SHEAR PERFORMANCE OF REINFORCED CONCRETE BEAMS STRENGTHENED BY POLYPROPYLENE FIBRE

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Abstract

Fibre Reinforced Polymer is comparatively a new category of material and it is produced as a combination of fibres and resins. It is a evidenced repair and strengthening material due to its efficient and economical uses in the construction industry. The mechanical properties of FRP composite materials are high. It includes impact resistance, strength, stiffness, flexibility and ability to hold masses. The FRP material has evidenced by its effective use in retrofitting and strengthening. The plan of this work is to strengthen the RC beam with FRP material and find out its mechanical behaviour. Mechanical characteristics of Polypropylene Fibre Reinforced Polymer (PFRP) confined concrete specimens were studied by conducting compression, split tension and flexural tests. Shear strength of PFRP wrapped RC beams were conjointly studied. By observing the experimental outcome it is concluded that PFRP wrapped beams have superior strength than the unconfined beams in both single and double layers of 28 days water curing.

Keywords: *Strengthening, Shear strength, PFRP, RC beams, Mechanical strength.*

1. Introduction

The repair and retrofitting of deteriorating structures has become a main part in the construction industry and different types of retrofitting materials and methods were followed around the world. Steel and cementitious materials are used as traditional methods in retrofitting techniques and they do not invariably supply the foremost applicable solutions. Compare to traditional techniques, retrofitting with FRP might give a lot of economical and technically superior alternative method in several situations. Numerous papers, reports and articles have been prepared illustrating how we could and should make greater use of FRP composite materials in the building sector. The type and properties of fibres, resins, and orientation of fibres and also the interface bond strength determine the strength of FRP confined concrete members. Various fibre reinforced polymers are available for strengthening and retrofitting works, among these carbon and glass fibre reinforced polymers are commonly preferred. This study makes an effort to assess a safe and economic use of FRP as strengthening material. Compressive strength, split tensile strength and flexural behaviour of FRP confined concrete specimens were studied. Many researchers have examined about the strengthening and retrofitting of structures using fibre reinforced polymers as strengthening material. The external retrofitting method was initially carried out in Japan and Europe. FRPs are normally used as an externally bonded repair materials. The preparation of specimens wrapping with FRP along with curing method influences the performance and properties of the concrete members and hence it could be worked with care and correct procedure.

In recent years researchers investigated on which strengthened by externally bonded fibre reinforced polymers. "Triantafillou and Antonopoulos (2000)" tested the concrete in shear for split tensile members strengthened with FRP. From the investigation it is noted that FRP strengthening improves the shear strength of split tensile members. "Lamanna et al. (2004)" performed an experimental study on RC specimen with mechanically attached fibre reinforced polymer strips and find it split tensile strength. It is summarized that the ductility of the mechanically attached FRP strips is higher than the bonded FRP strip. "Bousselham and Chaallal (2008)" carried out an experiment on concrete specimen in shear confirmed by externally bonded FRP. Test results recorded that the shear resistance of concrete specimens boostss when specimens strengthened by externally bonded FRP. "Ilki et al. (2008)" worked on the axial behaviour of RC columns wrapped with FRP composites. From the investigation it is observed that the columns with external confinement CFRP sheets show an increase in strength and ductility property of concrete. "Sangeetha and Sumathi (2010)" study the properties of RC columns cloaked with Glass fibre under uniaxial compression. From the experiments it is evident that the concrete columns loaded axially has increase in strength. "Beschi et al. (2011)" investigated on the performance of fiber reinforced concrete jacketing retrofitted on beam-column joint tested by static and cyclic loading. It is concluded that the bearing capacity along with the ductility of the column increases for the HPFRC jacketing column and hence boosts the behavior of the beam column joint. "Hassan and Bilal (2014)" conducted study on beam-column joints in existing concrete buildings by the seismic retrofit of shear. It is listed that the joint cyclic response of the beam-column joint inserted by the U-shape bars did not improved due to the less space available between beam bar hooks. "Vinodkumar and Muthukannan (2014)" presented a study on CFRP/GFRP composites made to strengthen the Reinforced Concrete Beams. From this study we learnt that the CFRP/GFRP laminated rectangular RC beams with different thickness and it's flexural and shear strength has been carried out. "Eslami and Ronagh (2015)" analyzed a mathematical approach of Flange-Bonded CFRP Composites on RC beam–column joint by seismic analysis. From this it is validated that the FE approach is a suitable numerical analysis method. Additionally through the numerical analysis the failure mechanism is predicted precisely. "Jafar Ali and Gayathri (2017)" have done an experiment by varying the thickness of CFRP and GFRP retrofitted sheets on RC beam column joint. As compare to GFRP the RC beam column joint retrofitted with CFRP will give 50% more strength.

2. Materials and Methods

The method and used in this research work were tested as per the guidelines of the relevant Indian Standard (IS) codes.

2.1. Materials and Properties

The concrete specimens were casted by ordinary Portland cement with 31% standard consistency, initial setting time as 60minitues and final setting time as 320minitus. The specific gravity of cement was 3.14. According to IS: 383-1970, the fine aggregate used was the river sand and coarse aggregate used was the crushed granite stone. The specific gravity of fine and coarse aggregate was 2.68 and 2.72 respectively. The values of fineness modulus and absorption of fine aggregate was 2.95 and 0.65%. Similarly for coarse aggregate it was found to be 6.80 and 0.45%. The size and diameter of reinforcement were selected with references to IS: 1786 - 1985. The 8, 10 and 12 mm diameter rebars were used and they have been tested for their tensile stress in a universal testing machine. The yield strength of steel was 415 N/mm^2 .The quality of water also influence the properties of concrete and hence the concrete members. The M_{25} grade concrete used in this investigation with the mixed ratio of 1: 1.42: 2.75 with water-cement ratio of 0.48. From the preliminary investigation the strength of concrete cubes found to be 34.52 N/mm^2

2.2. Methods of casting

Standard steel moulds were used for casting the specimen, after one day of casting the moulds were removed and kept in water for 28 days. Now the concrete specimen was make ready for FRP wrapping. The subsequent steps were adopted for FRP wrapping. Initially the exterior of the concrete specimens were scrubbed with a silicon carbide water-proof paper sheet to smoothen the surface. The prepared and cleaned surface was coated by a mixed material of Nitowrap 30 primer. Afterwards it was permitted to dry for one day. The density of primer was 1.14 g/cc. After the application of primer coating the Nitowrap 410 was done. The Nitowrap 410 saturant coating system consist resin and hardener. Before applying the coating the saturant was mixed perfectly by using hand. The density of the saturant was 1.25 – 1.28 g/cc and the application temperature should be maintained as 15ºC - 40ºC. The PFRP sheet was confined straight over the surface after the first coat of saturant was applied on the primer coat. To avoid the glide or debonding of fibres in the time of test PFRP layer was confined all over the concrete specimens with an overlap of $(¼)^{th}$ of the perimeter and to conform the improvement of total strength. The specifications of the PFRP material were tabulated in Table 1.

Table 1. Specifications of PFRP material

Properties	Polypropylene fibre (Bi-directional)
Weight of fibre (g/m^2)	910
Thickness (mm)	0.30
Nominal thickness per layer (mm)	0.5
Tensile strength (N/mm^2)	3200
Tensile modulus (N/mm^2)	100000

3. Experimental Investigation

Mechanical behaviour of PFRP confined concrete specimens were studied by conducting compression, split tension and flexural tests. Shear strength of PFRP wrapped RC beams were also investigated.

3.1. Compression test on concrete cubes

With reference to IS: 516 – 1959 (Reaffirmed 1999) the test was performed. Standard sizes of simple plain concrete cubes were used in this study. The experimental investigation has been conducted on 9 cubes. Out of the 9 cubes, three reference cubes were tested without any wrapping and the left 6 cubes were confined with PFRP mat with single and double layer. Three cubes were examined for each type trail and the median of the values was used out for future work. Table 2 presents the compressive strength of specimens.

Table 2. Compressive strength of Specimens

Number of layers	Compressive strength (N/mm^2)
Unconfined	34.52
Confined with single layer	44.66
Confined with double layers	54.12

The experimental test outcomes show that the concrete cubes confined with PFRP composites have compressive strength higher than the unconfined concrete cubes. The outcomes also show that the concrete cubes confined with double layers have more strength over the single layer of PFRP. The rate of increase of strength of concrete cubes confined with bidirectional PFRP mat was 29.37 % and 56.78 % for single and double layer respectively.

3.2. Split tensile test on concrete cylinders

The test was carried out as mention in IS: 5816 - 1999. Standard cylinders were used for this study. The experimental investigation has been conducted on 9 cylinders. Out of the 9 cylinders, three reference cylinders were tested without any wrapping and the left 6 cylinders were confined with PFRP mat with single and double layers. Three cylinders were examined for each type trail and the median of the values was used out for future work. Table 3 presents the type of concrete cylinders along with their split tensile strength.

Table 3. Split tensile strength of Specimens

Number of layers	Split tensile strength (N/mm^2)
Unconfined	4.21
Confined with single layer	5.84
Confined with double layers	7.32

The experimental results show that the concrete cylinders confined with PFRP composites have superior strength than the unconfined concrete cylinders. Results also show that the concrete cylinders confined with double layer have more split tensile capacity over the single layer of PFRP. The amount increase in split tensile strength of concrete cylinders confined with bidirectional PFRP was 38.72 % and 73.87 % for single and double layers respectively.

3.3. Flexure test on concrete prisms

The test was carried out as mention in IS: 516 - 1959 (Reaffirmed 1999). Standard sizes simple plain concrete prisms were used for this study. The concrete prism was loaded at one-third span points. Supporting span of the prism was kept as 400 mm. The experimental investigations have been conducted on 9 prisms. Out of the 9 prisms, three reference prisms were tested without any wrapping and the left 6 prisms were confined with PFRP mat with single and double layers. Three prisms were examined for each type trail and the median of the values was used out for future study. Table 4 presents the flexural strength of concrete prisms.

Table 4. Flexural strength of specimens

No. of layers	Flexural strength (N/mm^2)
Unconfined	4.32
Confined with single layer	5.92
Confined with double layers	7.44

The experimental results show that the concrete prisms confined with PFRP composites have higher flexural strength than the unconfined concrete prisms. Results also show that the concrete prisms confined with double layers have superior flexural capacity over the single layer of PFRP. The ratio of increase in flexural strength of concrete prisms confined with bidirectional PFRP mat was 37 % and 72.22 % for single and double layers respectively.

3.4. Shear strength of PFRP wrapped RC beams

The RC hollow and solid beams were cast with the help of wooden moulds of the inner dimensions 1200mm x 150mm x 250mm. In hollow beam, a core of dia. 76.2mm was introduced just below the neutral axis of beam to find the effect of hollow beam in shear strength. Three 12mm diameter bars at base and two 10mm diameter bars at top were used as longitudinal reinforcement and 8mm diameter bars were adopted as stirrups with a spacing of 150mm. The reinforcement of beam was designed in such a way that the failure of beam in shear not by flexure. Theoretical design strength of the beam by limit state method is presented in Table 5. The raw materials were batched as per the mix design and were mixed well using hand mixing technique. The mould was filled by the concrete in three layers and the needle vibrator was used for compaction. Uniform compaction and smooth surface finishing throughout the beam was done with proper care. The RC beams were demolded after the next day of casting and kept for curing using wet gunny bags for 28 days. After 28 days curing, RC beams were make ready for PFRP wrapping. The PFRP composites were wrapped in U-Jacketing technique in the shear zone of the beams. The RC beams were subjected to two point loading with an effective span of 900 mm. The UTM of 400kN was used for the testing of RC beams. The load was increased in the order of 10kN and the deflection readings were noted accordingly. Typical arrangement of testing of PFRP wrapped RC beams is shown in Figure1. Conventional hollow & solid RC beams and PFRP strengthened hollow & solid RC beams are shown in Figure.2 and Figure.3 respectively. Table 6 presents the shear strength of conventional hollow & solid RC beams and PFRP strengthened hollow & solid RC beams.

Table 5. Theoretical design strength of beam

Condition	Bending Moment (kN.m)	Shear strength (kN)
Limit state of collapse : Shear	-	53
Limit state of collapse : Bending (based on the tension reinforcement)	22	73
Limit state of collapse : Bending (based on the compressive strength of concrete)	25	83

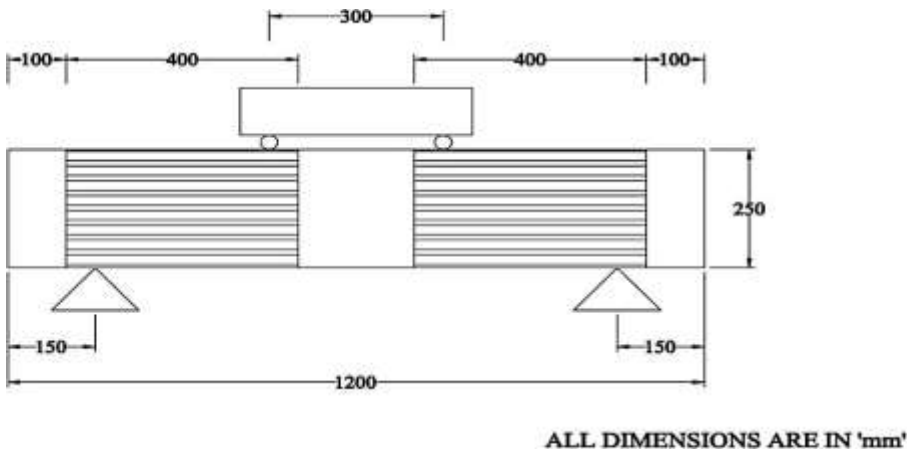

Figure1. Experimental setup of PFRP wrapped RC beam

a) Solid RC beam

b) Hollow RC beam

c) Shear crack in solid RC beam

d) Shear crack in hollow RC beam

Figure 2. Solid and hollow RC beams

a) PFRP strengthened solid RC beam

b) PFRP strengthened hollow RC beam

Figure 3. PFRP strengthened Solid and hollow RC beams

Table 6. Shear strength of RC beams

Type of beam			Total Load (kN)	Max. Shear Force (kN)	Corresponding displacement (mm)
Conventional RC Beams	Solid RC beam		110.0	55.0	9.4
	Hollow RC beam		102.4	51.2	10.2
PFRP Strengthened RC Beams	Solid RC beam	Confined with Single layer	120.8	60.4	7.1
		Confined with Double layers	131.2	65.6	5.2
	Hollow RC beam	Confined with Single layer	112.4	56.2	8.1
		Confined with Double layers	122.8	61.4	6.4

The experimental outcome show that the RC beams wrapped with PFRP composites have superior shear strength than the unwrapped RC beams for both solid and hollow RC beams. Results also show that the RC beams wrapped with double layers have superior shear capacity over the single layer. Figure. 4 shows the variation in shear strength of RC beams wrapped with PFRP composites.

- The ratio of increase in shear strength of solid RC beams wrapped by bidirectional PFRP mat were 9.82 % and 19.27 % for single and double layers accordingly.

- The ratio of increase in shear strength of hollow RC beams wrapped by bidirectional PFRP mat were 9.76 % and 19.92 % for single and double layer respectively.

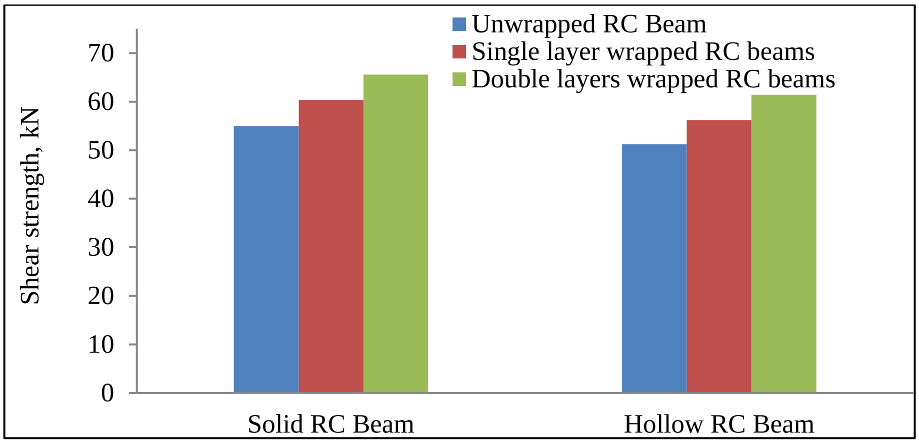

Figure 4. Effect of PFRP wrapping on the shear strength of solid RC beams

4. Conclusion

The strengthening of RC structures were studied by conducting compression, split tensile, flexural strength of concrete specimens with and without PFRP confinement and the shear strength of RC beams were also studied on RC beams with and without PFRP wrapping in shear zone.

- The feasibility of using PFRP in strengthening of beam is strongly linked to the capability of these materials to maintain their mechanical properties during service.
- According to the experimental results it is obserbed that the specimens confined with PFRP have superior strength when compared to unconfined specimens and double layers have superior strength than the single layer.
- The experimental results indicated that the beams wrapped with PFRP have higher strength than the unwrapped beams.

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