ISSN:2231-0711
www.ijcset.net

Flexural Behaviour of Composite High Strength Concrete – Fibre Reinforced Polymer Beams

R.S.Ravichandran, K. Suguna* and P.N. Raghunath*
Department of Civil and Structural Engineering,
Annamalai University, Chidambaram-608 001, India
*pnr_ks@yahoo.com

***Abstract*—This paper presents the results of an experimental study conducted to examine the effectiveness of Glass Fibre Reinforced Polymer (GFRP) laminates in enhancing the flexural capacity of high strength concrete beams. In this study, a total of ten beams of size 150 mm x 250 mm in cross-section with a total length of 3000 mm were cast and tested. Eight beams were strengthened with chopped strand mat glass fibre reinforced polymer and uni-directional cloth glass fibre reinforced polymer of 3mm and 5mm thickness. The study parameters included the reinforcement ratio, GFRP laminate material and their thickness. All the beam specimens were subjected to four-point bending test in a loading frame. Deflection and strain measurements have been made through appropriate instrumentation. The results show that the GFRP strengthened beams exhibit increased strength, flexural stiffness and composite action until failure.**

***Keywords*— GFRP, HSC beams, laminates, strengthened**

I. INTRODUCTION

There is a growing need to strengthen and upgrade the infrastructure because of over-loading, aging of structures, mistakes in constructional error, affected by earthquakes, fire, blast loading, corrosion of steel reinforcement, de-icing salts etc. Many traditional practices have been developed and adopted over the years. Recently, considerable attention has been focused on the use of Fibre Reinforced Polymer (FRP) for structural rehabilitation and strengthening. It has been recognized for high strength to weight ratio, good fatigue life, ease of transportation and handling, low maintenance cost and good corrosion resistance. They have been extensively used in aerospace, automotive and other fields.

A review of literature indicates that considerable research effort has been directed towards the use of FRP's for structural strengthening and rehabilitation applications in civil engineering. Numerous studies have been devoted to reinforced concrete beams strengthened with externally bonded steel plates, FRP laminates/sheets both experimentally and analytically.

Hamoush et al analytically investigated the behaviour of damaged concrete beams strengthened by externally bonded steel plates using linear elastic fracture mechanics and the finite element method. The results indicated that the flexural cracks exist within a short region in the mid-span of the beam. Hussain et al conducted a study on the flexural behaviour of pre-cracked RC beams strengthened externally by steel plates. The authors examined the effects of plate thickness and end anchorage on ductility, ultimate load and failure mode. They suggested a design procedure to avoid premature failure of plate. The results showed that the repaired beams exhibited higher strength than the virgin beams; the ductility of the repaired beams decreased with increase in plate thickness; the end anchorages provided only marginal effect in improving the ultimate strength. Suguna et al carried out an experimental investigation on the strength and ductility of RC beams externally bonded with corrosion resistant stainless steel (CRSS) plate. The study concluded that RC beams with externally bonded steel plates exhibited enhanced strength, improved flexural stiffness, adequate ductility and composite action until failure. A simple section analysis procedure has also been proposed for predicting the load - displacement response of the reinforced beams. A close agreement was observed with the test results.

Ritchie et al experimentally studied the effectiveness of strengthening concrete beams using FRP plates. The results showed a significant increase in stiffness and ultimate strength for beams strengthened with FRP plates. Spadea et al investigated the strength and ductility of R.C. beams repaired with CFRP laminates. They examined the effects of retrofitting on strength, deflection, curvature and energy. They concluded that suitably designed and positioned external anchorages enabled more ductile failures of the CFRP strengthened beams. Toutanji et al carried out a study on beams retrofitted with CFRP laminates. The study showed an increase of up to 170 % in ultimate as compared to control beams. Raghunath et al investigated the structural response of RC beams with externally bonded GFRP reinforcement. They concluded that significant improvement in structural performance can be realised through this technique. They also proposed an Adaptive Neuro - Fuzzy Inference System (ANFIS) model for the purpose. The predictions of the model were found to agree well with the experimental results.

High strength concrete (HSC) are used extensively in the construction projects throughout the world. It has proved to be popular in terms of economy, stiffness and durability. The lack of ductility of high strength concrete can result in sudden failure without warning in some structural members. In seismic prone areas, ductility is an important factor to be considered in design of HSC members under flexure. In spite of many studies, the effectiveness of fibre reinforced polymer in high strength concrete beams has not been explored. This study examined experimentally the flexural behaviour of HSC beams strengthened with different types of GFRP laminates. The main variables in this study were the reinforcement ratio, type of GFRP laminate and thickness of laminate.

II. MATERIALS AND METHODS

Materials used

The concrete used for all beam specimens had a compressive strength of 64MPa. The concrete consisted of

450 kg/m^3 of ordinary Portland cement, 780 kg/m^3 of fine aggregate, 680 kg/m^3 of coarse aggregate, 450 kg/m^3 of medium aggregate, 0.36 water/cement ratio and 0.8% of hyperplasticizer. The reinforcement of high yield strength deformed bars of characteristic strength 456MPa were used for the longitudinal reinforcement. The lateral ties consisted of mild steel bars of yield strength 300MPa. The specimens were provided with 8mm diameter stirrups at 150 mm spacing. Two types of GFRP laminates were used for the study, namely, Chopped Strand Mat (CSM) and Uni-directional Cloth (UDC) of 3mm and 5mm thickness. The properties of GFRP are shown in Table 1.

TABLE1 Properties of GFRP Laminates

Type of GFRP	Thickness (mm)	Elasticity Modulus (MPa)	Ultimate Elongation (%)	Tensile Strength (MPa)
Chopped Strand Mat	3	7467.46	1.69	126.20
	5	11386.86	1.37	156.00
Uni-Directional Cloth	3	13965.63	3.02	446.90
	5	17365.38	2.60	451.50

Details of Beams

A total of 10 beams were tested. The main test variables considered in the study were steel reinforcement ratio, type of GFRP laminate and thickness of GFRP laminate. The beams were 150 x 250 mm in cross-section and 3000 mm in length as shown in Figs.1-2. The beams of A series were reinforced with two numbers of 10 mm diameter bars giving a steel ratio of 0.419%. The beams of B series were reinforced with three 10 mm diameter bars giving a steel ratio of 0.628%. Stirrups of 8 mm diameter, at a spacing of 150 mm, were used for the beams. Out of ten beams, two served as control beams and the remaining beams were strengthened with GFRP laminate. The details of beams are presented in Table.2

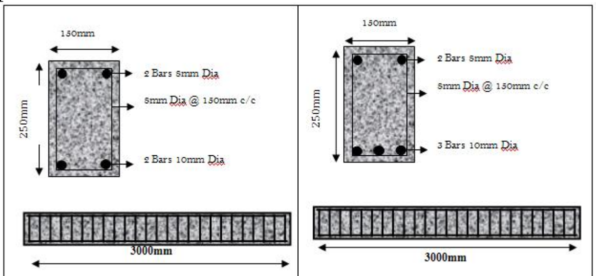

Fig.1 Details of A Series Beams Fig.2 Details of B Series Beams

TABLE 2 Specimen Details

Beam series	Beam Designation	% Steel Reinforcement	GFRP Laminate		Composite Ratio
			Type	Thickness	
A	RA	0.419	-	-	-
	RAC3	0.419	CSM	3	2.864
	RAC5	0.419	CSM	5	4.774
	RAU3	0.419	UDC	3	2.864
	RAU5	0.419	UDC	5	4.174
B	RB	0.628	-	-	-
	RBC3	0.628	CSM	3	1.909
	RBC5	0.628	CSM	5	3.183
	RBU3	0.628	UDC	3	1.909
	RBU5	0.628	UDC	5	3.183

GFRP Laminate Bonding Technique

Glass Fibre Reinforced Polymer (GFRP) laminates were used for strengthening the beams. The soffit of the beam was well cleaned with a wire brush and roughened with a surface-grinding machine. Two part epoxy adhesive consisting of epoxy resin and silica filler was used to bond the GFRP laminates. The adhesive was spread over the pasting surface with the help of a spreads. The GFRP laminate was applied gently by pressing the sheet from one end of the beam to the other along the length of beam.

III. TEST SET-UP AND PROCEDURE

All the beams were tested under four point bending in a loading frame of 750 kN capacity. The effective span of the beam was 2800 mm with 100 mm bearing at the ends. The deflections were measured at mid-span and load-points using dial gauges of 0.01 mm accuracy. The crack widths of beams were measured using a crack detection microscope with a least count of 0.02 mm. Figure.3 shows the loading arrangement and instrumentation adopted for the test.

Fig.3 Experimental Test Set-up

IV. RESULTS AND DISCUSSION

Table.3 summarises the test results at first crack, yield and ultimate stage of non-strengthened and strengthened beams.

TABLE 3 Principal Results of Tested Beams

Beam Designation	Loading Stages of Beams					
	First Crack Stage		Yield Stage		Ultimate Satge	
	P_{cr} (kN)	Δ_{cr} (mm)	P_y (kN)	Δ_y (mm)	P_u (kN)	Δ_u (mm)
RA	14.39	1.26	29.42	7.91	41.68	21.05
RAC3	16.52	1.41	36.77	9.02	51.48	33.46
RAC5	21.28	3.67	46.58	10.1	66.19	46.81
RAU3	32.94	7.98	51.48	11.42	71.09	53.26
RAU5	36.81	9.23	53.7	10.74	78.45	57.21
RB	28.32	3.68	39.22	8.11	53.93	31.28
RBC3	30.95	4.71	51.48	11.35	61.29	36.23
RBC5	32.17	4.97	53.24	12.41	63.74	56.91
RBU3	33.69	9.35	58.8	12.85	88.25	61.04
RBU5	39.41	11.14	63	12.69	100.51	65.59

The first crack loads were obtained by visual examination. At this stage, the strengthened beams exhibit a maximum increase of 155% compared to the control beams. The yield loads were obtained corresponding to the stage of loading beyond which the load-deflection response was not linear. At the yield load level, the GFRP strengthened beams showed an increase upto 82% compared to the control beams. The ultimate loads were obtained corresponding to the stage of loading beyond which the beam would not sustain additional deformation at the same load intensity. At the ultimate load level, the strengthened beams showed a maximum increase of 88% when compared with the control beams. From the experimental results, it can be observed that, at all load levels, a significant increase in strength was achieved by externally bonded GFRP laminates. This increase may be attributed to the increase in tensile cracking strength of Concrete due to confinement by the laminates.

Load-Deflection Response

The load - deflection response for tested beams is presented in Figs.4-5.

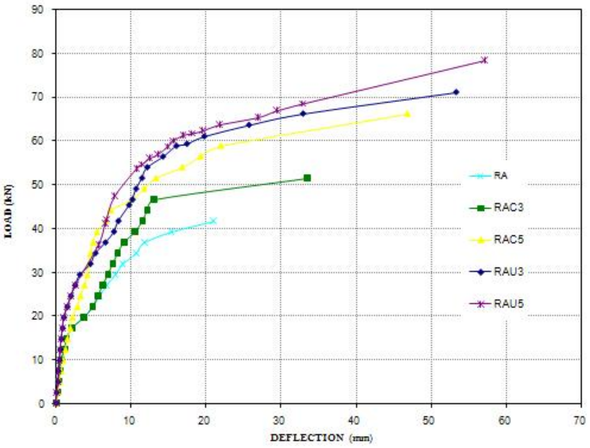

Fig.4 Load-Deflection response of A Series Beams

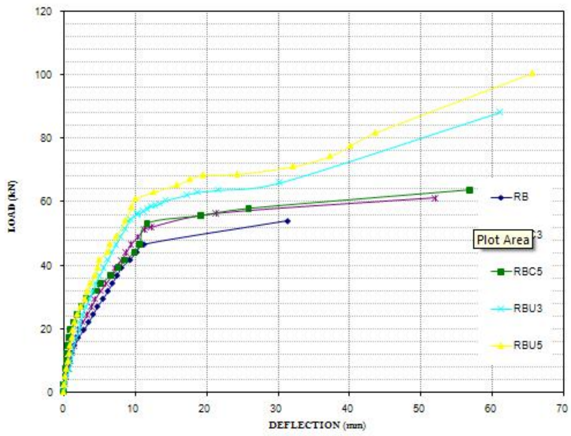

Fig.5 Load-Deflection response of B Series Beams

For the A series beams of steel ratio 0.419%, the ultimate load increased by 23.51% and 58.81% for 3mm and 5mm thick CSMGFRP laminated beams. For the beams strengthened with 3mm and 5mm thick UDCGFRP laminates, the ultimate load increased by 70.56% and 88.22%. The CSMGFRP strengthened beams exhibited an increase in deflection which varied from 58.95% to 122.38% at ultimate load level. The UDCGFRP strengthened beams exhibited an increase in deflection which varied from 153% to 171% at ultimate load level.

For the B series beams of steel ratio 0.628%, the ultimate load increased by 13.65% and 18.19% for 3mm and 5mm thick CSMGFRP laminated beams. For the beams strengthened with 3mm and 5mm thick UDCGFRP laminates the ultimate load increased by 63.64% and 86.37%. The CSMGFRP strengthened beams exhibited an increase in deflection which varied from 15.82% to 170.36% at ultimate load level. The UDCGFRP strengthened beams exhibited an increase in deflection which varied from 189.98% to 211.59% at ultimate load level.

Ductility of Beams

TABLE 4 Ductility Indices of Tested Beams

Beam Designation	Ductility		
	Deflection	Curvature	Energy
RA	2.66	4.16	4.16
RAC3	3.71	6.82	6.82
RAC5	4.63	7.81	7.81
RAU3	4.66	8.17	7.98
RAU5	5.33	10.68	9.27
RB	3.86	6.97	6.97
RBC3	3.19	7.58	7.58
RBC5	4.59	7.65	7.65
RBU3	4.75	8.41	7.78
RBU5	5.17	11.36	8.80

Ductility is considered as an important factor in designing of structures especially in the seismic prone areas. The ductility of a beam can be defined as its ability to sustain inelastic deformation without loss in load carrying capacity, prior to failure. The ductility values for the beams were calculated based on deflection and energy absorption. The deflection ductility values were calculated as the ratio between the deflection at ultimate point to the deflection at yield point. The energy ductility values were calculated as the ratio of the cumulative energy absorption at ultimate stage to the cumulative energy absorption at yield. The ductility indices for the tested beams are presented in Table 4. The deflection ductility for the strengthened beams showed a maximum increase of 100.38%.

V. CONCLUSIONS

Based on the experimental results the following conclusions are drawn:

- Strengthening of reinforced concrete beams using GFRP laminates resulted in higher load carrying capacity.
- The percentage increase in ultimate load ranged from 23.51% to 88.22% for GFRP strengthened beams.
- The percentage increase in deflection at ultimate stage varies from 15.82 % to 211.59% on beams strengthened with GFRP laminates.
- The strengthened beam show enhanced ductility. The increase in deflection ductility varies from 17.36% to 100.38%
- GFRP strengthened beams failed in flexural mode only.

REFERENCES

1. Ritchie, P.A., Thomas D.A., Le-Wu Lu and Connelly, G.M**.** , "External Reinforcement of Concrete Beams Using Fiber Reinforced Plastics," *ACI Structural Journal*, 88 (4), 490-500, 1990.
2. Arduini, M. and Nanni, A. , "Behaviour of Pre-cracked RC Beams Strengthened with CFRP Sheets, *Journal of Composites for Construction," ASCE*, 1(2), 63 -70, 1997.
3. Ganga Rao, H.V.S. and Vijay, P.V. , "Bending Behaviour of Concrete Beams Wrapped with Carbon Fabric, *Journal of Structural Engineering," ASCE*, 124 (1), 3 – 12, 1998.
4. Saadatmanesh, H. and Malek, A.M. , "Design Guidelines for Flexural Strengthening of RC Beams with FRP," *Journal of Composites for Construction, ASCE,* 2 (4), 158-164, 1998.
5. El – Mihilmy, M.T. and Tedesco, J.W. ," Deflection of RC Beams Strengthened with FRP Plates," *ACI Structural Journal,* 97(5), 679 – 688, 2000.
6. Hamid Rahimi and Allan Hutchinson , "Concrete Beams Strengthened with Externally Bonded FRP Plates," *Journal of Composites for Construction, ASCE*, 5 (1), 44 – 56, 2001.
7. Suguna, K., Thiruvenkatachari, V. and Raghunath, P.N., "Strength and Ductility of RC Beams with Externally Bonded CRSS Plate Reinforcement," *Annamalai University Journal of Engineering and Technology (AUJET)*, 207 – 216, 2006.
8. Raghunath, P.N., Suguna, K. and Nagardjane, V. (2006), Externally Bonded FRP for Strengthening Concrete Beams, Proceedings of the *10th International Conference on Inspection, Appraisal, Repairs and Maintenance of Structures,* Hong Kong, 329 - 336.
9. Hamoush, S.A. and Ahmad, S.H., "Debonding of Steel Plate-Strengthened Concrete Beams," *Journal of Structural Engineering, ASCE,* 116 (2), 356 – 371,1990.
10. Hussain, M., Sharif, A., Basunbul, I.A., Baluch, M.H. and Al-Sulaimani, G.J., "Flexural Behaviour of Pre-cracked RC Beams Strengthened Externally by Steel Plates," *ACI Structural Journal*, 92 (1), 14 – 22, 1995.
11. Toutanji, H., Zhao, L., and Zhang, Y., "Flexural behaviour of reinforced concrete beams externally strengthened with CFRP sheets bonded with an inorganic matrix Engineering Structures," 28: 557 -566, 2006.
12. Bencardino, F., Spadea, G. and Swamy, R.N.," Strength and Ductility of Reinforced Concrete Beams Externally Reinforced with Carbon Fiber Fabric, " *ACI Structural Journal*, 99(2), 163 -171, 2006.