An Experimental Study on Reinforced Concrete Beams with FRP Laminates

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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 concrete beams. In this study, a total of seven beams of size 150 mm x 250 mm in cross section with a total length of 3000 mm were cast and tested. Six beams were strengthened with chopped strand mat glass fibre reinforced polymer (CSMGFRP), woven roving glass fibre reinforced polymer (WRGFRP) and uni-directional cloth glass fibre reinforced polymer (UDCGFRP) of 3mm and 5mm thickness. The study parameters included the GFRP laminate material and their thickness. All the beam specimens were subjected to four-point bending test in a loading frame. The results show that the GFRP strengthened beams exhibit increased strength, deformation capacity, ductility and composite action until failure.*

Keywords – Ductility, GFRP, laminates, Strength

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1. 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, deicing 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. The most common types of FRP are aramid, glass, and carbon; AFRP, GFRP, and CFRP respectively. Many researchers have found that FRP composites applied to reinforced concrete members provide efficiency, reliability and cost effectiveness in upgradation. They have been extensively used in aerospace, automotive and other fields.

Hussain et al conducted a study on the flexural behaviour of reinforced concrete beams strengthened with steel plates. The authors examined the effects of plate thickness and end anchorage on ultimate load, ductility and failure mode of the beam. The author also suggested a design procedure to avoid premature failure of plate. The results showed that the reinforced concrete beams exhibited higher strength than the control beam; the ductility of the reinforced concrete 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 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 reinforced concrete beams repaired with CFRP laminates. They examined the effects of retrofitting on strength, deflection, curvature and energy. The author concluded that suitably designed and positioned external anchorages enabled more ductile failures of the CFRP strengthened beams.

2. EXPERIMENTAL PROGRAM

2.1 *Materials used*

The concrete used for all beam specimens had a compressive strength of 24MPa. The concrete consisted of 370 kg/m^3 of ordinary Portland cement, 585 kg/m^3 of fine aggregate, 702 kg/m^3 of coarse aggregate, 468 kg/m^3 of medium aggregate, 0.45 water/cement ratio. The reinforcement of high yield strength deformed bars of characteristic strength 456MPa was 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 125 mm spacing. Three types of GFRP laminates were used for the study, namely, Chopped Strand Mat (CSM), Woven Rovings (WR) and Unidirectional Cloth (UDC) of 3mm and 5mm thickness. The properties of GFRP are shown in Table 1.

Table 1: Properties of GFRP Laminates

Sl. No.	Type of GFRP	Thickness (mm)	Tensile Strength (MPa)	Ultimate Elongation (%)	Elasticity Modulus (MPa)
1.	Chopped Strand Mat	3	126.20	1.69	7467.46
2.	Chopped Strand Mat	5	156.00	1.37	11386.86
3.	Woven Rovings	3	147.40	2.15	6855.81
4.	Woven Rovings	5	178.09	1.98	8994.44
5.	Uni-Directional Cloth	3	446.90	3.02	13965.63
6.	Uni-Directional Cloth	5	451.50	2.60	17365.38

2.2 *Details of Beams*

Seven reinforced concrete rectangular beam specimens having 150mm x 250mm cross-section and 3000 mm length were cast and tested. Longitudinal steel ratio adopted for the beam specimens was 0.603% (2 bars, 12 mm diameter). 2-legged 8 mm diameter shear stirrups were provided at 125 mm c/c in order to avoid any shear failure and ensure flexural action of beams up to failure. The detailing of beam is shown through Figure 1. The details of beams are presented in Table 2.

2.3 *GFRP Laminates 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 beam soffit with the help of a spread. The GFRP laminate was applied gently by pressing the sheet from one end of the beam to the other along the length of beam.

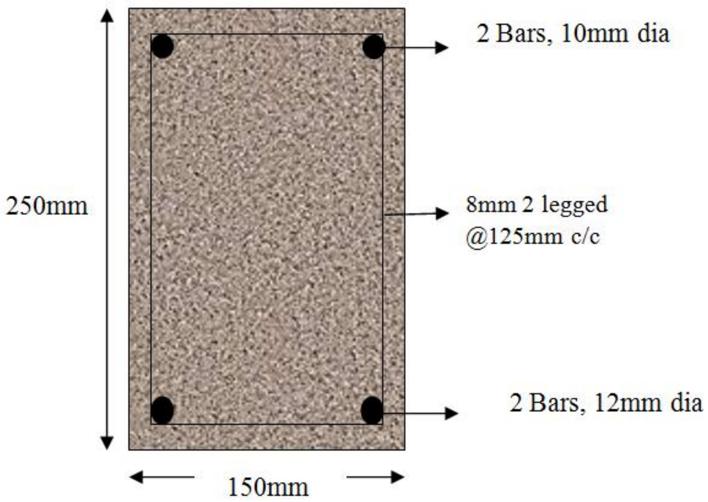

Figure 1: Reinforcement Details

Table 2: Specimen Details

Beam Designation	% of Steel Reinforcement	GFRP Laminate	
		Type	Thickness
SCB	0.603	-	-
SCSM3	0.603	CSM	3
SCSM5	0.603	CSM	5
SWR3	0.603	WR	3
SWR5	0.603	WR	5
SUDC3	0.603	UDC	3
SUDC5	0.603	UDC	5

2.4 *Experimental Test Set-up*

Seven beams were tested under four point-bending in a loading frame of 500 kN capacity. The beams were supported on hinge at one end and roller at the other end. The beams had 100 mm bearing on both ends, resulting in a test span of 2800mm. Two-point loads were applied through a spreader beam. The deflections were measured at mid-span and at load points using mechanical dial gauges of 0.01mm accuracy. Two dial gauges were mounted on the compression face of the specimen over supports to measure slope at both ends. Figure 2 shows the loading arrangement and instrumentation adopted for the test.

Figure 2: Experimental Test Set-up

3. RESULTS AND DISCUSSION

4.1 *Experimental Test Results*

Table 3 summarizes the test results at first crack, yield and ultimate stage of non-strengthened and strengthened beams. The Load-deflection response of tested beams was shown in Figure 3.

Table 3: Results of Tested Beams

Sl. No.	Beam Designation	First Crack Load in kN	Deflection at First Crack Load in mm	Yield Load in kN	Deflection at Yield Load in mm	Ultimate Load in kN	Deflection at Ultimate Load in mm
1	S-CB	12.5	0.95	40	3.3	65	9.2
2	S-CSM3	15	0.97	45	3.55	97.5	13.45
3	S-CSM5	17.5	1.02	50	3.65	102.5	14.4
4	S-WR3	20	1.1	52.5	3.7	100	14.1
5	S-WR5	22.5	1.12	60	3.88	107.5	15.5
6	S-UDC3	27.5	1.16	70	4.02	112.5	16.5
7	S-UDC5	37.5	1.28	82.5	4.33	117.5	18.6

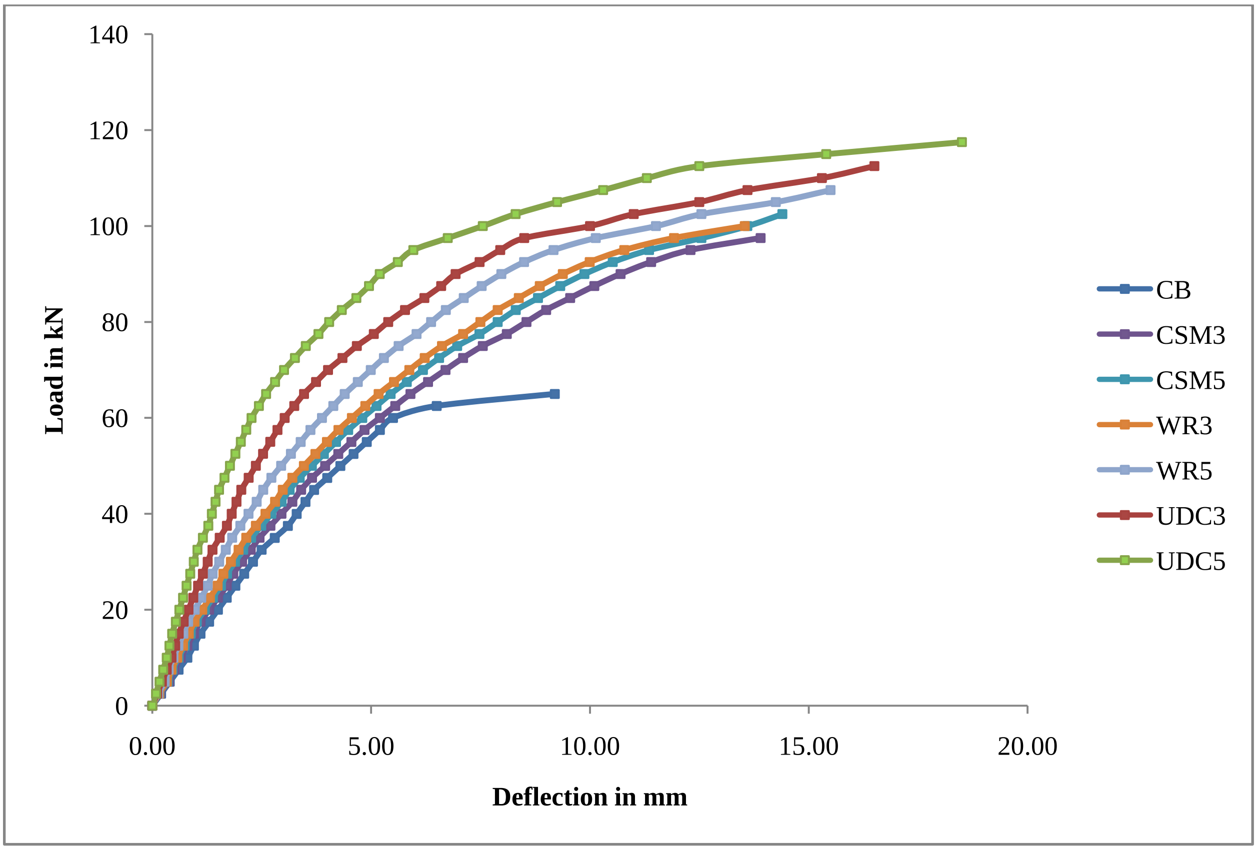

Figure 3: Load-deflection Response of Beams

The first crack loads were obtained by visual examination. At this stage, the strengthened beams exhibit a maximum increase of 200% 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 106.3% 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 80.8% 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. The ultimate load was increased by 50% and 57.7% for 3mm and 5mm thick CSMGFRP laminated beams. For beams strengthened with 3mm and 5mm thick WRGFRP laminates, the ultimate load increased by 53.8% and 65.4%. For beams strengthened with 3mm and 5mm thick UDCGFRP laminates, the ultimate load increased by 73.1% and 80.8%.

The 3mm and 5mm thick CSMGFRP strengthened concrete beams exhibited a decrease in deflection varying from 55.93% and 68.94% at ultimate load level. The 3mm and 5mm thick WRGFRP strengthened concrete beams exhibited a decrease in deflection varying from 77.83% and 109.21% at ultimate load level. The 3mm and 5mm thick UDCGFRP strengthened concrete beams exhibited a decrease in deflection varying from 165.51% and 254.02% at ultimate load level.

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 load point to the deflection at yield load 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 and Figures 4 to 5. The deflection ductility for the strengthened beams showed a maximum increase of 94.36%.

Table 4: Ductility Indices of Tested Beams

Sl. No.	Beam Designation	Deflection Ductility	Deflection Ductility Ratio	Energy Ductility	Energy Ductility Ratio
1	SCB	2.79	1.00	22.05	1.00
2	SCSM3	3.79	1.36	35.45	1.61
3	SCSM5	3.95	1.41	37.25	1.69
4	SWR3	3.81	1.37	39.15	1.78
5	SWR5	3.99	1.43	42.55	1.93
6	SUDC3	4.10	1.47	49.72	2.25
7	SUDC5	4.30	1.54	58.45	2.65

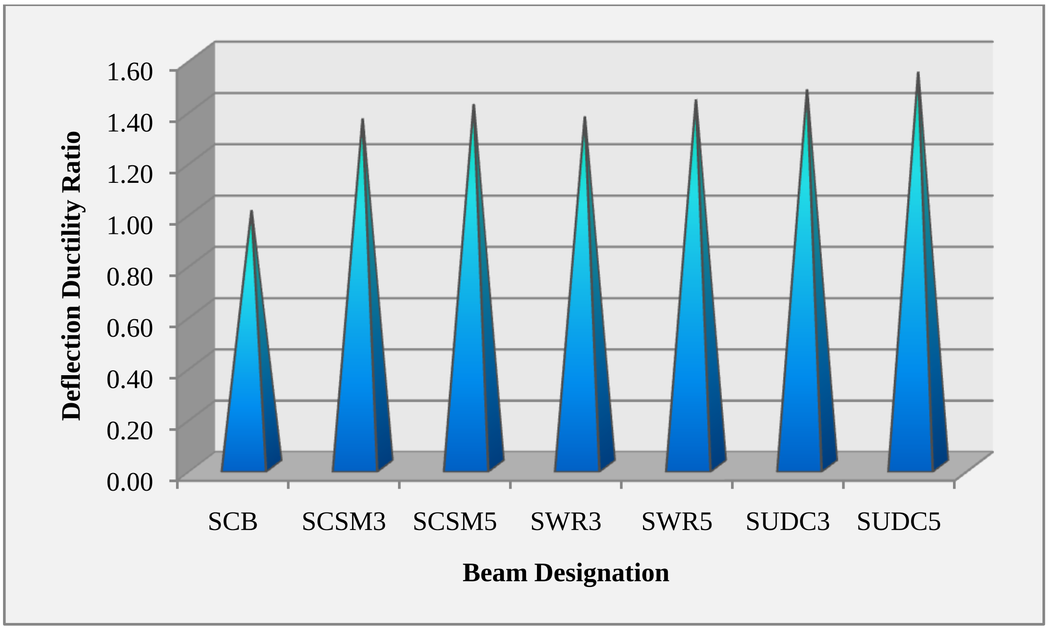

Figure 4: Deflection Ductility Ratio of Tested Beam

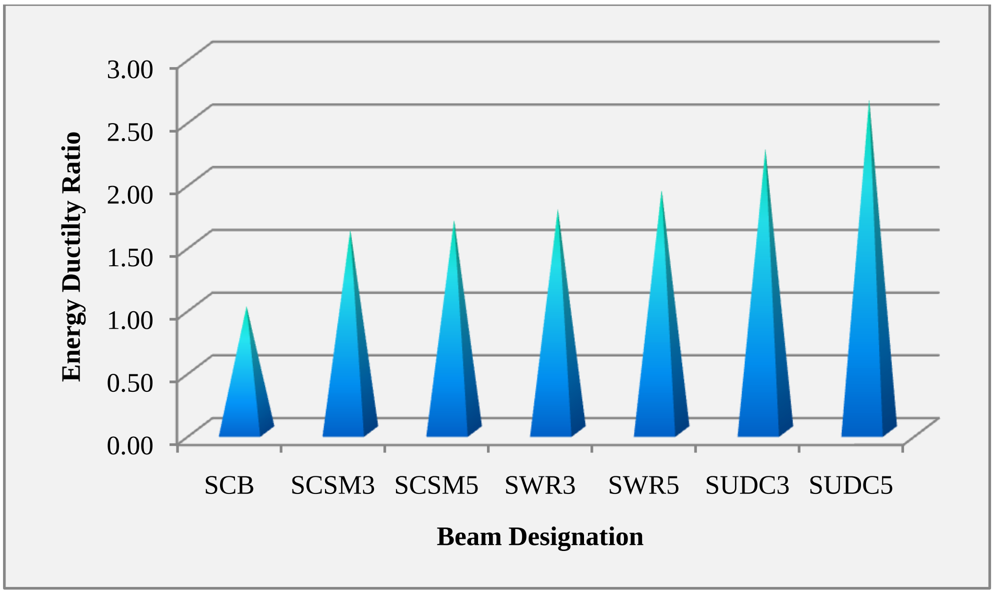

Figure 5: Energy Ductility Ratio of Tested Beam

4. CONCLUSION

Based on the experimental results the following conclusions are drawn:

- Strengthening of concrete beams using GFRP laminates resulted in higher load carrying capacity. The percentage increase in ultimate load varied from 50% to 80.8% for GFRP strengthened reinforced concrete beams.
- The percentage decrease in deflection at ultimate load varied from 55.93 % to 254.02% for reinforced concrete beams strengthened with GFRP laminates.
- The GFRP strengthened reinforced concrete beams shows enhanced ductility. The increase in deflection ductility was varied from 26.4% to 35.1%. The increase in energy ductility was varied from 37.8 to 62.3%.
- GFRP strengthened beams failed in flexural mode only.

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