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STRENGTHENING OF RC AND FRC BEAMS WITH PRECAST SIFCON LAMINATES- AN EXPERIMENTAL STUDY

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Abstract - *SIFCON is enormously superior variety of conventional fibre reinforced concrete, is a distinctive construction material having extraordinary properties in the kinds of both strength and ductility. This study presents a method for strengthening of reinforced concrete beams and fibre reinforced concrete beams to enhance the actual load carrying capacity using precast SIFCON laminates, which are directly bonded to bottom face and side faces of the beam by epoxy adhesives and are tested under two-point bending test. The concrete mix for RC beams has been intended to obtain a concrete grade of M30. The fibres used in the study were hooked end steel fibres having 0.5mm diameter and aspect ratio of 60. For laminates, fibre volume fraction was 5%. Results indicate that the strengthening of RC and FRC beams with SIFCON laminates have significant increase in first crack load and formation of large number of finer cracks.*

***Key Words*: SIFCON, Flexural strength, Steel Fibre Fibre Reinforced Concrete**

1.INTRODUCTION

Slurry infiltrated fibre concrete can be considered as a special type of fibre concrete with high fibre content. The matrix usually consists of cement slurry or flowing mortar. The use of SIFCON has an excellent potential for application in areas where high ductility and resistance to impact are needed. Moreover, SIFCON is different from normal FRC. The fibre content of FRC generally varies from 1 to 3 % by volume, but the fibre content of SIFCON varies between 5 and 20 %. In FRC, the fibre is added to the wet or dry mix of the concrete but SIFCON is prepared by infiltrating cement slurry into a bed of fibres preplaced and packed tightly in the molds. The use of SIFCON matrix in reinforced concrete flexural members leads to crack widths 10 times smaller than those obtained using plain concrete. The use of SIFCON matrix in conventional reinforced concrete beams will eliminate the needs for stirrup reinforcement. The use of SIFCON matrix in the compression zone of a flexural member leads to improve ductility and energy absorption. In columns, the use of SIFCON matrix will eliminate the need for ties. The slurry can contain cement and sand or cement and other additives. Due to its high fibre content, SIFCON demonstrates unique and superior mechanical properties in the areas of both strength and ductility. The main differences between FRC and SIFCON, in addition to the clear difference in fibre volume fraction, lie in the absence of coarse aggregates in SIFCON which, if used will hinder the infiltration of the slurry through the dense fibre network. Furthermore, SIFCON contains relatively high cement and water contents when compared to conventional concrete.

Designers refers usually to traditional strengthening techniques that are based on externally bonded steel plates or RC jacketing, while a new solution that is recently gained great favour concerns the use of externally bonded fibre reinforced concrete. All these techniques can be successfully used but have some limitations. In particular, the use of RC jacket is possible by adding a layer of concrete with thickness larger than 60-70 mm due to the presence of rebars that require a minimum concrete cover. The use of SIFCON for strengthening or to repair existing RC beams is proposed herein. The proposed technique considers the use of thin SIFCON laminates, having a thickness of 20mm. An experimental investigation has made to study the strength and behaviour of RC and FRC beams with precast SIFCON laminates subjected to two-point bending test.

2. METHODOLOGY

The work flow of the project starts with the study of various literature reviews. For this is the different journals related to the proposed work are to be collected. From those collected journals the progress of the work, materials to be used are understood. After studying the properties of material the idea for using the materials and their mix design are decided. The mix design is followed by casting, curing of beams. Then the laminate pasted on the beam. This laminate beam is tested. The flexural test is done to measure and identify its strength. After the test, the SIFCON laminate beams are compared with conventional RC beam based on the cracks and ultimate strength.

3. LITERATURE REVIEW

Beglarigale et.al (2016) studied flexural performance of SIFCON composites subjected to high temperature. High temperature resistance is one of the most important parameters which affects the durability and service life of materials. Due to synergistic interaction of different mechanisms, mechanical performance can be lowered especially for the multi- component composite materials exposed to high temperature. Standard or steam cured slurry infiltrated fibre concrete (SIFCON) and slurry specimens were subjected to 300, 600, 750 and 900°C.

Exposing the specimens to 300°C enhanced the mechanical performance, while higher temperatures have detrimental effects on the SIFCON composites such as the loss in the cross section of steel fibres and the destruction of C–S–H structure. Mechanical test results were in accordance with micro-structural and thermal analyses. Microstructural investigation revealed that the loss in the cross section of steel fibres and the destruction of C–S–H structure become greater with an increase in temperature.

Based on the results of this research, it is recommended that SIFCON composites may be produced with a concrete cover against high temperature oxidation of steel fibres, especially for military structures. Further research is required to develop a high temperature oxidation-resistant coating material for steel fibre or a high temperature resistant alloy can be used for fibre reinforcement purposes. [1]

Farnam et.al (2010) studied behaviour of SIFCON under triaxial compression. The stress-strain responses of HSC, HPFRC and two types of SIFCON with 0, 2, 5 and 10% volume fraction of steel fibres subjected to triaxial compression have been investigated via a comprehensive experimental program. The triaxial mechanical properties of SFRC directly depend on two significant parameters including the steel fibre volume and confining pressure. Increase of volume fraction of steel fibres and confining pressure leads to ductile behaviour in SFRC and consequently its softening behaviour changes to plastic and hardening behaviour. Increasing confining pressure and steel fibres volume increases the peak triaxial compressive strength. Also, adding steel fibres increases the Poisson's ratio for high strength concrete particularly for SIFCON with 10% volume fraction of steel fibres. Both confining pressure and fibre content have good effect on the toughness indices and they can raise the toughness of HSC up to 78 times. Shear failure occurred for HSC and HPFRC; whereas a combination of shear and crushing mode of failure was observed for SIFCON with 5% steel fibres. SIFCON with 10% of steel fibre, only crushing mode of failure was observed. SIFCONs have unique triaxial compression characteristics such as high ductility, high triaxial compressive strength and hardening behaviour. [2]

Wang and Maji (1993) studied the shear properties of SIFCON by testing cored cylindrical specimens under pure torsion. Specimens of two different diameters and fibre aspect ratios were tested. Deep beams of SIFCON were tested in bending to obtain the shear resistance properties. Anisotropy in SIFCON was investigated by coring specimens from a slab of SIFCON with the fibres oriented both perpendicular and parallel to the direction of coring. The torsion of cored samples was selected as the testing technique both for the ease of obtaining specimens at a job site, and for the simplicity of analysis. This paper discusses the experimental programme and design implications when a high volume of fibres (up to 12% by volume) is used in a cementitious composite. The fracture patterns observed provided a better insight into the failure of composite materials under the combined action of compressive, shear or tensile stresses, and also the failure along the weak plane. Shear strengths were correlated with the compressive strengths to provide an easy means of determining shear strengths from compressive strength results. [3]

Rao et.al (2010) carried out an experimental program to investigate the behaviour of slurry-infiltrated fibrous concrete slabs under impact loading. Fibre-reinforced concrete, reinforced cement concrete and plain cement concrete slabs were also cast and tested for comparison purposes. The impact force was delivered with a steel ball drop weight. The test results revealed that SIFCON slabs with 12% fibre volume fraction exhibit excellent performance in strength and energy-absorption characteristics when compared with other slab specimens. Regression models have been developed for predicting the energy-absorption capacities for reinforced and unreinforced SIFCON slabs. Energy-absorption capacity of SIFCON slabs increases with increase of fibre volume. The damage under impact in reinforced SIFCON slabs is less when compared with SIFCON slabs without conventional reinforcement. The damage in FRC and RCC slabs is comparatively more than that in SIFCON slabs. [4]

Abdollahi et.al (2012) studied SIFCON strengthening of concrete cylinders in comparison with conventional GFRP confinement method. The experimental part of the work is focused on the investigation of confinement in concrete specimens with unconfined strength ranging from 15 to 40 MPa, enclosed with GFRP sheets or SIFCON jacket. Several parameters such as number of layers, fibre length and jacket thickness for SIFCON method have been investigated. Increase in the thickness of the SIFCON jacket as well as increasing the GFRP layer numbers led to a significant improvement of stress–strain response of confined concrete samples. Thickness of the confining layer is found to be the most effective parameter to improve the confined concrete behaviour in both methods. In many cases, the ultimate strength and absorbed energy of SIFCON-confined concrete is very similar to the results of GFRP-confined cylinders. The comparison shows that SIFCON confinement method can be regarded as a competitive method with respect to the well-known FRP confinement technique. [5]

Yazici1 et.al (2010) studied the effects of steel fibre alignment and high-volume mineral admixture replacement [Class C fly ash (FA) and ground granulated blast furnace slag (GGBS)] on the mechanical properties of SIFCON have been investigated. Ordinary Portland cement was replaced with 50% (by weight) FA or GGBS in SIFCON slurries, and two different steel fibre alignments (random and oriented in one direction) were used. Test results showed that FA and GGBS replacement positively affected mechanical properties (compressive and flexural strength and fracture energy) and fibre alignment is an important factor for superior performance. Binary combination of improved matrices (low water/binder ratio and mineral admixture replacement) and proper fibre orientation enhances mechanical performance, particularly flexural properties of SIFCON. Flexural strength and fracture energy of this composite are 138 MPa and 195,815 N/m, respectively. Scanning electron microscope investigations revealed tobermorite-like structures having different morphology such as foiled, fibrous, and honeycomb with low Ca/Si ratio after autoclaving. [6]

Balaji and Thirugnanam (2013) studied the behaviour of reinforced concrete beams strengthened with precast SIFCON laminates. It is corresponding to two test series has been cast and tested under cyclic loading to study the first crack load, ultimate load and the load deformation behaviour. Control specimen has withstood two cycles of loading and unloading. The maximum deflection was observed under an ultimate load. Numbers of cracks have been observed during the final failure of the specimen. This paper concludes that, the use of SIFCON laminates for reinforced concrete beams improves the load carrying capacity, ductility and energy absorption capacity of the beams. [7]

Nag et.al (2001) investigated about the structural repair of shear deficient reinforced concrete beams using SIFCON. Structural behaviour of shear deficient reinforced concrete beams repaired with SIFCON. Here 14 shear deficient RC beam was studied by externally applied SIFCON jacket. Those repaired with SIFCON displayed an excellent shear capacity. The use of SIFCON jackets as external shear reinforcement has eliminated the brittle shear failure and increased the ultimate strength of repaired beams from 25-55%. This indicates that SIFCON may be considered as a promising material for design – maintain – rehabilitate program of concrete structure. [8]

Bayasil and Zeng (1997) studied about the slurry infiltrated mat concrete is a new kind of fibre reinforced concrete with fibres preplaced in a mat form. In this paper the mechanical properties of SIMCON such as flexural strength and toughness are improved significantly compared with conventional fibre reinforced concrete, due to the high fibre volume fraction and aspect ratio. Twelve series with a total 36 SIMCON specimens were tested under third-point bending. The effects of fibre volume fraction and fibre mat thickness on flexural behaviour of SIMCON were studied. A special failure mode, consisting of a major vertical crack and horizontal branches was observed. [9]

4. EXPERIMENTAL PROGRAM

4.1 Testing Programme

The experimental study consists of casting of three sets of Reinforced Concrete (RC) beams and three sets of Fibre Reinforced Concrete (FRC) beams. In SET1 (CB1, CB2, CB3) beams, three beams weak in flexure were cast which control beams are. In SET2 (SB1,SB2,SB3) beams, three beams weak in flexure were strengthened by pasting laminate at the bottom face. In SET3 (SB4, SB5, SB6) beams, three beams weak in flexure were strengthened by pasting laminate at the bottom and side faces. Similarly, for FRC beams, in SET1 (CB1, CB2, CB3) beams, three beams weak in flexure were cast which control beams are. In SET2 (SB1, SB2, SB3) beams, three beams weak in flexure were strengthened by pasting laminate at the bottom face. In SET3 (SB4, SB5, SB6) beams, three beams weak in flexure were strengthened by pasting laminate at the bottom and side faces. Summary of beam designations are shown in Table 4.1

Table 4.1 Summary of beam test

Beam group	Laminate Confinement	Beam designation	Type of strengthening
Set I	Nil	Control beam CB1 CB2 CB3	No Strengthening
Set II	Single face confinement	Strengthened beam SB1 SB2 SB3	Flexural Strengthening
Set III	Three face confinement	Strengthened beam SB4 SB5 SB6	Flexural Strengthening

4.2 Casting of Specimens

4.2.1 Casting of Cubes

For finding the optimum percentage of steel fibre in SIFCON compression test in cubes were performed. The cubes of size 100 mm× 100 mm ×100 mm where cast at different percentage of steel fibres such as 0%, 5%, 7%, 9%, 11%. First, the mold was filled to the capacity by steel fibres.30 mm long steel fibres with 0.5 mm were used for fibre reinforcement. The procedure was done in three stages along the height of the specimens from bottom to top. To ensure an even dispersion of fibres at each stage, the volume content of fibres was controlled in a way that the same amount of fibre was used for each quarters of specimens. The fibre network was infiltrated by slurries using a light vibration. For each percentage of steel fibre, 3 cubes were cast. The cubes where cured for 28 days.

4.2.2 Casting of Laminates

4.2.2.1 Composition of SIFCON

The matrix in SIFCON has no coarse aggregates, but high cement content. Hooked end fibres of 0.5 mm diameter and aspect ratio of 60 are used to cast SIFCON laminates. Cement, micro silica, fly ash, quartz powder were used for making cement slurry with mix proportion 1:0.1:0.5:0.5. Ordinary portland cement of 53 grade was used. The matrix fineness must be designed so as to properly penetrate (infiltrate) the fibre network placed in the molds, otherwise large pores may form leading to a substantial reduction in properties. In this project we use 0.45 as w\c ratio and the Micro silica (0.1%) of its total volume. Micro silica is used to improves the characteristics of both fresh and harden concrete. Fly ash is 0.5%, used to make substantial contributions to its workability, chemical resistance and the environment. Quartz powder (0.5%) is used to make the concrete denser. The volume of fibre fractions used are 0%, 5% ,7% ,9% ,11%. Fibre volume was calculated according to the volume of the mold for each specimen. Placement of steel fibre to the mould is shown in Fig.4.1.

Fig.4.1 Placement of Steel Fibres in a Mould

3.5.3.2 Preparation

SIFCON is a fabrication method in which steel fibres are pre-placed in the form or in the mould to its full capacity and it is prepared by infiltrating cement slurry into a bed of preplaced fibre as shown in Fig.4.2. Fibre placement is accomplished by hand. External vibration can be applied during the fibre placement operation. After placement of fibres, fine-grained cement based slurry is poured or pumped into the fibre network, infiltrating the air space between the fibres while conforming to the shape of the form or mould. External vibrations can also be used to aid infiltration of the slurry. The main advantage of SIFCON is that very high steel fibre contents can be obtained.

The slurry must be flowable and liquid enough to have sufficient fineness to infiltrate thoroughly the dense matrix in the fibre filled forms. The infiltration step is accomplished by simple gravity-induced flow or gravity flow aided by external vibration or pressure grouting from the bottom of the bed. The choice of infiltration technique is dictated largely by the ease with which the slurry moves through the packed fibre bed. The degree of voids or honey combing extent depends on how flowable is the slurry and the vibration effect.

Fig.4.2 Slurry poured over preplaced fibre matrix

The laminates of size 1000 mm × 100 mm × 20 mm and 1000 mm × 120 mm × 20 mm were cast with 5% of steel fibres. The laminates where cured for 28 days. Typical images of laminates cast were shown in Fig.4.3.

Fig.4.3 Typical Photograph of Laminates

4.3 Strengthening of specimen

Strengthening is done by using SIFCON laminates. SIFCON laminates of 20 mm thick are used for externally strengthening the RC beams. The soffit of the beams and bonding face of SIFCON laminates are sand blasted to remove the surface laitance and then blown free of dust. After surface preparation the adhesive Epoxy resin and hardener with a proportion of 1:1 is applied - No More Nails, paste like consistency is used to bond laminates to the beam soffits. The SIFCON laminates already cast are placed over the beam and held in position by dead weights. For ease of work, the beams are inverted and the laminates placed at the top in the laboratory. But in the field the laminate has to be bonded at the bottom of the beam. The laminate has to be fixed after proper gluing at the bottom of the beam and can be jacked up. The strengthened beams are tested after an interval of 14 days.

Fig.3.8 Typical Photograph of Beam Strengthened with Bottom Face Confinement

Fig.3.9 Typical Photograph of Beam strengthened with three face confinement

5. RESULTS AND DISUSSIONS

5.1 GENERAL

The compression strength of Control Mix and SIFCON cubes for different percentage of steel fibre where tabulated. Analyse the optimum percentage of steel fibre for SIFCON where determined. The tests were done after 28 days of curing.

5.2 CUBE COMPRESSION TEST RESULTS

The compressive strength test result for control mix are shown in Fig 5.1

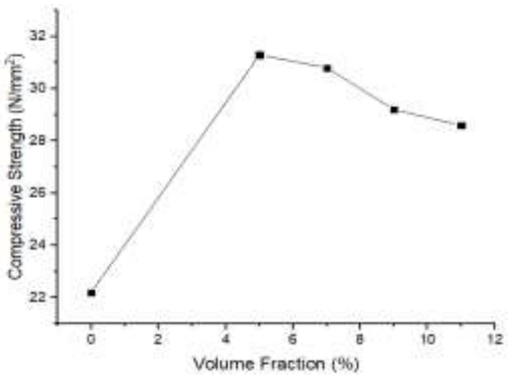

Fig .5.1 Compressive Strength Result Vs Volume Fraction

The compressive strength test results are shown in fig 4.1. The test results of 5.0 percent gives better results, when the volume fraction and consequent fibre content increases, the penetration capacity of cement matrix into the fibre reduces and this could be the reason for reduction in strength for higher volume fraction.

5.3 FLEXURAL TEST RESULT

5.3.1 Test results of RC beams

The variation of deflection with load increment was noted for each sample. The ultimate load of failure was obtained during the test. The nature of failure of the beams were also noted. The average value of ultimate load carrying capacity of all set of beams along with the nature of failure and deflections are described in the table 4.1.

Table 4.1 Experimental result of RC beam

Beam Designation	Laminate Confinement	First Crack Stage		Ultimate Stage	
		Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
SET I	No confinement	20	5.8	37	9.95
SET II	Bottom face Confinement	25	5.6	42	13.01
SET III	Three face Confinement	35	7.01	48	15.05

5.3.2 Load Vs Deflection

The load deflection variation of all the beams was recorded. The load deflection behavior was compared between three set of beams. The graph showing the variation of deflection with load for each set of beams was plotted. The use of SIFCON laminates had influence in delaying the crack formation. Gradual variation of deflection with load is for SET III compared to SET II samples. For a certain value of load, deflection is maximum for SET I sample followed by SET II and SET III.

1) Comparison of Load Vs Deflection

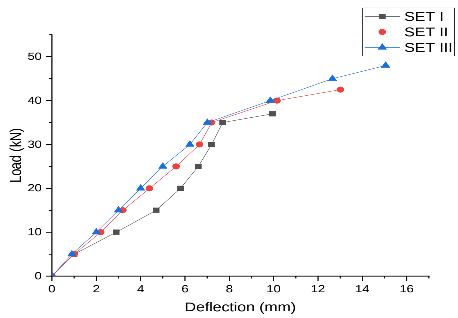

Fig.5.2 Comparison of Load Vs Deflection of RC Beams

5.3.3 Ultimate Load Carrying Capacity

The ultimate load carrying capacity of the control beams and the strengthen beams were found out. It was noted that of all the beams, the strengthen beams had the higher load carrying capacity compared to the SET I. SET III beams have higher load carrying capacity than SET II. The ultimate load carrying capacity was 37kN, 42.5 kN and 48 kN respectively for control, single face confined samples and three face confined samples as shown in Fig.4.6.

It is clear that strengthening of beams with laminates increases the load carrying capacity of beams. The load carrying capacity of beams increases with three face confinement. In a reinforced concrete beam, which has reinforced internally with steel and externally bonding of laminates, there would always remain a substantial reserve capacity of beam, even after the yielding of the steel reinforcement. The beam would continue to carry increasing loads, by virtue of the reserved beam capacity due to laminate bonding, but the rate of carrying increasing amount of load would decrease as compared to the rate of carrying increase the amount of load before steel yielding.

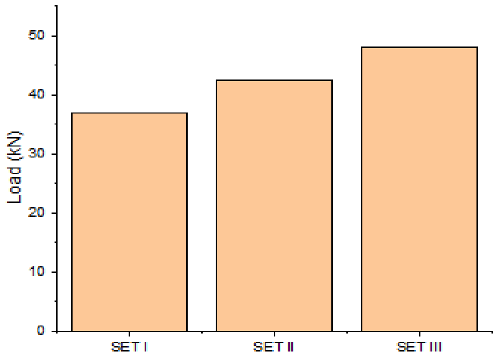

Fig.4.6 Ultimate Load Carrying Capacity of Beams

5.3.4 Behaviour and Modes of Failure

Since all the strengthened and unstrengthened beams were simply supported, hence a large number of flexural cracks developed in the tension zone and these cracks propagates during the increase in loading. In unstrengthened beams, only flexure cracks were seen in the flexural zone, and these cracks propagated with the increase in the magnitude of applied loads until failure. In SET I, the controlled beam had widely spaced and more number of cracks. The beam curvature and deflection increases the collapse by yielding of steel and crushing of concrete in compression zone.

In the case of strengthened beams, cracks were at relatively close spacing. During loading of specimens, then the rupture was observed at the center and followed by the laminate debonding. Debonding occurs at the two sides as well as on the bottom side of the beam. Rupture of the laminate is assumed to occur when the strain in the laminates reaches its design rupture. The beams with laminates in three faces suffer lesser damage as compared to the other specimens. The failure patterns of beams are shown in Fig.5.4

Fig.5.4 Failure Patterns of Beams

6. CONCLUSIONS

This study presents a method for strengthening of reinforced concrete beams and fibre reinforced concrete beams to enhance the actual load carrying capacity using precast SIFCON laminates. Based on the experimental investigations the following conclusions were drawn.

- The optimum percentage of SIFCON was obtained by compression testing. Cubes were casted and tested on different steel fibre volumes of 5% ,7% ,9%, 11%. The SIFCON samples of 5% steel fibre volume were attained as optimum value. When the volume fraction and consequent fibre content increases, the penetration capacity of cement matrix into the fibre reduces and this could be the reason for reduction in strength for higher volume fraction.
- SIFCON laminates properly bonded to the tension face of RC beams can enhance flexural strength substantially.
- The ultimate load carrying capacity of RC beams with confinement only on bottom face was found to be 14% more than that of conventional RC beams.
- The ultimate load carrying capacity of beams with three face confinement was found to be 29 % more than that of conventional RC beams.
- Similarly, for FRC beams strengthened beams exhibited more strength. For single face confinement beam had 55% extra load carrying capacity than control beams. Three face confinement beam had 133% extra load carrying capacity than the control beams.

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