Strengthening of RC Beam with Sifcon Laminates

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Abstract— Now a days natural and manmade disaster like earthquake, cyclone etc., play an important role in the behaviour of structures. Hence the structures has to be designed in a good manner which resists higher seismic and impact forces. Strengthening of existing RC framed buildings for impacting seismic resistance is a challenging engineering problem. Many of the existing buildings are found to have inadequate strength, ductility, or stiffness because they were designed and build when modern seismic requirements did not exist. SIFCON possess high strength, improved ductility, impact resistance and enhanced energy absorption capacity, so it is used as an option for strengthening the conventional reinforced concrete beam. The main thrust of the study has been aimed at characterizing the flexural strength of the beam strengthened with precast SIFCON laminate externally.

Key words: SIFCON Laminates, Strengthening of RC Beam

I. Introduction

A. General

Concrete is the most extensively used material in Civil Engineering and is the primary component in most infrastructures. In future, there seems to be no alternative to concrete as a construction material. Although strength of the concrete is most important, it is also necessary that concrete is durable, workable, and possess a good service life. For bridges, offshore structures, highway and airport pavements and machine foundations, concrete should possess high fatigue strength. For nuclear containers exposed to very high temperatures, the concrete must have high resistance to thermal cracking. All these requirements have made the engineers to think seriously and to find the appropriate technology for improving the performance of concrete. Concrete is remarkably strong in compression but it is equally weak intension. Hence, the use of plain concrete as a structural material is limited to situations where significant tensile stresses and strains do not develop. In the past, attempts have been made to impart improvement in tensile properties of concrete members by way of using conventional reinforced steel bars and also by applying restraining techniques. In some instance, simultaneous improvement in a combination of properties is needed. Such materials are often called “High performance materials” and “Advanced materials” and they are basically different from other conventional materials.

B. Advancement in Concrete Technology

It has been recognized that the addition of small, closely spaced and uniformly dispersed fibres to concrete would act as crack arrestor and would substantially improve its static and dynamic properties. Fibre reinforced concrete is increasingly used on account of advantages of increased static and dynamic tensile strength, energy absorption characteristics and better fatigue strength.

The strength of the composite largely depends on the quantities of fibre used. The increase in the volume of fibres increases the tensile strength and toughness of the concrete. The improvements in the performance of the concrete can be grouped such that its mechanical properties such as compression strength, tensile strength, impact and toughness can be improved.

Better durability is attained by means of increased chemical and freeze-thaw resistance. SIFCON gains importance because it eliminates the use of coarse aggregates. The principle of sustainable construction development requires prudent use of natural resources with best quality. SIFCON could be the one better solution.

Strengthening of existing RC framed buildings for improving seismic resistance is a challenging engineering problem. Many of the existing buildings are found to have inadequate strength, ductility, or stiffness because they were designed and built when modern seismic requirements did not exist.

Various strengthening techniques are used such as,

- Addition of Infill Walls
- Various precast panel walls
- Steel bracings
- Concrete jacketing of frame members
- Increase in beam length

The basic aim of strengthening techniques is to upgrade strength, ductility, and stiffness of the member or the structural system as a whole.

C. Fibre Reinforced Concrete

1) General

Fibre Reinforced Concrete (FRC) is the concrete containing fibrous material which increases its structural integrity. It contains short discrete fibres that are uniformly distributed and randomly oriented. Fibres include steel fibres, glass fibres, synthetic fibres and natural fibres each of which lend varying properties to the concrete. In addition, the character of fibre reinforced concrete changes with the, fibre materials, geometries, distribution, orientation and densities.

2) Effects of Fibres in Concrete

Fibres are usually used in concrete to control cracking due to plastic shrinkage and to drying shrinkage. They also reduce the permeability of concrete and bleeding of water. Some types of fibres produce greater impact and abrasion resistance in concrete.

The amount of fibres added to the concrete mix is expressed as a percentage of total volume of the composite (concrete and fibres), termed as volume fraction (Vf).

Vf typically ranges from 0.1 to 3 %. The aspect ratio (l/d) is calculated by dividing fibre length (l) by its diameter (d). Fibres with the non-circular cross section use an equivalent diameter for the calculation of aspect ratio.

Increasing the aspect ratio of the fibre usually segments the flexural strength and toughness of the matrix.

Steel fibres can improve structural strength, reduce steel reinforcement requirements, improve ductility, impact and abrasion resistance, improves freeze-thaw resistance.

D. Slurry Infiltrated Fibrous Concrete

1) Introduction

Slurry infiltrated fibrous concrete (SIFCON) is one of the new addition to the high performance concrete family. SIFCON is the extension of conventional FRC that differs in terms of fabrication and composition. In FRC, the fibre content varies from 1 to 3 % by volume whereas, in SIFCON, the fibre content varies from 6 to20 %.SIFCON is prepared by cement slurry into a mixing of fibres. Even though, SIFCON is a recent construction material, it has found application in the areas of pavement repairs, repair of bridge structures, safe vaults and defence structures due its excellent absorption capacities. Due to its extraordinary ductility characteristics, it has a lot of potential for application in structures subjected to impact and dynamic loading.

The matrix in SIFCON has no coarse aggregates but has a high cementitious content. However, it may contain fine or coarse sand and additives such as fly ash, micro silica and latex emulsions.

The matrix fineness must be designed so as to properly penetrate (infiltrate) the fibre network placed in the moulds, which could cause substantial reduction in properties.

SIFCON, a high performance material containing a relatively high volume percentage of steel fibres as compared to steel fibre reinforced concrete. It is also termed as a "high-volume fibrous concrete".

SIFCON is a high-strength, high-performance material containing a relatively high volume percentage of steel fibres as compared to steel fibre reinforced concrete (SFRC). It is also sometimes termed as „high- volume fibrous concrete‟. The origin of SIFCON dates to 1979, when Prof. Lankard carried out extensive experiments in his laboratory in Columbus, Ohio, USA and proved that, if the percentage of steel fibres in a cement matrix could be increased substantially, then a material of very high strength could be obtained, which he christened as SIFCON.

While in conventional SFRC, the steel fibre content usually varies from 1 to 3 percent by volume, it varies from 4 to 20 percent in SIFCON depending on the geometry of the fibres and the type of application. The process of making SIFCON is also different, because of its high steel fibre content. While in SFRC, the steel fibres are mixed intimately with the wet or dry mix of concrete, prior to the mix being poured into the forms, SIFCON is made by infiltrating a low-viscosity cement slurry into a bed of steel fibres „pre-packed‟ in forms / moulds. The matrix in SIFCON has no coarse aggregates, but a high cementitious content. The matrix fineness must be designed so as to properly penetrate (infiltrate) the fibre network placed in the moulds, since otherwise, large pores may form leading to a substantial reduction in properties. A controlled quantity of high - range water -reducing admixture (super plasticizer) may be used for improving the flowing characteristics of SIFCON. All types of steel fibres, namely, straight, hooked, or crimped can be used.

2) Properties of SIFCON

SIFCON is a high performance material that possesses excellent mechanical properties coupled with greater energy absorption characteristics.

SIFCON possess properties such as strength (compression, tension, bending and shear), ductility, toughness, durability, stiffness and energy absorption capacity under cyclic loads.

These properties are achieved through an optimized combination of matrix properties, fibre reinforcing parameters and fibre content.

Some of special properties of SIFCON are as follows,

- It has maximum value of shear strength
- It has high modulus of elasticity
- It exhibits an extreme ductility behavior under compression monotonic and high amplitude cyclic loading.
- It has a larger strain capacity
- Flexural Strength found to be very high

3) Application of SIFCON

SIFCON is the best suited material for the application in the following areas,

- Pavement Rehabilitation
- Overlays, Bridge decks and protective revetments
- Seismic and explosive resistant structure
- Security concrete application (Safety vaults, Storing rooms, etc.)
- Precast concrete products
- Protective works in marine environment
- Primary nuclear containment shielding

4) Constituent materials and mix proportions

The primary constituent materials of SIFCON are steel fibres and cement-based slurry. The slurry can contain only cement, cement and sand, or cement and other additives. In most cases, high-range water-reducing admixtures are used in order to improve the flowability of slurry without increasing the water-cement ratio. Fly ash and micro-silica (cementitious materials) are also used as filler material with the replacement of sand in varying proportions.

5) Fibres

A large variety of fibres have investigated for use in SIFCON. Crimped and straight fibres have also been used for some applications. Fibres made from steel, plastic, glass and natural materials such as wood, cellulose are available in variety of shapes, size and thickness. They may be round, flat, crimped and deformed with typical lengths of 6 mm to 150 mm and thickness ranging from 0.005 mm to 0.75 mm.

Main factors that control the performance of the composite material as follows,

- Physical properties of fibres and matrix
- Strength and bond between fibres and matrix
- Physical and chemical adhesion
- Friction

a) Steel Fibres

Early steel fibres used as concrete reinforcement where round and smooth. Today, smooth and straight fibres have largely been replaced by fibres that have either rough surface, hooked ends, or crimped or undulated throughout their length. The use of steel fibre in concrete can improve many properties.

The addition of steel fibres significantly improves many of the engineering properties of mortar and concrete, notably impact strength and toughness. The compressive strength gets slightly affected by the presence of fibres. The addition of 1.5 % by volume of steel fibres can, however, increase the direct tensile strength by up to 40 % and the flexural strength up to 150 %.

The benefits of using steel fibres in concrete are as follows,

1) The steel fibres are generally distributed throughout the given cross section whereas reinforcing bars or wires are placed only where required.
2) Steel fibres are relatively short and closely spaced as compared with continuous reinforcing bars of wires.
3) It is generally not possible to achieve the same area of reinforcement to area of concrete using steel fibres as compared to using a network of reinforcing bars of wires.
4) Steel fibres typically do not significantly alter free shrinkage of concrete, however at high enough dosages they can increase the resistance to cracking and decrease crack width.

Fig. 1: Hook End Steel Fibre

b) Application of Steel Fibres

The applications of steel fibres are as follows,

- Pavement rehabilitation and precast concrete products
- Seismic and explosive resistant structures
- Security concrete applications (Safety vaults, strong rooms, etc.)
- Refractory applications (Soak-pit covers, furnish lintels, etc.)
- Sea protective works
- Primary nuclear containment shielding
- Aero space launching platforms
- Repair, rehabilitation and strengthening of structures
- Concrete mega-structures like off shore and long span structures, solar towers, etc.

E. *Need for Study*

Now-a-days natural and manmade disasters like earthquake, cyclone, etc., play an important role in the behavior of structures. Hence, the structures has to be designed in a good manner, which resists higher seismic and impact forces.

Concrete structures need to be strengthened to increase the load carrying capacity and to make inadequate structures to adequate. Slurry infiltrated fibrous concrete possesses high strength, improved ductility, impact resistance and enhanced energy absorption capacity. So it becomes necessary to study the behavior of SIFCON as strengthened material.

F. *Objective*

This study focuses on Slurry infiltrated fibrous concrete (SIFCON) as an option for strengthening the conventional reinforcement concrete beam. The main thrust of the study has been aimed at characterizing the flexural strength of the beam strengthened with precast SIFCON laminate confinement. The slurry of SIFCON matrix includes cement, and fine aggregate with mix proportions.

II. METHODOLOGY

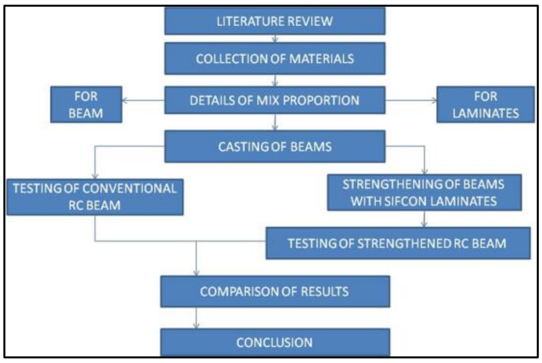

Fig. 2: Methodology

III. EXPERIMENTAL INVESTIGATION

A. *General*

The main objective of present study is to provide a better understanding of the strength and behavior of SIFCON using steel fibres. Therefore, the behavior of such material has to be studied. The structural behavior of reinforced concrete beams strengthened with precast SIFCON laminates is studied through the experimental investigations.

B. *Experimental Procedure*

The experimental program consists of testing of beams with and without SIFCON laminates. Two beams were casted with M30 grade concrete. Three SIFCON specimens were casted and it was left for 28 days of curing. Stirrups with 100mm c/c were used in beams. SIFCON laminates are then bonded to the beam at bottom face. Then test were conducted to study the flexural behavior of strengthened beam.

C. *Collection of Materials*

- Portland Pozolana Cement of 53 grade is used
- Fine aggregate passing through 300µ sieve is used for SIFCON laminates
- Natural river sand has been used as fine aggregate for beams
- Coarse aggregate of size 12mm to 20mm is used for conventional concrete beam
- 12 mm and 6 mm diameter Fe415 HYSD bars are used as main reinforcement and shear reinforcement respectively
- Steel fibres of length 30 mm and 0.5mm diameter is used (Aspect ratio 60)
- Potable water is used for mixing and curing the concrete

D. *Material Properties*

1) *Cement*

The cement used was ordinary Portland cement of 53- grade conforming to IS 12269. The cement should be fresh and of uniform consistency. Where there is evidence of lumps or any foreign matter in the material, it should not be used. The cement should be stored under dry conditions and for as short duration as possible.

2) Aggregates

a) Fine Aggregates

Sand shall be obtained from a reliable supplier .It should be clean, hard, strong, and free of organic impurities and deleterious substance. It should inert with respect to other materials used and of suitable type with regard to strength, density, shrinkage and durability of mortar made with it. Grading of the sand is to be such that a mortar of specified proportions is produced with a uniform distribution of the aggregate, which will have a high density and good workability and which will work into position without segregation and without use of high water content. The fineness of the sand should be such that 100% of it passes standard sieve No.8.The fine aggregate which is the inert material occupying 60 to 75 percent of the volume of mortar must get hard strong nonporous and chemically inert. Fine aggregates conforming to grading zone II with particles greater than 2.36 mm and smaller than 150 mm removed are suitable.

b) Normal Weight Coarse Aggregate

Machine crushed hard granite chips of 67% passing through 20 mm sieve and retained on 12 mm sieve and 33% passing through 12 mm and retained on 10 mm sieve was used a coarse aggregate throughout the work.

3) Water

Water used in the mixing is to be fresh and free from any organic and harmful solutions which will lead to deterioration in the properties of the mortar. Salt water is not to be used. Potable water is fit for use mixing water as well as for curing of beams.

E. Details of Mould

- Beam mould - 1500 mm x 100 mm x 200 mm
- Laminate mould - 500 mm x 100 mm x 50 mm

F. Details of Mix Proportion

1) Design Stipulations for Proportioning

- Grade designation: M30
- Type of cement: PPC cement conforming to IS: 1489 (Part 1)
- Maximum nominal size of aggregate: 20mm
- Minimum cement content: 320 kg/m3
- Maximum water cement ratio: 0.50
- Workability: 50 – 75 mm (slump)
- Exposure condition: Moderate
- Type of aggregate: Crushed angular aggregate
- Maximum cement content: 450 kg/m3

2) Test Data for Materials

- Cement used: PPC
- Specific gravity of cement: 3.05
- Specific gravity of
  - Coarse aggregate: 2.68
  - Fine aggregate: 2.66
- Water absorption
  - Coarse aggregate: 0.85%
  - Fine aggregate: 1.15%
- Sieve analysis
  - Coarse aggregate: conforming to Table 2 IS: 383
  - Fine aggregate: conforming to zone II IS: 383

3) Target Strength for Mix Proportioning

fck = fck+1.65 s

Where

fck = Target average compressive strength at28 days
fck= characteristic compressive strength at 28 days
s= standard deviation
From table 1 standard deviation, s = 5N/mm^2
fck = 30+1.65 x 5 = 38.25 N/mm^2

4) Selection of Water Cement Ratio

From table of IS 456-2000, maximum water cement ratio = 0.50(Moderate exposure)

Based on experience adopt water cement ratio as 0.45

0.45< or = 0.5, hence ok

5) Selection of Water Content

From table of IS 456-2000 maximum water content = 186 liters (for 25mm-50mm slump range and for 20mm aggregates)

Reduce water by about 20%as0.75% SP is used (Based on laboratory trail‟s)

Estimated water content = 152 liters

6) Calculation of Cement Content

Water cement ratio =0.45

Cement content = 152/0.45 =337.7

Say 340 kg/m^3>320 kg/m^3 (given)

From table 5 of IS: 456-2000, minimum cement content for moderate exposure condition=300kg/m^3

Hence OK

7) Proportion of Volume of Coarse Aggregate and Fine Aggregate Content

From table 3 of IS: 456-2000, volume of coarse aggregate corresponding to 20mm size aggregate and fine aggregate (zone II) for water cement ratio of 0.50=0.62.Modify this as w/c is 0.45. The new value is 0.63. Volume of fine aggregate is 0.37

8) Mix Calculations

The mix calculations per unit volume of concrete shall be as follows

- Volume of concrete = 1m
- Volume of cement = (mass of cement / specific gravity of cement) x (1/1000) = (340/3.05) x (1/1000) =0.112m^3
- Volume of water =(152/1)x(1/1000) =0.152m3
- Volume of all in aggregate =a-(b+c) =1-(0.112+0.152) =0.736 m^3
- Weight of coarse aggregate =e x volume of CA x specific gravity of CA =0.736 x 0.63 x 2.68 x 1000 = 1242kg
- Weight of fine aggregate = e x volume of FA x specific gravity of FA =0.736 x 0.37 x 2.66 x 1000 =724kg

9) Mix Proportions

Cement =340 kg/m^3
Water =152 kg/ m^3
Fine aggregate =724 kg/ m^3
Coarse aggregate =1242 kg/ m^3
Water cement ratio =0.45
Mix proportions =340: 724: 1242 = 1: 2.12: 3.65

a) Conventional Concrete

M30 grade concrete is used for making RC beams. The mix proportion of RC beam is shown in Table 1.

Water	Cement	Fine aggregate	Coarse aggregate
0.45	1	2.12	3.65

Table 1: Mix proportion of RC beam

b) Slurry

The slurry consists of cement and fine aggregate. The suitable mix proportion is selected from trial and error method of selection. The optimized mix ratio of 1:3 was selected to prepare the slurry for making SIFCON laminates. The mix ratio was based on cube compressive strength.

c) Steel fibre & volume fraction

The steel fibres used in the study were round crimped fibres having 0.5mm diameter and aspect ratio of 60.

IV. CASTING DETAILS

A. Beams

The mould is arranged properly and placed over a smooth surface. The sides of the mould exposed to the concrete are oiled well to prevent the side walls of mould from absorbing water from concrete and to facilitate easy removal of the specimen.

The reinforcement cages are placed in the moulds and cover between the cage and the form provided is 20mm.Cement mortar block pieces are used as cover blocks. The concrete contents such as cement, sand and water are weighed accurately and mixed. The mixing is done until uniform mix is obtained. It is then well compacted. The test specimens are remoulded after end of 24 hours of casting.

Fig. 3: Casting of Beams

B. Laminate

The mould was arranged properly and placed over watertight smooth surface. The bottom corners of the mould were sealed with POP to prevent leakage. Steel fibres mixed with cement slurry. The casting of SIFCON laminates were shown.

The steps involved in SIFCON mix preparation are

– Dry mixing
– Slurry preparation
– Adding Steel fibres to Cement Slurry
– Slurry infiltration
– Finished SIFCON laminate

Fig. 4: Cement Slurry with Steel fibre

Fig. 5: Finished Sifcon Laminate

V. CURING

Curing is the process in which the concrete is protected from loss of moisture. By this process strength is increased and permeability is decreased. Specimens are cured with jute bags for 28 days. After 28 days of curing, specimens were dried in air and pasted to the beams.

VI. STRENGTHENING OF BEAMS BY LAMINATES

Strengthening is the process to make the elements stronger or more effective. Strengthening may be done either to carry additional loads or make structure adequate. Strengthening of RC structures is frequently required due to inadequate maintenance, excessive loading, and change in use or in code of practice and to adverse environmental conditions. Each strengthening technique will be suited well for given situation. Some of the techniques are as follows.

– Cement Grouting
– Ferro cement laminates
– Section enlargement
– External Plate Bonding
– External Post Tensioning

The SIFCON laminates were used to strengthen the RC beams. The laminates were pasted at the bottom face of the beam. The laminates were bonded to the RC beams with the help of ISO resin for which methyl ethyl ketone peroxide and cobalt octoate (Aeroldite Paste) were used as catalyst and accelerator respectively.

The concrete surface is made rough by wire brush and it is thoroughly cleaned to remove all dirt and debris. The epoxy resin and hardener are weighed in the ratio of 1:1 and mixed thoroughly and applied over the concrete surface. The laminate is then placed on the top of epoxy resin coating such that the warp direction of the fabric is kept along the longitudinal reinforcement of the beam. During hardening of the epoxy, a constant uniform pressure is applied to ensure good contact between the epoxy, the concrete and the laminate. Concrete beams with laminate are cured for 1 days at room temperature before testing.

Fig. 6: Attaching Sifcon laminate over the beam surface

Fig. 7: Conventional and Strengthened beams

VII. TEST SETUP AND TESTING PROCEDURE

The beams were tested under two point loading system. The spandrel beam was placed at one third distance in the mid span of the beam. The beams were placed such that the load from the hydraulic jack is transferred equally to the beam.

The load is increased gradually up to the final failure of the specimen. The test set up was shown.

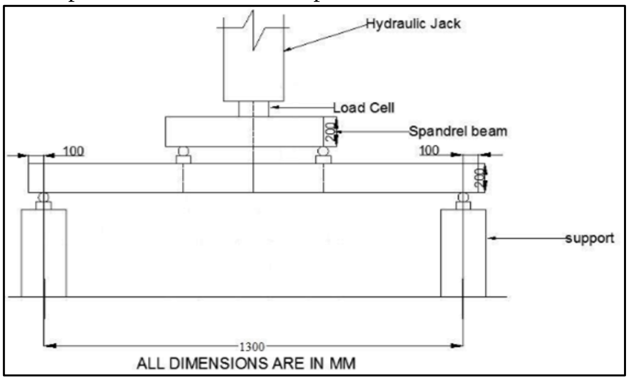

Fig. 8: Test set up

VIII. TESTING OF BEAMS

All the specimens were tested under two point loading condition. The specimen was loaded up to the final failure of the specimens.

Fig. 9: Testing of conventional beam

Fig. 10: Testing of strengthened beam

IX. RESULT AND DISCUSSION

A. Behavior of Beams

1) General

In most field applications, SIFCON is subjected to bending stress, at least partially. Hence, the behavior under flexural loading plays an important role in many applications. An experimental investigation was carried out to study the behavior of flexure RC beam specimens under cyclic loading. The parameters like first crack load and ultimate load carrying capacity were observed. The results of the investigation were discussed in this chapter.

2) Load Behavior

The maximum load level was increased. The beam specimen was loaded with two point loading. The specimen must be carefully aligned with the axis of loading device. The load was increased and decreased in each stage. The first crack load for conventional beam and strengthened beams was found to be 28 kN and 39kN respectively. The ultimate load carrying capacity of strengthened beams was found to be 57 kN whereas the corresponding value for conventional beam were 72kN. The comparison of first crack load and ultimate load for conventional beam and strengthened RC beams were shown

3) Test Results

Beam	First crack Load	Ultimate Load
Conventional	28kN	57kN
Strengthened	39kN	72kN

Table 2: Test Results

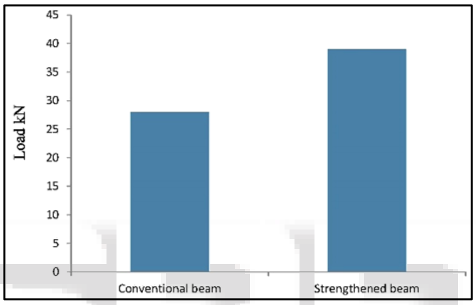

Fig. 11: Comparison of First Crack load

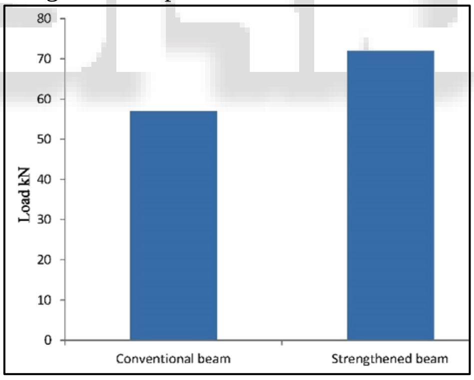

Fig. 12: Comparison of Ultimate load

4) Behavior and Mode of Failure

Conventional beam and strengthened beam have failed in flexure more by yielding steel for RC beams, crushing and spalling of concrete takes place after the yielding of steel in tension zone. Behavior of RC beams under two point loading are listed below,

1) The ultimate load was observed 57kN. More number of cracks have been observed during final failure of the specimen.
2) In strengthened specimen ultimate load was observed 72kN.Less number of cracks have been observed during the final failure of the specimen. This may be due to laminate confinement in bottom face.

Flexural beam with laminate suffers lesser damage as compared to control specimen. The failure pattern of the conventional beam is shown and strengthened RC beam is shown.


Fig. 13: Failure pattern in conventional beam


Fig. 14: Failure pattern in strengthened RC beam

5) Modulus of Rupture

Beam	Maximum load (P)	Modulus of Rupture (fb)
Conventional beam	57kN	0.0214kN/mm^2
Strengthened beam	72kN	0.027kN/mm^2

Table 3: Modulus of Rupture

fb = (P x l) / (b x d2)

Here,

P = Maximum load applied to the specimen

l = length of the specimen

b = Measured width of the specimen

d = Measured depth of the specimen

fb for conventional beam = (57 x 1500) / (100 x 2002) = 0.0214 kN/mm^2

fb for strengthened beam = (72 x 1500) / (100 x 2002) = 0.027 kN/mm^2

X. Conclusion

Based on the results obtained from the experiments, the following conclusions are drawn:

1) SIFCON laminates properly bonded to the tension face of the RC beams can enhance the flexural strength substantially. The SIFCON strengthened beams exhibit an increase in flexural strength based on volume fraction and aspect ratio.
2) At any given load level, the deflections are increased significantly thereby increasing the stiffness for the strengthened beam.
3) A flexible epoxy system will ensure that the bond line does not break before failure and participate fully in the structural resistance of SIFCON.

The tests results are compared with that of conventional RC beam subjected to similar loading condition.

– The first crack load of strengthened beam was found to be greater than that of conventional flexural beam.
– The ultimate load carrying capacity of strengthened beam was found to be higher than that of conventional flexural beam.

From the test results it can be seen that SIFCON strengthened beams perform well in all aspects when compared to conventional beam. Hence, SIFCON proves to be an effective material to enhance the strength and for the repair or strengthening of RC beams.

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