CFRP Enabled Novel Approach to Strengthen the Concrete Structures

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ABSTRACT

Concrete structures are popular infrastructure past few decades. A large number of concrete structure is constructed annually all over the world. After a certain period of time these structures get deteriorated. Rehabilitation or restoration required strengthening of these structures for safe usage. There are various materials and technique available in the market for restoration work, but these methods increases structural load and reduces clear space. It is a great invention of Carbon Fiber Reinforced Polymer (CFRP) material to repair the old structure. It increases the life of the structure. CFRP contain properties like high tensile strength, light weight and flexible. In this paper we inspect the performance of CFRP wrapped concrete with conventional concrete. CFRP wrapped to concrete grade M25 & M30 in the form of strips at 20, 40, 60, 80 and 100 percent of the applicable area of structure. Various test like Compressive test, Split tensile test and Flexural test were conducted and properly analyzed for better results. Various strength parameters are examined of prepared samples. By these results it can conclude that wrapping CFRP over deteriorated structure also increase their strength in a similar manner without increasing self-weight of structure.

Keywords
CFRP, Flexural Strength Failure, Textile Reinforced Mortar, Reinforcement.

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Introduction

There is limited availably of sources in nature and for maintaining the ecological balance. There is a solution to destruct the old buildings and construct the new building in place of them, it is totally waste of material. Deteriorated or old structures at some point should be repaired or strengthened to improve its auxiliary life and exhibitions. This paper is about strengthening structure even more than its original designed capacity without increasing its size, by using Carbon Fiber Reinforced Polymer (CFRP) wrapped in a strip around its sides. CFRP composite materials have accomplished the height of use in structural enhancement as well as in rehabilitation applications around the globe in last several years. It has versatile usage in various industries. Using CFRP turns beam into a composite material beam which has increased a moment bearing and shear resistance capacity, since CFRP is low density its weight is very less than steel [1][2].

CFRP, products are a composite of a polymer or resin with carbon fibre that when combined offers a durable, strong, more corrosion and heat resistant product than is found anywhere else. CFRPs are used for repairing work mostly as a jacketing component, but different types of CFRPs have different characteristics like high or low rigidness or ductility, this depends on the composition of CFRP. These composites are also used for enhancing the bearing capacity of an existing component or for seismic strengthening. CFRPs offer highest weight to strength ratio which also enables to make lightweight prefabricated structures as well.

The most proficient procedure for improving the shear quality of disintegrated RC is CFRP sheets or plates. CFRP has not only great moment and shearing capacity, it also proves very good in seismic shear bearing, fatigue, thermostatic behavior, weathering effects, no corrosion etc. Despite CFRP is composite of resins and fiber material and in compare with the traditional substance it's found costlier. One note taken in consideration that tools used for the establishment of CFRP frameworks are less expensive. As the new practice CFRP can be recognized as a resettlement and strengthen material for reinforced concrete structures.

How Carbon Fiber are Made?

Carbon fibre is composition of 90% polyacrylonitrile (PAN) and 10% rayon or petroleum pitch. These materials come in the category of organic polymers.

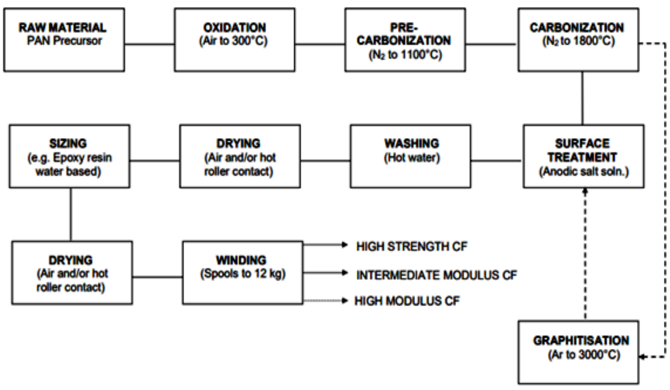


Fig. 1. Process flow for the manufacturing of PAN based Carbon Fibre

Applications of CFRP

The main application area of CFRP is to strengthen building components like columns, beams, slabs of buildings, and bridges. Two procedures are commonly received for the fortifying of shaft that is flexural strengthens or shear strengthens. To gain the flexural as well as shear strengthen of a beam and slab, CFRP sheets are applied to the tension face or on the web of a member respectively[3]. CFRP is expensive to produce but used when high strength to weight ration and modulus of rigidity required.

Throughout the paper we are going to fulfill following objectives: strengthening concrete structure by wrapping CFRP strips. Investigate the strength of a cube, cylinder and beam with CFRP strip wrapped concrete at different percent of the area covered without increasing dead load.

Literature Search

A lot of research is headed by many authors in this direction of strengthen the concrete structures by using CFRP. This chapter introduced detailed analysis and literature search to establishes the credibility of this work.

Ratish Y et al.[4] (2018), this paper is carried out to investigate the overall actions of RC columns, strengthened with wrapped CFRP. Compressive strength of unconfirmed concrete and composite layers is the basic parameters for investigation in this work. Saad M. et. al. [5] (2017), this paper uses fibre-reinforced polymers (FRP) and textile-reinforced mortar (TRM) as main strengthen material. And compare the flexural characteristics of RC beam, FRP and TRM. Paper concludes that the impact of TRM in terms of load bearing capacity is less than that of FRP.

Khalid et al. [6] (2017) this paper evaluates the impact of CFRP on the uniaxial compression stress-strain behavior of columns. It was found that CFRP jacketing increase the ultimate axial strain and peak strength of the confined prisms. Zoi C. et al. [7] (2016) this paper shows the effect of RM jacketing on RC-T beams. It is observed that the use of TRM jacket anchor increases effective strains. Values with and without anchors are in rang of 3.24% to 5.21% and 2.03%-2.58% respectively.

Zoi C. et al. [8] (2016), paper evaluates performance of TRM and FRP jackets by including both medium scale rectangular beams and full scale T-beams at high temperature. In order to improve the shear capacity of reinforced concrete beam TRM proves better than FRP. Chen et al. [9] (2016), this paper analyze the behavior of FRP on recycled aggregate concrete (RAC) by applying various test. Results say utilization of higher amount of recycled aggregate decreases the compressive strength of concrete. Marwan et al. [10] (2014), this paper provides deep study and addresses the various issues occurs on shear strength of beam with CFRP. Author concludes with an economical and versatile solution that increases the service life of concrete structure.

Mahmoud et al. [11] (2014), this paper attempts to strengthen the RC exterior beam by using CFRP material. To identify the possible defects experimental testing is done on 10 half scale specimens. To rehabilitate the defected structures, mounted CFRP strips are used as a strengthen materials. Ratan et al. [12] (2014), the load carrying capacity and ductility of beams are investigated throughout the paper. From an economical point of view it is desirable to use CFRP at tension phase rather than parallel sides. Amrul et al. [13] (2013), this paper proposed a sublime square jacketing technique for the re-strengthen of existing RC columns. Two basic procedural elements were used that is stress reduction and strengthen comers.

Material Used

Cement

Cement is a binder material which is used in construction to bind fine and course aggregates. Key components of cement are silica, alumina, blast furnace slag, lime etc. Ordinary Portland cement (OPC) comes in the category of most widely used cement because consume less time for gaining strength. Depending on the strength parameter, OPC is categorized into three grades named as 33, 43 and 53 grade. In this work OPC-43 grade cement is used.

Aggregate

Aggregate are the significant ingredient that gives body to the concrete. In the total volume of concrete 70 to 80 percent part of concrete is covered by aggregates. It reduces the creep and shrinkage from concrete but proper analysis and standard test as per IS code need to be done before using in concrete.

To control the quality of concrete we used coarse aggregate (CA) and fine aggregate (FA) with suitable IS codes.

Carbon Fibre Reinforce Polymer (CFRP)

Carbon fiber strengthened polymer is a very solid and light fiber-fortified plastic which contains carbon strands. It is flexible, light weight, easy to install and have very less construction period with long life. Degree of carbonization is the most addressable point to determine the characteristics of CFRP. Basic uses of CFRP is fortifying, fixing and retrofitting of workmanship, solid, steel and wooden substrates. FRP composite reinforcing of segments, shafts, pieces, dividers, heaps, wharf tops in the building, connect, thruway, railroad, passages, docks and common air terminal. Table 1 describes the technical specifications of CFRP.

Table 1 Technical Specification of CFRP

Sr. No.	Features	CFRP FABRIC 200GSM
1	Weight	200g/sqm
2	Thickness	0.111mm
3	Density	1.8g/cm³
4	Packing	100 meters/roll
5	Width	500 mm
6	Tensile Strength	1400 MPa
7	Compressive Strength	980 MPa
8	Flexural Strength	1290 MPa

Epoxy Material

Epoxy Material is used to wrap concrete with CFRP to provide proper bonding and adhesive surface over the concrete on which CFRP wrapped properly. PERMA-Concrete Coating Epoxy has been used in this project which is easily available in the market. Epoxy is limited to interior use because it changes color with UV light.

Material Testing

Mix Designing (IS 10262:2009)

Mix Designing of Grade M-25 & M-30 is done as per IS 10262:2009. Following are the specification for different grades for control mix.

Table 2 Specification of M25 & M30 grade

Sr. No	Material	M-25	M-30
1	Cement	395 kg/m^3	438kg/m^3
2	Water	196 kg/m^3	196kg/m^3
3	FA	718 kg/m^3	686kg/m^3
4	CA	1077 kg/m^3	1073kg/m^3
5	W/C Ratio	0.5	0.45
6	Mix Proportion	**1:1.82:2.73**	**1:1.57:2.45**
7	Achieved Slump	92 mm	88 mm

Slump Test (IS 1199:1959)

This test is used to identify the consistency and workability of concrete. This test was conducted as per IS 1191:1959. Dimensions of apparatus frustum of the cone is shown below in figure 2.

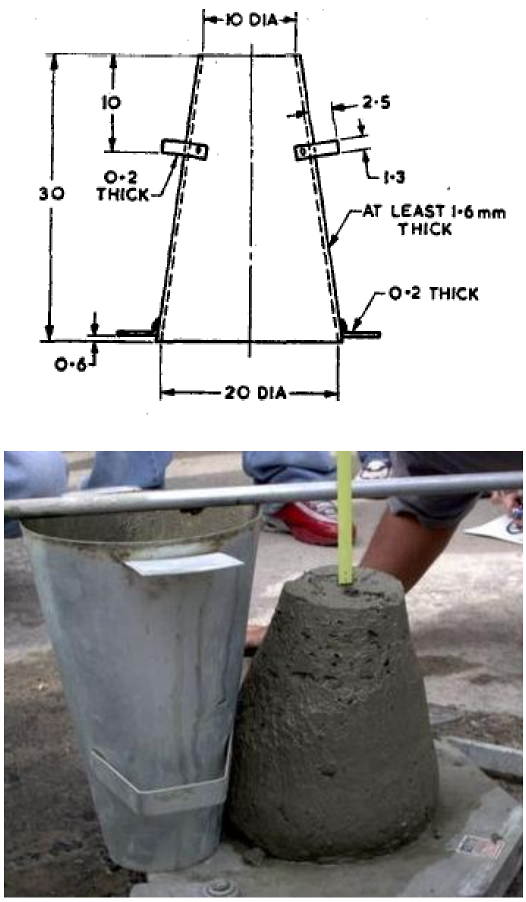


Fig. 2 Slump Test frustum Specification

Compressive Strength Test (IS 516-1959)

This test is performed on concrete mould to calculate the compressive strength by using compressive testing machine (CTM). The entire test done under the guidelines of IS code 516:1959. It is performed in the duration of 7, 14 and 28 days on standard specimen size of 150 mm x 150 mm x150 mm.

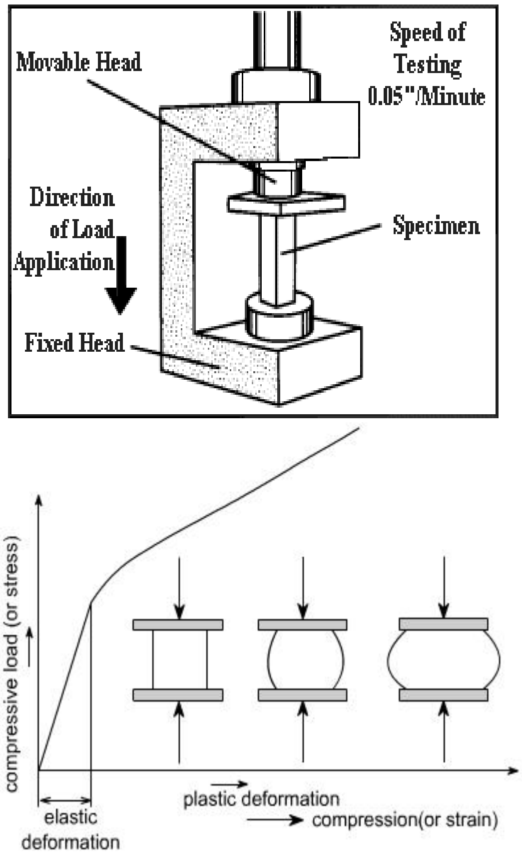


Fig. 3. CTM with deformation of Cube

Split Tensile Test (IS 5816-1999)

Splitting tensile strength of concrete is inspected under the guidelines of IS Code 5816:1999. The size of specimen is 300mm(length)x150mm(diameter). It is performed after 28 days.

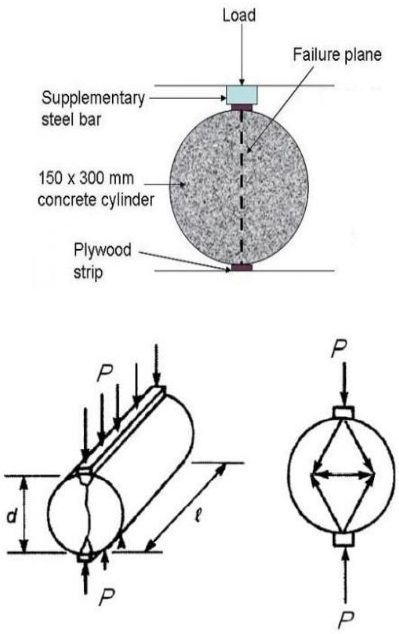
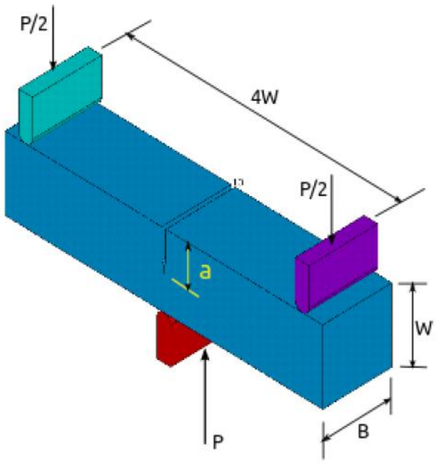


Fig. 4. Splitting Tensile Specimen with failure diagram

Three Point Bending Test (IS 516:1959)

Flexural strength of concrete is measured by using IS Code 516:1959. Beam size is 500mm x 100mm x 100mm. By using central point loading technique beam is tested after 28 days.



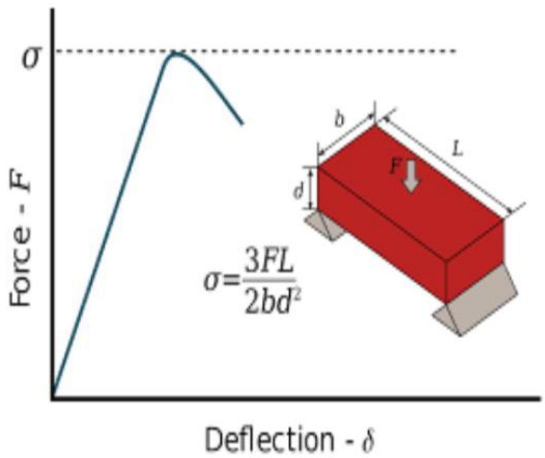


Fig.5. Three Point Bending Test with Loading Diagram

Details of Casting Specimen

All the specimens were prepared of grade M25 and M30 also cured in the water tank for 7, 14 and 28 days with CFRP wrapped at 20, 40, 60, 80 and 100% area cover respectively.

- **Cube Specimen:** This specimen tested for the compressive strength test. Four side face (**4 X 150 X 150**) were considered as fully cover area and for covering this 20, 40, 60, 80 and 100% area 30 mm wide strips of CFRP are used to wrapping the concrete cube.

$$\text{Required Area} = \frac{\text{Compressive Strength of Control mix specimen} \times \text{Cross sectional area of specimen}}{\text{Compressive Strength of CFRP wrapped specimen}}$$

Here, Cross sectional area = 150 X150 =22500 mm^2

Cylinder Specimen: This specimen tested for the tensile strength test. Circumference (**π X 150 X300**) is consider as fully cover area and for covering this 20, 40, 60, 80 and 100% area 30 mm wide strips of CFRP use to wrapping the concrete cylinder.

$$\text{Required Area} = \frac{\text{Tensile Strength of Control mix specimen} \times \text{sectional area of specimen}}{\text{Tensile Strength of CFRP wrapped specimen}}$$

Here,

$$\text{Sectional Area of Cylinder} = \frac{\pi \times 150 \times 300}{2} = 70685.84\ mm^2$$

- **Beam Specimen:** This specimen tested for bending test. Three faces are (**3 X100 X 500**) considered as fully cover area and for covering this 20, 40, 60, 80 and 100% area 25 mm wide strips of CFRP use to wrapping the concrete beam.

$$\text{Required Area} = \frac{\text{Flexural Strength of Control mix specimen} \times \text{sectional area of specimen}}{\text{Flexural Strength of CFRP wrapped specimen}}$$

Here,

$$\text{Sectional Area of Beam} = \frac{2 \times 100^3}{3 \times 500} = 1333.33\ mm^2$$

Result Discussion

Deep observation done by doing various test using CFRP as a strengthen material and receive satisfactory results.

Compressive Strength Test

For compressive test specimen were prepared of grade M25 and M30 also cured in the water tank for 7 and 28 days with CFRP wrapped at 20, 40, 60, 80 and 100% area cover respectively. Four side faces (**4 X 150 X 150**) are considered as fully cover area and for covering this 20, 40, 60, 80 and 100% area 30mm wide strips of CFRP are used to wrapping the concrete cube.

Table 3 Comparison of compressive test on M25 & M30 grade after 7, 28 days

CFRP Cover	Compressive Strength (N/mm^2)			
	Grade M25		Grade M30	
	7 days	28 days	7 days	28 days
0%	21.67	31.80	26.30	38.70
20%	22.37	36.50	27.72	43.10
40%	24.13	39.80	29.73	47.97
60%	25.70	45.70	32.17	52.50
80%	28.04	51.47	36.53	58.37
100%	31.90	56.20	38.49	63.30

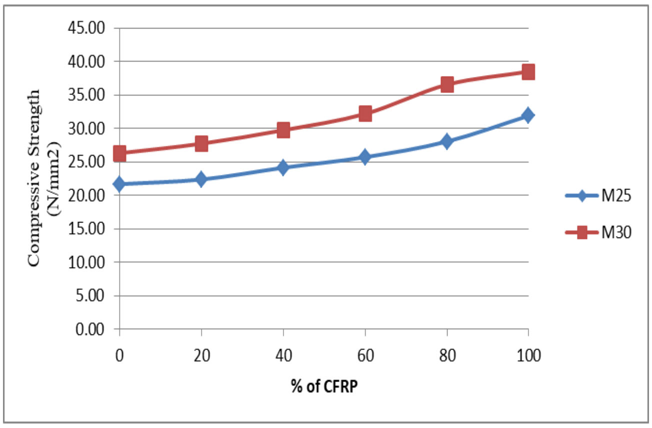


Fig. 6 Comparative results of compressive test on M25 & M30 grade after 7 days

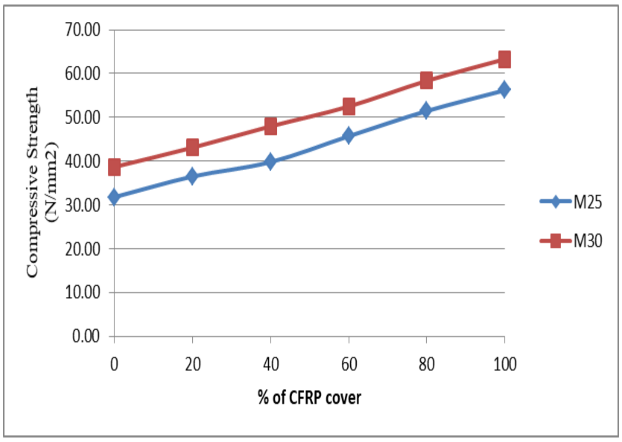


Fig. 7. Comparative results of compressive test on M25 & M30 grade after 28 days

Table 4 Comparison of percent of increment in compressive strength on M25 & M30 grade after 28 days

CFRP Cover	Compressive Strength (N/mm^2)			
	Grade M25		Grade M30	
	28 days	Percent of Increment	28 days	Percent of Increment
0%	31.80	100.63	38.70	101.18
20%	36.50	115.51	43.10	112.68
40%	39.80	125.95	47.97	125.40
60%	45.70	144.62	52.50	137.25
80%	51.47	162.87	58.37	152.59
100%	56.20	177.85	63.30	165.49

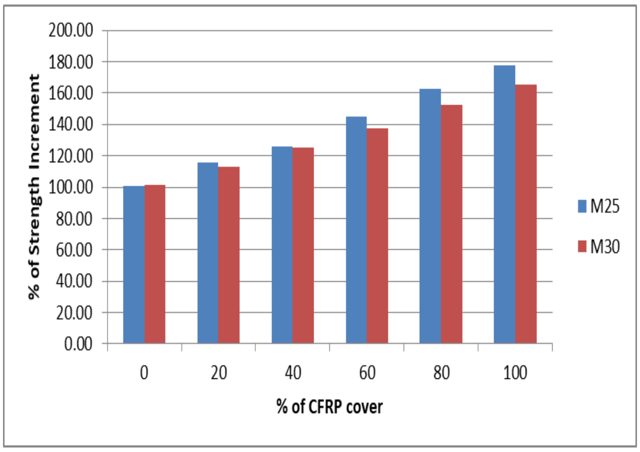


Fig. 8. Comparison of percent of increment in compressive strength on M25 & M30 grade after 28 days

Split Tensile Test

For Spilt Tensile test specimen were prepared of grade M25 and M30 also cured in the water tank for 28 days with CFRP wrapped at 20, 40, 60, 80 and 100% area cover respectively. Circumference area (**π X 150 X300**) were considered as fully cover area and for covering this 20, 40, 60, 80 and 100% area 30 mm wide strips of CFRP use to wrapping the concrete cylinder.

Table 5. Comparative results of tensile strength on M25 & M30 grade

CFRP Cover	Tensile Strength (N/mm^2)			
	M25	Percent of Increment	M30	Percent of Increment
0%	3.98	101.23	4.34	100.33
20%	4.27	108.51	4.86	112.34
40%	5.08	129.10	5.32	122.81
60%	5.28	134.18	5.58	128.81
80%	5.70	144.94	6.39	147.68
100%	5.87	149.26	6.58	151.99

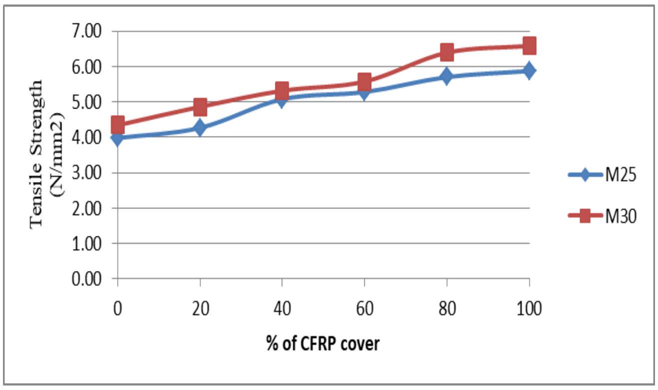


Fig. 9 Comparative results of tensile strength on M25 & M30 grade

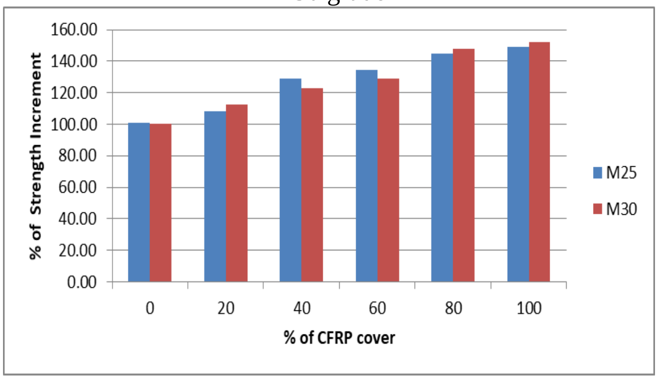


Fig. 10 Comparison of percent of increment in tensile strength

Flexure Test

For Flexural test specimen were prepared of grade M25 and M30 also cured in water tankfor 28 days with CFRP wrapped at 20, 40, 60, 80 and 100% area cover respectively. Three faces area (3 X100 X 500) were considered as fully cover area and for covering this 20, 40, 60, 80 and 100% area 25 mm wide strips of CFRP use to wrapping the concrete beam.

Table 6. Comparative results of Flexural strength on M25 & M30 grade

CFRP Cover	Flexural Strength (N/mm^2)			
	M25	Percent of Increment	M30	Percent of Increment
0%	3.94	100.04	4.33	100.09
20%	4.49	114.11	4.90	113.18
40%	5.11	129.78	5.40	124.81
60%	5.34	135.79	5.68	131.28
80%	5.77	146.72	6.53	150.83
100%	5.92	150.36	6.68	154.30

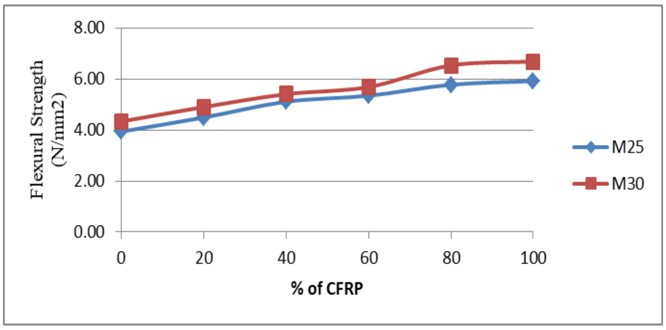


Fig. 11 Comparative results of flexural strength on M25 & M30 grade

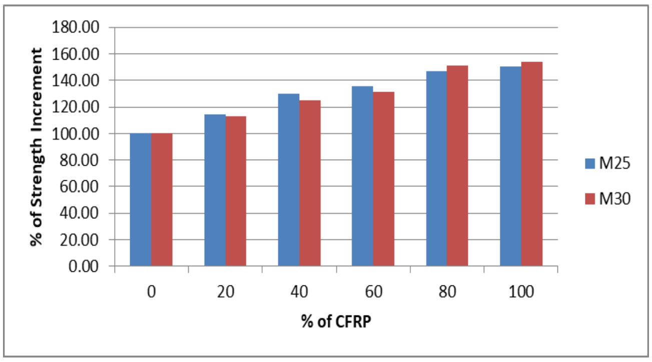


Fig. 12 Comparison of percent of increment in flexural strength

Analytical Area Calculation for CFRP cover specimen compare to control mix

Comparison between percentage of reduction in area with respect to CFRP cover due to different strengths for M25 and M30 shown in figure13 and 14 respectively.

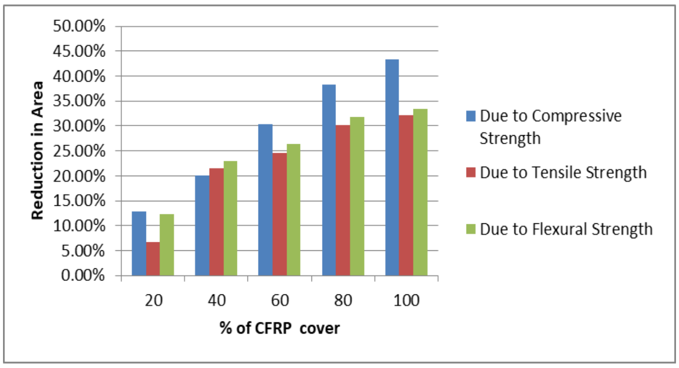


Fig.13 Percent of Reduction in area due different strength w.r.t control mix strength for M25 grade

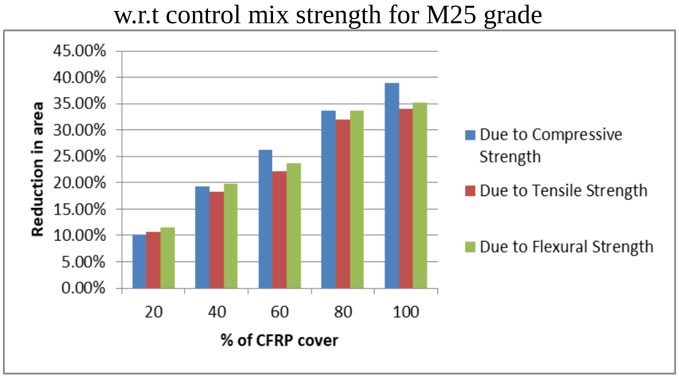


Fig.14 Percent of Reduction in area due different strength w.r.t control mix strength for M30 grade

Conclusion

Observing results of compressive, splitting tensile and flexural on concrete of M25 and M30 grades with 0, 20, 40, 60, 80 and 100 % cover with CFRP were analyzed. Wrapped CFRP concrete specimen shows the gradual failure pattern where concrete fails suddenly. Wrapping structures with CFRP provides stability to structure during collapse or disaster. Repair or rehabilitation of damaged structure by CFRP is the easy convenient approach. Wrapping CFRP over damage or deteriorated members of RCC frame structures strength and service life can be increased. Also it is observed that compressive, tensile and flexural strength results increases with respect to CFRP cover on percent of area cover. From the research, we can conclude that the CFRP concrete structure increase the resistance and strength with conventional concrete. By stripping the CFRP over concrete we can rehabilitate the deteriorated structures. Investigation proves that durability and service life of deteriorated the structure is increased by wrapping CFRP over these structures.

In this paper CFRP wrapped over plain concrete specimen so analysis on the RCC structure should be done in the future. CFRP is composite material so the other effect should also to be inspected i.e. Acid test, Permeability, Corrosion test etc.

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