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Strengthening of Beams Using Carbon Fibre Reinforced Polymer

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Abstract: *Infrastructure development is raising its pace. Many reinforced concrete and masonry buildings are constructed annually around the globe. With this, there are large numbers of them which deteriorate or become unsafe to use because of changes in use, changes in loading, change in design configuration, inferior building material used or natural calamities. Thus repairing and retrofitting these structures for safe usage of these structures has a great market. There are several situations in which a civil structure would require strengthening or rehabilitation due to lack of strength, stiffness, ductility and durability. Beams, columns, plates may be strengthened in flexure through the use of CFRP bonded to their tension zone using epoxy as a common adhesive. Due to several advantages of carbon fiber wrapping over conventional techniques used for structural repair and strengthening, the use of CFRP has becoming popular. The paper makes a comparative study between the load carrying capacity and ductility of an RCC beam and other beams with CFRP bonded. An experiment study is carried out to study the change in the structural behavior of R.C.C. beams wrapped with carbon fiber of different thickness, orientation and length to enhance the flexural and shear capacity of the beams along with the existing practice of doing the repair work.*

Keywords: *carbon fibre, epoxy, flexural, retrofitting, rehabilitation*

1. Introduction

A Fiber Reinforced Polymer (CFRP) composite is defined as a polymer (plastic) matrix, either thermo set or thermoplastic, that is reinforced (combined) with a fibre or other reinforcing material with a sufficient aspect ratio(length to thickness) to provide a discernable reinforcing function in one or more directions. FRP composites are different from traditional construction materials such as steel or Aluminium. FRP composites are anisotropic (properties apparent in the direction of the applied load) whereas steel or aluminium is isotropic (uniform properties in all directions, independent of applied load). Therefore, FRP composite properties are directional, meaning that the best mechanical properties are in the direction of the fiber placement. Reinforced concrete buildings may be vulnerable to progressive collapse due to a lack of continuous reinforcement. Carbon fiber reinforced polymer (CFRP) may be used to retrofit existing reinforced concrete beams and provide the missing continuity needed to resist progressive collapse. A Fiber Reinforced Polymer (FRP) composite is defined as a polymer (plastic) matrix, either thermo set or thermoplastic, that is reinforced (combined) with a fiber or other reinforcing material with a sufficient aspect ratio(length to thickness) to provide a discernable reinforcing function in one or more directions.

2. Literature Review

Investigation on the behavior of FRP retrofitted reinforced concrete structures has in the last decade become a very important research field. In terms of experimental application several studies were performed to study the behavior of retrofitted beams and analyzed the various parameters influencing their behavior.

Triantifillou and Plevris (1991) used strain compatibility and fracture mechanics to analyze reinforced. The same assumptions as An et al. (1991) were used with the inclusion of an rectangular compression stress distribution in the concrete at failure. The applied moments that would cause each of the three failure modes were predicted. The failures were yielding of the steel reinforcement followed by CFRP rupture; yielding of the steel reinforcement followed by the crushing of the concrete compression zone; and concrete crushing before either tensile component fails. These models were compared with experimental studies and deemed creditable.

Moment, stiffness, and deflection models of reinforced concrete beams with applied FRP were developed by Bhutta (1993). Glass, carbon, and kelvar fiber reinforced plastics were utilized. Beams reinforced with kelvar showed the highest increase in moment capacity and stiffness, while the smallest was the beams reinforced with glass. The moment capacity of beams reinforced with carbon fell between these two composites.

Norris and Saadatmanesh (1994) casted thirteen concrete beams for flexural tests to compare three different fiber /epoxy systems and several orientations of fiber. Norris et al. concluded that off-axis CFRP laminates need to be studied at length. Use of different orientations could increase the strength and stiffness of concrete beams without causing catastrophic, brittle failures associated with unidirectional laminates. He suggested that provides ductile yielding properties that are very important in the civil engineering field.

The research by Bazaa *et al.* (1996) was based on optimizing the length and orientation of the CFRP to increase beam strength and ductility. Eight beams (8”x12”x120’) were minimally reinforced with steel (two 7/16” diameter bars) and overdesigned for shear to cause a flexural failure. One beam was used as a control while the others were bonded with three layers of CFRP (0.012”x6.6”). The results of the experiment showed an increase in strength and stiffness and a decrease in deflection as compared to the control beam. All failures occurred at a load at least 57% higher than the control beam.

Amir A. Abdelrahman and Sami H. Rizkalla(1997)examined the flexural behavior of concrete beams partially prestressed by CFRP reinforcement. The parameters considered in the experimental program were the prestressing ratio, degree of prestressing, and distribution of the CFRP bars in the tension zone. He stated that the number of cracks of beams partially prestressed by CFRP is less than that of comparable beams partially prestressed by steel strands.

Rayn D. Morphy.(1999) showed that Fiber reinforced polymers (FRP) provide an alternative that does not corrode and has many other benefits such as a high strength to-weight ratio. Based on the results, recommendations were made and he presented design guidelines for the use of FRP as shear reinforcement.

Shahawy *et al.*(2000)assessed the effectiveness of external reinforcement in terms of the cracking moment, maximum moment, deflection, and crack patterns. The deflection and cracking patterns showed results similar to experiments previously discussed. The deflection decreased inversely with the number of CFR Players on each beam. This, alternatively, caused the stiffness to increase.. The control had wider cracks while the repaired beams showed smaller cracks at relatively close spacing. This shows an enhanced concrete refinement due to the CFRP sheets.

Almusallam in the year 2001 examined a straightforward and efficient computational analysis to predict the nominal moment carrying capacity of RC beams strengthened with external FRP laminate. They investigated the determination of the limits on the laminate thickness in order to guarantee tensile failure due to steel yielding and to avoid tensile failure due to FRP laminate rupture. They found that beam strengthened with CFRP laminate require less number of layers than those strengthened with glass FRP laminate for the same load capacity.

Dr. Sujeeva Setunge (2002) observed behavior of the confined columns was similar to the unconfined columns up to the peak load of the unconfined columns. Increases in the lateral deflection of the confined columns resulted in the concrete failing in compression and rupturing the FRP confining jacket at approximately mid-height. The deflected shape of the columns at peak load was symmetrical, and there was no local buckling in the columns.

Pantelides and Gergely (2002**)** presented analysis and design procedures for a CFRP composite seismic retrofit of a reinforced concrete three-column bridge bent. In situ test results showed that the seismic retrofit was successful, and the bridge bent strengthened with CFRP composite reached a displacement ductility level and doubled the hysteretic energy dissipation of the as-built bent.

Zhichao Zhang (2003) carried out the experimental and the analytical study of the shear strengthening in RC beams using Carbon Fiber Reinforced Polymer (CFRP) laminates was carried out in this research. The beams studied are ranged from regular beams to deep beams with various configurations of CARP laminates. The present research also included studying the repair of shear damaged beams using CFRP laminates. Results of test performed in the study demonstrated the feasibility of using externally applied, epoxy-bonded CARP system to restore or increase the load carrying capacity in shear of RC beams. The CFRP system can significantly increase the serviceability, ductility, and ultimate shear strength of a concrete beam if proper configuration is chosen. Restoring beam shear strength using CARP is a highly effective technique.

Jian Chen(2005) investigated the detailed structural behavior of confined concrete members using CFRP fabric jackets by both analytical and experimental approaches. A series of CFRP wrapped concrete cylinder tests were conducted to study the compressive stress-strain behavior for CFRP confined concrete members. He concluded that the CFRP fabrics can increase the splitting tensile strength of normal concrete. The more layers applied to the specimens, the more increase in tensile strength can be attained. However when compared to the greater strength increase in compression, the strengthening effect on tension is still lacking. It is concluded that the tensile strength of the fabric-confined concrete can be ignored in design.

A 2007 experiment investigated twelve 2.8 m long reinforced concrete beams and tested till failure..It was concluded that by bonding GFRP laminates to the tension face of flexural RC beams, both strength and stiffness of the beams can be increased.

K. Olivova, J. Bilcik(2008) presented the results of an experiment at study on the structural behavior of reinforced concrete columns strengthened with carbon fiber sheets and strips in pre-cut grooves The observed behavior of the confined columns was similar to the unconfined columns up to the peak load of the unconfined columns. Increase in the lateral deflection of the confined columns resulted in the concrete failing in compression and rupturing the FRP confining jacket at approximately mid-height. The deflected shape of the columns at peak load was symmetrical, and there was no local buckling in the columns.

Xiaosong Huang (2009) reviewed the research and development activities conducted over thepast few decades on carbon fibers.He made attempts to cover the research on other precursor materials developed mainly for the purpose of cost reduction Optimizing the carbon fiber microstructure can improve carbon fiber strength through decreasing its flaw sensitivity. The carbon fiber microstructure is dependent on the precursor morphology and processing conditions. Research in these two areas will aid in the development of carbon fibers with improved performance.

Romuald-Kokou Akogbe (2011) conducted study to size effect of compressive strength of CFRP confined circular concrete cylinder. The experiment included testing under pure axial load in which 24 concrete cylinders (small, medium and big) specimens were tested. From stress strain curve comparison analysis, it was noticed that the scattering of plain concrete strength evaluated between small, medium and big specimens explains why the curves are not totally overcome.

Murali G. and Pannirselvam N.(2011) made an attempt to address an important practical issue that is encountered in strengthening of beams with different type and different thicknesses of fiber reinforced polymer laminate.. The thickness of FRP in the strengthening system provides an economical and versatile solution for extending the service life of reinforced concrete structures.

Dr. Gopal Rai and Yogesh Indolia (2011) Beams, Plates and columns may be strengthened inflexure through the use of FRP composites bonded to their tension zone using epoxy as a common adhesive. The direction of fibers is kept parallel to that of high tensile stresses. Both prefabricated FRP strips, as well as sheets (wet-layup) are applied. Hence, FRP composites are finding ways to prove effective and economical at the same time. If the cost constraint is kept aside, the fiber wrapping system has been proved to be a system which has many added advantages over conventional strengthening processes.

2.1 Summary of Literature

From the above literature review we have observed the following results. Shear failure occurs usually without advanced warning therefore it is desirable that beam fails in flexure than in shear. Many existing reinforced concrete members are found to be deficient in shear strength and need to be repaired. These deficiencies occurs due to several reasons such as insufficient shear reinforcement or reduction in steel, due to corrosion, increased due to load and due to construction defects therefore to reduce or to minimize these deficiencies externally bonded reinforcement such as Carbon Fiber Reinforced Polymer is an excellent solution in these situation.

3. MIX DESIGN

The specified design strength of concrete is 30MPa at 28 days. The specific gravity of Fine Aggregates (FA) and Coarse Aggregates (CA) is 2.29 and 2.70 respectively. The standard deviation can be taken as 5MPa. Ordinary Portland cement was used of 53grade. Coarse aggregate is found to be Absorptive to the extent of 1% and free surface moisture in sand is found to be 2%.According to IS10262-1982 clause 3.3 Table no 4. The mixing water content calculated is 185 kg/m^3.

Table 1. *Mix Proportion*

Water	Cement	Fine Aggregates	Coarse Aggregates
185	411.11 kg	654 kg	1097 kg
0.45	1	1.59	2.67

Table 2. *Concrete mix design quantities*

Grade of concrete: M30	Coarse aggregate(20mm): 2.65
Type of exposure: Mild	Coarse Aggregate(10mm): 2.65
Sp. Gravity of cement: 3.15	Maximum Water Cement Ratio: 0.4
Fine Aggregate: 2.65	

Table 3. *Quantity of Materials for casting beams considering 20% wastages:*

Materials	*One mould (in kg)*	*Three moulds (in kg)*
Cement	2.816	8.448
Fine aggregate	5.736	17.208
Coarse aggregate 1	4.870	14.610
Coarse aggregate 2	2.590	7.770
Fly ash	0.256	0.768
Water	1.270	3.810
Addmixture	0.028	0.084
TOTAL	**17.56**	**52.698**

Table 4 . *Curing Specimens Details (500x100x100mm):*

Cured	Plain concrete beams	One side wrapped beams	Two side wrapped beams	Three side wrapped beams
7 days	3nos.	3nos.	3nos.	3nos.
28 days	3nos.	3nos.	3nos.	3nos.

4. EXPERIMENTAL STUDY

4.1 Analysis of Beams for Seven Days

The beams B1 B2 B3 cured for 7 days and 28 days were tested on the Flexural Testing machine. The following results of failure load were found out for Plain concrete beams, One sided CFRP wrapped concrete beams, Two sided parallel CFRP wrapped concrete beams ,Two sided parallel CFRP, Three sided continuous CFRP.The details of the load are thus given in the table 5.below.Figure (4-7) shows the failure modes for these beams. Figure (8-9) shows the graphical representation of the results.

Table 5. *Load in kN for seven days and 28 days*

Beam	Plain cement concrete beams		One sided CFRP wrapped concrete beams		Two sided CFRP wrapped concrete beams		Three sided continuous CFRP wrapped concrete beams	
	Load in kN		Load in kN		Load in kN		Load in kN	
	(7 days)	(28 days)	(7 days)	(28 days)	(7 days)	(28 days)	(7 days)	(28 days)
B-1	27	32	32	41	27	33	38	49
B-2	24	31	30	39	29	31	37	54
B-3	27.5	32	31	40	30	38	38	57
Average load (kN)	26.16	31	31	40	28.67	34	37.33	53.33

Figure2. *Failure of Plain Concrete Beam.(7 days)*

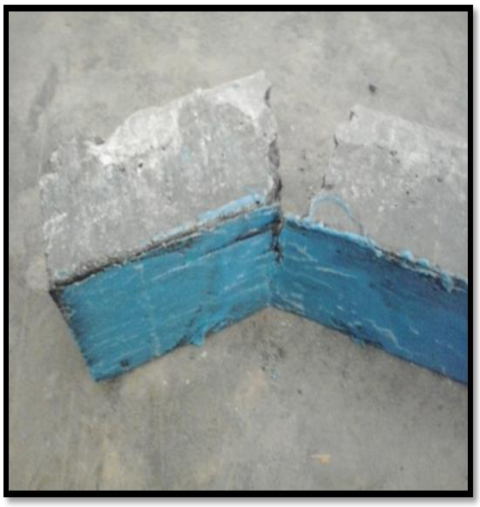

Figure 3. *Failure of one sided CFRP.(7 days)*

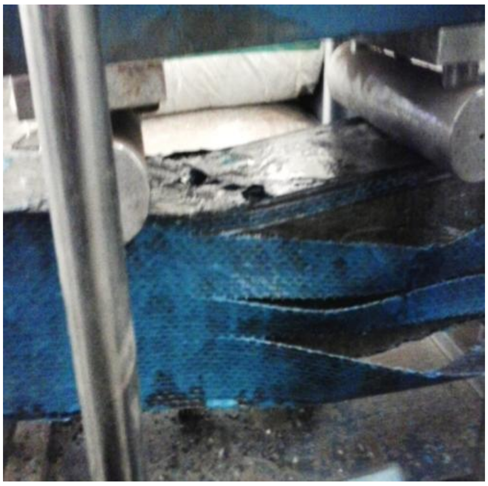

Figure 4: ***Failure of Two sided Parallel wrapped beam.(7 days)***

Figure 5. *Failure of Three sided continuous CFRP CFRP Wrapped Beam.(7 days)*

Figure 6. *Failure of Plain Cement Concrete Beam (28 days)*

Figure 7. *Failure of One sided CFRP wrapped Concrete Beam. (28 days)*

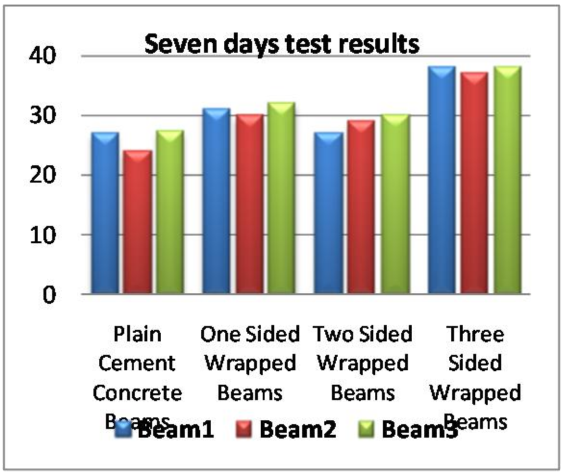

Figure 8. *Seven Days Test Results*

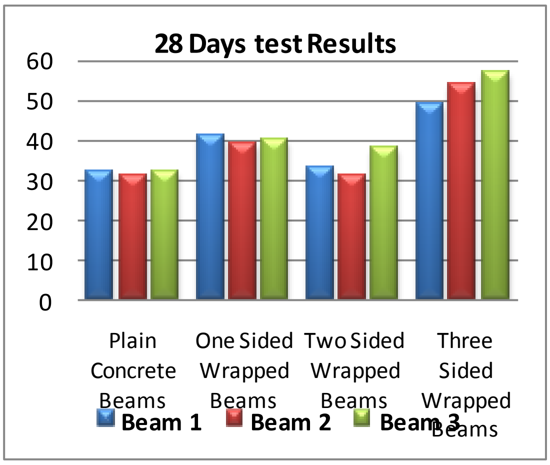

Figure 9. *Twenty Eight Days Test Results*

4.2 Results

From the above results and graphs following observations are made:

Sr.No	Beam description	Increase in Strength comparing with Plain Cement Concrete beam. (%)
1	strength of the beam wrapped tension side	20
2	strength of the beam wrapped at two parallel side	10.69
3	wrapped at three side	42.50

Also the strength of beam wrapped at tension side was greater than the beams wrapped at two parallel sides but less than the beam wrapped at three sides, were as the strength of beam wrapped at two sides was less than the beam wrapped at three sides.

Therefore, from the above results the beam wrapped at tension side gives better results so from economic point of view CFRP wrapped at tension sides is desirable.

5. CONCLUSION

From this research and from the result of this research project we can conclude that the CFRP wrapped at tension side gives better strength as compared to CFRP wrapped at two parallel sides but gives less strength as compared to CFRP wrapped at three sides. CFRP wrapped at three sides gives higher strength but as the CFRP composite is costly it increasing the cost of construction so from an economic point of consideration CFRP wrapped at tension side to the beam is desirable.

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