JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Structural Strengthening of Beam Using Fibre Reinforced Polymer Laminate

P.Manicanda Sinouvassane[1*], Dr.V.Ramasamy[2], S.Karthikeyan

[1]PG Scholar, Department of Civil Engineering, Adhiparasakthi Engineering College, Melmaruvathur, Tamilnadu, India

[2]Professor, Department of Civil Engineering, Adhiparasakthi Engineering College, Melmaruvathur, Tamilnadu, India

[3]Assistant Professor, Department of Civil Engineering, Adhiparasakthi Engineering College, Melmaruvathur, Tamilnadu, India

Abstract

Due to their superior performance as reinforcing material for restoration projects, Fibre Reinforced Polymer (FRP) composites are widely used in Civil Engineering. In this study, first, the basic tests were performed on the materials and based on its properties the mix design arrived for M30 grade of concrete. Fresh and hardened tests were conducted to evaluate the performance of concrete. An experimental investigation was performed on Reinforced Concrete (RC) beams improved in flexure with FRP composites, with carbon and glass fibre in the form of sheets. Five RC beams will be cast and tested using a 4-point bending configuration. The steel reinforcement ratio used for designing RC beams is 0.419%. The thickness of FRP laminates were the main varied test factor used in this investigation. In this paper, one of the five beams is a control beam, while the other four were strengthened using FRP laminates. The findings demonstrated that using FRP laminates effectively upgraded the load-bearing capability of the RC beams. However, using thicker FRP sheets to increase strength is not advised because flexural strength is controlled by epoxy properties and concrete surface quality. The ductility of the strengthened beam using thicker FRP sheets leads to failure during an earthquake.

Keywords – CFRP, Compressive strength, Deflection, Flexural Strength, GFRP.

1. Introduction

Reinforced concrete bridges are an important component of land transportation routes. However, the durability and serviceability of reinforced concrete structures in harsh environments are becoming increasingly problematic due to the susceptibility of concrete to cracking under tension [1]. Therefore, there is an increasing demand for strengthening and retrofitting the current reinforced concrete structures. The repair and strengthening of structures using traditional concrete suffers high reinforcement costs, long periods, and complex processes. Currently, new reinforcement materials mainly include steel plates [2]. Externally bonded fiber Reinforced Polymer composites have been gradually introduced as a new construction material for strengthening the concrete structures over the past two decades, and have been shown to have many prominent advantages, such as the high tensile strength, light weight and excellent corrosion resistance of the FRP composites [3]. At present, the reinforcement methods mainly include increasing the section, sticking or anchoring steel plate, sticking fiber-reinforced material, replacing concrete, and combined reinforcement, among which the method of attaching steel plates and fiber reinforced material is the most widely used [4]. Among these materials, Carbon Fiber Reinforced Polymer (CFRP) is widely used for strengthening RC beams. CFRP possesses unique features, such as non-corrosiveness; high longitudinal tensile strength; stiffness; strength-to-weight ratio; resistance to insect, fungi, and chemical attack; low thermal transmissibility; and simple installation [5]. Carbon fiber is produced by the controlled oxidation process, in which the two types of method is used first carbonisation and second graphitisation of carbon-rich organic precursors, which are

already in fiber form. The fibers are also be made from pitch or cellulose and polyacrylonitrile fiber and rayon fiber. The tensile stress-strain curve is linear at the point of rupture [6]. Strengthening the structures, the dimensions of the structures are enlarged, reinforced and some additional supports may be used. So, by strengthening, the structures will be able to resist the forces and tension caused while applying load. Some of the common methods used like Glass Fiber Reinforced polymer (GFRP) and CFRP techniques [7]. FRP composites are widely used for strengthening and retrofitting reinforced concrete structures due to its corrosion resistance, durability and flexibility [8]. The efficacy of using the FRP in flexural and shear strengthening of RC beams, specifically considering using up to three layers of CFRP [9,10].
RC rectangular beams strengthened with externally bonded CFRP and GFRP laminates are evaluated in this study.
1. To study the mechanical properties of manufactured sand as fine aggregate in concrete.
2. To experimentally investigate the ultimate flexural behaviour of rectangular RC beams strengthened with fibre reinforced polymer system in different layers.
3. To investigate and compare the effectiveness of the different types of FRP. viz., CSM and GFRP composites to the soffit of the beam to evaluate.

2. Literature Review

Abed *et al.*, (2022) investigated the effectiveness of Externally Bonded Reinforcement on Grooves (EBROG) as a strengthening technique to overcome the debonding issue. It was found that the beam strengthened by EBR shows 24.8 - 48.2% higher load carrying capacity than the control beam. Also, the beam strengthened by EBROG shows 31.7-76.7% higher load carrying capacity than the control beam. The failure of the beam was changed from the debonding of the CFRP to rupturing of the CFRP, which shows the predominant behaviour of this strengthening technique than the conventional techniques.

Shivankar *et al.*, (2021) Beams strengthened with CFRP exhibit improved flexural strength in comparison to control beams that are 430 GSM single layer, 430 GSM double layer and 230 GSM double layer respectively, by about 300, 160 and 150%. Comparing the cracking pattern to the control beam reveals differences.

Yusuf *et al.*, (2020) The increment of flexural strength offered by the boned CFRP laminated was investigated and failure mode is identified and compared with unstrengthen beam. It was found that the flexural strength was increased as layer of laminates increases. The flexural capacity of the single and triple layered laminated beam was 20 and 52% increased that of control beam. The beam strengthen with single layer of CFRP laminates increases the first crack load by 29.80%. The strengthening of beam with double layer of CFRP laminates increases the first crack load by 56.80%. The strengthening of beam with triple layer of CFRP laminates increases the first crack load by 81.10%. It was concluded that CFRP laminates was appropriate strengthening material, which significantly influences the performance of the beam.

Siddika *et al.* (2019) examined the load versus deflection performance of the CFRP strengthen beam. It was reported that the CFRP strengthen beam shows enhanced ultimate load and ductility due to the better stiffness and grip offer by the CFRP. The ultimate load carrying capacity was improved in the range of 1.7 - 60.9%. It was concluded that full-length U-wrapping of the CFRP is appropriate for flexural strengthening, whereas strip U-wrapping as an alternate to internal stirrups is suitable for shear strengthening.

Yasmin Murad (2018) examined the flexural performance of the RC beam strengthen with CFRP sheets at the tension face at an angle of 0, 45, 60 and 90˚ to the longitudinal axis. It was found that the CFRP sheet orientation angle highly influences flexural performance of the beam. The orientation angle plays a vital part in failure mode and crack pattern. The maximum flexural strength of the beam strengthens with CFRP sheets at 45˚, which was found to be 12% high, that of control beam. In addition, the beam strengthens with CFRP sheets at longitudinal and transverse direction possess approximately 8% less flexure strength and 33-37% less ductility than the beam strengthens with CFRP sheets at inclined direction. The beam strengthens with CFRP sheets at angle of 45˚ increases the ultimate deflection by 14%, whereas beam strengthens with CFRP sheets at angle of 60˚ increases the ultimate deflection by 9%.

Srinath (2021) examined the flexural and shear characteristics of reinforced concrete (RC) beams by using Glass Fiber Reinforced Polymer (GFRP). The beams which are to be examined is strengthened with 1.5 mm epoxy bonded GFRP and tested. It was found that the strength was increased by 12.82, 22.17 & 40.31% in unstrengthen beam but in strengthen UB, SFB and FB strength was observed while concluding the unstrengthen beam there is an increase by strength were noted. During the comparison of beam 9.36% FB & 28% UB under ultimate load carrying capacity SFB is least. FB is less under ultimate load carrying capacity when compared to UB beam. SFB with respect to the load by 12% through GFRP for to amplify the strength of the beam by supplying 24% of GFRP strength is increased at the soffit of the beam and UB is strengthen by 42%.

Benjeddou *et al.*, (2021) performed a parametric study on RC beam strengthen by CFRP laminates at their tensile faces tested under four-point loading. It was observed that the load carrying capacity and rigidity of the strengthened beam was increased from 56 to 112% and 57 to 214% on increasing the width of laminate from 50 to 100 mm. On increasing the thickness of the laminates from 1.2 mm to 2.4 mm, the load carrying capacity increases for 56 to 76%. The failure mode of the strengthen beam was highly influenced by the width and length ratio of the laminates. Increasing the laminate width from 50 mm to 100 mm, the failure pattern of the beam was changes from debonding to peeling of laminates.

Miruthun *et al.*, (2020) studied the strengthening and stiffness of concrete while using FRP laminates. The ultimate load of RC beam is at 85.78 kN and RC beam complete failure occurred at 110 kN. The ultimate load of strengthened beam of RCint, RCcro, and RCinc are reduced at the percentage of 24.39, 36.82 and 43.34% respectively. Hence among these three strengthened beams RCint shows better strength property than other two strengthened beams. As in the case of deflection the deflection of the RC beam at ultimate load is 11.46 mm. The rate of deflection of strengthened beams of RCint, RCcro and RCinc are increased at the percentage of 10.64, 28.27 and 65.57% respectively.

3. Materials and Methodology

3.1 Cement

Ordinary Portland cement of 53 grade confirming to IS 12269-2013 is used in this project work. The physical properties of the cement used in this work were tested in accordance with IS: 4031-1988 and the test values are given in Table 1.

Table 1 Physical Properties of Cement

Properties	Test values
Specific gravity test	3.15
Fineness	7.11%
Standard consistency	32%
Initial setting time	60 minutes
Final setting time	400 minutes
Compressive strength at 28 days	53 N/mm^2

3.2 Fine Aggregate

M sand passing through 4.75mm was used in the experiment work. The properties of fine aggregate are determined as per IS 383:2016 is given in Table 2.

Table 2 Physical Properties of Fine Aggregate

Properties	Test values
Specific gravity test	2.73
Zone	II
Fineness modulus	2.84
Water absorption, %	0.50

3.3 Coarse Aggregate

Crushed granite stone was used as coarse aggregate for experiment work. The coarse aggregate passing through 16mm and retaining on 4.75mm were used for experimental work. The following properties of coarse aggregate are determined as per IS: 383:2016 and given in Table 3.

Table 3 Physical Properties of Coarse Aggregate

Properties	Test values
Specific gravity	2.67
Fineness modulus	7.33
Crushing value	18.50
Impact value	17.60
Water absorption	0.98
Abrasion	10.80
Shape	Angular

3.4 Superplasticizer

In order to improve the workability of fresh concrete superplasticizers (Classic Crete Superflo SP) were used for concrete mixture as water-reducing agents. The superplasticizer was a dark brown solution containing 35% solids. Details of superplasticizer are presented in Table 3.4.

Table 4 Properties of Superplasticizer

Contents	Test value
Specific gravity	1.170 +/- 0.015 at 27°C°C
Total solids, %	452
Chloride content, %	Nil
Air entrainment, %	Up to 2% additional air
Appearance	Brown Liquid

Source: M/s. *Fosroc Chemicals (www.fosroc.com)*

3.5 Water

Potable drinking water available has been used for making concrete.

3.6 Steel

High Yield Strength Deformed (HYSD) having yield strength having yield strength of 415.67MPa were used for longitudinal reinforcement. Mild steel rods having yield strength of 250MPa were used for lateral ties.

3.7 Carbon and Glass Fibre Mat

The bi-directional CFRP 160 GSM laminates of thickness 0.3 mm was used for flexural strengthening of RC beams. Carbon fiber has high electro-thermal efficiency because of its low electrical resistivity. The glass fiber mat consists of fibers glass woven the bi-directionally of thickness 0.5 mm was used as one of the strengthening materials for the beam in this study. Reported that glass fiber reinforced polymer mat which was laminated into the beam can offer high strength, high modulus of elasticity and also improves flexural and shear capacity of the beam. The bi-directional GFRP laminates 400 GSM of thickness 0.5 mm was used for flexural strengthening of RC beams. The properties of CFRP and GFRP which is given by the manufacturer are tabulated below in Table 5 and Table 6.

Table 5 Properties of Carbon Fibre Mat

Mass (g/m^2)	Fibre diameter (μ)	Glue content (%)	Density (kg/m^3)	Fibre modulus (GPa)	Water content (%)	Modulus of Elasticity (GPa)	Ultimate tensile strength (MPa)	Poisson's ratio
22	6	1-20	75	207	< 0.5	285	3450	0.32

Table 6 Properties of Glass Fibre Mat

Tensile strength (MPa)	Young's modulus (GPa)	Tensile modulus (MPa)	Bending strength (MPa)	Compressive Strength (MPa)	Ultimate elongation (%)	Elasticity modulus (MPa)	Poisson's ratio
3445	76	7800	204	900	6	2600	0.26

4. Mix Proportion

Following the identification of the physical characteristics of the components utilised in the concrete, early tests were conducted to prepare the concrete. The proportion of M30 grade concrete mix was calculated using the mix design specified in IS 10262:2019 and IS 456:2000. The mechanical and fresh properties of the concrete mixture were evaluated. The mix proportions for M30 grade concrete with manufactured sand with w/c 0.45 are shown in Table 7.

Table 7 Mix Proportion for M30 Grade of Concrete

Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)	Super Plasticizer (kg/m^3)
425.73	671.17	1110.21	191.58	3.90
1	1.52	2.60	0.45	0.009

5. Fabrication of Steel Reinforcement

The flexural design of the beam of size 150 x 250 x 3000 mm was designed per the IS 456:2000 guidelines. All the flexural beams are designed as a single reinforced member with the provision of 2 nos of 12 mm diameter bar at the tension zone and 2 nos of 10 mm diameter bar at the compression zone.

6. Experimental Investigation

6.1 Preparation of Beam Specimens

Figures 1 and 2 depict the CFRP and GFRP materials utilized in the casting process. The experimental procedure entails creating and assessing five beam specimens. Among these, one specimen adheres to conventional reinforced concrete beam standards, while the remaining four are reinforced with varying layers of CFRP and GFRP laminate.

The beam specimens are meticulously cast and subjected to a curing period of 28 days. After the curing process, the lower surface undergoes cleaning via a mechanical grinding machine to remove any dust particles. Subsequently, epoxy is meticulously applied to the beam's underside, mirroring the preparation carried out for the specimens reinforced with two and three layers of CFRP and GFRP laminate.

To ensure proper bonding, a dead load is then placed on top of the beam specimens. After a 24-hour duration, the beams, both those with and without FRP reinforcement, are whitewashed to facilitate the assessment of crack formation.

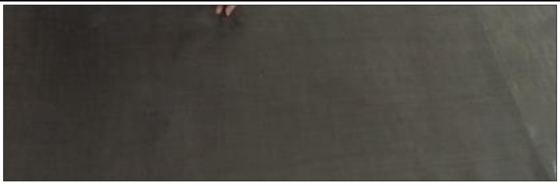

Figure 1 CFRP Sheet

Figure 2 GFRP Sheet

6.2 Experimental Configuration and Test Protocol

The Demountable Mechanical Strain Gauge, featuring a precision least count of 0.001 mm, was meticulously calibrated for the accurate measurement of compressive strain, neutral axis, and centerlines. To initiate the testing process, the beam was incrementally loaded with 0.5 kN increments. These beams, with an effective span of 2800 mm and subjected to four-point flexural loading, were assessed within a loading frame boasting a capacity of 50 tonnes.

The primary objective of the testing procedure was to ascertain both the point at which the first crack occurred and the ultimate failure point of the beams, which was determined by measuring the load-deflection values. The experimental setup for these reinforced concrete beams is illustrated in Figure 3.

Figure 3 Experimental Testing Setup with Instrumentation

7. Results and Discussion

The casted specimens were tested to evaluate the mechanical properties of concrete, such as compressive, split tensile and flexural strength of concrete in the compression testing machine of 2000 kN capacity and tested at different curing periods are presented in Table 8 – 10. The compressive, split tensile and flexural strength clearly satifies the grade of concrete properties.

Table 8. Compressive Strength of M30 Concrete

Mix	Compressive Strength, N/mm^2		
	7 days	14 days	28 days
M30	19.33	29.31	38.40

Table 9 Split Tensile Strength of M30 Concrete

Mix	Split Tensile Strength, N/mm^2	
	7 days	28 days
M30	2.19	4.03

Table 10 Flexural Strength of M30 Concrete

Mix	Flexural Strength at 28 days, N/mm^2
M30	3.28

In the experiment, both the wrapped and unwrapped beams underwent static loading until they reached their ultimate load capacity. During the test, the load deflection and strain values at the yield and failure points were measured, and the summary of the results is furnished in Table 11.

Table 11 Summary of Test Results for RC Beam Specimens Undergoing Static Flexural Loading

S.No	Beam-ID	First crack load, kN	Deflection at first crack load, mm	Yield load, kN	Yield deflection, mm	Ultimate load, kN	Ultimate deflection, mm
1	R30M	16.50	1.42	23.00	2.33	30.95	7.24
2	2GFRP	18.00	1.53	25.50	3.05	33.31	9.03
3	3GFRP	19.00	2.87	28.00	3.42	36.65	9.35
4	2CFRP	35.00	3.45	35.50	6.21	42.85	12.21
5	3CFRP	37.50	4.13	39.50	7.09	49.25	14.13

8. Conclusions

1. The laboratory successfully attained the M30 concrete grade in accordance with the design specifications after conducting physical property tests.

2. In the case of the RC control beam, the initial crack emerged at the lower portion within a consistent moment area. Several flexural tension cracks developed within the same region as the load increased.

3. To mitigate stress concentrations in beam, an FRP affixed at the soffit of the beam by increasing laminate thickness reduces FRP strengthened beam ductility.

4. The FRP with CFRP of triple layer exhibits a notably elevated initial crack load, approximately 59.13% greater than the control beam.

5. The flexural failure occurred in conventional beam and whereas laminate fracture occurred in 2GFRP, 3GFRP,2CFRP. Laminate ripping with cover concrete occurred in 3CFRP.

References

[1] Abed RJ, Mashrei MA & Sultan AA, Flexural behaviour of reinforced concrete beams strengthened by carbon fiber reinforced polymer using different strengthening techniques, Advances in Structural Engineering, Volume 25 (2), (2022) pp. 355-373.

[2] Przemysław Bodzak, Flexural behaviour of concrete beams reinforced with different grade steel and strengthened by CFRP strips, Composites Part B, Volume 167, 2019, pp. 411–421.

[3] Yu-Zhou Zheng, Wen-Wei Wang, John C. Brigham, Flexural behaviour of reinforced concrete beams strengthened with a composite reinforcement layer: BFRP grid and ECC, Construction and Building Materials, Volume 115, 2016, pp. 424–437.

[4] Long Liu, Saisai Yu, Xingpeng Ma, Flexural capacity of RC beams reinforced with ECC layer and steel plate, Journal of Building Engineering, Volume 65, 2023, pp. 1-13.

[5] Siddika A, Saha K, Mahmud M, Roy SC, Mamun M, Al A & Alyousef R, Performance and failure analysis of carbon fiber-reinforced polymer (CFRP) strengthened reinforced concrete (RC) beams, SN Applied Sciences, Volume 1(12), 2019, pp. 1-11.

[6] Shivankar A, Dabhekar K R, Patil P B, Mase D P & Khedikar I P, Behaviour of simply supported concrete beam using CFRP (Carbon Fiber Reinforced Polymer), IOP Conference Series IOP Publishing: Materials Science and Engineering, Volume 1197, No. 1, 2021, pp. 120-133.

[7] Srinath T, Strengthening of beams using Glass Fiber Reinforced Polymer (GFRP) Laminate, Annals of the Romanian Society for Cell Biology, Volume 25 (6), 2021, pp. 2435-2447.

[8] Yasmin Murad, An experimental study on flexural strengthening of RC beams using CFRP sheets, International Journal of Engineering & Technology, Volume 7 (4), 2018, pp. 2075-2080.

[9] Yusuf N, Kaura JM, Ocholi A & Abbas M, Experimental assessment of the performance of reinforced concrete beams strengthened with carbon fiber reinforced polymer laminates, Nigerian Journal of Technology, Volume 39 (1), 2020, pp. 105-112.

[10] Benjeddou O, Alwetaishi M, Ben Ouezdou M & Beddey A, Parametric study of carbon fiber reinforced polymer laminates geometry on the mechanical behaviour of strengthened reinforced concrete beams under standard four point bending test, Polymer Composites, Volume 42 (9), 2021, pp. 4560-4572.

[11] Miruthun G, Vivek D, Remya PR, Elango KS, Saravanakumar R, Venkatraman S, Experimental investigation on strengthening of reinforced concrete beams using GFRP laminates, Materials Today: Proceedings, Volume 37 (2), 2020, pp. 2744-2748.