Strengthening and Retrofitting of Reinforced Concrete Beam by Using Composite Materials

Priyanka S. Mirajkar, P. M. Pawar, and Sonali P. Patil

Abstract The strength and flexural behavior of RCC beams strengthened and retrofitted with glass fiber sheet (GFRP) and carbon fiber sheet (CFRP) with two layers of jacketing, were investigated experimentally. For strengthening and retrofitting, we created two RCC beam groups were tested under single point load. One group of beams was evaluated in their natural state and use for retrofitting, while another group was examined for strengthened with FRP. A vacuum bagging machine was used to airtight bond and beams are tested under loading frame; deflection is monitoring by LVDT. In the result of 2 methods, retrofitted beams have a large load caring capacity as compare to strengthened beams. The experimental results indicated jacketing beams with CFRP got greater strength and less deflection as compare with control beam and jacketing beam with GFRP in both the methods. Jacketed beams with FRP sheets have less cracks and fiber damage is also negligible.

Keywords Glass fiber sheet (GFRP) · Carbon fiber sheet (CFRP) · Strengthening · Retrofitting · Jacketing · Reinforced concrete beam · Loading frame machine · LVDT

1 Introduction

Composite materials are being used worldwide for the strengthening and retrofitting of deficient and old infrastructures. Over the years, these structures have suffered severe weakness and stiffness because of aggressive environmental conditions like humidity, saltwater, and alkali solutions. Advanced fibrous composite materials like GFRP, CFRP, etc. can substantially increase the strength and stiffness of reinforced concrete beams. In the case of Reinforced Concrete (RCC) beams, remove deflection and repair with filling crack and expose them to aggressive environmental conditions. The bond between the composite material sheets and the surface of the RCC beam

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significantly affects the strength of externally reinforced RC beams. Thus, it's essential to analyze the overall response of the RCC beams when externally strengthened with composite material sheets and fabrics and exposed to different environmental conditions. Because it offers high strength, low weight, corrosion resistance, high fatigue resistance, easy and rapid installation, and minimal change in structural geometry, strengthening concrete structures with jacketing of composite materials sheets is a more economical and technically superior alternative to the old technique used in many situations. This technique has been largely used because of the high specific stiffness and strength of these materials. External bonding of high-strength Fiber Reinforced Polymers (FRP) to structural concrete members has grown in popularity in recent years, especially in rehabilitation and new construction projects. Experimental analysis conducted in the past has shown that this strengthening method has several advantages over the making of new, especially due to its corrosion resistance, high stiffness-to-weight ratio, improved durability, and flexibility in its use over steel plates. The use of fiber Reinforced Polymer (FRP) materials in civil infrastructure for the repair and strengthening of reinforced concrete structures and also for new construction has become stronger [1, 2]

2 Objective

- To design various approaches of strengthening techniques using composite materials.
- To analyze the performance of beam strengthened using composite materials.
- To design various approaches of retrofitting techniques using composite material for partially damaged beams.
- To analyze the performance of beam retrofitting techniques using composite materials for partially damaged beams.
- To understand the failure pattern of the RCC beams.

3 Methodology

3.1 Basic Terminology

Strengthening: To enhance resistance to aggressive environmental conditions of a building by strengthening. This method adds higher strength and ductility to any part of current building than the primary building. Strengthening can be done for seismically weak building.

Retrofitting: Resistance to aggressive environmental conditions can be upgraded to level of the present-day by adequate retrofitting techniques. Enhancing the strength of a damaged building is called retrofitting. It has been found that the retrofitting costs are much lower than constructing a new building.

3.2 Material Used

1. **Cement**

Ordinary Portland cement (OPC)-43, Wonder Cement Grade adhering to IS: 8112-1989, was used in the current experiment. In accordance with Indian Standard Specifications, physical properties were tested.

2. **Coarse Aggregate**

Aggregates with a size range of 10–20 mm and a coarse aggregate specific gravity of 2.8 are obtained from authorized quarries. According to IS 2386-1963, tests on coarse aggregate are carried out.

3. **Fine Aggregate**

M sand with a specific gravity of 2.65 that passes through a 4.75 mm sieve is employed. Zone II is the fine aggregate grading zone. Per IS 383-1970, the physical characteristics of fine aggregates were determined.

4. **Water**

The water on the college campus complies with the IS: 456-2000 criteria for water for curing and concreting.

5. **Reinforcement**

HYSD bars made of Fe 415 with a diameter of 12 mm were employed as longitudinal reinforcements, while bars with a diameter of 10 mm were used as hanger bars. Fe 250 mild steel bars with an 8 mm diameter were used to make the stirrups.

6. **Epoxy Resin**

Essentially, epoxy resins are low-molecular-weight pre-polymers that can be treated in a variety of ways. It is a thermosetting polymer produced by the interaction of polyamine “hardener” and epoxy “resins.”

7. **Glass Fiber Sheet**

A popular type of fiber-reinforced plastic that uses glass fiber is fiberglass. The fibers can either be braided into glass cloth or alternately arranged before being flattened into a sheet known as a chopped strand mat. The thermoset polymer matrix, which is most frequently built on thermosetting polymers like epoxy and polyester resin, may make up the plastic matrix (Table 1).

Table 1 GFRP sheet properties

Fiber type	Tensile strength (MPa)	Compressive strength (MPa)	Young's modulus E (GPa)	Density (g/cm^3)	Thermal expansion (μm/m °C)	Softening T (°C)
GFRP	3445	1080	76.0	2.58	5	1000

Table 2 CFRP sheet properties

Fiber type	Tensile strength (MPa)	Compressive strength (MPa)	Young's modulus E (GPa)	Density (g/cm^3)	Thermal expansion (μm/m °C)	Softening T (°C)
CFRP sheet	4900	896	230	1.78	1.7	1000

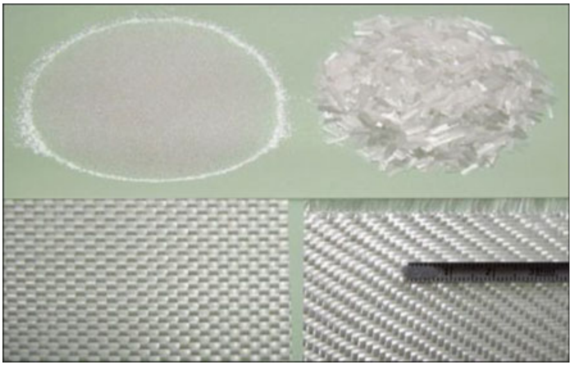

Fig. 1 GFRP sheet

8. **Carbon Fiber Sheet**

The carbon atoms are bonded each other's in crystals that are more aligned parallel to the fiber is long axis as the crystal alignment gets the fiber a high strength-to-volume ratio (in other words, it is strong for its size). Several more carbon fibers are bundled together to form a tow, which may be used by itself or woven into a fabric (Table 2).

3.3 Mix Proportion of Concrete

M 20 grade concrete was proportioned in line with Indian Standards 10262:1982 and 10262:2019. A concrete mix design was carried out based on the results of components. For mix design, a water to cement ratio of 0.47 was used Proportion of M20 mix (Table 3).

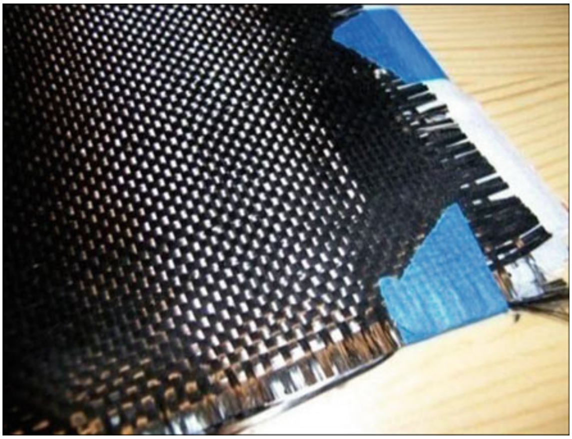

Fig. 2 CFRP sheet

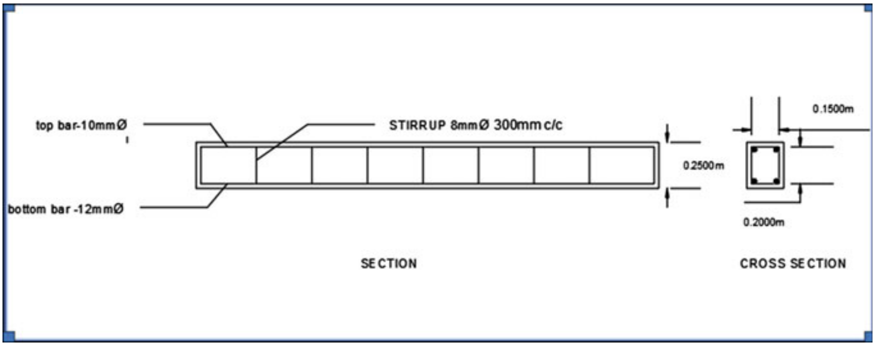

Fig. 3 Beam design

Table 3 Material required for 1M^3 concrete

Content	Quantity	
Cement	350.64 kg	
Water	164.8 kg	
Fine aggregate	M sand—414.36 kg Dust sand—276.24 kg	Total—690.60 kg
Coarse aggregate	20 mm dia—760.35 kg 10 mm dia—536.88 kg	Total—1279.23 kg
Water cement ratio	0.47	

3.4 Casting of Beams

All four beams were created in accordance with the IS: 456-2000 standards utilizing the limit state technique, with the section being under-reinforced. Molds with dimensions of 2500 × 200 × 250 mm were made out of plywood. The machine-mixed concrete was made in accordance with IS10262-1982 and had a 1:2.1:2.95 mix ratio. (Cement:sand:coarse aggregate). The following methods were employed for casting beams:

- All of the mould was first lubricated. After 24 h, the beams can be easily removed from the mould.
- To provide uniform covering after the reinforcing bars have been fitted, cover blocks of 20 mm are used.
- The concrete mix was poured in layers and crushed with a vibrator and tamping rods until the mould was entirely filled. This process was completed with no voids.
- After a 24-h period, the beams were taken out of the moulds. The beams were then left to cure for 28 days.

3.5 Jacketing of FRP Sheet on the RCC Beam

FRP sheets were jacketed on RCC beams using the brash layup procedure. For optimal bonding with FRP sheets, the surface of the beams was roughened after curing and then wiped with water to eliminate all dirt. After that, the beams were left to cure for two hours. For the over-round part of the beams, the FRP sheets were cut to a width of 1 m for two layers and a length of 0.9 m. After that, the epoxy resin primers are correctly taken in a plastic container at a ratio of 1:2 (hardener:resin) to generate a homogeneous mix. Then, with the help of brash, it was painted on the surface of beams for good bonding of FRP sheets with the beams. Then FRP sheets were placed on the top of the epoxy resin layer, and another coating of epoxy resin was applied on the top of the FRP sheets. Another layer of FRP sheet was applied over it, and the final coating was done with epoxy resin. This procedure is performed at room temperature (Figs. 4, 5 and 6 [3].

3.6 Vacuuming of FRP Sheet Jacket with Vacuum Bagging Machine

After doing jacketing immediately apply the cloth on the jacket of the FRP sheet on the beams and plastic paper is airtight attach overall with the help of a double-stick like an airtight bag. Attach vacuum bagging machine pipe in plastic airtight bag system and start the machine for 1 h to remove all air and make all bond of beams, FRP sheets layer with each other stronger. Make bond stronger with epoxy resin.

Fig. 4 Appling Epoxy Resin on beam

Fig. 5 Jacketing

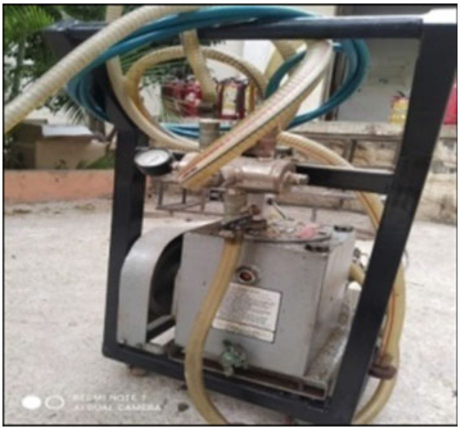

Fig. 6 Vacuum machine

3.7 Testing of Control Beam and FRP Sheet Strengthened Beams

Testing of control beam and FRP sheet strengthened beams under loading frame machine of 200 kN capacity with data acquisition program system and flexural strength is also recorded during the testing with the help of LVDT (Figs. 7 and 8) [4, 5].

Fig. 7 GFRP jacketing beam test

Fig. 8 CFRP jacketing beam test

3.8 Repair of the Pre-cracked Beam Using Mortar

This methodology is useful for retrofitting method (for the 3rd objective) for repairing pre-cracked beams pre-cracked. The cracked beams were clean with polished paper. The lose parts of the beams are removed from the beams and wash the crack with water. Take it 2 h to dry and after that fill the crack with mortar (cement:sand) and attach the jack to the bottom of the beam to remove the bend of the beam for 1 day (Figs. 9 and 10) [6, 7].

Fig. 9 Cleaning of crack

Fig. 10 Filling of crack

Table 4 Compressive strength of the beams

Beams	Load taken by the beam (kN)	Increased load caring capacity
Control beam	58	0
Strengthened beams		
Strengthened beam by GFRP sheet	60.1	2.1
Strengthened beam by CFRP sheet	63.4	5.4
Retrofitted beam		
Retrofitted beam by GFRP sheet	75.6	17.6
Retrofitted beam by CFRP sheet	77.8	19.8

4 Result

4.1 Compressive Strength

Strengthened beams and retrofitted beams with GFRP and CFRP sheet are compared with Control beam (Table 4).

4.2 Deflection

Strengthened beams and retrofitted beams with GFRP and CFRP sheet are compared with Control beam (Table 5).

Table 5 Flexural strength of the beams

Beam	Deflection (mm)	Flexural strength (N/mm^2)	Failure effect
Control beam	43	11.6	Concrete fracture
Strengthened beams			
Strengthened beam by GFRP sheet	39	12.2	GFRP sheet fracture is very less
Strengthened beam by CFRP sheet	33.58	12.68	CFRP sheet fracture is very less
Retrofitted beam			
Retrofitted beam by GFRP sheet	44.68	15.12	GFRP sheet fracture is very less
Retrofitted beam by CFRP sheet	41.2	15.56	CFRP sheet fracture is very less

5 Conclusion

- In this research paper one point bending test were carried on the RCC beam (control beam) and strengthened as well as retrofitted beam with GFRP and CFRP sheet Jacketing with 2-layer Jacketing configuration.
- GFRP sheet and CFRP sheet strengthened beam have a more load caring capacity up to 5% to 10% respectively as compare to control beam and flexural behavior is also improved 10% and 21.9% respectively with compare to control beam. Deflection of GFRP and CFRP is less and fiber damage is negligible.
- GFRP sheet and CFRP sheet retrofitted beam have a more load caring capacity up to 2.5% and 2% respectively as compare to control beam and flexural behavior is also improved 30% to 34% respectively with compare to control beam. Deflection of GFRP and CFRP is less and fiber damage is negligible.
- The flexural behavior is also improved in of strengthened beams and retrofitted beams with GFRP and CFRP sheet.
- Failure of the material of the beam is also less as compare to the strengthened beams and retrofitted beams, fiber damage also less (negligible).

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