Improvement of flexural strength of reinforced concrete beams using CFRP wraps

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ABSTRACT

In this paper are presented the results of an experimental study on flexural behavior of reinforced concrete beams strengthened with Carbon Fiber Reinforced Polymer (CFRP) wraps. Three identical reinforced concrete beams of a section dimensions of 210 mm x 270 mm and span of 2.5 m were built and tested in the laboratory under four-point flexural test. The CFRP technique was applied on a pre-cracked beam, and on an un-cracked beam.

The results were compared with the control specimen parameters. The CFRP system provided a considerable increase in those parameters; 133 - 156 % in terms of load bearing capacity and 128 - 131 % in deformation capacity.

Keywords: CFRP, strengthening, reinforced concrete beam, four-point flexural test

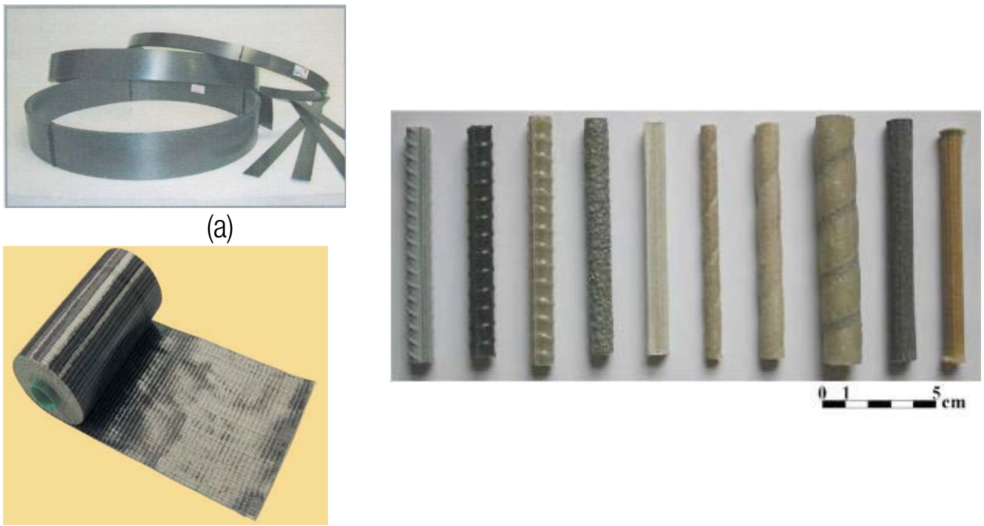
INTRODUCTION

Since its discovery in the 19th century, reinforced concrete was proven to be a highly versatile material for construction of various types of civil engineering structures. It is one of the most widely used construction materials and the first choice of selection for many architects and engineers.

Despite all the advantages such as versatility, durability, economy, energy efficiency, resistance to fire and ability to be cast on-site, over time and due to many external factors, old reinforced concrete buildings have degraded and have lost their initial design characteristics. Moreover, old reinforced concrete structures and bridges located in highly active seismic regions are found to have insufficient capacities to comply with modern seismic design standards or with today's vehicular traffic flow. For this reason, there is a need for an upgrade of their structural elements in order to resist higher forces.

Strengthening of reinforced concrete elements such as beams or columns by was done by inserting additional reinforcing steel bars, jacketing of elements with new reinforced concrete of higher resistance, increasing the elements' cross-sectional area, thus increasing the overall weight of the structure.

To overcome this drawback, fiber reinforced polymeric (FRP) materials in the form of wraps, strips, laminates, rods or ropes are used to strengthen the structural elements are widely applied for repairing and strengthening of RC beams, columns, frames, column joints, deep beams, etc. A FRP system is a composite material made of a continuous polymer resin called matrix and reinforcing fibers. For the resins, putty fillers, saturants and adhesives are used. The fibers, made of very thin filaments of glass (GFRP), carbon (CFRP) or aramid (AFRP) are the most important element which provides the system strength and stiffness. The FRP fibers' density varies from 1.2 to 2.1 g/cm^3. The FRP systems' characteristics are defined by type of fiber volume, orientation and thickness and type of resin. One of the most important characteristics of FRP composites is that when a structural member is reinforced with FRP, stresses are transferred from substrate to the FRP through shear and epoxy interface. In general, FRPs are used to increase out-of-plane flexural strength, in-plane shear strength and stiffness at service loads.



(a)

(b) (c)

Figure 1. FRP laminate (a), sheet (b), bars (c) [1]

Some of the advantages why these materials are used are: lower cost, corrosion resistance, flexibility in usage, minimum disturbance to structure, minimum of loss of free space, impermeability to water, resistance against chemicals, good material properties and could be easily removable. They are available in two types: single layered and multi layered [4].

Application of CFRP wraps to increase the flexural resistance of RC beams was firstly used by Meier by the end of 1980s [2].

In later studies conducted by other researchers [3-15] were documented the successful applications of FRP materials for improvement of structural performance.

MATERIALS AND METHODS

In this study, three beams of a span of 2.5 meters with nominal cross-sections of 210 mm x 270 mm were tested in bending. One of the beams was strengthened with CFRP prior to testing whereas another one was repaired with CFRP after testing and re-tested. The main aim was to assess the effect of CFRP system on the flexural capacity of the beams.

Construction of beams

The beams were built of concrete class C25/30 and were reinforced with 3H12 for tension reinforcement and 2H8 compression reinforcement. The shear links were H8 @ 100 mm centers. Before mixing of concrete, coarse aggregate granulometry was measured to be well-graded (Figure 2). The cement used was 42.5 R and water/cement ratio was 0.6.

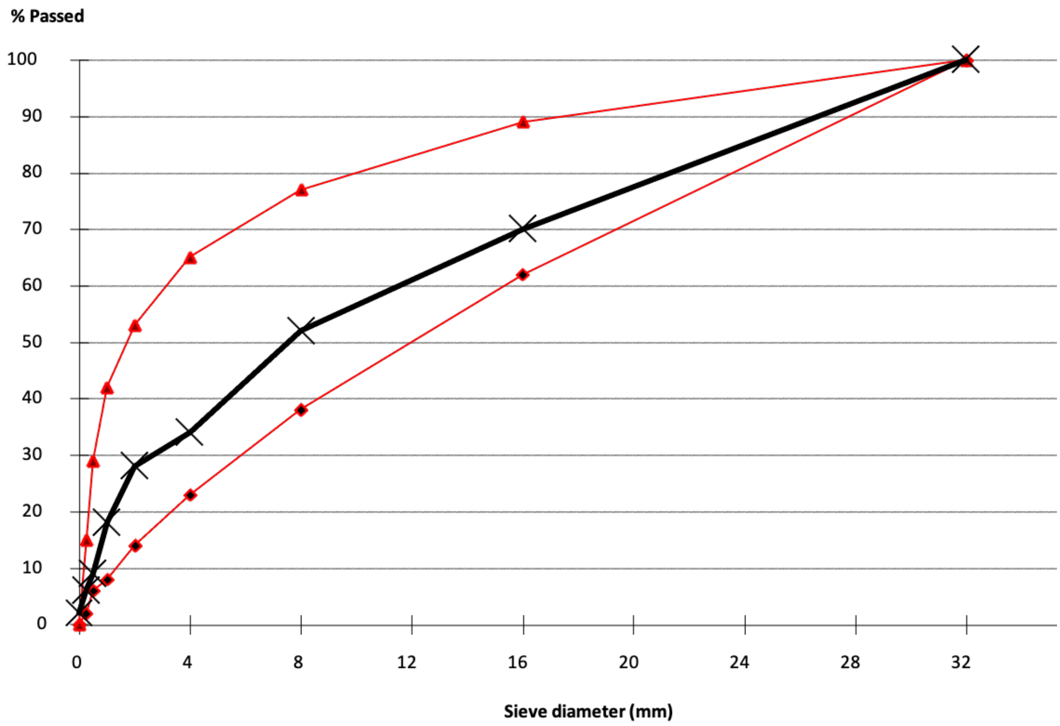


Figure 2. Aggregate grading test results.

Figure 3. Step-by-step construction of the beams.

Strengthening of Beams using Carbon Fiber Reinforced Polymer (CFRP) Wraps

The application of CFRP wraps is a three-step procedure. Firstly, surface preparation is required. The beam faces are cleaned from any grease, oil, dust residual or other contaminants that might impair adhesion. Secondly, epoxy primer is applied. It is a two-component solvent-free epoxy system which when mixed yields a penetrating medium viscosity primer [16-18]. Then, a layer of epoxy adhesive is applied, followed by the application of CFRP wrap and finished with the second layer of the adhesive.

Figure 4. (a) Epoxy Primer, (b) Epoxy Adhesive.

In Figure 5 and 6, is presented a sketch view of the reinforcement scheme and the application of all the steps.

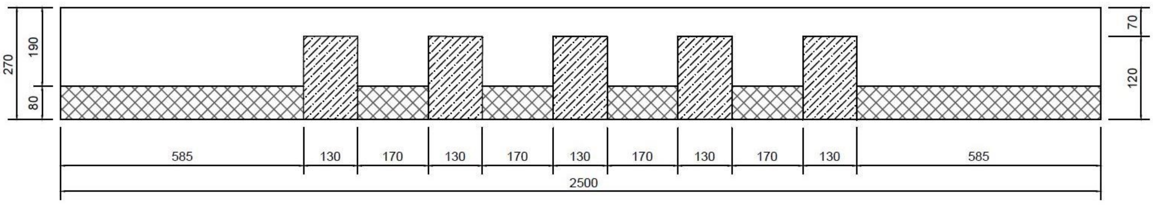


Figure 5. Reinforcing scheme.

Figure 6. Application of CFRP on beam B2.

Test set-up

All three RC beams were tested under flexural loading simply supported with a clear span 2200 mm and internal span 900 mm. Three Digital Vernier Calipers were fixed on the bottom part of the beams to measure the vertical displacements. The four-point bending (flexural) static loading was performed using a hydraulic jack as described in Figures 7 and 8. Testing continued until the load reading of the hydraulic jack showed a few to zero kN.

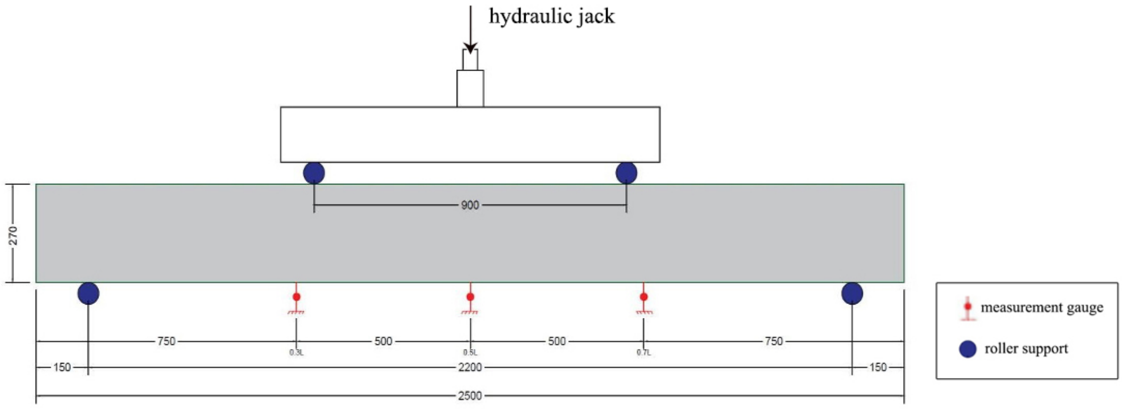


Figure 7. Four-point bending test set-up scheme.

Figure 8. Four-point bending test.

RESULTS AND DISCUSSIONS

The analysis results are expressed in terms of load-deflection curve as well as crack patterns. The Beam (B1) failed at an ultimate load of 137.34 kN and the maximum deflection was 47.93 mm. The Beam (B2) failed at an ultimate load of 127.53 kN and deflected 38.7 mm. It was then, repaired with CFRP and tested again. After the second test, the ultimate load was 176.58 kN and the maximum deflection was 50.42 mm. The Beam (B3) strengthened with CFRP wraps failed at a load of 215.80 kN with a maximum deflection of 45.65 mm. In Table 1 is presented a summary of these results.

Table 1. Ultimate load and maximum deflection of the tested beams.

Specimen name	Ultimate Load (kN)	Maximum deflection (mm)
B1	137.34	47.93
B2	127.53	38.70
B2(CFRP)	176.58	50.42
B3(CFRP)	215.80	45.65

In Figure 9, are presented the beams after testing. It can be seen the development of tension cracks at the bottom of the unreinforced beams (B1 and B2) and compressive cracks at the top of the beam. In the repaired and strengthened beams, it was observed that the CFRP wraps failed from rupture.

Figure 9. All the beams after failure.

In Figure 10 it is presented the load-deflection curves of all the tested beams. As it is seen from the graph, Beam B3(CFRP) has the highest ultimate load but is not the most ductile beam of all.

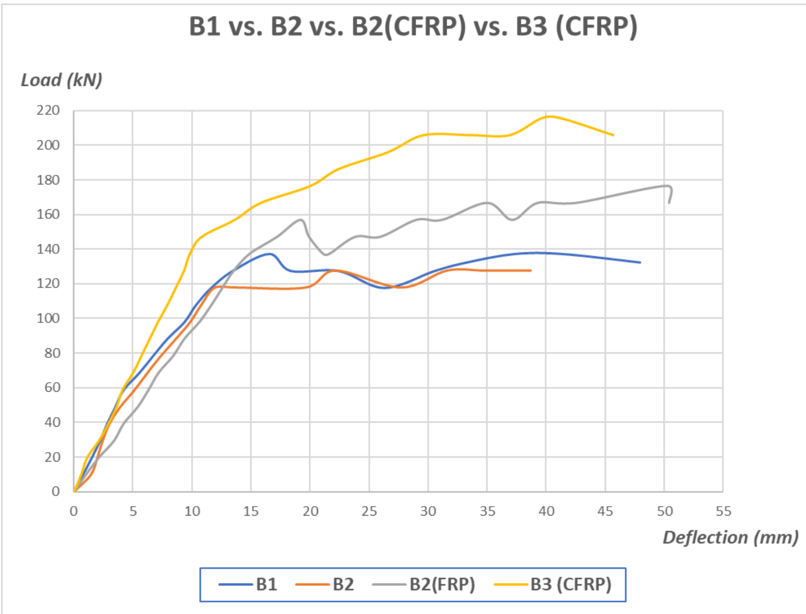


Figure 10. Load-deflection curve of all the tested beams.

CONCLUSION

From the test results it was observed that CFRP wrap strengthening system performed satisfactorily and could be a useful method to increase the flexural resistance of the reinforced concrete beams. It was observed that the repaired beam had a 138% increase in ultimate load and 131% in the maximum deflection. The CFRP strengthened beams achieved a 159% higher ultimate load but a similar maximum deflection.

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