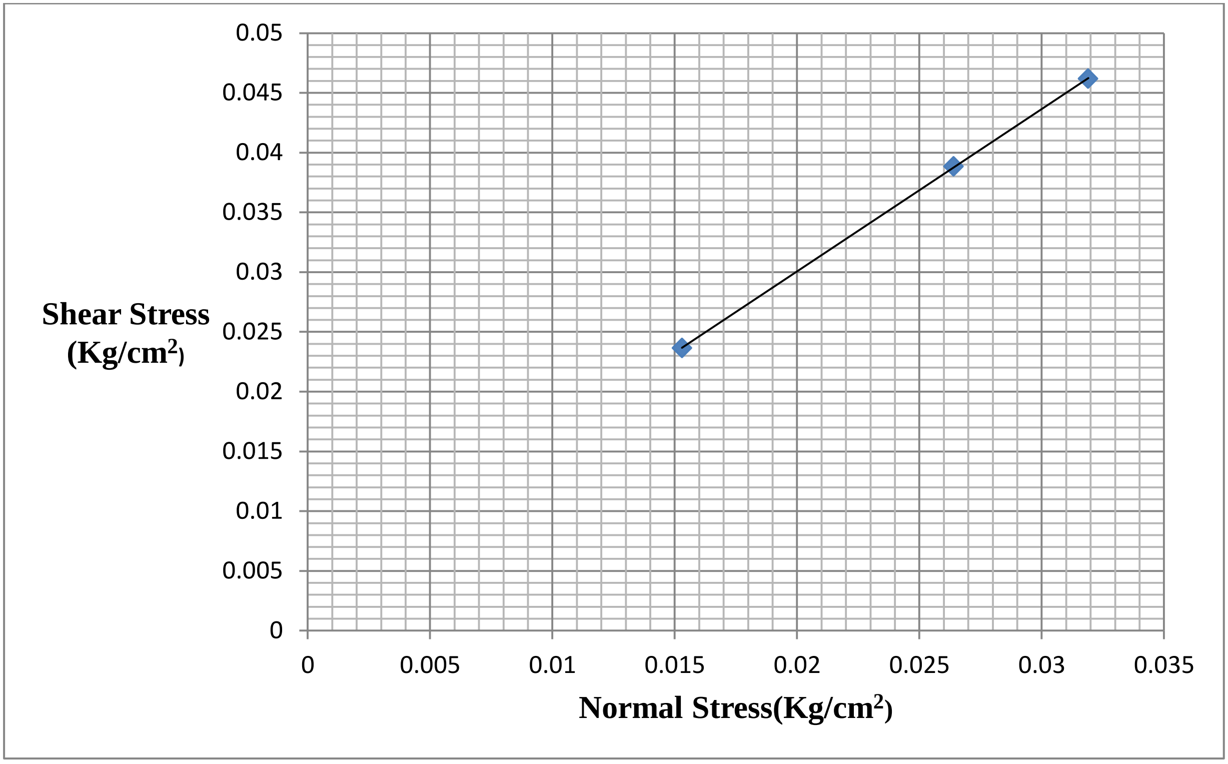


**Fig. 31: Shear stress vs normal stress for sand reinforced with 3% fibre**

From the above graph the following results were obtained:

C (cohesion) = **0.005** & ϕ (angle of internal friction) = **52.05°**

- The graph between shear stress and shear strain for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the figure below when 4% by weight of fibre was added to the sample.

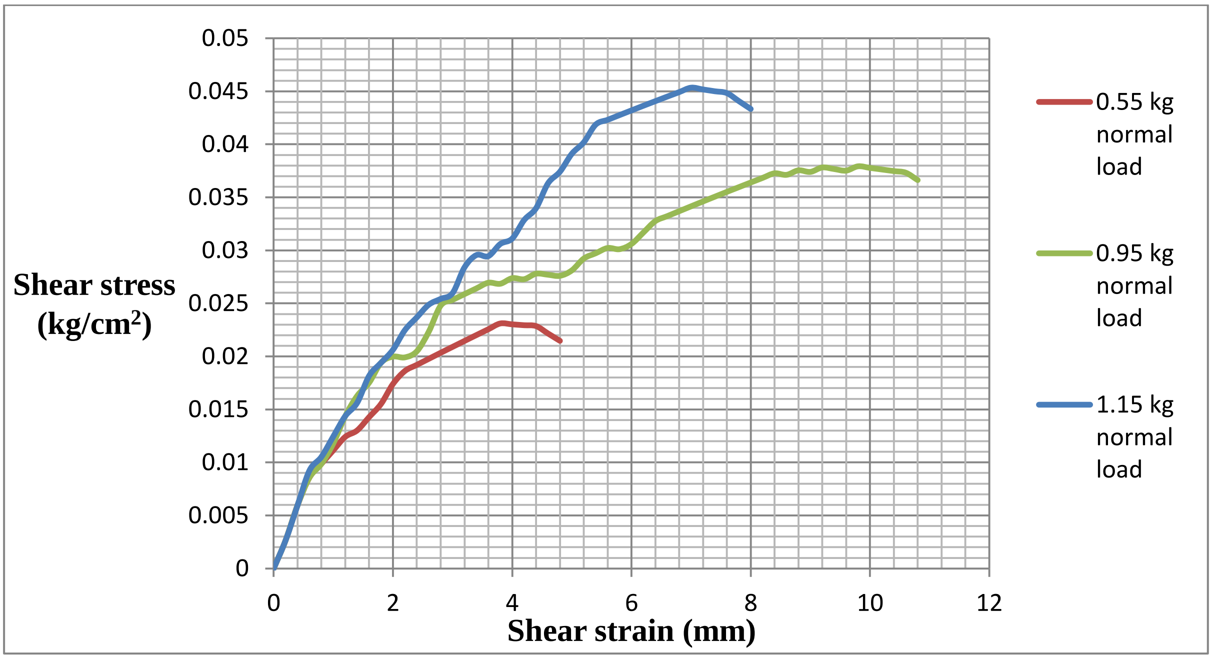


**Fig. 32: Shear stress vs shear strain for sand reinforced with 4% fibre**

The sand sample failed at the shear stress of 0.0231 kg/cm$^2$, 0.03792 kg/cm$^2$ and 0.04534 kg/cm$^2$ under 0.55 kg, 0.95 kg and 1.55 kg normal loads.

The table for shear stress and normal stress for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown below.

| Normal Stress (Kg/cm$^2$) | Peak Shear Stress (Kg/cm$^2$) |
|---|---|
| 0.0153 | 0.0231 |
| 0.0264 | 0.03792 |
| 0.0319 | 0.04534 |

**Table 25: Normal stress & Shear stress for jute reinforced sand (fibre content = 4%)**

The graph between normal stress ($kg/cm^2$) & shear stress ($kg/cm^2$) was plotted using the data provided in the above table.

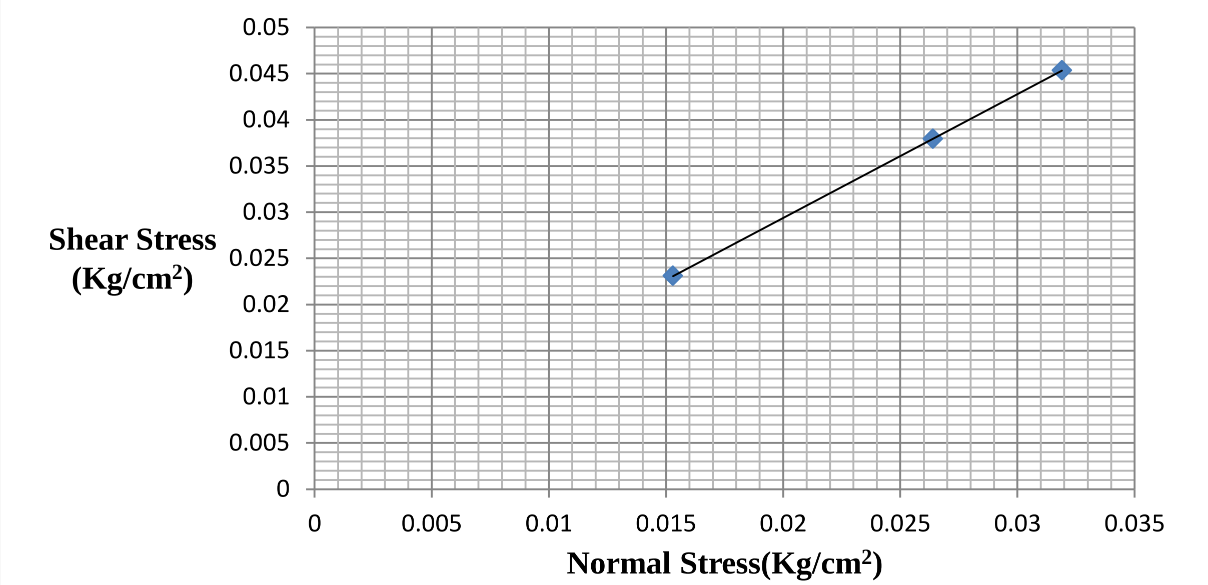


**Fig. 33: Shear stress vs normal stress for sand reinforced with 4% fibre**

From the above graph the following results were obtained:

C (cohesion) = **0.0075** & ϕ (angle of internal friction) = **49.24°**

### 6.4.6.1 COMPARISON OF RESULTS

Through the direct shear test conducted on jute reinforced sand samples following results were obtained.

- % Increase in φ

| Mix proportion (%) | Cohesion ($kg/cm^2$) | Φ (degree) | % Increase in φ w.r.t pure sand |
|---|---|---|---|
| 2 | 0.0075 | 48.86 | 8.57 |
| 3 | 0.005 | 52.05 | 15.66 |
| 4 | 0.0075 | 49.24 | 9.4 |

**Table 26: Comparison table of φ for jute fibre**

For the most appropriate aspect ratio of 10 maximum percentage increase in the φ value was observed to be 15.66% at 3% mix proportion.

- Change in shear strength of reinforced sand with respect to natural sand at 2% mix proportion

| Normal load (kg) | Natural sand maximum shear strength ($kg/cm^2$) | Jute (As = 10) maximum shear strength ($kg/cm^2$) | % Change in Shear strength |
|---|---|---|---|
| 0.55 | 0.0173 | 0.02253 | 30.23 |
| 0.95 | 0.0284 | 0.03697 | 30.17 |
| 1.15 | 0.0339 | 0.04409 | 30.058 |

**Table 27: Comparison table of shear strength for jute fibre at 2% mix proportion**

An average 30% increase in the shear strength of the sand was observed when 2% jute fibre (As = 10) was added to the natural sand.

- Change in shear strength of reinforced sand with respect to natural sand at 3% mix proportion

| Normal load (kg) | Natural sand maximum shear strength (kg/cm$^2$) | Jute (As = 10) maximum shear strength (kg/cm$^2$) | % Change in Shear strength |
|---|---|---|---|
| 0.55 | 0.0173 | 0.02364 | 36.64 |
| 0.95 | 0.0284 | 0.03883 | 36.72 |
| 1.15 | 0.0339 | 0.04617 | 36.19 |

**Table 28: Comparison table of shear strength for jute fibre at 3% mix proportion**

An average 36% increase in the shear strength of the sand was observed when 3% jute fibre (As = 10) was added to the natural sand.

- Change in shear strength of reinforced sand with respect to natural sand at 4% mix proportion

| Normal load (kg) | Natural sand maximum shear strength (kg/cm$^2$) | Jute (As = 10) maximum shear strength (kg/cm$^2$) | % Change in Shear strength |
|---|---|---|---|
| 0.55 | 0.0173 | 0.0231 | 33.52 |
| 0.95 | 0.0284 | 0.03792 | 33.15 |
| 1.15 | 0.0339 | 0.04534 | 33.74 |

**Table 29: Comparison table of shear strength for jute fibre at 4% mix proportion**

An average 33% increase in the shear strength of the sand was observed when 4% jute fibre (As = 10) was added to the natural sand.

### 6.4.7. SAND SAMPLES REINFORCED WITH COIR FIBRES AT 1% AND 3% MIX PROPORTIONS

The direct shear test was performed on sand reinforced with coir fibre (As = 15) at the normal loads of 0.55 kg, 0.95 kg and 1.15 kg.

The fibre percentage was taken as 1% and 3%.

- The graph between shear stress and shear strain for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the figure below when 1% by weight of fibre was added to the sample.

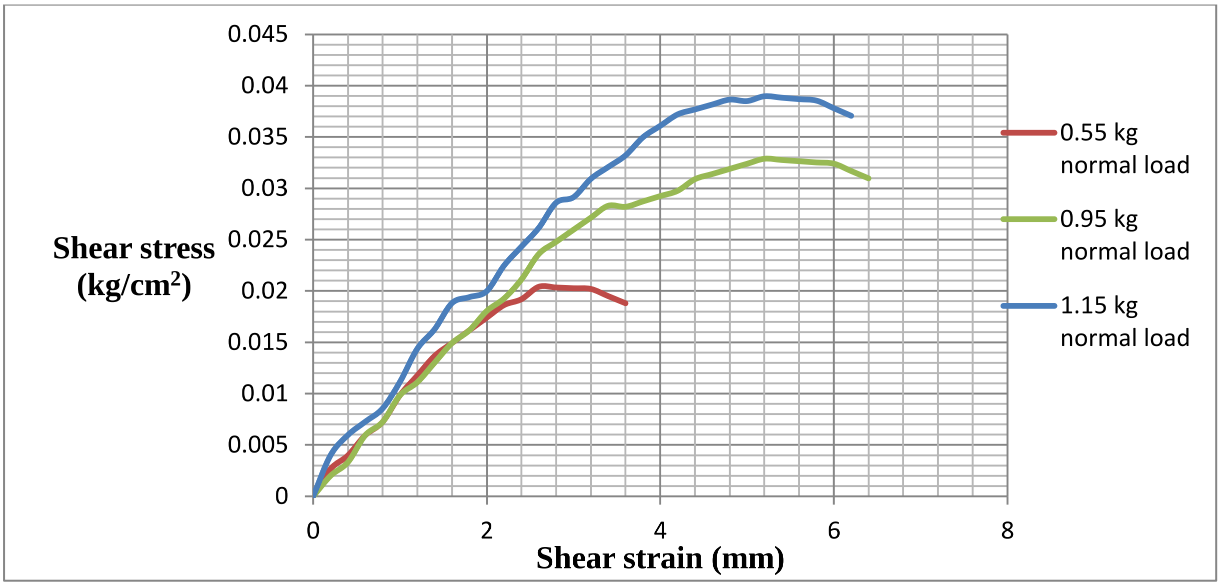


**Fig. 34: Shear stress vs shear strain for sand reinforced with 1% fibre**

The sand sample failed at the shear stress of 0.0204 kg/cm$^2$, 0.03288 kg/cm$^2$ and 0.03896 kg/cm$^2$ under 0.55 kg, 0.95 kg and 1.55 kg normal loads.

The table for shear stress and normal stress for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown below.

| Normal Stress (Kg/cm$^2$) | Peak Shear Stress (Kg/cm$^2$) |
|---|---|
| 0.0153 | 0.0204 |
| 0.0264 | 0.03288 |
| 0.0319 | 0.03896 |

**Table 30: Normal stress & Shear stress for coir reinforced sand (fibre content = 1%)**

The graph between normal stress (kg/cm$^2$) & shear stress (kg/cm$^2$) was plotted using the data provided in the above table.

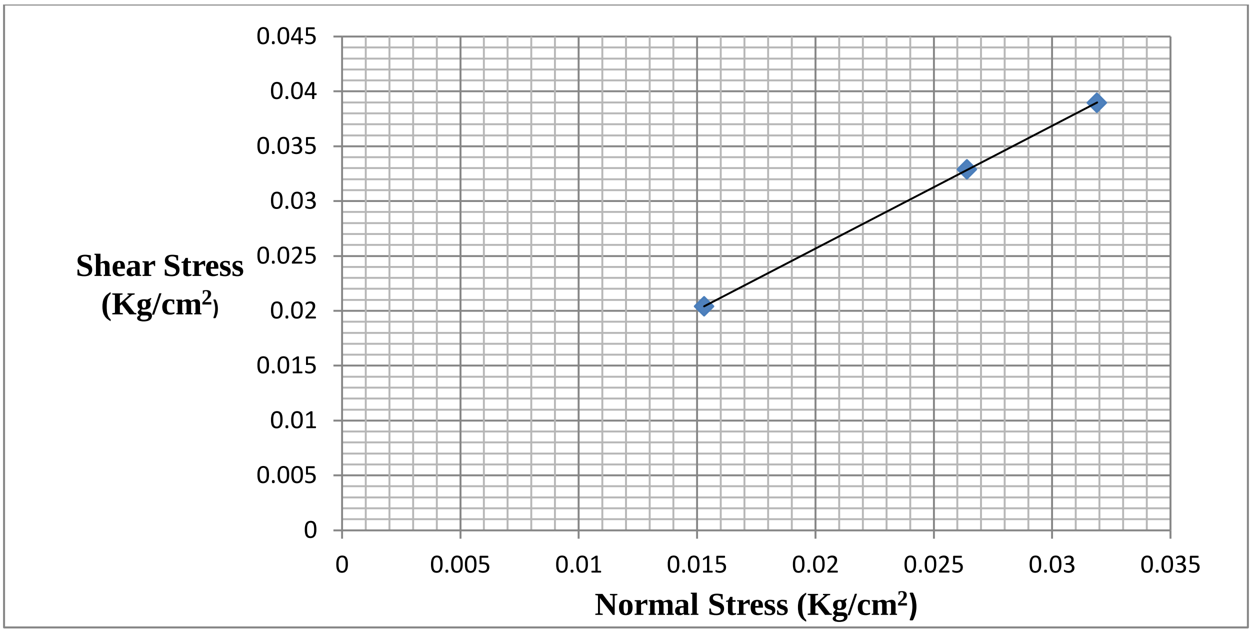


**Fig. 35: Shear stress vs normal stress for sand reinforced with 1% fibre**

From the above graph the following results were obtained:

C (cohesion) = **0.005** & ϕ (angle of internal friction) = **46.25°**

- The graph between shear stress and shear strain for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown in the figure below when 3% by weight of fibre was added to the sample.

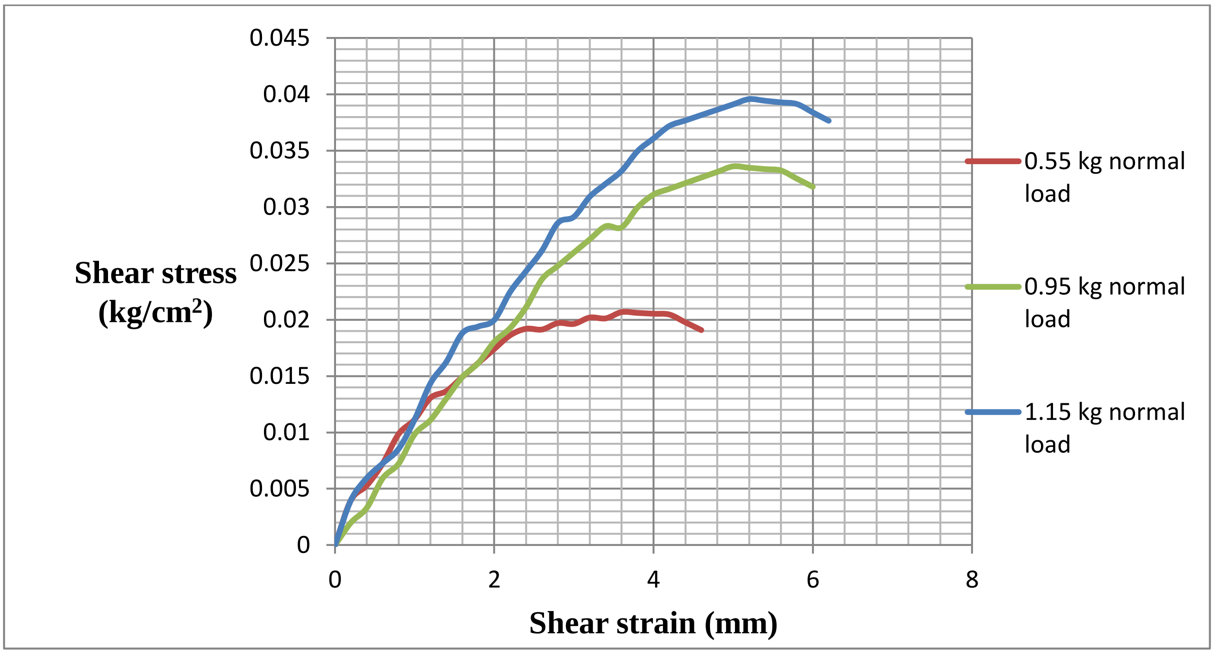


**Fig. 36: Shear stress vs shear strain for sand reinforced with 3% fibre**

The sand sample failed at the shear stress of 0.0205 $kg/cm^2$, 0.0336 $kg/cm^2$ and 0.0395 $kg/cm^2$ under 0.55 kg, 0.95 kg and 1.55 kg normal loads.

The table for shear stress and normal stress for the direct shear test done on reinforced sand sample for normal loading of 0.55 kg, 0.95 kg and 1.15 kg is shown below.

| Normal Stress ($Kg/cm^2$) | Peak Shear Stress ($Kg/cm^2$) |
|---|---|
| 0.0153 | 0.0205 |
| 0.0264 | 0.0336 |
| 0.0319 | 0.0395 |

**Table 31: Normal stress & Shear stress for coir reinforced sand (fibre content = 3%)**

The graph between normal stress (kg/cm$^2$) & shear stress (kg/cm$^2$) was plotted using the data provided in the above table.

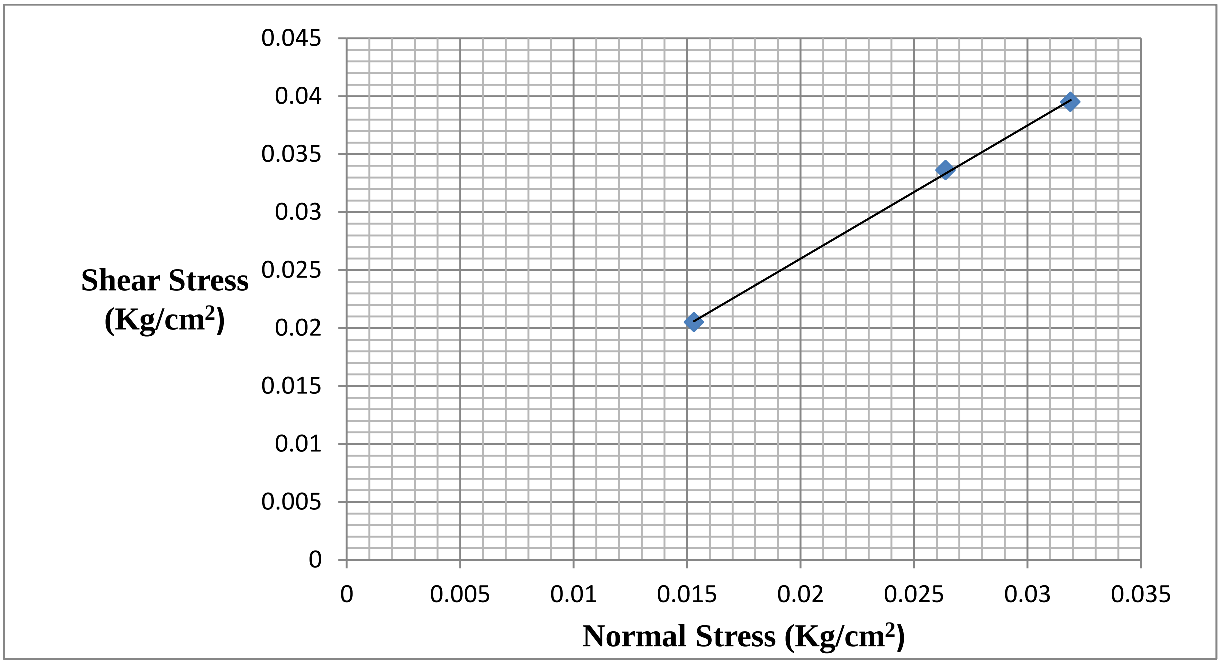


**Fig. 37: Shear stress vs normal stress for sand reinforced with 3% fibre**

From the above graph the following results were obtained:

C (cohesion) = **0.0065** & ϕ (angle of internal friction) = **45.74°**

### 6.4.7.1 COMPARISON OF RESULTS

Through the direct shear test conducted on coir reinforced sand samples following results were obtained.

- % Increase in φ

| Mix proportion (%) | Cohesion ($kg/cm^2$) | Φ (degree) | % Increase in φ w.r.t pure sand |
|---|---|---|---|
| 1 | 0.005 | 46.25 | 2.77 |
| 2 | 0.01 | 47.72 | 6.04 |
| 3 | 0.0065 | 45.74 | 1.64 |

**Table 32: Comparison table of φ for coir fibre**

For the most appropriate aspect ratio of 15 maximum percentage increase in the φ value was observed to be 6.04% at 2% mix proportion.

- Change in shear strength of reinforced sand with respect to natural sand at 1% mix proportion

| Normal load (kg) | Natural sand maximum shear strength ($kg/cm^2$) | Coir (As = 15) maximum shear strength ($kg/cm^2$) | % Change in Shear strength |
|---|---|---|---|
| 0.55 | 0.0173 | 0.0204 | 17.91 |
| 0.95 | 0.0284 | 0.03288 | 15.77 |
| 1.15 | 0.0339 | 0.03896 | 14.92 |

**Table 33: Comparison table of shear strength for coir fibre at 1% mix proportion**

An average 15% increase in the shear strength of the sand was observed when 1% coir fibre (As = 15) was added to the natural sand.

- Change in shear strength of reinforced sand with respect to natural sand at 2% mix proportion

| Normal load (kg) | Natural sand maximum shear strength (kg/cm$^2$) | Coir (As = 15) maximum shear strength (kg/cm$^2$) | % Change in Shear strength |
|---|---|---|---|
| 0.55 | 0.0173 | 0.021 | 21.38 |
| 0.95 | 0.0284 | 0.034 | 19.71 |
| 1.15 | 0.0339 | 0.04 | 17.99 |

**Table 34: Comparison table of shear strength for coir fibre 2% mix proportion**

An average 19% increase in the shear strength of the sand was observed when 2% coir fibre (As = 15) was added to the natural sand.

- Change in shear strength of reinforced sand with respect to natural sand at 3% mix proportion

| Normal load (kg) | Natural sand maximum shear strength (kg/cm$^2$) | Coir (As = 15) maximum shear strength (kg/cm$^2$) | % Change in Shear strength |
|---|---|---|---|
| 0.55 | 0.0173 | 0.0205 | 18.49 |
| 0.95 | 0.0284 | 0.0336 | 18.33 |
| 1.15 | 0.0339 | 0.0395 | 16.51 |

**Table 35: Comparison table of shear strength for coir fibre at 3% mix proportion**

An average 17.77% increase in the shear strength of the sand was observed when 3% coir fibre (As = 15) was added to the natural sand.

# 7. COMPARISON

## 7.1. Comparison on the basis of maximum % increase in φ w.r.t pure sand

Comparing nylon, jute and coir with each other for the mix proportions at which maximum % increase in the value of angle of internal friction is observed for each fibre.

| Fibre | Most appropriate Aspect Ratio | Mix proportion at which maximum φ is obtained (%) | Cohesion ($kg/cm^2$) | φ | Maximum % Increase in φ w.r.t pure sand |
|---|---|---|---|---|---|
| Nylon | 15 | 3 | 0.005 | 50.08 | 11.28 |
| Jute | 10 | 3 | 0.005 | 52.05 | 15.88 |
| Coir | 15 | 2 | 0.01 | 47.72 | 6.04 |

**Table 36: Comparison table**

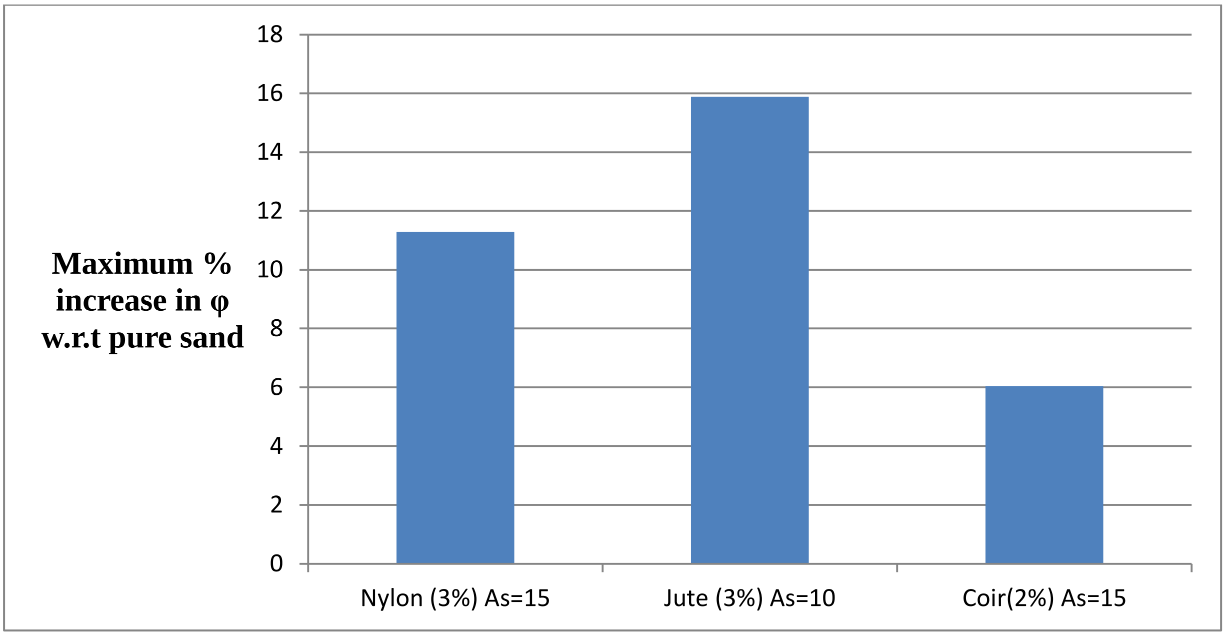


**Fig. 38: % Increase in the value φ w.r.t pure sand for nylon, jute and coir fibres**

From the above graph and table it can be concluded that amongst the given fibres, the maximum increase in the value of the angle of internal friction is observed for jute fibre i.e. 15.88% having an aspect ratio of 10 at the mix proportion of 3%.

## 7.2. Comparison on the basis of maximum % change in shear strength with respect to pure sand

To compare the different fibres used i.e. Nylon, jute and coir with respect to the change in the shear strength at the most appropriate aspect ratio the following table and graph is used

| Fibre | Most appropriate aspect ratio | Mix proportion at which maximum change in Shear strength is obtained (%) | Maximum % change in Shear strength |
|---|---|---|---|
| Nylon | 15 | 3 | 29 |
| Jute | 10 | 3 | 36 |
| Coir | 15 | 2 | 19 |

**Table 37: Comparison table**

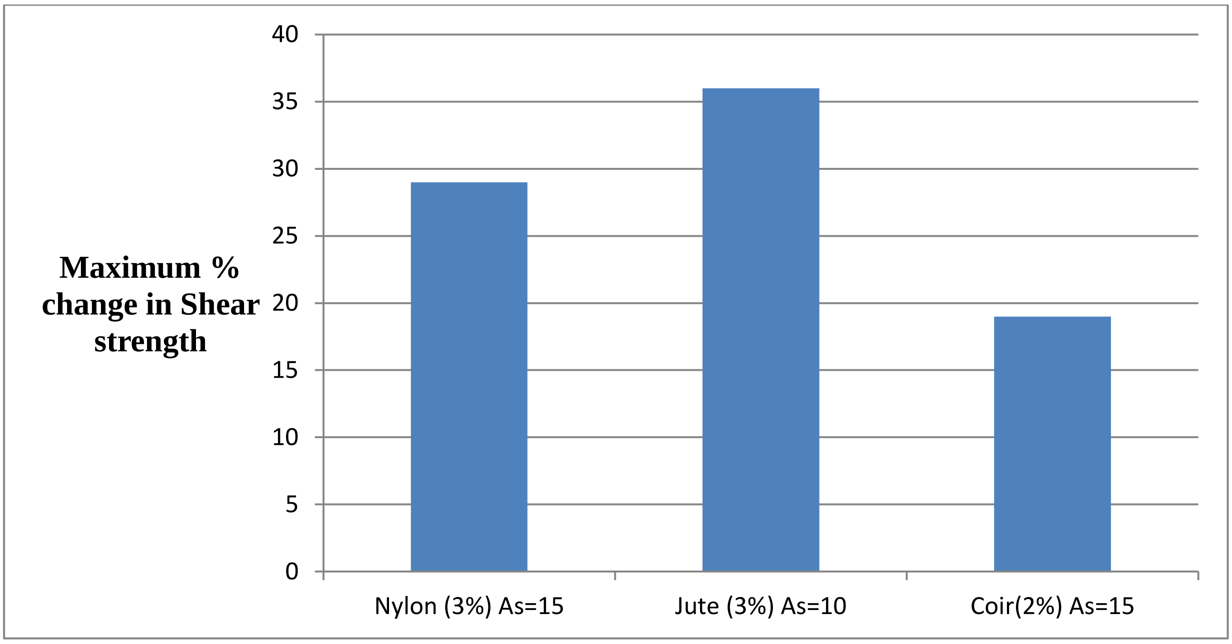


**Fig. 39: % change in the value shear strength w.r.t shear strength of pure sand for nylon, jute and coir fibres**

From the above graph and table it can be concluded that at the mix proportion of 3% by weight the maximum change in the value of shear strength is observed for jute fibre having an aspect ratio of 10.

Thus on the basis of the change in the values of shear strength and angle of internal friction it can be concluded that at the mix proportion of 3% jute (aspect ratio of 10) is the most appropriate fibre which can be used for reinforcing natural sand.

# 8. CONCLUSION & DISCUSSION

8.1 Most appropriate aspect ratio

- The optimum aspect ratio for nylon is found to be 15.
- The optimum aspect ratio for jute is found to be 10.
- The optimum aspect ratio for coir is found to be 15.

8.2 Effect on cohesion on addition of fibres at most appropriate aspect ratio

- On the intrusion of nylon fibre the maximum cohesion was observed to be 0.009 at the mix proportion of 2%.
- On the intrusion of jute fibre the maximum cohesion was observed to be 0.0075 at the mix proportion of 4%.
- On the intrusion of coir fibre the maximum cohesion was observed to be 0.01 at the mix proportion of 2%.

From the above results it can be concluded that there is negligible increase in the value of cohesion when fibres (nylon, jute, coir) were introduced in pure sand.

8.3 Effect on Angle of internal friction (φ) on addition of fibres at most appropriate aspect ratio

- On the addition of nylon fibre at the mix proportion of 3% the maximum φ was observed to be 50.08 (an increase of 11.28%).
- On the addition of jute fibre at the mix proportion of 3% the maximum φ was observed to be 52.05 (an increase of 15.88%).
- On the addition of coir fibre at the mix proportion of 2% the maximum φ was observed to be 47.72 (an increase of 6.04%).

From the above results it can be concluded that the maximum increase in the value of φ was observed for jute fibres (3%) followed by nylon (3%) and coir (2%) at the most appropriate aspect ratio for each fibre.

## 8.4 Effect on the shear strength of sand on addition of fibres at most appropriate aspect ratio

- On the addition of nylon fibre (As = 15) at the mix proportion of 3% a maximum change of 29% was observed in the shear strength value.
- On the addition of jute fibre (As = 10) at the mix proportion of 3% a maximum change of 36% was observed in the shear strength value.
- On the addition of nylon fibre (As = 15) at the mix proportion of 2% a maximum change of 19% was observed in the shear strength value.

From the above results it can be concluded that the maximum increase in the value of φ was observed for jute fibres (3%) followed by nylon (3%) and coir (2%) at the most appropriate aspect ratio for each fibre.

## 8.5 Discussion

- The increase in the angle of internal friction was observed because of the addition of fibres.
- The increase in the value cohesion although negligible was also because of the addition of fibres.
- The increase in the shear strength was observed because of the addition of fibres.

This project can further be extended developing a mathematical model. The mathematical model formulated can be used to determine the behaviour of the sand reinforced with fibres. Thus decreasing the work for the selection of a suitable fibre reinforcement for a particular type of sand.

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