EFFECTS OF GLASS FIBRES ON THE SHEAR STRENGTH OF SOIL

A Dissertation Submitted
In Partial Fulfillment of the Requirements
for the degree of

MASTERS OF ENGINEERING
IN
CIVIL INFRASTRUCTURE ENGINEERING

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JULY 2016

DECLARATION

I,Vishal Singh Chib, hereby declare that this thesis entitled **"EFFECTS OF GLASS FIBRES ON THE SHEAR STRENGTH OF SOIL"** in fulfillment of the requirement for the award of the Degree of **Master of Engineering** in **Civil Infrastructure Engineering** and submitted in the Civil Engineering Department, Thapar University, Patiala is an authentic record of my work carried out during a period from July 2015 to July 2016 under the supervision of **Mr. Rajesh Pathak, Associate Professor and Mr. Tanuj Chopra, Assistant Professor,** Department of Civil Engineering, Thapar University, Patiala.

This matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other University.

Date: 15/07/2016

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CERTIFICATE

This is to certify that above statement made by the student concerned is correct and true to the best of my knowledge and belief.

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ACKNOWLEDGMENT

A thesis cannot be completed without the help of many people who contribute directly or indirectly through their constructive criticism in the evolution and preparation of this work. It would not be fair on my part, if I don’t say a word of thanks to all those whose sincere advice made this period a real educative, enlightening, pleasurable and memorable one.

First of all, a special debt of gratitude is owned to my supervisors, **Mr. Rajesh Pathak, Associate Professor and Mr. Tanuj Chopra, Assistant Professor,** Department of Civil Engineering, Thapar University, Patiala for their gracious efforts and keen pursuits, which has remained as a valuable asset for the successful completion of research work. Their dynamism and diligent enthusiasm has been highly instrumental in keeping my spirit high. His flawless and forthright suggestion blended with an innate intelligent application has crowned my task a success.

I would like to express my gratitude to **Dr. Naveen Kwatra, Head of department of Civil Engineering**, Thapar University, Patiala for his kind cooperation and encouragement which helped in the completion of work.

I am extremely thankful **to Mr. Munesh Kapila and Mr. Avtar Singh** for helping me carry out experimental work.

I would also like to thank my parents, brother, sister and my friends for their constant encouragement during the entire course of my thesis work.

July, 2016

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ABSTRACT

Soil reinforcement is not a new concept; it was used since ancient times to improve the shear strength/stiffness of soil. Fibre reinforced soil is termed as plysoil is a composite material obtained by mixing randomly distributed discrete fibres to soil (RDFS). The technique used for fibre inclusion in soil, is common, similar to soil stabilization. The main advantages of randomly distributed discrete fibres are the simplicity in mixing, maintaining the strength of reinforced soil over a long period of time. Reinforced soil can be advantageously used in civil engineering projects as a soil improvement technique with respect to; for providing sharp differences of level between two horizontal platforms, for providing horizontal platforms on sloping ground, as quay walls, as bridge abutments, subgrade/sub-base and in similar other slope stability problems.

In present study glass fibre is used as a reinforced material to improve the shear strength of soil. Glass fibre is a non biodegradable material which provides durability to reinforced soil. The various physical properties of three different types of soils are found such as plastic limit, liquid limit, plasticity index, dry density, optimum moisture content etc. Inclusion of glass fibre at aspect ratio of 30, 45 and 60 to the soil with three different fibre content i.e. 0.5%, 1.0% and 1.5% was done. Then a series of direct shear test and triaxial test was conducted on both unreinforced and reinforced soil to study the behavior soil reinforced with glass fibre. After studying the results it clearly shows that the use of glass fibre with increase in aspect ratio and fibre content also increases the shear strength parameters of soil effectively.

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ABBREVIATIONS AND DESIGNATIONS

Abbreviation	Designation
FS	Fine sand
F	Fibre
FS+F	Fine sand-Fibre mix
1%F	1% fibre content
RD	Relative density
CS	Coarse sand
FC	Fibre content
Φ	Angle of internal friction
L/d	Aspect ratio
Sample A	Clayey soil
Sample B	Coarse sand
Sample C	Fine sand
σ_d	Deviator stress
σ_n	Normal stress

CHAPTER - 1
INTRODUCTION

1.1 General

Soil is the cheapest and readily available construction material, it has been popular with in civil engineers, even though it being poor in mechanical properties. It has been the constant endeavour of research workers to put forth innovative ideas to improve its mechanical properties to suit the requirement of engineering structures.

Various soil improvement methods have been suggested by the researchers, by means of which the shear strength or mechanical properties of soil can be modified by soil stabilization techniques such as physically or chemically treated the soil particles together in such a manner that the bonding between the soil particles increases which will affects the overall performance of soil. Soil stabilization techniques are widely used in areas where soils are very poor and not able to take structural load. In such cases binding agents (such as lime, bitumen, cement, chemicals, fibres etc.) are used to overcome this problem. During the construction of dams or roads, if the locally available material is not sufficient to take design load of structure, then to transport soil from some other adjacent area becomes uneconomical. In this case soil stabilization technique becomes economical.

Among the recent development, introduction of reinforcement in different forms is being tried to improve the overall soil behavior. The reinforcement in the form of sheets, strips, bars, grids or fabrics is introduced in the soil mass in such a way so as to minimize or suppress the tensile strain. This material is termed as “reinforced soil” and can be regarded as soil strengthens at the “macro-scale”. Soil stabilization is effective and reliable soil improvement technique with respect to retaining structures, embankments and subgrade beneath footings and pavements.

The present study involves mixing of randomly distributed glass fibres to the soil. The soil strengthening technique investigated in the present study involves mixing of randomly distributed discrete fibres to the soil. This soil-fibre mix is termed as "plysoil' (McGown et al, 1978). The technique is similar to stabilization by admixtures, in its preparation i.e. discrete fibres are simply added and mixed with soil, much the same way as cement, lime or other additives. But, engineering behaviour of plysoil is similar to the traditional reinforced soil. Thus, the role of fibre reinforced soil lies between existing soil reinforcement and soil stabilization techniques and may be described as soil strengthening at the "meso-scale".

It has been established that strength and deformation characteristics of soils can improved by fibre inclusions, fibre reinforced soil exhibits greater extensibility and small loss of post peak strength (i.e. greater ductility in the composite material) as compared to unreinforced soil or soil reinforced with high modulus inclusions. One of the main advantages of randomly distributed fibres is the maintenance of strength isotropy and the absence of potential planes of weakness which may develop parallel to the oriented reinforcement.

Randomly distributed fibre reinforced soils (RDFS) can be advantageously employ ground improvement techniques with respect to embankment, subgrade and in similar other problems. Sand-fibre columns may be utilized to treat deep deposits of soft clay. It is also considered possible that discrete fibres may be employed in conjunction with traditional soil reinforcement or soil stabilization techniques.

Concept of soil reinforcement is not new, the basic principles are demonstrated abundantly in nature by animals and birds and the action of tree roots (Jones. 1985). There is evidence that asbestos fibres were used in reinforced clay posts about 5000 years ago. Some examples of animal hair to reinforce masonary mortar and those of straw to reinforce mud huts are also known. The synthetic fibres have been used to improve the performance of conventional materials like gypsum, plaster, cement paste and cement concrete during last few years (Vasan, 1989). The use of fibres, both natural and synthetic in strengthening soil has received the attention in recent years when McGown et al (1978) put forward the concept of plysoil.

1.2 Glass fibre

Glass fibres are among the most versatile industrial materials known today. They are readily produced from raw materials, which are available in virtually unlimited supply. They exhibit useful bulk properties such as hardness, transparency, resistance to chemical attack, stability, and inertness, as well as desirable fiber properties such as strength, flexibility, and stiffness. Glass fibers are used in the manufacture of structural composites, printed circuit boards and a wide range of special-purpose products.

A brief review of experimental investigations and theoretical approaches has been presented here.

1.3 Experimental Investigation

Experimental investigations on soil reinforced with discrete fibres have been reported by various investigators; notable among them are: McGown et al,(1978), Rosa L. Santoni, Jeb S. Tingle and Steve L. Webster (2001), Kameshwar Rao Tallapragada, Anuj Kumar Sharma and Tarulata Meshram (2009), Mousa F. Attom and Adil K. Al-Tamimi (2010), Amin Chegenizadeh and Hamid Nikraz (2012), Shivanand Mali and Baleshwar Singh (2013), H. P. Singh and M. Bagra (2013), Rabindra kumar kar, Pradip Kumar Pradhan and Ashutosh Naik (2014), S. Yari, A. Bagheri and M. Yousefi Rad (2014), Shivanand Mali and Baleshwar Singh (2014), Himadri Baruah (2015), Dinesh Kumar, R. Shanmuga and G. Kalyan Kumar (2015), Dimpa Moni Kalita, Indrani Mili, Himadri Baruah and Injamamul Islam (2016). It was reported that fibre reinforcement causes significant improvement in strength and stiffness of sand. More importantly it exhibits greater extensibility and small loss of post peak strength (i.e. greater ductility in the composite material) as compared to sand soil or soil reinforced with high modulus inclusions (Gray and Ohashi, 1983; Gray and Al-Refeai, 1986). The increase in strength and stiffness is reported to be a function of sand characteristics e.g. particle size, shape and gradation, fibre characteristics e.g. weight fraction, aspect ratio, skin friction and modulus of elasticity and confining stress and axial strain. It has been reported that the strength of reinforced soil increases with increase in fibre content, aspect ratio and soil fibre surface friction, analyzing the results of a series of laboratory compression and DST tests on a clay and sand reinforced with randomly distributed glass fibres (< 1.5% by weight) observed that the presence of fibres increased the angle of internal friction and ductility of the soil.

1.4 OBJECTIVE AND SCOPE OF PRESENT STUDY

Keeping in view the limitations in the available literature on randomly distributed fibre reinforced soils, it was planned to study the load-deformation behaviour of sands i.e. coarse sand and fine sand and clay reinforced with glass fibres. The influence of various soil-fibre parameters, axial strain and confining stress has been investigated through direct shear tests and triaxial compression tests. The parameters investigated through testing are as follows:

- Effect of fibre parameters i.e. weight fraction, aspect ratio (length over diameter), surface friction and modulus on the strength of fibre reinforced soils.
- Effect of confining stress on the failure envelopes of soil-fibre composite.
- Effect of degree of compaction, degree of saturation and rate of axial strain on the strength and deformation behaviour of RDFS.
- Effect of randomly distributed discrete fibre inclusions on load-deformation behaviour and shear strength of clayey soil.

1.5 ORGANIZATION OF THESIS

The complete thesis has been arranged in five chapters. A brief scope of each chapter has been outlined in the following paragraphs.

Chapter-1: Deals with introduction of fibre reinforced soils and its practical benefits.

Chapter-2: Presents the review of literature on experimental investigations and mechanism of fibre reinforced soils.

Chapter-3: Describes the details of experimental programme and properties of the materials used. The preliminary tests were carried out on soils, fibres and soil-fibre composites have been described and the test results have been presented. The description of equipments used, methods of preparing samples and testing procedures has been given in details.

Chapter-4: Brings out the analysis of test results and their discussion. The effect of soil-fibre parameters and confining stress on load-deformation behavior and shear strength of RDFS have been presented through figures and tables which has been discussed in detail.

Chapter-5: Conclusions

CHAPTER - 2

LITERATURE REVIEW

2.1 Literature Review on Natural fibre and Synthetic fibre:

Rosa L. Santoni, Jeb S. Tingle and Steve L. Webster (2001), to study the performance of fibre-stabilized sand specimens a series of unconfined compression tests were performed on the sand specimens reinforced with randomly distributed discrete fibres. Addition of randomly distributed discrete fibres significantly improved the unconfined compressive strength of sands. Optimum fibre length of 51mm was identified for the reinforcement of the sand specimens. The maximum increase in the values of strength and internal angle of friction was achieved at a fibre dosage rate between 0.6% and 1.0% by dry weigth. Specimens were performed in both wet and dry of optimum conditions. Finally the addition of up to 8% does not affect the performance of fibre reinforcement.

Cheng-Wei Chen (2006), a series of CU and CD type triaxial compression tests were performed on comparable unreinforced and fiber-reinforced specimens of Ottawa Sands to evaluate the effective stress strain-pore pressure-volume change behaviour of fibre-reinforced soils. The results show that inclusion of fibres increase the cohesion (c) and effective friction angle (φ) for Ottawa Sands. The c and φ determined for the reinforced specimens increases with strains. Reinforced loose specimens tend to have a higher friction angle, but lower cohesion intercept than the reinforced medium-dense specimens. In addition, the inclusion of fibers with loose specimens has a significant effect in increasing effective friction angle than with medium-dense specimens. In CU tests, the loose reinforced specimens exhibited lower pore pressures than unreinforced specimens. In CD tests, the loose and medium-dense reinforced specimens showed more dilation than unreinforced specimens at moderate and larger strains. These are in agreement with the response observed in undrained tests. For Ottawa sands, the fiber resistance is mobilized at small strains in both undrained and drained conditions. However, the mobilized shear resistances in drained tests occur sooner than in undrained tests.

Kameshwar Rao Tallapragada, Anuj Kumar Sharma and Tarulata Meshram (2009), to minimize the swelling properties of expansive subgrade, locally available Black cotton soil is taken to study its behavior with randomly mix of (1) Monofilament and (2) Nylon threads. The main purpose behind this investigation to study the variations of values in

UCS, CBR, c-φ and swelling pressure of black cotton soil due to randomly distributed fibres in different aspect ratio and concentrations. After studied the results, it showed that there was decrease in the value of cohesion and significantly increase in the value of φ with the addition of 0.75%, 1.5% and 2.25% of discrete fibres in black cotton soil. Value of CBR also increased when fibres was added to the black cotton soil. Maximum stress value of soil increase with increasing fibres content and aspect ratio when UCS was conducted. Addition of some percentage of fibres in soil swelling pressure of soil also decreases.

The value of CBR increases with increase in percentage content of fibres, but its value remains same after 2.25%. Nylon threads seem to give better outputs in terms of CBR as compared to monofilament. Cohesion of soil considerably decreases with monofilament whereas with nylon thread it is marginal. In case of addition of both the reinforcing materials F value increased. Also the values of UCS increase with addition of both monofilaments and nylon threads but seem well with nylon threads. When both materials were added swelling pressure of soil decreases but marginal difference when compared. From above the conclusion reveals that nylon thread of 1.6mm thick and 2.25% by weight of all the aspect ratios gives better results as compare with monofilaments.

Majid Ali (2010), paper presents the versatility of coconut fibres and its applications in different branches of engineering, particularly in civil engineering as a construction material. Coconut fibre is one of the natural fibres abundantly available in tropical regions, and is extracted from the husk of coconut fruit. Not only the physical, chemical and mechanical properties of coconut fibres are shown, but also properties of composites (cement pastes, mortar and/or concrete etc), in which coconut fibres are used as reinforcement, are discussed. The research carried out and the conclusions drawn by different researchers in last few decades are also briefly presented. Coconut fibres reinforced composites have been used as cheap and durable non-structural elements. The aim of this review is to spread awareness of coconut fibres as a construction material in civil engineering.

Mousa F. Attom, Adil K. Al-Tamimi (2010), two types of polypropylene fibres on shear strength parameters of sandy soil were used for study. A sandy soil was obtained from a depth of 40 cm from the natural ground surface around American University of Sharjah.

One fibre is highly flexible with flat profile and the other with relatively high stiffness and the crimpled profile were used, with four different aspect ratios (L/d) for each type.

The unreinforced physical properties of the sand such as specific gravity, angle of internal friction and shear strength were obtained in accordance with American Standard for Testing and Materials (ASTM). The sandy soil was reinforced with two different type of fibres at different percentages by dry weigth of the sand and four different aspect ratios. The test results showed that the shear strength and angle of internal friction of the sand increased with increase in flexible flat profile fibres content and aspect ratio. In case of crimpled profile, fibre increased the shear strength of the sand under high normal load and has small or no effect on shear strength of the sand at low aspect ratio under low normal load.

From above study, the final conclusions are:

1) The shear strength of sand increased by increasing the percentage flat profile fibre with high flexibility (type A fibre). The increase of in the percentage of the crimped profile fiber with high relative stiffness (type b fibre) increase the shear strength at high normal stress.
2) The increase of the percentage of the both type of fibre will result in increasing the angle of internal friction of sand.
3) The ductility of sand increased by adding the two types of fibres.
4) The sand showed no peak strength at four percentages of fibres.

Amin Chegenizadeh & Hamid Nikraz (2012), effect of fibre inclusion on the strength and other parameters of clayey sand composite material. To investigate the behaviour of clayey sand with using plastic fibre and natural fibre with different percentages and fibre length. Unconfined compressive strength tests were carried out to investigate behaviour of the reinforced clayey sand under different condition. The fibre percentage varied from 0% to 4% and fibre length varied from 8 mm to 25 mm. The fibre length and fibre content are found to play important roles in the strength of fibre reinforced composite. It was also observed that ductility of clayey sand increased by fibre inclusion.

The shear strength increased with increase in fibre content. The shear strength value increased by six times by increasing in the fibre content by four times. The above study also shows that with increase in fibre length, also increase the strength of reinforced sample. When fibre length increase from 8 mm to 25 mm, the shear strength values increase from 125 kPa to 340 kPa.

From above study, it proved that increasing in strength of reinforced material was more considerable in case of plastic fibre when compared to natural fibre. The main important reason can be found as skin friction difference as the interlock forces for plastic fibre was more than natural fibre.

H.P. Singh & M. Bagra (2013), a series of triaxial compression tests under different confining pressure were conducted on locally available (Itanagar, Arunachal Pradesh, India) soil unreinforced and reinforced with jute fibre. Different percentage of jute fibre was taken as 0.25%, 0.5%, 0.75% and 1% and they were randomly mixed with soil sample. The soil samples of unreinforced and reinforced soil for triaxial tests were prepared at maximum dry density corresponding to optimum water content. The shear strength parameters (c and ϕ) and stiffness modulus (σ_d/ε i.e. ratio of deviator stress to corresponding strain) of soil corresponding to each fibre was determine in the geotechnical engineering laboratory of NERIST. With change in diameter of fibre, there effects on soil sample were also investigated. The triaxial tests results shows that on inclusion of jute fibre, the strength parameters (c and ϕ) and stiffness modulus (σ_d/ε) of soil are increases. With different length, diameter and different fibre contents will considerably increase the load carrying capacity and also reduces to value of immediate settlement of soil significantly.

From present investigation it is concluded that the preparation of identical samples of jute fibre reinforced soil beyond 1% of fibre content was not possible and hence optimum fibre content is 1%. The stiffness value of reinforced soil increases with increase in fibre content and the maximum percentage increase is 48% over the plain soil for fibre diameter of 1 mm and at fibre content of 1%. The maximum increase in values of (C) and (φ) are 214% and 41% respectively over the unreinforced soil at fibre content of 1% for fibre diameter of 1 mm. Stiffness modulus of reinforced soil increases with increase in fibre diameter and its maximum percentage increase is 92% over the unreinforced soil for fibre diameter of 2 mm and at fibre content of 1%. The shear strength parameters (c and φ) increase with the increase in fibre diameter. The maximum values of (c) and (φ) are 311% and 41% respectively for fibre diameter of 2 mm at fibre content of 1%.

Shivanand Mali & Baleshwar Singh (2013), soil sample of fine sand were used to investigating the behavior of fine sand on which series of direct shear tests have been carried out on unreinforced and reinforced samples. Glass fibre was used as a reinforced material with 20 mm in length and three different percentages (say 0.5%, 0.75% and 1.0%) by dry weigth of soil sample. The shear stress to horizontal strain response of the fine sand modified by the addition of glass fibres has been studied. The addition of fibres to the sand specimens results in substantial increases in the measured values of the cohesion and friction angle. The outputs of present study have practical significance as a ground improvement technique, with respect to the use in subgrade, embankment and other applications.

Dilip Kumar and Ashish Gupta (2014), construction of buildings and many civil engineering structures on weak or soft soil is very risky and dangerous on geotechnical grounds because this type of soil is take place settlements, poor bearing capacity, weak strength parameters and high compressibility of soil. Improvement of load bearing capacity of the soil may be undertaken by a variety of ground improvement techniques like soil stabilization, vibroflotation and fibre reinforced earth technique of soil etc. Fibre reinforced earth technique is a very effective ground improvement technique because of its cost effectiveness, easy adaptability and reproducibility and workability etc. Therefore, it is experimentally carried out to investigate the effects of the fibre on engineering properties of the soil at different layers. Polypropylene fibre has been used as the reinforcement material and it was included in to the soil at two different layers, i.e. 0, 40 and 80 mm. The main objective of this investigation had been focused on the strength behavior of the soil reinforced with polypropylene fibre. The fibre reinforced soil samples were subjected to compaction, permeability, shear strength and California Bearing Ratio (CBR).

Rabindra kumar kar, Pradip Kumar Pradhan and Ashutosh Naik (2014), to investigating the effect of coir fibre which was used to mix with cohesive soil. Three different aspect ratio (say 75, 100 and 125) are used as reinforcement of soil sample. Standard proctor was used to compact the soil at maximum density with low percentage of reinforcement (0 to 1.6% by weigth of oven dried soil). To investigate the strength parameters of fibre-reinforced soil, a series of direct shear tests, unconfined compression tests and CBR tests were performed on both unreinforced and reinforced soil. The test results showed that the addition of randomly distributed coir fibres in soil increase the peak and residual shear strength, unconfined compressive strength and CBR values of soil. The optimum fibre content for achieving maximum strength is 0.8% of the weight of oven-dried soil revealed from the direct shear tests and unconfined compression tests and 1.4% from CBR tests, for fibre aspect ratio is 100.

Coir fibre up to 0.8% showed the maximum increase of shear strength, for all three different fibre lengths which was considered in the investigation, beyond which it decreases. The 20 mm (L/d=100) length of fibre showed that the increase is maximum, when it compared with unreinforced soil. Values of both internal friction (φ) and cohesion (c) increases with increase in fibre content

Shivanand Mali & Baleshwar Singh (2014), the strength behavior of cohesive soils reinforced with coir fibres, polypropylene fibres and scrap tire rubber fibres as reported from experimental investigation, that includes triaxial, direct shear and unconfined compression tests.

Triaxial test results indicate that the stress-strain behavior of soil is improved by incorporating coir fibres in the silty soil, and the deviator stress at failure is increased up to 3.5 times over plain soil by fibre inclusion. The maximum increase of stress is observed when the fibre length is between 40 and 60% of the least lateral dimension of the specimen (i.e. between 15 and 20 mm for a 38 mm diameter specimen). For a constant fibre length, major principal stress at failure increases with increase in fibre content. However, the additional gain in strength is smaller when the fiber content is increased beyond 1%. At any fibre content, the strength is noted to increase with aspect ratio even up to 150.

Direct shear test results show that the shear strength of polypropylene fiber-reinforced soil increases with inclusion of fibres up to 0.4%, beyond which it decreases. For fibre length of 20 mm (L/d=100) the increase is maximum, when compared with the unreinforced soil. The cohesion value of soil increases with increased fibre content. On the other hand, the friction angle either increases or does not change significantly with fiber content.

Unconfined compression test results indicate that the UCS of polypropylene fibre-reinforced soil is greater than those of the parent soil. With increasing fibre content, there is an initial increase followed by a decrease and the optimal fibre length is observed to be about 10-15 mm. When tire rubber fibres are used, the optimum fibre length is 10 mm and the optimum fibre content is 2%.

S. Yari, A. Bagheri and M. Yousefi rad (2014), Typha fibre was used by author to investigate the behavior reinforced soil. To study the behavior of typha fibre with soil sample, the number of direct shear test was conducted to the sample of reinforced soil in different percentages of fibres i.e by dry weight of unreinforced sample, with three different normal stresses of 100, 200 and 300 (kPa). After finding the results, showed that the addition of fibres to soil sample increases the values of cohesion and the angle of internal friction of soil.

The main purpose behind this study was to find out the effects of typha fibres on the shear strength of soil. For study, a weak soil sample was tested and the following results were obtained:

The results of direct shear test showed that the fibres increase the shear strength of soil under the load of 100 kPa and 200 kPa to 64% and 68% respectively. In load of 300 kPa the shear strength variations are about 70% compared to the unreinforced soil.

Examination of the components of soil and fibres in different percentages under different loads showed that the most of these variations were changed between 100 to 200 kPa in reinforced soil with 1% of fibre content.

By addition of 0.25% of fibre to the soil we observe that the 22% variation in the level of cohesion of soil and this amount is equal to 7% for the internal angle of friction. The maximum soil cohesion increase is equal to 66% and this is 49% for the internal angle of friction.

Dinesh kumar, R. Shanmuga & G.Kalyan Kumar (2015), work is carried out to investigate and understand the effect of mixture of polypropylene fibre and lime on marine clay, clay specimens were prepared and tested at five different percentages of fibre content (i.e. 0%, 0.25%, 0.50%, 0.75% and 1.0%) by weight of the unreinforced soil and six different percentages of lime (i.e. 0%, 2%, 3%, 5%, 7% and 9%) by weight of unreinforced soil. Also considering the effect of different i.e. 35%, 50% and 65%.

The maximum shear strength has been observed for fibre reinforced lime treated marine clay for 0.75% fibre content. Strength increase is more for 12 mm fibre compared to 6 mm fibre.

Himadri Baruah (2015), Traditional geosynthetics such as geotextile, geogrid etc. have been proved to be efficient, and they are being increasingly used in geotechnical engineering but the use of glass fibre reinforced with soil is started recently. A series of unconfined compressive strength were performed with red loam soil with glass fibre as reinforcement at various percentage content to study the effects on the soil and to find whether the red loam soil-reinforcement combination is useful.

The liquid limit and plastic limit was determined as per IS: 2720 part 5. It is observed that as the fibre content was increased from 0% to 1.5%, the liquid limit and plastic limit of the soil sample increased. The increased in the value of the liquid limit and plastic limit show that the glass fibre have tendency to absorb water. The plasticity index reduced as the glass fibre content increased. This indicated that the soil became less compressible when the fibres are increasing to the soil.

Dimpa Moni Kalita, Indrani Mili, Himadri Baruah and Injamamul Islam (2016), the main objective to carried out series of unconfined compressive test to find out the conclusion by comparing the initial properties and the final properties of unreinforced and reinforced soil specimens after use of the waste coconut, glass fibre and cement bag.

It is seen that all three different types of reinforcement have effectively led to increase in the strength of soil with increase in fibre content. Among all the fibres, cement bag fibres at 1.0% content have the maximum strength. Cement bag fibres are recently used to engineering constructional purposes and it is economical as well to used as a reinforced soil material.

CHAPTER - 3

EXPERIMENTAL PROGRAMME

3.1 Materials Used:

Three soil samples A, B & C were collected from different locations. Sample A was collected from Shambhu (near Ambala cantt, India) region whereas; Sample B and C were collected from Ghaggar river at Patiala Punjab. The properties which are required for soil samples A, B and C were determined as shown in Table 3.1 to Table 3.3. Sample A is clayey in nature, sample B is coarse sand and sample C is fine sand, by using grain size analysis.

3.2 Properties of Soil Sample A:

Table 3.1: **Properties of tested soil specimen A**

S.No.	Tests	Properties	Description	Relevent IS Codes
1.	Grain Size Analysis	Fines, < 75µ (%)	53.7	IS 2720 Part IV
		Sand (%)	46.3	IS 2720 Part IV
2.	Compaction Test	MDD (kN/m^3)	20.40	IS 2720 Part VIII
		OMC (%)	12%	IS 2720 Part VIII
3.	Casagrande Tests	Liquid Limit (%)	32.5	IS 2720 Part V
		Plastic Limit (%)	20	IS 2720 Part V
		Plasticity Index (%)	12.5	IS 2720 Part V
		Flow Index	29	IS 2720 Part V
		Toughness Index	0.68	IS 2720 Part V
4.		Classification	CL (Clay and silt with low compressibility	IS 1498-2007

3.3 Grain Size Distribution of soil Sample B:

The coarse sand sample was taken from Ghaggar River at Patiala & used for the study. The grain size distribution showed that the percentage passing the 2.36 mm sieve was 100% with 1.7% passing the 0.075mm sieve. As per Indian classification soil system the material is classified as a silty Sand material with a group symbol of SM.

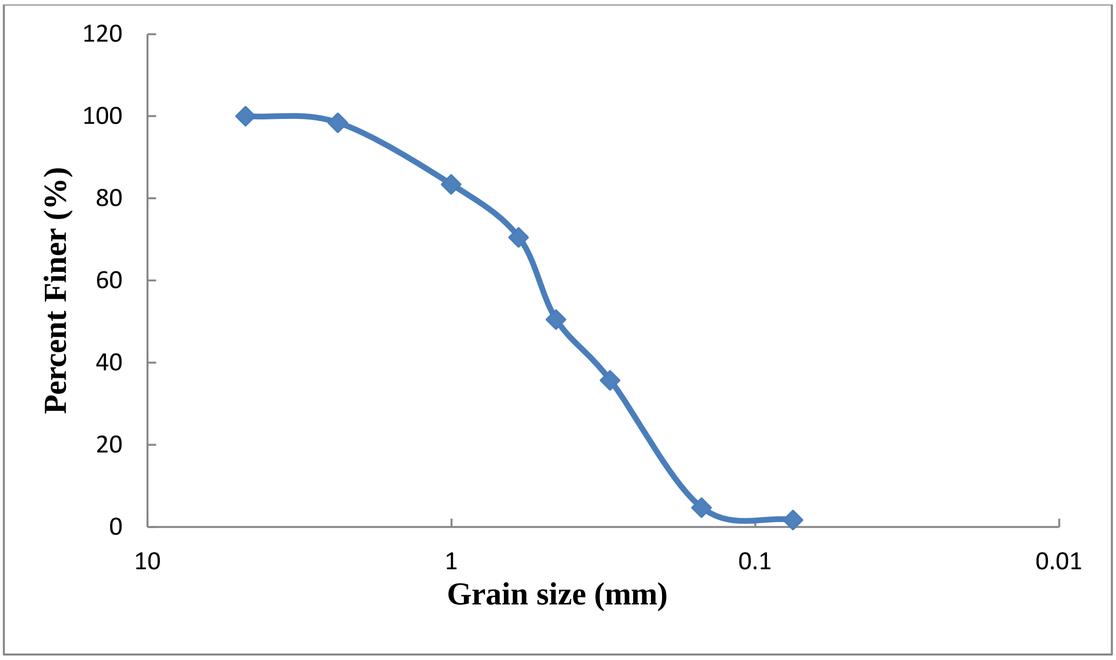

Figure 3.1: **Grain Size Distribution of soil Sample B**

3.3.1 Properties of Soil Sample B:

Table 3.2: **Properties of tested soil specimen B**

S.No.	Tests	Properties	Description	Relevent IS Codes
1.	Grain Size Analysis	Fines, < 75µ (%)	1.7	IS 2720 Part IV
		Sand (%)	98.3	IS 2720 Part IV
		Effective size (D_{10}) (mm)	0.180	IS 2720 Part IV
		D_{30} (mm)	0.320	IS 2720 Part IV
		D_{60} (mm)	0.520	IS 2720 Part IV
		Uniformity coefficient, C_u	2.88	IS 2720 Part IV
		Coefficient of curvature, C_c	1.09	IS 2720 Part IV
2.		Classification	Sand	IS 1498-2007

3.4 Grain Size Distribution of soil Sample C:

It is done to determine the percentage of various grain sizes. The grain size distribution helps in determining the textural classification of soils whether it is gravel, sand, silt, clay, etc. which is then useful in evaluating the engineering characteristics. IS: 2720- Part IV (2006) is used. The sieves for soil tests used are 4.75 mm to 75 microns and grain size distribution is shown in Figure. 3.2

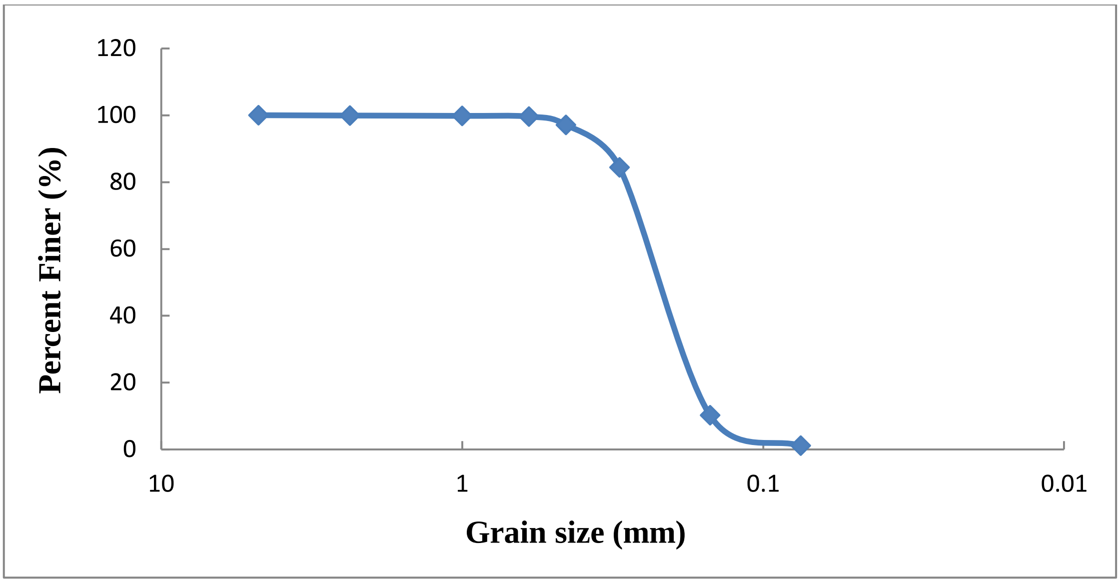

Figure 3.2: **Grain Size Distribution of soil Sample C**

3.4.1 Properties of Soil Sample C:

Table 3.3: **Properties of tested soil sample C**

S.No.	Tests	Properties	Description	Relevent IS Codes
1.	Grain Size Analysis	Fines, < 75µ (%)	0	IS 2720 Part IV
		Sand (%)	100	IS 2720 Part IV
		Effective size (D_{10}) (mm)	0.14	IS 2720 Part IV
		D_{30} (mm)	0.17	IS 2720 Part IV
		D_{60} (mm)	0.22	IS 2720 Part IV
		Uniformity coefficient, C_u	1.5	IS 2720 Part IV
		Coefficient of curvature, C_c	0.93	IS 2720 Part IV
2.		Classification	Sand	IS 1498-2007

3.5 Properties of Glass fibre:

The properties of the glass fibre used in this study are as under:

Table 3.4: **Properties of glass fibre (www.fassmer.de)**

Fibre type	**Diameter d (mm)**	**Aspect ratio L/d**	**Tensile strength (kPa)**	**Tensile modulus (kPa)**	**Ultimate strain**
Glass	0.35	30, 45, 60	2.30	76	0.018

Figure 3.3: **Pictorial Representation of glass fibre**

3.6 Direct shear test:

3.6.1 Applications

The purpose of direct shear test is to get the ultimate shear resistance, peak shear resistance cohesion, angle of internal friction and shear stress-strain characteristics of the soils.

Shear parameters are used in the design of earthen dams and embankments. These are used in calculating the bearing capacity of soil foundation systems. The soil parameters help in estimating the earth pressures behind the retaining walls. The values of these parameters are also used in checking the stability of natural slopes, cuts and fills.

Figure 3.4: **Direct Shear Test set up**

3.6.2 APPARATUS

The shear box grid plates, porous stones, base plates, and loading pad and water jacket shall conform to IS: 11229-19857.

Loading Frame - It shall satisfy the following requirements:

a) The vertical stress on the sample shall remain vertical and constant during the test and there shall be arrangement to measure compression.

b) The shear stress or strain can be applied in the dividing plane of the two parts of the shear box.

c) It shall be possible to maintain a constant rate of increase in stress during the test (irrespective of the strain rate) with arrangement to get different rates of stress increase.

d) In case of a strain-controlled apparatus, the strain rate should remain constant irrespective of the stress. Suitable arrangement shall be provided to obtain different strain rates.

e) No vibrations should be transmitted to the sample during the test and there should not be any loss of shear force due to friction between the loading frame and the shear box-container assembly.

3.7 TRIAXIAL COMPRESSION TEST:

3.7.1 Applications:

Confining pressures play the important role in changing the behavior of soils especially in deep foundations. Confining pressure also plays a crucial role in high rise earth dam because of very high magnitude of confining pressure. The only test to stimulate these confining pressures condition is triaxial test. For a short term stability of foundations, dams and slopes, shear strength parameters for consolidated undrained or unconsolidated undrained conditions are used, while for long term stability of foundation shear parameters corresponding to consolidated drained conditions will give more reliable results. All the above conditions can be achieved only in triaxial tests.

3.7.2 SCOPE

As per IS 2720 (Part II): 1993

This standard describes the test for the determination of the compressive strength of a specimen of saturated cohesive soil in the triaxial compression apparatus under conditions in which the cell pressure is maintained constant and there is no change in the total water content of the specimen.

In this standard the term sample is used to denote the soil submitted to the laboratory for the testing and the term specimen refers to a portion of the sample upon which the test is performed.

The result of any test made in accordance with this standard requires interpretation in relation to the nature of the soil and the way in which the specimen was obtained and prepared.

This test is limited to specimens in the form of right cylinders of nominal diameter 38, 50, 70 and 100 mm and of height approximately equal to twice the nominal diameter. In case of remoulded samples; ratio of diameter of specimen to maximum size of particle in the soil should not be less than 5.

The diameter of the specimen is to be selected having regard to the character of the soi1 and the maximum size of the particles present in the sample. Generally, a diameter of 38 mm will be suitable for homogeneous fine-grained soils.

3.7.3 APPARATUS:

1. Split mould

2. Trimming Knife

3. Piano Wire Saw

4. Metal Straight edge

5. Metal Scale

6. Non-Corrodible Metal or Plastic End- Caps

7. Seamless Rubber Membrane

8. Membrane Stretcher

9. Rubber Rings

10. Apparatus for Moisture Content Determination

11. Balance

12. Extruders

13. Thin-walled Tubes

14. Soil Lathe

15. Meter Box

16. Triaxial Test Cell

17. An Apparatus for Applying and Maintaining the Desired Pressure on the Fluid within the Cell

18. Machine Capable of Applying Axial Compression to the specimen

Figure 3.5: **Triaxial set up**

Figure 3.6: **Sample in confining cell**

Figure 3.7: **Glass fibre reinforced soil samples after triaxial test**

Figure 3.8: **Glass fibre reinforced soil samples after triaxial test**

Figure 3.9: **Glass fibre reinforced soil samples after triaxial test**

CHAPTER - 4
RESULTS AND DISCUSSIONS

4.1 Shear strength parameters of coarse sand

Direct shear test was conducted on Sample B to unreinforced and reinforced samples, randomly mix glass fibre with different fibre content (0.5%, 1.0% and 1.5%) and different aspect ratio 30, 45 and 60.

Table 4.1: **Shear parameter of glass fibre reinforced coarse sand obtained from direct shear test (L/d=30)**

RD	MIXES	Φ (degree)
0%	CS	32.65
	CS+0.5%F	33.22
	CS+1.0%F	34.17
	CS+1.5%F	34.37
41%	CS	34.91
	CS+0.5%F	34.48
	CS+1.0%F	35.22
	CS+1.5%F	35.75
100%	CS	37.01
	CS+0.5%F	38.69
	CS+1.0%F	38.86
	CS+1.5%F	39.48

Table 4.2: **Shear parameter of glass fibre reinforced coarse sand obtained from direct shear test (L/d=45)**

RD	MIXES	Φ (degree)
0%	CS	32.65
	CS+0.5%F	34.68
	CS+1.0%F	34.99
	CS+1.5%F	35.94
41%	CS	34.91
	CS+0.5%F	35.94

	CS+1.0%F	36.50
	CS+1.5%F	37.66
100%	CS	37.01
	CS+0.5%F	39.14
	CS+1.0%F	39.18
	CS+1.5%F	39.79

Table 4.3: **Shear parameter of glass fibre reinforced coarse sand obtained from direct shear test (L/d=60)**

RD	MIXES	Φ (degree)
0%	CS	32.65
	CS+0.5%F	34.29
	CS+1.0%F	35.90
	CS+1.5%F	37.63
41%	CS	34.91
	CS+0.5%F	36.27
	CS+1.0%F	35.94
	CS+1.5%F	37.08
100%	CS	37.01
	CS+0.5%F	39.45
	CS+1.0%F	39.92
	CS+1.5%F	41.18

The series of direct shear test was conducted on unreinforced sample B. The inclusion of glass fibre results in increases the values of shear stress and angle of internal friction. Coarse sand samples are reinforced with glass fibre of three different aspect ratio of 30, 45 and 60 with three different fibre contents of 0.5%, 1.0% and 1.5% at normal loads equals to 5 N/cm^2, 10 N/cm^2 and 15 N/cm^2.

4.1.1 Effect of aspect ratio on shear strength of coarse sand at different relative densities

Figure 4.1 to Figure 4.9 shows that the shear stress and normal stress plots of glass fibre reinforced coarse sand with three different relative densities. The results have shown the variation of shear stress parameters with fibre content and relative density. The values of shear stress and angle of internal friction increases with any of mix used with any relative density.

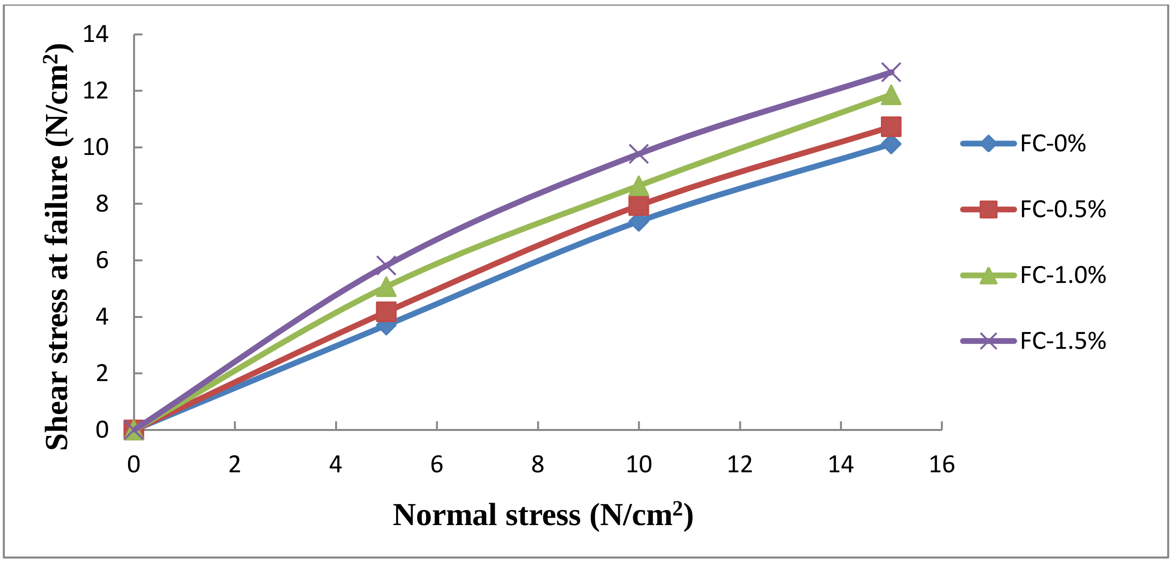

Figure 4.1: **Shear stress vs. Normal stress plots for CS+F mix at 0% relative density (L/d=30)**

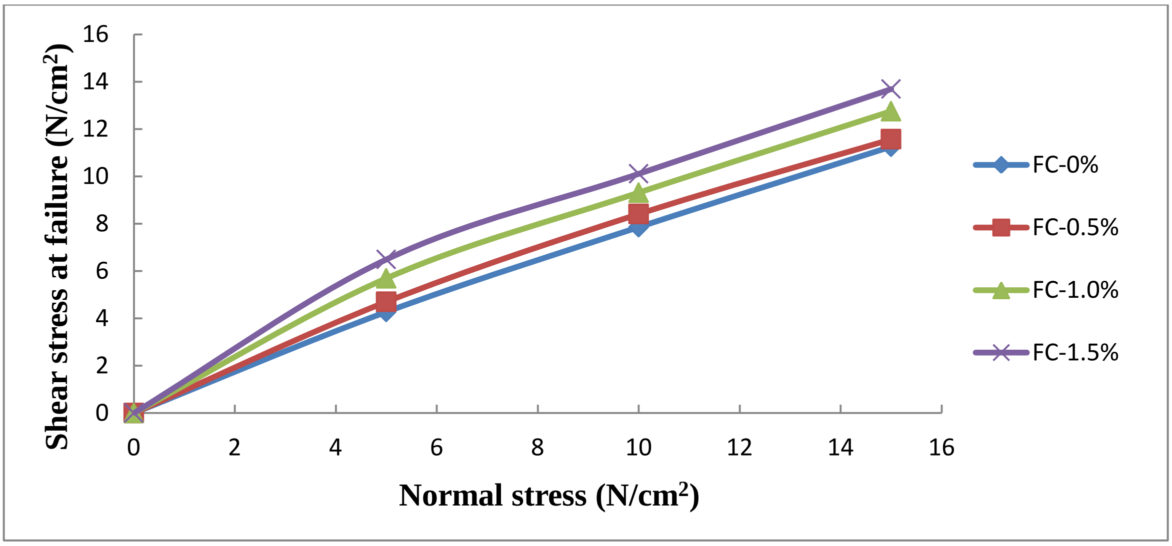

Figure 4.2: **Shear stress vs. Normal stress plots for CS+F mix at 41% relative density (L/d=30)**

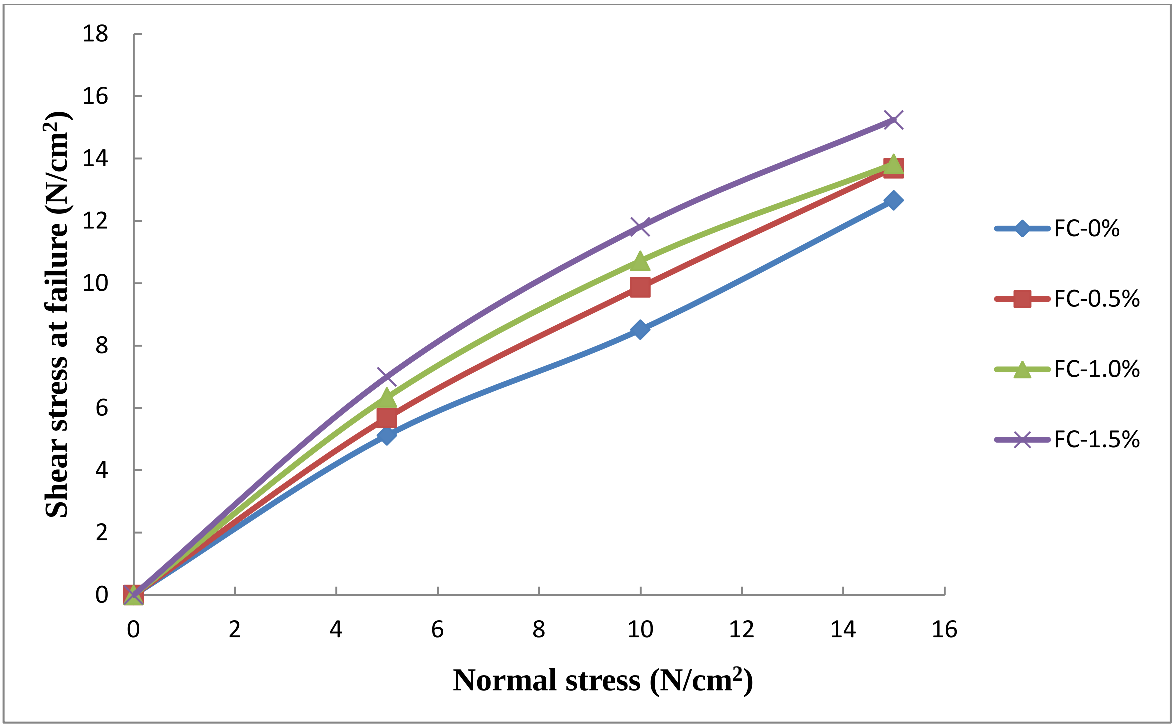

Figure 4.3: **Shear stress vs. Normal stress plots for CS+F mix at 100% relative density (L/d=30)**

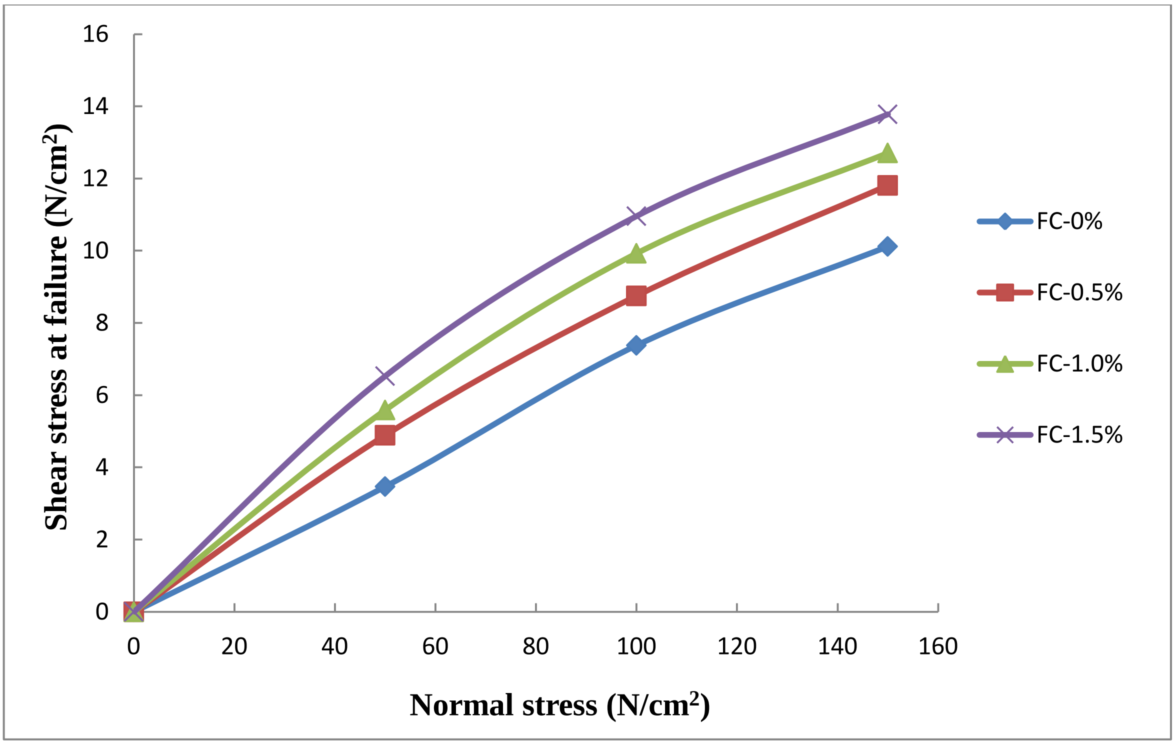

Figure 4.4: **Shear stress vs. Normal stress plots for CS+F mix at 0% relative density (L/d =45)**

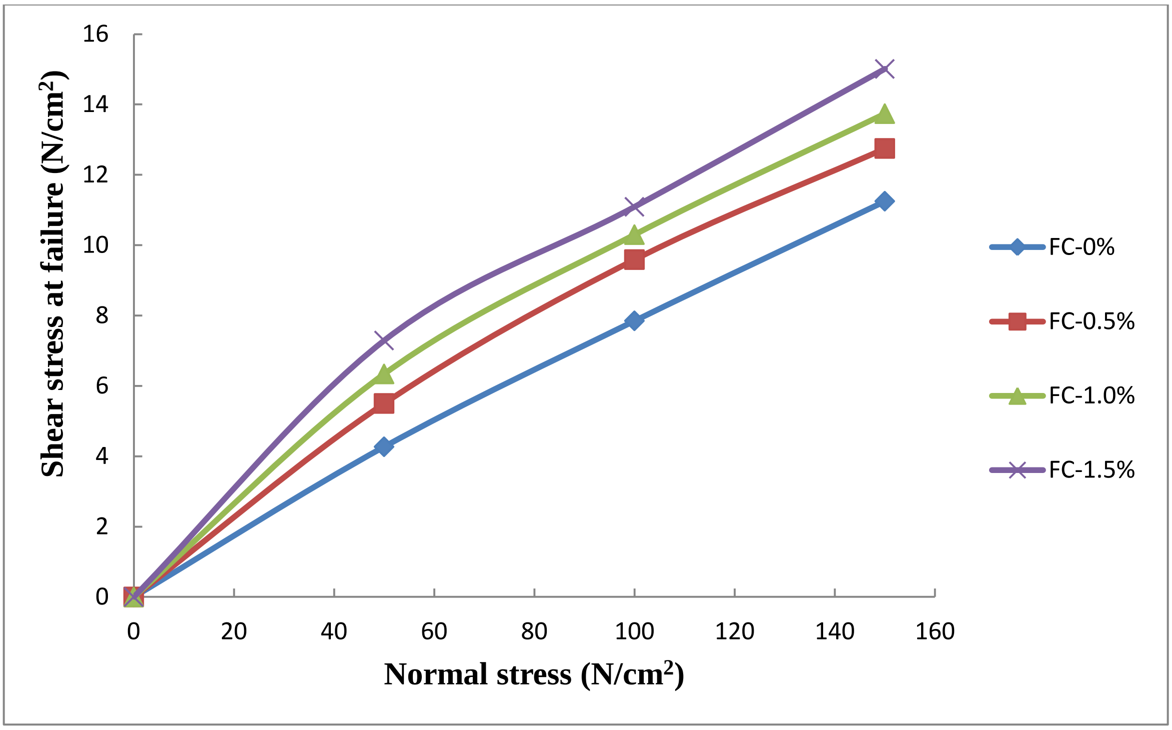

Figure 4.5: **Shear stress vs. Normal stress plots for CS+F mix at 41% relative density (L/d=45)**

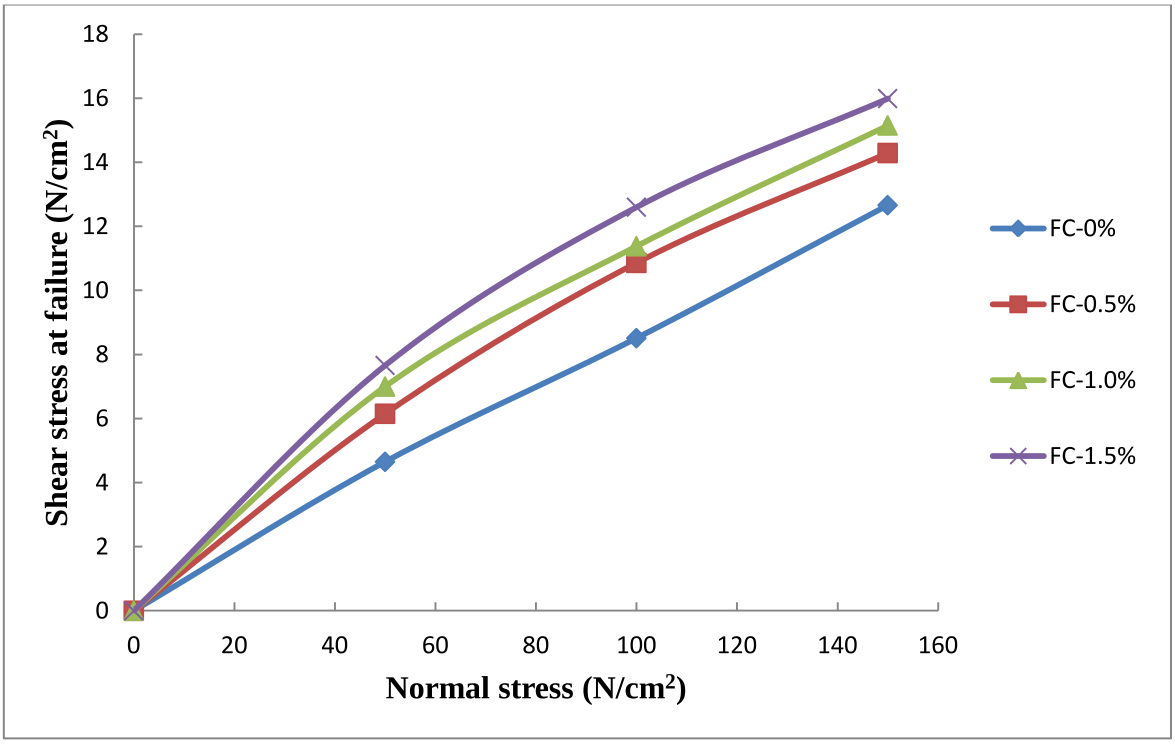

Figure 4.6: **Shear stress vs. Normal stress plots for CS+F mix at 100% relative density (L/d=45)**

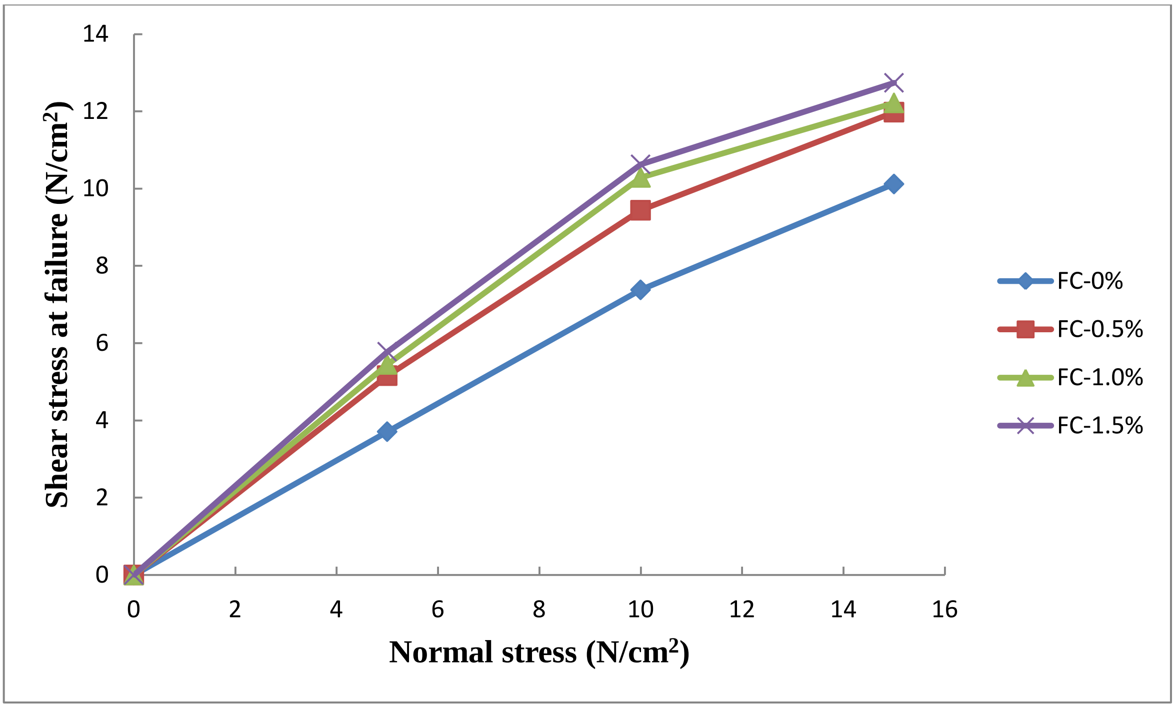

Figure 4.7: **Shear stress vs. Normal stress plots for CS+F mix at 0% relative density (L/d= 60)**

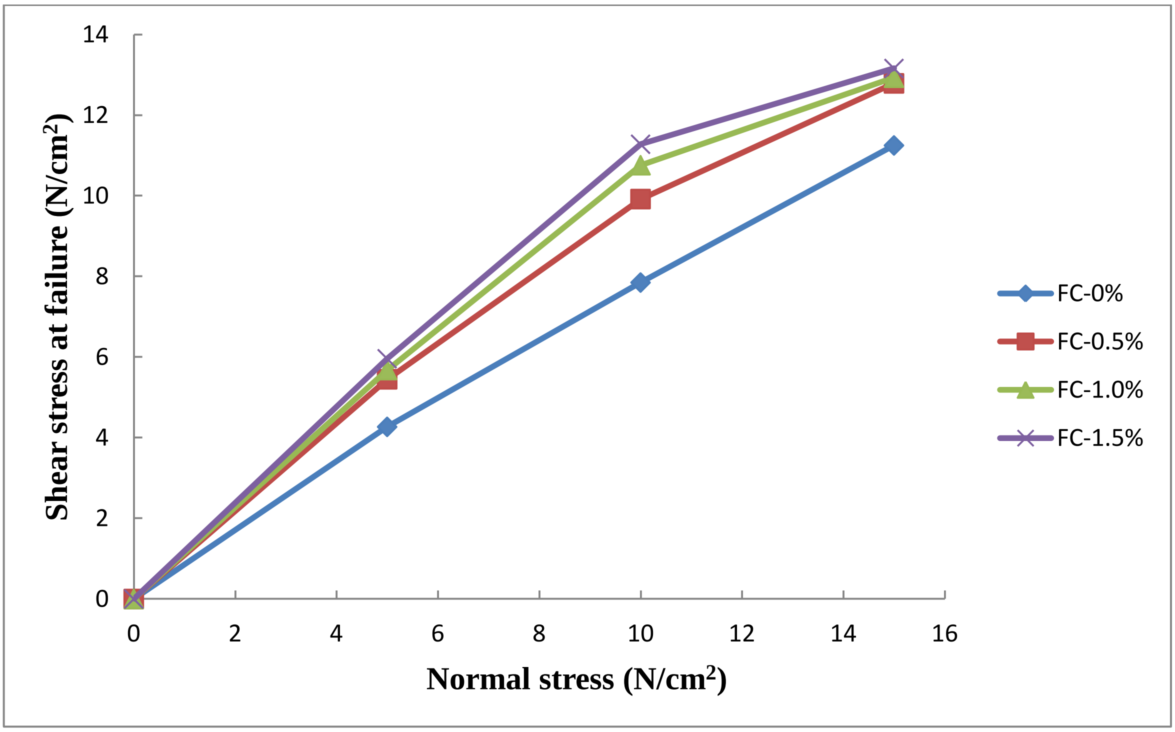

Figure 4.8: **Shear stress vs. Normal stress plots for CS+F mix at 41% relative density (L/d=60)**

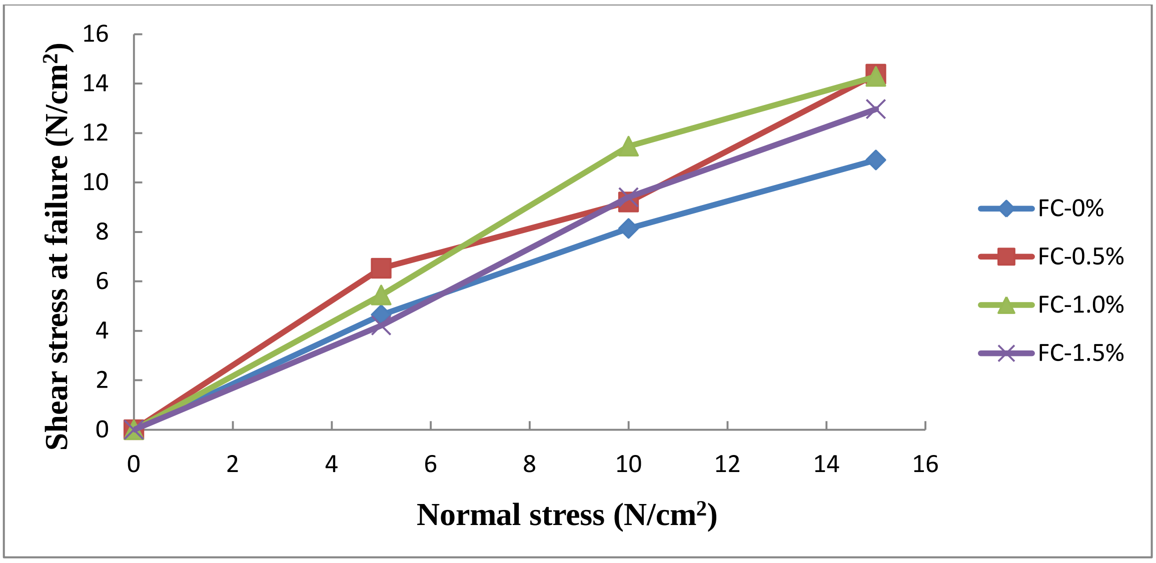

Figure 4.9: **Shear stress vs. Normal stress plots for CS+F mix at 100% relative density (L/d=60)**

4.1.2 Effect of percentages of fibres on the shear stress of coarse sand at different relative densities

Figure 4.10 to Figure 4.18 shows that the inclusion of glass fibres with three aspect ratio 30, 45 and 60, with three different fibre contents of 0.5%, 1.0% and 1.5% under three different normal stresses of 5 N/cm^2, 10 N/cm^2 and 15 N/cm^2 increases the shear stress of the coarse sand as compared with virgin sand.

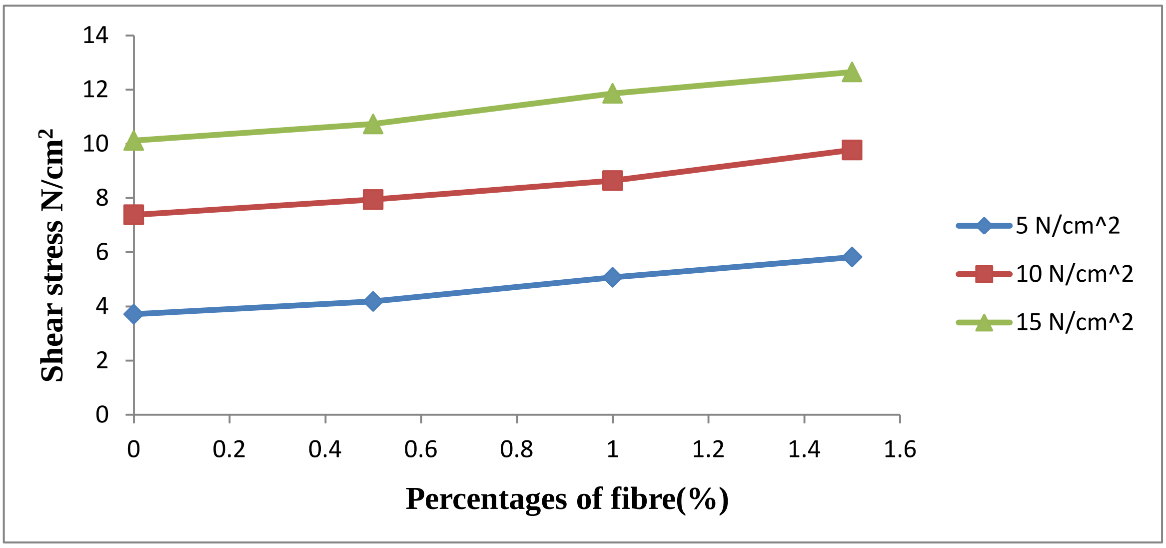

Figure 4.10: **The effect of percentages of fibres on the shear stress of the coarse sand under three different normal stresses at relative density 0% (L/d=30)**

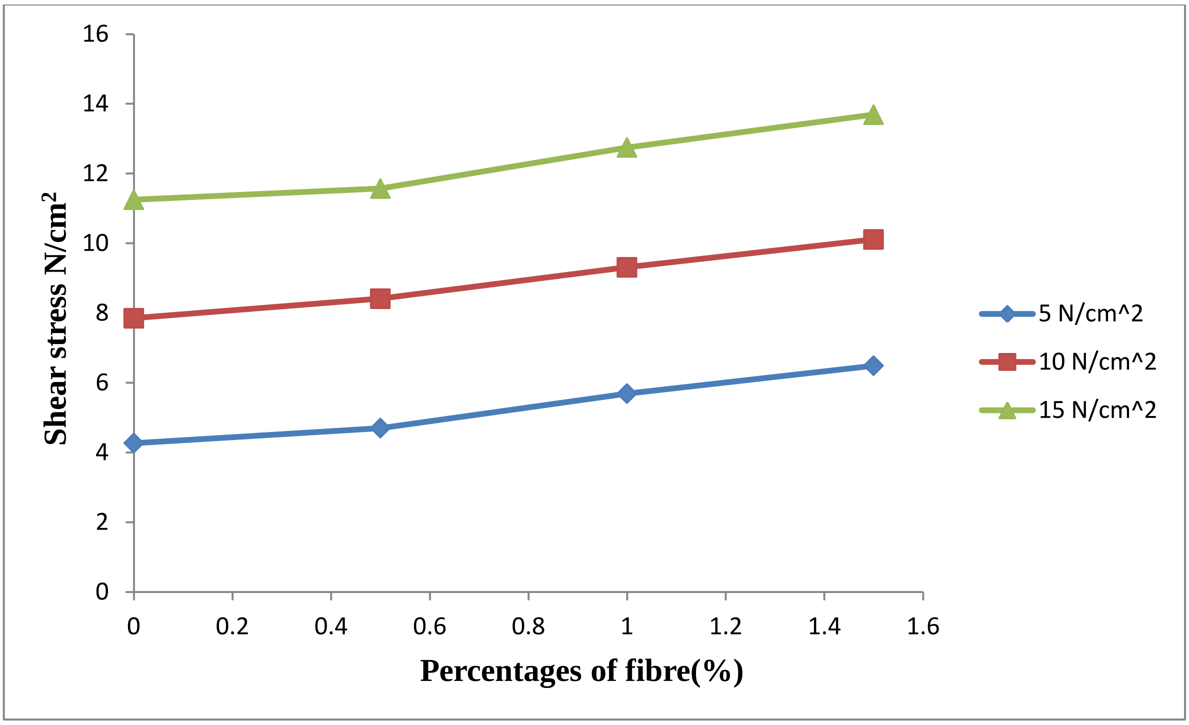

Figure 4.11: **The effect of percentages of fibres on the shear stress of the coarse sand under three different normal stresses at relative density 41% (L/d=30)**

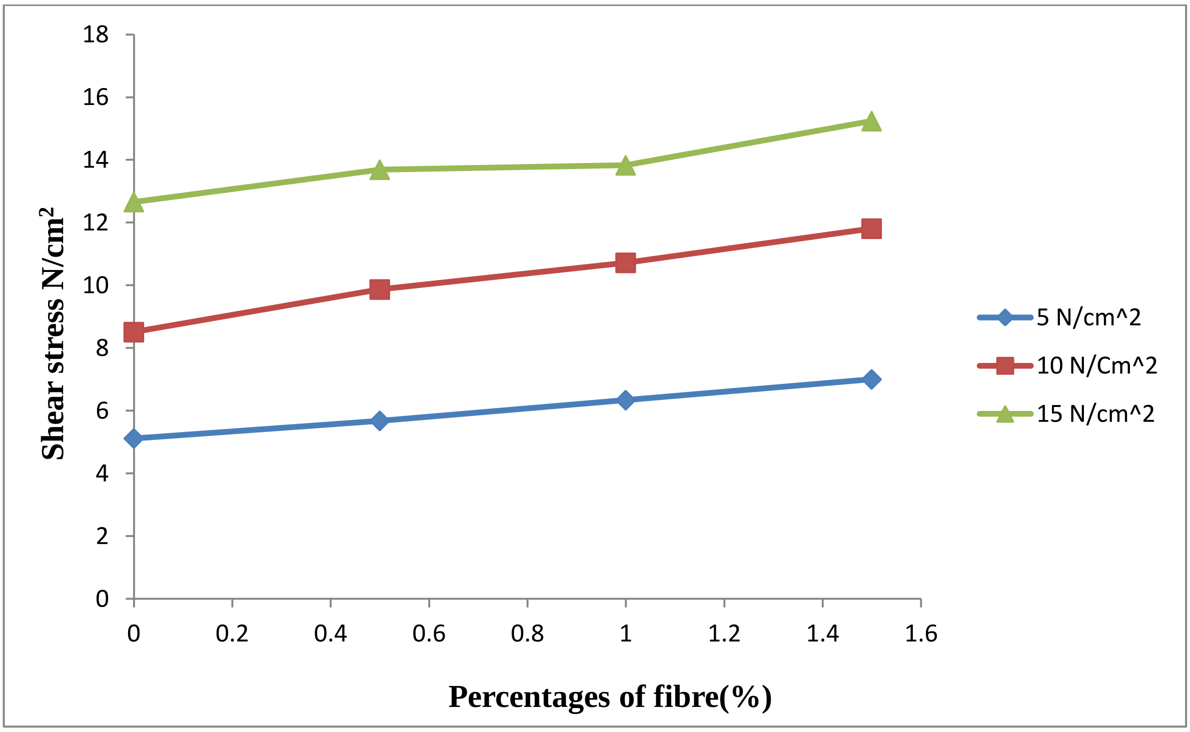

Figure 4.12: **The effect of percentages of fibres on the shear stress of the coarse sand under three different normal stresses at relative density 100% (L/d=30)**

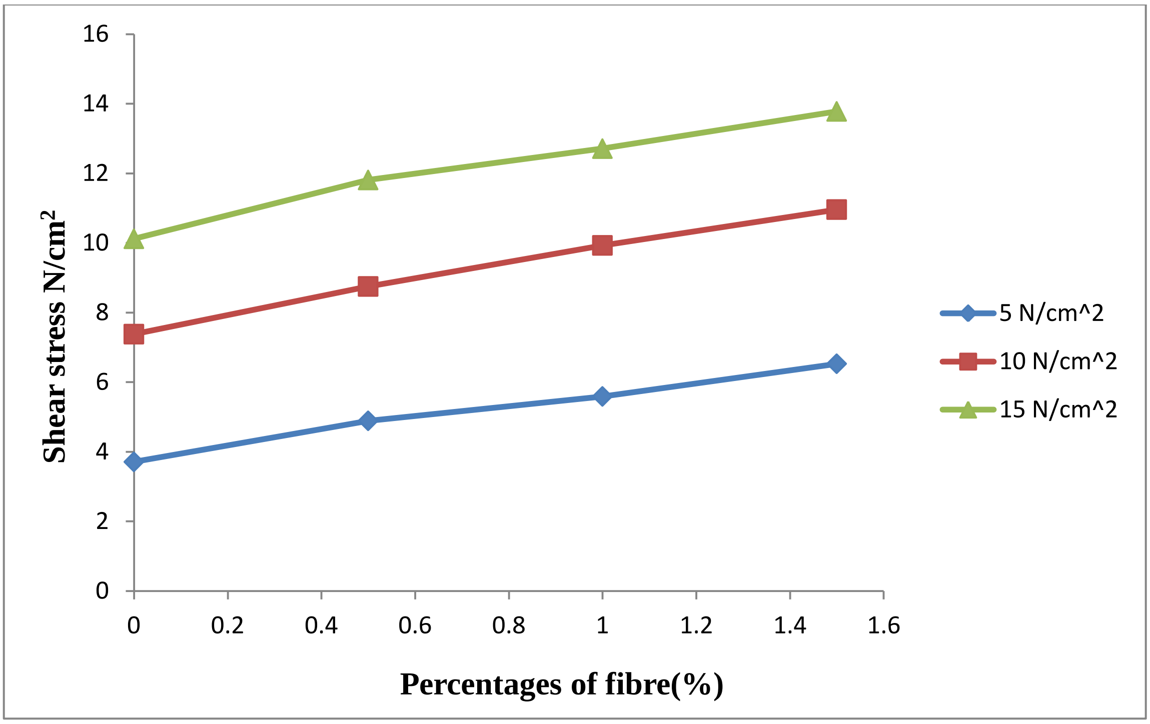

Figure 4.13: **The effect of percentages of fibres on the shear stress of the coarse sand under three different normal stresses at relative density 0% (L/d=45)**

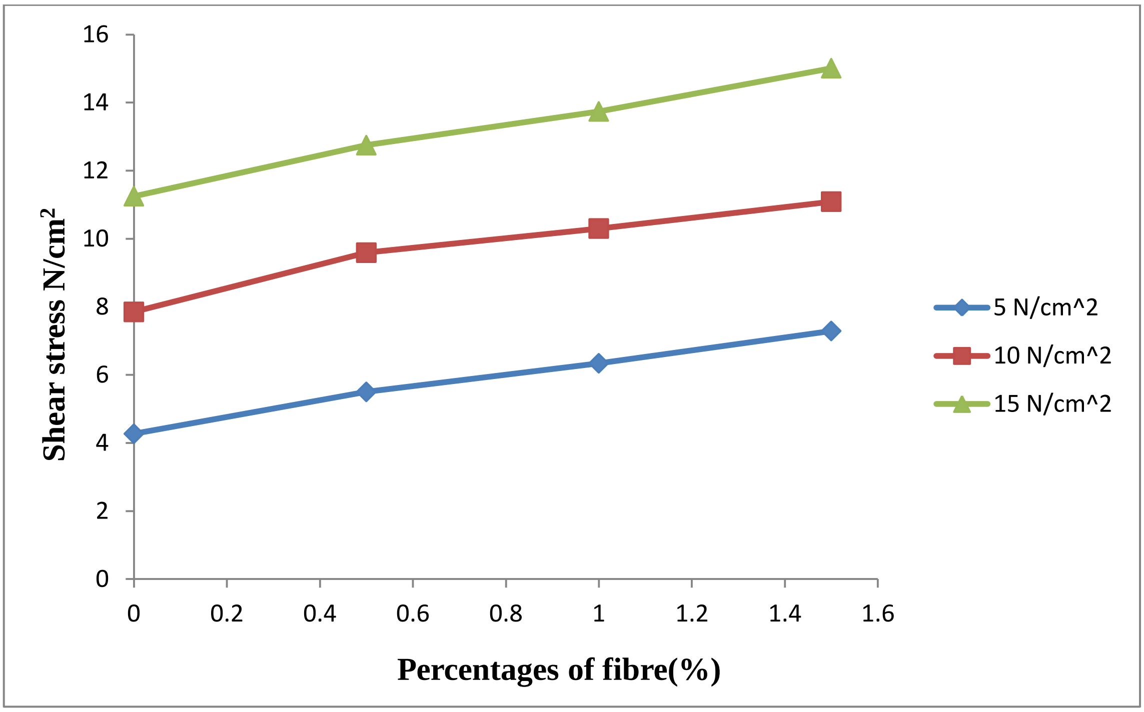

Figure 4.14: **The effect of percentages of fibres on the shear stress of the coarse sand under three different normal stresses at relative density 41% (L/d=45)**

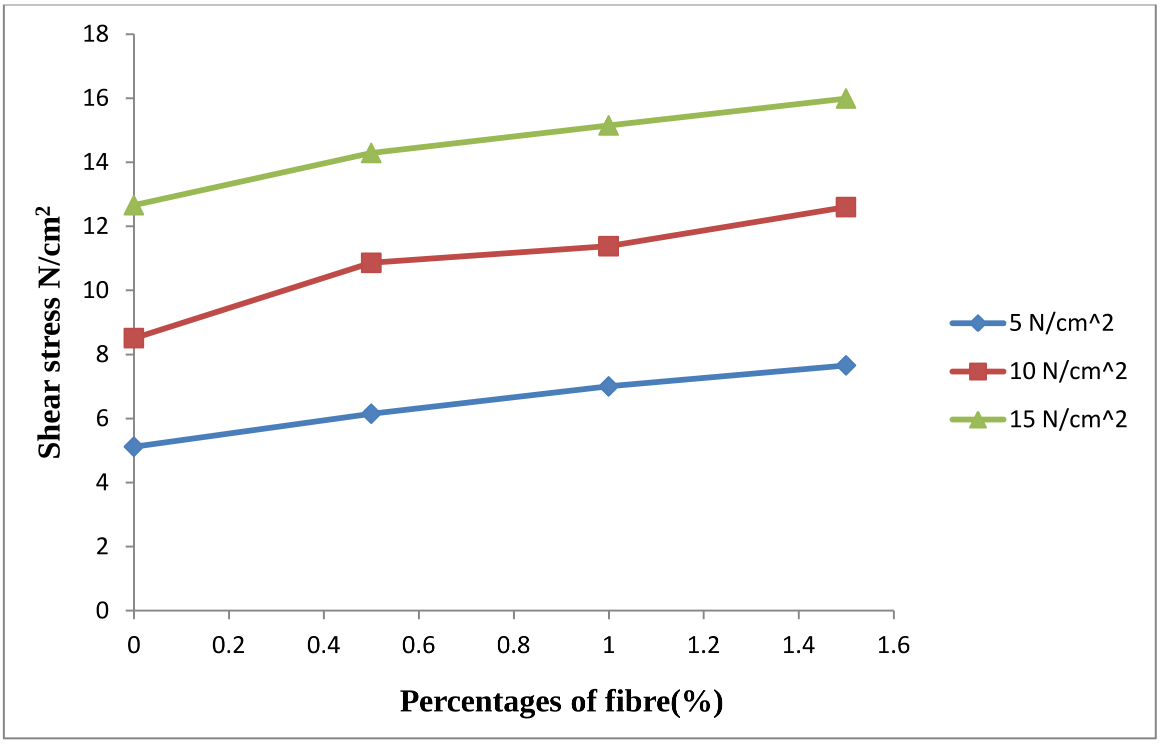

Figure 4.15: **The effect of percentages of fibres on the shear stress of the coarse sand under three different normal stresses at relative density 100% (L/d=45)**

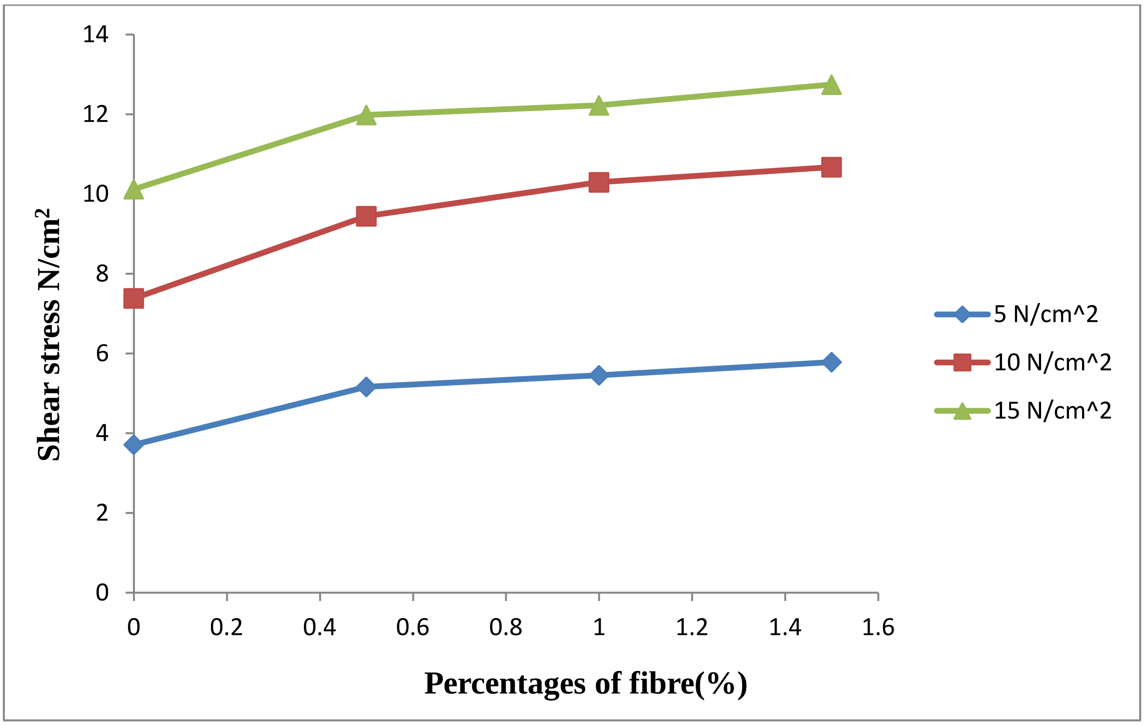

Figure 4.16: **The effect of percentages of fibres on the shear stress of the coarse sand under three different normal stresses at relative density 0% (L/d=60)**

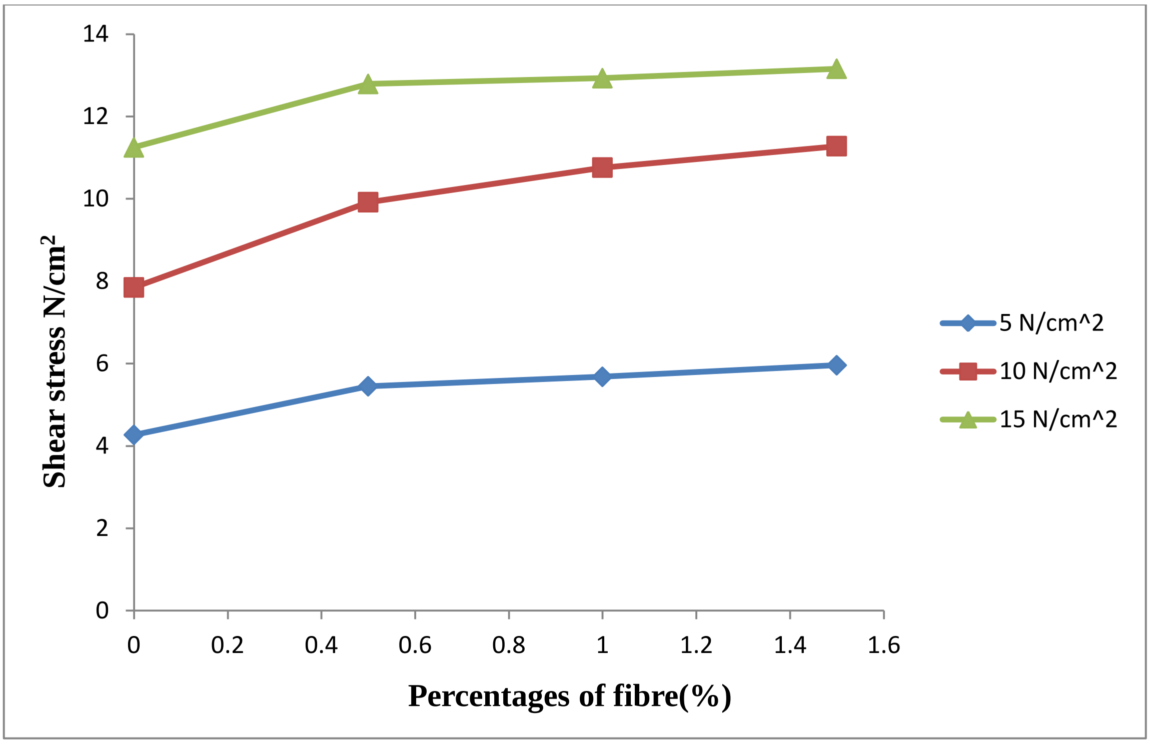

Figure 4.17: **The effect of percentages of fibres on the shear stress of the coarse sand under three different normal stresses at relative density 41% (L/d=60)**

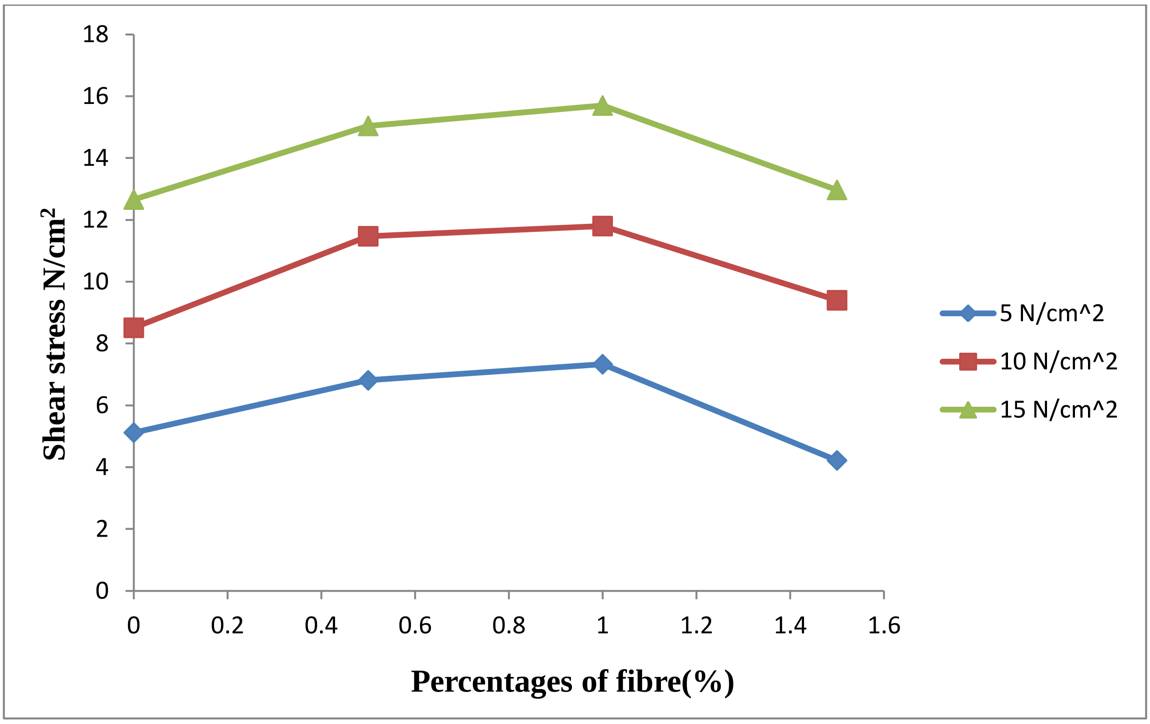

Figure 4.18: **The effect of percentages of fibres on the shear stress of the coarse sand under three different normal stresses at relative density 100% (L/d=60)**

4.1.3 Effect of percentages of glass fibres on the angle of internal friction of fine sand

Figure 4.19 to Figure 4.21 shows that the increase in angle of internal friction (φ) with increase in aspect ratio 30, 45 and 60, with increase in percentages of glass fibre from 0% to 1.5% at three different relative densities of 0%, 41% and 100%.

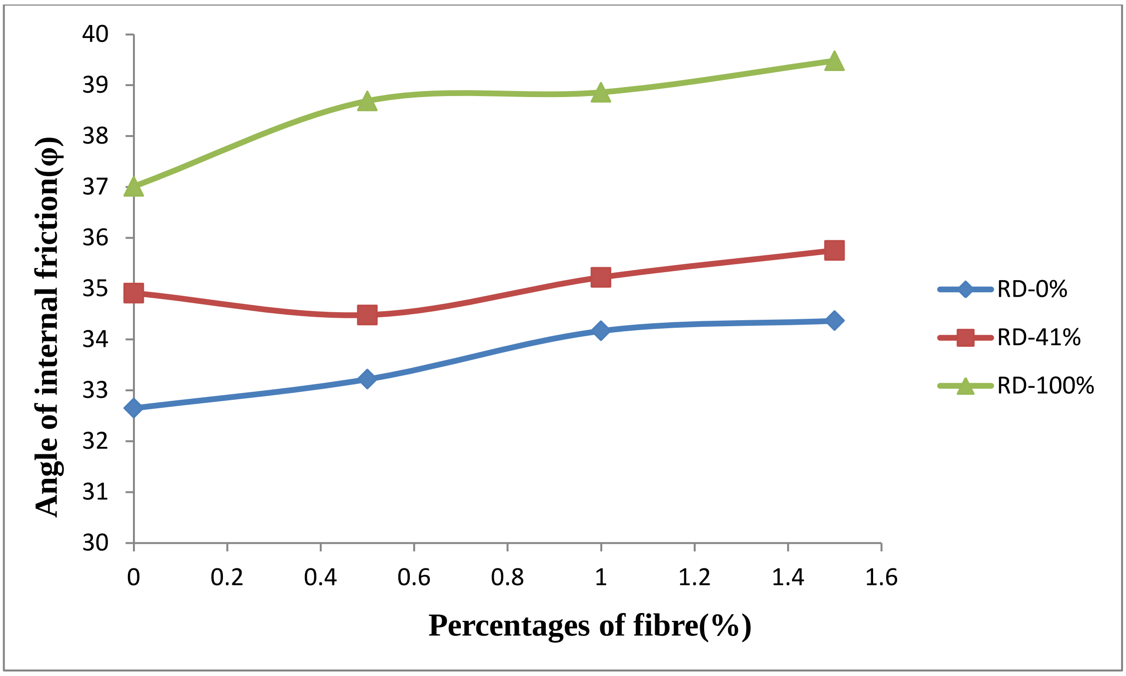

Figure 4.19: **Variation of angle of internal friction vs. Percentages of fibre (L/d =30)**

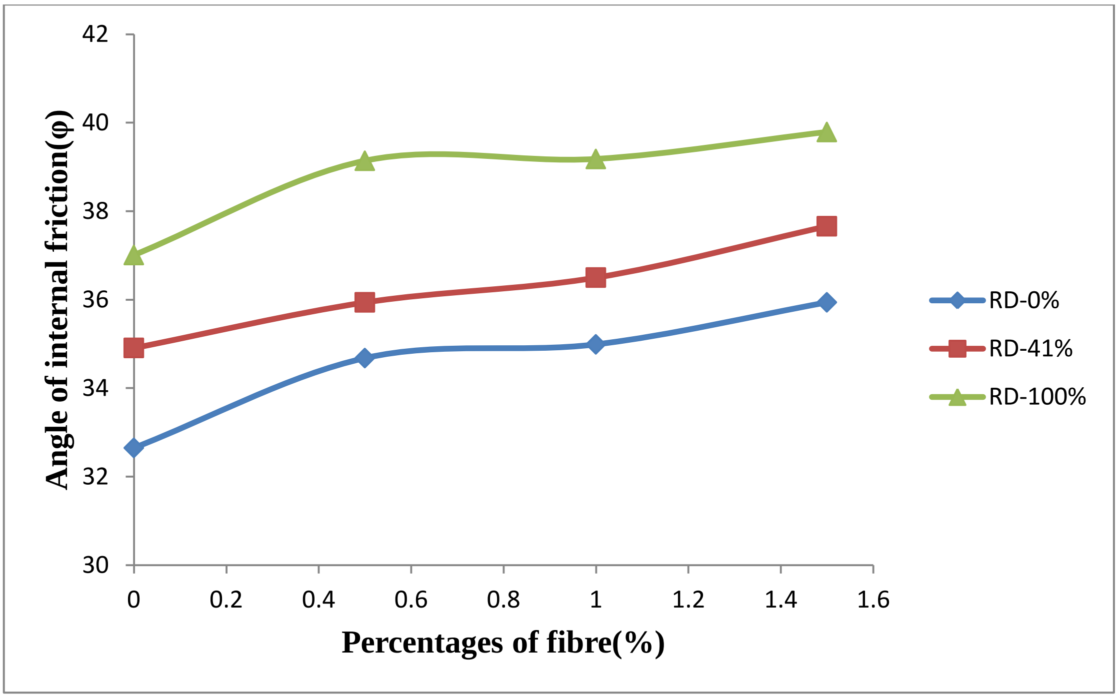

Figure 4.20: **Variation of angle of internal friction vs. Percentages of fibre (L/d= 45)**

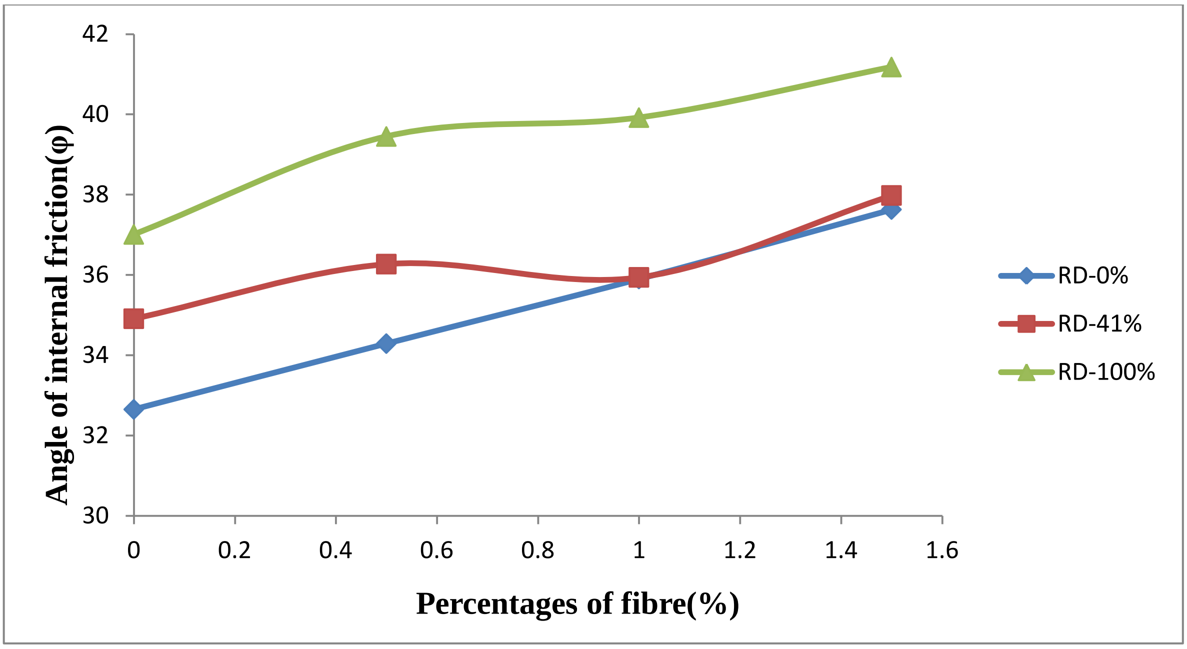

Figure 4.21: **Variation of angle of internal friction vs. Percentages of fibre (L/d =60)**

In sample B, after conducting a series of direct shear test the minimum value of ϕ is 32.65^o at 0% fibre content and 0% relative density. And the maximum value of ϕ is 39.48^o at 1.5% fibre content and 100% relative density for aspect ratio i.e. L/d=30. Percentage increase in ϕ value is 21.00%. Similarly for aspect ratio 45, the minimum value of ϕ is 32.65^o at 0% fibre content and 0% relative density. And the maximum value of ϕ is 39.79^o at 1.5% fibre content and 100% relative density. Percentage increase in ϕ value is 22.00%. Similarly for aspect ratio 60, the minimum value of ϕ is 32.65^o at 0% fibre content and 0% relative density. And the maximum value of ϕ is 41.18^o at 1.5% fibre content and 100% relative density. Percentage increase in ϕ value is 26.00%.

4.2 Shear strength parameters of fine sand:

Direct shear test was conducted on Sample C to unreinforced and reinforced samples, randomly mix glass fibre with different fibre content (0.5%, 1.0% and 1.5%) and different aspect ratio 30, 45 and 60.

Table 4.4: **Shear parameter of glass fibre reinforced fine sand obtained from direct shear test (L/d=30)**

RD	MIXES	Φ (degree)
0%	FS	32.04
	FS+0.5%F	32.98
	FS+1.0%F	33.74
	FS+1.5%F	33.78
52%	FS	32.41
	FS+0.5%F	33.34
	FS+1.0%F	34.48
	FS+1.5%F	34.83
100%	FS	34.09
	FS+0.5%F	36.27
	FS+1.0%F	36.50
	FS+1.5%F	36.97

Table.4.5**: Shear parameter of glass fibre reinforced fine sand obtained from direct shear test (L/d=45)**

RD	MIXES	Φ (degree)
0%	FS	32.04
	FS+0.5%F	32.82
	FS+1.0%F	34.68
	FS+1.5%F	35.01
52%	FS	32.41
	FS+0.5%F	34.45
	FS+1.0%F	34.83
	FS+1.5%F	35.37

100%	FS	34.09
	FS+0.5%F	37.81
	FS+1.0%F	37.45
	FS+1.5%F	38.65

Table 4.6: **Shear parameter of glass fibre reinforced fine sand obtained from direct shear test (L/d=60)**

RD	**MIXES**	**Φ (degree)**
0%	FS	32.04
	FS+0.5%F	38.34
	FS+1.0%F	37.30
	FS+1.5%F	39.35
52%	FS	32.41
	FS+0.5%F	37.95
	FS+1.0%F	41.18
	FS+1.5%F	41.37
100%	FS	34.09
	FS+0.5%F	35.14
	FS+1.0%F	35.60
	FS+1.5%F	36.05

The series of direct shear test was conducted on unreinforced sample C. The inclusion of glass fibre results in increases the values of shear stress and angle of internal friction. Fine sand samples are reinforced with glass fibre of three aspect ratio 30, 45 and 60 with three different fibre contents of 0.5%, 1.0% and 1.5% at normal stresses equals to 5 N/cm^2, 10 N/cm^2 and 15 N/cm^2.

4.2.1 Effect of aspect ratio on shear stress of fine sand at different relative densities

Figure 4.22 to Figure 4.30 shows that the shear stress and normal stress plots of glass fibre reinforced fine sand with three different relative densities. The results have shown the variation of shear stress parameters with fibre content and relative density. The values of shear stress and angle of internal friction increases with any of mix used with any relative density.

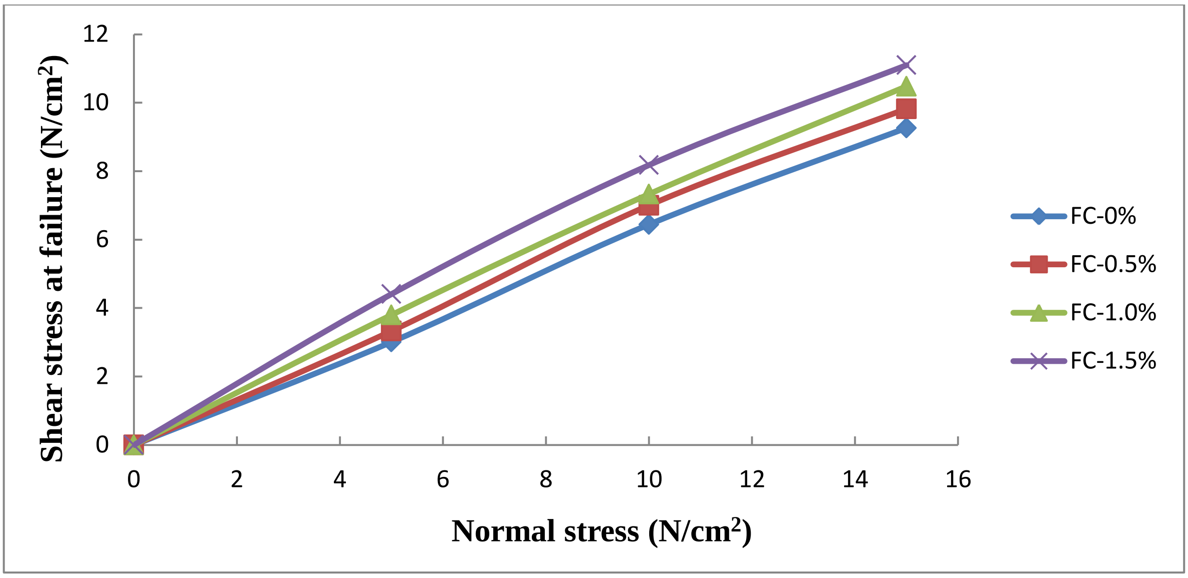

Figure 4.22: **Shear stress vs. Normal stress plots for FS+F mix at 0% relative density (L/d=30)**

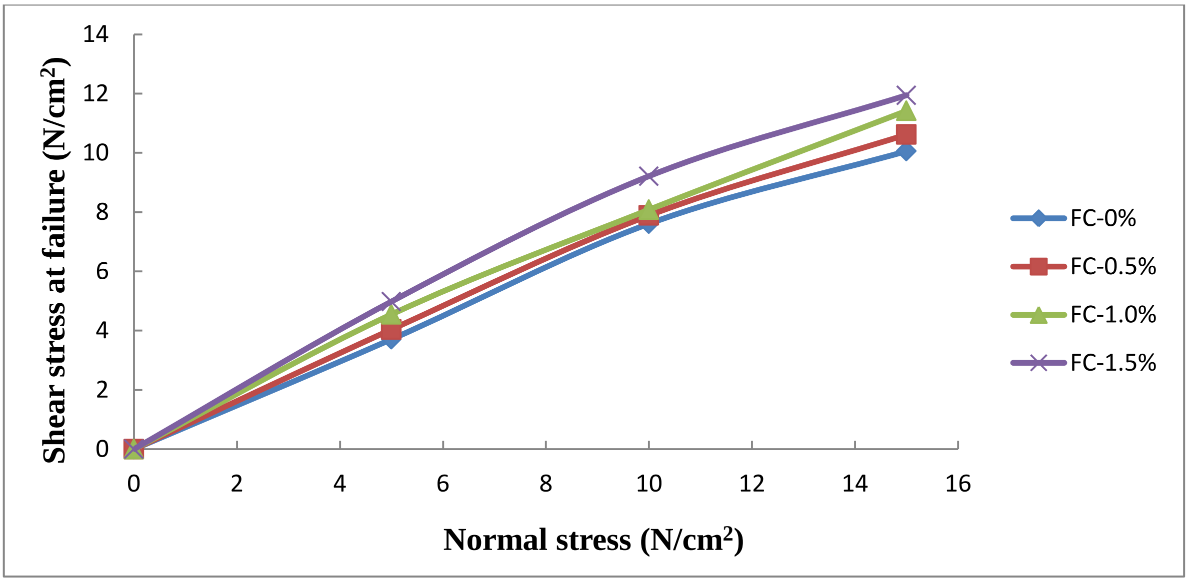

Figure 4.23: **Shear stress vs. Normal stress plots for FS+F mix at 52% relative density (L/d=30)**

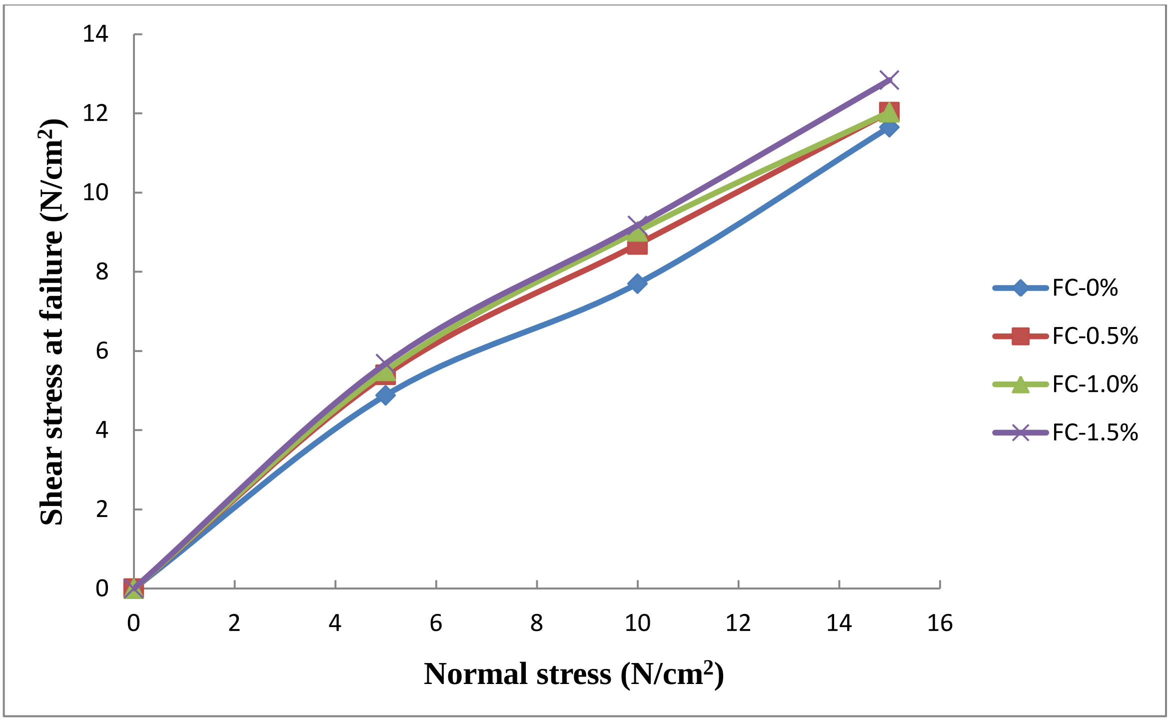

Figure 4.24: **Shear stress vs. Normal stress plots for FS+F mix at 100% relative density (L/d=30)**

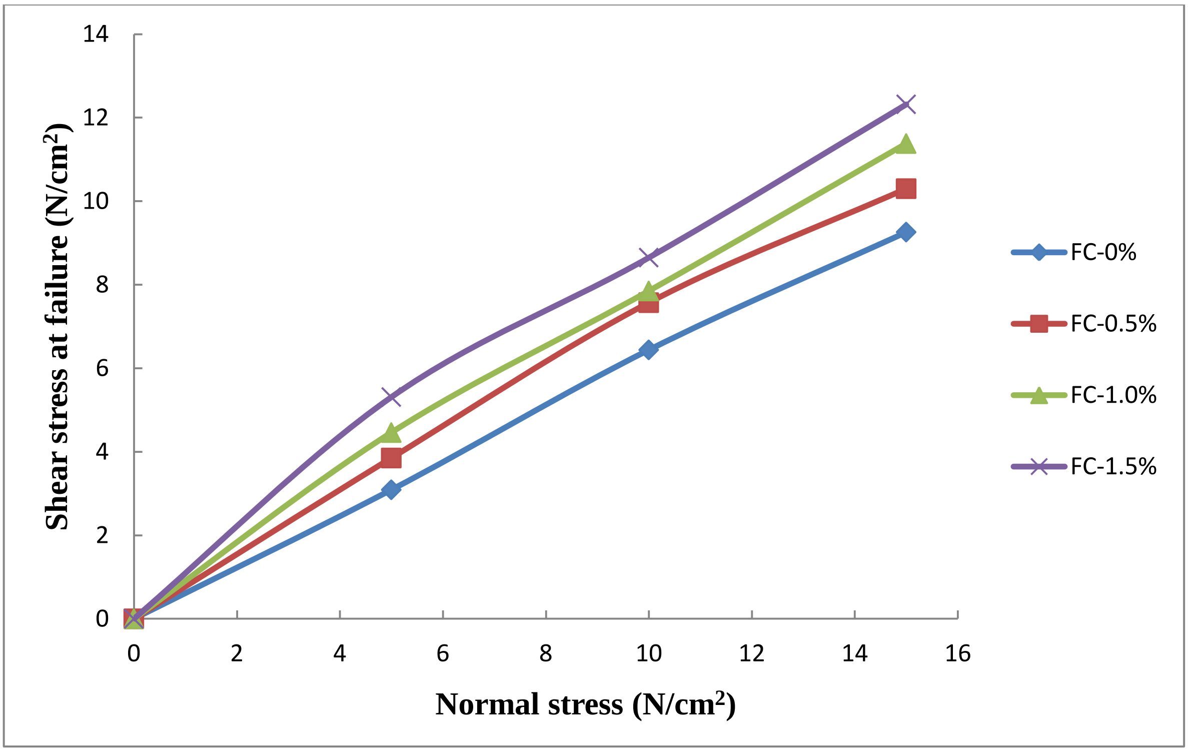

Figure 4.25: **Shear stress vs. Normal stress plots for FS+F mix at 0% relative density (L/d=45)**

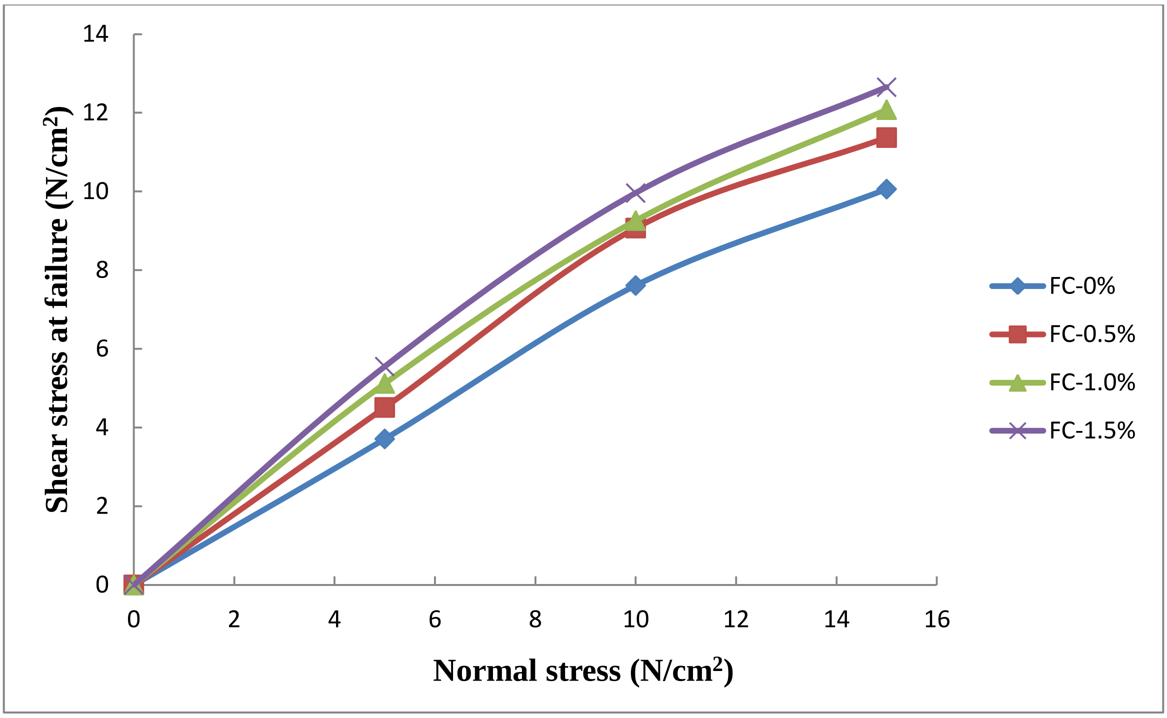

Figure 4.26: **Shear stress vs. Normal stress plots for FS+F mix at 52% relative density (L/d=45)**

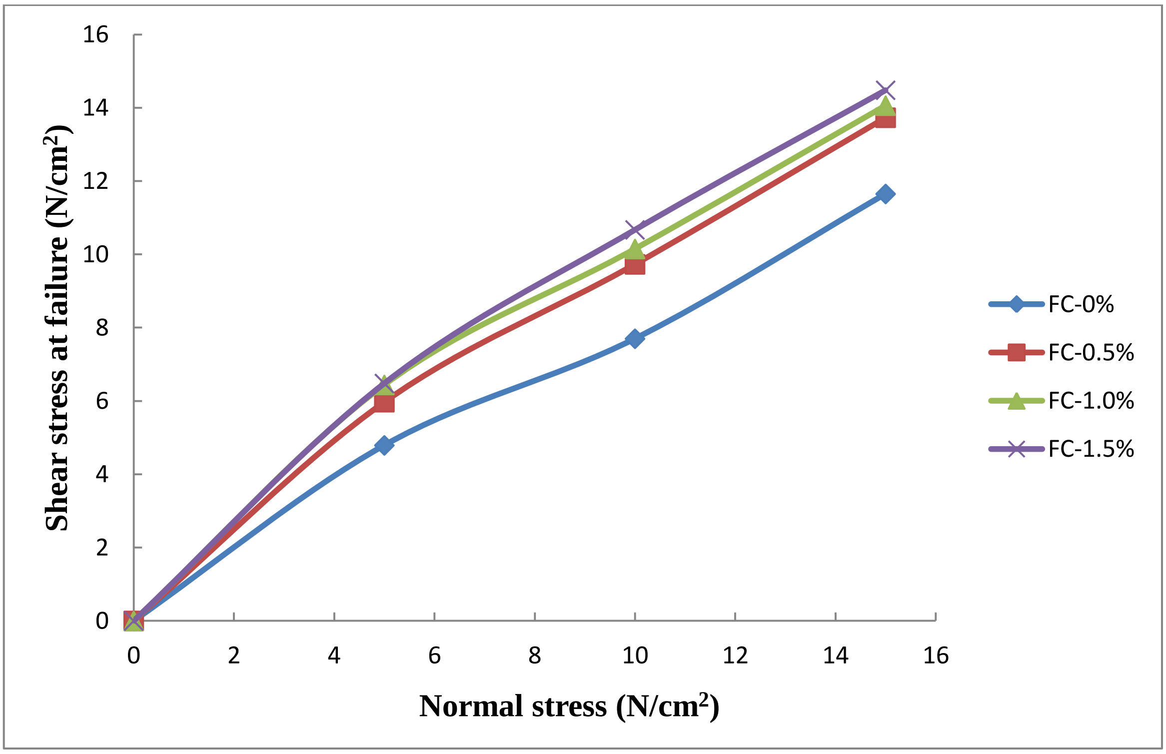

Figure 4.27: **Shear stress vs. Normal stress plots for FS+F mix at 100% relative density (L/d=45)**

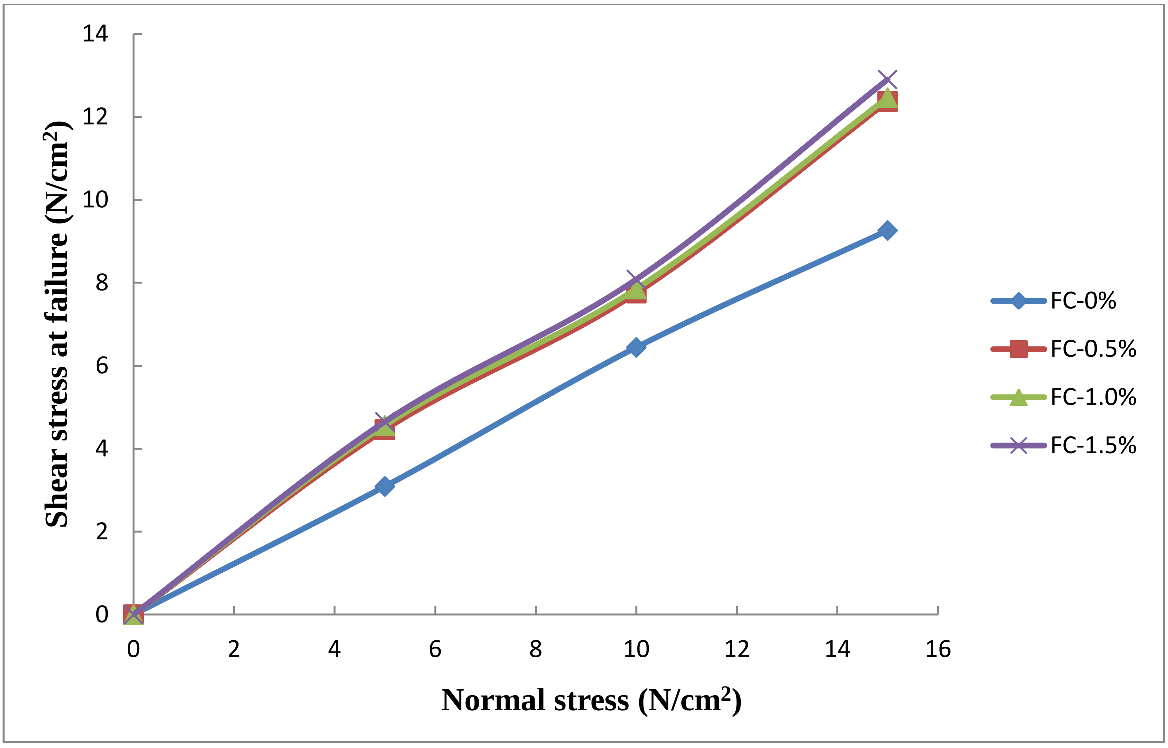

Figure 4.28: **Shear stress vs. Normal stress plots for FS+F mix at 0% relative density (L/d=60)**

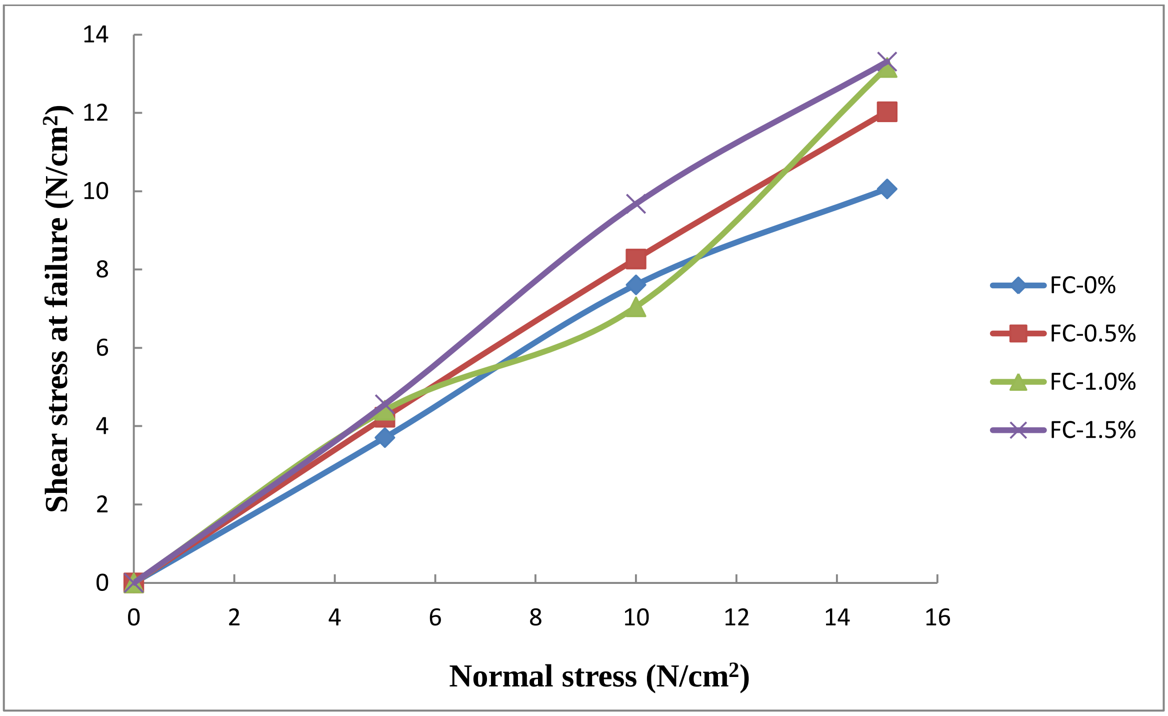

Figure 4.29: **Shear stress vs. Normal stress plots for FS+F mix at 52% relative density (L/d=60)**

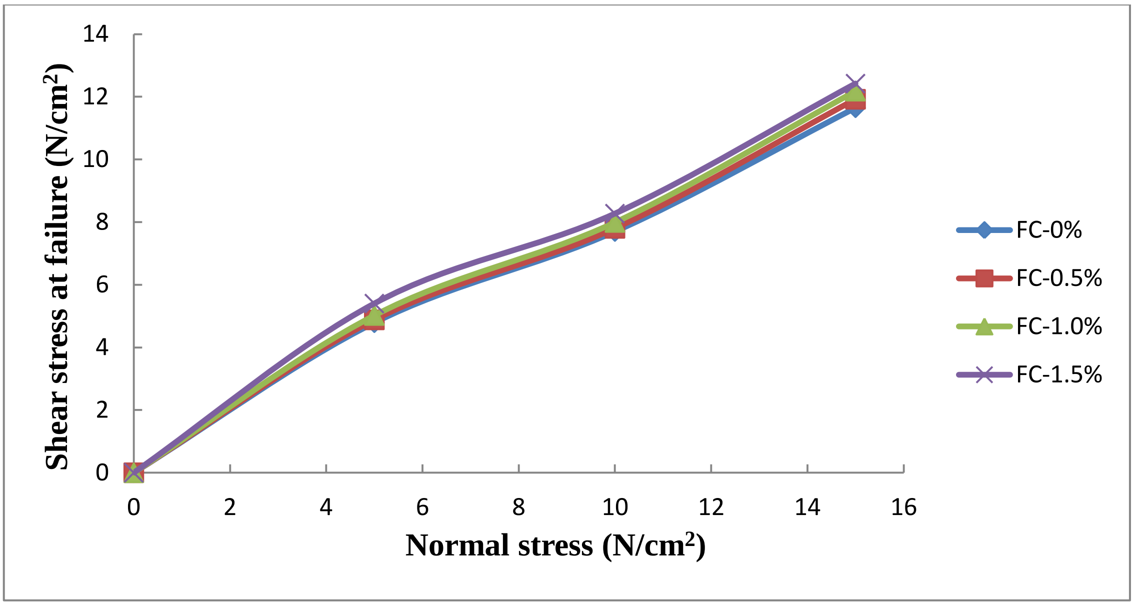

Figure 4.30: **Shear stress vs. Normal stress plots for FS+F mix at 100% relative density (L/d=60)**

4.2.2 Effect of percentages of fibres on the shear stress of fine sand at different relative densities

Figure 4.31 to Figure 4.39 shows that the inclusion of glass fibres with three aspect ratio 30, 45 and 60, with three different fibre contents of 0.5%, 1.0% and 1.5% under three different normal loads of 5 N/cm^2, 10 N/cm^2 and 15 N/cm^2 increases the shear stress of the fine sand as compared with virgin sand.

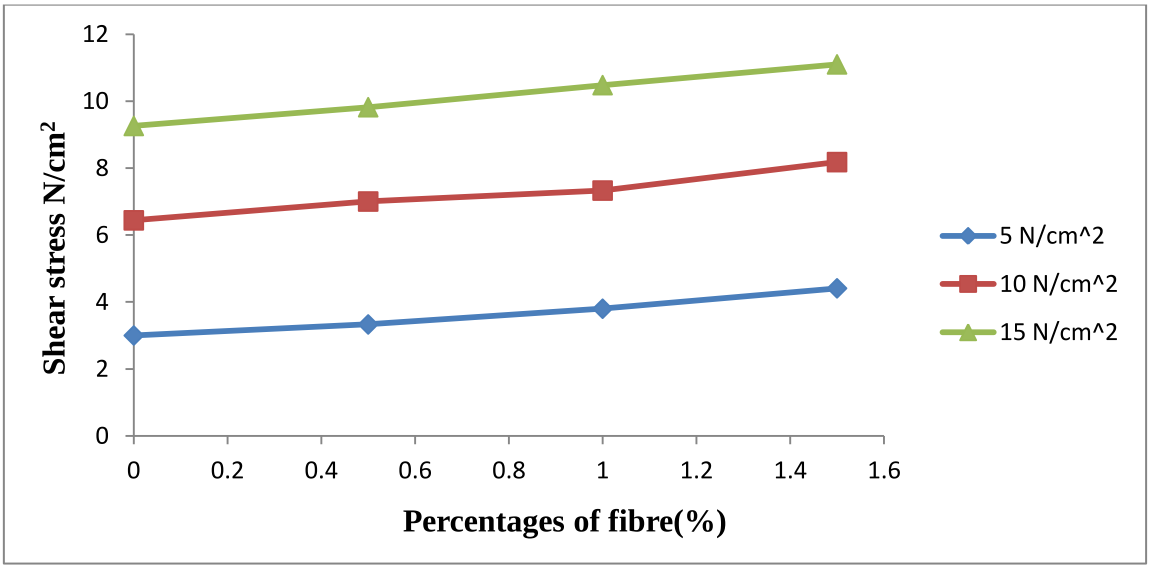

Figure 4.31: **The effect of percentages of fibres on the shear stress of the fine sand under three different normal stresses at relative density 0% (L/d=30)**

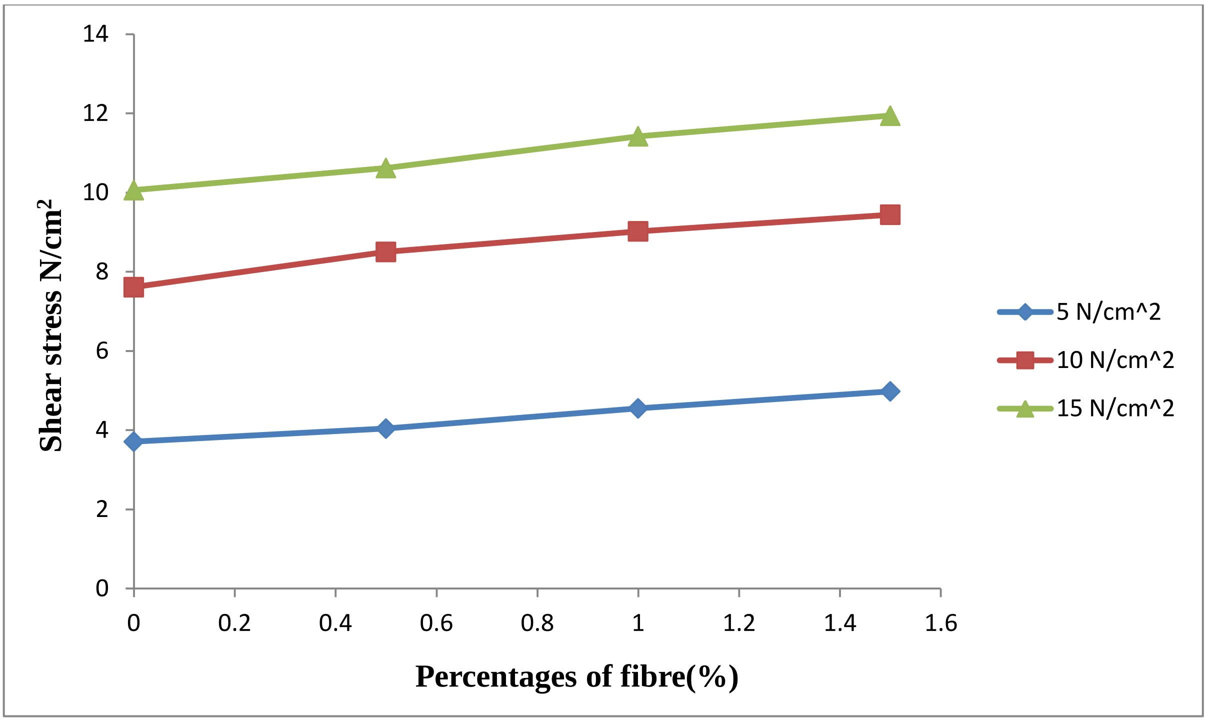

Figure 4.32: **The effect of percentages of fibres on the shear stress of the fine sand under three different normal stresses at relative density 52% (L/d=30)**

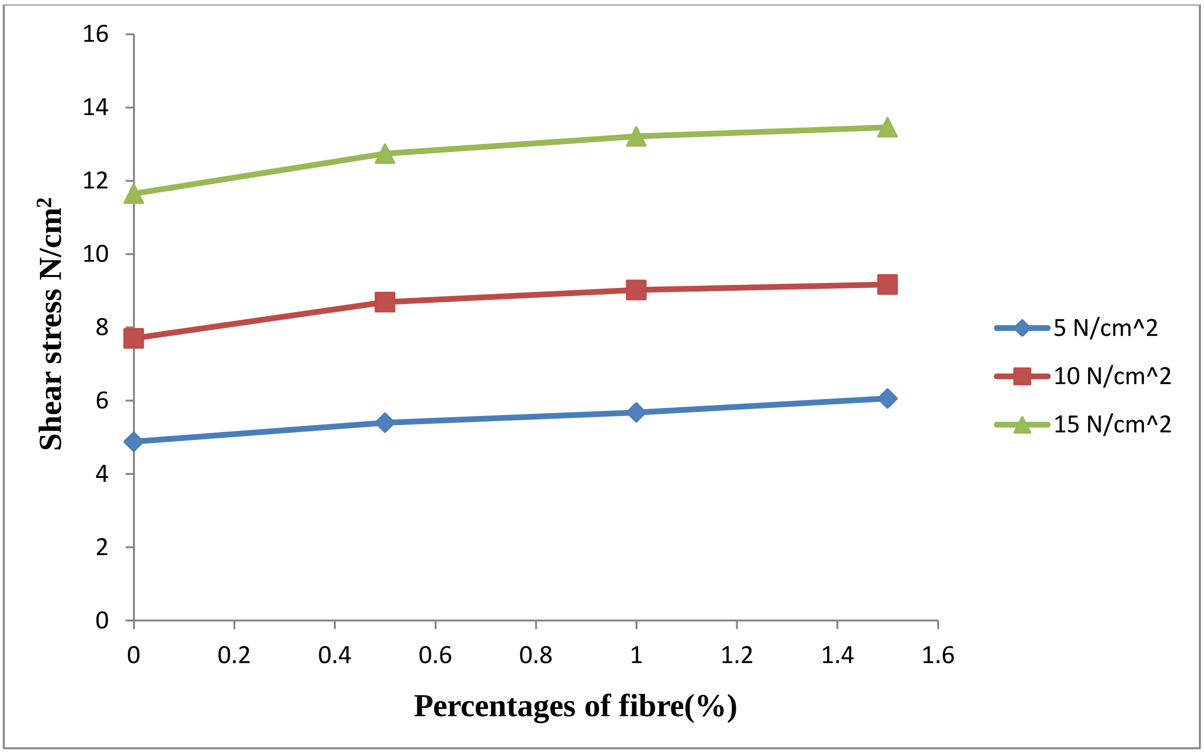

Figure 4.33: **The effect of percentages of fibres on the shear stress of the fine sand under three different normal stresses at relative density 100% (L/d=30)**

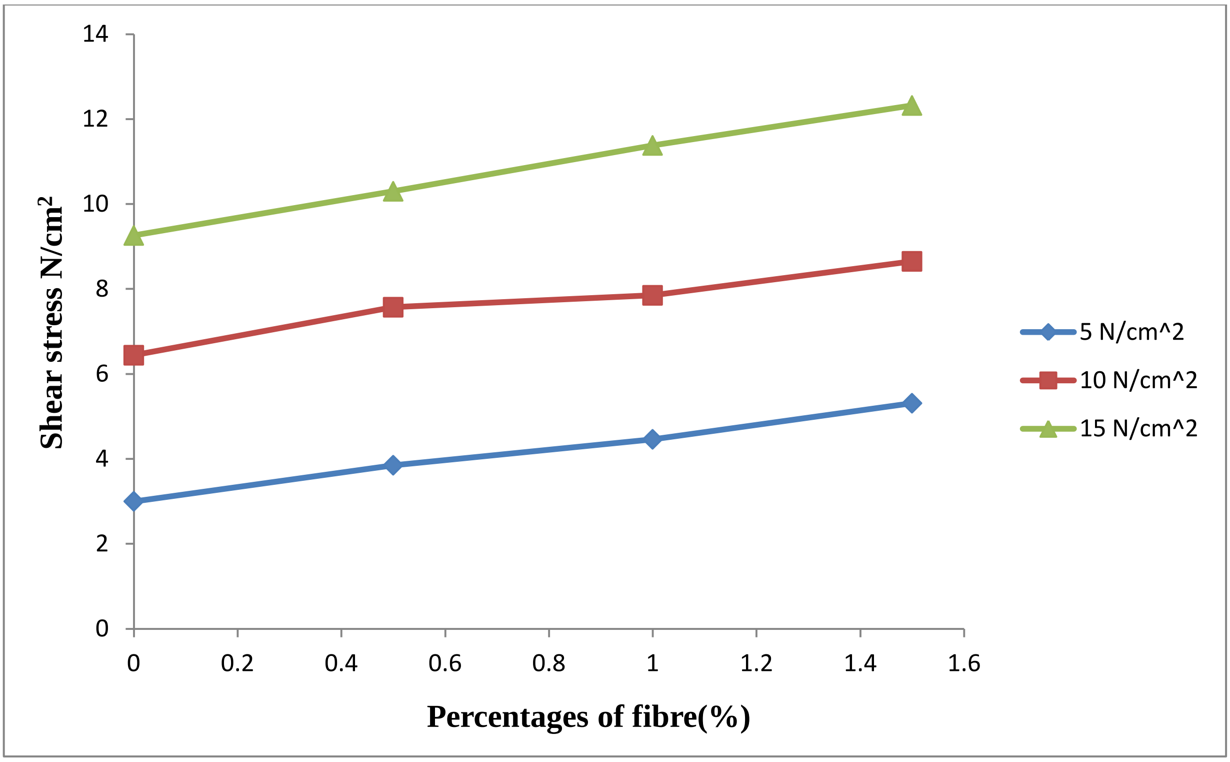

Figure 4.34: **The effect of percentages of fibres on the shear stress of the fine sand under three different normal stresses at relative density 0% (L/d=45)**

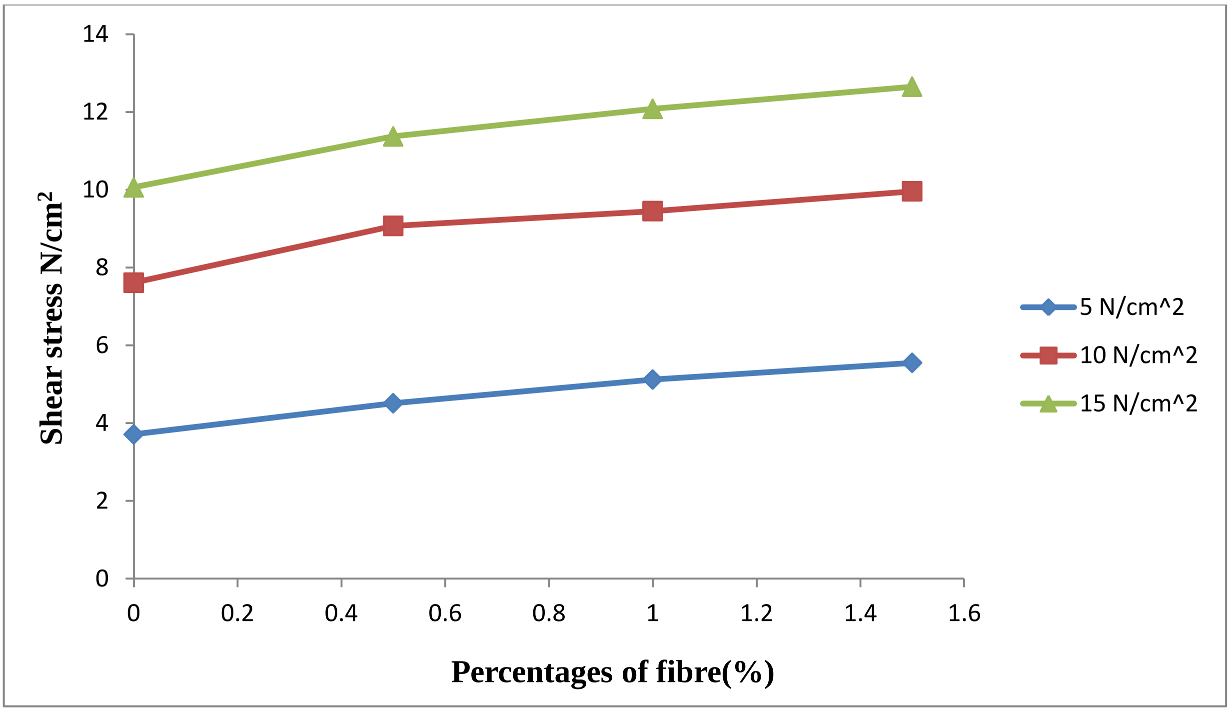

Figure 4.35: **The effect of percentages of fibres on the shear stress of the fine sand under three different normal stresses at relative density 52% (L/d=45)**

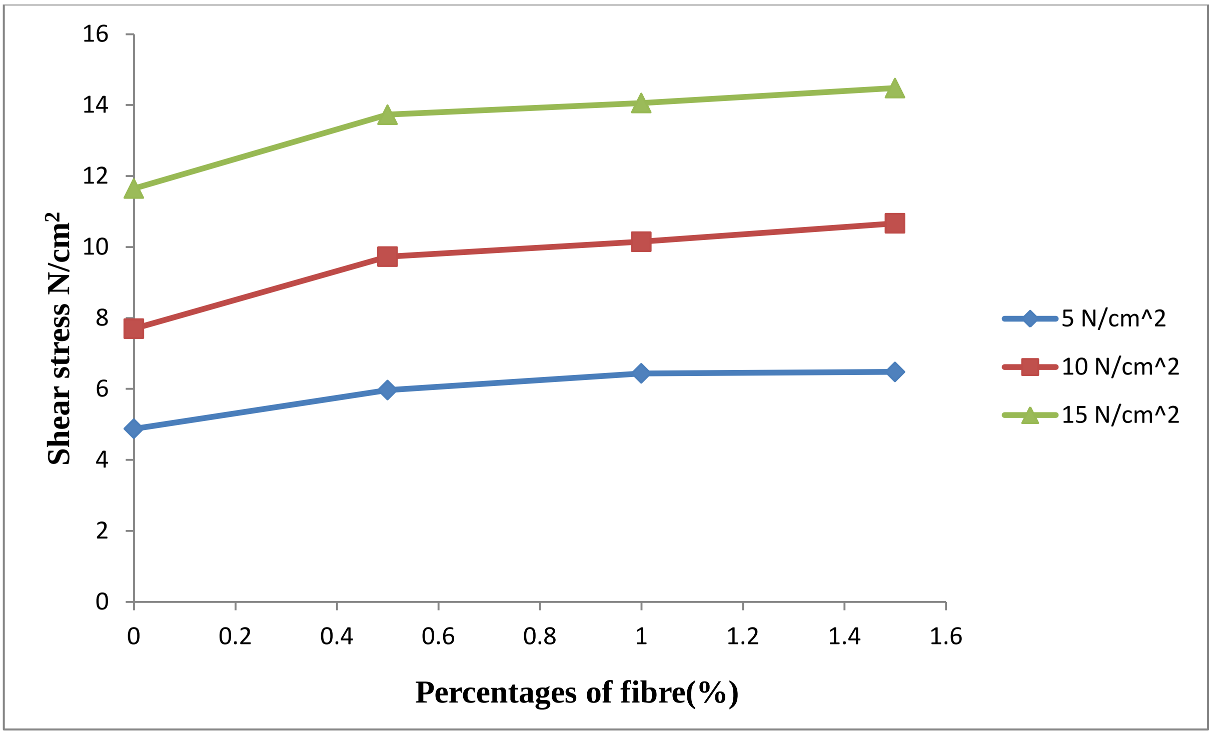

Figure 4.36: **The effect of percentages of fibres on the shear stress of the fine sand under three different normal stresses at relative density 100% (L/d=45)**

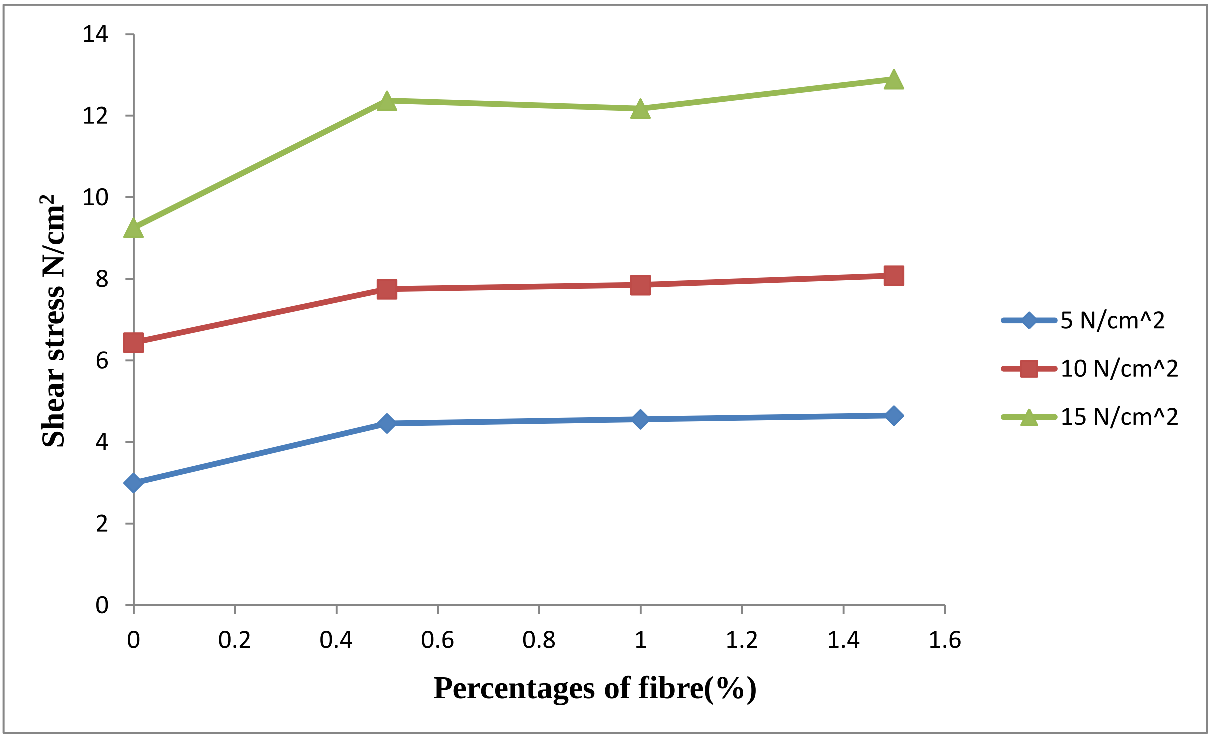

Figure 4.37: **The effect of percentages of fibres on the shear stress of the fine sand under three different normal stresses at relative density 0% (L/d=60)**

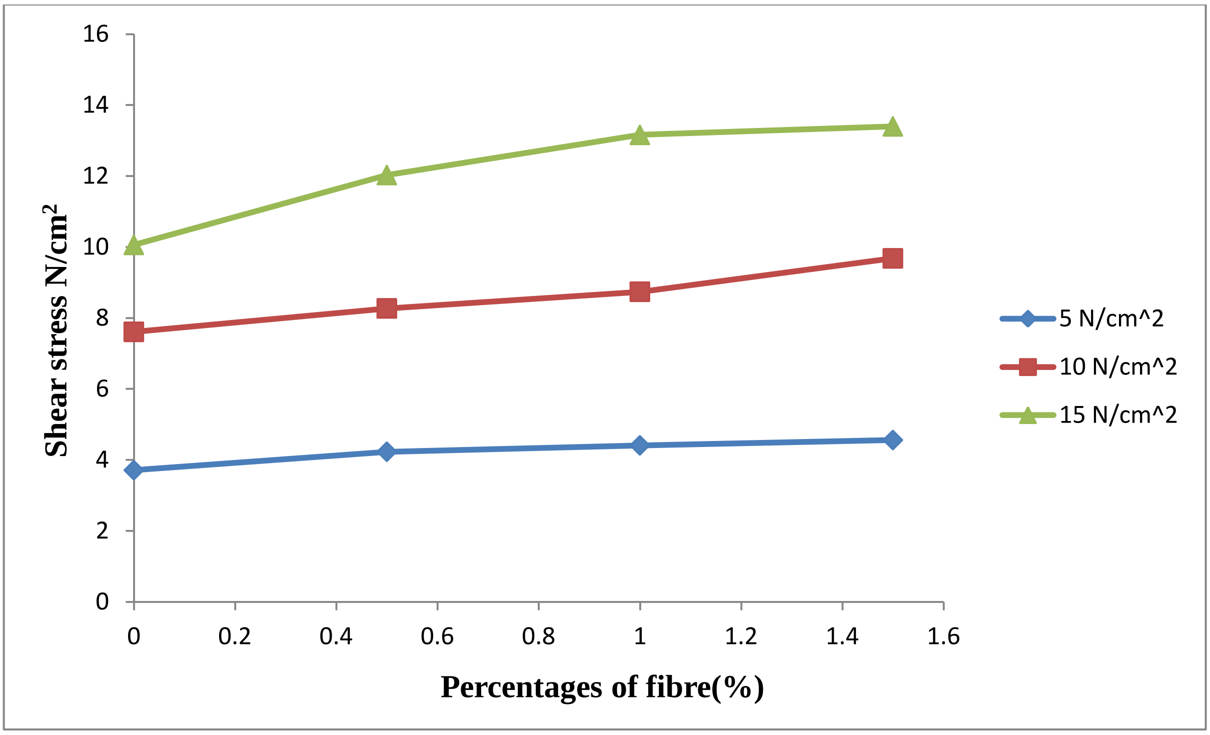

Figure 4.38: **The effect of percentages of fibres on the shear stress of the fine sand under three different normal stresses at relative density 52% (L/d=60)**

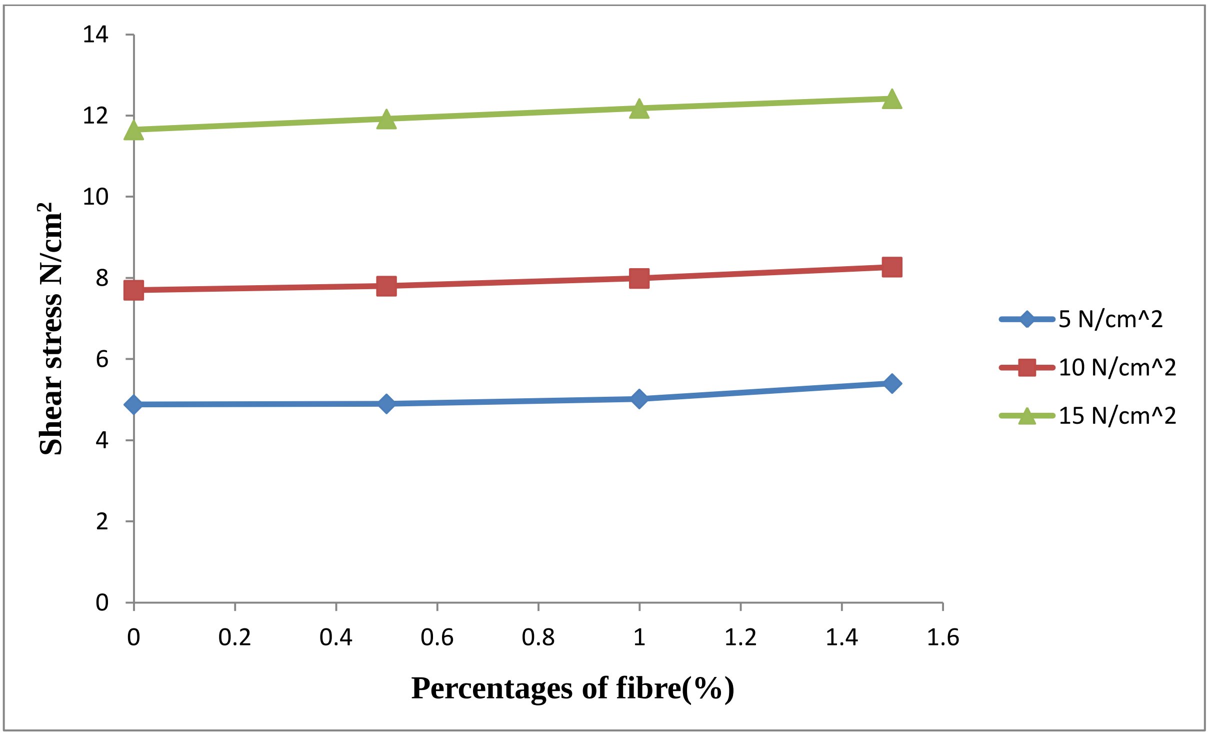

Figure 4.39: **The effect of percentages of fibres on the shear stress of the fine sand under three different normal stresses at relative density 100% (L/d=60)**

4.2.3 Effect of percentages of glass fibres on the angle of internal friction of fine sand

Figure 4.40 to Figure 4.42 shows that the increase in angle of internal friction (φ) with increase in fibre aspect ratio 30, 45 and 60.with increase in percentages of glass fibre from 0% to 1.5% at three different relative densities of 0%, 52% and 100%.

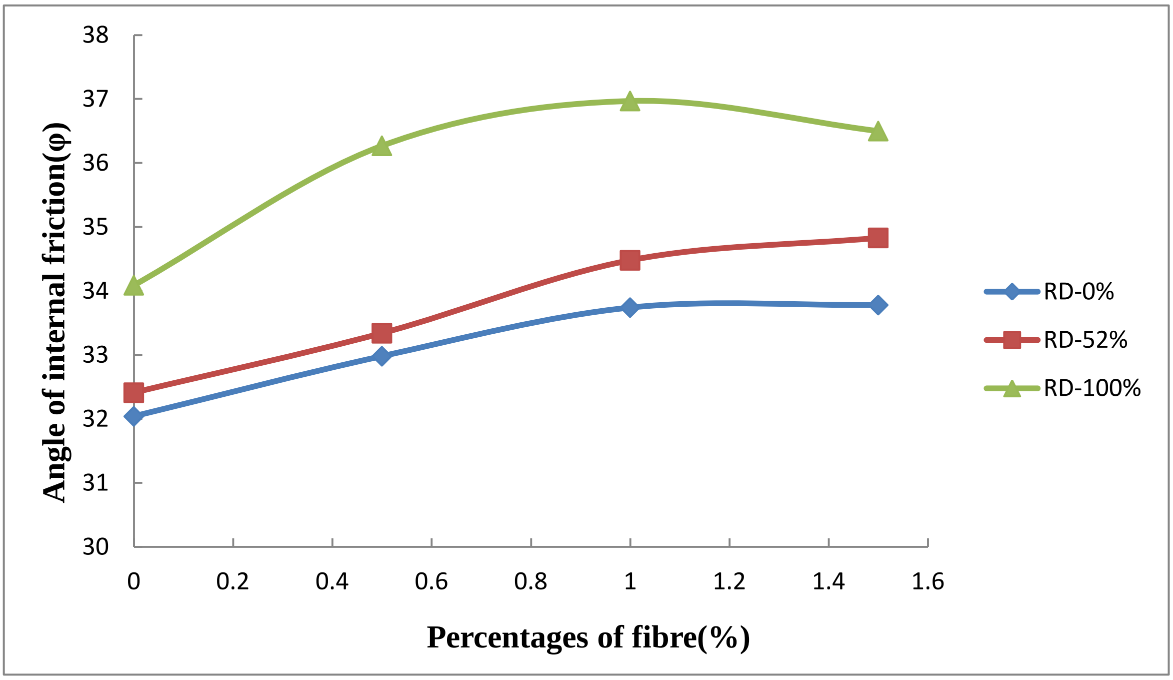

Figure 4.40: **Variation of angle of internal friction vs. Percentages of fibre (L/d=30)**

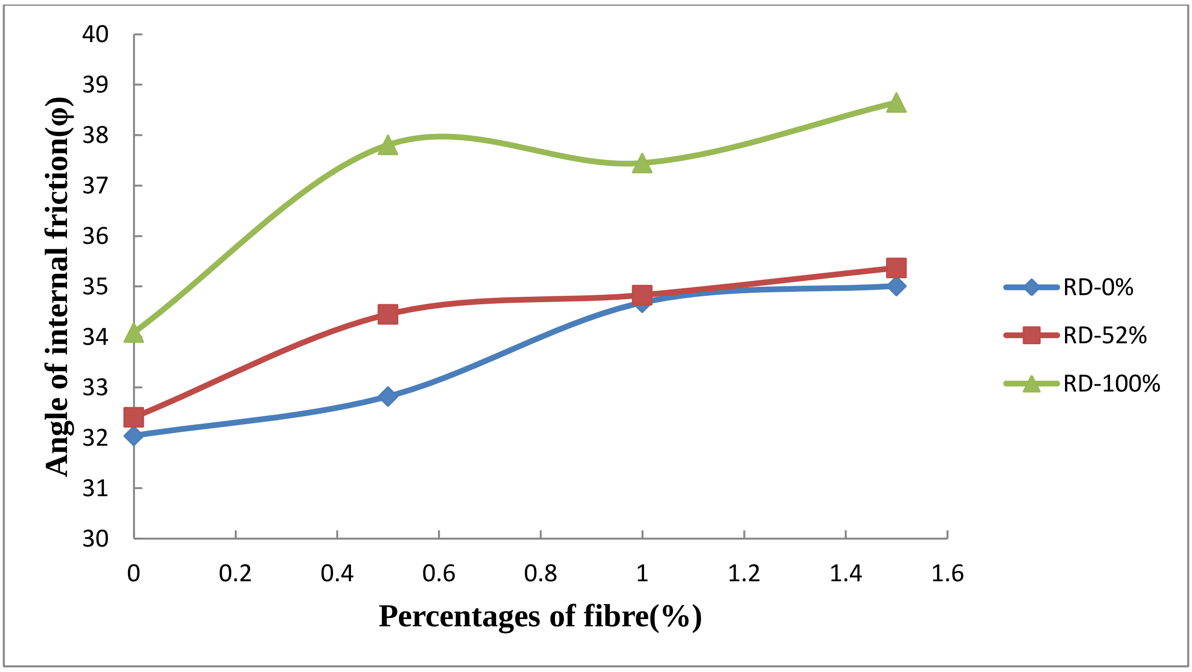

Figure 4.41: **Variation of angle of internal friction vs. Percentages of fibre (L/d=45)**

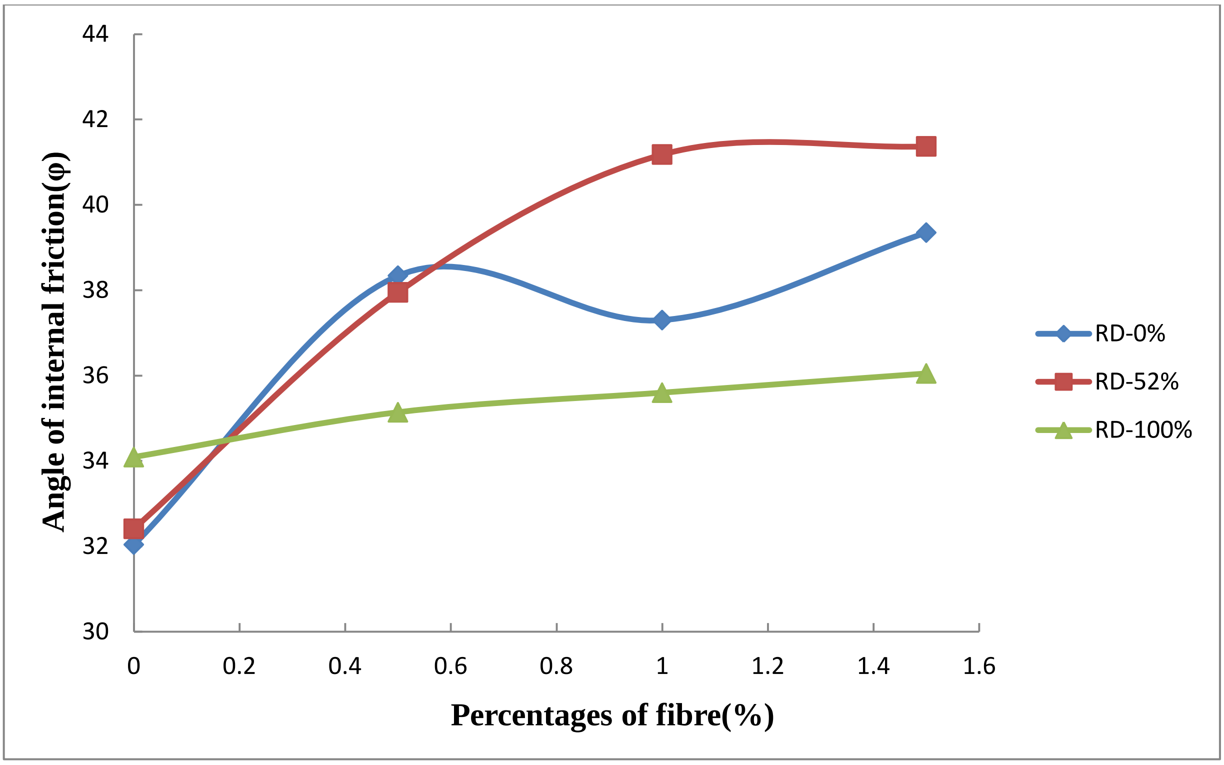

Figure 4.42: **Variation of angle of internal friction vs. Percentages of fibre (L/d=60)**

In sample C, after conducting a series of direct shear test the minimum value of ϕ is 32.02^o at 0% fibre content and 0% relative density. And the maximum value of ϕ is 36.97^o at 1.5% fibre content and 100% relative density for aspect ratio i.e. L/d30. Percentage increase in ϕ value is 15.50%. Similarly for aspect ratio 45, the minimum value of ϕ is 32.02^o at 0% fibre content and 0% relative density. And the maximum value of ϕ is 38.65^o at 1.5% fibre content and 100% relative density. Percentage increase in ϕ value is 20.65%. Similarly for aspect ratio 60, the minimum value of ϕ is 32.04^o at 0% fibre content and 0% relative density. And the maximum value of ϕ is 41.37^o at 1.5% fibre content and 52% relative density. Percentage increase in ϕ value is 29.11%.

4.3 Shear strength of clayey soil from triaxial test:

The composite material of clayey soil and glass fibre was mixed homogenously at 12% optimum moisture content (OMC). Glass fibre reinforced clay was compacted in five different layers in a cylindrical mould of 100 mm diameter and 120 mm high to a standard Proctor's maximum density. Then the specimen was extracted for triaxial test. The series of Unconsolidated Undrained (UU) triaxial tests were conducted on samples prepared by glass fibre mix clayey soil with three different aspect ratio 30, 45 and 60 with three different fibre contents (0.5%, 1.0% and 1.5%) at a constant strain rate of 1.2mm/min as per Indian Standards Specifications IS 2720 (Part II): 1993. Three different confining pressures (50 kPa, 100 kPa and 150 kPa) were used during testing. Three unreinforced and reinforced specimens were tested for each combination of variables. Results clearly show that the increase in strength/stiffness and angle of internal friction of glass fibre reinforced soil over unreinforced soil.

4.3.1 Effect of aspect ratio on stress-strain behavior

Figure 4.43 shows the typical deviator stress-axial strain plots from triaxial tests on unreinforced clayey soil (Sample A) at the Proctor's maximum dry density, Υ_{dmax} of 20.40 KN/m^3 under confining stress of 50 kPa, 100 kPa and 150 kPa.

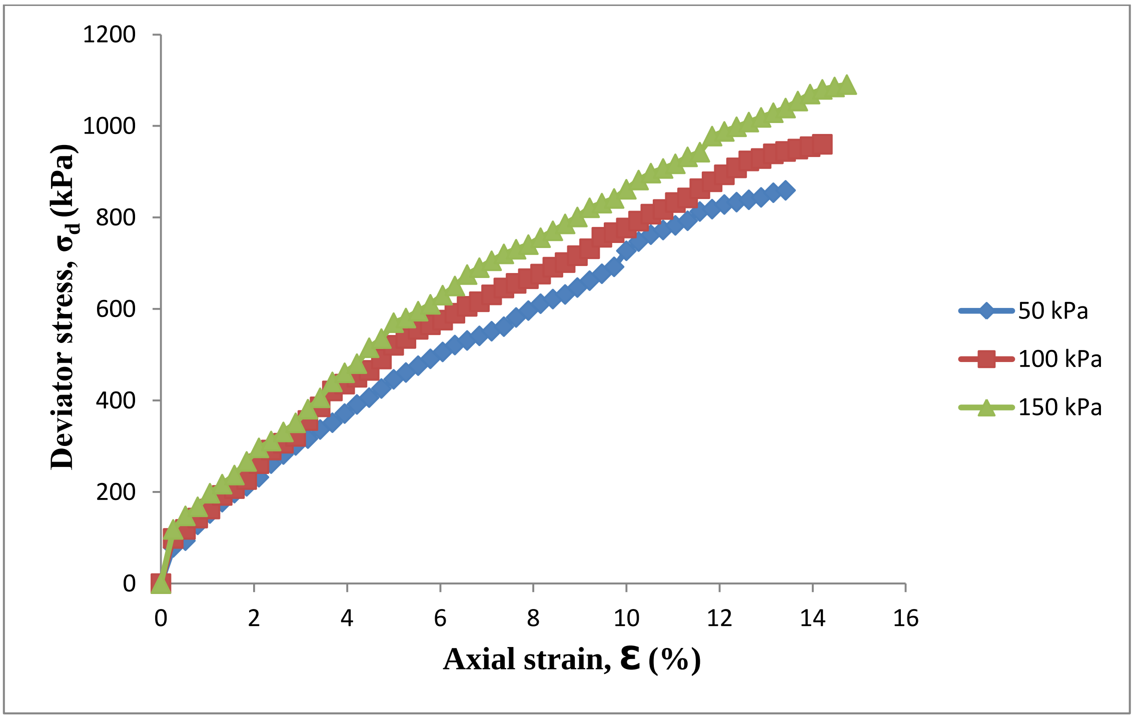

Figure 4.43: **Deviator stress – axial strain plots of unreinforced clayey soil**

A glance of the figure indicates that under a constant confining stress, σ_d the deviator stress increases with the increase in the axial strain. The peak/maximum deviator stress is attained at an axial strain of about 14.20% which is independent of the confining stress. Though, higher the confining stress, higher is the deviator stress.

Figure 4.44 shows the plots of deviator stress-axial strain from triaxial tests under confining stress of 50 kPa on glass fibre reinforced clayey soil at an aspect ratio of L/d of 30 and at different fibre contents from 0% to 1.5%.

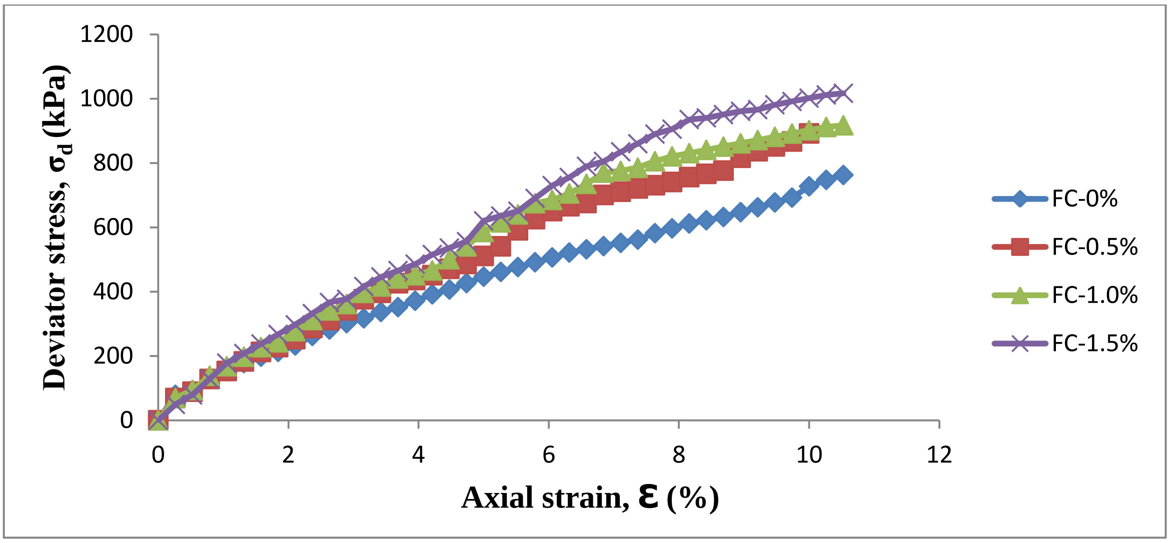

Figure 4.44: **Variation of deviator stress vs. axial strain plots of unreinforced and reinforced clayey soil at σ_3 = 50kPa (L/d=30)**

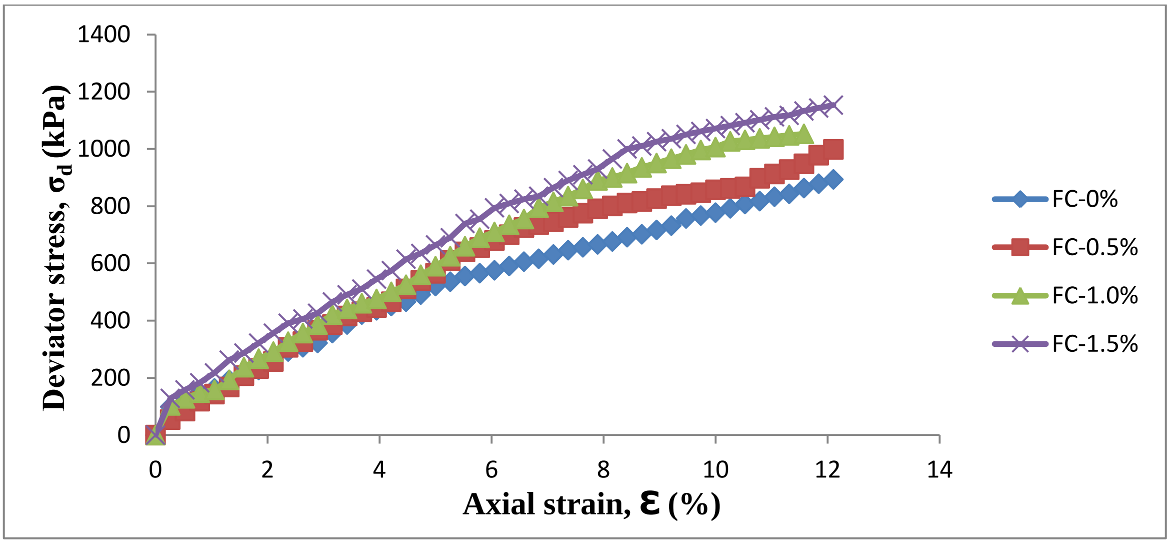

Figure 4.45: **Variation of deviator stress vs. axial strain plots of unreinforced and reinforced clayey soil at σ_3 = 100kPa (L/d=30)**

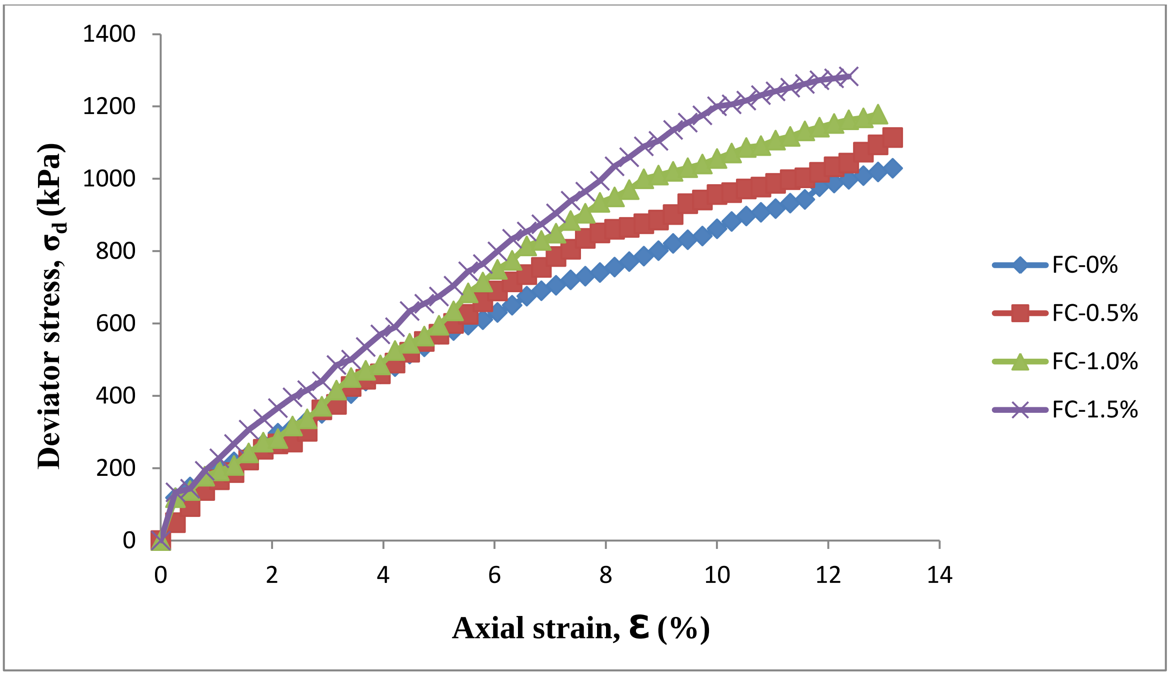

Figure 4.46: **Variation of deviator stress vs. axial strain plots of unreinforced and reinforced clayey soil at σ_3 = 150kPa (L/d=30)**

All the samples were prepared at the Proctor's maximum dry density of 20.40 KN/m^3. For the sake of comparison, test results of unreinforced clayey soil have been plotted. Similar curves under confining stresses, σ_3 of 50 kPa, 100 kPa and 150 kPa have been plotted in the Figures 4.44 to Figure 4.46 respectively.

A glance of the Figure 4.44 indicates that the deviator stress-axial strain plots of fibre reinforced clayey soil do not exhibit any peak stress. Also, the deviator stress-axial strain curves of fibre reinforced clayey soil do not indicate the decreasing trend for any value of fibre content and confining stress. The deviator stress continuously increases with increase in axial strain. Similar stress-strain behavior of clayey soil reinforced with glass fibre is observed for high confining stresses as shown in Figure 4.45 to Figure 4.46.

Figure 4.47 shows the plots of deviator stress-axial strain from triaxial tests under confining stress of 50 kPa on glass fibre reinforced clayey soil at an aspect ratio of L/d of 45 and at different fibre contents from 0% to 1.5%.

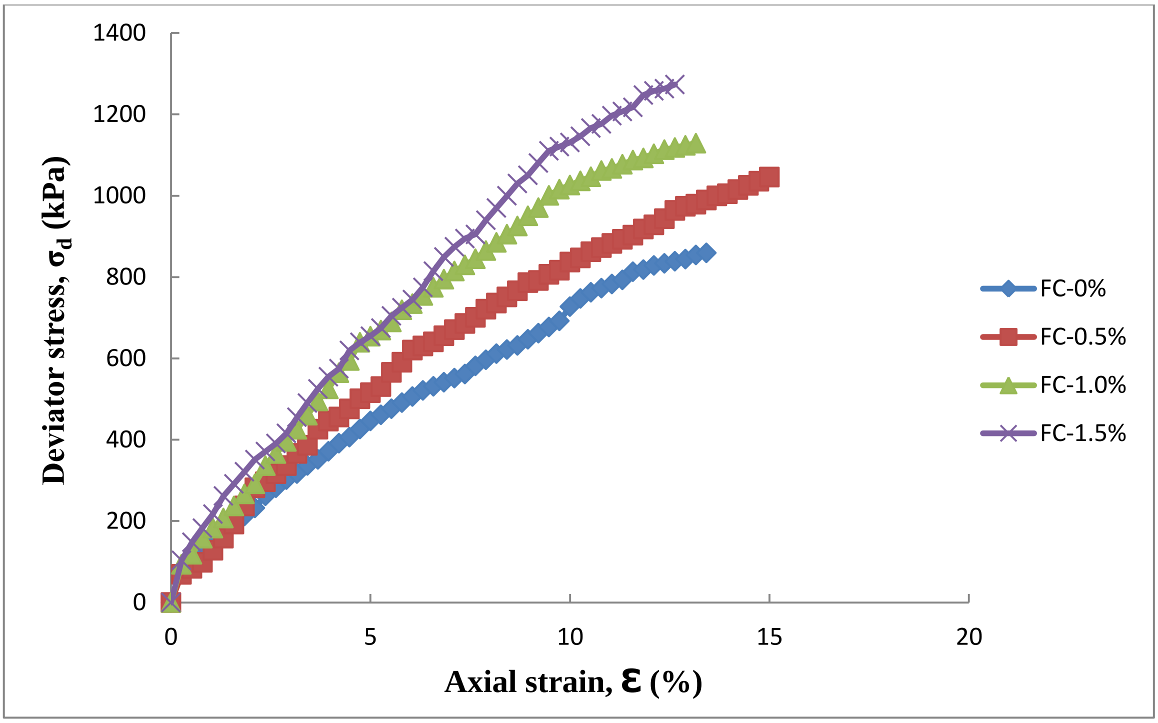

Figure 4.47: **Variation of deviator stress vs. axial strain plots of unreinforced and reinforced clayey soil at σ_3 = 50kPa (L/d=45)**

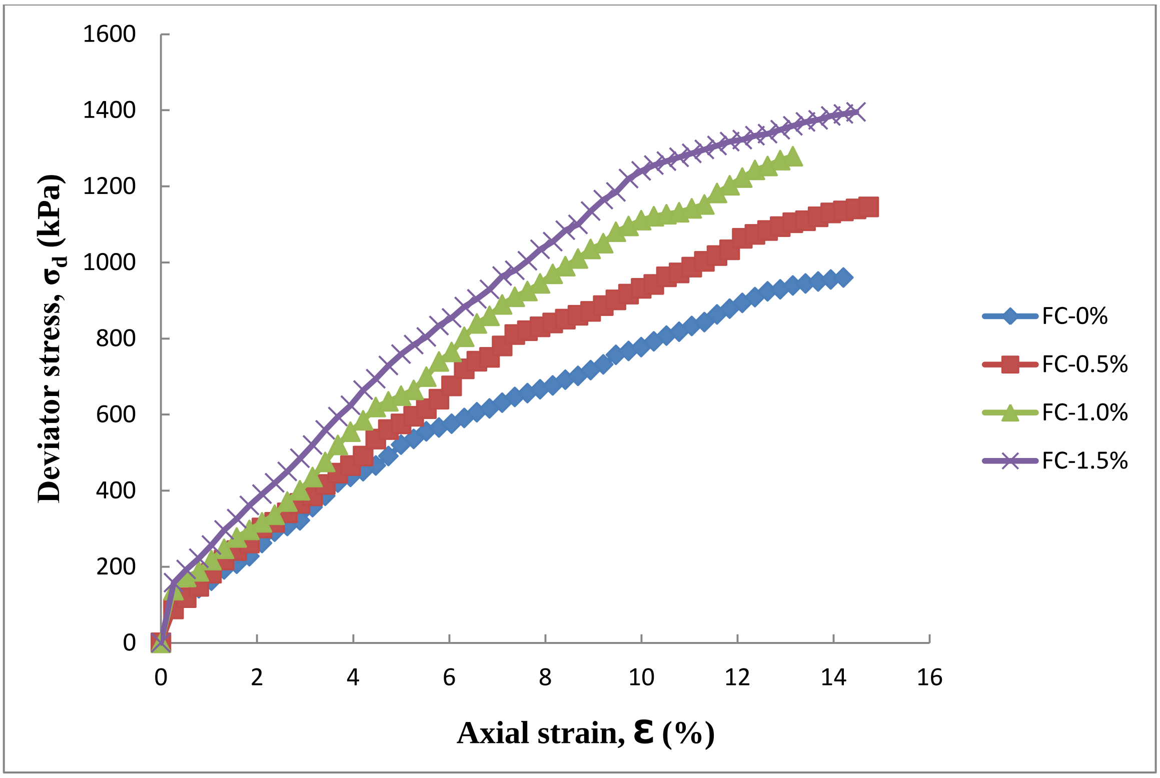

Figure 4.48: **Variation of deviator stress vs. axial strain plots of unreinforced and reinforced clayey soil at σ_3 = 100kPa (L/d=45)**

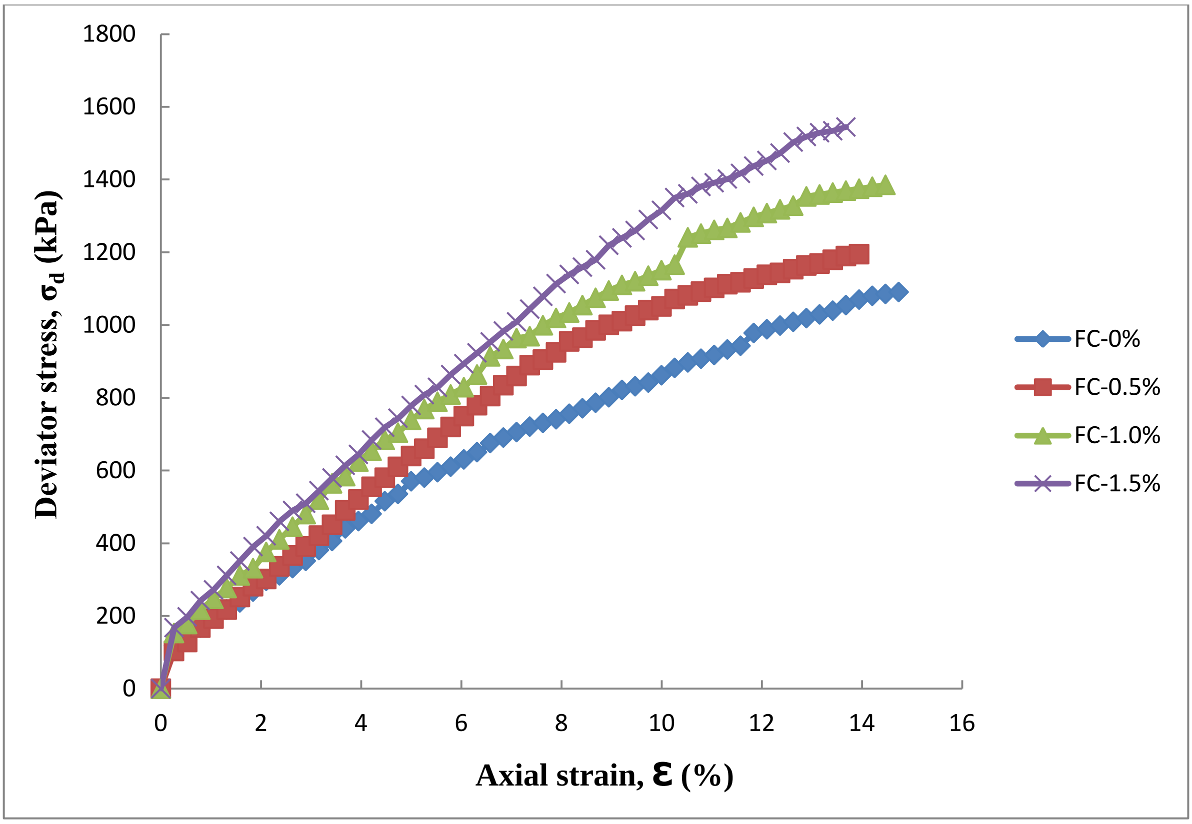

Figure 4.49: **Variation of deviator stress vs. axial strain plots of unreinforced and reinforced clayey soil at σ_3 = 150kPa (L/d=45)**

All the samples were prepared at the Proctor's maximum dry density of 20.40 KN/m^3. For the sake of comparison, test results of unreinforced clayey soil have been plotted. Similar curves under confining stresses, σ_3 of 50 kPa, 100 kPa and 150 kPa have been plotted in the Figures 47 to Figure 49 respectively.

A glance of the Figure 47 indicates that the deviator stress-axial strain plots of fibre reinforced clayey soil do not exhibit any peak stress. Also, the deviator stress-axial strain curves of fibre reinforced clayey soil do not indicate the decreasing trend for any value of fibre content and confining stress. The deviator stress continuously increases with increase in axial strain. Similar stress-strain behavior of clayey soil reinforced with glass fibre is observed for high confining stresses as shown in Figure 4.48 to Figure 4.49.

Figure 4.50 shows the plots of deviator stress-axial strain from triaxial tests under confining stress of 50 kPa on glass fibre reinforced clayey soil at an aspect ratio of L/d of 60 and at different fibre contents from 0% to 1.5%.

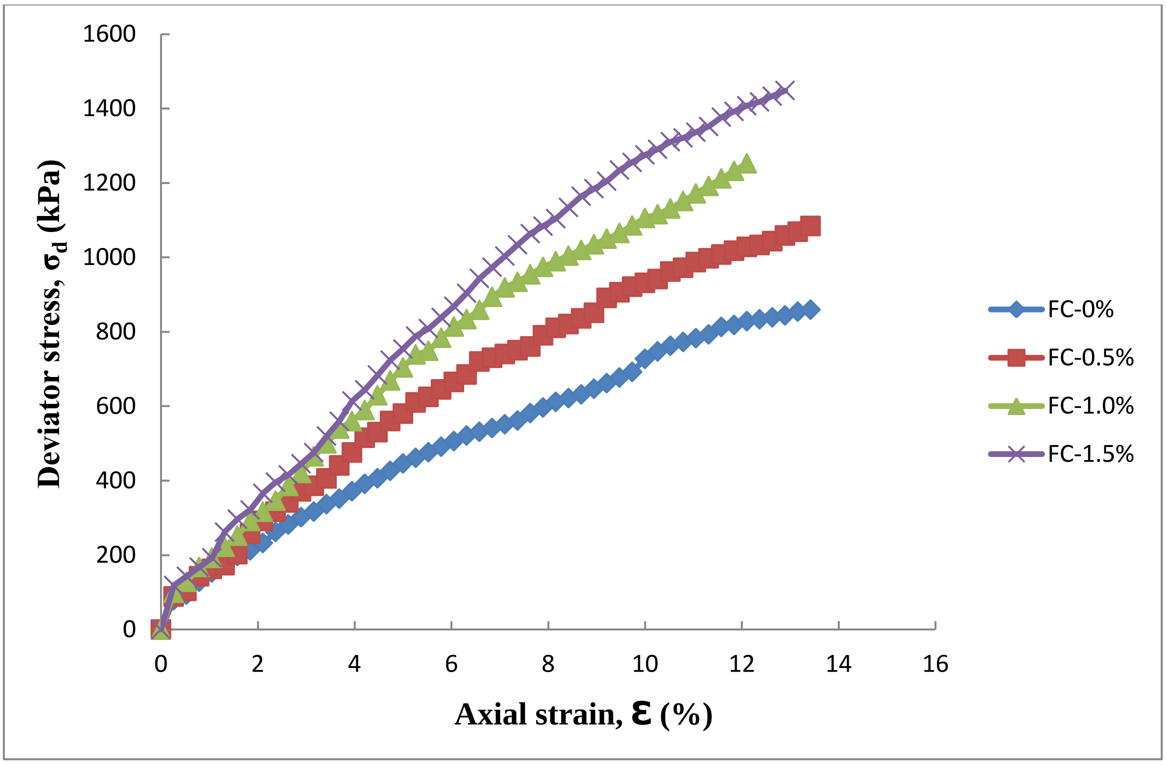

Figure 4.50: **Variation of deviator stress vs. axial strain plots of unreinforced and reinforced clayey soil at σ_3 = 50kPa (L/d=60)**

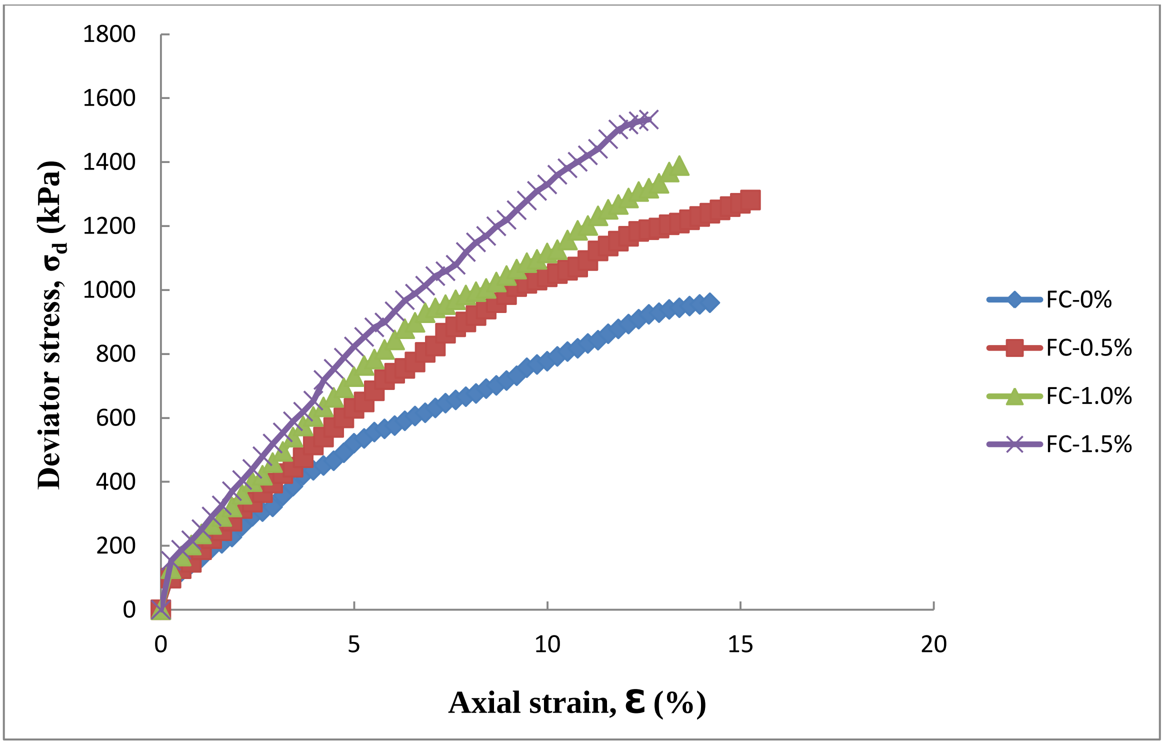

Figure 4.51: **Variation of deviator stress vs. axial strain plots of unreinforced and reinforced clayey soil at σ_3 = 100kPa (L/d=60)**

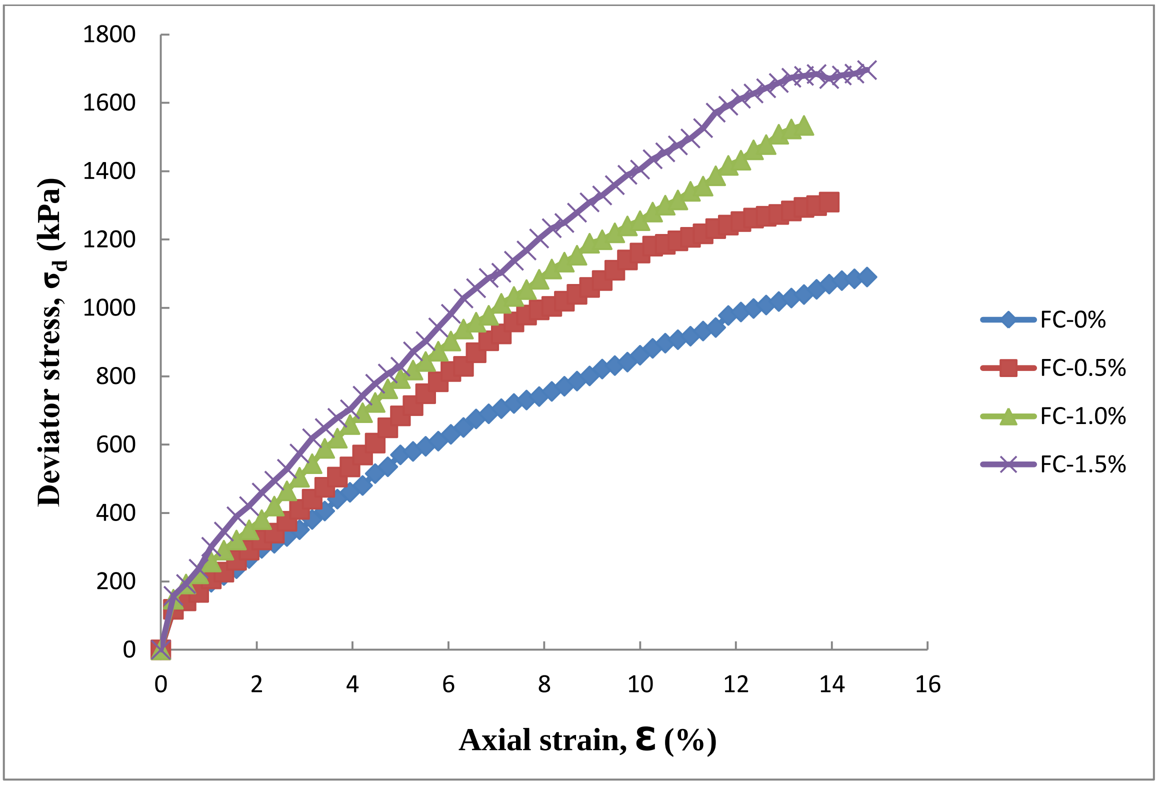

Figure 4.52: **Variation of deviator stress vs. axial strain plots of unreinforced and reinforced clayey soil at σ_3 = 150kPa (L/d=60)**

All the samples were prepared at the Proctor's maximum dry density of 20.40 KN/m^3. For the sake of comparison, test results of unreinforced clayey soil have been plotted. Similar curves under confining stresses, σ_3 of 50 kPa, 100 kPa and 150 kPa have been plotted in the Figures 4.50 to Figure 4.52 respectively.

A glance of the Figure 4.50 indicates that the deviator stress-axial strain plots of fibre reinforced clayey soil do not exhibit any peak stress. Also, the deviator stress-axial strain curves of fibre reinforced clayey soil do not indicate the decreasing trend for any value of fibre content and confining stress. The deviator stress continuously increases with increase in axial strain. Similar stress-strain behavior of clayey soil reinforced with glass fibre is observed for high confining stresses as shown in Figure 4.51 to Figure 4.52.

Table 4.7: **Stiffness Modulus of Reinforced Soil for Various Fibre contents at Different confining Pressure.**

Fibre Content (%)	Confining Pressure (kpa)	Length of Fibre=10mm			Length of Fibre=15mm			Length of Fibre=20mm		
		Stiffness Modulus (σ_d/ε)	Average Stiffness Modulus	Increase in Average Stiffness modulus	Stiffness Modulus (σ_d/ε)	Average Stiffness Modulus	Increase in Average Stiffness modulus	Stiffness Modulus (σ_d/ε)	Average Stiffness Modulus	Increase in Average Stiffness modulus
0	50 100 150	6405 6757 7400	6854	-	6405 6757 7400	6854	-	6405 6757 7400	6854	-
0.5	50 100 150	6847 7456 7773	7358	504(7%)	6974 7775 8566	7771	917(13%)	7509 8394 9390	8431	1577(23%)
1.0	50 100 150	7407 7921 8801	8043	1189(11%)	8233 9719 9892	9281	2427(35%)	10060 10350 11430	10613	3759(54%)
1.5	50 100 150	8413 8761 9641	8923	2069(30%)	10079 9647 11294	10340	3486(50%)	11233 12137 11506	11625	4771(69%)

Table 4.8: **Shear Strength Parameter (c and ɸ) of Reinforced Soil for Various Fiber Contents**

Fibre Content	Length of Fibre = 10mm				Length of Fibre = 15mm				Length of Fibre = 20mm			
	Shear Strength Parameters (c and φ)				Shear Strength Parameters (c and φ)				Shear Strength Parameters (c and φ)			
	C (kN/m^2)	Φ (Degree)	Percentage Increase in (c)	Percentage Increase in (φ)	C (kN/m^2)	Φ (Degree)	Percentage Increase in (c)	Percentage Increase in (φ)	C (kN/m^2)	Φ (Degree)	Percentage Increase in (c)	Percentage Increase in (φ)
0	22	28	-	-	22	28	-	-	22	28	-	-
0.5	24	30	9	7	28	29	27	4	36	32	64	14
1.0	26	31	18	11	33	32	39	14	36.5	35	66	25
1.5	28	33	27	18	33	35	39	25	37.5	37	71	32

4.3.2 Effect of glass fibre aspect ratio and fibre content on stiffness modulus of reinforced soil at various confining pressure (Refer Table No. 4.7)

Based on the results of triaxial compression tests performed on reinforced soil at different fibre content varying from 0.0% to 1.5% for fibre lengths of 10 mm, 15 mm and 20 mm, the computed values of stiffness modulus and shear strength parameters of reinforced soil are shown in Table 4.7 and Table 4.8 respectively. It is observed that from Table 4 the stiffness modulus of reinforced soil increase with increase in confining pressure, fibre content and change in length. The results of column 3, column 6 and column 9 of Table 4 shows the values of stiffness modulus of reinforced soil corresponding to a different confining pressures for fibre lengths of 10 mm, 15 mm and 20 mm respectively. Column 4, column 7 and column 10 of Table 4 show the average value of stiffness modulus for fibre lengths of 10 mm, 15 mm and 20 mm respectively. It is clear from the values of stiffness modulus that it increases with the increase in confining pressures and this aspect can be observed for all the fibre contents and all the lengths. This is due to the fact that under higher confining pressures soil samples are more confined and more resistant to deformation which results into higher deviator stress at failure.

It is further observed that the average increase in stiffness modulus of reinforced soil increase with the increase in fibre contents and this trend is observed for all the lengths of fibre i.e. 10 mm, 15 mm and 20 mm. For instance the average stiffness modulus of unreinforced soil is 6854. When 0.5% glass fibre having length 10mm is added to the soil, the stiffness modulus of soil increases to 7358 i.e. improvement in stiffness modulus of soil is 7% due to 0.5% inclusion of glass fibre. Similar trend is observed from the results of Table 4 for fibre contents of 1.0% and 1.5% also and the maximum improvement in average stiffness modulus of soil is 69% for fibre content of 1.5% of fibre length of 10 mm. For 15 mm fibre length the improvement in average stiffness modulus of soil is 50% and similarly for 20 mm fibre length the improvement in average stiffness modulus of soil is 69%. The significant increase in average stiffness modulus of soil due to addition of glass fibre improves the load-settlement characteristics of soil and the amount of immediate settlement would be reduced significantly.

4.3.3 Effect of glass fibre aspect ratio and fibre content on shear strength parameters of (c and φ) of reinforced soil (Refer Table No. 4.8)

It is observed from Table 4.8 that the shear strength parameters (c and φ) of reinforced soil increase with increase in fibre content and this aspect can be observed for all lengths i.e. 10 mm, 15 mm and 20 mm. Column 2 and column 3 show the values of cohesion (c) and angle of internal friction (φ) of reinforced soil for fibre length of 10 mm. The results of column 2 and column 3 of Table 4.8 show the amount of percentage increase in (c) and (φ) values of soil due to inclusion of glass fibre of length 10 mm. The results of column 4 and column 5 clearly show that the percentage increase in (c) value and (φ) value are 9%, 18%, 27% and 7%, 11% and 18% respectively for fibre contents of 0.5%, 1.0% and 1.5%. Similar trend is observed from the results of column 8 and column 9 for fibre length 15 mm and here corresponding percentages increase in (c) and (φ) values are 27%, 39%, 39% and 4%, 14%, 25% respectively and similarly in column 12 and column 13 for 20 mm fibre length percentages increase in (c) and (ϕ) values are 64%, 66%, 71% and 14%, 25%, 32% respectively. The significant increase in shear strength parameters of soil due to addition of glass fibre improves the load carrying capacity of soil and glass fibre reinforced soil can be used as foundation soil for supporting heavier loads of civil engineering structures.

The increase in stiffness modulus and shear strength parameters of soil due to inclusion of glass fibre is due to the fact that randomly oriented discrete inclusions incorporated into soil mass improves its load deformation behavior by interacting with the soil particles mechanically through surface friction and also by interlocking.

4.3.4 Soil characteristics (Sample A)

Triaxial compression tests have been carried on clayey type of soil, to evaluate the effect of soil type on the strength of fibre reinforced soil. For the purpose of analysis, the influence of soil type has been examined based on grain size analysis and casagrande test.

The clayey soil sample A (Table 3.1) has been tested to study the influence of silt or clay content on the shear strength of fibre reinforced soils. The soil are having silt or cly content (i.e. material passing from 75 micron sieve) from 53.7%. They are non-plastic in nature and are classified as mixture clay and silt with low compressibility (CL).

From casagrande test liquid limit is 32.5%, plastic limit 20%, plasticity index 12.5%, flow index 29 and toughness index is 0.68.

CHAPTER - 5

CONCLUSIONS

Based on the experimental results of this study the following conclusions are drawn:-

1 In sandy soil, glass fibre can be used as a reinforcing material resulting an increase in shear strength of soil when glass fibres are randomly mixed.

1. The effect of increase in length from 10 mm to 20 mm and fibre content from 0% to 1.5% increases the shear strength parameters which are useful in geotechnical engineering structures.
2. In coarse sand, after conducting a series of direct shear test the maximum percentage increase in ϕ value is 21.00% for aspect ratio 30 and similarly for aspect ratio 45 and 60 the maximum percentage increase in ϕ value is 22.00% and 26.00% respectively.
3. In fine sand, after conducting a series of direct shear test the maximum percentage increase in ϕ value is 15.50% for aspect ratio 30 and similarly for aspect ratio 45 and 60 the maximum percentage increase in ϕ value is 20.65% and 29.11% respectively.
4. In clayey soil, after conducting a series of triaxial test the maximum percentage increase in (c) and (ϕ) value is 27.00% and 18.00% respectively over virgin soil at fibre content 1.5% for aspect ratio 30. Similarly for aspect ratio 45 and 60 the maximum increase in (c) and (ϕ) value is 39.00% and 25.00%, 71.00% and 32.00% respectively at fibre content 1.5%.

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