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EXPERIMENTAL ASSESSMENT OF THE PERFORMANCE OF REINFORCED CONCRETE BEAMS STRENGTHENED WITH CARBON FIBER REINFORCED POLYMER LAMINATES

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ABSTRACT
In this study, experimental research is carried out to assess the flexural performance of RC beams strengthened with different amount of CFRP laminates at the tension face. Twelve rectangular RC beams were fabricated and three are un-strengthened and used as reference beams and the remaining nine are strengthened with different amount of CFRP varying from single to triple layers and all are tested to failure under three points bending test. The increase of ultimate strength provided by the bonded CFRP laminates is assessed and failure modes is identified and compared to the un-strengthened RC beams. The results indicated that the flexural capacity of the beams was significantly improved as the amount of the laminates increases that ranged from 20% to 52% increased for single to triple layers laminates. It is concluded that the attachment of CFRP laminates has substantial influence on the performance of CFRP strengthened RC beams. Based on the observed results, recommendations are made that externally application of CFRP laminates can be used for a significant enhancement of the strength deficient RC beams in increasing the ultimate load carrying capacity.

Keywords: *CPRP laminate, Reinforced concrete, ductility, index, epoxy resin, flexural strengthening*

1. INTRODUCTION

Some of the factors that commonly contributed to the reduction of the load carrying capacities of reinforced concrete beams include, environmental effects on structural behavior; evolution of design loads, such that structures cannot safely carry loads required by updated versions of design codes; evolution of design guidelines; and increased traffic volume on for example bridges, not accounted for at the design stage [1]. The conventional methods for improving the performance of reinforced concrete structural members to take care of any of the above factors are either to demolish and recast the existing members or provide additional member [2]. In recent years, we have seen much interest in the study of the use of some novel construction materials to enhance the load carrying capacities of reinforced concrete members without recourse to wasteful demolition or introduction of new structural members. Some traditional strengthening techniques include steel plate bonding, section enlargement, jacketing or external post-tensioning. However, these techniques show some imperfections and therefore not much efficient. The use of Fibre Reinforced Polymer (FRP) (which is a high performing civil engineering construction material) in strengthening reinforced concrete members is now gaining ground. So many studies were conducted on the use of this material. Some of these studies include [3-7]. The present research paper is aimed at providing further experimental assessment of the efficacy of the use of the FRP in flexural and shear strengthening of RC beams, specifically considering the use of up to three layers of Carbon Fibre Reinforced Polymer (CFRP). Flexural and shear modes of failure are the two prime failure modes for RC beams. Flexural failure is

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generally preferred to shear failure as the former is ductile whilst the latter is brittle. A ductile failure allows stress redistribution and provides warning to occupants, whilst a brittle failure is sudden and thus catastrophic [8].

2. MATERIAL AND METHODS

2.1. Materials

2.1.1. Cement

Ordinary Portland Cement (OPC) conforming to BS EN 197-1 [9] of Dangote brand is used throughout the investigation. The specific gravity of cement is found as 3.14.

2.1.2. Aggregates

The coarse aggregate used in this investigation is crusher broken hard granite chips, maximum size is 20 mm with specific gravity 2.62, and grading confirming to BS EN 12620 [10].The fine aggregate used is clean river sand passing through 4.75 sieves with specific gravity of 2.50 and all of which were obtained in Zaria.

2.1.3. Reinforcing steel

All longitudinal reinforcement used is High yield steel bars of 8mm diameter and 10mm diameter conforming to BS EN 10080 [11]. The stirrups used are 6 mm diameter mild steel bars obtained and assembled in Zaria market.

2.1.4. The Carbon Fibre Reinforced Polymer (CFRP)

The Carbon Fibre Reinforced Polymer (CFRP) – CXS 200, used in this study was purchased from Beijing Glass Fiber industries, China. The physical properties of the CFRP as provided by the manufacturer are presented in Table 1.

The Epoxy Resin used in this research is Araldite GY epoxy bonding agent, purchased from Super Floors Company, Lagos. The material was used as the matrix for the CFRP and also as the bonding adhesive between the CFRP and the concrete. The properties of the Resin are presented in Table 2.

2.1.5. Water

Ordinary clean potable tap water free from suspended particles was used for mixing and curing of concrete throughout the experiments in accordance with BS EN 1008 specifications [12].

2.2. Methods

2.2.1. Manufacturing of the Test Beams Specimens

The test program consist of casting and testing of twelve grade M25beams (1:1:2 concrete mix ratio), designed in accordance with the Eurocode 2 [13]. Three of the test beams are the controls and marked as RB01, RB02 and RB03. The cross sectional dimensions of the beams are 150x150x750 mm and the curing period is 28 days. Two 10mm diameter steel reinforcing bars were used in the tension zone of the beam while the compression zone was reinforced with 8mm diameter steel reinforcing bars. 6mm diameter bars spaced at 100mm c/c were used as links. The structural detailing of the beams is shown in Figure 1.

The strengthening of the test beams was implemented using CFRP sheets. The surface of each beam was first roughened to remove the weak concrete surface layers and to expose the aggregates. The Epoxy resin glue was then applied to the surface of the beams and the CFRP sheet placed on top of epoxy resin coating and the resin was squeezed with a roller. The strengthening plan for the test beams is shown in Figure 2 and the strengthened specimens are shown in Plate 1.

Table 1: Physical Properties of the CFRP (CXS-200), (Source: Beijing Glass Fiber Industries)

S/No	Physical properties	Value
1	Tensile strength (MPa)	3400
2	Modulus of Elasticity (MPa)	240
3	Density (g/cm^3)	1.76
4	Thickness (mm)	0.11
5	Ultimate strain (%)	1.7
6	Width (mm)	200

Table 2: Properties of Epoxy Resin, (Source: Super Floors Company, Lagos)

S/No	Physical properties	Values
1	Mix ratio	2:1
2	Colour	Brown
3	Pot Life @ 30° C (mins.)	± 30-40
4	Cure time (days)	7
5	Tensile strength, 7 days (N/mm^2)	10.4
6	Compressive strength, 7 days (N/mm^2)	60
7	Flexural Strength (N/mm^2)	28.1

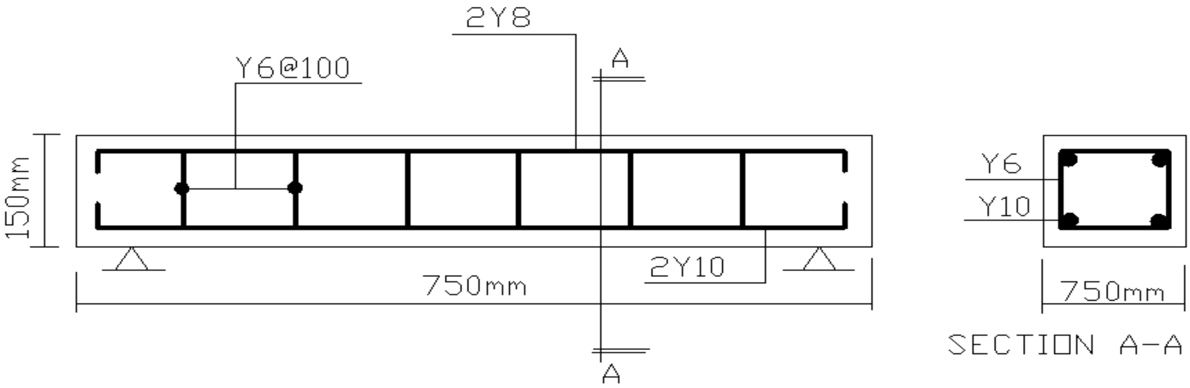


Fig. 1: Structural Detail of the Control Beams

2.2.2. The Bending Tests Setup

The beams were tested at the concrete laboratory of the Department of Civil Engineering, Ahmadu Bello University, Zaria, at the age of 28 days after casting. All the beams were tested as simply supported subjected to three-point load system. The test setup is shown in Figure 2. Dial gauge was placed below the center of the beam, to measure the bending deflection. Twelve beams were tested; the first three beams are the controls with designation CB01, CB02 and CB03 denoting control beam number one, control beam number two and control beam number three respectively. The other sets are SL01, SL02, SL03, DL01, DL02, DL03, TL01, TL02 and TL03. SL, DL and TL denotes single layer of CFRP sheets, double layer of CFRP sheets and Triple layer of CFRP sheets respectively.

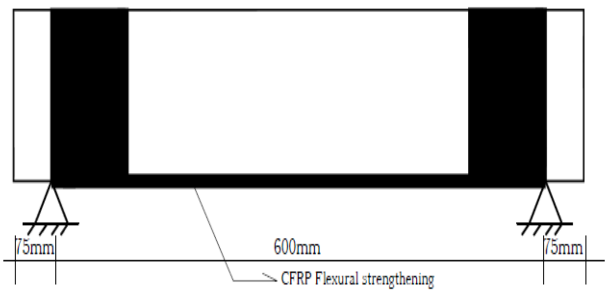


Fig. 2: The strengthening plan of the test beams

Plate 1: The CFRP Strengthened Beams

3. RESULTS AND DISCUSIONS

3.1. The Compressive Strength of the Concrete for the Test

The concrete used for all the test beams are grade M25. The mix design was based on BS EN 206-1 [14]. The water/cement ratio was taken as 0.46. Fifty test cubes were prepared from the mix and tested at the age of 3 day, 7 days, 14 days, 21 days and 28 days and compressive strength corresponding to the results are presented in Table 3. The compressive strength at 28 days is 32N/mm^2.

3.2. The Reference (Control) Beam (RB)

The control beams were only reinforced with steel bars. The beams were marked CB01, CB02 and CB03 and subjected to three-point bending test. The ultimate load for the beams is 51kN, 49kN and 50kN respectively for CB01, CB02 and CB03, corresponding to the ultimate deflection of 7.43, 7.11 and 7.52mm respectively. The average load-deflection plot from the tests are presented in Figure 3.

3.3. Single Layer Beam (SL)

The single layer CFRP strengthened beams were marked SL01, SLO2 and SL03 and subjected to three-point bending test as the control specimens. The ultimate loads for the beams are 60KN, 59KN and 61KN respectively for SL01, SL02 and SL03, corresponding to the ultimate deflection of 6.33, 6.19 and 6.25mm respectively.

The average load-deflection plot from the tests are presented in Figure 4.

3.4. Double Layers Beam (DL)

The double layers CFRP strengthened beams were marked DL01, DL02 and DL03 and subjected to three-point bending test as the control specimens. The ultimate loads for the beams are 69kN, 67kN and 68kN respectively for DL01, DL02 and DL03, corresponding to it with an ultimate deflection of 5.79, 5.88 and 5.83mm respectively. The average load-deflection plot from the tests are presented in Figures 5.

3.5. Three Layers Beam (TL)

The three layers CFRP strengthened beams were marked TL01, TL02 and TL03 and subjected to three-point bending test as the control specimens. The ultimate loads for the beams are 77kN, 75kN and 76kN respectively for TL01, TL02 and TL03, corresponding to it with an ultimate deflection of 5.82, 5.46 and 5.85mm respectively. The average load-deflection plot from the tests are presented in Figure 6.

3.6. Effect of first crack load on strengthened beams

The first crack load of reference control beam (RCB) and beams strengthened with different amounts of FRP are presented in Figure 7. It is observed that the first crack load for SL beams is increased by 29.80% (avrg.), 56.80% (avg) for DL beams and 81.1% (avg) for TL beams all as compared to RCB.

Figure 7 First crack load for control and strengthened beams

3.7. Effect of Ultimate load carrying capacities on strengthened RC beams

The ultimate load carrying capacities of reference control beam (RCB) and strengthened beams with different amount of FRP is presented in Fig. 8. It is observed that the ultimate load carrying capacity of beams SL is increased by 20% (avrg.), 36% (avg) for DL beams and 52% (avg) for TL beams as compared to reference control specimen (RCB).

3.8. Effect of strengthening on stiffness of beams

The stiffness of the reference control beam (RCB) and beams with single layer, double layers and three layers CFRP laminated beam are presented in Table 4. Average values for the strengthened beams is used; it is observed that the stiffness for the strengthened beams was improved as compared to the control beams.

3.9. Effect of Strengthening on ductility of beams

The displacement ductility index is shown in Figure 9 It is observed that the ductility of SL laminated beams is decreased by 16.80% (avg), 27.10% (avg) for DL laminated beams and 33.60% for TL (avg) all as compared to RCB. In general, it was observed that the ductile property of the beams reduces as the number of FRP laminates increases from 1-3.

3.10 Failure pattern

The cracking patterns of the strengthened specimens wrapped in flexural zone for all the strengthened specimens in various layers are shown in plates 2-10. Debonding of CFRP wraps occurred after the initial crack appeared and this is as a result of shear cracks and flexural cracks at the tip of the laminates.

Table 3: Compressive strength test result for the considered mix ratio

S/No	Compressive Strength (N/mm^2)				
	3 days	7 days	14 days	21 days	28 days
1	6.9	11.4	20.0	20.1	25.3
2	4.6	14.8	22.7	31.7	29.6
3	5.2	16.1	20.5	19.8	21.4
4	3.9	12.4	20.5	19.5	42.1
5	6.2	13.0	22.1	17.8	34.2
6	5.3	15.6	21.5	27.7	36.3
7	5.4	12.4	20.2	21.6	34.2
8	6.9	14.1	19.7	24.3	31.2
9	4.7	10.4	23.9	18.4	29.8
10	5.3	11.7	22.1	27.2	33.9
Mean	5.4	12.5	20.9	22.7	32.0

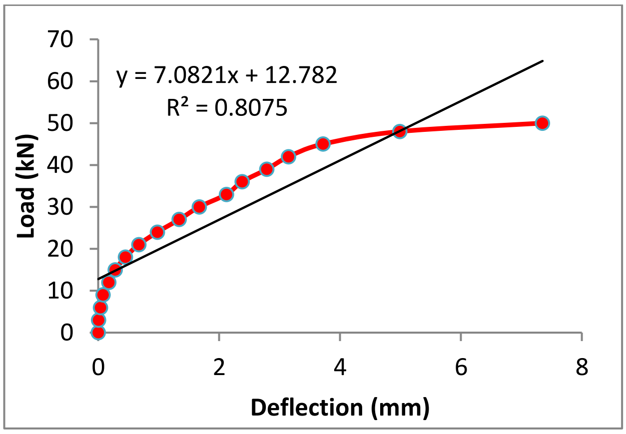


Fig. 3: Average Load deflection plot for the control beams

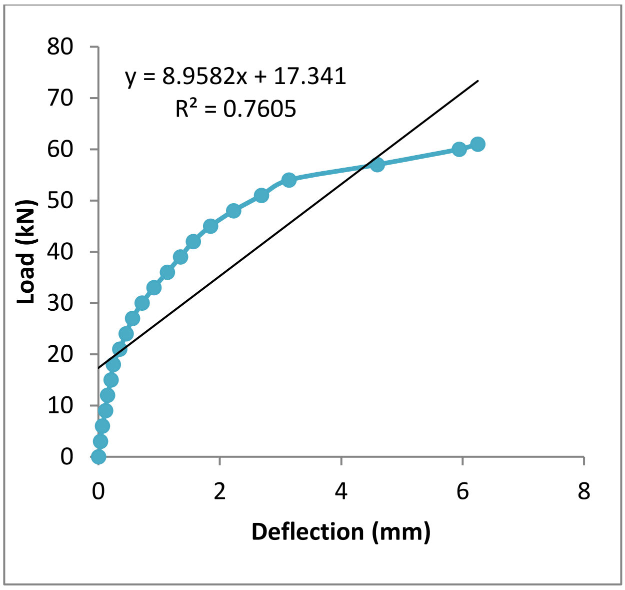


Fig. 4: Average Load deflection plot for single layer beams

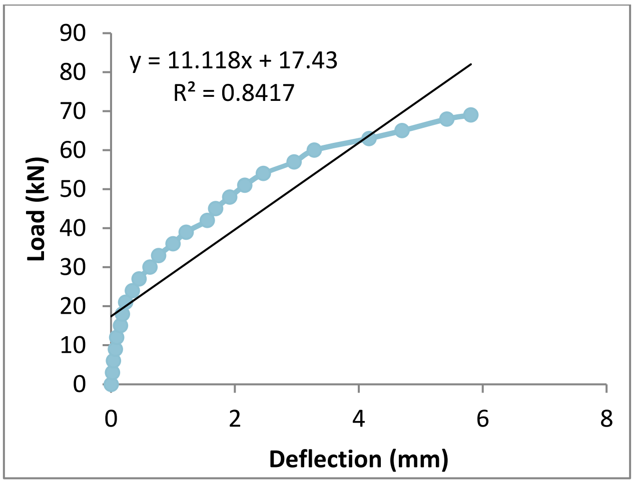


Fig. 5: Average Load deflection plot for double layers beams

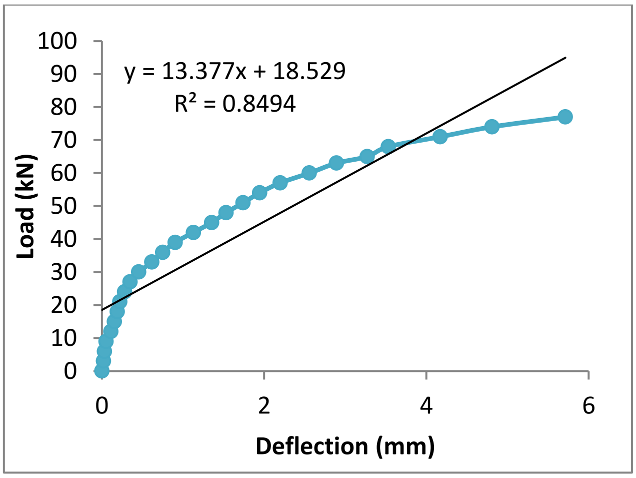
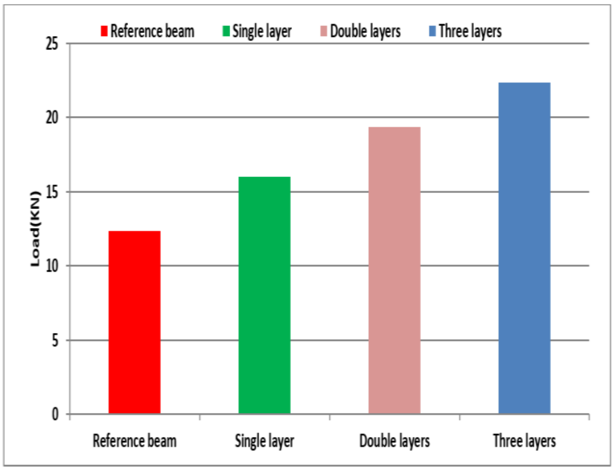


Fig. 6: Average Load deflection plot for three layers beam



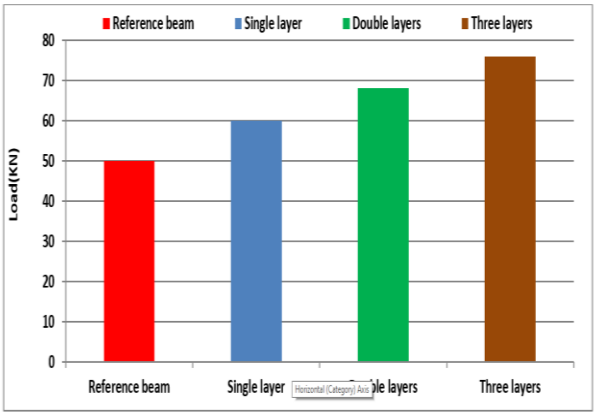


Fig. 7: Ultimate load for control and strengthened beams

Table 4: Flexural modulus

Beam ID	Stiffness N/mm^2	Percentage changed (%)
Reference beam	3.89E+12	-
Single layer	5.48E+12	40.9
Double layers	6.67E+12	71.5
Three layers	7.62E+12	95.9

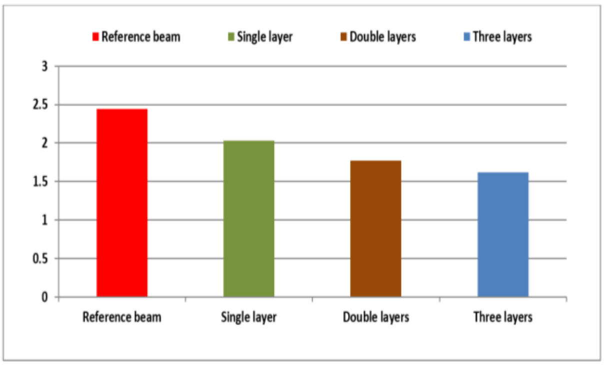


Fig. 8: Ductility index for control and strengthened beams

Table 5: Summary of test results

S. No.	Beam ID	First crack load(KN)	Ultimate load(KN)	Deflection (δ) max (mm)	% decrease with respect to control beam
1	RB	12.33	50	7.35	-
2	SL01	15	60	6.33	-
3	SL02	17	59	6.19	-
4	SL03	16	61	6.25	5.58
5	DL01	19	69	5.79	12.54
6	DL02	20	67	5.88	11.18
7	DL03	19	68	5.83	11.93
8	TL01	22	77	5.82	12.1
9	TL02	24	75	5.46	17.52
10	TL03	21	76	5.85	11.63

Plate 2: Crack pattern for SL01 beam

Plate 3: Crack pattern for SL02 beam

Plate 4: Crack pattern for SL03 beam

Plate 5: Crack pattern for DL01 beam

Plate 6: Crack pattern for DL02 beam

Plate 7: Crack pattern for DL03 beam

Plate 8: Crack pattern for TL01 beam

Plate 9: Crack pattern for TL03 beam

Plate 10: Crack pattern for TL02 beam

4. CONCLUSION

From the experimental results of this research we can conclude that CFRP laminates contribute to the flexural capacity of RC beams. For this particular strengthening method adopted for this research and based on the research findings, the following conclusion can be deduced;

1- From the experimental results it is clearly noticed that the externally bonding of CFRP to the tension face of the beams contributes in flexural strength increase of the laminated beams over the control specimen with an average increase of 20%, 36% and 52% for single layer beams, double layer beams and three layers laminated beams, respectively, over the un-strengthened beam.

2- The improvement of ultimate load and first crack load of strengthened beams can be attributed to the increase of stiffness due to the laminates restraining effect.

3- It is observed that the increase in flexural strength of the strengthened RC beams is due to the sacrifice of ductility of the strengthened laminated beams, as it was observed to decrease with an increase in number of FRP with 16.80%, 27.10% and 33.60% decrease for single layer, double layer and three layers laminated specimens respectively as compared with un-strengthened specimen.

4- From the experimental results it is clearly noticed that a minimum of two layers of this particular CFRP fabric and epoxy resin properties used for this research should be bonded to get an optimum strength increase of strengthened or repaired members so as to allow a reasonable ductile failure or signs over time.

4.1. Recommendation

Based on the experimental finding it is recommended that Carbon fiber reinforced polymer of this particular properties and the matrix used should be adopted for the strengthening process of deficient structures to increase the load carrying capacities of the structural members.

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