

**Behavior of RC beams retrofitted in shear using coir and flax fiber  
reinforced polymer composites**

**A**

**Dissertation Report**

**Submitted in Partial Fulfillment of the Requirements**

**For the Award of the Degree of**

**Master of Technology**

**in**

**Structural Engineering**

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**Under the Supervision of:**

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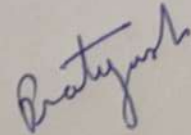
**2019**

## DECLARATION

I hereby declare that the work which is being presented in dissertation entitled “**Behavior of RC beams retrofitted in shear using coir and flax fiber reinforced polymer composites**” submitted by me for the award of the degree of **Master of Technology** in Civil Engineering, TIET, Patiala (India) is true and original record of my own independent and original research work carried out under the supervision of **Dr. Heaven Singh**. Further, I declare that no part of this dissertation has been submitted to any other University/Institute for the award of any degree in India or abroad.

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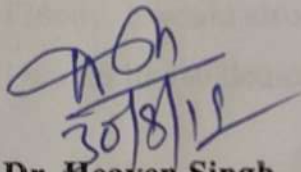
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Pratyush Kumar Mandoria

## CERTIFICATE

This is to certify that the dissertation entitled “**Behavior of RC beams retrofitted in shear using coir and flax fiber reinforced polymer composites**” submitted by **Mr. Pratyush Kumar Mandoria** (Roll. No. 801724022) in partial fulfillment of the requirement for the award of the degree of **Master of Technology** in Structural Engineering, TIET, Patiala (India) is the record of the candidate’s own independent and original research work carried out under my supervision and guidance. The matter embodied in this dissertation has not been submitted in part to any other University/Institute for the award of any degree or diploma in India.



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## **Abstract**

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Worldwide, a great deal of research is currently being carried out concerning the use of fiber reinforced plastic wraps, laminates, sheets in repair and strengthening of reinforced concrete beams. FRP application is a very effective way to repair and strengthen structures that have become structurally weak over their life span. FRP repair system provide an economically viable alternative to traditional repair system and materials.

Experimental investigation on shear behavior of RC beams strengthened using natural fibers, coir fiber and flax fiber reinforced polymer sheets are carried out. Externally reinforced concrete beams with epoxy bonded CFRP and FFRP sheets were tested to failure using symmetrical two-point loading system. Eight beams were casted out of which 2 beams were control beams, Other 6 beams were retrofitted using varying combination of the fiber and wrapping technique.

Experimental data on load and deflection of each of the beams were obtained. The detailed procedure and application of CFRP and FFRP for shear strengthening of RC beam is also includ

# CHAPTER 1

## INTRODUCTION

### 1.1 GENERAL

Repair and restoration of prevailing and old reinforced concrete structures has been a major concern in terms of public safety, these safety measures were taken according to new seismic design requirements. Upgradation or repairing of structures is required because of weakening of structure because of corrosion in steel caused by adverse environmental conditions and various natural calamities such as earthquakes, some other reasons are wrong constructional work, poor material quality, and flawed design work (Al-Rousan *et al.* 2016). Full replacement of structure has many disadvantages such as high expenditure, impact to ecosystem, inconvenience due to interruption to traffic. Therefore, repair and retrofitting reduce the cost, increases life safety and increases life of a structure. Use of Fiber Reinforced Polymer (FRP) is greatly increasing these days for retrofitting as it is light weight and its formability makes it easy to use. It becomes an excellent option as they are non-corrosive, resistant to chemicals and non-magnetic. Currently FRP sheets which are bonded externally are used for strengthening many structures such as columns, beams, slabs, walls, chimneys, tunnels, silos (Khalifa *et al.* 1998). FRP has been used to increase flexural strength as well as shear strength of members. Shear Strengthening makes the structure diagonally strong that is it becomes stronger in shear. However external bonding is only possible by suitable adhesive and proper consideration of the adhesive is given which is to be used for external fabric bonding.

### 1.2 HISTORY ON FRP

The progression of FRP in business usage was broadly surveyed during 1930-40. In United Kingdom, pioneers attempted an impressive research. It was especially important to the aviation business. In 1940s the primary utilization of glass fiber reinforce polyester composites was in the flying machine industry. This was pursued a few years after the fact in the marine area by the application in the non-military application, some places FRP demonstrated a total advancement making a revolution in the manner boats were assembled. Carbon fiber production started in the late 1950s and was utilized, in British industry starting in the mid 1960s. First successful application of FRP as repair and rehabilitation was initiated in early 1990s.

#### 1.2.1 FIBER REINFORCED COMPOSITES

Composite which are characterized into two unique materials which on combination become sturdier than the solo materials.' Composites are both natural and manufactured and as resources innovation pushes toward progressively feasible arrangements, the emphasis on the utilization of natural, or characteristic materials, particularly as reinforcement, expands every year. Composites are either particle type or fiber type. Fiber type composites are utilized for structural reinforcement applications which is made out of fibers and resins. The polymer utilized for resins are two fundamental items that are thermosets and thermoplastics. The polyester and epoxies are the thermosetting polymers applied in the development industry. Resins such as epoxies cannot be solely used for manufacturing structures as their mechanical properties are not up to the mark in comparison to metals. But, they have many necessary properties, most prominently their capacity to be effectively framed into complex shapes.

### 1.2.2 NATURAL FIBERS

Natural fibers are classified into three classes: seed hair (cotton), bast fibres (jute, flax) and leaf fibers (sisal, abaca). As polymer composites jute, flax, sisal are the natural fibers which are used most commonly.

**Table 1.1 Natural Fibers and their mechanical properties**

<b>FIBER</b>	<b>SPECIFIC GRAVITY</b>	<b>TENSILE STRENGTH (MPa)</b>	<b>ELASTIC MODULUS (GPa)</b>	<b>REFERENCE</b>
Cotton	1.5-1.6	400	5.5-12.6	Wambua, P. <i>et al</i> (2003)
Jute	1.3	393-773	26.5	Wambua, P. <i>et al</i> (2003)
Flax	1.5	500-1500	27.6	Faruk, O. <i>et al</i> (2014)
Hemp	1.47	690	70	Faruk, O. <i>et al</i> (2014)
Sisal	1.5	511-635	9.4-22	Holbery, J. <i>et al</i> (2006)
Coir	1.2	593	4-6	Hajnalka, H. <i>et al</i> (2008)
E-Glass	2.5	2000-3500	70	Hajnalka, H. <i>et al</i> (2008)

### 1.2.3 ADVANTAGES OF FRP

The advantages of composite materials have powered development of new applications in market, for example, transportation, construction, marine, infrastructure, electrical, airplane and aviation and apparatuses and business gear. Advantages of utilizing composite materials are as follows:

**High Strength:** A particular strength requirements for a work can be expected to meet by composite materials. The most important aspect of composite materials over other materials is its ability to access various combinations of resins and reinforcements, which helps in designing the mechanical and physical properties of a structure.

**Light Weight:** High strength in combination with light weightiness is put into consideration when designing composite materials. Composite material are considered to have largest strength to weight ratio materials in the entire world (Al-Osta *et al.* 2018).

**Corrosion Resistivity:** Composites items give prevention from severe chemicals and temperature circumstances in long term. The composite material which are easily chosen for outside exposure, chemicals that are to be handled and severe environmental exposure.

**Design Flexibility:** Because of composites ability to get moulded into intricate shapes with minimum efforts they have an advantage over other materials. The trademark composites can be easily accessible to researches as composites have the adaptability of making complex shapes. To avoid the problem of twisting of fiber in one direction it is made sure that most of the fibers can be arranged perpendicular to that of the bending stress which allows the hardening of structure in a single direction (Bakis *et al.* 2015). What this gives advantage over metallic material is that when the quality is to be increased in one direction for a metal to be used it should be made thicker and larger which affects the overall heaviness of the members whereas in case of composites weight is not an issue so, more material can be used where it is required (Ali *et al.* 2012). Tailor ability that is why gives additional advantage of FRP at low cost.

**Durability:** Durability of composite material is one other advantage as they have long life expectancy at a very low maintenance requirement. Long life span of composites is very advantageous for elementary applications. In 50 years of composites improvement composite structures which were well planned are showing no signs of wear and tear.

Magnetic Resistivity: They are without any attraction to magnetic field and can offer extensive protection from electric sparkles, subsequently it is an excellent choice for the power industry.

#### **1.2.4 APPLICATIONS OF FRP**

Significant development has been observed in the usage of FRP composites as a construction material over the last decade. These composites have been valuable in constructing new structures as well as upgrading the existing structures

Rehabilitation: Structural rehabilitation can be done using FRP composites when there are deficiencies at the stage of designing or there is use of inferior quality material or the construction quality is poor. Rehabilitation is also required when there is change in service as there might be increased safety requirements. Accidents such as fire or earthquakes also make it important to rehabilitate the structure. Rehabilitation is further divided into:

- 1) Repair and Strengthening: Repairing is done to structure when there is structural deficiency for example cracks or severely damaged member on the other hand strengthening is done when there is need to add to the existing designed performance level. Repair using FRP composites has been positively used on concrete, timber, masonry structures etc. The basic technique that is used is wet lay up using cured adhesive bonding.
- 2) Seismic Retrofit: Structural deficiency in seismic region of existing structures is a point of major concern. The enhancement of deficient concrete columns in active seismic zones is one of the major applications of FRP materials. The use of FRP not only confines without increase in stiffness but also allows rapid fabrication at a very low cost and durable jacketing with little interference.

#### **1.3 STRENGTHENING OF RC BEAM**

The strengthening of structural members of reinforced concrete using FRP is done by various techniques like external bonding, surface mounting and wrapping. FRP sheets when glued to tension side increase the flexural strength and when glued to web side increase the shear strength. FRP sheets increase the shear strength when wrapped around a RC beam and when it is wrapped around a column it provides confinement (Chen *et al.* 2003).

### **1.3.1 FLEXURAL STRENGTHENING OF RC BEAM**

FRP has been recently involved in strengthening of different members flexurally. FRP is attached with a structure in such a technique that fibres come parallel in the direction of principle stress. FRP plates are known enhance load carrying capacity, decreases deflection in members as it increases the stiffness due to the addition of FRP plate or sheet. Also as the no. of layers FRP sheets are added it further decreases the deflections in the structural member (De Lorenzis *et al.* 2001). Increment in no. of layers of FRP sheet increases the load carrying capacity also increases, hence FRP can be used as reinforcing agent in case of flexural strengthening.

### **1.3.2 SHEAR STRENGTHENING OF RC BEAM**

Beam's shear strengthening has been a major concern nowadays keeping in mind the active movements of tectonic plates of the Earth which initiates an earthquake. That is why scientists are coming up with various ways of strengthening a structure in shear. FRP usage as a retrofitting agent is on of the way which is getting common as it not only increases the capacity of load carrying but also manages to decrease the deflection in the structure. Strengthening in shear is provided by attaching FRP externally to edges of the beam with fiber orientation perpendicular to the beam axis with an angle to the direction of principle stress. U-wrapping technique is considered to be the most effective when load carrying capacity is concerned as it not only increases shearing capacity but also enhances the beam's flexural capacity which prevents brittle failure as well (Ghalieh *et al.* 1998).

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 GENERAL

Use of FRP is greatly increasing these days for retrofitting as it is light weight and its formability makes it easy to use. It becomes an excellent option as they are non-corrosive, resistant to chemicals and non-magnetic. Currently FRP sheets which are bonded externally are used for strengthening many structures such as columns, beams, slabs, walls, chimneys, tunnels, silos (Chin *et al.* 2018). FRP has been used to increase flexural strength along with member's shear strength. Shear Strengthening makes the structure diagonally strong that is it becomes stronger in shear. However external bonding is only possible by suitable adhesive and proper consideration of the adhesive is given which is to be used for external fabric bonding.

#### 2.2 SHEAR STRENGTHENING OF RC BEAMS

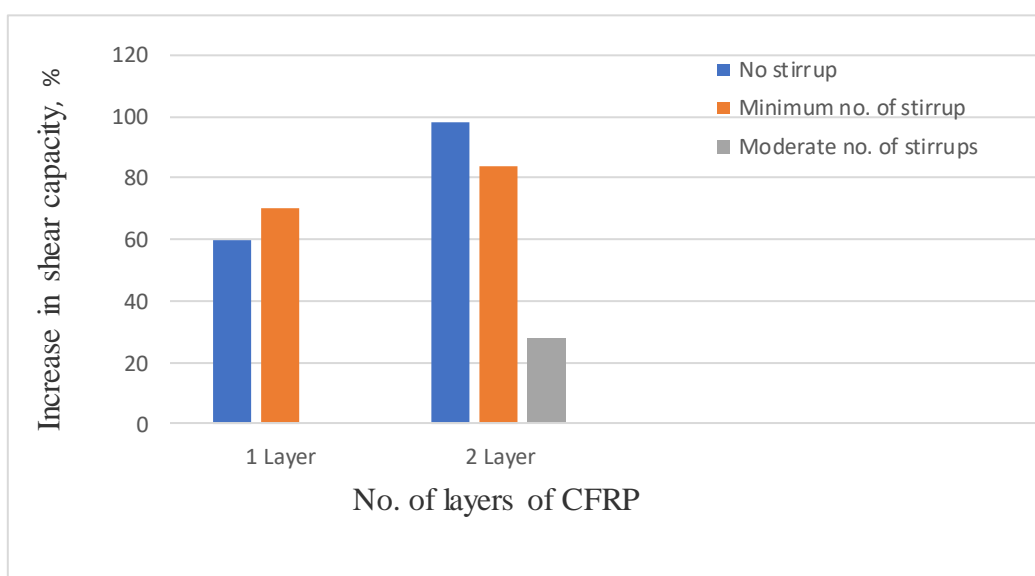
**Khalifa *et al.* (1998)** reviewed the researches that were happening on strengthening member in shear with FRP and give procedures for designing and figure out FRP's contribution to shear strength. It was also considered that the shear stress can be not more than the ultimate stress because of stress contributions. Based on experimental and analytical results collected it was concluded capacity of shear of RC beam can computed using 2 design approaches when CFRP sheets are bonded externally.

First method was effective for continuous sheets for any angle orientation in fiber and its suitability was fit when failure was measured by rupturing of FRP sheet. Second method involved the bond mechanism of concrete with CFRP sheets and this was also valid for continuous sheets and failure control is done by CFRP sheet delamination.

**Karzad, A.S. *et al.* (2019)** conducted a research program for behavioral study of RC beam strengthened using carbon fiber reinforced polymer (EB-CFRP) which was bonded externally. The study included 19 reinforced concrete beams 7 were tested without CFRP. The remaining 12 were sub divided into groups of 6 each. The first 6 beams were first stressed to failure then layered using epoxy and later CFRP sheets were bonded. The other six were wrapped with CRRP sheets and tested. The chief motive of research was to analyze the efficiency of

EB-CFRP strengthening of damaged reinforced concrete beams in shear. Conclusions from the figure 2.1 were that the shear deficient beam's capacity in shear was increased by one layer of CFRP up to 60% for no stirrups and for minimum no. of stirrups the increase was around 70% and there was further increase of 90%. When another layer was added, for minimum and moderate no. of stirrups the increase was 82% and 28% respectively.

**Figure 2.1: Contribution of CFRP to shear capacity of tested beams [Karzad, A.S. *et al.***



(2019)]

**Alam, M.A. *et al.* (2017)** investigated and developed a large strength fiber based composite plate applied in reinforced concrete structure for shear strengthening. Fibers used for fabricating plates were jute, jute rope fibers and kenaf. Eight beam specimens were casted and were strengthened in shear using composites of natural fiber and CFRP coats. These eight beams included 2 control beam, 3 beams each strengthened using jute, kenaf, jute rope fiber (all untreated), 3 beams each strengthened using jute, kenaf, jute rope fiber (all treated in 6% NaOH). The beams strengthened with jute showed 36% higher failure loads than the control beam while beams strengthened with jute rope and kenaf showed 34% and 35% higher failure load than the control beam, where as for the treated version of these fibers the percent higher loads were 10%, 23% and 31% for Jute, Kenaf, Jute Rope fiber respectively. Figure 2.2 to figure 2.5 show the different mode of failures of beams strengthened using different fibers. There were conclusions that the beams strengthened with natural fiber composite plate showed more ductility and higher failure loads than laminates of CFRP. Although the failure load in addition with ductility and crack patterns of beams with natural fibre were quite relatable with CFRP laminate beams.



**Figure 2.2: Mode of failure of control beam [Alam, M.A. *et al.* (2017)]**



**Figure 2.3: Mode of failure of Untreated jute fiber beam [Alam, M.A. *et al.* (2017)]**

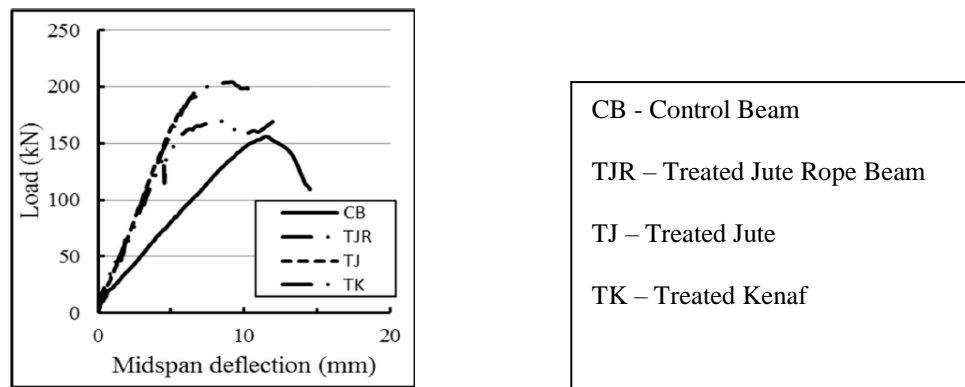


**Figure 2.4: Mode of failure Untreated kenaf fiber beam [Alam, M.A. *et al.* (2017)]**

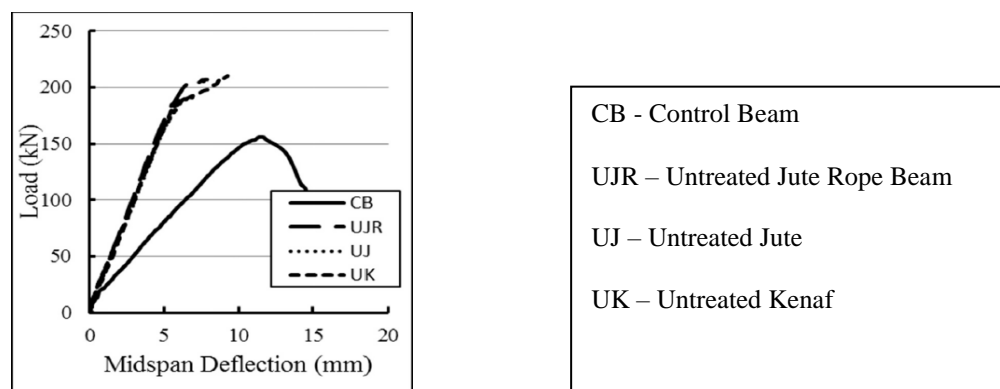


**Figure 2.5: Mode of failure of Untreated jute rope fiber beam [Alam, M.A. *et al.* (2017)]**

The figure 2.6 and 2.7 shows the difference in deflection behavior of treated and untreated fiber beam to that of the control beams and it was clearly detected that the retrofitted beams carried more loads than control beam at lesser deflection from which we can conclude increase in stiffness of the beams.



**Figure 2.6: Deflection behavior of treated fiber beam specimens [Alam, M.A. *et al.* (2017)].**



**Figure 2.7: Deflection behavior of untreated fiber beam specimens [Alam, M.A. *et al.* (2017)]**

**Triantafillou, C.T. *et al.* (1998)** The study manages usage of FRP fabric as strengthening resource in shear for deficient beams. The investigation goes for expanding the test record on shear strengthening of solid utilizing mixtures and building up a investigative model for the structure of individuals inside the system of present day codal designs. Eleven beams were tested which were wrapped with CFRP in various regions so as to strengthen them in shear. It is demonstrated that the adequacy of the strategy increments nearly straightly with the FRP pivotal inflexibility and achieves a most extreme, past which it differs very little.

**Ruano, G. *et al.* (2014)** Keeping in mind the target of assessing the presentation of reinforcing concrete using the steel fibre (SFRC) as a material for RC beams retrofication the exploratory investigation of SFRC jacketing strengthening of reinforced concrete beams and tested for shaer is exhibited in the following research. The strengthened beams of concrete were planned in such a manner that they have high percentage of steel in longitudinal

direction and lesser amount of steel in transverse direction so that they result in shear failure for further testing. Then some parts of the beam were wrapped using high quality SFRC and tested while some beams were put under service load to crack in shear and to be strengthened using the similar process of jacketing. Plain concrete was wrapped using SFRC which had 2 does of fiber that is  $30 \text{ kg/m}^3$  &  $60 \text{ kg/m}^3$ . Experiments demonstrated likelihood of playing out the retrofitting under any circumstances. The strengthened beams indicated fantastic increase in load bearing capacity and showed deformation capacity compensation.

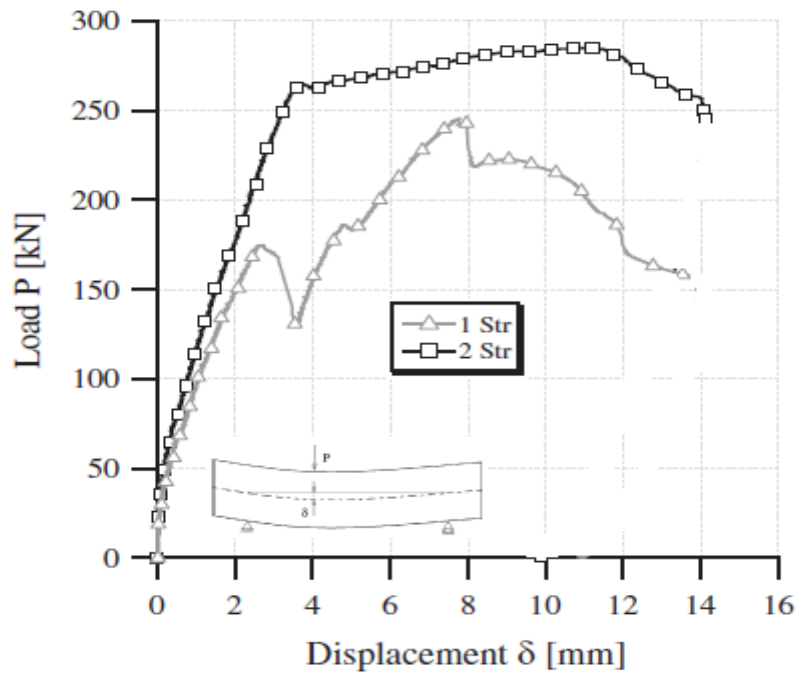


Figure 2.8: Load vs Displacement curve of control beam [Ruano, G. *et al.* (2014)]

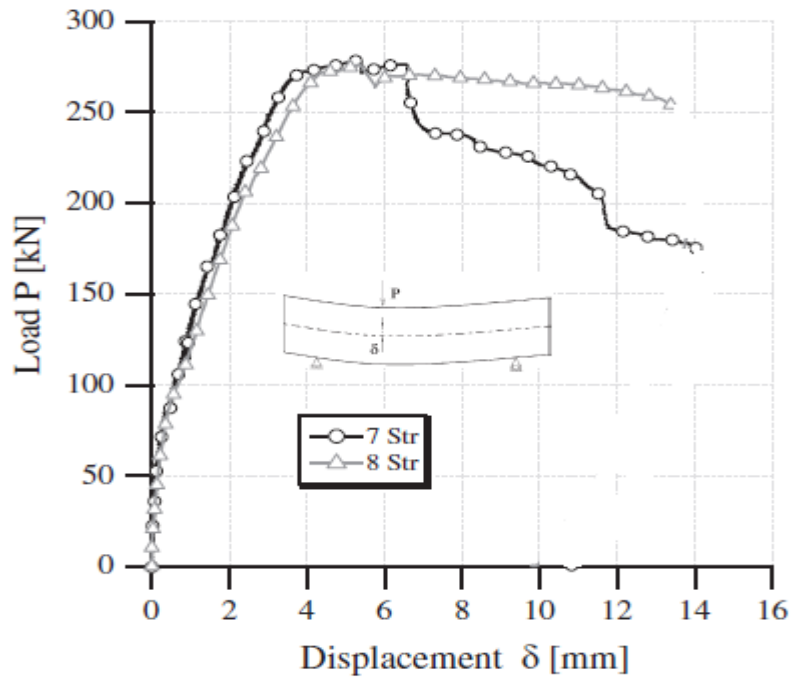


Figure 2.9: Beams strengthened with FRC with  $30 \text{ kg/m}^3$  of fiber's Load vs Displacement curve [Ruano, G. *et al.* (2014)]

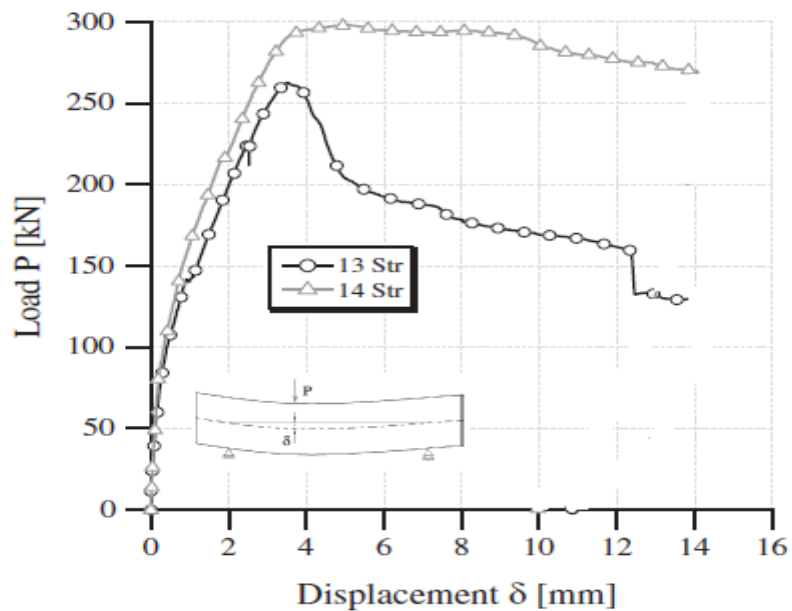


Figure 2.10: Load vs Displacement curve for beams strengthened with FRC with  $60 \text{ kg/m}^3$  of fibers [Ruano, G. *et al.* (2014)]

As it was concluded from the graphs beams wrapped with fiber reinforced composite of 60 kg/m<sup>3</sup> reached higher peak loads for same amount of displacement as that of control beams and beams wrapped with FRC of 30 kg/m<sup>3</sup> of fiber

**Sen, T. *et al.* (2014)** In this research of mechanical properties of natural kind of fibers such as jute fabric and jute fabric which were treated in heat, with epoxy gum used like a framework were arranged and tested. Tests for carbon and glass FRP composites arranged additionally were also completed. The heat treatment given to the jute fabric gave a boost to ductility and flexural properties. At that point heat treated jute FRP composites, artificial carbon and glass FRP composites were utilized for firming of beams, intended to experience failure in shear. The research gave the better knowledge of impact of different wrapping designs, for example U and strip wrapping technique, for strengthening in shear and furthermore intended to comprehend load vs deflection curve.

Full wrapping technique showed more rise in ultimate shear strength than strip wrapping technique. Jute fabric strengthening with full wrapping technique showed 67% rise in ultimate shear strength meanwhile there was 25% increase in strip wrapping technique.

The target of this research was to explain the efficiency of normal jute FRP fabric for the application of strengthening in shear. Also incorporated into the research was capacity of load carrying, behavior of deflection of load, first cracking load etc. Following investigation reasoned jute FRP retrofitting plan had a few favorable returns over glass and carbon FRP retrofitting plan, and changed brittle failure to a failure that was ductile. CFRP and GFRP retrofitting showed abrupt debonding, rupture in FRP whereas none of these things were faced in case of natural fiber composites. Non-linear finite element investigation was done and the outcomes were in great similarity with the experimental results.

**Sen, T. *et al.* (2016)** In this study it was investigated the shear strengthening effects and shear strength enhancement on RC beam using the composite system of natural sisal FRP and jute FRP. Following conclusions were computed from the research

The tensile strength and flexural strength are computed and sisal fiber reinforced composite displayed 223.4 MPa and 350 MPa tensile strength and flexural strength respectively. The jute fiber fabric displayed 189.5 MPa and 208.7 MPa flexural and tensile strength respectively. The glass and carbon fibre fabric showed 678.6MPa and 923.1MPa tensile strength respectively. The flexural strength exhibited by glass and carbon fibre were 666.9MPa and 1587.1MPa. When these jute and sisal fibre were heat treated both the

flexural and tensile strength of the system was enhanced in comparison with natural FRP composite.

The strengthening effect with one layer only was significant as there was 77.8% increase in ultimate shear strength in sisal FRP strengthening technique, it was also noted that the technique without concrete crushing, any abrupt FRP failure, debonding at larger loads encouraged ductile failure. Similar behavior was seen in case of jute FRP strengthening technique as it gave 66.7% increase in ultimate shear strength. When the specimens were U wrapped with carbon there was 88.9% increase in shear strength and with U wrapped glass fibre the shear strength increased by 83.4%.

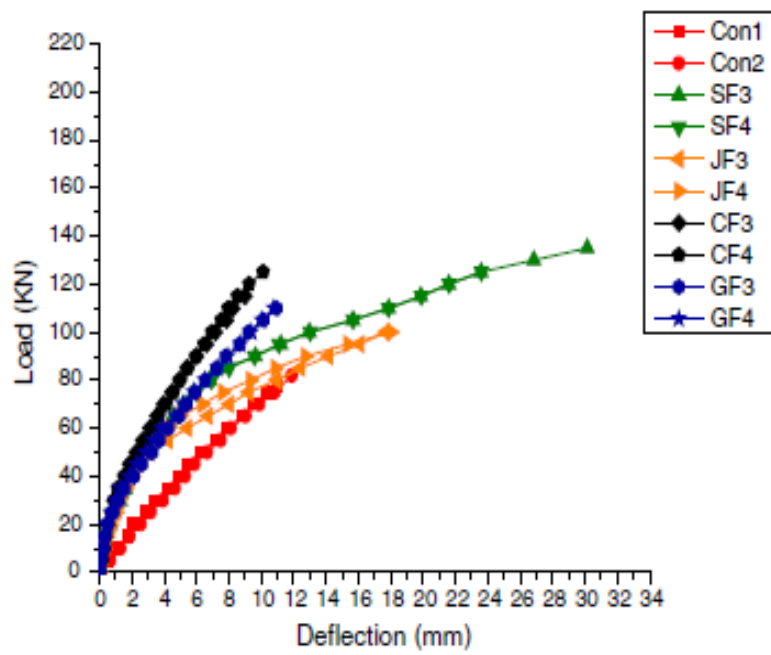
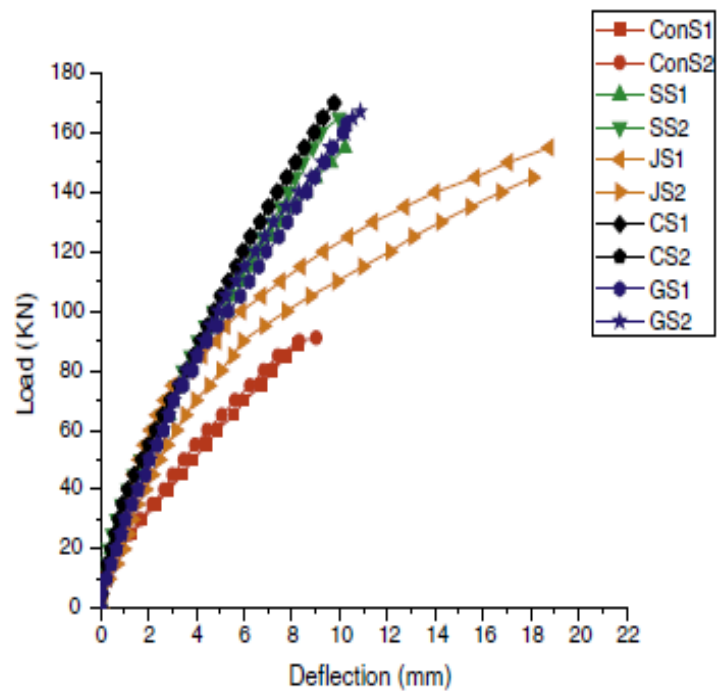
In case of strip wrapping technique the sisal FRP shows 33.4% increase, jute FRP shows 22.3 % increase, while 44.5% and 33.4% increase was seen in carbon and glass FRP respectively. The cracks were seen at a very high loads than the control beams which shows that the use of natural in addition to artificial FRP have great effect on strengthening of RC structures in shear. It was also noticed that when FRP strips were widened the percent rise in shear strength also increased.

The load deflection behavior with natural in addition to artificial FRP was improved than the control beams. A higher stiffness was noted in comparison with control beams and the stiffness in strip wrapped beams was lesser than in U wrapped beams.

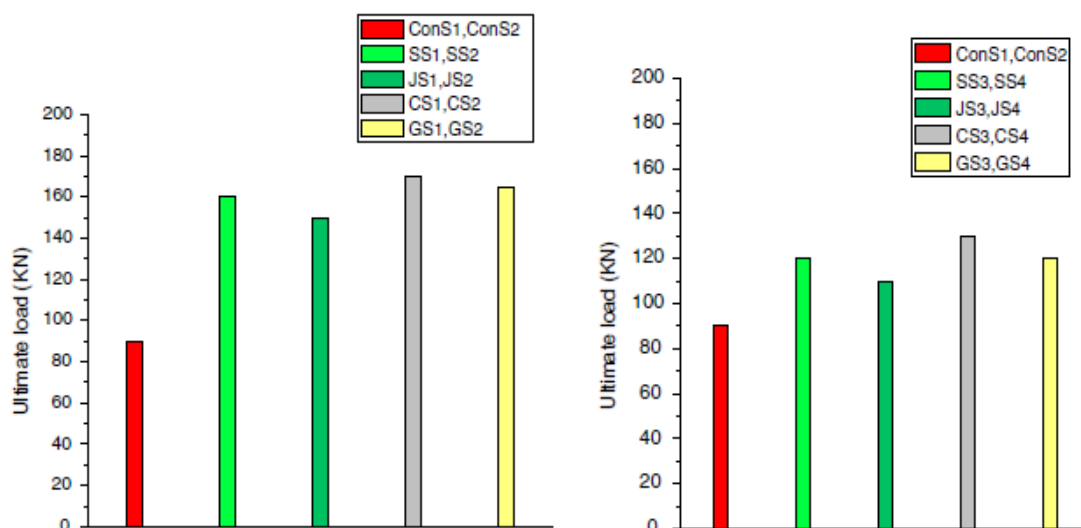
The tensile trials demonstrated that fabric of sisal FRP composite treated under heat had increased rigidity estimation of 189.779 N/mm<sup>2</sup> than crude fabric of sisal fiber fortified composites having rigidity estimation of 83.856 N/mm<sup>2</sup>.

**Table 2.11: Tensile and Flexural properties of fiber-reinforced composite**

<b>Mechanical Property</b>	<b>Sisal FRP (MPa)</b>	<b>Jute FRP (MPa)</b>	<b>CFRP (MPa)</b>	<b>GFRP (MPa)</b>
<b>Tensile Strength</b>	223.36	189.779	923.056	678.571
<b>Tensile Modulus</b>	42500	32500	125000	95000
<b>Flexural Strength</b>	350.034	208.705	1587.134	666.871
<b>Flexural Modulus</b>	4200	4500	42500	17000



**Figure 2.11: Load vs deflection at midspan of controlled beams using U wrapping technique and strip wrapping technique [Sen, T. *et al.* (2016)]**

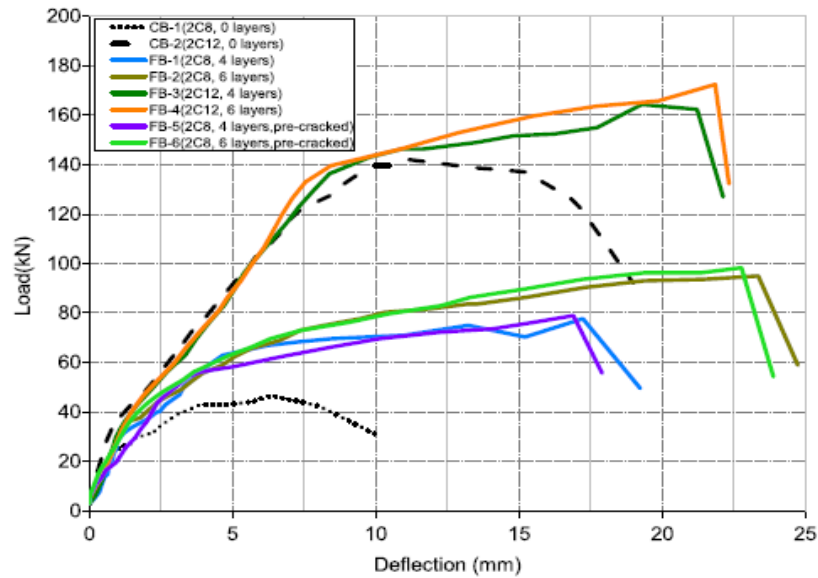


**Figure 2.12: Comparison of ultimate shear load carrying capacity of controlled beams, U wrapped and strip wrapped beams [Sen, T. *et al.* (2016)]**

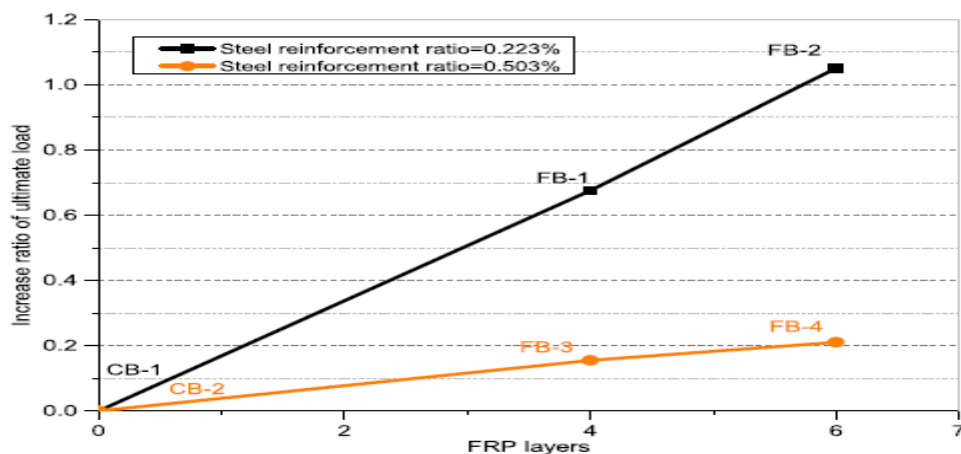
### 2.3 FLEXURAL STRENGTHENING OF RC BEAMS

**Huang, L. *et al.* (2016)** This research paper dealt with the usage of Flax Fiber reinforced polymer as a strengthening agent of RC beams. The reinforced concrete shafts of length 2000 mm having a clear span of 1.8 m which was tested under 4-point loading, the distance between two loading points were 0.6 m. 8 Beams of cross-section 150 x 300 mm were casted, 2 were control beams and the other six beams were strengthened with FFRP. The FFRP were arranged into 2 different type of thickness that is 4 layer and 6 layer. The other variable was the reinforcement ration of steel which were 0.223% and 0.503%. The beams were applied to an eighty percent yield load before reinforcing them with FFRP. From the test results it was concluded that the ductility and ultimate load of the RC beam both increased, on the other hand the deflection decreased. The RC beams with 0.223% steel ratio showed development in ductility and load even more. The reinforced beams demonstrate a comparative failure mode, for example steel yielding and afterward rupture of the FFRP plate. It was also observed that the same failure mode were seen in FFRP strengthened beam, however the beams strengthened using FFRP showed wider cracks than that of control beams. As it can be seen in figure 2.14 the beams retrofitted with 6 layers having 0.503% reinforcement ratio steel of FFRP show larger load carrying capacity and even larger deflections than the control beams. When these results were compared with beams of similar dimensions externally reinforced by artificial fibers glass and carbon it showed that the results are very much comparable with

natural fiber reinforced although, the natural fibers have lesser tensile strength than those of artificial fibers.



**Figure 2.13: Load Deflection curve of all tested beams [Huang, L. *et al.* (2016)]**

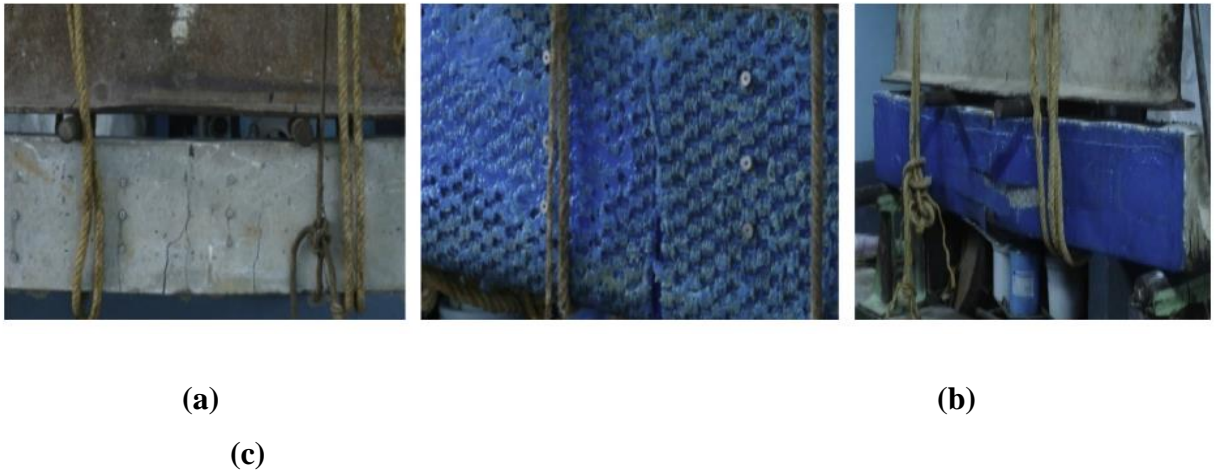


**Figure 2.14 The effect of FRP layers on load carrying capacity with different steel reinforcement ratio [Huang, L. *et al.* (2016)].**

As it is seen from the figures above, strengthening with more layers gives more ductility and higher capacity of load carrying to the beam, it was also detected that the added no. of layers increases the stiffness of the beam when related with control beam.

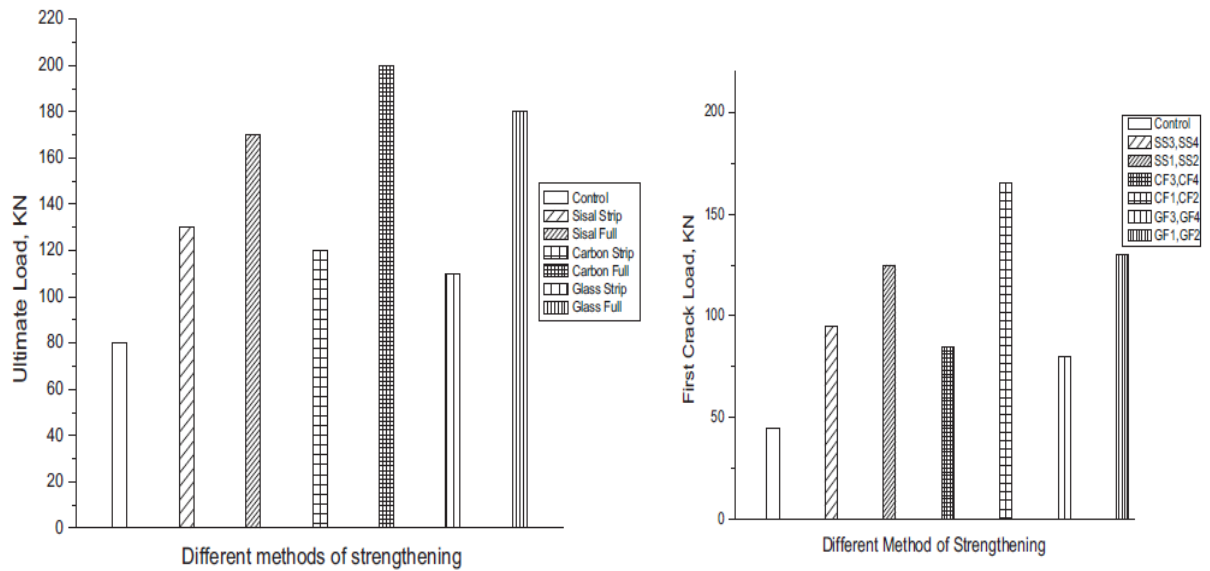
**Sen, T. *et al.* (2013)** In present study composite of polymers strengthened by sisal fiber was tested for its tensile and flexural conduct which was compared with the polymer composite of artificial fibers such as glass and carbon. For the process to be done 8 beams were casted

including 2 control beams and three each for U type wrapping and strip wrapping using sisal fiber, CFRP, GFRP. The testing was done using two point loading and the deflection, increment in load and failure type were carefully observed.



**Figure 2.15: (a) Control beams ; (b) Formation of flexure crack : (c) Rupture of FRP**  
[Sen, T. *et al.* (2013)]

The work did incorporate the investigation of failure modes, flexural reinforcing impact on extreme burden conveying limit and burden diversion conduct of RC beams which were fortified remotely with natural and artificial fibers, wrapped on three sides, along whole length using two distinct techniques, for example U wrapping and wrapping using strips. SFRC reinforcing of RC bars indicated great increment in its flexural quality and improvement in burden diversion conduct like carbon and glass strengthening. The reinforced concrete beams pillar reinforced by sisal indicated most astounding measure of flexibility, and furthermore deferred the arrangement of breaks, without crack disappointment of FRP as on account of CFRP fortified bars and furthermore without debonding disappointment of FRP as on account of GFRP reinforced shafts. Subsequently sisal texture fortified polymer composite framework, with its different ecological advantages, being a natural fiber with lower cost values can be used as a replacement of artificial fibers which come at a higher rates.



**Figure 2.16: Comparison of capacity of load carrying and Comparison of load on appearance of first crack [Sen, T. *et al.* (2013)]**

The bar graph in the figure above shows that full wrapping technique gave better results than the strip wrapping technique and hence showed higher load carrying capacity in every fiber composite system. The natural fiber sisal (112.5% increase in load carrying capacity in full wrap) showed relatively comparable results as that of the artificial fibers glass (125% increase) and carbon (150% increase) hence giving advantages in terms of cost and environment friendly than those of artificial fibers.

**Esfahani, M.R. *et al.* (2013)** This paper researches the flexural conduct of reinforced concrete beams strengthened utilizing Carbon Fiber Reinforced Polymers (CFRP) sheets. The impact of reinforcing bar proportion on the flexural quality of the reinforced shafts is analyzed. Twelve solid bar examples with measurements of 150 mm width, 200 mm height, and 2000 mm length were made and tested. Beam segments with three diverse reinforcing proportions,  $\rho$ , were utilized as longitudinal tensile support in specimens. Nine beams were strengthened in flexure by CFRP sheets. The other three examples were considered as control beams. The width, length and number of layers of CFRP sheets changed in various examples. The flexural quality and stiffness of the retrofitted beams increase contrasted with the control examples. From the consequences of this investigation, it is inferred that the design guidelines of ACI 440.2R-02 and ISIS Canada overestimate the impact of CFRP sheets in expanding the flexural quality of bars with little  $\rho$  qualities contrasted with the greatest worth,  $\rho_{max}$ , indicated in these two rules. With the expansion in the  $\rho$  esteem in bars, the proportions

of test burden to the heap determined utilizing ACI 440 and ISIS Canada expanded. Along these lines, the conditions proposed by the two plan rules are progressively suitable for shafts with huge  $\rho$  values. In the fortified examples with the large strengthening bar proportion, near the most extreme code estimation of  $\rho_{\max}$ , disappointment happened with adequate ductility.

**Li *et al.* (2005)** conducted experimental studies to put light on capacity of load carrying of concrete beams (reinforced) strengthened by means of carbon fiber reinforced plastics (CFRP) composites. Under reinforced beams of cross-section 120 x 120 and length 2 m were tested using four-point bending test on a testing frame of capacity 2000 KN. It was concluded that CFRP enhance ultimate loads, stiffness in addition to the ductility and initial cracking loads of the concrete beams. It was observed that the debonding failure had a much larger influence on initial cracking load but had lesser influence on stiffness, ductility and ultimate load but it all these properties significantly.

**Dong, J. *et al.* (2013)** This study showed that beams bonded with CFRP or GFRP sheets on both side faces and bottom face enhances both flexural and shear strength of beams. It showed enhancement in flexural capacity varying from 41% and 125% over the control beams and there was 31% to 74% enhancement in capacity of the beams in shear. Further deductions were made that it not only boosted the strength and beam's stiffness but also decreased the possibility of cracks and increased ductility. Hence it was concluded that the beam not only enhances the flexural strength of the system but similarly enhances shearing prowess of the structure.

**Duthinh *et al.* (2002)** The study included casting of seven reinforced concrete beams with varying steel and CFRP plates which were bonded externally after cracking them under service load were tested for their strength and durability. The test results clearly portrayed that the carbon fiber plates were very effective for strengthening the beams flexurally on the provision of proper anchorage of FRP. It was noted that there was decrement in the strength imparted by CFRP as the amount of steel reinforcement was increased. Satisfactory deformation capacity was also observed with heavily steel reinforced beam and carbon fiber irrespective of their brittle failure mode.

## **2.4 NEED OF PRESENT STUDY**

This literature review clearly shows the focus of researchers regarding retrofitting for flexural strength of reinforced concrete beams. There have been some studies of retrofitting using composites of fibers found naturally for example sisal, jute but that too for flexural strengthening. There have been lesser studies made for RC beams strengthened in shear using a fibre found naturally in the ecosystem. Over the past few decades artificial fibres have been applied in numerous extents to improve load carrying capacity, ductility, stiffness of structural members but they come at high prices and they some-what harm the environment which is major issue nowadays considering the issues like climate changes and global warming.

This research is focused on use of natural fibers for example coir and flax fiber on shear deficient initially stressed RC beams as a retrofitting agent. The objectives are:

- 1) To compare the capacity of load carrying of control beams to that of beam retrofitted with coir fibre fabric, flax fiber fabric, or both of these used together in 2 layers.
- 2) To compare the effect of side wrapping and U type wrapping technique used for retrofitting.

## CHAPTER 3

### EXPERIMENTAL PROGRAMME AND METHODOLOGY

#### 3.1 GENERAL

This chapter includes the compilation of results attained by conducting several tests on RCC beams retrofitted by coir and flax fiber laminates. An experimental procedure has been strategized to examine the shear strengthening of RCC beams using natural fiber fabric for the study.

#### 3.2 MATERIALS

Different materials used for present study were 43 grade Cement (Conforming to IS 8112-1989(reaffirmed 2000)), Coarse Agregate, Fine aggregate, Coir Fibre Fabric, Flax fiber fabric. The objective of studying the different characteristics of every material is to verify the codal provisions and mix design the concrete that is to be casted. The following report is given on the different materials used in the study.

##### 3.2.1 Portland Cement

OPC of Shree Brand (Grade 43) was utilized throughout progression of study. The cement was safely stored so it stays fresh and had no contact with moisture to prevent lumps. Several tests in compliance to Indian Standard IS: 8112-1989 (Reaffirmed 2000) are recorded and noted as in the table below. Initial setting time, final setting time, specific gravity, fineness and compressive strength are the tests that were performed.

**Table 3.1: Properties of Ordinary Portland Cement.**

S No.	Characteristic	Experimental Value	IS code specified value (IS 8112:1989)
1	Specific Gravity	3.1	–
2	Standard Consistency (%)	24	–
3	Initial Setting Point (mins)	105	Not less than 30 mins
4	Final Setting Point (mins)	295	Not more than 600

5	Soundness of cement by Le Chatelier Apparatus	–	Not more than 10mm
6	Fineness of cement retained on 90 $\mu$ sieve (%)	1.8	10
7	Compressive Strength (N/mm <sup>2</sup> )		
	3 Days	27.04	23
	7 Days	33.61	33
	28 Days	41.12	43

### 3.2.2 Coarse Aggregates

Natural Disintegration of rocks or manual crushing of rocks form the aggregates and if they pass through sieve of 75 mm IS sieve and deposit on 4.75 mm IS sieve then they are considered under coarse aggregate. The qualities required from these aggregates as per IS: 383-1970 are hard, strong, dense, clear and adherent coating. They should also not be flaky, elongated, not free from vegetable matter. The present study included dry, dirt free crushed stones of 20mm and 10mm sizes. The sieve analysis is tabulated in the table below.

**Table 3.2: Coarse Aggregate's Sieve Analysis**

S NO.	Aggregate size	Sieve	Weight Retained (gm)	Percentage weight retained	Cumulative percentage retained	Percentage passing
1	20 mm	40 mm	0.00	0.00	0.00	100.00
2		20 mm	37.00	0.37	0.37	99.63
3		10 mm	7893.00	78.93	79.30	20.7
4		4.75 mm	1646.00	16.46	95.76	4.24
5		Pan	424.00	4.24		
	TOTAL =				175.43	
1		40 mm	0.00	0.00	0.00	100.00

2	10 mm	20 mm	0.00	0.00	0.00	100.00
3		10 mm	870.00	8.70	8.70	91.30
4		4.75 mm	8220.00	82.20	90.90	9.10
5		Pan	910.00	9.10		0.00
		TOTAL =			99.60	

Fineness Modulus =  $(99.60 + 500)/100 = 6.00$  for 10mm aggregates

Fineness Modulus =  $(175.43 + 500)/100 = 6.75$  for 20 mm aggregates

### 3.2.3 Fine Aggregates

The aggregates that are generally made from natural sand and having size of the particle greater than 0.075mm and lesser than 4.75mm are called fine aggregates. Fine aggregates according to Indian Code IS 383-1970 divide it into 4 grades on the basis of particle size, the finer the sand the higher is the grading zone. The fine aggregate used in this study was transported from Patiala and it lies in Grade II. The fine aggregates were tested for physical properties and sieve analysis was also done as shown in Table no. 3.3 and Table no. 3.4.

**Table 3.3 Fine Aggregates's sieve analysis**

S No.	IS Sieve (mm)	Weight Retained (gm)	Percentage Retained	Percentage Passing	Cumulative Percentage Retained
1	4.75	14.7	1.47	98.53	1.47
2	2.36	38	3.8	94.73	5.27
3	1.18	245.3	24.53	70.20	29.8
4	0.6	246.9	24.69	45.51	54.49

5	0.3	266.9	26.69	18.82	81.18
6	0.15	157.4	15.74	3.08	96.92
7	Pan	30.8	3.08	0	
	Total	1000.00		SUM	268.83

Total weight taken of sample = 1000 gm

Fine aggregate's fineness modulus = 2.68

**Table 3.4 Physical Properties of Fine Aggregates**

<b>S No.</b>	<b>CHARACTERISTICS</b>	<b>VALUE OBTAINED</b>
<b>1</b>	Specific Gravity	2.68
<b>2</b>	Grading Zone	II
<b>3</b>	Water Absorption	1.05%
<b>4</b>	Type	Natural Sand
<b>5</b>	Moisture Content	0.10%
<b>6</b>	Fineness Modulus	2.615

### **3.2.4 Water**

As per Indian Standards the water which was used as a binding agent in a concrete mix and for curing purposes does not have any organic things, silt, oil, sugar, chlorine and acidic materials. The water used for casting concrete was accessible in the testing laboratory.

### 3.2.5 Reinforcing Steel

The HYSD steel of Grade Fe-500 was provided as the reinforcement steel, longitudinal steel was made up from 12mm dia bars and 8mm dia bars. Tension reinforcement was done by 12mm dia bars and compression reinforcement was done by 8mm dia bars. Shear stirrups were provided using 8mm dia bars, four shear stirrups were provided spaced out at 200 mm c/c so as to make it shaer deficient.

### 3.2.6 Coir Fiber Fabric

Coconut husk is the source of natural kind of fibre called coir fiber. It is bundled between the inside shell and outer covering of the coconut. Coir fibre's general usage includes doormats, brushes, mattresses, etc. Coir fiber is considered to have highest toughness and has the capability of taking four times more strain when only natural fibers are taken into consideration and because of this property it can be used as a reinforcement in structures especially in earthquake prone areas (Ali *et al.* 2012). The coconut fibres are divided into two types, matured coconuts give brown fibre while immature coconuts give white fibres. In this study brown fabric was used for reinforcing the beams after applied service load.



**Figure 3.1: Coir Fiber Fabric**

### 3.2.7 Flax Fiber Fabric

Flax Fibre is the bast kind of fibre it is taken from the skin of flax plant's stem. It is manufactured in a linen yarn that is why it is often called linen. Flax is a very strong fiber its average length is around 18-30 inch for every fiber. It is light brownish in colour and has a specific gravity of 1.5. It is considered to be stronger than many natural fibers but lacks elasticity to some (Faruk, O. *et al* 1999). Some common uses of flax fiber are for clothing

apparel, sewing and surgical threads, curtains etc. As the use of natural fibers as a reinforcing composite is increasing day by day, flax fiber can be considered one for the work.



**Figure 3.2: Flax Fiber Fabric**

### **3.3 DESIGN OF CONCRETE MIX**

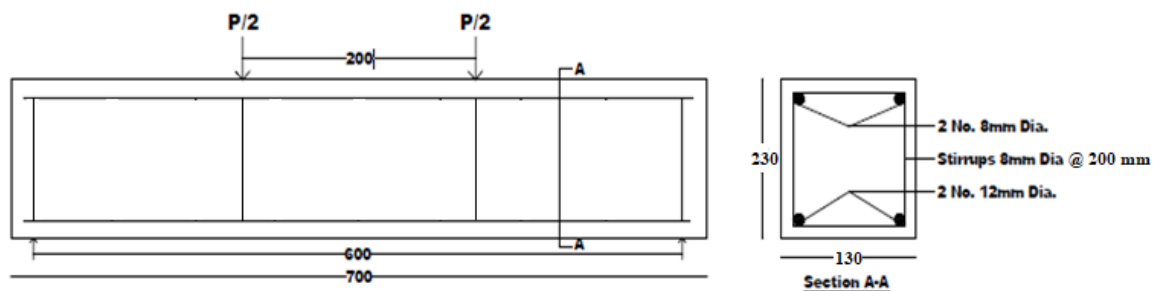
According to IS:10262-2009 guidelines consuming the properties of cement, fine aggregate and coarse aggregate, M25 concrete mix was designed. The water/cement ratio was considered as 0.45. The mix proportions of the concrete mix are tabulated in Table 3.5. Three cubes each testing the mix proportion at 7 days and 28 days were prepared. The cubes (Average of 3 cubes) tested for compressive strength at 7 days was 20.3 MPa and at 28 days was 34.9 MPa.

**Table3.5- Mix Proportions for M25 grade concrete**

Water	Cement	Fine Aggregate	Coarse Aggregates
186 kg	413.33 kg	689 kg	1091.6 kg
0.45	1	1.66	2.64

### 3.4 RCC BEAM DESIGN

Limit state design method was used to design the RCC beam, M-25 grade concrete and Fe 500 steel was used in designing. The beam was designed under-reinforced so as to get shear cracks as the further study was to be done on shear strengthening. The beam dimensions were fixed to 230 x 130 mm overall. The beam was designed using two HYSD bars of 8mm diameter and two HYSD bars of 12mm diameter at compression face and tension face respectively. The beam was under reinforced in shear hence, four shear stirrups were provided at a distance of 200 mm center to center. The length of the beam was 700 mm.



**Figure 3.3: Longitudinal and Cross-section of Beam**

### 3.5 CASTING OF RCC BEAM

Moulds of size 230 x 130 and length 700 mm were used in casting of beams. Initially the moulds were oiled in order to easily remove the the beam from the mould in a given period of time. 25 mm sized spacers were placed and the reinforcement was rested over it. After placing the bars the concrete was transferred into the mould while simultaneously vibrating it using a needle vibrator. The vibration is continued until unless there are there were no openings left. Beams were demolded after one day which were later cured using jute bags for a month.

### 3.5 TESTING ARRANGEMENT

The beams were tested a month prior to the date of casting. Beams were tested using 2-point loading with the loads applied at  $L/3$  distance from both ends, when it was simply supported at two ends here the effective span was 600mm. The moment was applied linearly varying between loads and supports. The procedure was same for every beam. The Universal Testing Machine (UTM) of  $10^3$  KN capacity was used to test beams. Displacement control method was applied for the testing procedure and the loads applied to the beam were scrutinized

through load cells that have high accuracy and have a load sensitivity of 0.001 KN. Applied loads were at the rate 4 KN/min. Measurement of deflection was done using dial gauge that got placed at the center of the beam. Readings were taken at regular space of time and the cracks were monitored and marked using permanent markers. To get a clearer view of failure mode, the beams were painted white before testing.



**Figure 3.4 – Experimental setup used for testing**

### **3.6 RETROFITTING OF BEAMS**

The beams to be retrofitted are pre-cracked to 70% of the failure load and later the fiber fabric is used to retrofit the beam using epoxy as a bonding mediator. Before applying the fiber sheets the surface of the beams were prepared which involved the procedure of cleaning and scratching the surface for better adhesion then the cracks were filled with epoxy and fibers were bonded to the beam surface using two different retrofitting techniques were used in this study, Side face retrofitting and U type retrofitting.

In U-Type procedure 3 sides of the beam are bonded with fabric fiber using epoxy i.e. both sides and bottom as shown in the figure 3.5. Firstly, the beam is cleansed on all the sides then the cracks that appeared on the surface were filled with epoxy layer and the fabric is placed over it and left to be bonded.



**Figure 3.5 – Beam after U-Type retrofitting using flax fiber**

In Side face retrofitting technique only the sides of the beam are bonded with fabric fiber using epoxy and the same procedure was followed as mentioned in the above technique. Only difference is the no. of sides that are covered and 2 sides were enclosed in this case. The beam retrofitted using this technique is revealed in figure 3.6.



**Figure 3.6 – Beam after Side face retrofitting using coir fiber**

## **CHAPTER 4**

### **RESULTS AND DISCUSSION**

#### **4.1 INTRODUCTION**

The results obtained in the experimental procedure are conversed in this chapter. In this study the beams casted were shear deficient and were studied on the effect of retrofitting them and imparting shear strength using natural fiber fabrics. For these studies the beams were originally stressed to 70% of failure load and later retrofitted by way of 2 different techniques that is side face and U-type retrofitting. A comparative study on control beam and retrofitted beams are done on the basis of their load carrying capacity.

#### **4.2 TESTING METHODOLOGY**

Firstly the control beams were tested till they fail and simultaneously data was recorded. Then 6 beams were casted each for a combination of fiber used for retrofitting to the type of retrofitting used in that sample. Before retrofitting of the beams they are stressed to 70% of failure load which was predecided. The failure load observed from load deflection curve of control beam 118 KN for shear deficient RC beams. The corresponding load for 70% service load is 82.6 KN, after applying the service load retrofitting was done using the two techniques mentioned above. The beams were designated as follows.

Control Beam – CB

Beam retrofitted using Coir Fiber Fabric using side wrapping retrofitting – CS

Beam retrofitted using Coir Fiber Fabric using U-type wrapping retrofitting – CU

Beam retrofitted using Flax Fiber Fabric using Side wrapping retrofitting - FS

Beam retrofitted using Flax Fiber Fabric using U type wrapping retrofitting - FU

Beam retrofitted using Coir and Flax Fiber Fabric using Side wrapping retrofitting- CFS

Beam retrofitted using Coir and Flax Fiber Fabric using U-type wrapping retrofitting- CFU

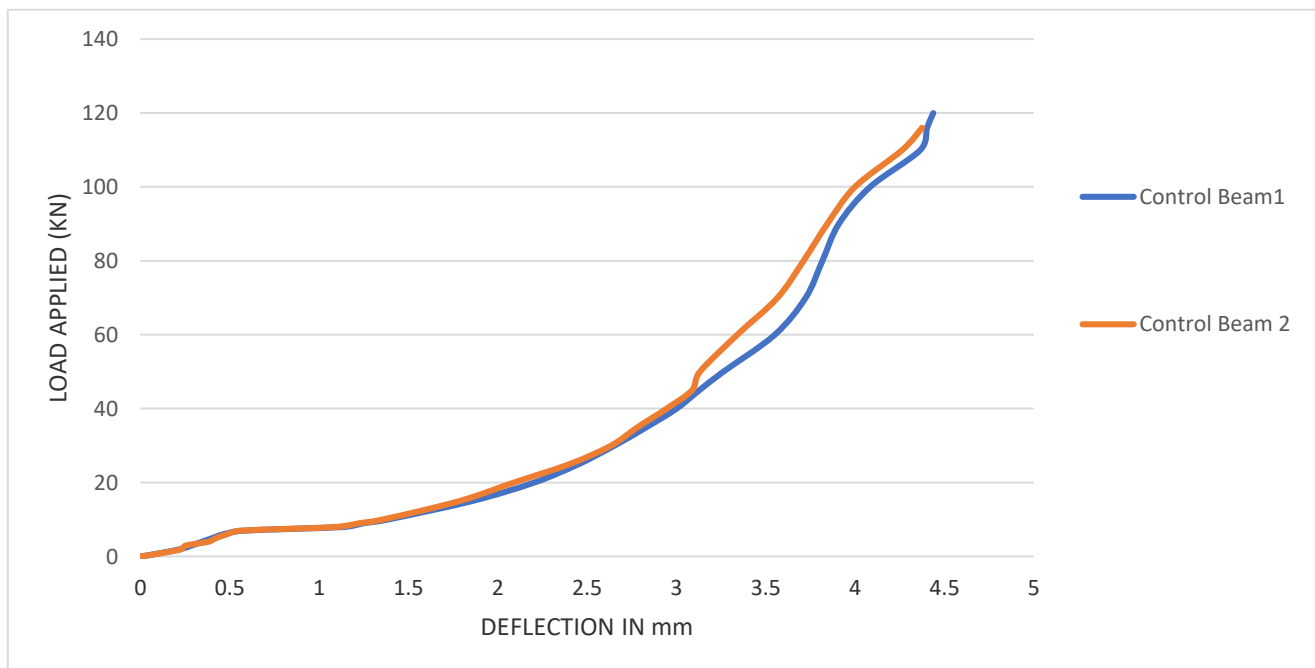
#### **4.3 CONTROL BEAM**

Two beams of under reinforced in case of shear were verified using 2-point loading system. The deflection at central span was measured by a dial meter and the crack patterns were noted during the testing procedure. The cracks started appearing when the load reached 57

KN mark and noticeable shear crack appeared around 82 KN which was also the 70% of the failure load. When further load was applied shear crack got more clear as they propagated from support to one end of the two point loading, finally the beam failed at 120 KN and highest deflection noted was 4.438 mm at the center. As it can show in the graph below the control beam failed at 120 KN.



**Figure 4.1: Testing of Control beam and crack pattern of control beam**



**Figure 4.2: Load vs Mid span deflection of Controlled Beam**

## 4.4 COMPARISONS OF RETROFITTED AND CONTROLLED BEAM

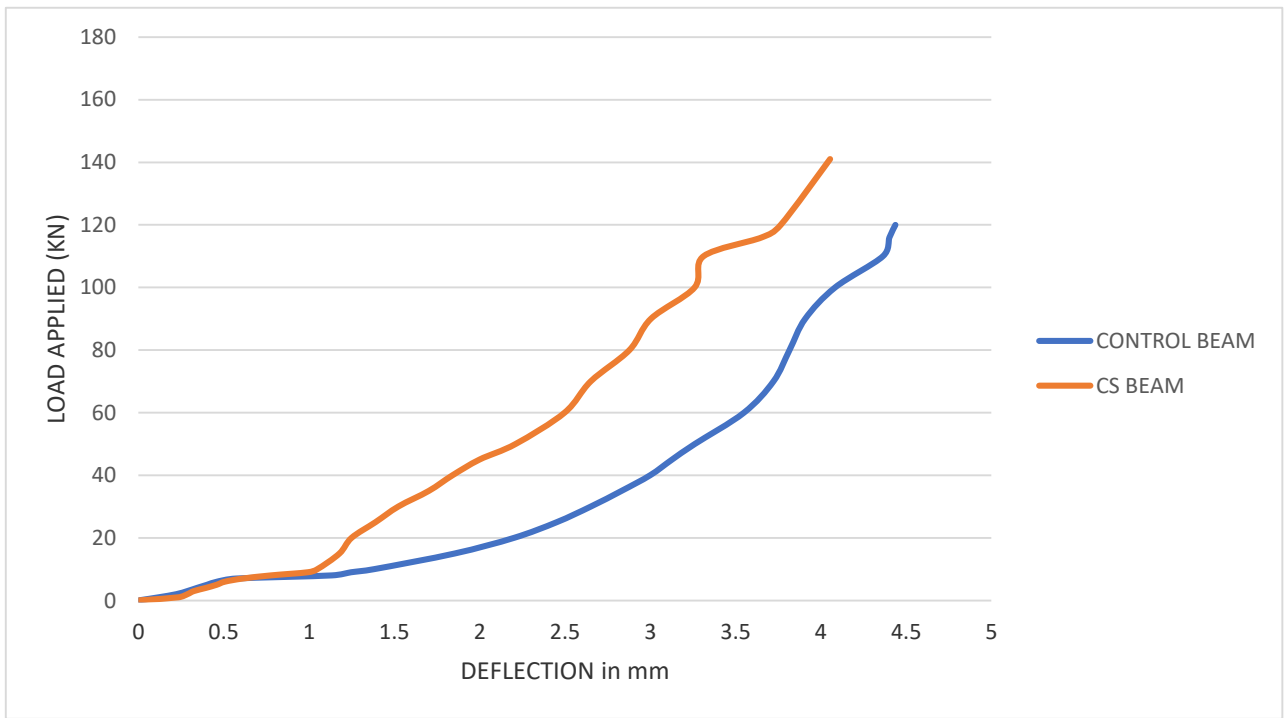
### 4.4.1 Beams retrofitted with side retrofitting technique

Beams were retrofitted along the sides using coir fiber fabric, flax fiber fabric and the combination of both these fibers. The effect observed on the strength of RC beams which were shear deficient stressed up to 70% of the ultimate load and were retrofitted is shown in figure 4.4 ,4.5, 4.6. It was observed that load carrying capacity increased from 120 KN to 141 KN for coir fiber, it was even better for flax fiber as it reached 145 KN, the combination of both that is a layer of each coir and flax increased the load carrying capacity to 155 KN. The deflection at the central span was decreased as coir fiber retrofit confines it from 4.438 mm to 4.054 mm, 3.872 mm for flax fiber and the combination of both further reduced the deflection to 3.555 mm.

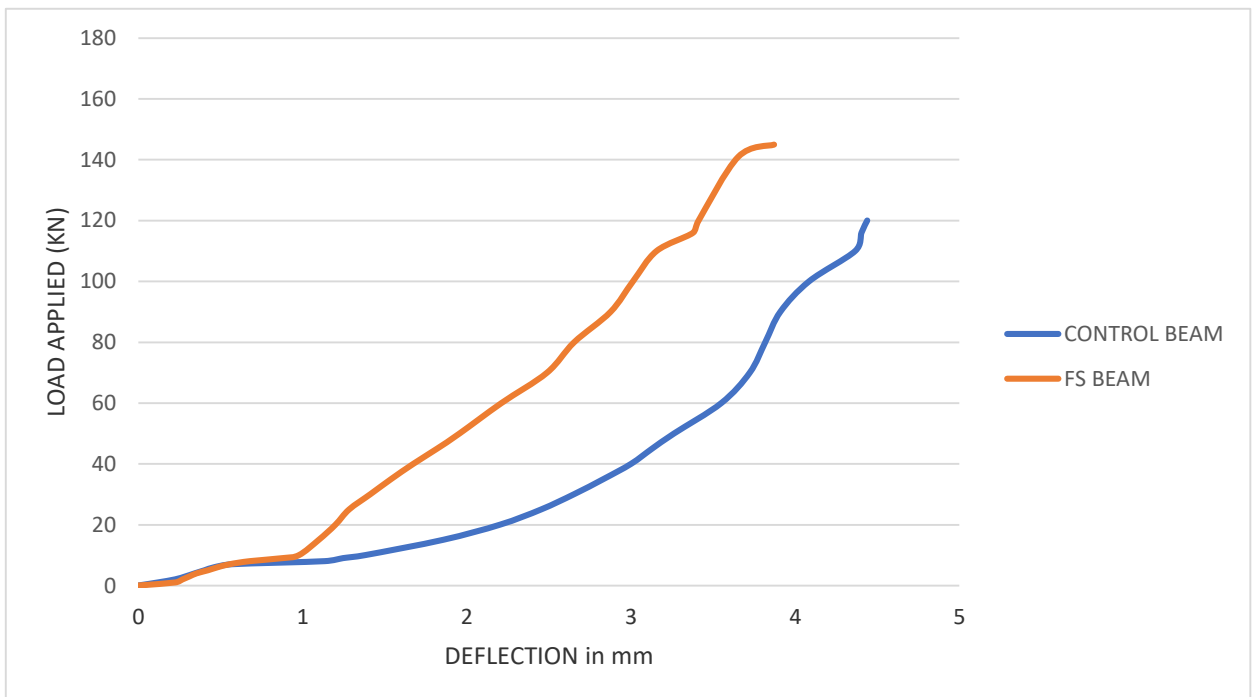
The percentage increase in capacity of load carrying was measured highest 22.58% for CFS beam, 17.24% for FS beam and 14.89% for CS beam



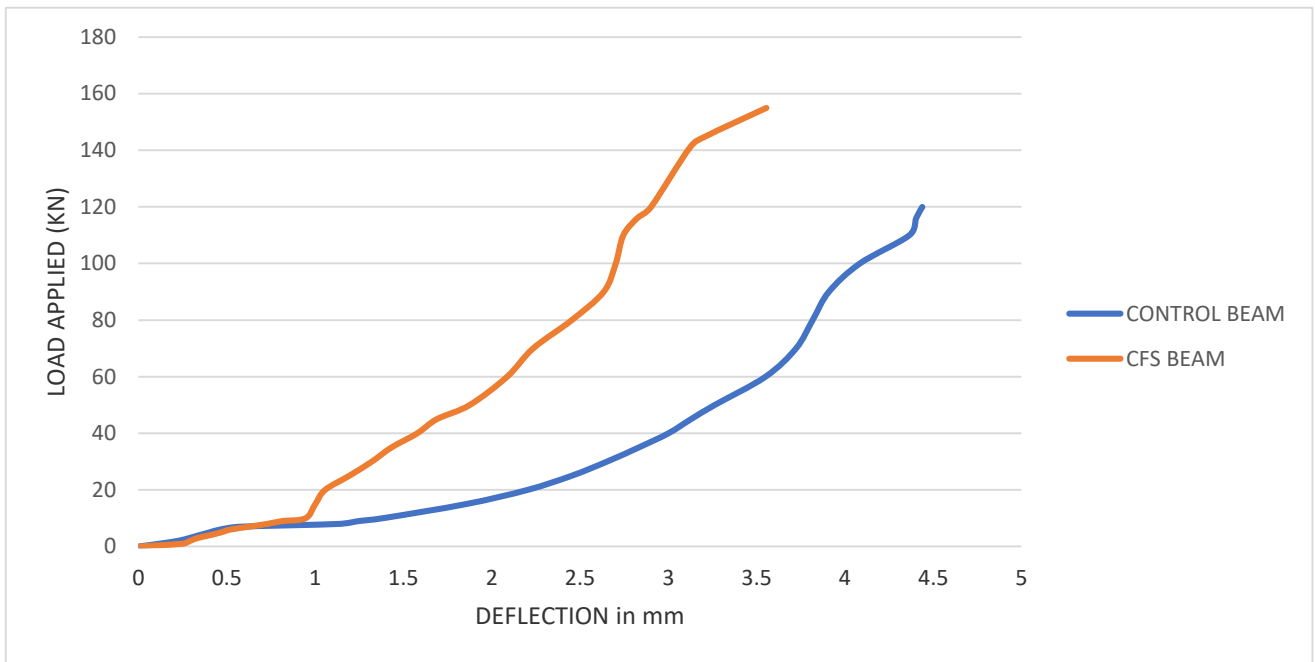
**Figure 4.3: Testing of CF beam and debonding around the shear crack failure**



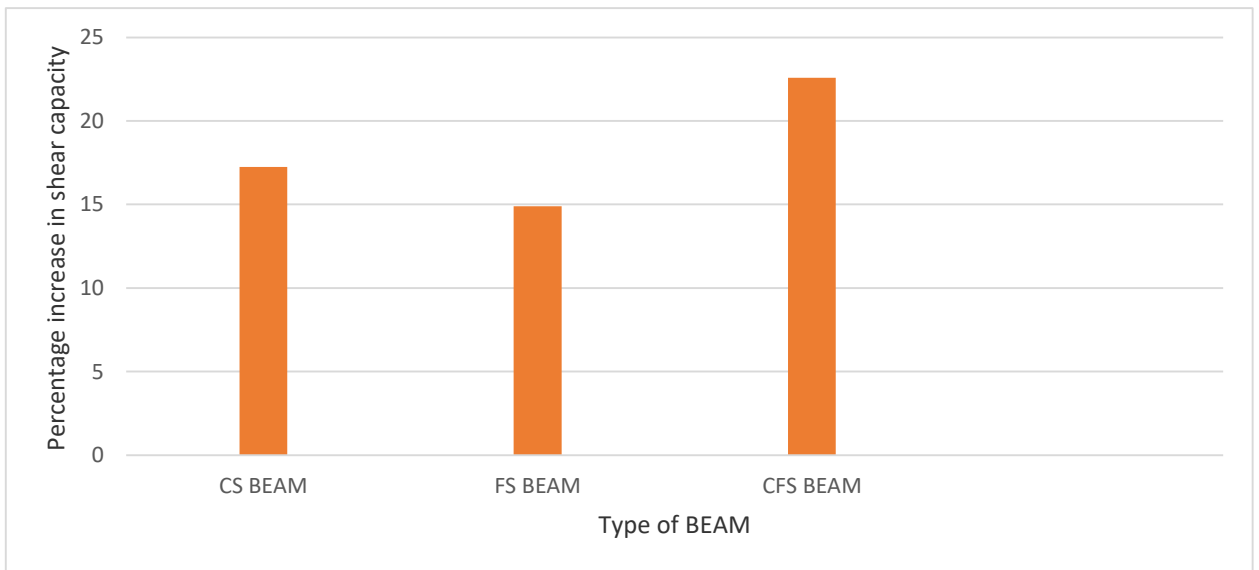
**Figure 4.4: Comparison of Load vs Mid span deflection of CS beam and Control beam**



**Figure 4.5: Comparison of Load vs Mid span deflection of FS beam and Control beam**



**Figure 4.6: Comparison of Load vs Mid span deflection of CFS beam and Control beam**



**Figure 4.7: Percentage increase of shearing capacity of retrofitted beams than control beams**

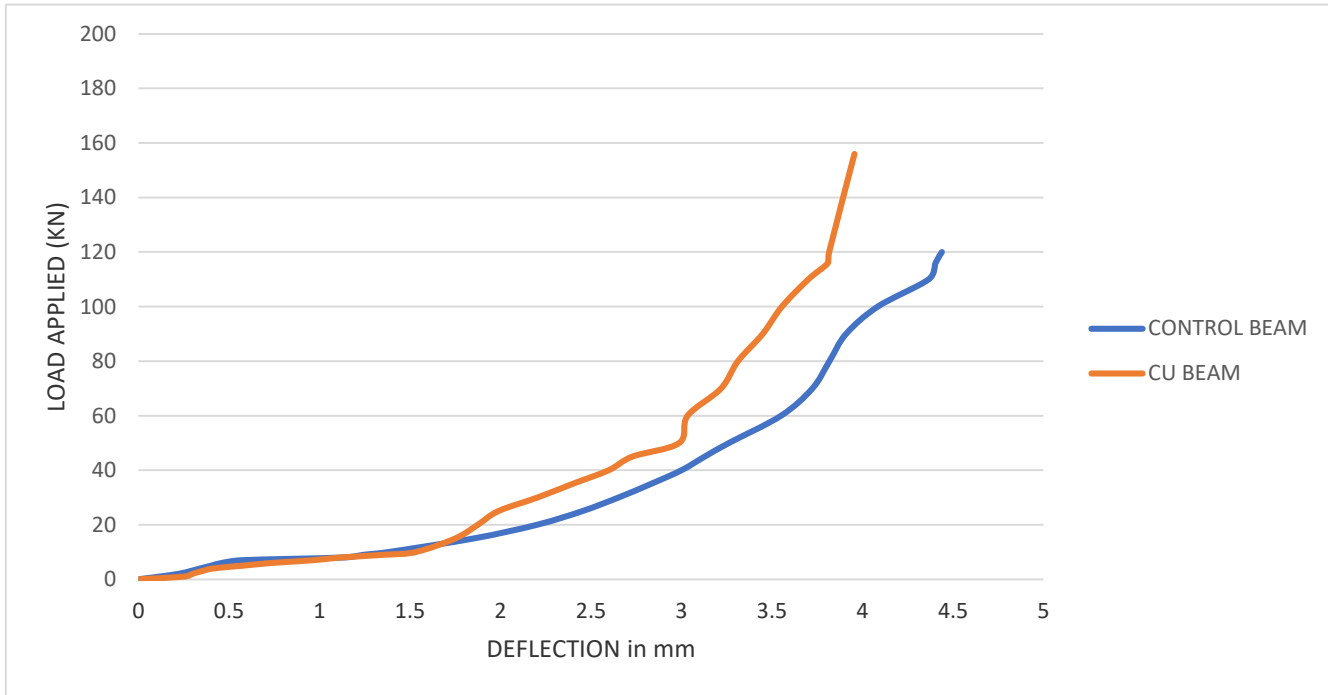
#### 4.4.2 Beams retrofitted with U-Type retrofitting technique

Beams were retrofitted along the three sides using coir fiber fabric, flax fiber fabric and the combination of both these fibers. The effect observed on the strength of RC beams which were shear deficient stressed up to 70% of the ultimate load and were retrofitted is shown in figure 4.9,4.10,4.11. It was observed that load carrying capacity increased from 120 KN to 156 KN for coir fiber, it was quite similar for flax fiber as it reached 157 KN, the combination of both that is a layer of each coir and flax increased the load carrying capacity to 172 KN. The deflection at the central span was decreased as coir fiber retrofit decreased it from 4.438 mm to 3.956 mm, 3.801 mm for flax fiber and the combination of both the fiber enhanced deflection at center to 3.342 mm.

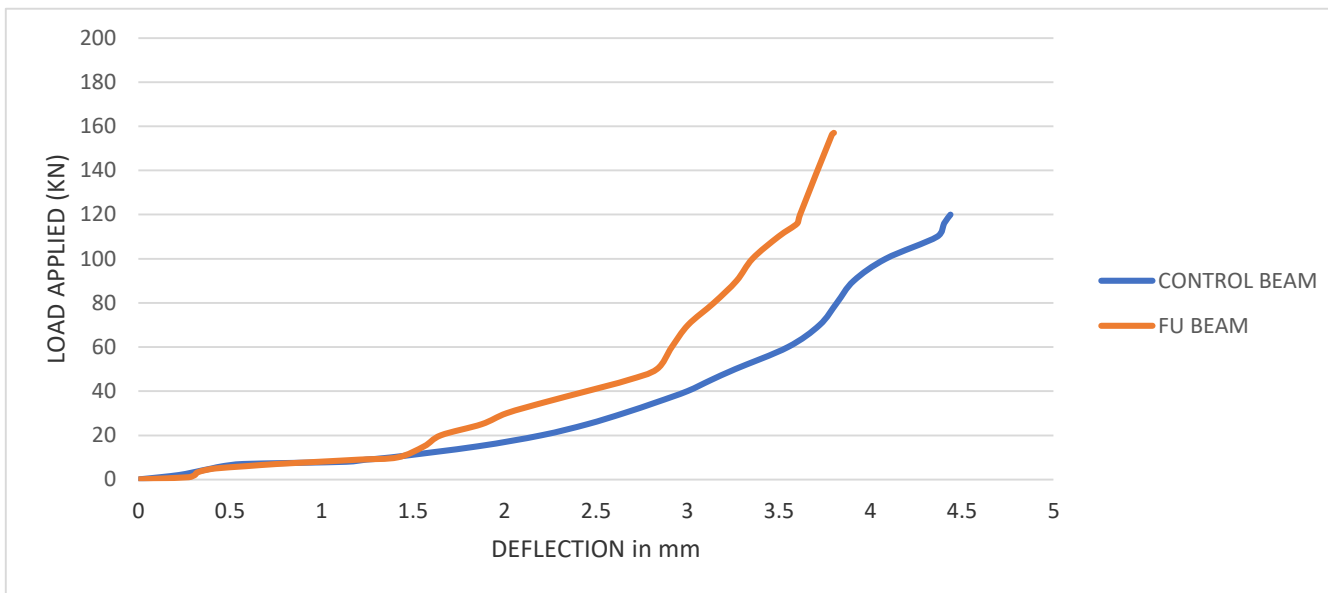
The percentage increase in capacity of load carrying was measured highest 30.02% for CFU beam, 23.56% for FU beam and 23.07% for CU beam.



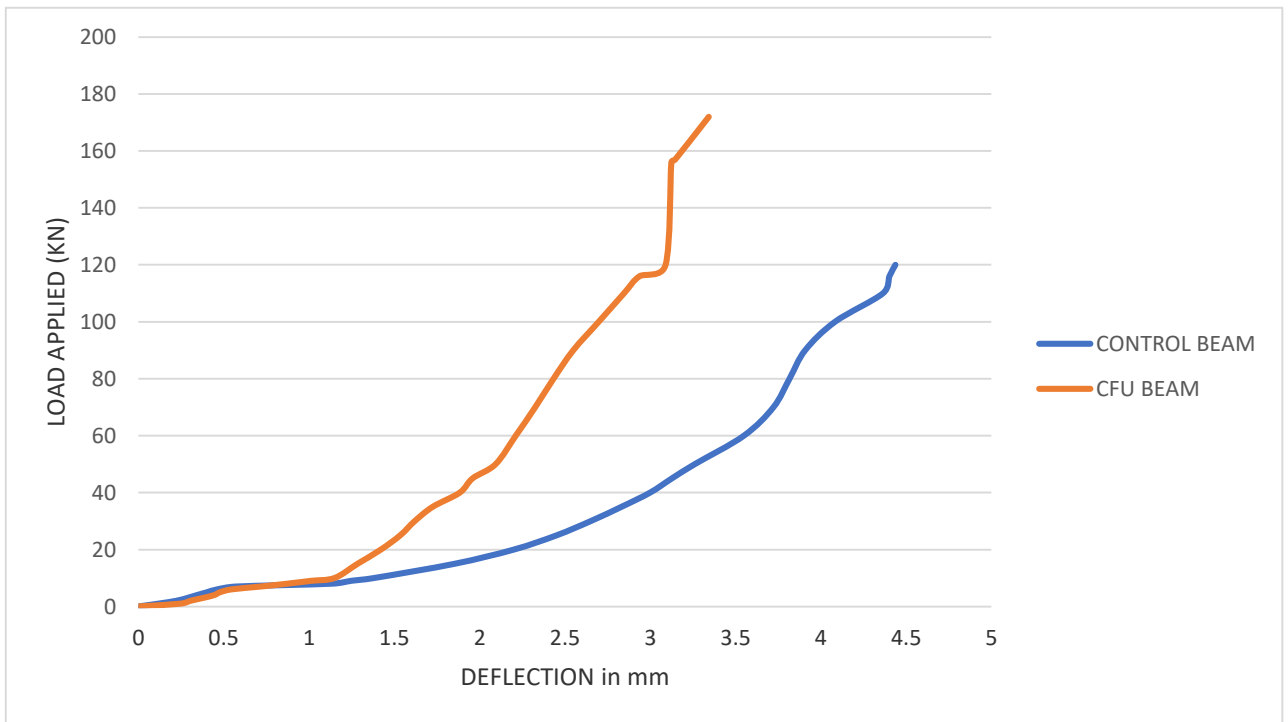
**Figure 4.8: Retrofitting of CFU beam and CFU beam after shear failure**



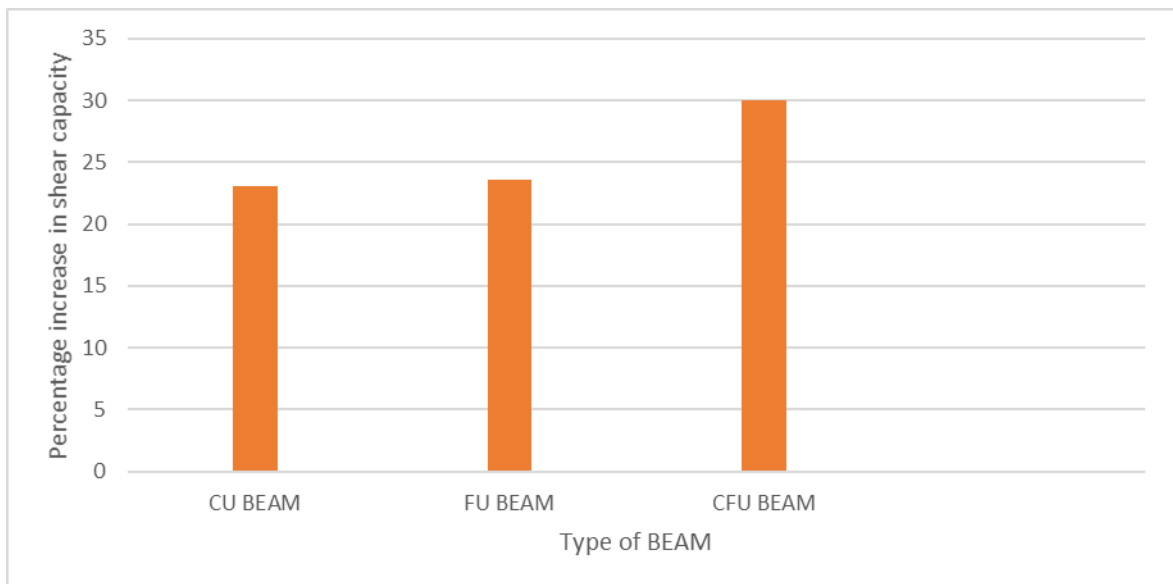
**Figure 4.9: Comparison of Load vs Mid span deflection of CU beam and Control beam**



**Figure 4.10: Comparison of Load vs Mid span deflection of FU beam and Control beam**



**Figure 4.11: Comparison of Load vs Mid span deflection of CFU beam and Control beam**



**Figure 4.12: Percentage increase of shearing capacity of retrofitted beams than control beams**

## CHAPTER 5

### CONCLUSIONS AND FUTURE SCOPE

#### 5.1 CONCLUSIONS

Based upon the results of experimental work that were conducted following inferences can be :-

1. Retrofitting using natural fibers increases the of load carrying capacity of reinforced concrete beams which were shear deficient and were prestressed (70% of the failure load).
2. The deflection also decreases when the RC beams are retrofitted using fibres available naturally such as coir and flax.
3. The failure load increased by 14.89%, 17.24% and 22.58% for CS, FS and CFS beams respectively for side face retrofitting of the beams. Each beam failed in shear but at higher load. Debonding was also observed in case of CS beam.
4. Similarly, the failure load increased by 23.07%, 23.56% and 30.02% for CU, FU and CFS beam respectively in case of U-Type retrofitting. Deflections decreased from 4.438 mm of control beam to 3.956 mm, 3.801 mm and 3.342 mm for CU, FU and CFU beams respectively which shows that retrofitting increases the stiffness of the structural member.
5. It can also be concluded that the natural fiber not only doesn't harm the environment but also helps in cost cutting of repairing old structure which is a great expense otherwise.

Finally, it is resolved that the usage of natural fibres in the retrofitting of initially stressed beams enhanced the capacity of load carrying of the beams.

#### 5.2 SCOPE FOR FUTURE STUDY

There are many creative ways in which retrofitting of beams using fibers that are found naturally such as coir and flax fibre can be studied and applied in the future some of them are.

1. Beam length and size can be changed and tested as it will change the  $a/d$  ratio and hence might give different failure mode and load carrying behavior.
2. In this study the beams were prestressed to 70% of the failure load, in future the prestressing value can be changed and the no. of layers of each fiber can be varied simultaneously or both at the same time.
3. There are many fibres found naturally on the planet, some other natural fibres such as

hemp, sisal, jute can be combined with coir and flax and test them for retrofitting on beams of various sizes which can be prestressed at different percentages of the failure loads.

4. This research mainly imparted light on the shear strengthening of beams. These fibres can also be used to retrofit and be studied for the flexural strength of the beam.

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