STRENGTH BEHAVIOUR OF FIBRE REINFORCED POLYMER STRENGTHENED BEAM

N. Pannirselvam[1], V. Nagaradjane[2] and K. Chandramouli[3]
[1]VIT University, Vellore, India
[2]Department of Structural Engineering, Annamalai University, Annamalainagar, India
[3]Priyadrashini Institute of Technology for Women, Tenali, Guntur, Andhra Pradesh, India
E-Mail: npannirselvam@vit.ac.in

ABSTRACT

Strengthening of structures using Fibre Reinforced Polymer (FRP) shows better promise for extending the life span of structures. The advantages of using FRP include light weight, ease of installation, minimal labour costs and site constraints, high strength-to-weight and durability. The objective of this work is to evaluate the structural behaviour of reinforced concrete beams with externally bonded FRP reinforcement. Beams bonded with four different types of Glass Fibre Reinforced Polymer (GFRP) having 3.50 mm thickness were used. Totally five rectangular beams of 3 m length were cast. One beam was used as reference beam and the remaining beams were provided with GFRP laminates on their soffit. The variable considered for the study is type of GFRP laminate. The study parameters of this investigation included first crack load, yield load, ultimate load, first crack deflection, yield deflection, ultimate deflection, crack width, deflection ductility, energy ductility, deflection ductility ratios and energy ductility ratios of the test beams. The performance of FRP plated beams was compared with that of unplated beam. The test results showed that the beams strengthened with GFRP laminates exhibited better performance.

Keywords: beams, deflection ductility, energy ductility, fibre reinforced polymer, reinforced concrete, strength.

INTRODUCTION

FRP composite materials have been successfully used in the construction of new structures and in rehabilitation of existing structures. FRP composite materials hold great promise for the future of construction industry. Strengthening of reinforced concrete and pre-stressed concrete structural elements may be required as a result of increase in service loads, change in usage pattern, structural degradation of concrete or defects in design or construction. Repair with externally bonded FRP reinforcement is a highly practical strengthening system, because of ease and speed of installation, efficiency of structural repair and corrosion resistance of the materials. The application of FRP poses minimal modification to the geometry, aesthetics and utility of the structure. Several studies on the behavior of reinforced concrete beams strengthened with FRP composite sheets provided valuable information regarding the strength, deformation, ductility and long-term performance of the FRP strengthening systems. Installation of externally bonded up-gradation systems using FRP is faster and less labour-intensive.

FRP plating is a versatile technique which can be applied equally well for existing RC beams and new ones. Plating of FRP laminates results in increase of composite moment of inertia of the section, thus making it behave with more stiffness after plating. The present study is aimed at investigating the effect of FRP plate on the performance of FRP plated RC beams.

FRP is a composite material generally consisting of carbon, aramid or glass fibres in a polymeric resin matrix. FRP composites are, as the name suggests, a composition of two or more materials which, when properly combined, form a different material with properties not available from the ingredients alone. Depending on the ingredients chosen and the method of combining them, properties of FRP can be controlled. Reinforced Concrete (RC) is a good example of a composite. The steel rebars provide excellent tensile strength and the concrete provides compressive strength and transfers the load between the steel bars.

The major constituents of FRP are the fibre and the resin. The mechanical properties of FRP are controlled by the type of fibre and durability characteristics are affected by the type of resin. The commonly used types of FRP are: i) Carbon Fibre Reinforced Polymer (CFRP), ii) Glass Fibre Reinforced Polymer (GFRP), iii) Aramid Fibre Reinforced Polymer (AFRP).

Different systems of externally bonded FRP reinforcement exist. The two commonly used systems include wet lay-up system and prefab system. In the former system, dry unidirectional fibre sheet, dry multidirectional fabric, resin pre-impregnated uncured unidirectional fabric sheet, resin pre-impregnated uncured multi-directional fabric/sheet, dry fibre tows or pre-impregnated fibre tows are utilized. The fabric can be either directly applied into the resin that has been applied on the concrete surface or can be impregnated with resin and then applied wet on the concrete surface. In the latter system, pre-manufactured cured laminates, shells, jackets or angles are installed through the use of adhesives.

FRP can be applied for strengthening a variety of structural members like beams, columns, slabs and masonry walls. Beams and slabs may be strengthened in flexure by bonding FRP strips at the soffit portion along the axis of bending. Shear strengthening of beams may be achieved by bonding vertical or inclined strips of FRP at the side faces of beams. Strengthening of beams in both flexure and shear may be achieved by wrapping around the cross section of beams in U-Shape.

LITERATURE REVIEW

Teng *et al*. (2002) presented a finite element study for interfacial stresses in reinforced concrete beams strengthened with a bonded soffit plate. They validated the finite element results with the predictions of the approximate analytical solution by Smith and Teng. The authors varied parameters such as thickness of adhesive layer, the elasticity modulus of adhesive layer, the thickness of soffit plate. They concluded that the interfacial stresses were found to increase with a reduction in adhesive thickness and an increase in adhesive elastic modulus, plate thickness/elasticity modulus. They have used fine mesh for analyzing the point of stress singularity in a plated RC beam.

Chen and Teng (2003) developed a simple, accurate and rational design model for the shear capacity of FRP strengthened beams which fail mainly by FRP debonding. The authors validated their model against experimental data collected from the existing literature. Their model explicitly recognizes the non-uniform stress distribution in the FRP along a shear crack as determined by the bond strength between FRP strips and concrete. The design proposal developed by them can be directly used for practical design.

Francois Buyle-Bodin (2004) examined the performance of rectangular simply supported reinforced concrete beams with externally bonded reinforcement made of carbon fibre reinforced polymer plates. The author studied the load-carrying capacity of CFRPEBR beams by delaying end peel failure. The author prevented the brittle failure by use of clamps at the ends of the beam, bonding of lateral perpendicular or inclined strips and U-wrapping of shear spans with carbon fibre textile. The author concluded that the lateral bonding of CFRP strips and U-wrapping using carbon fibre textile controls the debonding cracks and delay the premature end failure of the beams. The load carrying capacity is enhanced, and the ductility is increased.

Lin *et al.* (2005) presented an experimental study on strengthening reinforced concrete beams using pre-stressed glass fibre reinforced polymer (PGFRP). The ultimate loads and the deflections of strengthened RC beams using GFRP and PGFRP sheets were tested and compared. They reported that the beams strengthened with PGFRP sheets can withstand larger ultimate loads than beams with ordinary GFRP sheets. The deflections of the beams with PGFRP sheets are smaller than those of beams with GFRP sheets under the same external loads. The ductility of the over-strengthened beams was especially smaller.

Ginseppe Campione (2006) has studied on the influence of FRP wrapping techniques on the compressive behaviour of concrete prisms. The specimens were prism with square cross section externally wrapped with carbon fibre reinforced plastic sheets. The parameters analyzed were local reinforcements at the corners and continuous layers, horizontal and vertical continuous strips, number of continuous layers, and length of the specimens. The author concluded that the test results showed a good agreement with an analytical model prepared to determine the maximum bearing capacity of compressed concrete members with square cross section and externally wrapped with FRP with different configuration.

Xiong *et al*. (2007) have tried to device a way for preventing tension delamination of concrete cover at midspan of FRP strengthened beams by combining CFRP and GFRP sheets at midspan of a beam. They have used unidirectional carbon fibre reinforced polymer sheets on the tension face of the beams and bi-directional GFRP sheet wrapped on 3 sides of the beam continuously. The feasibility and potential advantages of the attempt are discussed. They have concluded that the hybrid CFRP-GFRP system could not only prevent the tension delamination of the bottom concrete cover, but also lead to a significant increase of deformation capacity of the strengthened beams at a very low cost compared to CFRP strengthening.

OBJECTIVES OF THE STUDY

The objectives of the current research work include:

a) To study the impact of externally bonded Chopped Strand Mat (CSM), Woven Roving (WR), CSMWRGFRP and Uni-directional (UD) GFRP laminates on strength, deformation and ductility of the test beams;
b) To examine the composite action of the GFRP laminates at all load levels; and
c) To understand the associated cracking and failure mechanisms.

RESEARCH SIGNIFICANCE

FRP strengthening provides an ideal system for achieving the strength and ductility requirements of new constructions as well as existing structures. Beams occupy a vital role in the load transfer mechanism of all structures. Beams form the first line of defense against almost all types of failures found in structural systems. In a developing country like India, the cost of FRP system is also a major concern. Since the cost of GFRP is the lowest and since it is the most commonly available material GFRP was considered suitable for the study. Hence, this research study investigated the characteristics of RC rectangular beams strengthened with externally mounted GFRP laminates.

MATERIALS AND METHODS

Materials

Cement concrete having characteristic compressive strength of 33.50 MPa was used for casting the beams. The longitudinal steel reinforcement was provided using Fe 415 grade steel rods and shear stirrups were provided using Fe 250 grade steel rods of 8 mm diameter. The tensile steel reinforcements were provided at 0.40% of the gross cross sectional area of the beam.

The properties of FRP used for the experimental work were tested in an independent laboratory and listed in Table-1.

Table-1. Properties of GFRP laminates.

Property	CSM	Woven rovings	Uni-directional
Glass content %	25-40	45-60	60-90
Specific gravity kg/cm^3	1.4-1.5	1.5-1.8	1.7-2.2
Tensile strength MN/m^2	63-140	230-340	530-1730
Tensile modulus GN/m^2	6-12	13-17	28-62
Compressive strength MN/m^2	130-170	100-140	310-480
Flexural strength MN/m^2	140-250	200-270	600-1800

Specimens

A total of five reinforced concrete beams were cast. One without plating and four with CSMGFRP, WRGFRP, Uni-directional GFRP and combination of CSMWRGFRP plating of 3.5 mm thickness. The details of the specimen are presented in Table-2.

Table-2. Specimen specifications.

S. No.	Beam designation	% Steel reinforcement	Type of GFRP	Thickness of GFRP
1.	SR	0.40	-	-
2.	SRCSM	0.40	CSM	3.50
3.	SRWR	0.40	WR	3.50
4.	SRUD	0.40	UD	3.50
5.	SRCSMWR	0.40	CSM+WR	3.50

Note: CSM- Chopped Strand Mat; WR- Woven Rovings; UD- Uni-Directional FRP Plating

The soffit portions of beams were cleaned and GFRP plates were bonded using adhesive. Figure-1 shows the application of GFRP plate to beam soffit. The beams were cured for seven days to permit the adhesive to gain strength before testing.

Figure-1. Bonding GFRP plate using adhesive.

Figure-2. Test setup.

Testing of beams

The beams were tested under four point bending by applying two equal loads dividing the span into three equal parts. Deflectometers were fixed at the mid span and below the loading points to measure the deflection. Two deflectometers were fixed on top of the beam near a support at a spacing of 100 mm in order to measure the

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curvature. The load was applied through a hydraulic jack placed on top of a spreader beam. The test setup is shown in Figure-2.

The strains near top and bottom of the beam were measured using DEMEC gauge with four measuring pins located at 200 mm c/c distance. The loading was applied monotonically at increments of 2500 N and all deflection readings were measured for each load increment. The extension at rebar level and compression at top of the beam were measured using the DEMEC gauge. The readings on the two dial gauges placed on top surface of the beam over support section were also taken.

The failure of reference beams without any GFRP plating was preceded by high levels of deformation after yield point. But, the failure of GFRP plated beams was observed to be due to one of the following reasons: delamination, ripping of cover concrete along with GFRP plate or fracture of laminate.

RESULTS AND DISCUSSIONS

The load-deflection curves for five beams are shown in Figure-3. In all the cases, the beams with GFRP plating reached higher load levels. The stiffness of the GFRP plated beams was higher than that of the unplated beams, resulting in higher load carrying capacity at lower deformation levels.

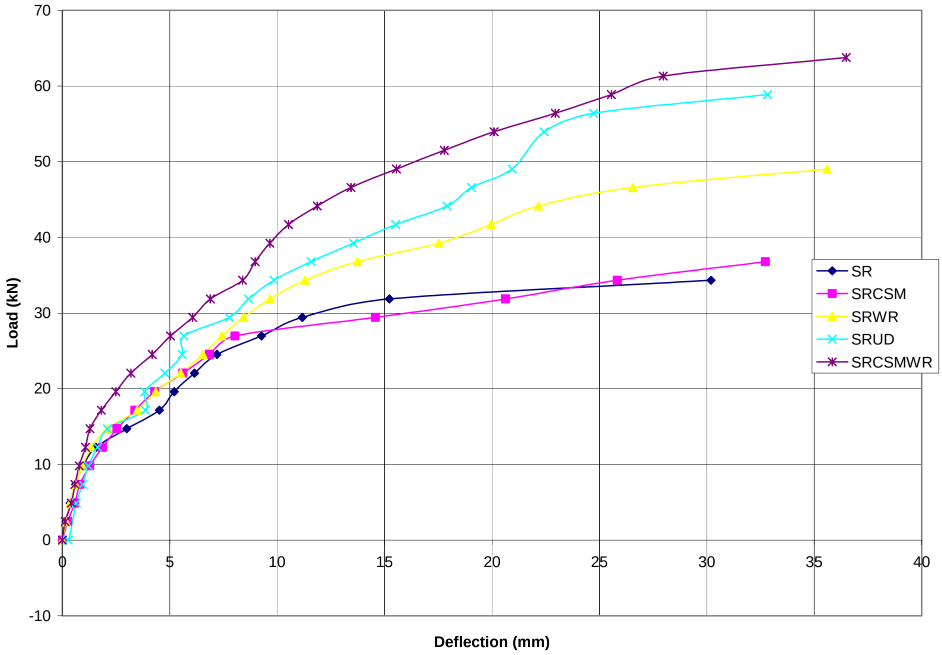

Figure-3. Load deflection behaviour.

The summary of salient load-deflection results is presented in Table-3. For WRGFRP plated beams, the first crack loads showed increase of 71.43% over the corresponding reference specimens.

Table-3. Loads, deflections and crack width at salient stages.

S.N0.	Specimen designation	First crack load (kN)	Yield load (kN)	Ultimate load (kN)	Deflection at first crack (mm)	Yield deflection (mm)	Ultimate deflection (mm)	Crack width at yield (mm)	Maximum Crack width (mm)
1.	SR	17.17	17.17	34.34	4.52	11.17	30.20	0.12	1.20
2.	SRCSM	17.17	22.07	36.79	3.38	8.04	32.73	0.14	1.00
3.	SRWR	24.53	39.24	49.05	6.55	8.44	35.60	0.18	0.60
4.	SRUD	29.43	44.15	58.86	7.77	11.58	32.83	0.36	0.82
5.	SRCSMWR	34.34	51.50	63.77	7.39	7.98	35.49	0.24	0.62

The increase in yield load was higher for WRGFRP plated beams when compared to the CSMGFRP plated beams. Plating with CSMGFRP laminates resulted in less deflection compared to plating with WRGFRP.

This might not be taken as an indication of increase in stiffness value of CSMGFRP plated beams, since the yield load attained by these beams are much lower than those attained by WRGFRP plated beams. The application of WR fibre reinforced laminate resulted in higher ultimate strength values compared to CSM reinforced laminates.

Table-4. Deflection and energy ductility values.

S. No.	Specimen designation	Deflection ductility	Energy ductility	Deflection ductility ratio	Energy ductility ratio
1.	SR	2.70	3.81	1.00	1.00
2.	SRCSM	4.07	6.63	1.51	1.74
3.	SRWR	4.22	8.28	1.56	2.17
4.	SRUD	2.84	4.93	1.05	1.29
5.	SRCSMWR	4.45	8.34	1.64	2.11

Table-4 shows the deflection and energy ductility values. In the case of GFRP plated beams, the deflection ductility values showed a reduction or very meagre increase. The beams SRCSM, SRWR, SRUD and SRCSMWR showed increase in deflection ductility by 50.57%, 56.29%, 5.18% and 64.48%, respectively, over the control beam. Energy ductility was higher for beams with thicker GFRP plating. The beams SRCSM, SRWR, SRUD and SRCSMWR with steel ratio of 0.40% exhibited 74.01%, 117.32%, 29.40% and 118.90% increase in energy ductility over the beam SR.

The results indicate that energy ductility is clearly influenced by the thickness of GFRP plating, exhibiting higher levels of increase for higher thickness of plating. The application of GFRP plating contributes to the increase in strength as well as deflection capacities in combination. Yield ductility, which depends only on deflection values, does not show as much improvement as the energy ductility in response to applied thickness of GFRP plating. Deflection ductility and Energy ductility values are presented in Figures 4 and 5.

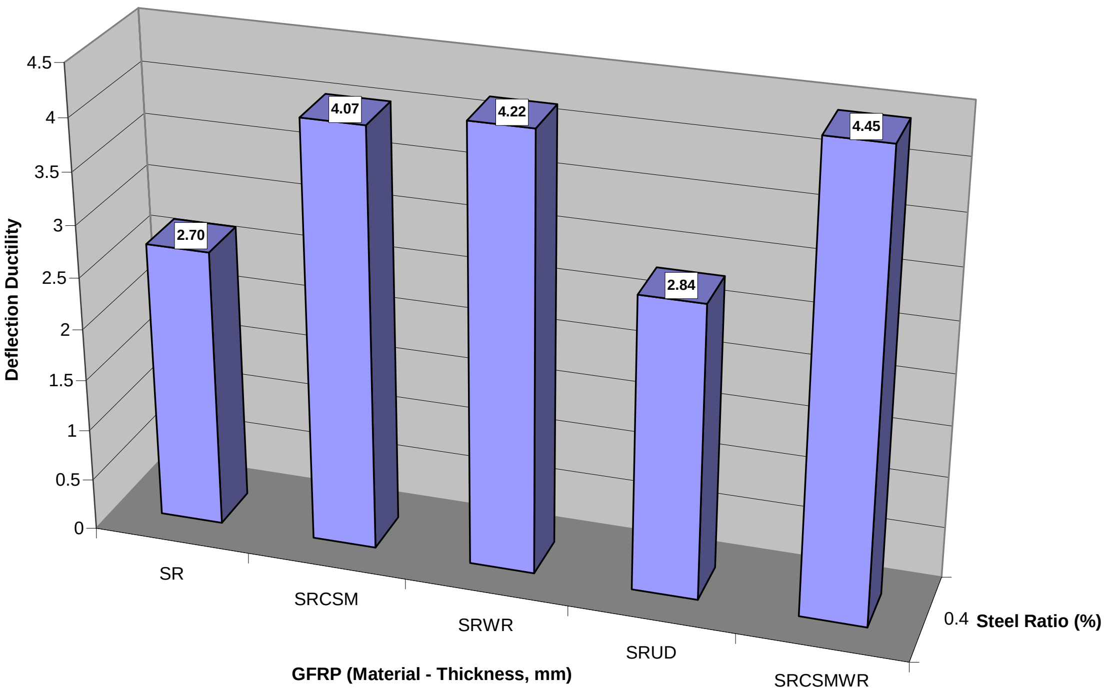

Figure-4. Deflection ductility.

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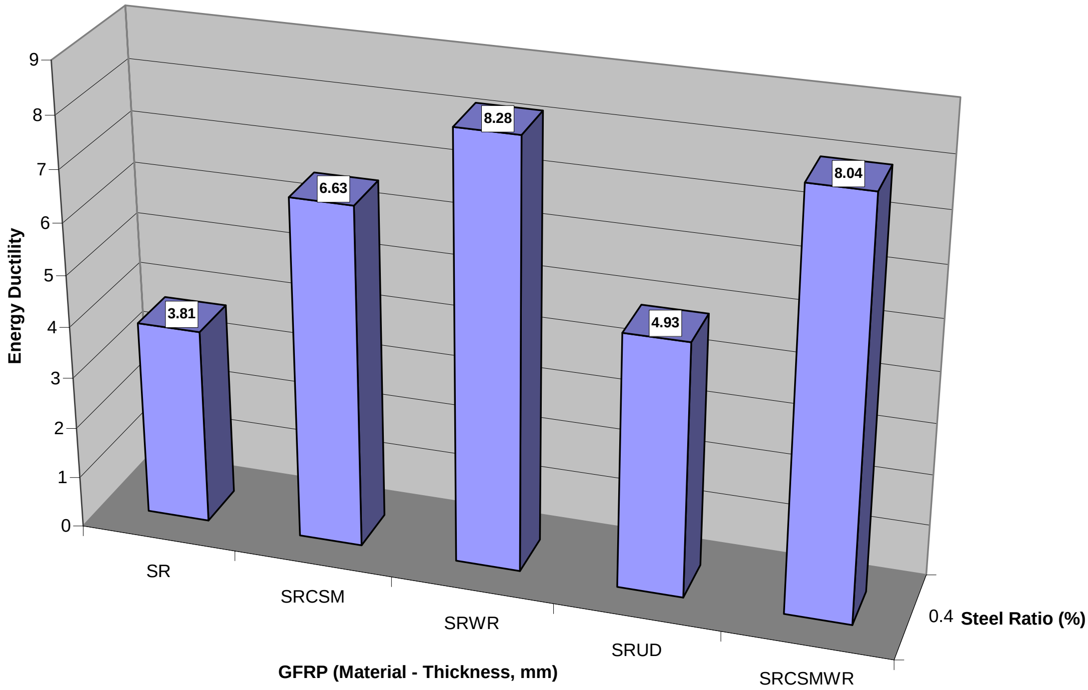

Figure-5. Energy ductility.

CONCLUSIONS

The performance of GFRP plated RC beams increased with regard to strength and deformation capacity. The following salient conclusions were drawn from the present investigations:

i) The ultimate load for GFRP plated RC beams increased by a maximum of 42.84% for SRWRGFRP plated beam, by 71.40% for SRUDGFRP plated beam and by 85.70% for SRCSMWRGFRP plated beam, when compared to the reference beam.
ii) The type of GFRP influenced the performance of the GFRP plated beams. SRUDGFRP resulted in better performance when compared to SRCSMGFRP.
iii) Deflection ductility values for beams showed increase up to 64.48% over the corresponding reference beams.
iv) Energy ductility values increased by up to 118.90% for 3.5 mm thick GFRP plated beams.

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