International Journal of Information Movement Vol.3 Issue II (June 2018)
Website: www.ijim.in ISSN: 2456-0553 (online) Pages 10-17

AN EXPERIMENTAL STUDY ON IMPROVEMENT OF RCC BEAM USING FRP COMPOSITES

Er. Vishal Prashar
Research Scholar
M.Tech- Civil (Structural Engg.),
Maharaja Ranjit Singh Punjab Technical University, Bhatinda

Sameer Malhotra
Associate Professor
Civil Engineering Department
Maharaja Ranjit Singh Punjab Technical University, Bhatinda

Abstract-Corrosion of steel in reinforced concrete structures is one of the biggest challenges faced by the civil construction industry today. In reinforced concrete structures, corrosion of steel reinforcement due to harsh environmental conditions considerably reduces the durability and life span of these structures. To overcome this corrosion problem, many new techniques have been tried and found to be either expensive or ineffective. Fiber Reinforced Polymer (FRP) materials in the form of solid bars has been successfully tried as a substitute for steel reinforcement in concrete structures. FRP materials are anti-corrosive, have low weight to strength ratio and are used for various modern engineering applications. After analysis of the experimental results, a design equation was formulated to predict the shear carrying capacity of GFRP web reinforced deep beams. The results obtained by using this equation were found to be acceptable and so, this equation may be adopted for predicting the shear load capacity of deep beams reinforced with GFRP web reinforcement and loaded within a small 'shear span to depth 'ratio.
Index Terms: Fiber Reinforced Polymer, reinforced concrete structures, GFRP, Corrosion

1.0 Introduction

An RCC structure consists of various elements such as columns, beams, slabs, frames, etc. FRP is applied to different RCC structural elements to provide substantial increase in strength and durability.

2.0 RCC Beams

Beams predominantly resist the loads in shear and bending. Improving the behaviour of the beams involves increasing the bending moment and shear capacities.

A. 4.2.1 Flexural Strengthening of RCC Beams

Flexural strengthening of beams or slabs is necessary when the tension steel has yielded or it has deteriorated due to corrosion. Flexural member that are found to have inadequate reinforcement can also be strengthened by this method. The moment-carrying capacity of beams can be increased by external application of FRP plates or sheets with fibre parallel to their longitudinal axes (Meier and Kaiser, 1991). Strengthening of RCC beams or slabs in flexure can be done by bonding the FRP composite to the tension zones of RCC beams with the fibres parallel to the principal stress direction.

B. 4.2.2 Shear Strengthening of RCC Beams

Externally bonded FRP sheets can be used to increase the shear strength of reinforced concrete beams. The shear cracks are often observed at the ends of the beams and sometimes, at several places throughout the span of the beam. The shear capacity of beams can be increased by bonding FRP composites: These includes bonding FRPs on the sides of a beam only, bonding U-jackets to cover both sides and the soffit, and wrapping FRPs around the cross section if possible.

Conventionally both FRP strips and continuous sheets have been used for strengthening of beams both in flexure and shear.

3.0 Assumptions In The Use Of Frp As External Reinforcement

The following assumptions are considered valid for the design of FRP externally bonded reinforcement (Rehabcon, 2000):

- Plane sections remain plain after bending
- There is no slip between the FRP and the concrete
- The tensile strength of concrete is ignored
- The stress-strain response for concrete and steel reinforcement follows the curves presented in codes
- FRP has a linear strain-stress relationship to failure

4.0 Objectives Of The Present Work

It is well known that carbon fibre composites could be extensively used for strengthening of RCC structural elements. However, the major drawback is the heavy cost of the fibres. To overcome this difficulty to some extent, the present work has, for the first time, attempted to use the discontinuous carbon fibres (Carbon Fibre Scrap) which is a waste product of carbon fibres continuous tow obtained from “The Defence Research Development Laboratory” (DRDL), Hyderabad, India. The scrap fibres are used in this work to demonstrate their possible utility in strengthening of structural members at much cheaper cost compared to the conventional fibres used so far. The fibres used in the study were of short length of approximately 150 mm. This work aims at studying the effectiveness of using carbon fibre scrap [CF(S)] composites experimentally for strengthening of RCC structural elements; and to compare its performance with that of the other conventionally used composites. The use of CF(S) as a monolithic fibre and hybrid fibre composite has been investigated.

5.0 Experimental Programme

Three types of RCC structural elements have been considered for study. They are:

- RCC beams subjected to flexural failure
- RCC beams subjected to shear failure
- RCC columns subjected to uniaxial compressive loads

The loading conditions of the RCC specimens along with the measures of rehabilitation adopted for them in this study are presented in the following paragraphs.

C. 5.2.1 Beams Subjected to Flexural and Shear Failures

Simply supported RCC beams were subjected to pure flexural failure by subjecting them to **Four point loading test.** Also shear failure was introduced in beams by increasing the spacing of the stirrups near the supports. Two types of RCC beams have been considered for both, studying the effect of flexural as well as shear failure in beams. They are:

a) Beams having cross section of 100 mm × 100 mm and 500 mm long
b) Beams having cross section of 150mm × 150 mm and 1000 mm long

D. 5.2.2 Details of RCC Beams used in the Study

1) 5.2.2.1 Beams with Cross Section of 100 mm × 100 mm

The beams used in this study were 100 mm × 100 mm in cross section and 500 mm in length. Beams subjected to flexural failure were reinforced with four numbers of 8 mm diameter Tor steel bars (Fe 415) as longitudinal reinforcement. To take care of the shear force near the supports, stirrups of 6 mm diameter mild steel bars (Fe 250) at a spacing of 50 mm centre to centre as per requirements have been used as shown in the Figure 5.1. For beams subjected to shear failure, the reinforcement details were similar to those of the flexural specimens, the only difference being in the spacing of the stirrups. The stirrups were spaced at 230 mm centre to centre as per requirements so as to introduce shear failure. The reinforcement details are shown in Figure 5.2. A cover of 20 mm was provided for all the beams of both types.

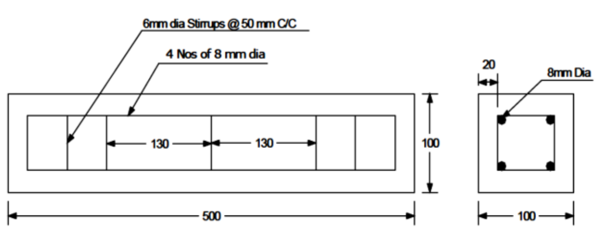

Figure 5.1 Reinforcement Details of Flexure Beams (Size: 100mm × 100 mm)

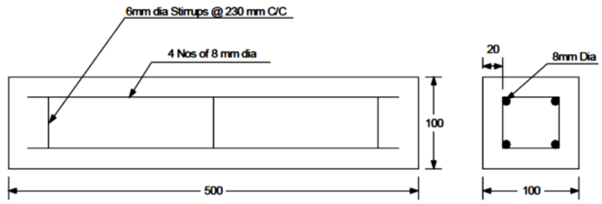

Figure 5.2 Reinforcement Details of Shear Beams (Size: 100mm × 100 mm)

A comparative test programme including twenty four beams [Nine control beams and fifteen beams to be rehabilitated] each for both flexural and shear failures was carried out. Control beams were the ones tested to failure without treatment. Whereas the beams to be rehabilitated were initially loaded to 75% of estimated ultimate load (Virgin beams) (Alfarabi Sharif, 1994) and then rehabilitated using the appropriate FRP composite and finally tested to failure. Three types of strengthening systems, namely:

In this experimental study, the H-CF (S) /GF-RP has been used as an external reinforcement for both the beams failing in flexure and shear. The specifications and properties of CF(S) [obtained from DRDL, Hyderabad] and GF are given in Table 5.1. Epoxy resin was used for binding the fibres to the beams. The resin consisted of two parts namely: Epoxy resin of the specifications Araldite GY 257 and Hardener HY 840 with resin to hardener proportion of 1: 0.5 by weight of resin (data given by the manufacturer and also tested before use). The specification of resin used is given in the Table 5.2. The resin to fibre proportion used in the test obtained by conducting coupon test as per ASTM D 638-1968 was 1:0.5. The glass to carbon fibre proportion was 1:0.25. Figure 5.3 shows the tensile test specimen used in the study. The thickness and tensile strength of the H-CF(S)/GF-RP composite used in the study was 3 mm and 160.9 N/mm² respectively. A total of six beams (three control beams and three rehabilitated beams) each for both flexural and shear failures has been used for the investigation.

Table 5.1 Properties of Carbon and Glass Fibres

Parameters	Carbon fibre scrap	Glass fibre (CSM)
Areal Density	300gms / m^2	300gms / m^2
Diameter	9μ	11μ

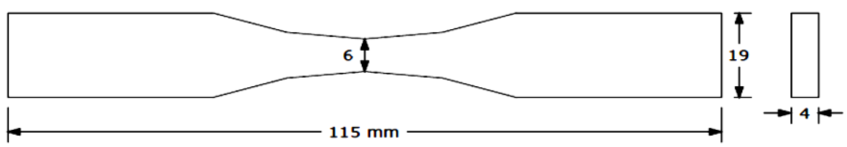

Figure 5.3 FRP Tensile Test Specimen

Table 5.2 Mechanical Properties of Epoxy Resin (as given by the manufacturer)

S.No.	Properties	Araldite GY 257	Hardener HY 840
1.	Density at 25° C g/cc	1.15	0.98
2.	Specific Gravity	1.8	2.0
3.	Flexural Strength N/mm2	45 - 55	30 - 40

2) *5.2.3.2 Strengthening of RCC beams (failing in flexure and shear) using CFRP(S) Composites: (Type 2 beams)*

i) Materials used in Beams

Concrete mix and the reinforcement details used in the beams are the same as given in section 5.2.3.1. i).

ii) Materials used for Rehabilitation of Beams

In this experimental study CFRP(S) has been used as an external reinforcement for both the beams failing in flexure and shear. The CFRP(S) with the specification given in Table 5.1 was used. Resin used for strengthening was the same as discussed under section 5.2.3.1.ii). The resin to fibre proportion used was 1:0.2. The thickness and tensile strength of the CFRP(S) composite used in the study was 3 mm and 146 N/mm² respectively. A total of six beams (three control beams and three rehabilitated beams) each for both flexural and shear failures has been used in the investigation.

3) 5.2.3.3 Strengthening of RCC Beams (Failing in Flexure and Shear) using GFRP (CSM) Composites: (Type 2 beams)

i) Materials used in Beams

Concrete mix and the reinforcement details used in the beams are the same as given in section 5.2.3.1. i).

ii) Materials used for Rehabilitation of Beams

In this study GFRP (Chopped Stranded Mat -CSM) has been used as an external FRP reinforcement for both the beams failing in flexure and shear. The specifications and properties of glass fibre are given in Table 5.1. Epoxy resin of the same specifications addressed in 5.2.3.1.ii) was used. The resin to fibre proportion used was 1:0.2. The thickness and tensile strength of the GFRP composite used in the study was 3 mm and 194 N/mm² respectively. A total of six beams (three control beams and three rehabilitated beams) each for both flexural and shear failures has been used in the investigation.

4) 5.2.3.4 Strengthening of RCC Beams (Failing in Flexure and Shear) using H-CF(S)/GF-RP and H-CF(C)/GF-RP Composites: (Type 3 beams)

To investigate the performance of the hybrid composite using H-CF (S) /GF-RP, a comparative study of the above said type with that of a hybrid of HCF(C) /GF-RP has been made in this study. A total of nine beams (Control beam-3 nos. and Rehabilitated beams- 6 nos.) each for both flexural and shear failures have been used in the investigation.

i) Materials used in Beams

Concrete mix and the reinforcement details used in the beams are the same as given in section 5.2.3.1. i).

ii) Materials used for Rehabilitation of Beams

In this work a comparative performance of two types of hybrid strengthening systems has been made. For this, CFRP(S) and GFRP with the same properties discussed earlier have been used. Also CFRP(C) has been used. The properties of CFRP(C) (as given by the manufacturer) are given in Table 5.3. Epoxy resin of the same specifications addressed in 5.2.3.1.ii) was used.

Table 5.3 Properties of Carbon Fibre (Continuous Tow)

Parameter	Carbon Fibre Continuous Tow
No of filaments	3,20,000
Density	1.36 – 1.39 gm/cc^3
Breaking Strain	15% (Minimum)
Single filament diameter	11 – 14 Micrometer
Tensile Strength	160 Mpa (Minimum)

The resin to fibre proportion used was 1:0.5 for both the hybrids of CFRP(S) and CFRP(C). The glass to carbon fibre proportion was 1:0.3 for both the composites. The thickness of the hybrid composite used in the study was 3 mm for both the types and the tensile strength was 160.9 N/mm² and 81.21 N/mm² for hybrid of CFRP(S) and CFRP(C), respectively.

E. 5.2.4 Beams with Cross Section of 150mm × 150 mm: (Type 1 & 2)

The beams used in this study were of 150 mm x 150 mm in cross section and 1000 mm in length. Beams subjected to flexural failure were reinforced with three numbers of 10 mm diameter Tor steel bars (Fe 415) on the tension side and two 8 mm diameter Tor steel bars (Fe 415) on the compression side. To take care of the shear force near the supports, stirrups of 6 mm diameter mild steel bars (Fe 250) at a spacing of 160 mm centre to centre as per requirements have been used as shown in the Figure 5.4. For beams subjected to shear failure, the reinforcement details were similar to those of the flexural specimens, the only difference being in the spacing of the stirrups. The stirrups were spaced at 250mm centre to centre so as to introduce shear failure. The reinforcement details are shown in Figure 5.5. Figure 5.6 shows the cross sectional details of the beams. A cover of 20 mm was provided for all the beams of both types.

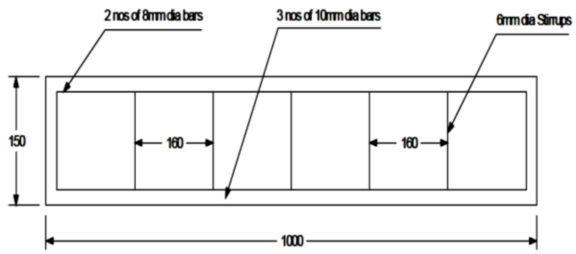

Figure 5.4 Reinforcement Details of Flexure Beams (Size: 150mm x 150mm)

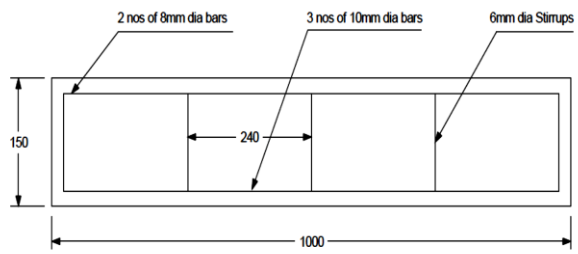

Figure 5.5 Reinforcement Details of Shear Beams (Size: 150mm x 150mm)

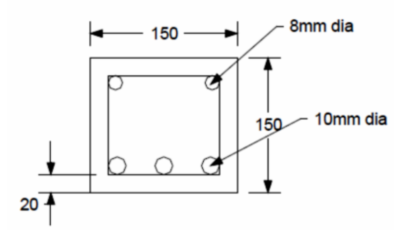

Figure 5.6 Cross Sectional Details of Flexure and Shear Beams (Size: 150mm x 150mm)

A comparative test programme including nine beams (three control beams and six rehabilitated beams) each for both flexural and shear failures was carried out. Two types of strengthening systems have been used. They are:
a) Monolithic composite of carbon fibre (scrap) [CFRP(S)] and
b) Monolithic composite of carbon fibre (continuous tow) [CFRP(C)]
To investigate the performance of the monolithic composite of carbon fibre (scrap) a comparative study between the above mentioned systems have been made.

i) Materials used in Beams

Concrete mix used in these beams was the same as given under section 5.2.3.1. i).

ii) Materials used for Rehabilitation of Beams

In this work a comparative performance of two types of monolithic strengthening systems has been made. For this, CFRP(S) and CFRP(C) with the same properties as discussed earlier have been used. Epoxy resin of the same specifications discussed earlier has been used to bind the fibres. The resin to fibre proportion used in the test was 1:0.2 for both the composites of CFRP (S) and CFRP (C). The thickness of the hybrid composite used in the study was 3.0 mm for both the types and the tensile strength were 146 N/mm² and 179 N/mm² for CFRP(S) and CFRP(C) respectively.

F. 5.2.5 Technique of Bonding FRP to Concrete Specimens

The fibres were bonded to the specimens to be rehabilitated (beams failing in flexure, shear and columns subjected to axial compressive loads) using epoxy resin by **hand lay-up technique.** The process of applying a fibre sheet to concrete specimens involved the following operations **(ACI, 2000)**:

• **Surface Preparation**

The surface of the test specimens to be rehabilitated with composites was initially roughened by chipping of the surface by means of a pointed chisel. This ensures good bonding of the fibres to the surface. The surface was then cleaned to remove of all loose and spalled portions.

• **Resin Undercoating**

Epoxy resin and hardener in correct proportion were taken and mixed thoroughly till a uniform colour was obtained. Also depending on the fibre composite, the correct resin to fibre proportion obtained from the coupon test was used to bind the fibres. Initially a thin coat of this mixture was applied over the prepared surface. The resin flows and fills the cracks in the specimen.

• **Fibre Sheet Application**

The fibres were oriented according to the nature of the structural element and the loading conditions as discussed earlier. Extensive care was exercised to ensure that there was no gap left between the fibres.

• **Resin Over Coating**

Finally a layer of resin-hardener mixture was applied. Care was taken to see that uniform thickness of the composite was maintained throughout the specimen by placing small weights uniformly over the specimens. The specimens bonded with FRP composites were allowed to cure and acquire strength for a period of two to three days before they were taken for testing.

G. 5.2.6 Experimental Set Up of Specimens and Details of Measurements Done for RCC Beams Subjected to Both Flexural and Shear Failures

All beams (both 500mm and 1000mm lengths) were tested as simply supported beams under four point loading, over an effective span of 400 mm and 900 mm in case of beams with 500 mm and 1000 mm length respectively.
Some of the beams were tested to failure. These beams (referred as "**Control beams**" in this report) serve as reference to ascertain the actual capacity of the beams. The beams to be strengthened were initially loaded to 75 % of the estimated ultimate capacity. These beams were then strengthened with the appropriate FRP composite and tested to failure (referred as "**rehabilitated beams**"). The loads were applied at a distance of 66.7 mm on either side of the mid span of the beams of 500 mm length, as shown in Figure 5.19. For beams of 1000 mm length, loads were applied at a distance of 150 mm on either side of the mid span of the beams as shown in Figures 5.20. Beams of length 500 mm

were tested in the Universal Testing Machine of capacity 100 tonnes. Beams of length 1000 mm were tested in a loading frame of 50 tonnes capacity. The loads were monitored through a high accuracy load cell with a load sensitivity of 0.1 tonnes. In both the cases the mid span deflection was measured using dial gauges of least count 0.01mm. The parameters such as initial cracking load, ultimate load and the deflected shape of the specimens were noted.

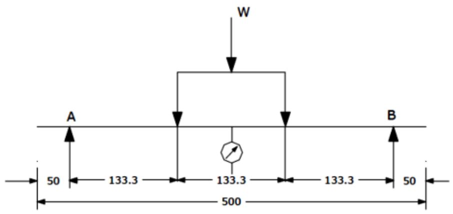

Figure 5.19 Experimental Set up of Beam of Length 500 mm

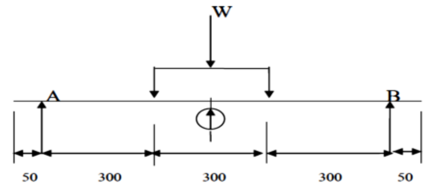

Figure 5.20 Experimental Setup of Beam of Length 1000 mm

6.0 Results And Discussion

H. 6.1.1 Tensile Strength Test on Composites

As discussed in the previous Chapter, the FRP composites used in the experimental study were tested for their tensile strength values using coupons as per **ASTM D 638-1968**. Table 6.1 depicts the tensile strength of the composites used throughout in the experimental study.

Table 6.1 Tensile Strength Values of FRP Composites

S. No	Type of Composite	Resin to Fibre Proportion	Glass to Carbon fibre Proportion	Tensile Strength N/mm^2
1.	CFRP(S)	1:0.2	___	146
2.	GFRP	1:0.2	___	194
3.	CFRP(C)	1:0.2	___	179
4.	H-CF (S) /GF-RP	1:0.5	1:0.3	161
5.	H-CF (C) /GF-RP	1:0.5	1:0.3	81.2

II. 6.2 BEAMS SUBJECTED TO FLEXURAL FAILURE: (SIZE: 100MM × 100MM AND 500MM LONG)

RCC beams of size 100mmx100mm and 500 mm long were experimented. As indicated in Chapter 5, the beams were subjected to three types of treatment measures namely:

• **Type 1:** involving control beams and beams treated with H-CF(S)/GFRP composite
• **Type 2:** involving control beams and those beams treated using monolithic fibre composites namely:
i) CFRP (S) and
ii) CFRP composites
• **Type 3:** involving control beams and those beams treated with two types of hybrid composites namely:
i) H-CF(S)/GF-RP composite and
ii) H-CF(C)/GF-RP composite

The results of the experimental study are shown in Table 6.2 and the comparisons of their experimental results are shown in Table 6.3.

Table 6.2 FLEXURE BEAM (100mm × 100mm, 500mm long)

S. No	Parameters	Type-1		Type-2			Type-3		
		Control beam	H-CF(S)/ GF-RP treated	Control beam	CFRP (S) Treated	CFRP composites treated	Control beam	H-CF(S)/ GF-RP treated	H-CF(C)/ GF-RP treated
1	Initial crack load (kN)	29	49.7	18	49	21	17	23.7	45.3
2	Ultimate load (kN)	58	76	48.6	85	55.6	76	82	85
3	Ultimate deflection (mm)	1.56	1.87	1.86	3.25	1.6	2.04	4.37	2.79
4	Yield load (kN)	38	40	20	15	20	44	38	40
5	Yield deflection (mm)	0.82	0.80	0.67	0.45	0.51	0.85	1.23	0.92
6	Deflection ductility	1.90	2.34	2.78	7.22	3.14	2.4	3.55	3.03
7	Stiffness at yield load (kN/mm)	46.3	50	29.9	33.33	39.2	51.8	30.9	43.5
8	Stiffness at ultimate load (kN /mm)	37.2	40.6	26.13	26.15	34.75	37.3	18.8	30.5
9	Energy Absorption (kN-mm)	53.8	82.8	20.43	133.8	52.3	93	217.5	136.1

Table 6.3 FLEXURE BEAM (Comparison of results) (100mm × 100mm, 500mm long)

S. No	Parameters	Type-1	Type-2			Type-3		
		Comparison of treated beams with that of control beams %	Comparison of treated beams with that of control beams %		Comparison of GFRP treated beams with that of CFRP(S) treated beams %	Comparison of treated beams with that of control beams %		Comparison of H-CF(C)/GFRP Treated beams with that of H-CF(S)/GFRP treated beams %
			CFRP (S) Treated	CFRP		H-CF(S)/ GFRP	H-CF(S)/ GFRP	
1	Initial crack load (kN)	71.4	172	16.67	-19.0	39.41	166.5	91.04
2	Ultimate load (kN)	31.03	74.9	14.4	-34.6	7.9	11.84	3.66*
3	Deflection ductility	23.16	159.7	12.95	-56.51	47.92	26.25	-14.65**
4	Stiffness at yield load (kN/mm)	7.8	11.37	31.1	-17.72	-40.35	-16.02	40.78
5	Stiffness at ultimate load (kN /mm)	9.14	0.19	33.14	-32.88	-49.6	-18.23	62.23
6	Energy Absorption (kN-mm)	53.9	569.6	156	-61.77	133.87	46.34	-37.43

*** shows % increase in values, ** shows % decrease in values**

A. 6.2.1 Comparison of rehabilitated beams with those of their control beams (size 100 × 100 × 500 mm long) under flexure

- The Type 1 beams rehabilitated using the hybrid combination of HCF(S)/GF-RP composite showed 71%, 31.03%, 23.16%, 7.8%, 9.14% and 53.9% increase in initial cracking load, ultimate load, deflection ductility, stiffness at yield load, stiffness at ultimate load and energy absorption values respectively when compared with their control beams.
- The beams rehabilitated using CFRP(S) composites in Type 2 beams showed an increase of 172%, 74.9%, 159.7%, 11.37%, 0.19% and 570% respectively in initial cracking load, ultimate load, deflection ductility, stiffness at yield load, stiffness at ultimate load and energy absorption values respectively when compared with their control beams.
- The beams rehabilitated using GFRP composites in Type 2 beams showed an increase of 16.67%, 14.4%, 12.95%, 31.1%, 33.14% and 156% respectively in initial cracking load, ultimate load, deflection ductility, stiffness at yield load, stiffness at ultimate load and energy absorption values respectively when compared with their control beams.
- In Type 3 beams, the beams rehabilitated using the hybrid combination of H-CF(S)/GF-RP composite indicated an increase of 39.41%, 7.9%, 47.92% and 134% respectively in initial cracking load, ultimate load, deflection ductility and energy absorption values and a decrease of 40.35% and 49.6% in stiffness at yield load and stiffness at ultimate load values respectively when compared with the control beams.
- The beams rehabilitated using the hybrid combination of H-CF(C)/GF-RP composite in Type 3 variety of flexure beams showed an increase of 166.5%, 11.84%, 26.25% and 46.34% respectively in initial cracking load, ultimate load, deflection ductility and energy absorption values respectively and a decrease of 16.02% and 18.23% in stiffness at yield load and stiffness at ultimate load respectively compared to the control beams.

Inference on the above results

From the above results it can be clearly seen that all the FRP composites with monolithic fibres used [namely CFRP(S), GFRP and CFRP(C)] for rehabilitation of flexural beams of size 100mm x 100mm and 500mm length show enhanced performance with respect to parameters such as initial cracking load, ultimate load, deflection ductility, energy absorption, stiffness at yield and stiffness at ultimate load when compared with the control beams. This shows that these monolithic composites are very effective in rehabilitation of RCC beams failing in flexure. Similar behaviour was noticed for CF(C) by Alfarabi Sharif et al, (1994); Triantafillou (1992); Nanni, (1997) and Ayman M. Okeil, (2001). Similarly the hybrid FRP composites [namely, HCF(S)/GF-RP and H-CF(C)/GF-RP] used for treatment of RCC beams also show better performance with respect to parameters such as cracking and ultimate loads, deflection ductility and energy absorption of control beams. However the stiffness of these hybrid composites at yield and ultimate loads were lower than those of the control beams. Similar behaviour was reported for CF(C) by Xiong et al, (2004). Hence it can be concluded that the CFRP(S) composite behaves in the same way as GFRP and CFRP(C) composite.

B. Comparison of performance of beams rehabilitated with other composites with those of beams rehabilitated using CFRP(S) composites

- In Type 2 variety of beams, the beams rehabilitated using GFRP composites show a decrease of 19%, 34.6%, 56.51%, 17.72% and 61.77% in initial cracking load, ultimate load, deflection ductility, stiffness at yield load and energy absorption respectively and an increase of 32.88% in stiffness at ultimate load when compared to CFRP(S) treated beams.
- In Type 3 variety of beams, the beams treated using H-CF(C)/GF-RP indicated an increase of 91.04%, 3.66%, 40.78% and 62.23% respectively in initial cracking load, ultimate load, stiffness at yield load and stiffness at ultimate load respectively and a decrease of 14.65% and 37.43% in deflection ductility and energy absorption values compared to H-CF(S)/GF-RP treated beams.

7.0 Conclusion

From the above results it can be concluded that **the performance of Carbon fibre reinforced scrap [CFRP(S)] with that of Glass fibre reinforced (GFRP) polymer composite is superior** with respect to initial and ultimate load carrying capacities, stiffness at ultimate loads and energy absorption values. However the stiffness at ultimate load of CFRP(S) was lower than that of GFRP composite. This shows that when the CFRP(S) is used as monolithic fibres they show slightly brittle characteristics with low stiffness at ultimate load when compared to GFRP composites. However, when the CFRP(S) is used as a hybrid along with GFRP [i.e. H-CF(S)/GF-RP], its performance is better with respect to deflection ductility even though the other parameters are lower than that of the hybrid of HCF(C)/GF-RP composites. This shows that **when CFRP(S) is used as a hybrid it has better ductile properties compared with other composites**.

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