ISSN (Online) : 2454-4159
International Journal of Advanced Research in Science Management and Technology
Volume 2, Issue 5, May 2016

A Research Paper

"Experimental Study on Retrofitted RC Beams with Externally Bonded SIFCON Laminates"

Jitendra Nana Sandanshiv[1] , Dr. S. K. Dubey [2], Prof. S. S. Bachhav[3]

PG Scholar, Dept. of civil Engineering, S.S.V.P'S B.S. Deore college of Engg, Dhule,(M.S.), India[1]

Associate Professor, Dept. of civil Engineering, S.S.V.P'S B.S. Deore college of Engg, Dhule, (M.S.), India[2,3]

ABSTRACT— This paper presents the results of experimental Studies concerning the flexural strengthening of RC beam using externally bonded Slurry Infiltrated Fibrous Concrete (SIFCON) Laminates. Now days it is common observation that structures are unable to offer service as much as they are expected as per design. This is often as a result of deterioration of the concrete and reinforcements caused by environmental factors The Retrofitting will be used as an cost-effective solution to the replacement of these structures and is commonly the sole feasible option. Slurry Infiltrated Fiber Concrete (SIFCON) are well suited to the current application as a result of their high strength-to-weight ratio, good fatigue properties, and wonderful resistance to corrosion. This study presents a method for retrofitting of reinforced concrete beams to enhance the actual load carrying capacity using High Performance fibre Reinforced Cementitious Composites (HPFRCCs) laminates SIFCON and which are directly bonded to the tension face at the soffit of the beam by epoxy adhesives and are tested under compression cyclic loading. In this experimental study, A total of Six beams of size **150 mm width × 230 mm depth × 1650 mm** length and four SIFCON laminates of size **150 mm width × 25 mm depth × 1550 mm** length are casted and tested in the laboratory. The SIFCON laminates are bonded in between the beam supports. Four beams were retrofitted with SIFCON laminates (RBSF1,RBSF2,RBSF3,RBSF4) and remaining two beams were tested under compression loading (CB1 and CB2) and checked up to failure. Static responses of all the beams were evaluated in terms of strength, ductility ratio, stiffness ratio, compositeness between laminate and concrete, and the associated failure modes. Comparison was made between the Control specimen and Strengthened beams.. The results show that the strengthened beams exhibit increased flexural strength, enhanced flexural stiffness, and composite action until failure.

I. INTRODUCTION

The cost of civil infrastructure constitutes a major portion of the national wealth. The rapid deterioration of reinforced concrete structures has thus created an urgent need for the development cost-effective methods for repair, retrofit and new construction. As the number of civil infrastructure systems increases worldwide, the number of deteriorated buildings and structures also increases. Complete replacement is likely to be an increasing financial burden and might certainly be a waste of natural resources if upgrading or Strengthening is a viable alternative.

1.1. HPFRCCs

A new way of resolving this problem is to selectively use advanced composites such as High Performance Fiber Reinforced Cementitious Composites (HPFRCCs). With such materials repair, retrofit, and new construction approaches can be developed effectively. Normally two types of HPFRCCs available in the market namely SIFCON and SIMCON.

1.2. Slurry Infiltrated Fiber Concrete (SIFCON)

ISSN (Online) : 2454-4159
International Journal of Advanced Research in Science Management and Technology
IJARSMT
Volume 2, Issue 5, May 2016

SIFCON is a high-strength, high-performance material containing a relatively high volume percentage of steel fibers as compared to steel fiber 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 fibers 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 fiber content usually varies from 1 to 3 percent by volume, But it varies from 4 to 20 percent in SIFCON depending on the geometry of the fibers and the type of application. The process of making SIFCON is also different, because of its high steel fiber content.

The matrix in SIFCON has no coarse aggregates, but 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, 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. The HPFRCCs was developed in the 1990's to improve performance characteristics of fibre reinforced concrete. The discrete steel fibres and SIFCON laminates are as shown in Fig.1 and Fig. 2.

Fig 1. Discrete Steel Fiber

Fig 2. SIFCON Laminates

The resulting composite material possesses very high strength as well as ductility. In addition it has been demonstrated that SIFCON is highly resistant to dynamic loads such as blast pressure and ballistic penetration. SIFCON can be considered as a special type of fibre concrete with high fibre content. SIFCON has excellent potential for application in areas where high ductility and resistance to impact are needed. Two different volume fraction of steel fibres were used (6 percent and 8 percent).

II. LITERATURE REVIEW

2.1 General

Extensive literature is a major component of any research study. This helps to understand the topic in a better way and get an idea about how different people see the topic different angles the degree of extensibility depends on the magnitude of the research study. However the moderate study like this needs a fair work on literature study. Whatever available and accessible material can be made use of this purpose. The details regarding various references used are also given below.

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. Although, both these methods provide tensile strength to the concrete members but they do not increase the inherent tensile strength of concrete itself. In plain concrete structural cracks develop even before loading particularly due to drying shrinkage. It has been recognized that the addition of small, closely spaced and uniformly dispersed fibers to concrete would act as a crack arrestor and would substantially improve its static and dynamic properties. Fibre reinforced concrete is increasingly used on account of the advantages of increased static and dynamic tensile strength, energy absorption characteristics and better fatigue strength. The strength of composite largely depends on the quantity of fibers used. The increase in the volume of fibers increases the tensile strength and toughness of the concrete. But if a higher percentage of fiber i.e. more than 4% is used, it is likely to cause segregation and balling in concrete and in mortar. Slurry infiltrated fiber concrete (SIFCON) is a special type of fiber reinforced.

The details regarding various references used are also given below.

R.Balamurti Krishnan conducted the experimental study on cyclic behavior of Reinforced concrete Retrofitted with externally Bonded SIFCON laminates. Four laminates of size 125x25x29050 were casted with different volume fraction. and four beams of size 125x250x3200mm.were casted. Comparison was made numerical analysis &experimental results. The result show that the strengthened beam exhibit increased flexural strength enhanced flexural stiffeness, & compare action until failure.

Antany Jeyashear C. & R.Balamurali Krishnan conducted studies on Flexural strengthening of R.C.beams using external bonded high performance Fiber Reinforced Cementitious composites (HPFRCCS). Total of ten reinforced conc.beam were cast and tested in the laboratory. Eight beams were strengthened with bonded SIFON & SIMCON laminates at the bottom under virginal condition and tested until failure.

Nguyen van CHANH, Studies on “Steel Fiber Reinforced Concrete”, In this paper mechanic properties, technologies and application of Steel fiber Reinforced are discussed.

Prafull vijay,sandeep singh, Studies on “Physical and mechanical properties of steel fiber” In this paper Physical and mechanical properties of steel fiber are discussed.

Mr. Okan Duyar,sanjay. A.S., Mert yucel Yardimci, Serdar Audin, Conduct the experiment on “Improvement of self compacting cement slurry for autoclaved SIFCON.”In this study factor affecting the behavior of SIFCON,sample preparation, Test on SIFCON sample are discussed.

R.V.Sarthi &Rama mohan Rao. Conducted experimental study on optimum volume of fraction of fiber mat. Five laminates of size 100x20x500mm were casted with totally different volume fractions (vf) say 1%,2%,3%,4%,5% .and Five beams of size 100x200x1200mm were casted using M25 grade concrete. Flexural strength and deflection was noted.

S.Balagi, G.S.Thirugnanam. Slurry infiltrated fibers concrete (SIFCON) is a novel type of high performance fiber reinforced concrete made by infiltration steel fiber with specially designed concrete.

Abdul Aziz, Farah Nara Aznieta and Elliott Kims conduct the experiment on Flexural strengthening of reinforced concrete beams using precast SIFCON thin plate. Literature has shown that it has been successfully applied for strengthening application such as bridge deck pavement and beam-column joint this research had studied the use of SIFCON material as prefabricated thin (25mm) precast plate for strengthening application. These precast SIFCON this plates were bonded on sides and bottom surfaces of the beam of (experimentally convenient) 100mm x 200mm x 1376mm span were pre-loaded before being strengthened with the precast sifcon thin plates. Results show that, compared to an unstrengthened control beams increased by up to 88.7% whilst the elastic bending stiffness increased by 40%.

Yashar SHAFAEI, studies on "Influence of Hooked end steel fiber on SIFCON" In this paper most of the studies on the mechanical properties of SIFCON have focused on compressive strength and bending stress.

III. METHODOLOGY

Followings are the step wise details of work methodology.

A) Selection of size of Beams and SIFCON Laminates:

i) Beam Size : 150mm X 230mm X 1650mm

ii) SIFCON Laminates Size: 150mm X 25mm X 1550mm.

B) Materials:

1) Steel Fiber

i) Name of Supplier: M/s .STEWOLS India pvt Ltd, Nagpur.

ii) Type of Steel fibre : Hook fibre

iii) Diameter of hook steel fibre: 0.50 mm

iv) Length of steel fibre: 35mm

v) Aspect ratio. 70

2) Ordinary Portland cement of 53 grade.

3) Locally available river sand.

4) Aggregate of size 20mm

5) Grade of concrete used M20 (1:1.5:3) is used

6) Cement slurry for casting of SIFCON Laminates.

i) Sand/Cement ratio : 0.50

ii) water/cement ratio : 0.55

7) Steel for Beams:

i) Top Steel: 2 bars of 10mm dia

ii) Bottom steel: 2 bars of 12 mm dia.

iii) Stirrup: 6mm dia. (Tor steel) at spacing 150mmc/c.

C) Testing of Beams:

The Flexural strength test were conducted on prototype beam and checked up to collapse.

I. 04 numbers of retrofitted RC beams with externally bonded SIFCON laminates were tested on Beam testing Frame.

II. 02 number of control RC beams were tested on Beam testing Frame.

IV. FLOW CHART

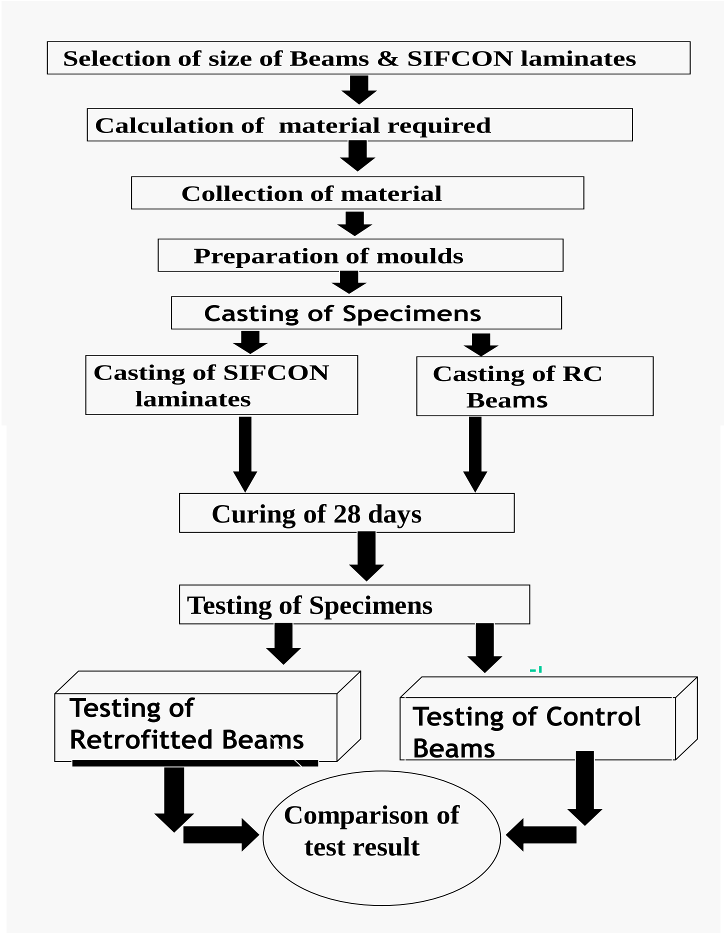

Fig 3. Flowchart

V. EXPERIMENTAL PROGRAM

A) CASTING OF SIFCON LAMINAETS

Four numbers of SIFCON laminates of size 150 × 25 × 1550 mm. Volume fraction Vf = 6.0 for RBSF1,RBSF2 and Volume Fraction 8.0 percent for RBSF3, RBSF4 ..The hand dispersion of steel fibers and grouting process are adopted. The completed SIFCON laminates are shown in Fig.4

ISSN (Online) : 2454-4159
International Journal of Advanced Research in Science Management and Technology
IJARSMT
Volume 2, Issue 5, May 2016

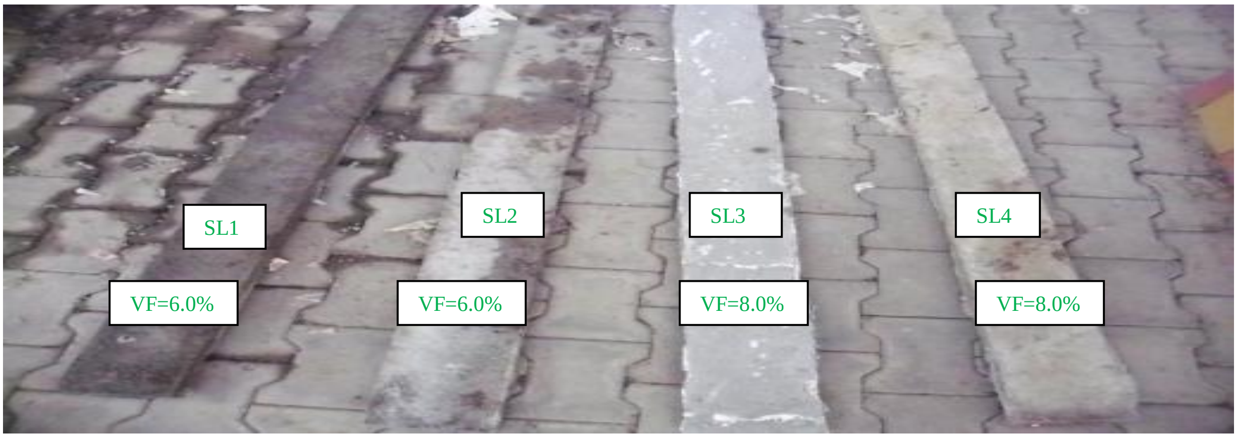

Fig 4. Casted SIFCON Laminates

B) CASTING OF RCC BEAMS

The Six number of RCC beams are casted in laboratory. Top reinforcement,2Nos 10mm dia bar and Bottom reinforcement, 2nos,12mm dia bar are used. Stirrups of 6mm dia Tor steel at spacing of 150 mm c/c are used.

Fig 5. Curing of Casted RCC Beams

ISSN (Online) : 2454-4159
International Journal of Advanced Research in Science Management and Technology
IJARSMT
Volume 2, Issue 5, May 2016

VI. REINFORCEMENT DEAILS OF RC BEAM

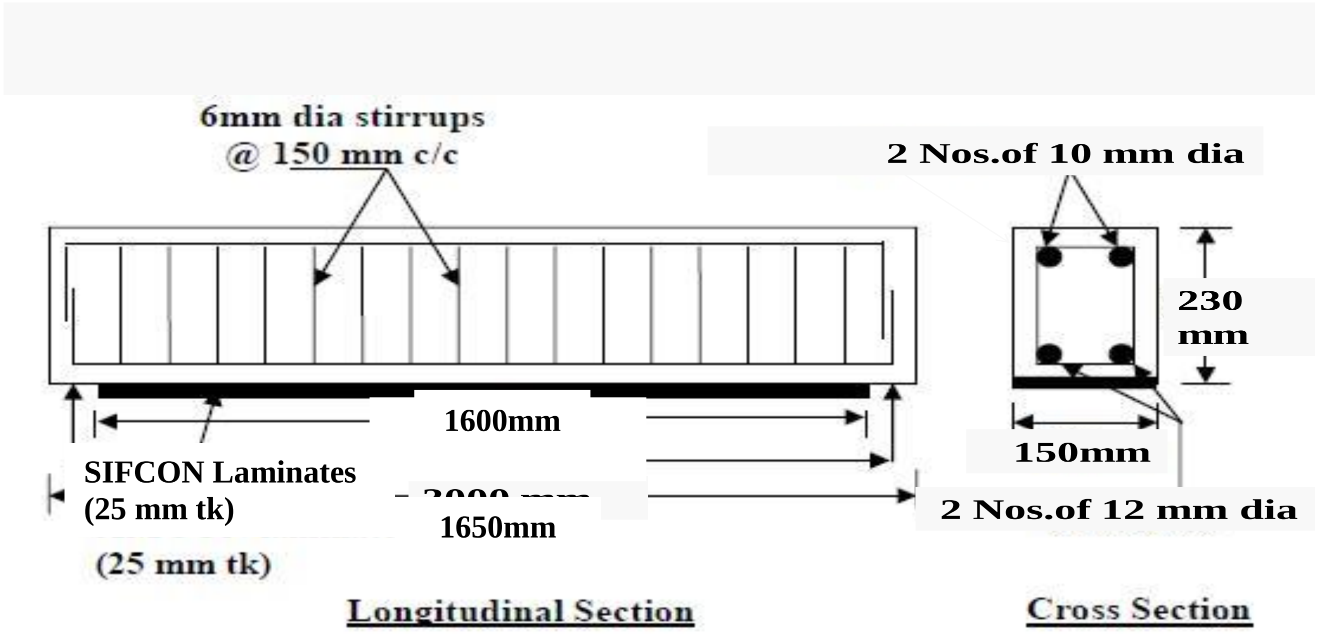

Fig. 6 Reinforcement Details Of RC Beam

Table 1: Details of Control Beams and Strengthened Beam.

Sr.no.	Beam code	Beam type	Steel fiber (SIFCON) Dia (mm)	Steel fiber (SIFCON) Volume Fraction(Vf)	Steel fiber (SIFCON) Aspect Ratio (l/D)	Type of loading	Performance Evaluation
1	CB1	Control beam				Compression Cyclic loading	Strength, Ductility factor, stiffness factor and the mode of failure
2	CB2						
3	RBSF1	Sifcon laminated beam	0.50	6.0 percent	70		
4	RBSF2						
5	RBSF3			8.0 percent	70		
6	RBSF4						

VII. BONDING OF SIFCON LAMINATES

Four numbers of SIFCON laminates of 25 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. After surface preparation, a two - part epoxy adhesive (Araldite Aw 106 as epoxy resins and HV953 IN as Hardener) with paste like consistency is used to bond laminates to the beam soffits. The adhesive has an ultimate tensile strength of 34.80 N/mm2 (ASTM D638), flexural modulus 3377 N/mm2 (ASTM D790), flexural strength 32.0 N/mm2 (ASTM D790), elastic modulus of 1500 N/mm2 (ASTM D638), density 1.35 g/cc (IS4456) the adhesive components are mixed thoroughly and are applied to the surface using a trowel as shown in Fig.7.

Fig.7 Bonding of beam soffit with SIFCON Laminates.

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. Curing time (air curing) required for epoxy resin is maximum of seven days and the temperature is less than 35º C but the test has been conducted after 14 days even though 7 days of curing for epoxy resin is normally adopted.

VIII. EXPERIMENTAL SETUP, TESTING AND MEASUREMENTS

Beams are tested in Two - point bending under compression cyclic loading. The beams are tested till the ultimate load is reached. This is represented in Fig. 8

Fig.8 Compression cyclic loading setup of Control beams and SIFCON laminated beams.

At each stage of loading, the deflections are measured. The crack development and propagation are monitored and marked during the progress of the test. The load - deflection relationships were obtained using deflection measurements. The load - mid span deflection curves are drawn for control (unstrengthened) and strengthened beams under compression cyclic loading conditions as shown in Figs. 8. From the load - deflection it is seen that beam RBSF3 and RBSF4 (under compression cyclic loading) exhibit increased deflection and appreciable flexural strength and enhanced ductility, stiffness when compared to control beams.

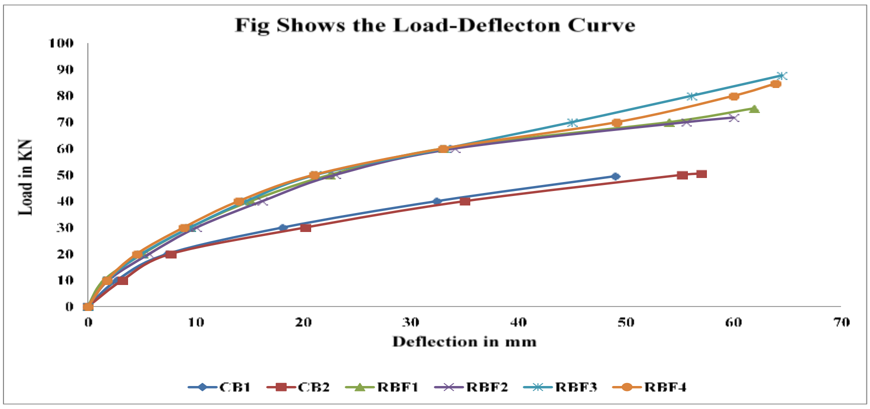

Fig.9 Load-deflection response of Control beams and SIFCON laminated beams

The first crack loads are obtained by visual examination only. The experimental ultimate loads are obtained corresponding to the load beyond which the beam would not sustain additional deformation at the same load intensity. The experimental service load can be calculated from experimental ultimate load divided by partial safety factor and experimental yield loads are obtained corresponding to the stage of loading beyond which the load - deflection response is not linear. The experimental ultimate loads are obtained corresponding to the stage of loading beyond which the beam will not sustain additional deformation at the same load intensity. Based on the experimental results, it can be observed that significant increase in strength can be realized at all the load levels by externally bonding SIFCON laminates. This increase may be attributed to the increase in tensile cracking strength of concrete due to confinement. Further, it is to be noted that increase in load carrying capacity is possible only when other modes of failure do not interfere. All the strengthened beams are also carefully examined prior to and after testing. It is found that failure does not occur at the laminate - concrete interface. This confirms that the composite action continues throughout the load spectrum. The test results on the strength and deformation properties of the control specimens and strengthened beams are reported in Table 2. The derived information is also presented in Table 3.

Table 2. Summaries of test results (SIFCON)

Beam code	First Crack stage		Service Stage		Yield Stage		Ultimate Stage		Average Crack width at Service Load (mm)
	Load (KN)	Central deflection (mm)	Load (KN)	Central deflection (mm)	Load (KN)	Central deflection (mm)	Load (KN)	Central deflection (mm)	
CB1	34.50	27.45	33.00	32.67	35.00	25.13	49.50	49.00	0.18
CB2	37.00	30.10	33.67	38.00	35.10	29.30	50.50	57.00	0.19
RBSF1	69.50	52.20	50.17	41.27	43.20	17.69	75.25	61.90	0.12
RBSF2	65.00	43.00	47.83	40.00	45.00	16.90	71.75	60.00	0.12
RBSF3	82.50	57.25	58.50	43.00	48.00	17.43	87.75	64.50	0.13
RBSF4	80.00	60.00	56.43	42.60	49.50	17.27	84.65	63.90	0.13

Table 3. Derived information (SIFCON)

Beam code	Ductility (deflection) Factor	Stiffness factor	Mode of failure	Type of loading
CB1	1.95	1.01	Flexure	Compression cyclic
CB2	1.95	1.00	Flexure	Compression cyclic
RBSF1	3.50	1.21	Flexure	Compression cyclic
RBSF2	3.55	1.19	Flexure	Compression cyclic
RBSF3	3.70	1.36	Flexure	Compression cyclic
RBSF4	3.71	1.32	Flexure	Compression cyclic

IX. MODES OF FAILURE

During the test, the crack patterns in the beams are noted and the crack patterns are closely analyzed. All the beams strengthened with SIFCON laminates with varying volume fraction experience flexural failure. None of the beams exhibits premature brittle failure. The maximum crack width near yield stage varies between 0.18 mm and 0.19 mm for beam CB1 to CB2, and between 0.12 mm and 0.13 mm for SIFCON strengthened beams (RBSF1 to RBSF4). The maximum crack spacing is 75 to 100 mm for all beams.

X. CONCLUSIONS

1. SIFCON Laminates properly bonded to the tension face of RC beams can enhance flexural Strength substantially.
2. The SIFCON strengthened beams exhibits an increased in flexural strength of 47 percents for laminates having volume of fraction 6 percent and aspect ratio 70.
3. The SIFCON strengthened beams exhibits an increased in flexural strength of 72.40 percents for laminates having volume of fraction 8 percent and aspect ratio 70.
4. At any given load level, the deflections are reduced significantly thereby increasing the Stiffness for the strengthened beams.
5. All the beams strengthened with SIFCON laminates does not exhibit premature brittle failure.
6. A flexible epoxy system will ensure that the bond line does not break before failure and Participate fully in the structural resistance of the strengthened beams.

REFERENCES

[1]. R.Balamurti Krishnan, 12 June 2015 Asian Journal of Civil Engineering (BHRC) Vol.16,No.8 (2015).Cyclic behavior of Reinforced Concrete beams retrofitted with externally bonded SIFCON Laminate.

[2]. C.Antany Jeyashear & R.Balamurali Krishnan , Flexural strengthening of R.C.beams using external bonded high performance Fiber Reinforced Cementitious composites.

[3]. Nguyen van CHANH, "Steel Fiber Reinforced Concrete" Prafull vijay,sandeep singh, "Physical and mechanical properties of steel fiber"

[4]. Mr. Okan Duyar,sanjay.A.S.,Mert yucel Yardimci,Serdar Audin, "Improvement of self compacting cement slurry for autoclaved SIFCON."

[5]. R.V.Sarthi &Rama mohan Rao, *International Journal For Technological Research In Engineering Volume 2, Issue 7,March-2015* "Retrofitting Of RC Beam Elements Using Fibre Reinforced Polymer (FRP), VIT University Vellore-14, Cdmm, Vit University, Vellore- 14.

[6]. A.D.Ambrist & F. focacci experimental study on the effectiveness of fiber reinforced cementious matrix (FRCM) materials for the strengthening of reinforced concrete (RC) beams.

[7]. www.elsevier.com/locate/conbuildmat. "Shear retrofitting of reinforced concrete beam with steel reinforced concrete".

[8]. S.Balagi, G.S.Thirugnanam slurry infiltrated fibers concrete (SIFCON)

[9]. Abdul Aziz, Farah Nara Aznieta and Elliott Kims Flexural strengthening of reinforced concrete beams using precast SIFCON thin plate.

[10]. Z.Bayasi and J.Zeng, "Flexeral behavior of slurry infiltrated Mat concrete (SIMCON)",ACI strruct.J,vol9(4),pp.194-199 November 1997.

[11]. Naaman AE. *Ferrocement Model Code*, International Ferrocement Society, 2003.

[12]. Hollaway LC, Leeming MB. Strengthening of reinforced concrete structures using externally-bonded FRP composites 2005.

[13]. Grace, N. F., G. A. Sayed, A. K. Soliman, and K.R. Saleh (1999b), "Strengthening Reinforced Concrete Beams Using Fiber Reinforced Polymer (FRP) Laminates," ACI Structural Journal/ September- October 1999, pp 865-874.

[14]. IS 456-2000, Code of practice for reinforced concrete design, New Delhi: Bureau of Indian Standards, 2000.