Application of CFRP Materials for Strengthening and Retrofitting Of RC Beams for Flexural and Shear Failure

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Abstract

Applications of fibre reinforced polymer (FRP) composites in civil engineering has increased significantly in recent years, both for the strengthening for new construction and retrofitting of RC (Reinforcement Concrete) existing structures. It is well known that the carbon fibre reinforced polymer (CFRP) has been widely used in the reinforcement of concrete structures owing to its light weight, high strength, excellent corrosion resistance and ease of construction. One of the primary areas of their application is the strengthening and retrofitting due to flexural and shear loading. Failures caused by flexural and shear loading are quite common occurrence during earthquakes as well as in cases of application of significant point loads. The role and effect of those applications are still subject to investigate with the varying number of influencing factors, significantly. The research on this field is very limited. Therefore, a research is needed in this field. The objective of this study is to investigate the feasibility for application of CFRP for strengthening and retrofitting of Reinforced concrete beam against flexural and shear failure and also observe the failure mode. The investigation was mainly focused on the effects of CFRP strengthening and retrofitting of RC beam. A series of test was conducted in this research for CFRP strengthen beam. Beam was tested under three point and four point loading by universal testing machine. The failure loads, failure modes and the load-deformation behaviour of the CFRP strengthen and retrofitting of RC beam are also presented. Based on test results, it was found that the CFRP strengthen and retrofitting of RC beam provided better performance significantly. It can be concluded that CFRP materials can be apply for strengthening and retrofitting of RC beam effectively.

Keywords: *CFRP; Concrete structure; Flexural member; Retrofitting, Strengthening*

1 Introduction

Strengthening and retrofitting of existing structures are among the major challenges that modern civil engineering is currently facing. The use of FRP for strengthening and retrofitting for concrete structures is rapidly increasing. Carbon fibre reinforced polymer (CFRP) is a non corrosive material that provides up to 10 times the tensile strength of steel yet is only one fifth of the weight of steel. In the civil engineering, the use of carbon-fibre reinforced polymer (CFRP) has become a viable alternative for strengthening and repair and is becoming more widely used to solve many of the current challenges with our aging infrastructure. Concrete beams can be subjected to significant reductions in the reinforcing steel due to the effects of corrosion or damage caused by impact. Sometimes the strength or load carrying capacity of the structure is reduced due to poor workmanship or use of substandard material or due to addition of extra load which was not included in original design or seismic loads had not been taken in consideration requires the upgradation or modification. Various method of structural upgradation and retrofitting has been found over the years. Some methods making the structure seismic resistant such as addition of new structural frames or shear wall found to be impractical for its high cost or restricted application to specific sectors only. Other methods of structure strengthening such as grouting, inserting rebar, pre-stressing etc. Besides the above mention methods require the use of skilled labour, and stops the regular functioning of structure. CFRP strengthening can be considered as alternative solution for this problem.

Extensive testing of such strengthened members has been carried out over the last two decades. A number of failure modes for RC beams bonded with FRP soffit plates have been observed in numerous experimental studies to date. Alagusundaramoorthy et al. (2003) and Esfahani et al. (2007) conducted research on flexural behavior of R/C beams strengthened with carbon fiber reinforced polymer sheets or fabric. Shear Strengthening on deap beam and T beam conducted by Zhang et al. (2004) and Bousselham and Chaallal (2013). Application of FRP materials for retrofitting of R.C beams after shear failure is investigated by Donchev, et al. (2008). Soliman et al.(2008) investigated. Experimental and numerically on R.C beams strengthened in bending with near surface mounted CFRP. A study about the behavior of concrete beams reinforced with carbon FRP stirrups was carried out by Ahmed et al. (2008). Byrne and Tikka (2008) conducted a research on repair and strengthening of severely damaged concrete beams with externally bonded CFRP. The effectiveness of different FRP and different adhesives on aluminum and stainless steel was investigated by Isa\lam and young (2011, 2012). However, a little research have been conducted on application of CFRP materials for strengthening and retrofitting of RC beams for flexural and shear failure. Therefore, it is a novel approach to study on strengthening and retrofitting of RC beams by FRP for flexural and shear failure.

In this study the feasibility for application of CFRP for strengthening and retrofitting of Reinforced concrete beam was investigated against flexural and shear failure. The investigation was mainly focused on the effects of CFRP strengthening and retrofitting of RC beam. A series of test was conducted in this research for CFRP strengthen beam. Beam was tested under three point and four point loading by universal testing machine. The failure loads, failure modes and the load-deformation behaviour of the CFRP strengthen and retrofitting of RC beam are also presented. Based on test results, it was found that the CFRP strengthen and retrofitting of RC beam provided better performance significantly. It can be concluded that CFRP materials can be apply for strengthening and retrofitting of RC beam effectively.

2 Material Properties

CFRP materials are composite materials that typically consist of fibres embedded in a resin matrix. Resin matrices are typically epoxies, polyesters, vinylesters, or phenolics. Epoxy resin is the most widely used resin. FRP could be more than 10 times higher strength than aluminium and stainless steel material. (Islam,2012). The CFRP sheet, epoxy adhesive (primer & saturant) is shown in Figure 1. Typical tensile properties of CFRP materials and epoxy adhesives are presented in Table 1 and Table 2 respectively.

Figure 1. CFRP sheet and epoxy adhesive (primer & saturant)

Table 1. Typical properties of CFRP used in FRP systems

Fiber -Reinforcement	Carbon-High modulus
Ultimate Tensile Force @ 0.2% strain/m width	200 KN
Fiber Modulus	640 Gpa
Ultimate Tensile Strength	2650 Mpa
Ultimate Tensile Elongation (Strain)	0.4 %
Fibre Density	2.1 gm per cubic cm
Thickness	0.19 mm

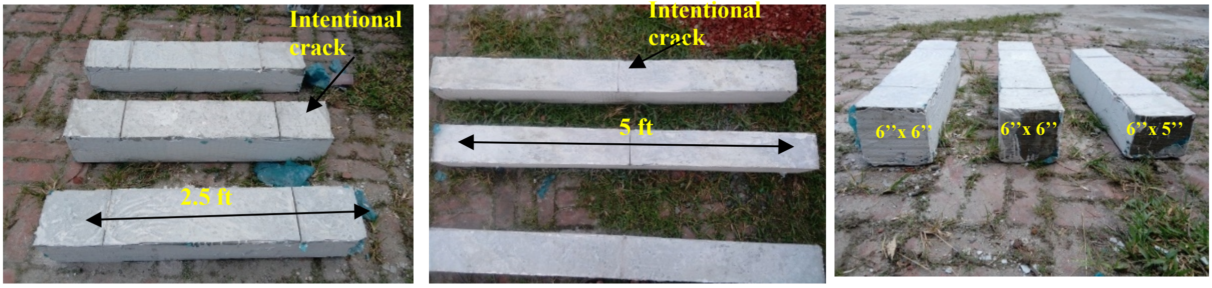
Table 2. Typical properties of epoxy adhesives

Aspect	Free flowing fluid
Mixing Ratio by Weight	100 (Base) : 50 (Hardener)
Bond Strength to Concrete	>1 Mpa or concrete failure
Pot Life	40 minutes @ 25 Celsius
Tack Free Time	6 hours @ 25 Celsius

3 Experimental Programs

3.1 Test Specimen

A total number of 6 beams were tested for the purpose. Three beams were tested for shear and the other three beams were tested for flexure failure. Among 3 beams which were subjected for shear failure, one beam was reference beam and the other two beams acted as a test beam. Same case for the other three beams was tested for flexure failure. The cross section of all the beams tested for shear and flexure failure were identical 6 inch x 6 inch but varied in length. The beams tested for shear failure were 30 inch in length but the beams tested for flexure failure were 60 inch in length. The specimen for shear & flexure test is shown in Figure 2.



(a) Specimen for shear test (b) Specimen for flexure test (c) Cross section view of specimen

Figure 2. Specimen for shear & flexure test

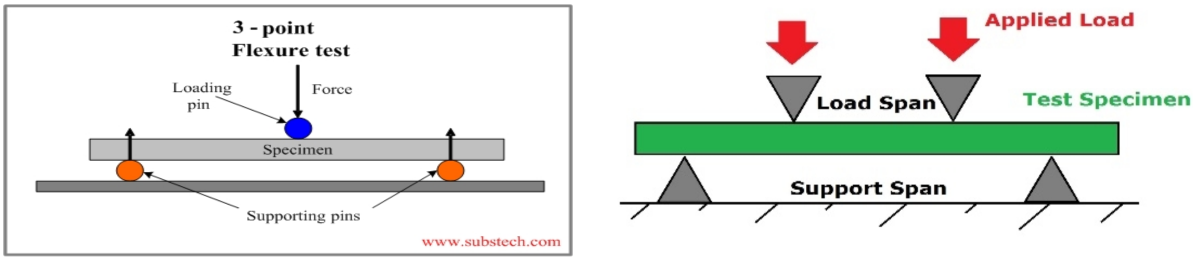
All four faces of the beams were painted with white chalk powder to identify the cracks easily and the case area was cleaned and smoothened before the application of epoxy adhesive. Primer (Mbrace Primer) was applied in the selected area. Then saturated (Mbrace Saturant) was applied in case area. After that CFRP was glued to the case area and left for 7 days to dry the adhesive and have enough bonding of CFRP with the beam case area. The FRP surface cleaning, smoothing and application of epoxy adhesive to CFRP to the selected area is shown in Figure 3.

(a) Surface cleaning & smoothing (b) Application of epoxy adhesive (c) Application of CFRP

Figure 3. Surface cleaning, smoothing and application of epoxy adhesive & CFRP to the selected area

3.2 Test Procedure

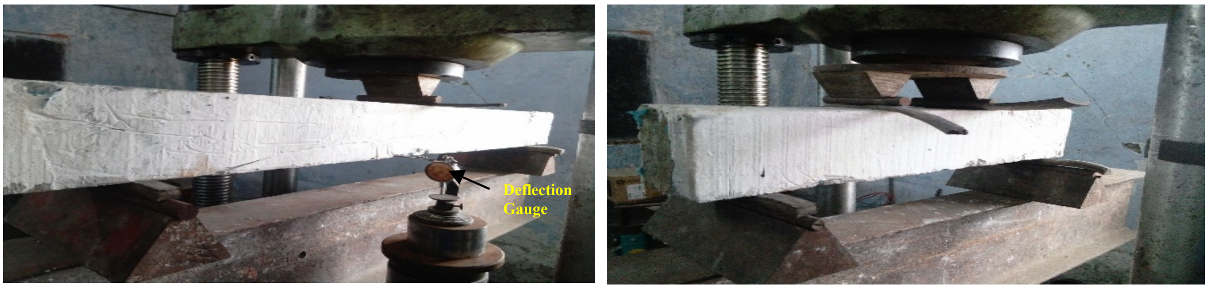
Shear and flexural test was conducted according to ASTM. Schematic view of three and four point loading condition is shown in Figure 4.



(a) Schematic view three of point loading (b) Schematic view of four point loading

Figure 4. Schematic view of three and four point loading condition

Each specimen is prepared in a similar manner and simulated a simple beam in the entire experiment. The load applied by the ram is simulated as a point load at the mid span location. Photographs of the test setup of three and four point loading conditions are shown in Figure 5. A servo-controlled hydraulic universal testing machine was used to apply a concentrated compressive force to the test specimens. Dial gauge was placed to measure the beam deflection.

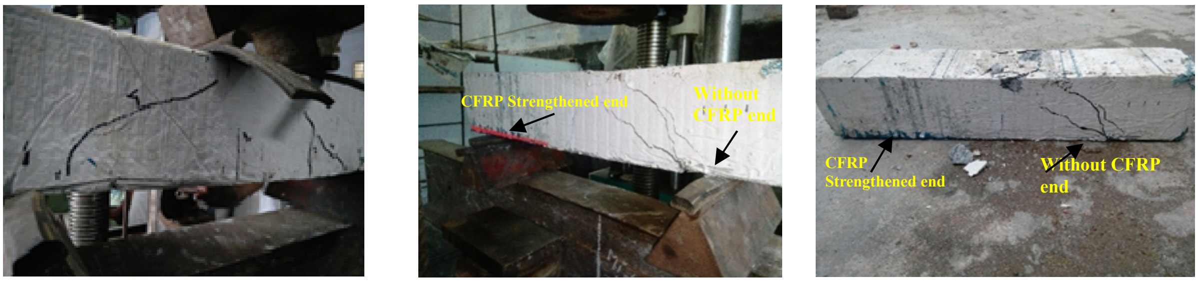


(a) Test setup of three point loading condition (b) Test setup of four point loading test setup

Figure 5. Test setup of three and four point loading conditions

5 Results and Discussions

The failure modes of reference beam & FRP strengthened beam subjected to shear failure are shown in Figure 6. Based on the observation for shear test that the crack was appeared on both ends near supports of the beam. The cracks propagated inward with the increasing load and at a certain point there was no significant increase in load carrying capacity and thereby the beam failed afterwards. For the test sample one end of the beam near the support was CFRP treated and the other end was as before. It was noticed that the CFRP treated end was crackles even though the untreated end of the beam gone through failure.



(a) Failure mode without FRP (b) Failure mode of beam with FRP (c) Crack of beam with FRP

Figure 6. Failure mode of reference beam & test beam and failure crack during shear test

The failure mode for flexure test was observed that failure crack was appeared on mid span as shown in Figure 7. The cracks propagated inward with the increasing load and at a certain point there was no significant increase in load carrying capacity and thereby the beam failed afterwards. For the test sample the crack moved from centre to the end of CFRP treated area. CFRP treated area was crackles and crack initiated from where CFRP treated zone ends. It can be conclude that the increase the CFRP treated zone, the crack can be shifted to end of CFRP end.

(a) Failure mode of beam without FRP b) Failure mode of beam with FRP

Figure 7. Failure pattern of reference beam & test beam during flexural failure test

Load-deflection comparison curve for shear failure test is shown in Figure 8. In the comparison graph, Blue line refers to the reference beam and the red line refers to the test beam with FRP. The highest peak point of red line indicates that the load carrying capacity of FRP treated beam is higher than the reference beam corresponding to respective deflection till failure. The load carrying capacity CFRP strengthened beam was higher that reference beam without FRP beam.

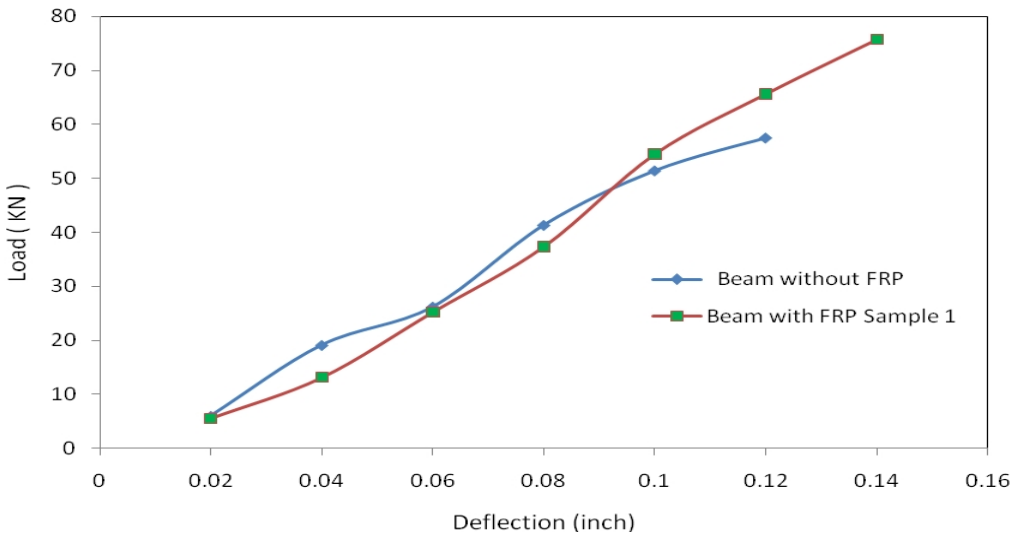


Figure 8. Load-deflection comparison curve for shear failure test

Load-deflection comparison curve for flexure failure test is shown in Figure 9. In flexure, the load carrying capacity of CFRP strengthened beam was higher that reference beam without FRP beam. From the graphical presentation, it was found that load carrying capacity was increase and deflection was reduced due to CFRP strengthening. From the test results, it was found that the flexural strength and stiffness of the strengthened beams increased compared to the without strengthen specimens.

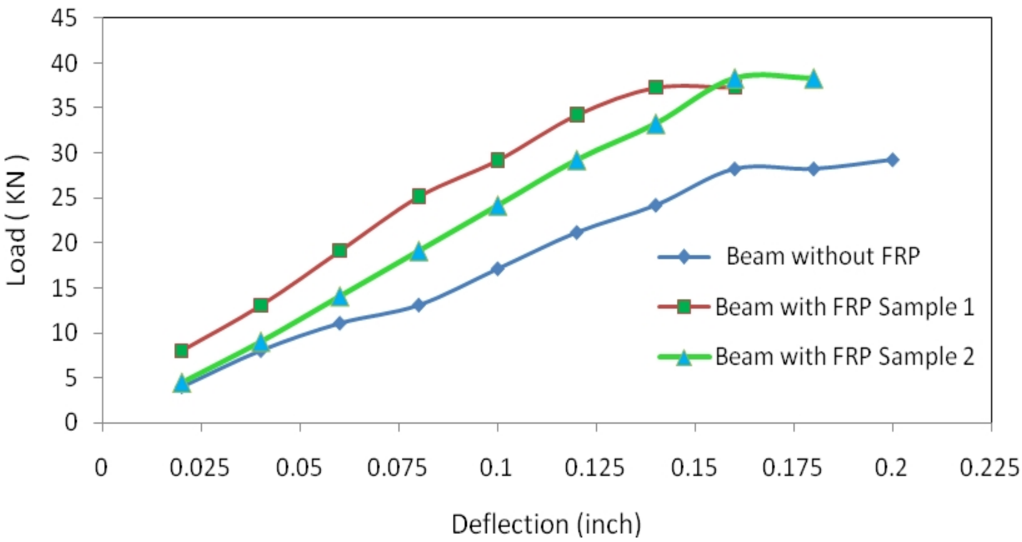


Figure 9. Load-deflection comparison curve for flexure failure test

Table 3. Maximum load deflection due to flexural and shear test

Specimen	Flexure test results		Shear test results	
	Max Load (KN)	Max Deflection (Inch)	Max Load (KN)	Max Deflection (Inch)
Beam without FRP	29.22	0.20	57.51	0.12
Beam 1 with FRP	37.30	0.16	75.70	0.11
Beam 2 with FRP	38.30	0.18	74.30	0.10

Maximum load -deflection relationship due to flexural and shear test is shown in Table 3. Data obtained from shear and flexural test which gives a comparison between reference beam and CFRP treated test beam. Comparison shows that the load carrying capacity of CFRP treated beam has increased though the deflection also reduced most of the cases. The load carrying capacity was increased about 31.63% while the beam was strengthened with CFRP for shear. Data obtained from flexure failure test shows that for both case of two sample of test beam the recorded deflection was smaller than the reference beam and the load carrying capacity also increased by 27. 65 % for test beam sample 1 and 31.07 % for test beam sample 2. The percentage of increase in load carrying capacity varied from 26- 31%.

5 Conclusions

The paper presents an experimental investigation on application of CFRP for strengthening and retrofitting of reinforced concrete beam against flexural and shear failure. Six concrete beam specimens were tested under three point and four point conditions The flexural and shear strengthen behaviour of reinforced concrete beams were investigated. The failure loads, failure modes and the load-web deformation behaviour of CFRP strengthened concrete beam are also presented. From the test results, it was found that the flexural strength and stiffness of the strengthened beams increased compared to the without strengthen specimens. The CFRP wrapping is the method with the minimum deflection recorded which indicates that the shear stiffness at this case is highest. The CFRP laminates were the easiest method to apply; it is less expensive than the CFRP wrapping and with relatively small deformability of the beam. In both case, the shear and flexure failure test the load carrying capacity was increased. The percentage of increase in load carrying capacity varied from 26- 31%. The CFRP was not subjected to full of its load carrying capacity because before the CFRP was subjected to full of its capacity debonding of CFRP or crushing of concrete occurred. This percentage of increase in load carrying capacity can be increased and effectively used for concrete structure .The test result was promising enough to apply CFRP not only for strengthening but also for retrofitting. The effectiveness of the applied methods is estimated qualitatively and proved that analyzed types of CFRP shear and flexural strengthening are effective for repairing of damaged (pre-cracked) reinforced concrete beams.

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